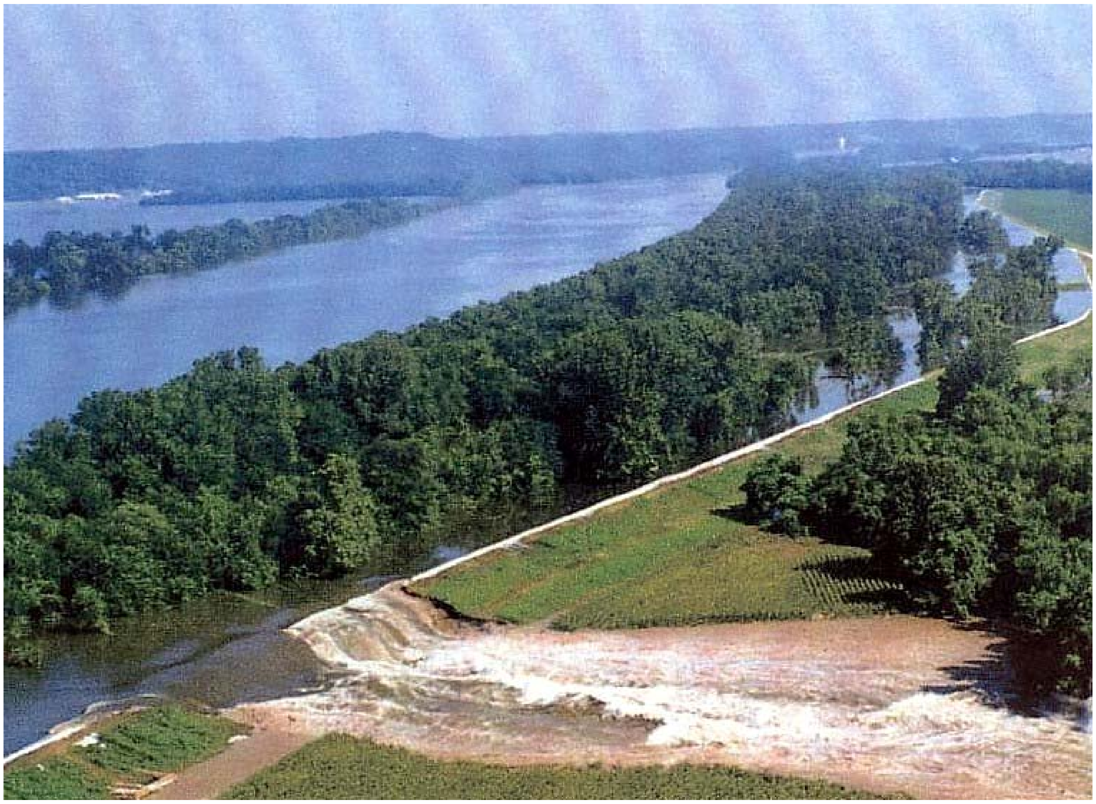
**US Army Corps
of Engineers**
Hydrologic Engineering Center

Mississippi Basin Modeling System – Development and Application



June 2002

PR-47

REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*
June 2002

2. REPORT TYPE
Project Report

3. DATES COVERED *(From - To)*

4. TITLE AND SUBTITLE
Mississippi Basin Modeling System – Development and Application

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
D. Michael Gee

5d. PROJECT NUMBER

5e. TASK NUMBER

5F. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
US Army Corps of Engineers
Institute for Water Resources
Hydrologic Engineering Center (HEC)
609 Second Street
Davis, CA 95616-4687

8. PERFORMING ORGANIZATION REPORT NUMBER
PR-47

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
US Army Corps of Engineers
Headquarters
441 G Street, NW
Washington, DC 20314-1000

10. SPONSOR/ MONITOR'S ACRONYM(S)

11. SPONSOR/ MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION / AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

13. SUPPLEMENTARY NOTES
This project was performed by several Corps District, Division, and Laboratories, the Acknowledgements list the individuals involved in this project.

14. ABSTRACT

This report documents the design, development and implementation of the Mississippi Basin Modeling System (MBMS) for real-time unsteady flow forecasting. Successful completion of this project hinged upon a team composed of individuals that blended geographical, technical, research and numerical model applications experiences. Many of the MBMS team members had participated in the prior study designs, model implementations and reporting of the Scientific Assessment and Strategy Team and the Floodplain Management Assessment study. The MBMS project developed and coalesced data acquisition and use, modeling software, communications, and reporting, Many ancillary issues such as data accuracy, physical features modeling (e.g., levees, lock and dam structures), selection of appropriate mathematical modeling techniques, model calibration, etc., were addressed during this study.

15. SUBJECT TERMS
Mississippi River, unsteady flow, forecasting, UNET, 1993 Flood

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			
U	U	U	UU	276	19b. TELEPHONE NUMBER

Mississippi Basin Modeling System – Development and Application

June 2002

Prepared for:
US Army Corps of Engineers
Headquarters
441 G Street, NW
Washington, DC 20314-1000

Prepared by:
US Army Corps of Engineers
Institute for Water Resources
Hydrologic Engineering Center
609 Second Street
Davis, CA 95616

(530) 756-1104
(530) 756-8250 FAX
www.hec.usace.army.mil

PR-47

ACKNOWLEDGMENTS

This report documents the design, development and implementation of the Mississippi Basin Modeling System (MBMS) for real-time flow forecasting using a one-dimensional unsteady flow model. Successful completion of this project hinged upon a team composed of individuals that blended geographical, technical, research and numerical model applications experiences. Many of the MBMS team members had participated in the prior study designs, model implementations, the Scientific Assessment and Strategy Team and the Floodplain Management Assessment study. The MBMS project developed and coalesced data acquisition and use, modeling software, communications, and reporting. Many ancillary issues such as data accuracy, physical feature modeling (e.g., levees and lock and dam structures), selection of appropriate mathematical modeling techniques, model calibration, etc. were addressed during this study.

Along with experience in the use of contemporary mathematical river modeling technology, a strong foundation of river engineering knowledge and experience was brought to this project by the team members. The primary participants from District and Division offices were: Stu Dobberpuhl (St. Paul Dist.), John Burant and S. K. Nanda (Rock Island Dist.), Jody Farhat (Northwest Division - Missouri River), Dan Pridal (Omaha Dist.), Rebecca Allison (Kansas City Dist.), Dennis Stephens (St. Louis Dist.), Stan Wisbith (Great Lakes and Ohio River Division), Don Flowers (Mississippi Valley Division). Technical support was provided by Tim Pangburn, Terry Birkenstock and Tim Baldwin of the Cold Regions Research and Engineering Laboratory, and Tom Evans and Michael Gee of the Hydrologic Engineering Center. Dr. Robert L. Barkau served as a consultant to the team and independently to several of the offices involved. Project management, guidance and coordination were provided by Ming Tseng of Headquarters Hydraulics and Hydrology Branch and Darryl Davis, Director of HEC. This report was prepared by Michael Gee.

Related HEC Documents:
HEC, "Mississippi Basin Modeling System Development and Application," Project Report-36, U.S. Army Corps of Engineers, Davis, CA, April 1998.
HEC, "Mississippi Basin Modeling System Operations Guide," Project Report-36A, U.S. Army Corps of Engineers, Davis CA, April 1999.
HEC, *UNET One-Dimensional Unsteady Flow Through a Full Network of Open Channels*, User's Manual, CPD-66, Ver. 4.0, U.S. Army Corps of Engineers, Davis, CA, April 2001.

Cover Photograph:
"Nutwood Levee break on the Illinois River," North Central Division, U.S. Army Corps of Engineers, 1994, *The Great Flood of 1993 Post-Flood Report - Upper Mississippi River and Lower Missouri River Basins*, Main Report, September 1994, p.18.

TABLE OF CONTENTS

APPENDICES

1. Introduction

1.1 Background and Overview. The genesis of the Midwest Flood of 1993 was in a combination of extreme hydrometeorological events. Precipitation during the winter of 1992-1993 was above normal throughout the upper Mississippi River basin and the lower Missouri River basin. This unrelenting rainfall, combined with an early snowmelt, produced high spring runoff. The wet-weather pattern persisted over the upper Midwest for about six months. The eastward-flowing jetstream became stationary; drawing warm, moist air from the Gulf of Mexico northward where it met the cooler air masses drawn southward from Canada. This situation resulted in successive occurrences of prolonged and excessive precipitation over the Upper Mississippi Basin leading to widespread, destructive, floods. These floods resulted in damages estimated at $12 to $16 billion (Interagency, 1994 - p. v), which were primarily agricultural. A detailed description of the hydrometeorology of the Midwest Flood of 1993 and its consequences can be found in "The Great Flood of 1993 Post-Flood Report – Upper Mississippi and Lower Missouri River Basins," (North Central Division, 1994).

Following the Midwest Flood of 1993 Congress tasked the Corps of Engineers to conduct a comprehensive, system-wide study to assess flood control and floodplain management practices in the areas that were flooded. That study was known as the Floodplain Management Assessment study (FPMA) (USACE, 1995). It encompassed three Corps of Engineer Division boundaries and five District boundaries. Participating Districts included: St. Paul, Rock Island, and St. Louis on the Mississippi River, and Omaha and Kansas City on the Missouri River. To accomplish the study objectives, an unsteady flow model of the Upper Mississippi and Lower Missouri Rivers was developed. Each District developed independent models which produced results that were assimilated by neighboring Districts so that floodplain management alternatives could be evaluated systemically. The unsteady flow model was used to evaluate the potential impacts of various levee modification alternatives and upland watershed measures, such as reservoirs and land treatments, on the 1993 flood. The model selected for use in the FPMA study was UNET (HEC, 2001). It is a one-dimensional unsteady open channel flow simulation model that is further described in Section 3 of this report.

Structural flood protection measures performed as designed and prevented significant damages during the 1993 flood. The Corps, however, did not have a uniform, system-wide unsteady flow model specifically designed and implemented for the Missouri and Mississippi Rivers and their tributaries to analyze and predict system-wide impacts of various alternative actions during such flood events. The need for such a river model was identified in a Federal Interagency study chartered by the White House (Interagency, 1994):

"A system-wide unsteady-flow model of the main stem rivers in the upper Mississippi River Basin would help evaluate the impacts of proposed structures and floodfighting, and could be used for coordinated ecosystem modeling, and for floodplain management decisions. Further, advanced hydrologic and hydraulic models can be combined with meteorologic observations and forecasts to provide information to enable better floodplain and water resources management." (Interagency, 1994 - p. 157)

The endeavor to develop such a model was initially known as the Mississippi River Forecast Model Development and is the subject of this report. The Corps team assembled to execute this effort was composed of representatives of the five Districts: St. Paul (MVP), Rock Island (MVR), St. Louis (MVS), Omaha (NWO) and Kansas City (NWK) involved in the FPMA study. Also included in this study were the Mississippi Valley Division (MVD), Great Lakes and Ohio River Division (LRD) and Southwestern Division (SWD). Technical support was provided by the Coastal and Hydraulics Laboratory, Cold Regions Research and Engineering Laboratory and Hydrologic Engineering Center (HEC). Study management, guidance and coordination were provided by Headquarters Hydraulics and Hydrology Branch (CECW-EH).

The objectives for development of the forecast system were established based on past flood experiences and are listed here in order of priority: 1) improve and facilitate the coordination, communication and sharing of data and forecasts among water control activities along the mainstem, 2) assess impacts of levee breaching and floodway operations on local and downstream areas, 3) support emergency management activities through timely prediction of river stage and rate of rise, 4) display areal extent of flooding due to levee overtopping and/or breaching associated with various potential weather scenarios, 5) identify navigation hazards and, 6) provide data for real-time flood damage assessment. Several of the objectives listed above are based on needs identified in the FPMA report (USACE, 1995); particularly the first four. It is also important to note that many of the experiences and much of the data obtained during the FPMA study contributed substantially to the forecast model development. The primary objective of this work was the development and implementation of a UNET-based flood event forecasting system. The capability to also analyze low flows so that routine day-to-day forecasting needs and project operation activities was recognized and can be accommodated as well.

1.2 Authority. Authorization and funding for this project were provided via CECW-EH letter dated 28 Feb. 1994, subject: Mississippi River Model Development. A comprehensive scope of work titled "Scope of Work for the Mississippi River Model Development" (dated 18 Feb. 1994) defined the features and functions of the Mississippi River (UNET forecast) Model. Subsequent acknowledgment by the working group of the large geographic extent involved in this study led to the product of the effort being identified as the "Mississippi Basin Modeling System" (MBMS).

1.3 Summary of Work History. The work was performed in four phases. Phase 1 (FY 1994) consisted of assembling and testing data files by the local District offices. Phase 2 (FY 1995) focused on improving and expanding data and increasing the capabilities of UNET. Investigation of the development of advanced hydrodynamic modeling techniques (e.g., two-dimensional for the floodplains) and use of data assimilation techniques for near real-time calibration were undertaken. Phase 3 (FY 1996) continued to refine data and UNET modeling capabilities. More emphasis was placed on integrating the MBMS into the Corps real-time water control system. HEC published a summary project report in 1998 (HEC, 1998) and an operations guide for field offices in 1999 (HEC, 1999). The fourth Phase, which ran concurrently with the others, was that of model support, maintenance and technology transfer.

1.4 Description of this Report. This report describes the history and status of the Mississippi Basin Modeling System development and application. Within this report, the term "model development" is sometimes used to describe software development and sometimes to describe data; i.e., its acquisition, preparation, and use in the UNET modeling system and for calibration adjustments. The context of the use will clarify the distinction. Implementation of the UNET modeling system and ancillary software for real-time forecasting is described. Coordinations and collaborations that were essential to the success of the effort are reported. Data acquisition, calibration of the modeling systems, and its use for real-time forecasting are summarized. Detailed descriptions of the MBMS model geographic coverage, data development and real-time application experiences are presented in Appendices that were prepared by the Corps District offices performing the system implementation.

2. Mississippi Basin Modeling System Summary

2.1 MBMS Overview. The MBMS can be characterized as a system that replicates and expands the functionality of the channel flow routing techniques used in day-to-day Corps forecasting activities. MBMS incorporates advanced hydraulic routing and contemporary software technology, and was designed to accommodate future developments such as the products of the Corps Water Management System (CWMS) modernization research program (HEC, 2000). There are several important technical differences between the MBMS flow routing and traditional hydrologic routing techniques:

- The routing module, which is used for the computation and prediction of discharge and stage hydrographs, is the full unsteady flow model - UNET (HEC, 2001).

- Because of the use of a physically based hydrodynamic model (UNET), any physical changes to the stream such as cross section changes, roughness changes, levee breaches, etc. can be depicted via physically based data with minimum reliance on empirical coefficients.

- Use of a physically based model increases confidence in simulated results for events outside the range of calibration events.

- Unsteady flow routing allows for the direct incorporation of backwater effects due to structures and tributaries in the routed hydrographs.

- UNET input and output is managed, processed, stored and disseminated via a common data storage system, HEC-DSS (HEC, 1995).

- The system is uniform among the field offices; that is, the software suite, computational techniques, field data interpretation, calibration techniques and presentation of results are the same for all system users.

- The data bases, parameter calibrations, and system operation are applicable to planning and design studies as well as forecasting.

2.2 Geographic Coverage. The MBMS covers an extensive area - from Anoka, MN to the Gulf of Mexico on the Mississippi River, from Gavins Point Dam on the Missouri River to St. Louis (confluence with the Mississippi) and from Lockport Lock & Dam to Grafton on the Illinois River. Portions of numerous smaller tributaries in the Basin are also modeled as unsteady flow routing reaches. Also included (although not simulated with UNET at this time) are the Ohio River (LRD) and the Arkansas and White Rivers (SWD). A schematic representation of the system showing key locations that are referred to later in this report is shown on Figure 1.

The main channel coverage by the Corps of Engineers District offices is as follows: St. Paul District (MVP), Mississippi R. from Anoka MN to Dubuque IA (289 river miles); Rock Island District (MVR), Mississippi R. from Guttenberg IA to Grafton IL (314 river miles) and the Illinois R. from Lockport L&D to Grafton IL (220 river miles); Omaha District (NWO), Missouri R. from Gavins Point Dam to St. Joseph MO (313 river miles); Kansas City District, Missouri R. from Rulo NE to St. Charles MO (498 river miles); St. Louis District (MVS), Mississippi R. from Lock & Dam 22 tailwater at Saverton MO to Birds Point MS (299 river miles) and the Illinois R. from Meredosia IL to Grafton IL (71 river miles); Mississippi Valley Division (MVD), Mississippi R. from Thebes IL to Venice LA (987 river miles); Great Lakes and Ohio River Division (LRD), Ohio R. from Pittsburgh (PA) to the mouth; and the Southwestern Division (SWD), Arkansas and White R. basins which comprise about 189,000 sq. mi., of which about 156,000 sq. mi. contributes to stream flow.

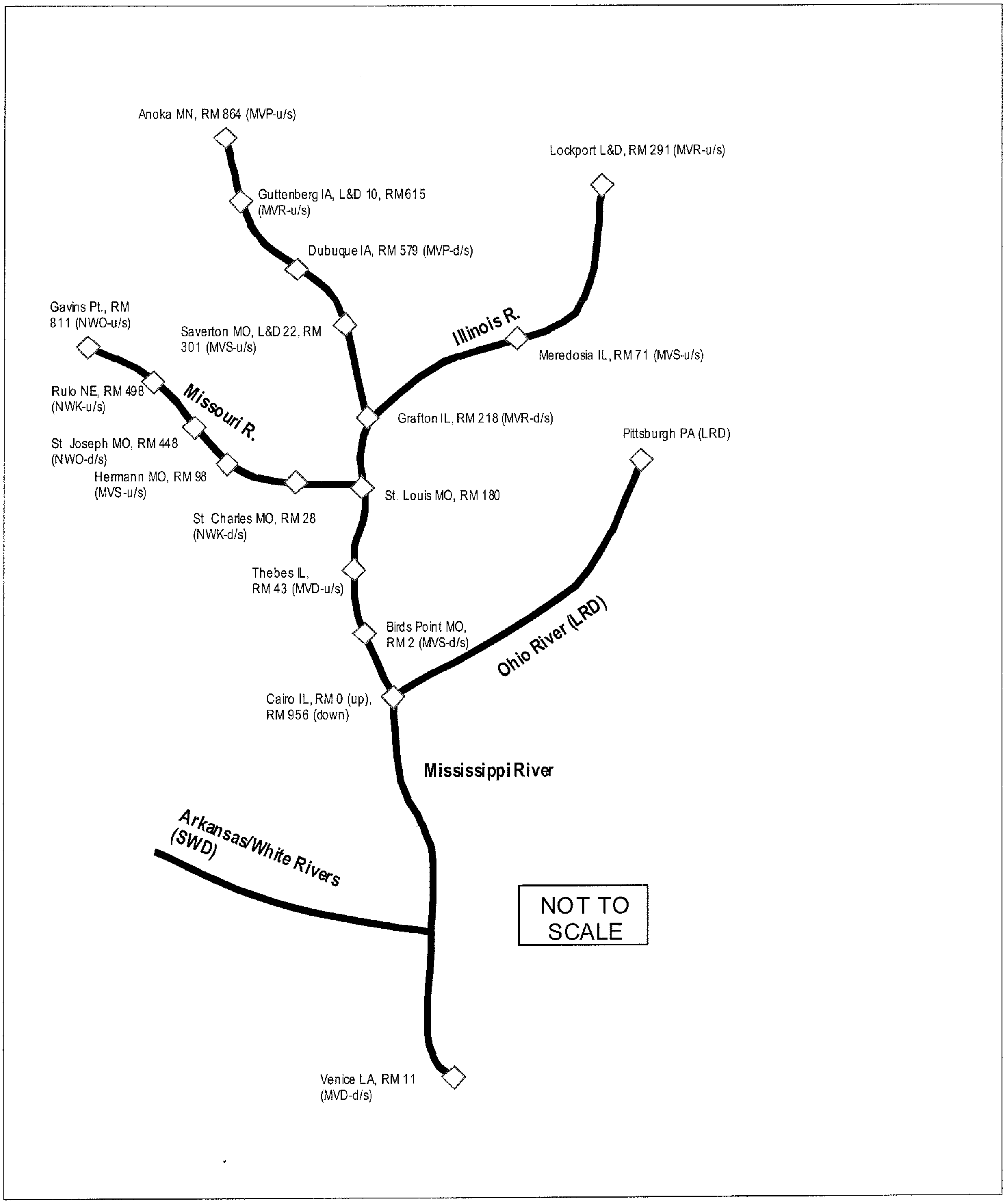


Figure 1. Schematic Diagram of MBMS Geographic Extent. (u/s = upstream location of UNET boundary condition, d/s = downstream location of UNET boundary condition.)

2.3 Components. MBMS consists of many individual components that may be grouped into data bases and software modules. Among the data bases are: (1) measured field data such as cross sections and hydrographs, (2) predicted (forecasted) inflows to the system such as runoff generated by a rainfall event, (3) project operation criteria such as navigation dam rule curves, (4) calibration data such as observed stage and flow hydrographs, (5) simulation parameters such as Manning's *n* values and discharge-conveyance relations, (6) computed forecast flow and stage hydrographs, and (7) geographic information system (GIS) data used for presentation of area maps, damage locations, gage locations, inundated areas, etc. The four primary software modules (each of which is composed of several sub-modules) comprising the MBMS are: (1) UNET, the one-dimensional unsteady flow hydrodynamic model, (2) a two-dimensional hydrodynamic model linked to UNET for overbank flow simulation, (3) HEC-DSS, the data management, manipulation and display module, and (4) the graphical user interface (GUI) that the forecaster uses to interact with the system. Also critical to successful operation of the MBMS are communication systems for the retrieval of real-time field data such as rainfall and gage readings, and the transmittal of forecasted information such as stage and flow hydrographs to other Districts and clients. The relationships among these components are depicted in Figure 2.

2.4 Forecast Operations. To produce reliable forecasts, the model must be calibrated to recent conditions. The primary parameter that is adjusted during calibration is the channel conveyance. Adjustment of channel conveyance is considered to be the equivalent of adjusting Manning's *n* (assuming that gross channel geometric properties do not change through scour, deposition, or avulsion). The concept implemented to date is that of performing a calibration outside of the real-time forecasting operation. Consideration may be given in the future to the use of real-time parameter adjustment schemes (data assimilation). At this time, however, the calibration will be updated periodically, perhaps seasonally, rather than for each forecast. The steps used to obtain that calibration are:

1. Adjust conveyance to match simulated flows and USGS gaged flows (base calibration).
2. Estimate ungaged inflows/outflows using the UNET null internal boundary condition (Barkau, 1995; HEC, 2001).
3. Calibrate stages to intermediate gages.
4. Estimate, for locks and dams, the ungaged inflow between gages.
5. Calibrate to secondary gages.
6. Fine tune by adjusting to the individual event using the discharge-conveyance change factors.

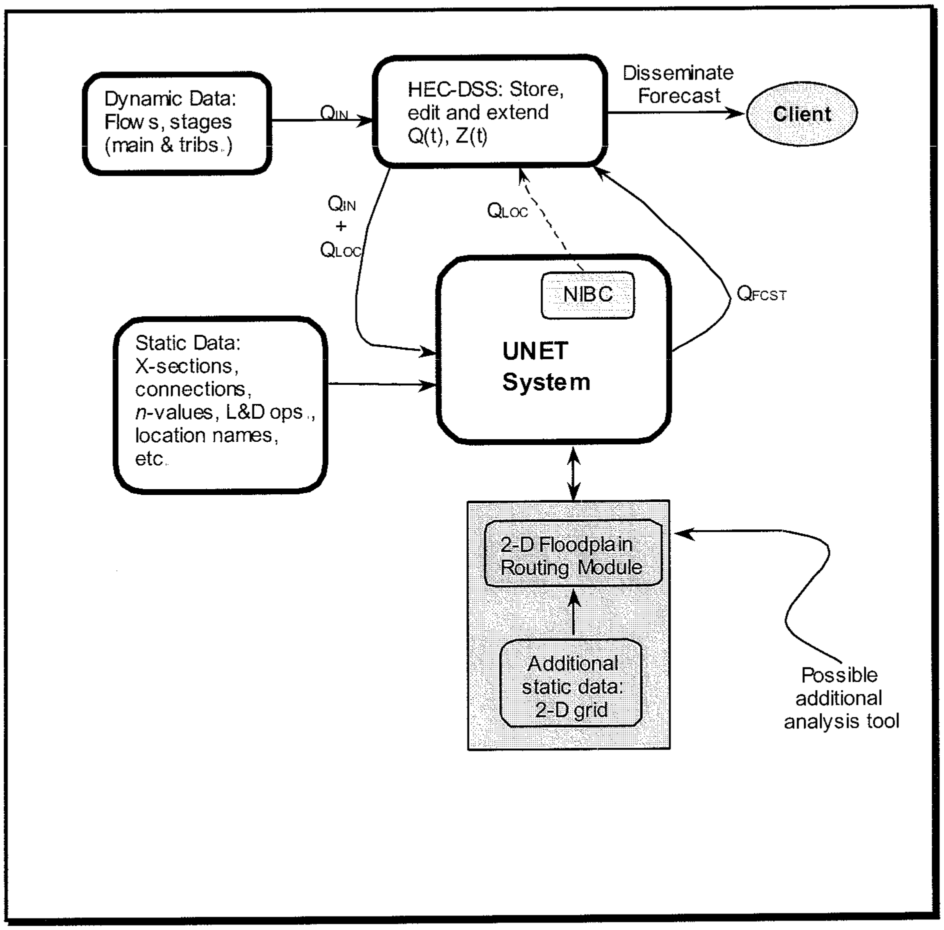


Figure 2. Components of MBMS. NIBC = Null Internal Boundary Condition.

Application of an unsteady flow modeling system to forecasting represents a significant departure from its use for simulation. Conceptually, the situation can be viewed as performing forecasting as usual, only using a more sophisticated routing technique. The need for uniformity among the offices, introduction of new technology and data systems to Water Control personnel, and requirements for timely and reliable forecasts required that significant effort be expended to develop and implement a GUI tailored for forecasting applications of the UNET system. The GUI is presented in more detail in Sec. 3.4.1.

Forecasting requires the introduction of the notion of "static" data. These are data that do not change each time that a forecast is prepared. In the UNET system, these data are primarily geometric (cross sections, energy loss coefficients, potential levee breach locations and parameters, etc.). Past observed and forecasted flows can also be considered static. What does change each forecast period are the inflows. The inflows for all inflow locations must be obtained from the time of forecast (say 08:00 today) to the end of the forecast period (say 08:00 today plus seven days). These inflow values may come from application of a hydrologic model to the subbasins or extrapolation based on experience. The ungaged flows derived by implementation of the null internal boundary condition (NIBC - Sec. 3.3.4) must also be extended into the future. This relies on the forecaster's experience and knowledge of the basins. Note that the flows used from the NIBC for the previous forecast may need to be updated to correspond with the observed flows during the period between the last forecast and the current forecast.

The static data may need to be modified periodically to reflect changes in river geometry or roughness. For example, the roughness characteristics of the Missouri and Mississippi Rivers change seasonally due to changes in water temperature, vegetation, and ice. This implies that the static data calibration may need to be updated periodically. This is best performed off-line; that is, not as part of the routine day-to-day forecast operation, and blended into the forecast operation. Techniques and protocols for doing so will be developed during the initial use of the MBMS.

MBMS is operational in all district offices in the system and is being used for real-time day-to-day forecasting. By the middle of FY 1997 the system had seen use in real-time floodfighting. A detailed description of the implementation and use of the MBMS can be found in the St. Paul District Appendix.

3. The UNET Modeling System

3.1 Description. UNET (HEC, 2001) was the primary hydraulic analysis tool used in the FPMA study. It simulates one-dimensional unsteady flow through a network of open channels. One element of open channel flow in networks is the split of flow into two or more channels. For subcritical flow, the division of flow depends upon the capacities of the receiving channels. Those capacities are functions of downstream channel geometries and backwater effects. A second element of a network is the combination of flow; termed the dendritic problem. This is considered to be a simpler problem than the flow split because flow from each tributary is dependent only on the stage in the receiving stream. A flow network that includes single channels, dendritic systems, flow splits, and loops such as flow around islands, is the most general problem. UNET has the capability to simulate such a system.

Another capability of UNET is the simulation of storage areas; e.g., lake-like regions that can either provide water to, or divert water from, a channel. This is commonly called a split flow problem. In this situation, the storage area water surface elevation will control the volume of water diverted. That volume, in turn, affects the shape and timing of downstream hydrographs. Storage areas can be the upstream or downstream boundaries for a river reach. In addition, the river can overflow laterally into storage areas over a gated spillway, weir, levee, through a culvert, or via a pumped diversion.

In addition to solving the one-dimensional unsteady flow equations in a network system, UNET provides the user with the ability to apply many external and internal boundary conditions including flow and stage hydrographs, gated and uncontrolled spillways, bridges, culverts, and levee systems.

To facilitate model application, cross sections are encoded in a modified HEC-2 (HEC, 1990) forewater (upstream to downstream) format. Many river systems have been modeled using HEC-2, and those existing data files can be readily adapted to UNET format. Boundary conditions (flow hydrographs, stage hydrographs, etc.) for UNET can be input from any existing HEC-DSS (HEC, 1995) data base. For most simulations, particularly those with large numbers of hydrographs and hydrograph ordinates, HEC-DSS is advantageous because it eliminates the manual input of hydrographs and creates an input file which can be easily adapted to a large number of scenarios. Hydrographs and profiles which are computed by UNET are output to HEC-DSS for graphical display and for comparisons with observed data. Guidance for numerical modeling of river hydraulics is given in the Corps of Engineers Engineer Manual on *River Hydraulics* (USACE, 1993).

3.2 UNET Versions. UNET version 3.1 was released by HEC for general use at the end of FY 1996. That release contained substantial changes from the prior (ver. 3.0) release of UNET. Some added features included greater use of DSS for graphical displays, additional simple spillway connections, tunnel simulation, embankment breach simulation, more types of boundary conditions, etc. Documentation of those changes is available from HEC. Near the end of FY 1997 version 3.2 was released for general use. This version corrected some errors in ver. 3.1

relative to DSS reads/writes and embankment breaches. The user's manual was substantially improved in its correspondence with the software.

A special version of UNET (different from ver. 3.2) is being used by all of those involved with the Mississippi River Basin forecasting project. Note that the modifications to the "Mississippi version" of UNET, some of which are described below, are not in HEC-UNET ver. 3.2. HEC has included appropriate features of the "Mississippi version" of UNET in HEC-UNET public release 4.0 (HEC, 2001).

3.3 Developments to UNET for this Project.

3.3.1 Levee Algorithms. The leeved areas along the Mississippi-Missouri River systems are substantial. Breaching of levees, as shown below in Fig. 3, results directly in flooding of areas meant to be protected by the levees. The water that floods those areas is stored for later return to the river. The modeling of this exchange and storage of water resulting from levee breaches is an important aspect of UNET. This feature is included in HEC-UNET Ver. 4.0.

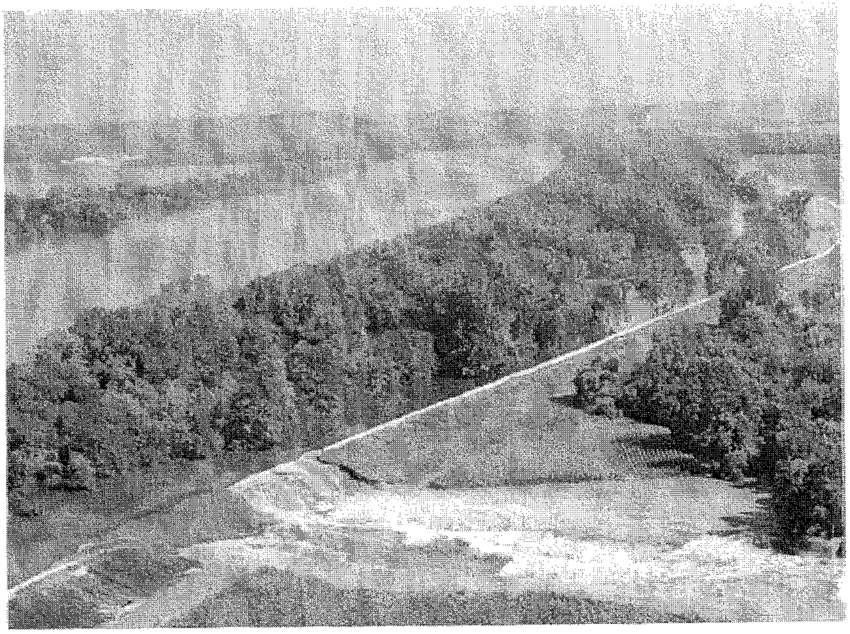


Figure 3. Levee Breach (North Central Division, 1994)

The UNET approach to simulation of the impact of levee overtopping and/or breaching on flood characteristics prior to the 1993 flood event considered the area behind the levee to be a storage area. That is, it fills and empties through a levee breach or overtopped area, but does not convey water in the downstream direction. This concept of storage areas is used to approximate a blend of one-dimensional and two-dimensional approaches to river modeling. For most confined locations and for overbank floods lesser than that of 1993, this has been an adequate assumption.

A simple reservoir routing algorithm is used in the existing UNET model to compute the flow through the levee breach; the routing coefficient can be fitted to observed data (hindcasting). Application of the UNET system to forecasting, however, should use coefficients and parameters derived as much as possible from field measurable information, rather than calibrated to past events. The routing coefficient that needs to be selected is the *k* in the equation:

$$Q_s = k\Delta V$$

where V is the volume of storage, Q_s is the flow of water to or from a storage cell (i.e., between cells or between the river and cell), ΔV is the volume to be filled or emptied, and *k* is a linear routing factor with the units of $time^{-1}$. In the UNET model, *k* can vary among storage cells, but does not change with time nor with breach parameters such as width.

The above description of levee breaches and the associated hydraulics is simplified. As a part of the MBMS development, research was performed to develop a physical interpretation of the linear routing coefficients (Shen and Zhao, 1995). This research involved comparing results using the storage area (linear routing) technique with those obtained using a fully two-dimensional hydrodynamic model. It was concluded that the routing coefficient required for the storage cell technique could only be accurately determined from past events and not from physical (e.g., topographic) data.

As a result of the 1993 flood on the Missouri River, a new capability for simulating the effects of levee breaches was added to UNET. During 1993 virtually all of the agricultural levees along the Missouri were overtopped, resulting in significant overbank conveyance. This situation poses a peculiar modeling problem. For flows below a certain transition discharge, the levee interior acts as a storage cell which communicates with the river through a breach, or breaches, in the embankment. When flow exceeds the transition discharge the area behind the levee no longer acts as a storage cell but becomes part of the river, conveying flow. Therefore, there are two situations that must be modeled; a storage cell and a flowing river. An algorithm was developed that allows the overbank storage areas to change to conveyance areas (and back) based upon a triggering river flow or stage. Consequently, the conveyance and storage of the levee cells is described by traditional cross section data rather than with a lumped routing coefficient. A detailed description of this technique, known as the "Kansas City Levee Algorithm", is given in the Kansas City District (NWK) Appendix and has been incorporated into HEC-UNET Ver. 4.0.

Note, however, that these techniques do not directly predict the location, size, or timing of a levee breach. Once these parameters are known or estimated, however, the impacts of the levee breach on upstream and downstream flows and stages can be computed. Operationally, from forecasted stages, the forecaster may be able to hypothesize the locations and times of potential levee breaches and use the MBMS to rapidly evaluate impacts of various scenarios. Such an application would require that the possible levee overtopping and/or breaching parameters be built into the geometric data.

3.3.2 Dike Fields. A dike field is defined as a system of structures that contract the low flow cross-section to the design width of the navigation channel. UNET is one-dimensional; therefore, the local effects of each individual dike cannot be simulated. Rather, the cross sections are contracted to simulate the flow contraction caused by the dike field. The area blocked by the dike field can be modeled as a storage area or as a dead area which is deducted from the cross-sectional area. The storage area simulates the condition where the area behind the dike has not filled with sediment and stores water. When the water exceeds the top of the dike, the storage area is assumed to return to active flow area, since the submerged dike field has little impact on the conveyance at high flow. Simulation of the added form roughness of the submerged dike is part of the model calibration. The dead area simulates the condition when the area behind the dike has filled with sediment and both the conveyance and storage of that area are lost for all river stages. Details of the operation and application of the UNET dike field simulation capability are presented in the Kansas City District (NWK) Appendix.

3.3.3 Navigation Dam Algorithms. A major effort was undertaken to provide the ability to simulate lock and dam operations (as shown in Fig. 4) with the UNET system (Barkau, 1996). The capability to use operating rule curves at navigation dams as internal boundary conditions was developed and implemented. Preparation of the input data necessary to describe these rule curves was accomplished by the District offices. Descriptions of the application of this feature may be found in the Rock Island District (MVR) and St. Louis District (MVS) Appendices.

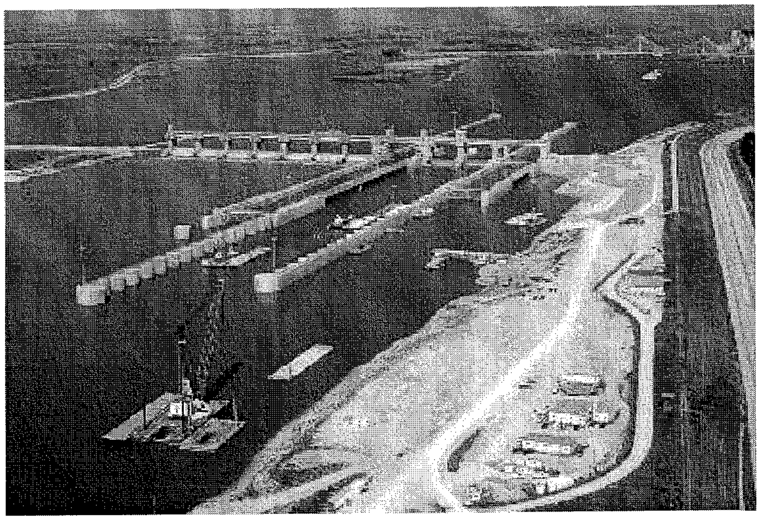


Figure 4. Melvin Price Lock and Dam

Two types of navigation dam operation can be simulated with the MBMS:

Control point within the navigation pool. For this type of operation, the navigation pool is adjusted to maintain a constant elevation at a control point in the navigation pool. This procedure is also called hinge pool operation because the pool conceptually tilts about the control point. The hinge pool operation was devised to minimize the amount of flooded land that had to be purchased by the Government in the upper reaches of the pool. The operation of a hinge pool is defined by an operating curve (essentially a rating curve) at the dam. The operating curve is usually derived from experience. Operating curves are a set of functions which relate control point elevation to pool elevation at constant flow. An example of the operation criteria that can be prescribed by input data for a hinge pool is shown on Figure 5. Figure 5 portrays a hinge pool operation as used by the St. Louis District. In this case, the instruction to the lockmaster is to maintain a target pool elevation.

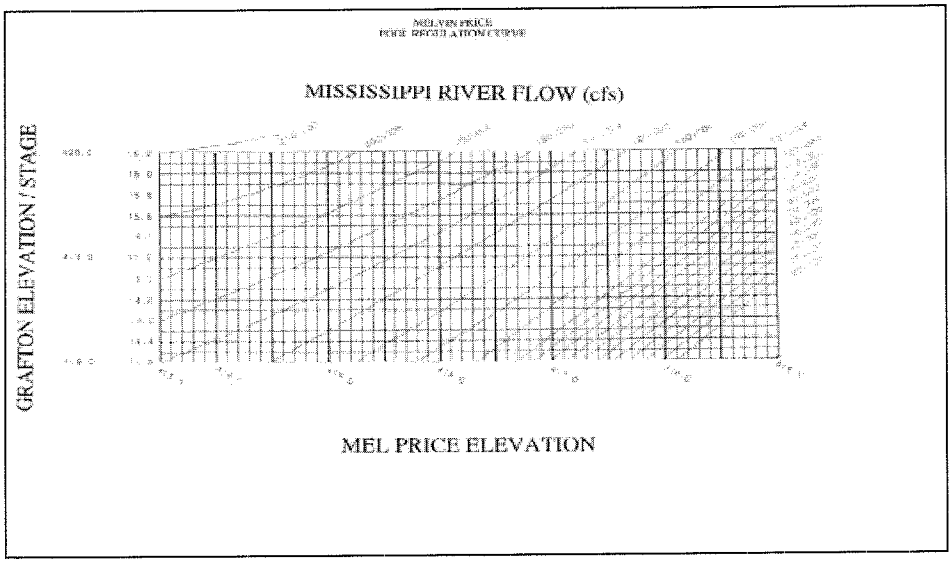


Figure 5. Melvin Price L&D Hinge Pool Operation

Control point at the dam. This is the simplest regulation procedure for a navigation dam. The navigation pool is maintained at a target elevation at the dam. When the tailwater elevation plus the swellhead through the structure exceeds the target elevation, the pool is no longer controlled by the dam and the dam is in open river condition. The target elevation can change with the seasons. Figure 6 reflects a general operation as performed by the St. Paul District. For high flows tailwater controls (open river condition) and the difference between the pool and tailwater is the loss at the structure (swellhead). For lesser flows, gates are set to maintain a constant pool elevation. For low flows, the pool level is increased to maintain an upstream navigation depth. In this case, the lockmaster is given gate settings. Flexibility must be provided to allow for seasonal variations (ice, wind, etc.) and local requirements.

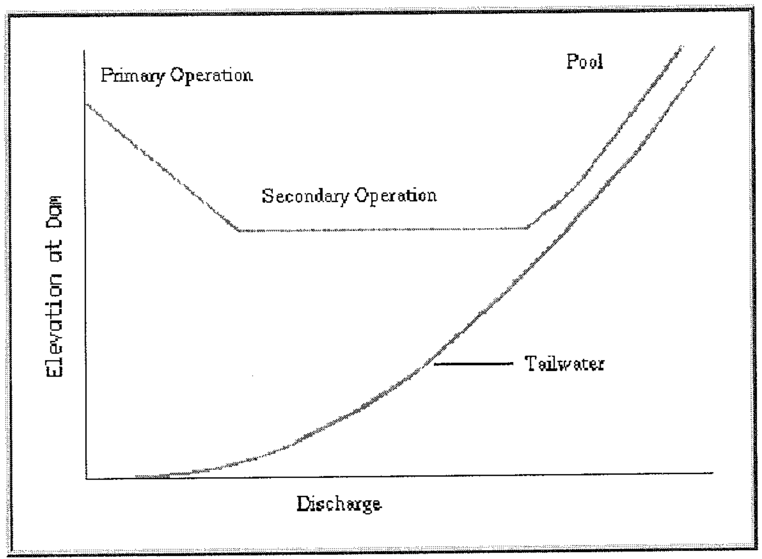


Figure 6. St. Paul Dist. L & D Operation

The UNET navigation dam algorithm functions for two modes of application - simulation application and forecast application.

Simulation vs. Forecast application. Under simulated operation, the navigation dam algorithm operates the dam exactly as specified in the regulation manual. At each time step, the UNET program (within the limits of computational, data and calibration accuracy) will exactly reproduce the target pool stage at the control point, whether that point is at the dam or within the pool.

Under forecast operation, the navigation dam algorithm will exactly reproduce pool stages at the dam until the time of forecast. After the forecast time, the program will either:

1. Simulate the target elevations as specified by the regulation manual.
2. Simulate target pool elevations as specified by the regulator.
3. Simulate an outflow hydrograph specified by the regulator.

The concept is to provide the forecaster with the information needed to make decisions quickly and easily.

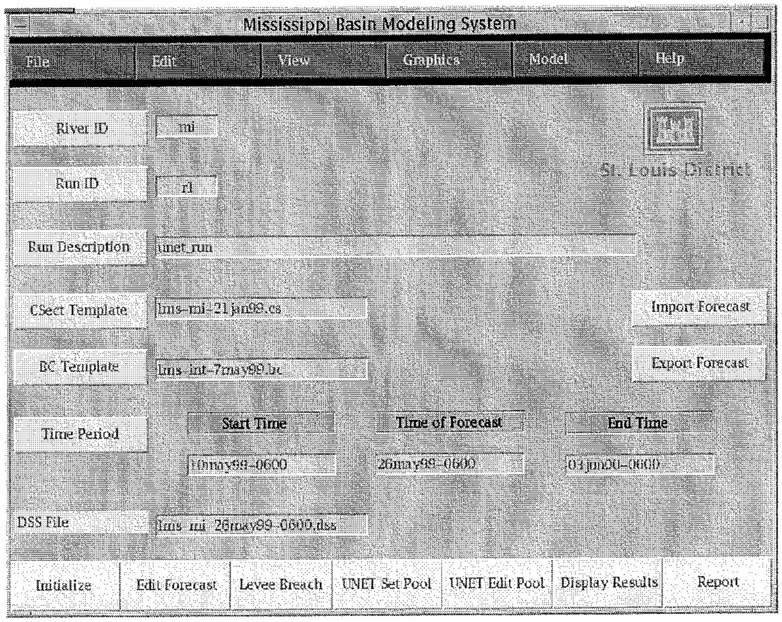
To assist with these forecast capabilities, Dr. Barkau revised the program LDGATE for the Rock Island District. The function of LDGATE is to provide suggested gate settings for a given flow; or, conversely, to compute a flow for given gate settings and water surface elevations. The program works from data definition files that describe the number, types, elevations and sizes of the gates for each of the structures so that appropriate hydraulic computations can be performed. Those files were developed by the offices responsible for the structures. The LDGATE program is not part of the MBMS UNET or HEC-UNET.

3.3.4 Null Internal Boundary Condition. The "null internal boundary condition" (NIBC) is a modification to the UNET system created by Dr. Barkau to estimate residual (incremental) flows between gages where hydrologic models were not available (Barkau, 1995; HEC, 2001). These may be thought of as ungaged lateral inflows or outflows. The NIBC is inserted between two identical cross sections that overlay each other. The NIBC assumes that the flow and stage at the two cross sections are the same. For any reach of river of substantial length, the NIBC is applied at the principal gage locations where the stage records are the most accurate. This procedure requires two executions of UNET. The first assumes stage continuity at gages, with each gage location being an internal boundary condition. This results in computed flows both upstream and downstream of the gage, which will most likely differ. DSSMATH (an HEC-DSS utility) is then used to compute the flow difference between gages to achieve flow continuity at the gages. The flow difference is then distributed throughout the upstream reach (usually uniformly) and lagged in time as deemed appropriate. The second execution uses these flows as (uniform) lateral inflow hydrographs and removes the internal boundary conditions, resulting in an open river condition at the gages. This technique assumes that the model is well calibrated. It has been applied to the Kansas City District's reach of the Missouri River and is available in ver. 4.0.

3.4 Migration to UNIX for Water Control Activities. The computer platform for water control applications is the Sun Sparc workstation with the Solaris operating system, which is UNIX. The development and application of the UNET system, however, has been on DOS personal computers. The HEC-DSS system has already been ported to UNIX as part of the real-time water control R&D effort. A substantial effort was performed in FY 1996 to make the MBMS version of UNET, with the recent updates to the software (levee breach algorithms, etc.) and the data, operational in the UNIX environment. Data files were tested and the proper interaction of the latest Mississippi version of UNET with the interface was confirmed. Many modifications to the UNET source code and file handling procedures were made. The UNET code, graphical user interface (GUI), data management and display systems continued to be developed throughout FY 1996 and 1997 as the system was adapted to the real-time forecasting work environment. Substantial effort was expended by HEC and ERDC/CECRL working with individual field offices to customize the GUI for local place names, etc.

3.4.1 Graphical User Interface. The GUI developed for the MBMS was based on work done by the Corps Cold Regions Research and Engineering Laboratory for the Missouri River Division. That work involved management of releases from mainstem Missouri River dams to ameliorate endangered species habitat. It was primarily a "simulation" application. That interface was expanded to meet the needs for forecasting applications. The enhancements to the interface included; consistent file management, implementation of a UNET hotstart capability, easy time window selection, and interaction with DSS-DSPLAY in a fashion consistent with water control needs. The GUI runs under UNIX (HEC, 1999). The GUI also interfaces with a geographic information system (GIS) to provide map-based interaction with the data displays.

Figure 7 shows the screen presented upon selection of the "Model" button on the entry screen. This screen provides the user with identification of the static data currently in use (River ID, CSect Template, and BC Template). The time period represents the entire simulation period which includes a warm-up period prior to the time of forecast and the forecast period. The warm-up period is used to blend in any changes to the system that have occurred since the last forecast. An example would be updating the



River ID: mi

Run ID: r1

Run Description: unet_run

CSect Template: lms-mi-21jan98.cs

BC Template: lms-int-7may99.bc

Time Period

Start Time	Time of Forecast	End Time
10may99-0600	26may99-0600	03jun00-0600

DSS File: lms-mi-26may99-0600.dss

Figure 7. MBMS GUI Control Screen

extrapolated local inflows to match the flows based on observed data from the last time of forecast to the present one. The execution of the UNET system is launched from this screen via the "Run UNET" button.

The "Edit Forecast" button allows the forecaster to edit the forecasted flows either graphically or by entering their new values. The "Display Results" button allows selection of a gage station, location or profile for display of computed hydrographs or water surface profile elevations. The "Levee Breach" button generates a scrollable display of the levees defined as having potential for overtopping/breaching. Breach parameters, such as time of initiation, can be interactively changed from this screen. Most of the GUI data edit capabilities are essentially DSS-DSPLAY operations and, therefore, are familiar to HEC-DSS users.

The GUI is operational at all District offices involved in this study. The GUI files have been customized by ERDC/CECRL and HEC to include local gage names, river names, etc. District H&H personnel have worked with ERDC/CECRL and HEC personnel to transfer this technology to local water control units. The GUI and the MBMS hydrodynamic software are uniform among the Districts. In addition to using utility software that was developed prior to the MBMS development and implementation, custom support software for data acquisition and transmittal has been developed by some offices.

4. Two-Dimensional Modeling Capability for Overbank Areas. An accurate description of combined channel and overland flood flow requires a blend of one- (1-D) and two-dimensional (2-D) surface water flow modeling concepts. Two-dimensional computations in a floodplain can range from being fully 2-D and dynamic to consisting of only a few large storage cells with momentum effects completely neglected. For example, through the use of storage cells, UNET provides a method to account for floodplain storage and allows a highly skilled modeler to approximate kinematic floodplain routing through a coarse network of storage cells. A recent evaluation of surface water flow models by ERDC/CHL suggested that it is possible to link 1-D channel flow models, such as UNET, with a 2-D finite volume overland flow model. The overall objective of this task has been to develop the 2-D model and then to formulate, implement, and test a linkage methodology which will allow combined channel and overland flood modeling. This methodology permits 2-D dynamic routing of flows across a floodplain represented by moderate to high resolution finite volume grids. The same linkage methodology could be applied to a number of different 1-D and 2-D routing models.

The 2-D floodplain routing model is similar to UNET in that conservation of mass and momentum equations are solved. For purposes of model flexibility, however, an explicit numerical solution has been selected. The 2-D finite-volume method divides the system into an unstructured grid of cells where stage is defined at the center of the cell. Flows are defined along one-dimensional channels that link the centers of the finite volume cells. The basic concept is illustrated in Figure 8.

In general, the 2-D finite-volume model solves one-dimensional equations in the channels for the conservation of momentum with the subsequent conservation of flow volume being determined by summing flows across the sides of the 2-D finite volume cells. This approach has three major assumptions: 1) the flow is predominantly unidirectional along each channel, 2) Coriolis and other accelerations normal to the direction of flow are negligible, and 3) individual channels have uniform cross-sectional areas. One feature of the 2-D finite-volume formulation is that it is easy to represent hydraulic structures such as culverts, weirs, and gates, by replacing the momentum equation with the appropriate hydraulic structure equation. The resulting system is highly flexible because complex geometries of interlinked waterways and overbank areas can be easily represented and solving a series of 1-D momentum equations along with the 2-D continuity equation provides an efficient solution scheme for long-term simulations.

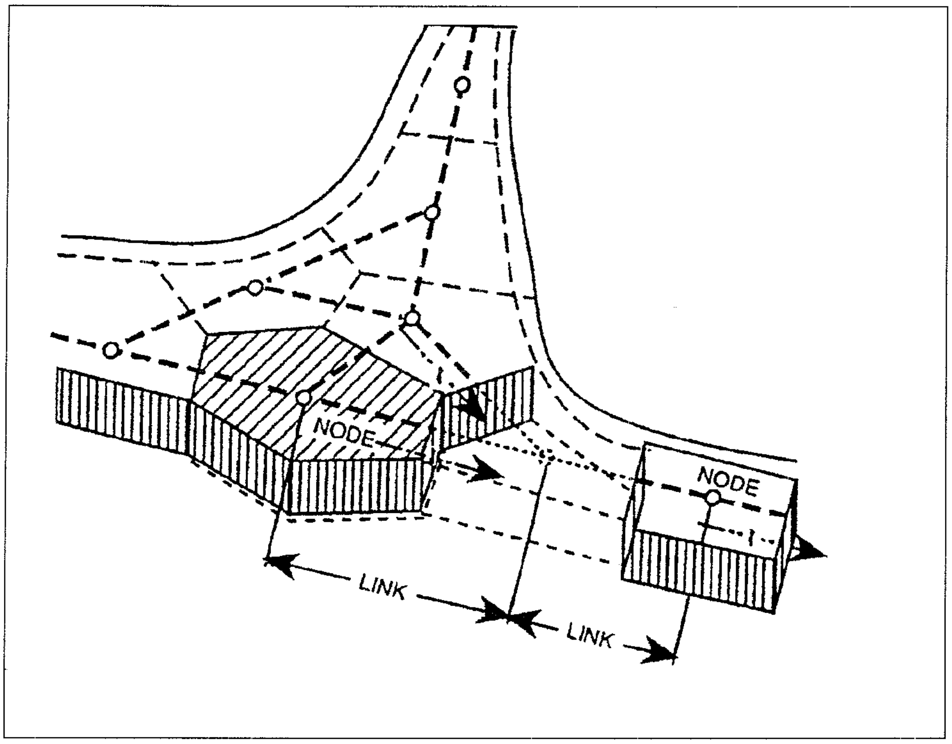


Figure 8. Depiction of Finite Volume Method

The linkage between UNET and the 2-D floodplain model was evaluated by ERDC/CHL via a series of idealized grid and interior boundary condition tests. These tests demonstrated that the coupling between the two models performed well in a highly stable manner and that flow volume was conserved. Following these tests, a 2-D model grid, Figure 9, was developed representing a portion of St. Charles County, MO, where cross-basin flows from the Missouri River into the Mississippi River occur during large floods.

Typically, cross-basin flows in this system occur when agricultural levees along the Missouri River overtop and/or breach, resulting in a significant diversion of flow into the Mississippi River. After levee crevassing occurs, the diverted flow is controlled by a railroad embankment that extends from high-ground in the vicinity of Orchard Farm, Missouri, downstream to West Alton, Missouri. Experiments conducted with the 2-D floodplain model revealed that the computed diversion hydrograph was sensitive both to assumed levee breach characteristics and the hydraulic geometry of the railroad embankment. Reliable forecasting of the diversion flow hydrograph will require research to improve methods for computing flow through levee crevasses. Subsequent to development of this model, high-resolution digital terrain models of the study area, including embankment profiles, have been developed which could be used to develop a more detailed and extensive 2-D hydraulic floodplain model representing existing conditions.

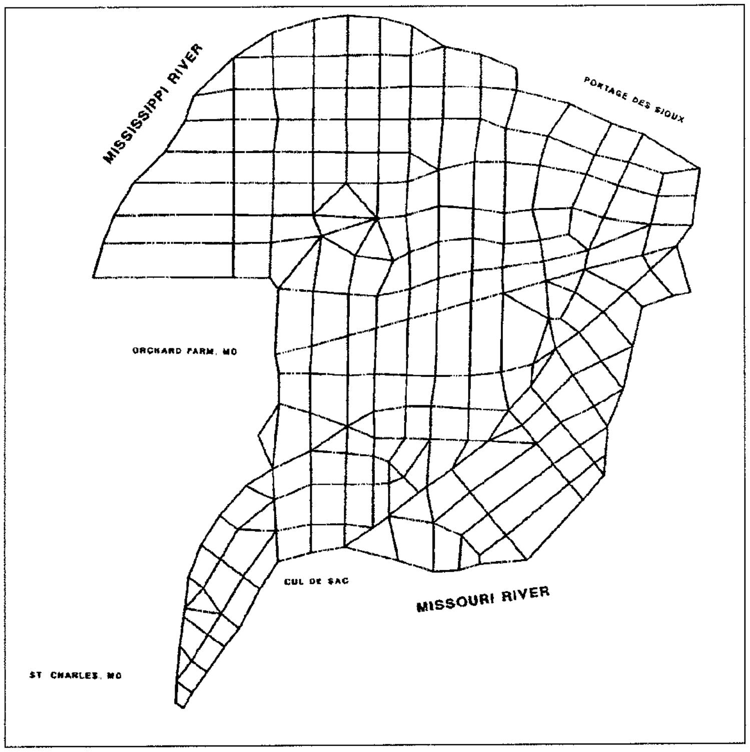


Figure 9. Two-Dimensional Model Grid for Crossover Area

A second 2-D floodplain model representing the Birds Point-New Madrid Floodway has been developed and linked to the Ohio River Forecast Model[1]. The 2-D floodway model is being used to simulate operation of the floodway during a hypothetical project flood. Floodway operation is a complex undertaking which includes phased creation of levee breaches at multiple locations and overtopping of fuse-plug segments at both ends of the frontline Levee separating the floodway from the Mississippi River. The floodway is also subject to backwater flooding through a gap between the setback and frontline levees at the lower end of the floodway. Determination of interior stages and flow distribution with a 1-D unsteady flow model would be very difficult given the irregular shape of the floodway boundary combined with multiple inflow/outflow locations. Many previous studies of the floodway were conducted using a large-scale physical hydraulic model, the Mississippi Basin Model (MBM), which has been retired from service. The 2-D floodplain model permits direct computation of spatially distributed stage and flow at a horizontal resolution of 300 to 1000 meters (with better resolution possible at the expense of greater computational time). Floodway inundation from both backwater flooding and levee crevasses may be visualized by creating animations directly from the stage computed by the 2-D model.

---

[1] The Ohio River Forecast Model is a 1-D unsteady flow model of the Ohio River, its major tributaries, and relevant portions of the Mississippi River that was developed by the WES in the early 1980's and subsequently enhanced by the Ohio River Division Reservoir Control Center (RCC) The model has been used as a forecasting tool since its delivery to the RCC in 1984.

5. Inundation Mapping. The integration and use of geographical information systems (GISs) and digital elevation models (DEMs) to develop, interpret and present the results of hydraulic modeling is available to users of the MBMS. Much of the software and data that are available was developed external to the MBMS (Fry and Dozzi, 1997). A key component of the GUI development was the incorporation of existing GIS sources into the use of UNET for the MBMS.

Inundation mapping allows one to graphically display model results of both the horizontal extent of the water surface and the water depths for a particular point in time. Procedures for conducting inundation mapping are being developed and tested for one demonstration area in each District involved in the MBMS project. During FY2001 GIS-based inundation mapping was completed for a Mississippi River reach from L&D 24 to L&D 25 in the St. Louis District and was initiated for a Missouri River reach below the Gavin's Point Dam in the Omaha District. The general inundation mapping procedures developed are described below using results from the St. Louis District study area.

ArcView and ArcInfo are the main software tools being used in this effort and several ArcInfo AMLs (Arc Macro Language) and ArcView Avenue scripts have been written to automate the spatial data processing requirements. To create a representation of the land surface, breaklines and elevation mass points (Figure 10) were processed in ArcView with 3D Analyst to generate a TIN (Triangulated Irregular Network). Hydrographic survey data in the form of mass points were included so that the channel's geometry is incorporated into the TIN. In significant channels where hydrographic survey data was lacking, elevations were interpolated using best available data. Breakline and mass point data can be provided in several formats including text files, CADD design files, or other standard digital elevation model formats. To handle text files, an ArcView avenue script was written to convert them to ArcView 3D shapefiles. After the land surface TIN was created and checked, it was converted into a lattice (grid) using ArcInfo.

The process of developing the water surface layer began by importing a HEC-RAS exported GIS file using an ArcInfo AML. This generated ArcInfo coverages for the cross sections and the clip polygon (maximum spatial extent of the cross-sections) (Figure 11).

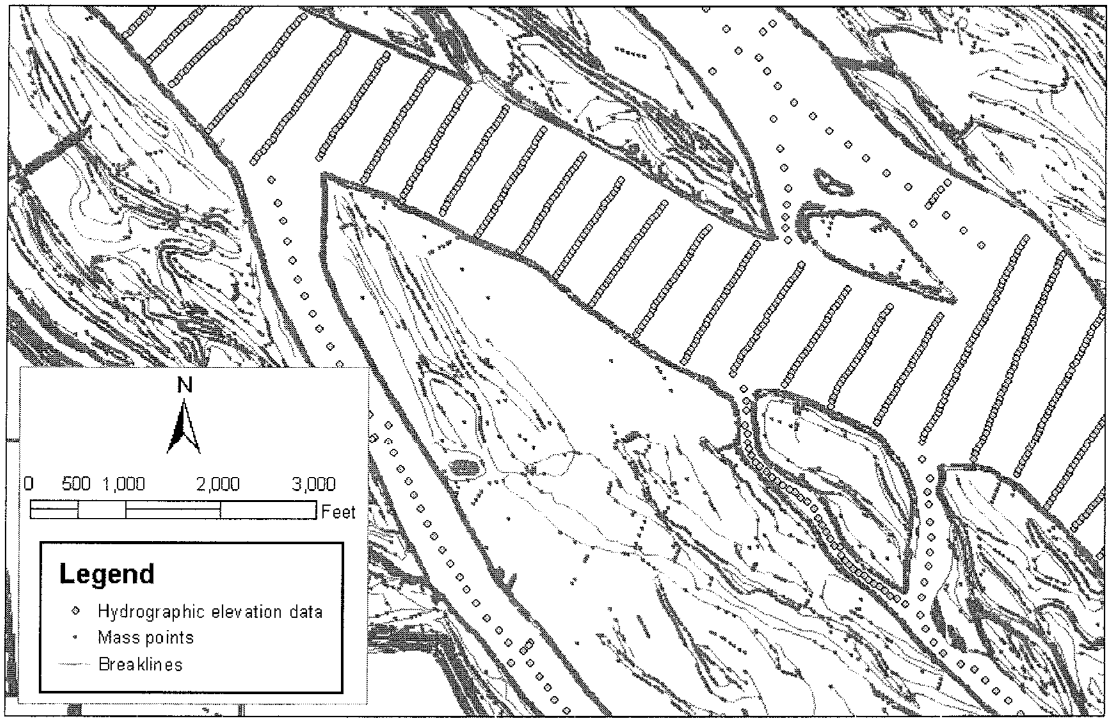


Figure 10. Breaklines and Mass Points That Were Used to Create the Land Surface.

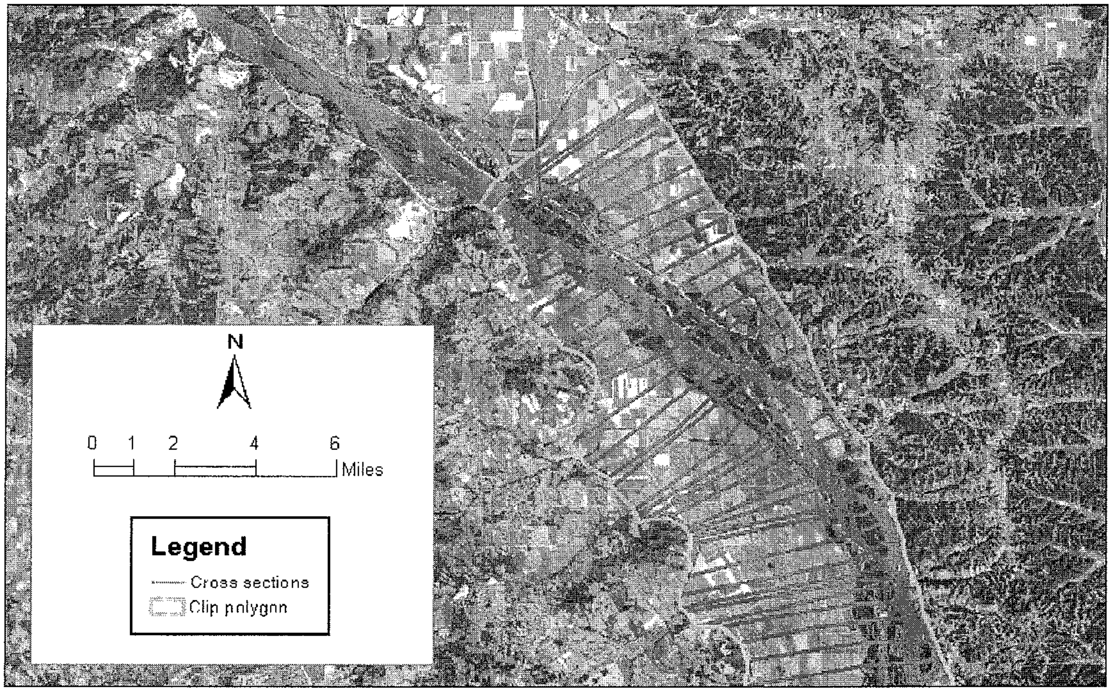


Figure 11. Cross Sections and the Clip Polygon That Were Used to Create the Water Surfaces.

Next, the cross sections not included in the inundation mapping area were deleted from the coverage. The clip polygon was likewise edited to only include the area of interest. In instances where levees are present in the study area, such as for the St. Louis District study area, a polygon coverage is needed to represent them. The coverage used here came from the Scientific Assessment and Strategy Team (SAST), but because coverage attributes (levee names) must correspond to the names in the UNET model output DSS file, the levee coverage names were changed where necessary to match those in the DSS file.

The next step used an AML to extract the results from the DSS file. This AML first runs DSSUTL macros to write out the stages of each cross section, and if necessary, the interior levee elevations of each levee to text files. The AML then reformats the data, creating new text files that can be imported into ArcInfo tables. After the data was imported into ArcInfo, the cross section stage attributes were joined to the cross section coverage and the levee elevation attributes were joined to the levee coverage.

Next, an AML was executed to create the final GIS layers. If levees are present, the AML first determines if a levee has been overtopped for a given time step. Next, it creates a TIN of the water surface by using the stages associated with each cross section for the time step. If a particular levee is not overtopped, then that area is removed from the water surface TIN. After the water surface TIN was created, the AML converts it to a lattice. The AML generates a second lattice by subtracting the land surface grid from the water surface grid. The final inundation grid (Figure 12) was created by removing the values that are negative (those areas where the land surface is greater than the water surface). In addition, a polygon coverage of the inundated areas was created by using the GRID-CODE field where a value of one indicates inundation.

In theory the process of generating an inundation water surface layer (inundation boundary) is straight forward; estimates of the earth's surface elevation are subtracted from spatially corresponding estimates of water surface elevations and all positive values are considered inundated. However, as described above, considerable data manipulation and other human intervention are typically required to develop a realistic flood inundation layer. The accuracy of the inundation layer produced can be affected by several factors. For example, variable resolution topographic and bathymetric data sets typically must be fused in some way to provide a model of the earth's surface above and below the water line. These data sets often come from diverse data collection systems and from a variety of collection dates and thus the uncertainty or error associated with them is complex. Further, rivers are dynamic systems and bed elevations are typically continuously changing and thus there is always a level of uncertainty in both estimates of elevations and in hydraulic model output. However, recent improvements in survey technologies are enhancing the ability to collect more accurate topographic and bathymetric data while decreasing its cost. As this improved data becomes more readily available, the accuracy associated with estimates of flood inundation boundaries will improve.

Inundation mapping under the MBMS project will be completed for the following areas upon completion of the DEMs and importing and calibrating the associated UNET geometric data:

1. Missouri/Mississippi River crossover area (St. Louis District)

2. Gavin's Point, SD to Sioux City, NE (Omaha District)
3. Jefferson City, MO (Kansas City District)
4. Davenport, IA (Rock Island District)
5. Lacrosse, WI (St. Paul District)

Because each of these areas is unique and may have different data processing requirements, the detailed procedures used for each area will be published in an Inundation Mapping Appendix to this report.

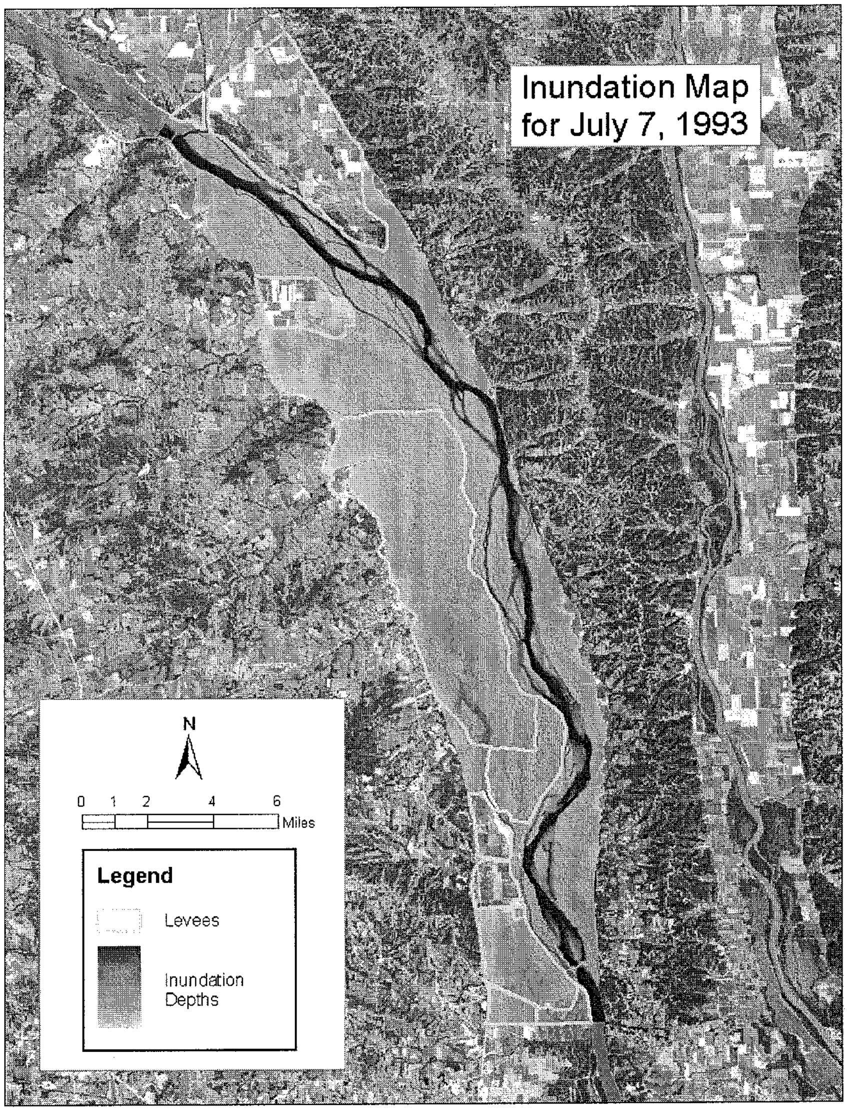


Figure 12. Inundation Map Showing the Water Extent and Depths of UNET Model Results for the Mississippi River on July 7, 1993. (Note the inundation inside some of the levees indicating that they have overtopped.)

6. History of Coordination and Contracting. The Mississippi Basin Model System development team consisted of representatives of the four Divisions involved (NWD-MR, LRD, MVD and SWD), active Districts (MVP, MVR, NWO, NWK and MVS), laboratories (HEC, ERDC/CECRL and ERDC/CHL) and HQ. Dr. Barkau served as a consultant to the team and individually to several of the offices involved. It is anticipated that future coordination will expand outside of the Corps to include the National Weather Service and, possibly, others.

This application of UNET to the Missouri-Mississippi system also provided an opportunity to coordinate with ongoing R&D activities. In particular, the Corps Water Management System (CWMS) software modernization research program will provide the framework within which this model will be used in the future. The UNET system will become integrated with the real-time water control system as a computational tool to perform flow routing and stage prediction for project operations. The components of the CWMS work involving graphical user interfaces and spatial displays of precipitation and inundated areas will support UNET forecasting applications. CWMS coordination meetings that were held at HEC approximately monthly during the latter part of this study included reporting of the status of the Mississippi Basin forecasting effort. Additionally, the HEC River Analysis System (HEC-RAS) is being developed such that UNET can be incorporated as its unsteady flow solver. Several meetings were held with Dr. Barkau to design HEC-RAS's management and use of geometric data to be consistent with UNET. HEC-RAS Ver. 3.0 includes utilization of UNET geometric data descriptions for unsteady flow modeling. These efforts continue to progress simultaneously, with interaction among the several teams.

Coordination and data exchange was also accomplished with the Corps Floodplain Management Assessment (FPMA) teams and the interagency Scientific Assessment and Strategy Team (SAST) (Freeman and Frazier, 1997). These were two complementary efforts to study the impacts of levees on the Missouri-Mississippi river system. The former used UNET to analyze the effects of an array of levee placement options on flood heights and the latter used an interdisciplinary approach to evaluate the consequences of levee placement on wetlands, environmental quality, agricultural use, local economies, etc.

6.1 Coordination Activities (FY1995). Following is a summary of the UNET forecast team meetings held during FY 1995. In general, these meetings served three purposes: 1) share with the group the status of each element's work, 2) identify problem areas and potential resolutions, and 3) identify near term schedules and goals.

19-22 Sept. 1994 in CEMVD. A workshop was presented by Dr. Barkau on the subject of calibration of the various portions of the Mississippi Forecast Model.

24-27 Oct. 1994 in NWD-MR. Discussions of use and selection of boundary conditions and model overlap areas (see Section 6) between offices.

29 Nov.-1 Dec. in MVS. Developed plans for involving Dr. Barkau to upgrade the UNET model being used by Mississippi River analysts to include various levee breach algorithms and lock and dam operations. Presentation of ERDC/CECRL UNET model GUI.

24-25 Jan. 1995 in MVS (SAST mapping). Meeting to prioritize data acquisition for both 2-D and 1-D modeling of the Missouri-Mississippi system.

6-8 Feb. in LRD. Focus was the use and operation of LRD's forecasting system for the Ohio River which uses an unsteady flow model (FLOSED).

25-26 May in MVR. Reporting on status of UNET applications for FPMA, ERDC/CHL 2-D application and data assimilation design.

10-13 July in Ft. Collins, CO. Focus was the design and details of operation and presentation of the UNET forecasting system.

28-30 Aug. in ERDC/CECRL. Focus was on migration of the UNET system to the Sun Solaris workstation and execution of the system with the three primary data files of interest (MVR, NWK, and MVS). Presentation of the "null internal boundary condition" by Dr. Barkau. This feature was designed to compute residual flows.

12-13 Sept. in HEC. Focus was on developing an operational demonstration using HEC equipment. The presentation included involvement of HEC water control staff.

6.2 Coordination Activities (FY1996). Following is a summary of the UNET real-time forecast team meetings held during FY 1996.

24-26 Oct. in MVS. This meeting was to tailor the applications; both UNET and the GUI, to forecasting. Accomplished were the design of data naming conventions and system execution protocols that support the real-time forecasting environment. A real-time oriented GUI design was developed.

6-7 Feb. 1996 in MVS. Design of specific modifications to UNET to simulate and facilitate the operation of lock and dam projects, particularly on the Middle and Upper Mississippi River.

13-15 Feb. in ERDC/CECRL. Testing of changes to the GUI that were defined at the 24-26 Oct. meeting. Kansas City District's data files were used.

28-29 Feb. in NWK. General meeting of the working group to communicate and coordinate activities and plans for FY96 and FY97. Preliminary planning for a demonstration of the system in the Washington D.C. area (HQ) to Corps executives and the NWS.

11-13 March in MVS. Working meeting to test use of the GUI with Rock Island, Kansas City and St. Louis data sets and continue planning for the demonstration.

2-4 April in MVS. Working meeting to further test and understand the use of the GUI and data transfer by Rock Island, Kansas City and St. Louis. Performed live data transfer of forecasts from upstream Districts to downstream Districts and used those data to prepare forecasts by downstream Districts. This effort included use of a remote site (Rock Island).

15-17 July in Washington DC. Presentations and demonstrations of the UNET forecasting system using 1993 data to HQ H&H staff, HQ executive staff and other agencies (see Sec. 6).

6-7 August in MVP. Meeting to review progress of Dr. Barkau on development and implementation of new lock and dam algorithms for UNET. Also prepared a preliminary formulation of detailed FY97 activities and budgets.

6.3 Coordination Activities (FY1997). Following is a summary of the UNET real-time forecast team meetings held during FY1997.

24-25 Oct. 1996 in New Orleans. Meeting to discuss and finalize several issues in preparation for closure of the project at the end of the FY. Some of these items were; provide suggestions for calibration strategy, define a procedure for project operation using the new lock and dam algorithms, define needed additions and changes to the GUI, discuss needs for migration of the system into the Water Control Data System modernization program in FY1998, and develop milestones and responsible offices for the remaining tasks.

7-8 Jan. 1997 in the Missouri River Division. Technical meeting of the UNET specialists and water control personnel. Objectives of the meeting were to define modifications to the graphical user interface (GUI) needed in the final year of the MBMS project for timely completion and to review and modify the final milestone schedule proposed by OCE and HEC.

19-20 March 1997 at the Waterways Experiment Station. The objectives of this meeting were to review study status in light of the identified milestones (see report of the Jan. MBMS working group meeting in NWD-MR), define tasks necessary to meet the remaining milestones, and identify any problems (and their solutions).

7. Data Development.

7.1 Definition of Data. It is useful to categorize "data" into three types:

1. Input (or run) data: The data necessary to operate a numerical model such as UNET. Topographic information (cross sections) and flows entering/leaving the modeled reaches fall into this category.

2. Calibration data: Field data (measurements) used to evaluate the performance of a numerical model and adjust model parameters as necessary to obtain a better match with the measurements. Typically, observed flows and/or stages within the modeled reach are used for the MBMS calibration. Note, these observations may be anecdotal in nature (e.g., "This flood was higher than the flood of 1882.").

3. Verification data (also known as confirmation or circumstantiation data): Additional field data, not used in calibration, that are used to verify that the model performs adequately under conditions other than those for which it was calibrated. It is rare, when dealing with a complex river system such as the Mississippi-Missouri, that verification data will be available. It is incumbent upon the modeler to demonstrate that the results are credible and reliable.

Throughout this report, the specific meaning of the word "data" at any point is communicated either explicitly or via context.

7.2 Data Requirements. In addition to the categories of data described above, the quality and reliability of the data are of interest. It is important to note that all field data contains some degree of measurement error. A continuing area of concern that arose many times during the course of this study is the quantification of the relationship between higher accuracy topographic data and increased accuracy and reliability of the results computed from those data. This has been studied and documented for the use of HEC-2, a one-dimensional steady flow model (HEC, 1986). That study determined that the primary source of uncertainty in computed results was the estimation of energy loss coefficients, not topographic data accuracy using normal surveying standards at that time. Experience with one-dimensional unsteady flow models, such as UNET, has confirmed and expanded that conclusion.

It is important, in the application of an unsteady flow model, that storage as well as conveyance be properly represented. This requires accurate definition of the conveyance and the flow-controlling elevations and locations (e.g., levees, weirs, etc.). Ground elevations in storage areas such as overbanks and leveed areas are not as critical, if the volumetric capacity of those areas is correct. Information based on topographic maps with 1.5m (5 ft.) contours is usually adequate for overbank areas for systems with broad floodplains. When applying a two-dimensional flow model, however, the ground topography becomes more important, particularly in areas of little vertical relief. It was decided that 0.5m (2 ft.) vertical resolution was needed in the cross-over area between the Missouri and Mississippi Rivers for reliable two-dimensional modeling. This requirement depends on the relationship between water depth and bed elevation changes. When applying any of these hydraulic modeling approaches, one must be aware that there is substantial uncertainty in past inflows to the system as well as the forecasted inflows, all of which will influence the reliability of the computed results. Note however, that for the purposes of mapping and producing inundation displays, more detailed overbank topography may be useful.

7.3 Data Access and Use. Specific descriptions of the geographic coverage of the data, its content and use are given in the appendices to this report for each of the offices involved. Also covered in the Appendices are their calibration processes and results. As the data will continue to be updated, the local office remains the primary source for access to UNET input data. Analysis of modeling results and their dissemination are the purview of the performing office.

8. Demonstration of the Modeling System. A demonstration of the operation of the UNET forecasting modeling system was held at Headquarters during 15-17 July 1996. It involved three Districts; Rock Island, Kansas City and St. Louis. These were chosen because their interactions reflect the general needs for data transfer and boundary condition selections that will occur in a real time forecasting environment. Early in the development of the forecasting model, it was conceived to be a single model of the entire Missouri-Mississippi system; this was subsequently deemed impractical for several reasons. First, each District office has knowledge and experience that are unique and valuable to the accuracy, reliability and timeliness of their forecasts. Second, operation of a single, integrated model would be computationally much more cumbersome than performing data transfers between the individual offices. Third, by using a stage boundary condition between segments, the accumulation of numerical error is reduced. Also, response time to locally changing conditions, such as rapidly changing tributary inflows and (potential) levee breaches, will be quicker if the analysis is performed by the local office.

The concept of model "overlap areas" that was developed in the FPMA study continued to be used in this effort. The purpose of these areas is to provide the hydraulic connectivity that couples the various segments of the UNET model together as if it were being run as a whole system. In general, the location of the data transfer (i.e., the passing of the upstream forecast to the downstream office) is within the upstream District. The computational boundary condition used for the upstream District model is located at that District's downstream boundary. This overlap minimizes the influence of uncertainty in the downstream boundary condition on computed results at the transfer location. Within the overlap area, both Districts use the same cross sections. Responsibility for forecasting local inflows within the overlap areas for the Upper Mississippi and Illinois Rivers is that of the downstream District, elsewhere it is that of the upstream District. Inflows to the UNET models are the responsibility of each District within its jurisdictional limits.

Preparation of the MBMS UNET model for the demonstrations took place at the Pulaski Building on the evening of July 14 1996 and the morning of July 15. Field personnel presented an informal demonstration the afternoon of Monday, July 15, to headquarters Hydraulics and Hydrology Branch personnel. Along with introductory text and technical information, the demonstration included execution of the MBMS UNET model with 1993 Flood data for different reservoir release and levee scenarios. The purpose of this demonstration was to present the MBMS and its graphical user interface (GUI) to headquarters H & H staff, and to provide information and visual aids for H&H staff to use in the Command briefing the following morning. This demonstration also served as a practice session for the demonstration scheduled on July 17 for representatives of other Federal agencies.

Both the Command briefing and the demonstration for other Federal agencies were held in a large conference room in the office of the Chief of Engineers. The Command briefing was held on 16 July. It was attended by General Genega and Corps executive staff members from Engineering Division. The progress, status and capabilities of the MBMS were very well received by General Genega and the Corps executive staff.

The MBMS was demonstrated to representatives of the NWS, USGS, FEMA, Federal Highway Administration, and Sun Microsystems (who loaned the computer for the demonstration) on 17

July 1996. One of the representatives of the NWS was Dr. Danny Fread, chief of their hydrology office. Dr. Fread said that he thought it was beneficial that the Corps had developed an unsteady flow model of the Mississippi Basin. He said the NWS is also working on an unsteady flow model, and communication and cooperation between the Corps and the NWS will be enhanced, since both agencies will be talking from the same basis. There were a few questions for more information following the demonstration. The reaction from the other agencies was positive and supportive of this effort.

Following is a brief summary of the components and sequence of the demonstration. First, H&H staff introduced the background, purpose, objectives, geographical coverage, and scope of the study; features of the UNET model; brief description of scenario examples; and current and future tasks of the study. The demonstration scenarios were then presented with HEC operating the graphical user interface (GUI) while the technical person from each District described the scenario being demonstrated. The parts of the GUI were explained. Scenarios that were demonstrated with a "live" run of UNET were: (1) impact of increased releases from a reservoir (Truman) by NWK, (2) impact of increased reservoir releases at St. Louis by MVS, and (3) impact of changes in levee breach characteristics (Sny Levee District) by MVR. MVS discussed the effects at St. Louis of various changes in levee configurations due to overtopping and/or breaching upstream (Sny Levee District) and downstream (Columbia Levee District) of St. Louis. The resulting flow and stage hydrographs computed with UNET were displayed and interpreted. ERDC/CHL discussed implementation of the 2-D model for the Missouri-Mississippi crossover area at St. Charles, Missouri and its connection to the MBMS UNET model. ERDC/CECRL presented the coupling of MBMS results (water surface profiles computed by UNET) and GIS topography to produce inundation maps.

9. Applications of the Modeling System. The St. Paul District (MVP) applied the system during the 1997 flood to forecast water surface elevations on the Mississippi River within the District and to provide the Rock Island District with predictions at Lock and Dam No. 10. The results of these forecasts were also furnished to MVP's Construction-Operations Division for emergency response activities. The results were also posted on the District's water control home page. Preparation of a UNET forecast, using the GUI, required about 20 minutes. Refer to the St. Paul District Appendix for details.

The Rock Island District (MVR) also used the MBMS during the spring flood of 1997. The accuracy of St. Paul District's forecast at Lock and Dam 10 and careful base calibration of the MBMS were key factors in the production of accurate forecasts. The MBMS was run daily by water control personnel from April 10 to May 7, 1997. This experience demonstrated both the accuracy and reliability of the MBMS in a real-time flood application. Details are given in the Rock Island District Appendix.

The St. Louis District (MVS) tested the MBMS in May 1996 during a flood. It was noted that stages at St. Louis were underpredicted by about 2 ft. Further investigation revealed that a shift in the rating curve had occurred. After appropriate conveyance adjustments were made, the forecasted stages were within 1 ft. of the observed. As this was a test application, no further refinements were made. After further calibration, GUI development, and implementation of Lock & Dam algorithms, the MBMS was extensively used during the spring 1997 flood. Generally, the model results deviated from the observations by less than 1 ft. A file transfer system was used to obtain forecasts from MVR for the Mississippi R. and NWK for the Missouri R. MVS's forecasts were then delivered to LRD and MVD. Details are given in the St. Louis District Appendix.

The Mississippi Valley Division (MVD) tested the MBMS during the 1997 flood. Because calibration was not completed at that time, the model was only used to forecast flows (not stages). The flow forecasts looked reasonable and were used to estimate the duration of the Bonnet Carre Spillway operation. See MVD's Appendix.

10. Forecast Availability. Results of MBMS forecasting is typically made available by the forecasting office for other Corps offices (upstream and downstream). These forecasts are being made available for wider distribution. For example, the St. Paul District has been routinely sharing the results of MBMS simulations with other federal agencies such as the National Weather Service and the public. Access to MBMS Modeling results is available via the District's web page as shown on Fig. 13.

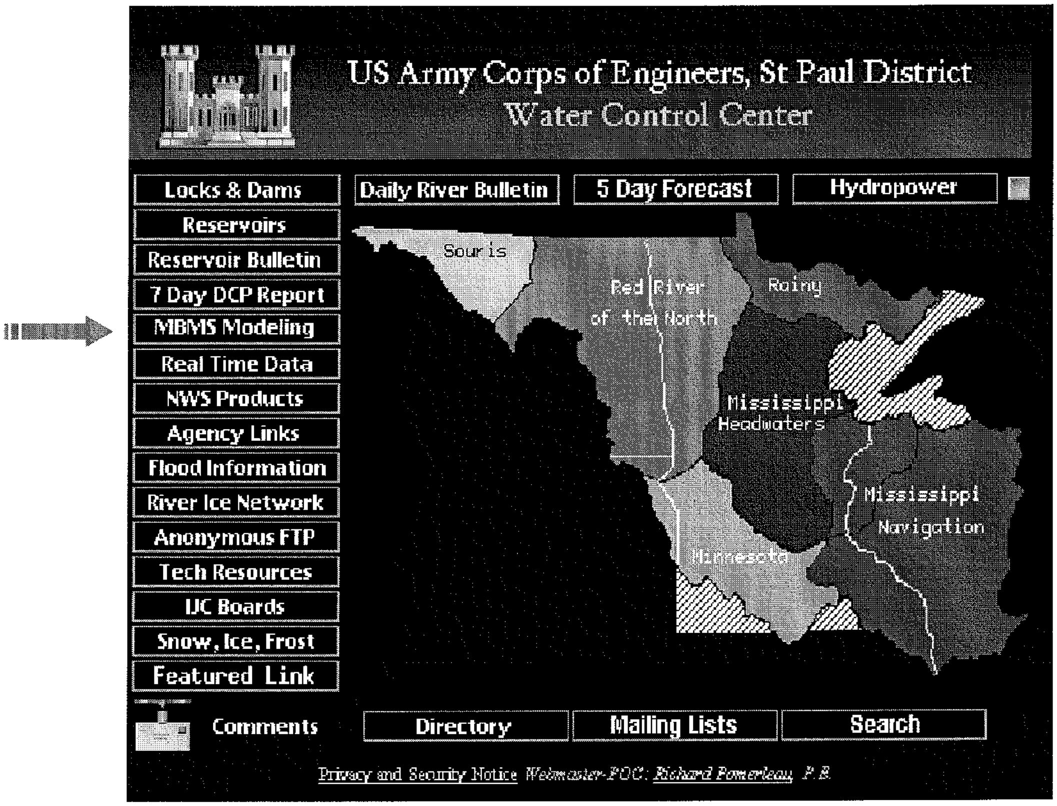


Figure 13. St. Paul District Web Site

The day-to-day operational output of the MBMS consists of observed and forecast flow and stage hydrographs as shown in Fig. 14.

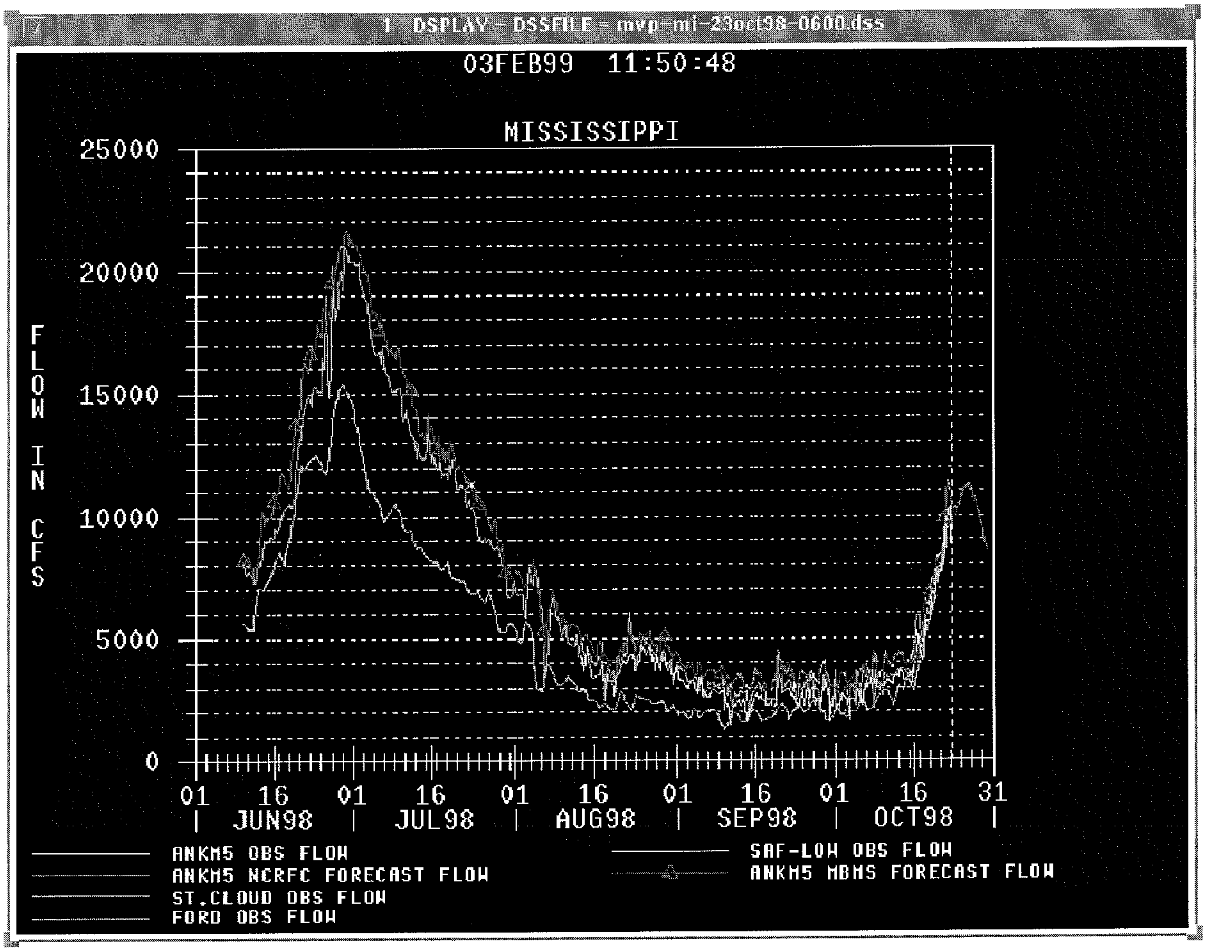


Figure 14. Example Display of MBMS Output and Observed Hydrographs

The MBMS work of the St. Paul District earned the 1999 Seven Wonders of Engineering Award by the Minnesota Professional Engineers.

11. Summary of Achievements Relative to the Enabling Scope of Work.

1. Improve and facilitate the coordination, communication and sharing of data and forecasts among water control activities along the mainstem Mississippi River during all hydrologic conditions ranging from low flows to floods. This can be accomplished through the use of a uniform and consistent channel routing model and data management/display system.

An integrated, uniform and reliable modeling system has been developed and implemented for all of the District offices involved in the Missouri-Mississippi Basin river flow and stage forecasting project. The components of this system are described in Sec. 2.3. The design of the system allows use of familiar software modules (e.g., UNET and HEC-DSS) operating under a common GUI with the integration of locally-developed utilities for data acquisition, manipulation and communication. This effort leveraged on past work (SAST and FPMA) to focus on forecasting, utilizing the available framework of data, software and experience. A prototype of the MBMS was demonstrated to Corps Engineering Division Executive staff and representatives of other Federal agencies in July 1996 (see Sec. 6). The success of this project is further evident in that the MBMS was used, on-line, in real-time, during flood events in the Mississippi River Basin in the Spring of 1997. The range of applications extended from assistance to emergency management (MVP) to the estimation of the duration of operation of the Bonnet Carre spillway (MVD).

2. Assess impacts of levee breaching and floodway operations on local and downstream areas.

Tools were developed and implemented for the analysis of the impacts of levee breaches. That effort consisted of an analysis of pre-MBMS capability (Sec. 3.3.1), development and application of new algorithms reflecting both the conveyance and storage of the leveed areas ("Kansas City Levee Algorithm", NWK), and detailed two-dimensional modeling of flows and stages in overbank areas (Sec. 4). Integration of the products of that effort into the real-time forecasting process requires off-line preparation of data descriptions that describe potential scenarios that can be activated at forecast time. A general analysis of the impacts of levee breaches and configurations was performed for the FPMA study.

3. Support emergency management activities through timely prediction of stage and rate of rise.

The MBMS computes both flow and water surface elevation as functions of time (both past and future) at locations of interest. The forecasts are dependent upon predicted inflows to the system. Modifications to predicted inflows can be rapidly (10-20 min.) accommodated and the changed forecast disseminated to clients. This functionality was demonstrated during the Spring flood of 1997 (MVP).

4. Display areal extent of flooding potential for various predicted weather scenarios and levee failures.

Software has been developed or modified to present hydrographs of both flow and stage to the forecaster reflecting various weather and levee breach scenarios. This information is of critical use for emergency response and was used during the 1997 flood by the St. Paul District. Corps of Engineer offices are using GIS technology based upon local data bases to blend the results of MBMS modeling with topographic information. The results of two-dimensional overbank flow modeling (Sec. 4) can be used to produce animated graphics of flooding.

5. Identify navigation hazards.

The MBMS was developed to simulate and forecast low-flow and routine day-to-day situations as well as those occurring during flood events (Sec. 1.1). A major developmental effort undertaken for this project produced the capability of the UNET system to simulate the operation of lock and dam structures (Sec. 3.3.3). These developments, combined with the modeling System's ability to route the impacts of lock and dam operational changes throughout the river system, allow the prediction and identification of resultant navigation hazards. The effectiveness of operational modifications proposed to alleviate those potential hazards can then be readily analyzed.

6. Provide data for real-time flood damage assessment.

A critical design component of the MBMS was the provision of data for post-forecast analysis. This primarily consists of providing information to potential users in readily accessible format. An important outcome of the MBMS implementation effort was the sharing of communication protocols and experiences among the District offices. HEC-DSS continues to be the backbone of data sharing and some offices are posting forecast information on their Web page. Interaction with the Corps Water Management System (CWMS) development will continue to be the mechanism by which the products of the MBMS development project will become integrated into routine usage within the Mississippi Basin, Corps-wide and externally.

12. References.

Barkau, R. L., 1994, "Impact of Levees on the Middle Mississippi River", a report prepared for The Scientific Assessment and Strategy Team, July 15, 1994.
Barkau, R. L., 1995, "The Estimation of Ungaged Inflow Using the Null Internal Boundary Condition", August 1995.
Barkau, R. L., 1996, "Navigation Dam Algorithm", a report submitted to the Hydrologic Engineering Center, December 1996 (Appendix J of HEC FY96 MBMS Status Report).
Freeman, G.E., and Frazier, A.G., 1997, "Proceedings of the Scientific Assessment and Strategy Team Workshop on Hydrology, Ecology, and Hydraulics", v. 5 *of* Kelmelis, J.A., ed., Science for Floodplain Management into the 21st Century: Washington, D.C., U.S. Government Printing Office.
Fry, W. G., and Dozzi, J. T., 1997, "A New Look at Old Man River", *Civil Engineering*, June 1997, pp. 49-51.
Gee, D. M., and Tseng, M. T., 1996. "Unsteady Flow Model for Forecasting Missouri and Mississippi Rivers", *Proceedings* RIVERTECH '96 1st International Conference on New/Emerging Concepts for Rivers, September 22-26 1996, Chicago, Illinois, pp. 869-876. International Water Resources Association, Urbana, IL, USA. (Also published as HEC Technical Paper No. 157, February 1997.)
Hydrologic Engineering Center (HEC), 1986, *Accuracy of Computed Water Surface Profiles*, RD-26, U.S. Army Corps of Engineers, Davis, CA, December 1986.
HEC, 1990, *HEC-2 Water Surface Profiles*, User's Manual, CPD-2A, U.S. Army Corps of Engineers, Davis, CA, September 1990.
HEC, 1995, *HEC-DSS User's Guide and Utility Manuals*, User's Manual, CPD-45, U.S. Army Corps of Engineers, Davis, CA, March 1995.
HEC, 1998, "Mississippi Basin Modeling System Development and Application," Project Report-36, U.S. Army Corps of Engineers, Davis, CA, April 1998.
HEC, 1999, "Mississippi Basin Modeling System Operations Guide," Project Report-36A, U.S. Army Corp of Engineers, Davis CA, April 1999.
HEC, 2000, "Corps Water Management System (CWMS), Technical Paper No. 158, June 2000.
HEC, 2001, *UNET One-Dimensional Unsteady Flow Through a Full Network of Open Channels*, User's Manual, CPD-66, Ver. 4.0, U.S. Army Corps of Engineers, Davis, CA, April 2001.
Interagency Floodplain Management Review Committee, 1994, *Sharing the Challenge: Floodplain Management into the 21st Century*, Report to the Administration Floodplain Management Task Force, U.S. Government Printing Office, Superintendent of Documents, Washington, D.C., 189 pp., June 1994.
North Central Division, U.S. Army Corps of Engineers, 1994, *The Great Flood of 1993 Post-Flood Report - Upper Mississippi River and Lower Missouri River Basins*, Main Report, September 1994.
Shen, H. W. and Zhao, D., 1995, "Two Dimensional Unsteady Flow Model for Levee Breach Studies", a report prepared for the U.S. Army Corps of Engineers Hydrologic Engineering Center, November, 1995.
U.S. Army Corps of Engineers (USACE), 1993, *River Hydraulics*, Engineer Manual 1110-2-1416, Headquarters, U.S. Army Corps of Engineers, Washington, DC, October 1993.

USACE, 1995, *Floodplain Management Assessment of the Upper Mississippi and Lower Missouri Rivers and Their Tributaries - Main Report*, U.S. Army Corps of Engineers, Washington, DC, June 1995.

Zhao, D. H., Shen, H. W., Tabios, G. Q., Lai, J. S., and Tan, W. Y., 1994, "Finite-Volume Two-Dimensional Unsteady-Flow Model for River Basins", *Journal of Hydraulic Engineering*, ASCE, Vol. 120, No. 7, pp. 863-883, July 1994.

St. Paul District

(MVP)

TABLE OF CONTENTS

MISSISSIPPI RIVER REAL-TIME FORECAST MODEL
St. Paul District

1.0 Geographic Coverage. The St. Paul District performed hydraulic modeling along the Mississippi River. The hydraulic modeling starts at Anoka, Minnesota, at river mile (RM) 864.8, and continues downstream to Dubuque, Iowa, at RM 582.0. Even though the model extends to Dubuque, it is intended to provide results only for the reach upstream of (and including) Guttenberg, Iowa, at Lock and Dam 10. Guttenberg marks the boundary of the St. Paul District and the Rock Island District on the Mississippi River. Extension of the UNET model to Dubuque provides a convergence reach taking care of any mathematical instability or errors introduced from the downstream boundary condition. A general location map illustrating significant project features within the study reach is shown on Figure MVP-1.

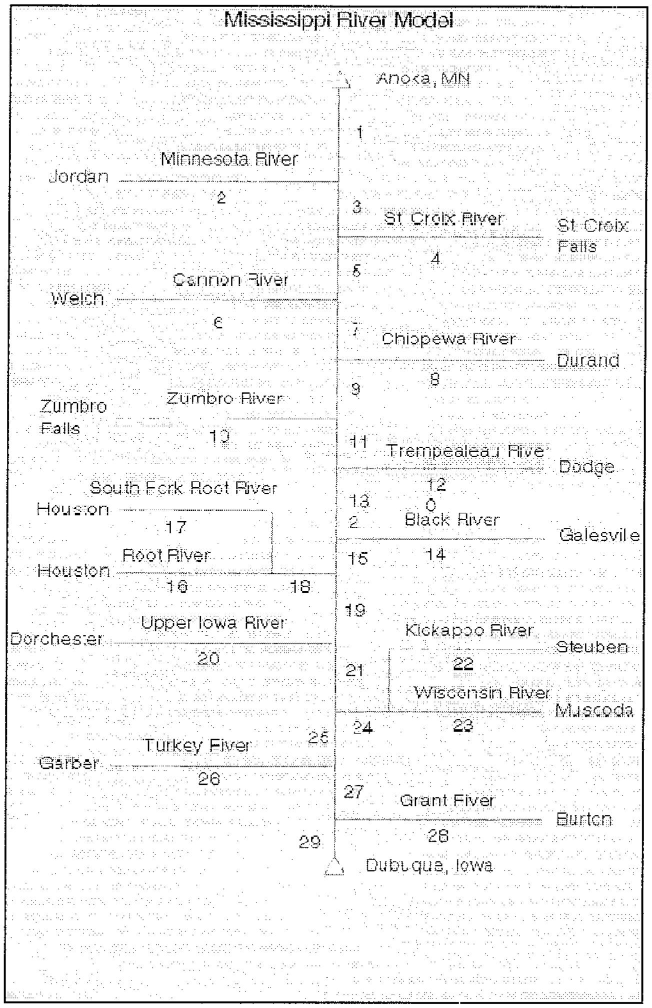


Figure MVP-1. Schematic of the St. Paul District MBMS Model.

2.0 Hydrologic/Geographic Description of the Area. The headwaters of the Mississippi River are in north central Minnesota in a region of dense forests, great swamps and thousands of lakes. The river begins at the outlet of Lake Itasca at an elevation of 1463 feet above sea level, and flows north, east and then southwest through timbered landscape to Brainerd, Minnesota. It flows south from Brainerd and then to the southeast through a broad, shallow glacial outwash valley to Minneapolis-St. Paul, Minnesota, and the confluence of the Minnesota River. At this point, it leaves the northern woodlands and lakes and meanders southward past fertile prairies and numerous towns and cities. High bluffs often bank the river. The St. Croix River flows into the Mississippi River at Prescott, Wisconsin. The Mississippi River forms the boundary between Minnesota and Wisconsin below this junction. Farther south, the river forms the boundary between Iowa and Wisconsin. Sixteen river miles above Lock and Dam 10 at Guttenberg, Iowa, the Wisconsin River joins the Mississippi River. The Mississippi River drops about 850 feet (almost 60 percent of its total fall) within the St. Paul District. The Mississippi River and its tributaries in the St. Paul District drain an area of almost 80,000 square miles, of which 45,000 square miles are in Minnesota, 32,000 square miles are in Wisconsin and the remainder are in South Dakota and Iowa. Between Anoka, Minnesota, and Guttenberg, Iowa, the Mississippi River drainage area increases from 19,000 square miles to 80,000 square miles.

3.0 Tributaries. The major tributaries to the Mississippi River from Anoka, Minnesota, to Dubuque, Iowa, are described in the following paragraphs.

a. Minnesota River - RM 844.0. The source of the Minnesota River is the Little Minnesota River, which flows into Big Stone Lake, located on the Minnesota-South Dakota border. There is a low divide between it and the Red River basin to the north. During the glacial epoch, the present-day Red River and Minnesota River valleys provided drainage for glacial Lake Agassiz. Lake Agassiz was a huge body of water about 110,000 square miles in area that occupied what is now the Red River basin in Minnesota and North Dakota and parts of Ontario and Manitoba, Canada. When the glacial ice that blocked the northern drainage of this lake melted, a tremendous volume of water passed down the present Minnesota River valley. As a result, the valley is characterized by wide floodplains, which have been developed for agriculture and agricultural communities. The Minnesota River passes through a rich agricultural area, and the valley bottomlands, which can be a mile or two in width, are very productive. The low, wide floodplains and the flat slope of the basin, however, make it especially susceptible to flooding. From Big Stone Lake, the Minnesota River flows in a southeasterly direction for about 225 miles to Mankato, Minnesota. At Mankato, the river turns abruptly to the northeast and flows another 106 miles to its mouth at St. Paul, Minnesota, on the Mississippi River. The basin consists generally of an undulating prairie region with the topography characterized by gently rolling hills separated by level outwash plains. The economy and occupations of the area are related chiefly to agriculture and agricultural-based industries. A large portion of the population is rural. The major cities are located along the main stem. The Minnesota River drains an area of about 16,900 square miles, of which nearly 90 percent is in south central Minnesota. The Minnesota River also drains 1,640 square miles in South Dakota and 370 square miles in Iowa. The basin is approximately 230 miles long and varies between 60 and 100 miles in width.

b. St. Croix River - RM 811.3. The St. Croix River is a left bank tributary located on the Minnesota-Wisconsin border. The St. Croix River is deeply entrenched, with rugged terrain. Approximately 38 miles upstream of Taylors Falls, Minnesota, it has its steepest gradient, about 100 feet per mile. The maximum depths and width of the St. Croix River occur on Lake St. Croix with a width of 7,500 feet and depths of 80 to 100 feet. Because of the ruggedness of the river and the lack of development along the upper reaches, the St. Croix River is designated as a Wild and Scenic River.

c. Cannon River - RM 795.7. The Cannon River basin covers 1,411 square miles in southeastern Minnesota. The river flows in an easterly direction, passing through the towns of Northfield, Cannon Falls, and Welch and eventually dumping into the Mississippi River at mile 793. The land use is largely agriculture on the western half of the basin. The east end of the basin has large bedrock gorges.

d. Chippewa River - RM 763.5. The Chippewa River basin covers 9,480 square miles through its entire length, 6,630 square miles of which is upstream of Eau Claire, Wisconsin. The basin includes all or part of 19 counties in Wisconsin and Upper Michigan. The Chippewa River rises in the northern Wisconsin lake region, which includes a small part of Upper Michigan. It flows generally to the southwest across northwestern Wisconsin to its confluence with the Mississippi River at the lower end of Lake Pepin, near Mississippi River Mile 763. The largest tributary to the Chippewa River is the Eau Claire River, which joins the Chippewa River at Eau Claire and drains an area of about 880 square miles. Other important tributaries are the Eau Galle, Red Cedar, Yellow, Jump and Flambeau Rivers. Basin topography in the upper reaches is typified by low, gently rolling hills with numerous potholes, lakes, marshes and swamps. Runoff is very low in this area. In the lower reaches of the basin, the country is more hilly and consists of coulees and uplands, some of which rise to a height of 200 to 400 feet above the floodplain. There is rapid runoff from the upland areas. The overall slope of the Chippewa River is 4 to 5 feet per mile and is controlled by a resistant crystalline bedrock surface. The flattest slopes are in the uppermost and lowermost reaches of the basin. In the uppermost reaches, including the Flambeau-Manitowash headwater system, drainage is through a glacial outwash plain. Here, the slope is only 1.3 feet per mile. In the lower reach, below Eau Claire, the river has a uniform slope of about 1.5 feet per mile and meanders broadly over its 1- to 2-mile-wide floodplain. Over the middle reaches, the river has an average slope of about 5.8 feet per mile. This part of the river is characterized by numerous rapids and falls, which create locally steep-sloped areas. Dams and impoundments, primarily for generating electric power, are located at a number of these steep gradient reaches. Many rapids, however, remain untouched, their primary uses being recreational. About 75 percent of the land in the basin consists of deciduous and coniferous forest, and wetland. The remainder, mostly in the lower reaches, is cropland. Major land uses are recreation, forest management, and agriculture. In the north, forests provide wood harvesting and related manufacturing and, along with the lakes and streams, offer recreation opportunities. Agriculture is dominant in the south.

e. Zumbro River - RM 750.3. The drainage basin in the upper reaches of the Zumbro River is gently undulating agricultural land. East of Rochester, Minnesota, the watershed area is a plateau-like surface dissected by narrow, steep-walled gorges and by tributary coulees, hollows, or ravines. Rochester is located in a bowl-shaped valley about 2 miles in diameter surrounded by bluffs cut by the valleys of the South Fork and its tributaries at that point. Beginning in the Rochester area and extending downstream, the river valleys become sharply defined and the adjacent rock-walled bluffs rise on steep gradients to heights of 100 to 200 feet above the valley floor. At Zumbro Falls, Minnesota, about 24 miles west of the mouth of the river, the valley floor is about 160 feet below the uplands and approximately one-eighth mile wide. Between Zumbro Falls and Kellogg, Minnesota, the upland areas are as much as 500 feet above the valley floor, which is a mile wide in several places. Near Kellogg, the Zumbro River leaves a well-defined valley and crosses a wide, gently sloping area before entering the Mississippi River. Average elevations vary from about 1,300 feet in the upland areas south of Rochester to about 1,000 feet at Rochester and 680 feet near the junction of the Zumbro and Mississippi Rivers. Other than some small marsh-type impoundments, there are no natural lakes in the basin.

f. Trempealeau River - RM 716.2. The Trempealeau River basin covers an area of about 750 square miles in west central Wisconsin about midway between La Crosse and Eau Claire. Its basin characteristics are very similar to those of the Buffalo River. The main stem rises about 9 miles east of Hixton, Wisconsin, about 84 miles above the confluence with the Mississippi River. It then flows in a generally westerly direction to Independence, Wisconsin, then to the south to join the Mississippi River near RM 716. The entire drainage area of the Trempealeau River lies within the unglaciated driftless area. Surface elevations range from about 1,360 feet in the headwaters to about 650 feet in the vicinity of the Mississippi River confluence. The uplands are deeply dissected into rugged ridges and rounded hills. Covered by relatively impervious soils, the steep slopes allow for rapid runoff of surface waters. The broad valley of the Trempealeau River is the result of lateral erosion by the meandering stream. The general slope of the Trempealeau River ranges between 3 and 4 feet per mile. There are steeper slopes in the headwaters of the basin, as much as 30 feet per mile in the uppermost reaches above Hixton. These increase the average slope of the stream, based on a total fall of 555 feet in 84 miles, to about 6.5 feet per mile. The river is free flowing throughout its length. Land use in the basin is primarily agricultural, with steeper sloped areas kept mainly in woodlot.

g. Black River - RM 708.7. The Black River is one of five principal tributaries to the Mississippi River above La Crosse whose course and drainage basins are entirely within Wisconsin. It drains an area of 2,080 square miles above Galesville, Wisconsin, near its confluence with the Mississippi River, and 1,290 square miles above the Hatfield Dam near Black River Falls, Wisconsin. The river drains at least part of six Wisconsin counties: Taylor, Clark, Jackson, Monroe, Trempealeau and La Crosse. Upstream of Black River Falls, the river flows through a region of flat to gently rolling terrain in a previously glaciated area. The drainage network is young and mainly postglacial, and valleys are shallow. There are widespread swampy areas east of Black River Falls. Compared to the upper reaches of other river systems in the region, the slope of the Black River is relatively mild and uniform, at about 6 feet per mile, in this area. This is due to the presence of a crystalline bedrock substrate which has limited downcutting. After passing Black River Falls, the river enters the unglaciated "driftless area," an area characterized by deeply cut valleys, or coulees, above which are areas of relatively uniform tableland. Here, the river flows in a meandering manner through a thick alluvial fill at a slope of about 2 feet per mile to its confluence with the Mississippi River at La Crosse, near Mississippi River Mile 699. There are two impoundments on the Black River: Lake Arbutus, formed by the Hatfield Dam; and an unnamed impoundment formed by the Black River Dam in Black River Falls. Land use in the basin is predominantly agricultural, with some recreational use around Lake Arbutus and along parts of the main Black River channel.

h. South Fork of the Root River. The South Fork of the Root River is a small tributary to the Root River within the Root River basin.

i. Root River - RM 693.8. The Root River basin is located in the southeastern portion of Minnesota. The basin has a drainage area of 1,630 square miles and is elliptical in shape, with a length of approximately 77 miles and a width of approximately 34 miles. The basin encompasses all or portions of Houston, Olmsted, Fillmore, and Mower Counties. The basin's major watercourse is the Root River. The Root River has steep slopes in the upper reaches of the basin and mild slopes near its confluence with the Mississippi River. The river passes through incorporated areas as well as large expanses of agricultural areas. A number of the communities in the upper reaches of the basin are flash flood prone.

j. Upper Iowa River - RM 671.0. The Upper Iowa River has its source in the southeast corner of Mower County, Minnesota. It flows in a southeasterly direction to Decorah, Iowa. It then flows in an easterly direction, entering the floodplain of the Mississippi River about 1.5 miles south of New Albin, Iowa. The total drainage area of the Upper Iowa River is about 1,020 square miles and includes parts of Allamakee, Winneshiek, Howard, and Mitchell Counties of northeastern Iowa, and small areas along the southern boundaries of Houston, Fillmore, and Mower Counties in southeastern Minnesota.

k. Kickapoo River. The Kickapoo River rises in Monroe County in southwestern Wisconsin and flows southwest through Vernon, Richland, and Crawford Counties. The river empties into the Wisconsin River near Wauzeka, about 16 miles upstream from the junction of the latter stream with the Mississippi River. The Kickapoo River basin includes about 776 square miles and is about 60 miles long and 10 to 15 miles wide. The largest tributaries are the West Fork, Taintor Creek, Morris Creek, and Billings Creek. The topography of the basin is comparatively rugged, consisting of narrow ridges and deep valleys. The ridge crests, which are distinctly round-topped, are 0.1 to 0.6 mile wide. The valley bottoms are 0.1 to 1.0 mile in width and are 300 to 400 feet below the upland level. The summits of the ridges generally slope southward with the dip of the rock strata.

l. Wisconsin River - RM 631.0. The Wisconsin River has an elongated drainage area of 12,200 square miles. It rises in Lac Vieux Desert, on the Wisconsin-Michigan Upper Peninsula border. From this point, it flows in a generally north to south direction, winding through heavily forested lands, agricultural lands, and then the rolling hills and bluffs of southwestern Wisconsin to its confluence with the Mississippi River at Prairie du Chien, Wisconsin, near Mississippi River Mile 631. The U.S. Geological Survey (USGS) divides the Wisconsin River basin into three sections. These are the upper basin, which is between the source at Lac Vieux Desert and Merrill, Wisconsin; the central basin, which extends from Merrill to Wisconsin Dells; and the lower basin, which extends from Wisconsin Dells to the confluence with the Mississippi River.

The drainage area of the upper Wisconsin River basin is about 2,780 square miles, including parts of six counties. The terrain varies from flat glacial outwash plains to hilly ground moraines. Most of the upper basin is made up of the flat outwash with a gentle slope and many shallow depressions occupied by lakes or bogs. Vegetation is mostly deciduous or coniferous forest except in boggy areas. There is very little runoff from this area. South of the Oneida County line, the terrain becomes more varied, and runoff increases. About half of this area is forest or pastured woodlot and has many lakes and bogs. The slope of the river through the upper basin is fairly uniform at 3.5 feet per mile. Principal tributaries in this reach are the Pelican, Tomahawk, Spirit, and Prairie Rivers. There are a number of impoundments both on the main stem and on the tributaries. These are used for water supply, recreation and some hydropower.

The drainage area of the central Wisconsin River basin is about 5,050 square miles, including parts of 12 counties. Here, the river flows through an extensive sand plain. Most of the terrain is flat to gently sloping, with a few isolated large hills such as Rib Mountain, near Wausau, Wisconsin. Like the upper basin, there are a number of large, flat, boggy depressions. Some of these have no surface outlets and are thus closed off from the rest of the river system in this way. Over 50 percent of the land in this area is used for agriculture. There is recreational and some hydropower use along the streams and impoundments. The slope of the river through the central basin averages 3.3 feet per mile from Merrill to Petenwell Lake, and 1.7 feet per mile from Petenwell Lake to Wisconsin Dells. Principal tributaries in this reach are the Rib, Eau Claire, Big Eau Pleine, Little Eau Pleine, Yellow, and Lemonweir Rivers. There are 14 impoundments on this reach of the Wisconsin River, the largest of which are Lake Dubay, between Stevens Point and Wausau, and Petenwell and Castle Rock Lakes, which are located, one immediately flowing into the other, between Wisconsin Rapids and Wisconsin Dells.

The remainder of the Wisconsin River basin, an area of about 4,450 square miles, comprises the lower basin. Here, the terrain is hilly; there was no glaciation in this area to level it out, as in the central and northern areas. There is high runoff in this area. Most of this portion of the basin is used for agriculture, except for the steeper slopes which have been retained mostly in woodlots, and the waterways which are used for recreation and some hydropower. The river channel meanders through its alluvium-filled valley at an average slope of about 1.5 feet per mile. The river has two major tributaries in this part of the basin, the Baraboo and Kickapoo Rivers. There is one last impoundment on the river before it flows unimpeded to its confluence with the Mississippi River. This is Lake Wisconsin, just downstream of Portage.

4.0 Gages and Data Sources. Flow and stage data are required to provide the boundary conditions that drive the model. For historic simulations, the inflow data for the model are from the records at the USGS gaging stations and the boundary stages are from the records of the St. Paul District. For the forecast simulations, the inflow data are computed from real-time stages applied to rating curves, and the boundary stages are from the real-time stages. The U.S. Geological Survey compiles flow data at the gaging stations listed in Tables MVP-1, MVP-2, and MVP-3. Flow data from these stations were collected for the period 1964 through 1994.

Table MVP-1. USGS Stream Gages

Stream	Station	River Mile
Mississippi River	Anoka	864.8
Mississippi River	St. Paul	839.3
Mississippi River	Winona	725.6
Mississippi River	McGregor	633.6
Minnesota River	Jordan	39.4
St. Croix River	St. Croix Falls	52.2
Cannon River	Welch	12.3
Chippewa River	Durand	17.6
Zumbro River	Zumbro Falls	47.5
Trempealeau River	Dodge	8.9
Black River	Galesville	13.8
South Fork Root River	Houston	3.7
Root River	Houston	18.5
Upper Iowa River	Dorchester	18.1
Kickapoo River	Steuben	20.5
Wisconsin River	Muscoda	92
Turkey River	Garber	19.9
Grant River	Burton	9.1

Table MVP-2. Mississippi River Gaging Stations

Station Name	River Mile	Station Code
Anoka	864.8	ANKM5
Upper St. Anthony Falls Headwater	853.9	USAFHW
Upper St. Anthony Falls Tailwater	853.9	USAFTW
Lower St. Anthony Falls Headwater	853.3	LSAFHW
Lower St. Anthony Falls Tailwater	853.2	LSAFTW
Lock and Dam 1 Headwater	847.6	LD1HW
Lock and Dam 1 Tailwater	847.5	LD1TW
St. Paul	839.3	STPM5
South St. Paul	833.7	SSPM5
Lock and Dam 2 Headwater	815.2	LD2HW
Lock and Dam 2 Tailwater	815.1	LD2TW
Prescott	811.0	PREW3
Lock and Dam 3 Headwater	796.9	LD3HW
Lock and Dam 3 Tailwater	796.9	LD3TW
Lake City	772.5	LKCM5
Wabasha	760.5	WABM5
Lock and Dam 4 Headwater	753.0	LD4HW
Lock and Dam 4 Tailwater	752.6	LD4TW
Lock and Dam 5 Headwater	738.3	LD5HW
Lock and Dam 5 Tailwater	738.1	LD5TW
Lock and Dam 5A Headwater	728.5	LD5AHW
Lock and Dam 5A Tailwater	728.5	LD5ATW
Winona	725.6	WNAM5
Lock and Dam 6 Headwater	714.3	LD6HW
Lock and Dam 6 Tailwater	714.3	LD6TW
Dakota	707.2	DKTM5
Lock and Dam 7 Headwater	702.6	LD7HW
Lock and Dam 7 Tailwater	702.5	LD7TW
La Crosse	696.7	LACW3
Brownsville	689.0	BRWM5
Lock and Dam 8 Headwater	679.4	LD8HW
Lock and Dam 8 Tailwater	679.2	LD8TW
Lansing	663.0	LNSI4
Lock and Dam 9 Headwater	648.1	LD9HW
Lock and Dam 9 Tailwater	647.9	LD9TW
McGregor	633.6	MCGI4
Clayton	624.8	CLAI4
Lock and Dam 10 Headwater	615.2	LD10HW
Lock and Dam 10 Tailwater	614.9	
Cassville	606.3	
Waupeton	599.9	
Spechts Ferry	592.3	
Lock and Dam 11 Headwater	583.0	
Lock and Dam 11 Tailwater	582.6	
Dubuque	579.3	

Table MVP-3. Tributary Gages

Stream	Station	Station Code	River Mile	Datum
Minnesota River	Jordan	JDNM5	39.4	690.00
St. Croix River	St. Croix Falls	SCFW3	52.2	689.94
Cannon River	Welch	WCHM5	12.3	699.16
Chippewa River	Durand	DURW3	17.6	694.59
Zumbro River	Zumbro Falls	ZUMM5	47.5	811.26
Trempealeau River	Dodge	DDGW3	8.9	661.42
Black River	Galesville	GALW3	13.8	658.43
South Fork Root River	Houston	HUSM5	3.7	680.41
Root River	Houston	HOUM5	18.5	667.00
Upper Iowa River	Dorchester	DCHI4	18.1	660.00
Kickapoo River	Steuben	STEW3	20.5	657.00
Wisconsin River	Muscoda	MUSW3	92.0	666.77
Turkey River	Garber		19.9	
Grant River	Burton		9.1	

5.0 Navigation Dams. The reach that was modeled contains 13 navigation dams, which are regulated to maintain navigation pools. The navigation dams are listed in Table MVP-4.

Table MVP-4. Navigation Dams

Dam	Tailwater River Mile	Pool Elevation (Feet NGVD)
Upper St. Anthony Falls	853.9	798.7
Lower St. Anthony Falls	853.2	749.5
1	847.5	724.6
2	815.1	686.7
3	796.9	674.5
4	752.6	666.5
5	738.1	659.5
5A	728.5	650.5
6	714.3	645
7	702.5	638.5
8	679.2	630.5
9	647.9	619.5
10	681.5	610.5

The upper three navigation pools behind the Upper St. Anthony Falls Dam, the Lower St. Anthony Falls Dam, and Lock and Dam 1 were simulated by rating curves at the structure. The lower 10 navigation dams are simulated according to operating rules presented in the Regulation Manuals for Dams 2 through 10 (St. Paul District, 1972). Each dam is regulated according to a hinge pool procedure which attempts to maintain a control point at stages given by a rating curve. The operating rule is a rating curve of flow versus stage that, through experience, has been shown to maintain the proper stage at the control point. An example of an operating rule curve is shown on Fig. MVP-2.

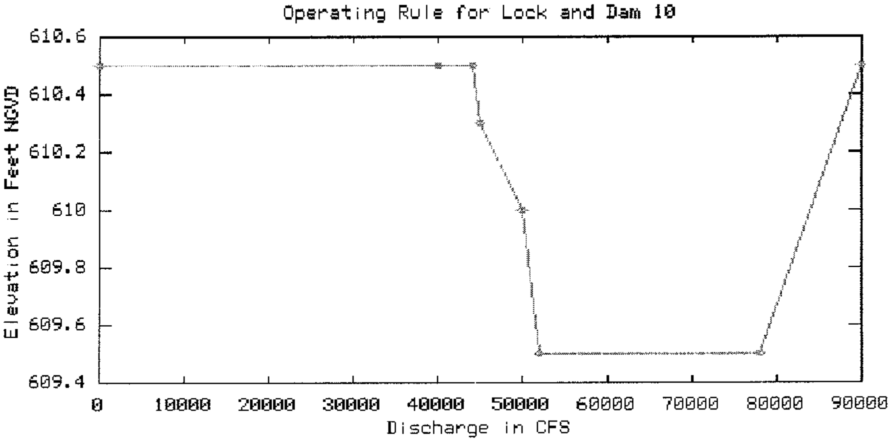


Figure MVP-2. Example Operating Rule Curve

The UNET program was modified (Barkau, 1996) to simulate navigation dams according to the operating rules. The program allows the operating rules to vary according to the seasons. Figure MVP-3 shows the entry of the operating rule for Lock and Dam 10. The ND card defines the navigation dam. The first set of NR cards defines the operating rule for the summer. The second set of NR cards defines the operating rule for the winter. The operating rules accurately simulated the operation of the navigation dams during the warm season. However, after reviewing the pool hydrographs, the dams were operated in a different manner during the winter. For example, a constant winter pool stage of 610.5 feet National Geodetic Vertical Datum (NGVD), no matter what the flow, adequately reproduced the pool stages at Lock and Dam 10.

```
NH  6820    .000      .0    .000      .0    .000      .0    .000      .0    .000
* LOCK AND DAM NO. 10 HW
X1615.20      36      .0  1210.0   520.0   520.0     .00    0.00       0
Z0    -.5
OH HISTMISS://DAM10-POOL/ELEV/01JAN1989/1DAY//
HY LD10HW
KR \SPMISS\RC\HSPMS:/MISSISSIPPI RIVER/DAM10_POOL/STAGE-FLOW/65 & 90 TO 94//OBS/
GR629.50      .0  591.00      .0  590.80    10.0  580.80    60.0  583.00   150.0
GR581.30   235.0  579.30   270.0  578.60   355.0  583.50   435.0  582.50   475.0
GR587.20   555.0  588.20   710.0  586.50   750.0  588.00   830.0  585.80   900.0
GR585.20   970.0  595.00  1125.0  590.10  1170.0  600.50  1210.0  602.30  1350.0
GR603.10  1505.0  599.50  1660.0  600.10  1720.0  603.50  1820.0  599.50  1855.0
GR599.50  2250.0  604.50  2280.0  604.50  2510.0  599.50  2550.0  599.50  2750.0
GR604.50  2780.0  604.50  4980.0  604.50  5680.0  599.50  5690.0  599.50  6700.0
GR629.50  6820.0     .00      .0     .00      .0     .00      .0     .00      .0
KR OFF

* L&D 10; POOL STAGE = 610.5
* R.M. 615.1
ND                 610.5                                     -.2        L&D10
* OPERATING RULE FOR SUMMER; NORMAL POOL IS 610.5
NR      8   610.5       0   610.5   40000   610.5   43000   610.5   45000  610.35
NR 50000     610   52500   609.5   78000   609.5   89000   610.5
* OPERATING RULE FOR WINTER; NORMAL POOL IS 610.0
NR      2   610.0       0   610.0   89000   610.0
* SUMMER SEASON IS FROM 01APR TO 28NOV AND THE WINTER SEASON IS FROM 01DEC TO
* 28MAR WITH TRANSITIONS IN BETWEEN.
NZ  28MAR 610.0   01APR 610.5  28NOV 610.5   01DEC 610.0


*
* POOL 11  POOL ELEVATION 603.00
*
*  STARTING ELEV IN PROP TABLE = ELSTRT - RISE = 598
*           RISE  ELSTRT
XK            50     648            2.25
XI    1

NH       6   0.040    5620   0.100    8900   0.040    9340   0.070   10000   0.028
NH 11050   0.120 13500.0   0.000     0.0   0.000     0.0   0.000     0.0   0.000
X1 614.9      40 10000.0 11050.0  1000.0  1000.0  1000.0    0.00    0.00       0
Z0    -.5
OH HISTMISS://DAM10-TAIL/ELEV/01JAN1989/1DAY//
HY L&D 10 TW
KR \SPMISS\RC\HSPMS:/MISSISSIPPI RIVER/DAM10_TW/STAGE-FLOW/65 & 90 TO 94//OBS/
GR650.00  4200.0  630.00  4250.0  620.00  4400.0  615.00  4450.0  604.00  4500.0
GR595.00  4600.0  595.00  5500.0  604.00  5620.0  612.00  5650.0  612.00  5920.0
GR610.00  6000.0  610.00  6250.0  610.00  6470.0  610.00  6700.0  612.00  6710.0
GR612.00  7650.0  606.00  7700.0  604.00  7720.0  600.00  7850.0  604.00  7940.0
GR606.00  7950.0  606.00  8020.0  608.00  8050.0  608.00  8220.0  608.00  8610.0
GR606.00  8880.0  604.00  8900.0  600.00  9000.0  600.00  9300.0  604.00  9340.0
GR608.00  9350.0  608.00  9650.0  606.00  9950.0  604.00 10000.0  586.00 10200.0
GR586.00 10900.0  604.00 11050.0  620.00 12600.0  630.00 13400.0  650.00 13500.0
```

Figure MVP-3. CSECT Data Entry for the Operating Rule Curve for Lock and Dam 10.

6.0 Digital Terrain Data. Aerial photography, airborne global positioning system (GPS) control, ground survey control, and aero triangulation were used in development of a digital terrain model (DTM) and digital elevation model (DEM) of the project area for the St. Paul District (Mississippi River from Anoka, Minnesota, to Lock and Dam 10 at Guttenberg, Iowa, RM 864.8 to 615.1). The aerial photography for the DTM was taken in April and May 1999 under the direction of the Scientific Assessment Study Team (SAST). The DTM data is composed of mass points and break lines that adequately define elevated roads, railroads, levees (features that would impede or direct flow) and other major topographic changes required for accurate DEM development. The aerial mapping is based on surveyed ground control points. These surveyed ground control points are very accurate, but the aerial mapping of well-defined features between the ground control points can vary by as much as 0.67 foot 67 percent of the time in accordance with the ASPRS Class I mapping standards. Ground surface elevations developed by the aerial mapping will be accurate to within 1.33 feet. This level of accuracy is much better than that used for previous hydraulic models along these rivers and is considered very good for the purposes of hydraulic modeling.

6.1 Verification of DTM Terrain Data. DTM's were verified using 1-foot topographic maps that covered areas around the locks and dams.

6.2 Merging of Terrain and Bathymetry. Hydrographic survey data taken in 1997-1999 was combined with cross-sectional data cut from the DEM to produce final cross-sections for use in the UNET model.

6.3 Geometry. The UNET model cross-section geometry was acquired from digital survey information of the Mississippi River channel and floodplain using new profile generating software. Digital cross-sections were cut along the entire reach of the Mississippi River within the St. Paul District from RM 645 to 865. The average distance between cross-sections was 2,000 to 3,000 feet. The digital terrain models of the project area were merged with hydrographic survey data of the Mississippi River and converted into triangulated irregular network (TIN) data sets. Electronically cut profiles through these TIN data sets generated cross-sections for the Mississippi River. The cross-section profiles were imported into HEC-RAS. Cross-section reach lengths, bridge pier data, and Manning's *n* value data were added to the HEC-RAS geometry file. This information was converted into a UNET geometry file. See Figure MVP-4.

6.4 Friction Values. Manning's *n* values for channel and overbank areas were calibrated using historical flood events. This *n* roughness value can vary from season to season, and change with depth of water. Manning's *n* values were adjusted in the form of conveyance during the calibration process in UNET to better simulate actual river stages at gaging sites.

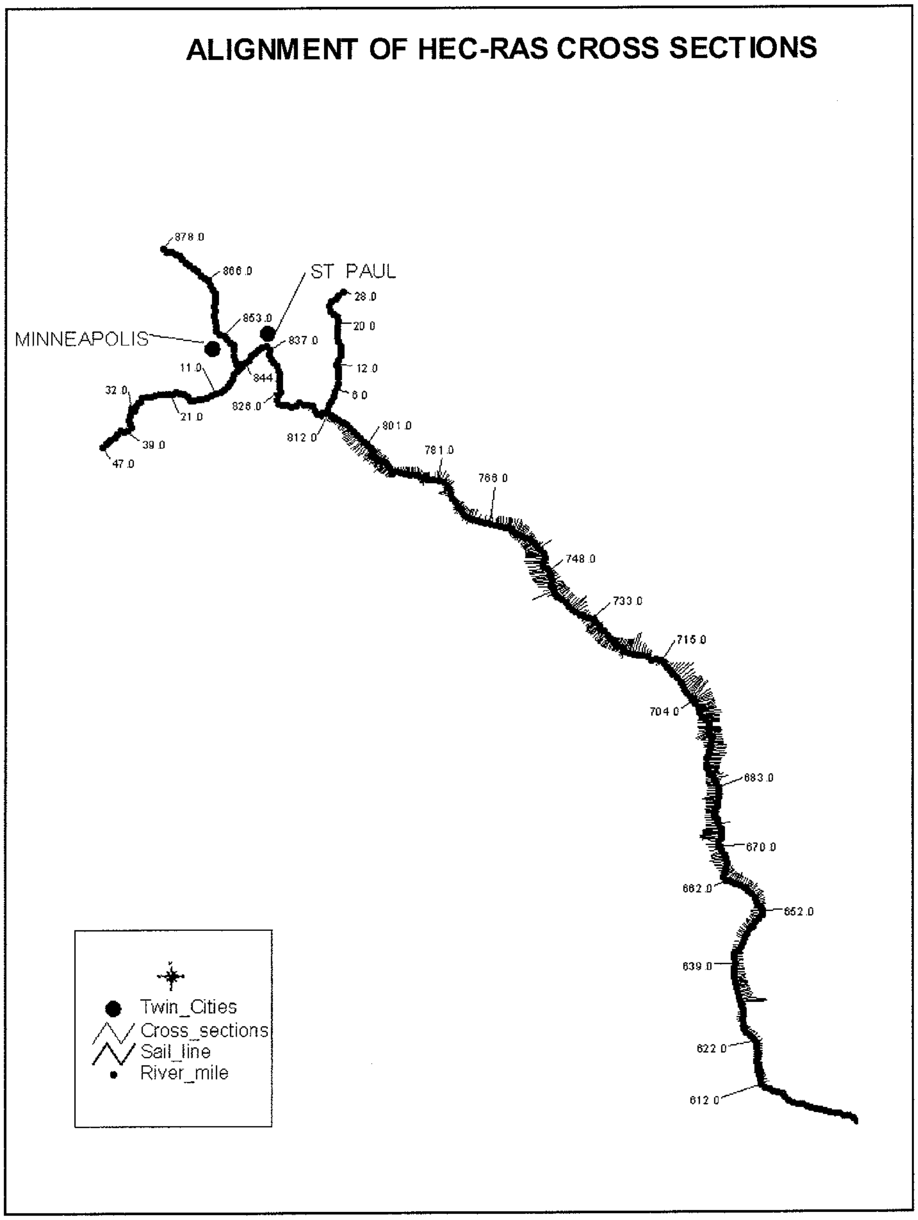


Figure MVP-4. HEC-RAS Cross Section Layout

7.0 Calibration. The model was calibrated to reproduce water years 1965 and 1993. The model was calibrated to reproduce low to moderate stages in 1993. The model was adjusted to reproduce the higher stages in 1965, which contained the flood of record. Ungaged lateral inflow into the model was estimated using the null internal boundary condition. The base calibration for the model used rating curves that were derived from the historic record. The final calibration used discharge-conveyance factors. The model was further verified against the period from water years 1991 through 1994. The model also simulated a forecast period from October 1, 1995 through July 31, 1996. During the forecast period, the tributary inflow was computed by applying observed stages to rating curves. The procedure simulates forecast operation.

7.1 Null Internal Boundary Conditions. An important component of the application of any unsteady flow model to an observed event is the estimation of ungaged lateral inflow in the study reach. Table MVP-5 is a drainage area summary of the reach between Anoka and Lock and Dam 10. Within this reach are 10,979 square miles of drainage area that are ungaged. If runoff from this area is not included in the model, the model will produce lower stages than the prototype.

Table MVP-5. Drainage Area Accounting

Mississippi River			Tributaries				
Station	**River Mile**	**Drainage Area (Sq. Mi.)**	**Name**	**Miss. River Mile**	**Last D/S Station**	**Drainage Area (Sq. Mi.)**	**Ungaged Drainage (Sq. Mi.)**
Anoka (USGS)	864.8	19,087					
			Minnesota River	844.0	Mankato	14,900	
L&D 1	847.6	19,700					
St. Paul	839.3	36,800					2,813
L&D 2	815.2	37,000					
Prescott (USGS)	811.4	44,800					
			St. Croix River	811.3	St. Croix Falls	5,930	
L&D 3	796.9	45,170					
			Cannon River	795.7	Welch	1,480	
			Chippewa River	763.6	Durand	9,010	
L&D 4	752.8	57,100					
			Zumbro River	750.1	Zumbro Falls	1,130	
L&D 5	738.1	58,845					
L&D 5A	728.5	59,105					
Winona (USGS)	725.7	59,200					4,850
			Trempealeau River	717.1	Dodge	643	
L&D 6	714.4	60,030					
			Black River	707.8	Galesville	2,080	
L&D 7	702.5	62,340					
			So. Fork Root River		Houston		
			Root River	693.7	Houston	1,270	
L&D 8	679.2	64,770					
			Upper Iowa River	671.4	Dorchester	991	
L&D 9	647.9	66,610					
McGregor (USGS)	633.4	67,500					3,316
			Kickapoo River		Steuben		
			Wisconsin River	631.0	Prairie du Sac		
L&D 10	615.1	79,370					

There are three procedures for estimating ungaged inflow:

- Index gages. The flow record at a similar drainage basin is multiplied by a factor to simulate the flow from the ungaged area.

- Hydrologic model. Observed rainfall and snowmelt are applied to a hydrologic model of the ungaged area and the runoff is computed.

- Null internal boundary condition (Barkau, 1995). Ungaged inflow is computed from an observed stage applied at (repeated) upstream and downstream cross-sections. The inflow is the difference between the routed flow from upstream and the computed flow downstream.

For the St. Paul District model, the first two procedures are impractical. The writer could not find any index gages that could be used to estimate ungaged inflow. Furthermore, no hydrologic model exists for the ungaged area of the Mississippi River. Therefore, by default, the null internal boundary condition must be used.

The null internal boundary condition applies an observed stage hydrograph at a repeated cross-section. By applying the stage hydrograph, the model effectively divides the river into an upstream reach and a downstream reach. The stage hydrograph at the upstream cross-section is a downstream boundary condition for the upstream reach. The flow at the upstream cross-section is the routed flow from upstream. The stage hydrograph at the downstream condition is the upstream boundary for the downstream reach. If the model is properly calibrated, the flow hydrograph at the downstream cross-section is the correct flow at that cross-section. The ungaged inflow is the difference between the flow hydrograph at the downstream cross-section and the flow hydrograph at the upstream cross-section. The key to the usage of the null internal boundary condition is the quality of the model's calibration. To verify the calibration, the null internal boundary condition is applied only at USGS gaging stations where a flow record is available. The quality of calibration is judged by the ability of the model to reproduce the USGS flow record.

7.2 Calibration to Discharge. Calibration to stage is used for large flood events for forecasting; optimization to flow is used when a flow record must be maintained such as a period of record frequency analysis. For the St. Paul District, calibration to flow is used for the real-time model for low flows when regulation with the locks and dams takes place. For low flows in the real-time model, experience has shown that the best source of information for discharge hydrographs is from the locks and dams. For that reason, the current real time model uses the discharge hydrographs at Locks and Dams 2, 5A, and 9 for the calibration to flow.

7.3 Ungaged Inflow. The Mississippi River model is divided into four reaches - from Anoka to St. Paul, from St. Paul to Winona, from Winona to McGregor, and from McGregor to Dubuque. Null internal boundary conditions are applied at St. Paul, Winona, and McGregor. No ungaged inflow is estimated downstream of McGregor. The ungaged inflow hydrographs for the three upstream reaches were distributed uniformly according to distance along the Mississippi River. Table MVP-6 shows the manner in which ungaged inflow was distributed uniformly between Anoka and McGregor.

The procedure for estimating ungaged inflow is as follows:

1) Simulate the model with the stage hydrographs at the null internal boundary conditions at St. Paul, Winona, and McGregor.

2) Subtract the downstream and upstream hydrographs using the DSSMATH program and the input macro QSLAT.IN in the model development phase. For the graphical user interface, the macro file is called null-bc-math.mac.

3) Remove the observed stage hydrographs at the null internal boundary conditions and insert the ungaged lateral inflow.

The computations for water year 1993 at Winona will be used to demonstrate the null internal boundary condition. Figure MVP-5 compares the computed flow hydrograph and the USGS observed flow hydrograph at Winona. The agreement is nearly exact. Figure MVP-6 compares the routed flow hydrograph from upstream with the computed flow hydrograph downstream. The difference is the ungaged lateral inflow. Finally, Figure MVP-7 compares the routed flow hydrograph upstream and the USGS flow hydrograph after the observed stages have been released and the input of the ungaged inflow. The agreement is once again nearly exact.

The null internal boundary condition was used to calculate inflow for water years 1965 and 1991 through 1994 and for the period October 1, 1995 through July 31, 1996.

Table MVP-6. Distribution of Uniform Lateral Inflow from Ungaged Areas

Reach No.	Reach	U/S River Mile	D/S River Mile	Weighting factor	DSS B Part	Ungaged Drainage Area
1	Anoka to Minnesota River	864.80	844.11	0.812	ANKM5 TO STPM5	
2	Minnesota River to St. Paul	844.10	839.31	0.188	ANKM5 TO STPM5	2813
3	St. Paul to St. Croix River	839.30	811.31	0.246	STPM5 TO WNAM5	
4	St. Croix River to Cannon River	811.30	795.71	0.137	STPM5 TO WNAM5	
5	Cannon River to Chippewa River	795.70	763.61	0.283	STPM5 TO WNAM5	
6	Chippewa River to Zumbro River	763.60	750.11	0.119	STPM5 TO WNAM5	
7	Zumbro River to Winona	750.10	725.71	0.215	STPM5 TO WNAM5	4850
8	Winona to Trempealeau River	725.70	717.11	0.093	WNAM5 TO MCGI4	
9	Trempealeau River to Black River	717.10	707.81	0.101	WNAM5 TO MCGI4	
10	Black River to Root River	707.80	693.71	0.153	WNAM5 TO MCGI4	
11	Root River to Upper Iowa River	693.70	671.41	0.242	WNAM5 TO MCGI4	
12	Upper Iowa River to McGregor	671.40	633.41	0.412	WNAM5 TO MCGI4	3316
13	McGregor to Wisconsin River	633.40	631.01			
14	Wisconsin River to Turkey River	631.00	608.21			
15	Turkey River to Grant River	608.20	593.31			
16	Grant River to Dubuque	593.31				

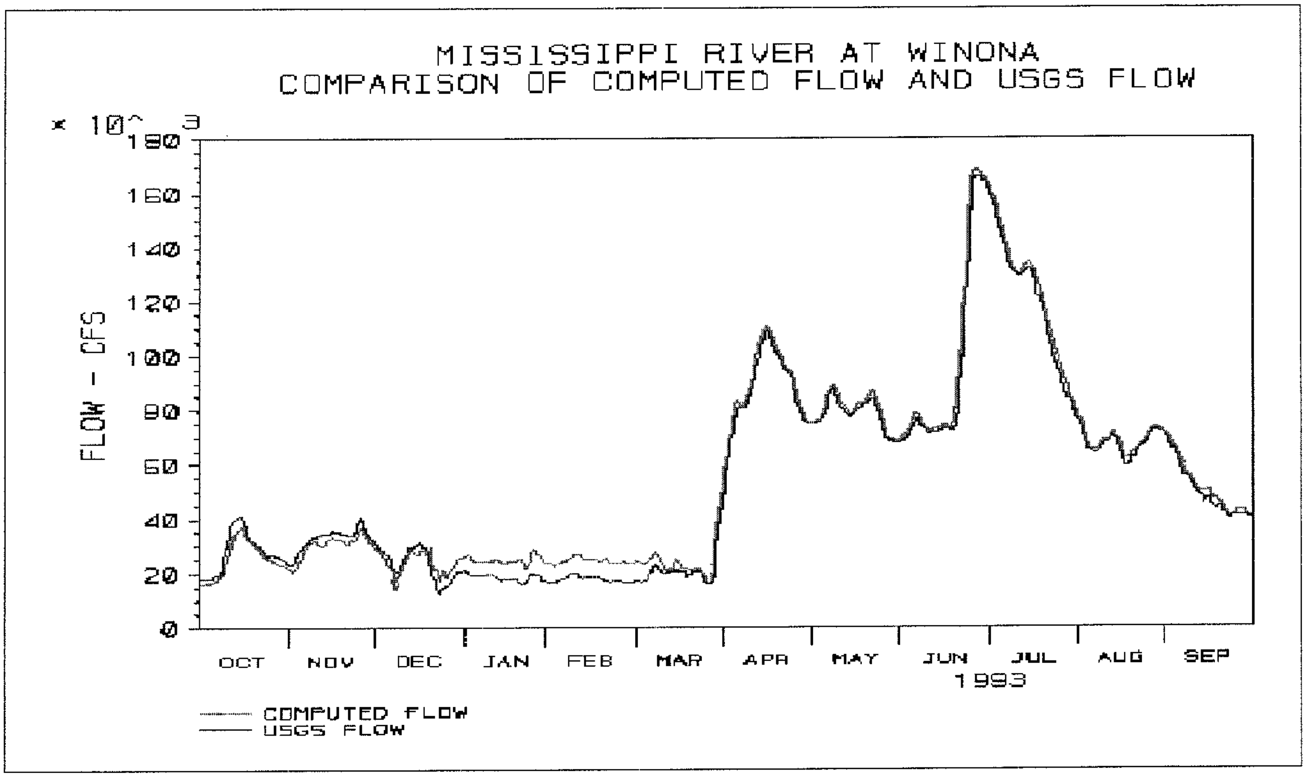


Figure MVP-5. Comparison of Computed and USGS Flows.

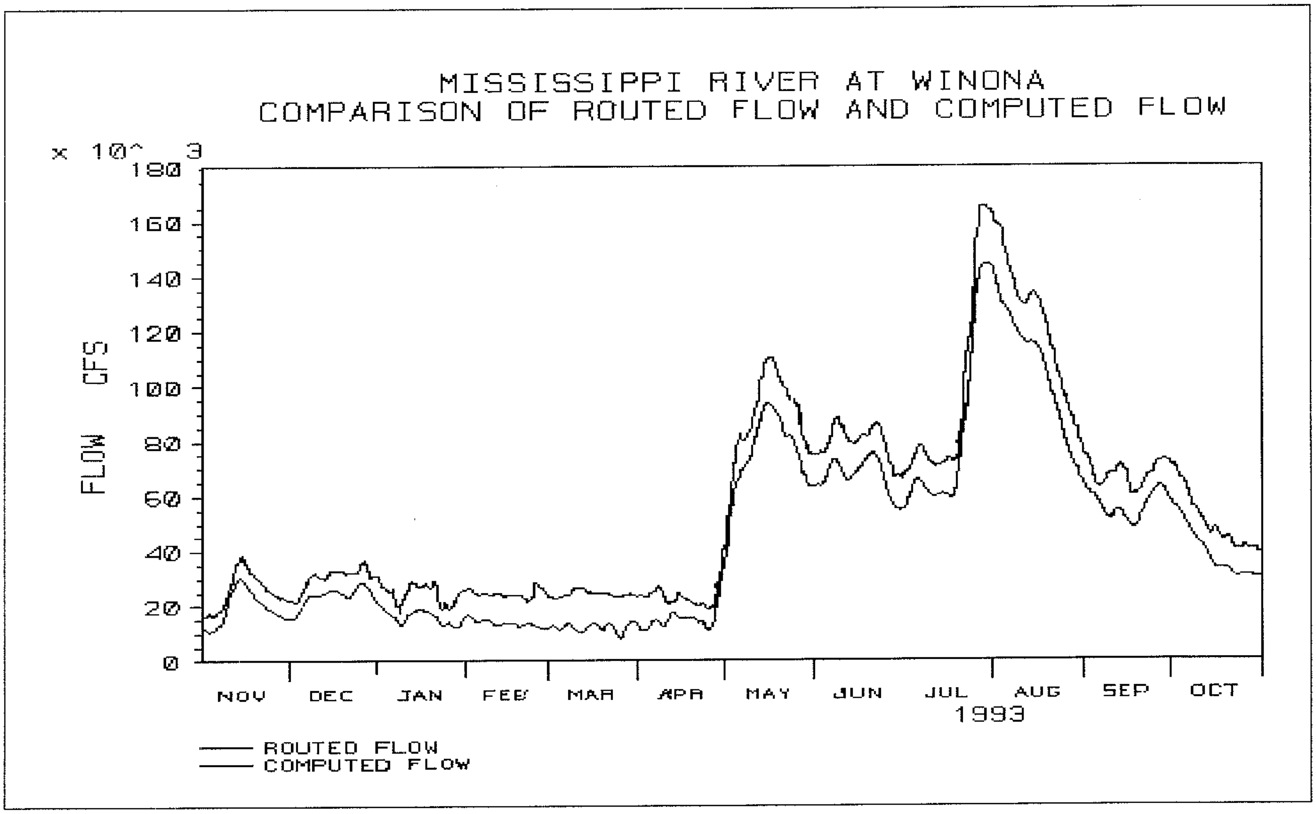


Figure MVP-6. Comparison of Routed and Computed Flows.

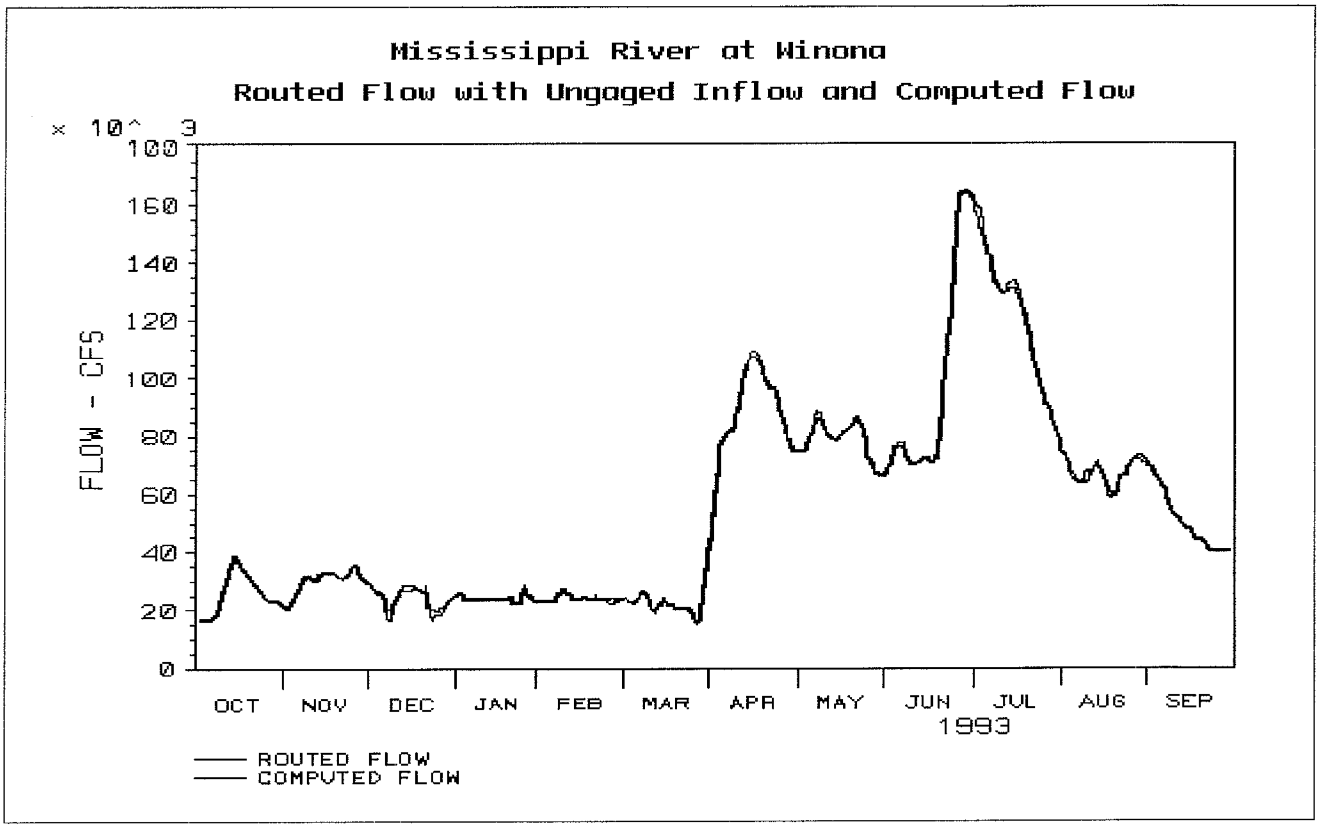


Figure MVP-7. Comparison of Routed and USGS Flows Including UNET-Computed Intervening Flows.

7.4 Base Calibration. For base calibration, the model was calibrated to reproduce rating curves at the principal gaging stations along the Mississippi River. The rating curve calibration technique is described in the report "Rating Curve Calibration" (Barkau, 1994). Rating curves are entered at principal gaging stations. The program adjusts the conveyance of the cross-sections between the gaging stations so that the rating curve at the upstream stations is reproduced exactly by backwater calculations.

For the St. Paul District model, the steps in the rating curve calibration are as follows:

1) Estimate rating curves at St. Paul, Winona, and McGregor from observed stage and USGS flow for water years 1965 and 1990 through 1993. Figure MVP-8 shows the rating curve and the scatter diagram at Winona.

2) Estimate rating curves at the dams from stage and computed flow for calendar years 1965 and 1990 through 1994. The computed flow data were calculated by the St. Paul District Water Control Center. Figure MVP-9 shows the rating curve and the scatter diagram at Lock and Dam 5.

3) Simulate water years 1965 and 1993.

4) Adjust the rating curves used for calibration to reproduce the USGS flow at St. Paul, Winona, and McGregor and to reproduce observed stages at the dams.

5) Repeat steps 3 and 4 until the best reproduction of flow and observed stages is attained.

6) Estimate rating curves used for calibration for the other stream gaging stations interior to the pools from observed stages and from the computed flow of step 2.

7) Simulate water years 1965 and 1993.

8) Adjust the rating curves to achieve a better fit of observed stages.

9) Repeat steps 7 and 8 until the best reproduction of the observed stages is attained.

Rating curves can be used to calibrate the model to an accuracy of about 0.5 foot. In many cases, the accuracy was somewhat greater. The shortcoming in rating curve analysis is not the procedure but rather the ability to adjust the rating curves using graphical editing on the computer. One simply cannot draw a rating curve on a computer to an accuracy of less than 0.5 foot.

7.5 Fine-Tuning. To fine-tune the model, calibration reaches were inserted between the principal gages. The tool for fine calibration was the discharge-conveyance change factors. For each calibration reach, a table of discharge and conveyance change factors was entered. A conveyance change factor for discharge Q_i is:

$$F_i = K_{new} / K_{old}$$

Where:
F_i = conveyance change factor for discharge i.
K_{new} = new conveyance value.
K_{old} = old conveyance value.

If the river discharge is Q_i, the conveyance property is multiplied by F_i, thereby adjusting the calibration of the model.

For calibrating the model, discharge conveyance factors were used primarily to adjust the low flow reproduction in the pools when Manning's *n* becomes very small.

Because the river is carved from granular alluvium, the channel is constantly being reworked by the flow. Therefore, the river changes from year to year. While the Upper Mississippi River is very stable, one should expect changes on the order of tenths of a foot from one event to the next. In real-time forecasting, the modeler would compensate for these changes using discharge conveyance change factors or using conveyance change factors.

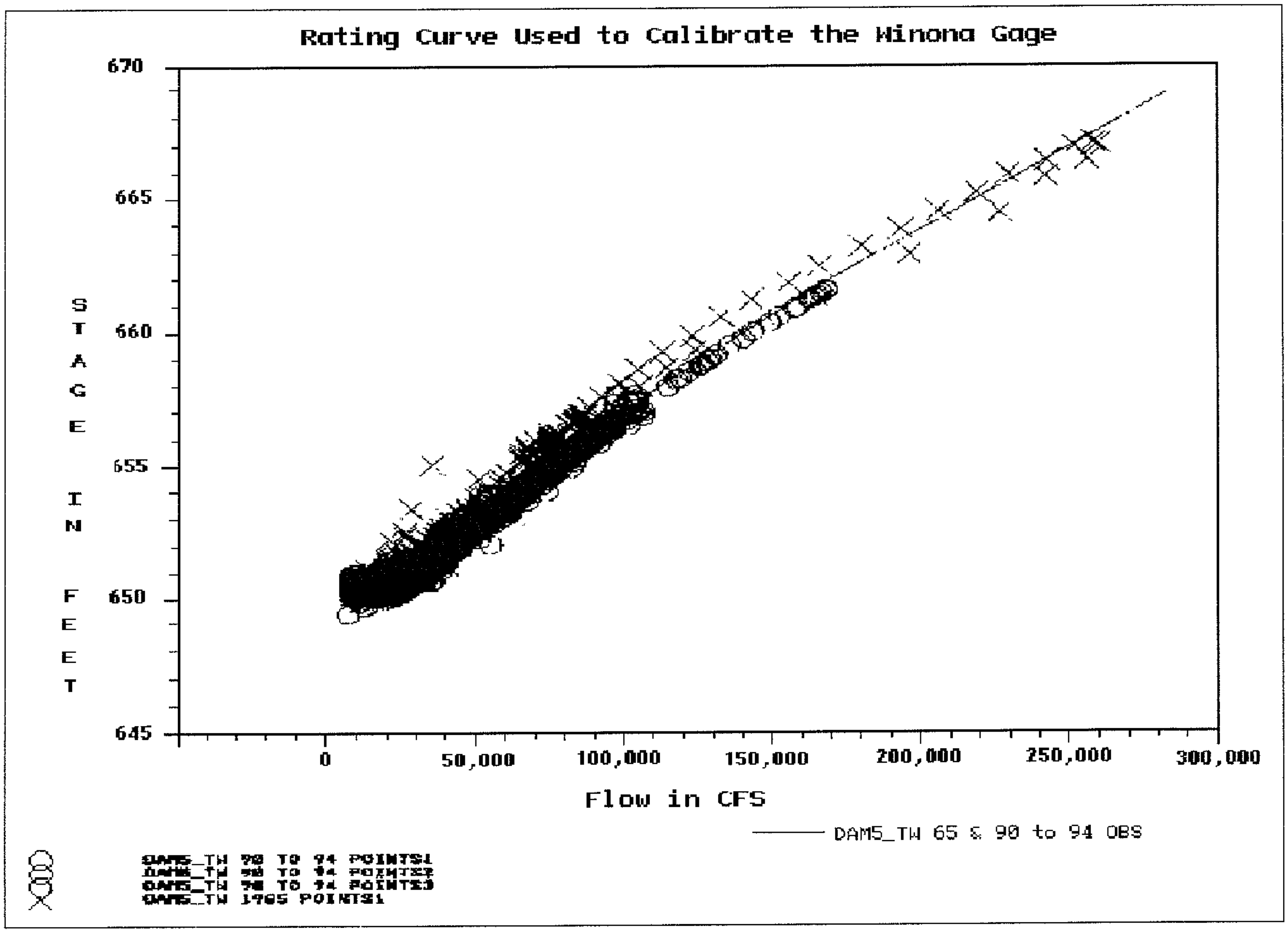


Figure MVP-8. Rating Curve Scatter Diagram at Winona

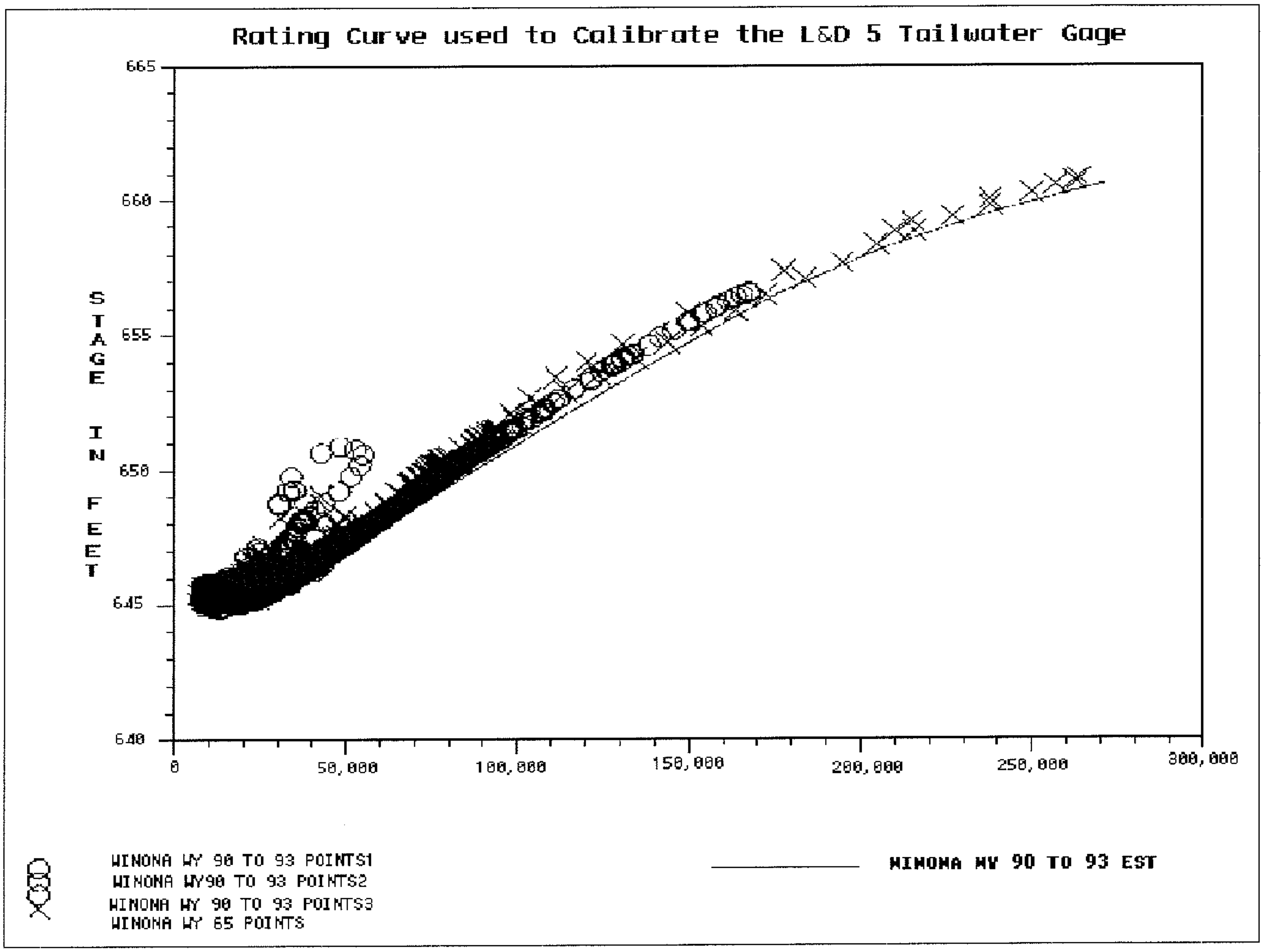


Figure MVP-9. Rating Curve and Scatter Diagram at Lock and Dam 5.

7.6 Calibration - 1993 Event. The model was calibrated to reproduce the stages and flow of water year 1993. Base calibration was from rating curves, and fine calibration was through discharge-conveyance change factors. The model accurately reproduced stages at all of the stations except Brownsville where the stages appeared to be systematically 1 foot low. The model could not be adjusted to add that 1 foot of stage; therefore, 1 foot was added to the gage zero at that location and the reproduction was acceptable.

Another problem was the computation of flow during the winter when the pools are covered with ice. The ice cover increases the wetted perimeter and the overall roughness of the cross-section; thus, the computed discharge from the normal cross-section will be too large. The computed discharge at the gages during the winter is always greater than the USGS flow. One solution to this problem would be to use seasonal conveyance adjustment factors during the winter. As of this writing, the seasonal adjustments have not been tried.

7.7 Calibration - 1965 Event. The 1965 flood was the flood of record on the Upper Mississippi River. The model was calibrated to reproduce high stages during the 1965 event. The calibration was accomplished by adjusting the upper part of the rating curves. The lower stages in the rating curves were not changed from the 1993 calibration. Still, the model reproduced the lower stages to within 0.5 foot and the higher stages nearly exactly. The difference in the lower stages between 1965 and 1993 demonstrates the change in river morphology over the 28-year period.

7.8 Water Years 1991 through 1994. The model simulated the river water years 1991 through 1994. Inflow to the model was from USGS flow records. The simulation verifies the calibration of the model to within 0.5 foot of the observed stage and the overall stability of the Upper Mississippi River. The simulation also shows that the morphology of the river changes with time and that the forecast model must be fine-tuned from year to year.

7.9 Forecast Period 1995 to 1996. During the period October 1, 1995 through July 31, 1996, the inflow from the model was computed by applying observed stage to rating curves at the tributary gages. This procedure simulates a real-time forecast situation where USGS records are not available, and the modeler must estimate inflow from the stage record collected from the DCP (on-site data collection platform). The stage record was of poor quality with numerous abrupt shifts, systematic errors, and long periods of missing data. However, the overall inflow was corrected using the null internal boundary conditions at St. Paul, Winona, and McGregor. The simulation was accurate with errors seldom exceeding 0.5 foot. Also, the errors were systematic, which means that fine-tuning the model using discharge conveyance change factors could eliminate the error.

7.10 Summary - Calibration and Forecast Simulations. The MBMS model was calibrated against water years 1993 and 1965 and verified against water years 1991 through 1994 and the period October 1, 1995 through July 31, 1996. The model provided a nearly exact reproduction of stage for the calibration period. For the verification events, the model was within about 0.5 foot of the observed stage.

The simulations demonstrate that the model can adequately simulate the Mississippi River for forecasting. However, the river, which flows through alluvium, is constantly reworking its bed, and the stage-discharge relationship is changing from year to year. The calibration of the model must be updated to reflect these changes and to give the maximum accuracy.

Ice cover during the winter increases the wetted perimeter and roughness of the river and undermines the accuracy of the null internal boundary condition. The null internal boundary condition computes flow from a stage hydrograph. The model, at present, assumes a free-flowing river, even in the winter when the river is covered by ice; therefore, the null internal boundary condition overestimates flow. A routine must be devised to simulate the increased roughness of the ice cover.

8.0 Operational Experience. The St. Paul District MBMS UNET model was calibrated and tested with forecast simulations prior to the 1997 flood. During April 1997, the graphical user interface was installed so that the model could be used to forecast water surface elevations on the Mississippi River within the St. Paul District and also to provide the Rock Island District predictions at Lock and Dam 10. The 1997 flood provided a great opportunity to further develop the graphical user interface, especially with regard to the features needed for the null boundary condition.

Experience during the 1997 flood indicated that the MBMS UNET model performed very well, especially once the crest had occurred at the upstream end of the model. From that point on, the simulation is essentially a hydraulic routing problem that UNET handles extremely well. Examples of the 1997 results are shown on Figures MVP-10 through MVP-12.

As of now, the upstream boundary conditions for the MBMS UNET model are at Anoka, Minnesota, on the Mississippi River and at Jordan, Minnesota, on the Minnesota River. For the upstream boundary conditions, the available National Weather Service predictions for the time of crest and the crest were used for extending the hydrographs to the end time of the time period. Extending the model farther upstream on the Minnesota and Mississippi Rivers could enhance the performance of the UNET model, especially in the vicinity of Minneapolis and St. Paul, Minnesota.

During the 1997 flood, the St. Paul District's Construction-Operations Division needed forecasts in a timely manner with the final computed values adjusted so that the computed values match exactly with the observed values at the time of forecast. Typically, there is always a small error between the observed and computed values. The adjustment that is needed to make the computed values match the observed values is defined as the trend adjustment. To satisfy the needs of the St. Paul District's Construction-Operations Division, the District developed a dssmath macro that automatically makes the trend adjustment to the computed results. The results are then written to a postscript file and converted to gif files that can be accessed through the District's water control home page at http://www.mvp-wc.usace.army.mil. This approach requires about 20 minutes of time for a UNET forecast to be prepared with the graphical user interface. Once the results are available, the information is updated on the WEB site. Graphical information from the St. Paul District's WEB site is shown on Figure MVP-13.

9.0 Interactions with Others. The St. Paul District's model starts at Anoka, Minnesota, which is the farthest upstream boundary on the Mississippi River. Consequently, no input is needed from another District for the upstream boundary condition. For the downstream tributaries and boundary condition on the Mississippi River, the following is imported from the Rock Island District:

- ▶ Stage hydrograph for the Mississippi River at Dubuque, Iowa.
- ▶ Discharge hydrograph for the Turkey River at Garber, Iowa.
- ▶ Discharge hydrograph for the Grant River at Burton, Wisconsin.

The St. Paul District exports the following to the Rock Island District:

- ◀ Discharge hydrograph for the Mississippi River at Lock and Dam 10.
- ◀ Tailwater stage hydrograph for the Mississippi River at Lock and Dam 10.

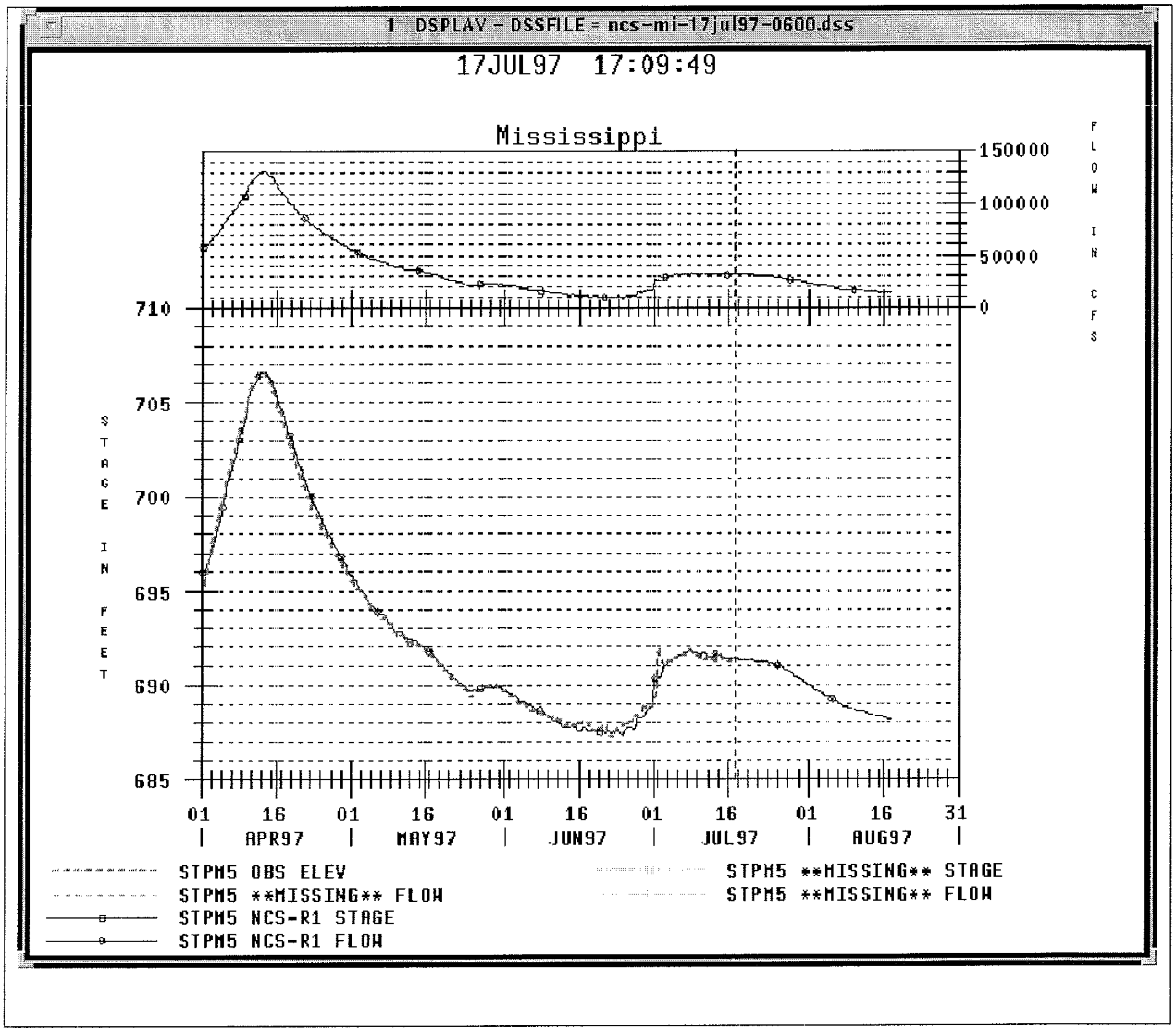


Figure MVP-10. 1997 Results for Location STPM5.

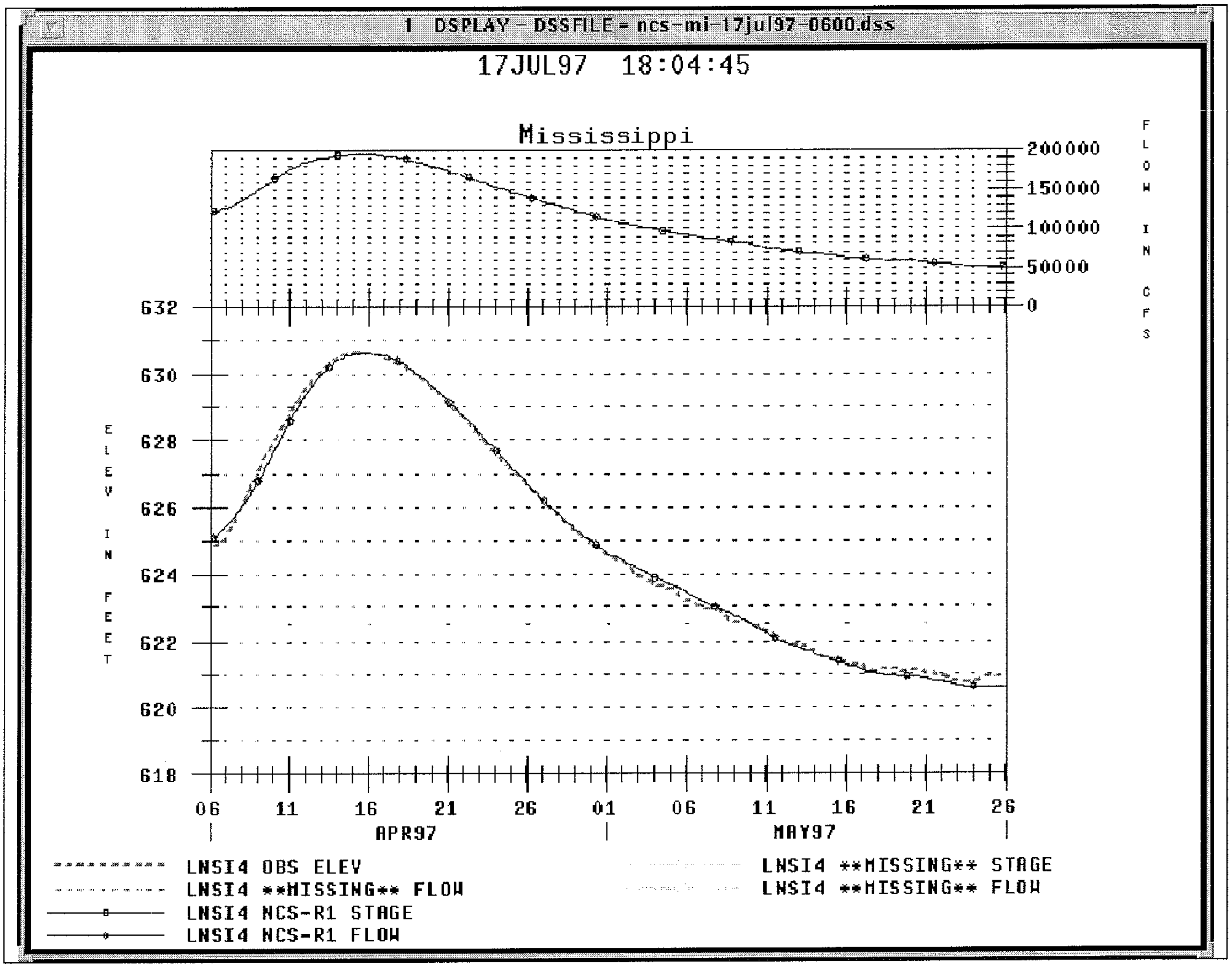
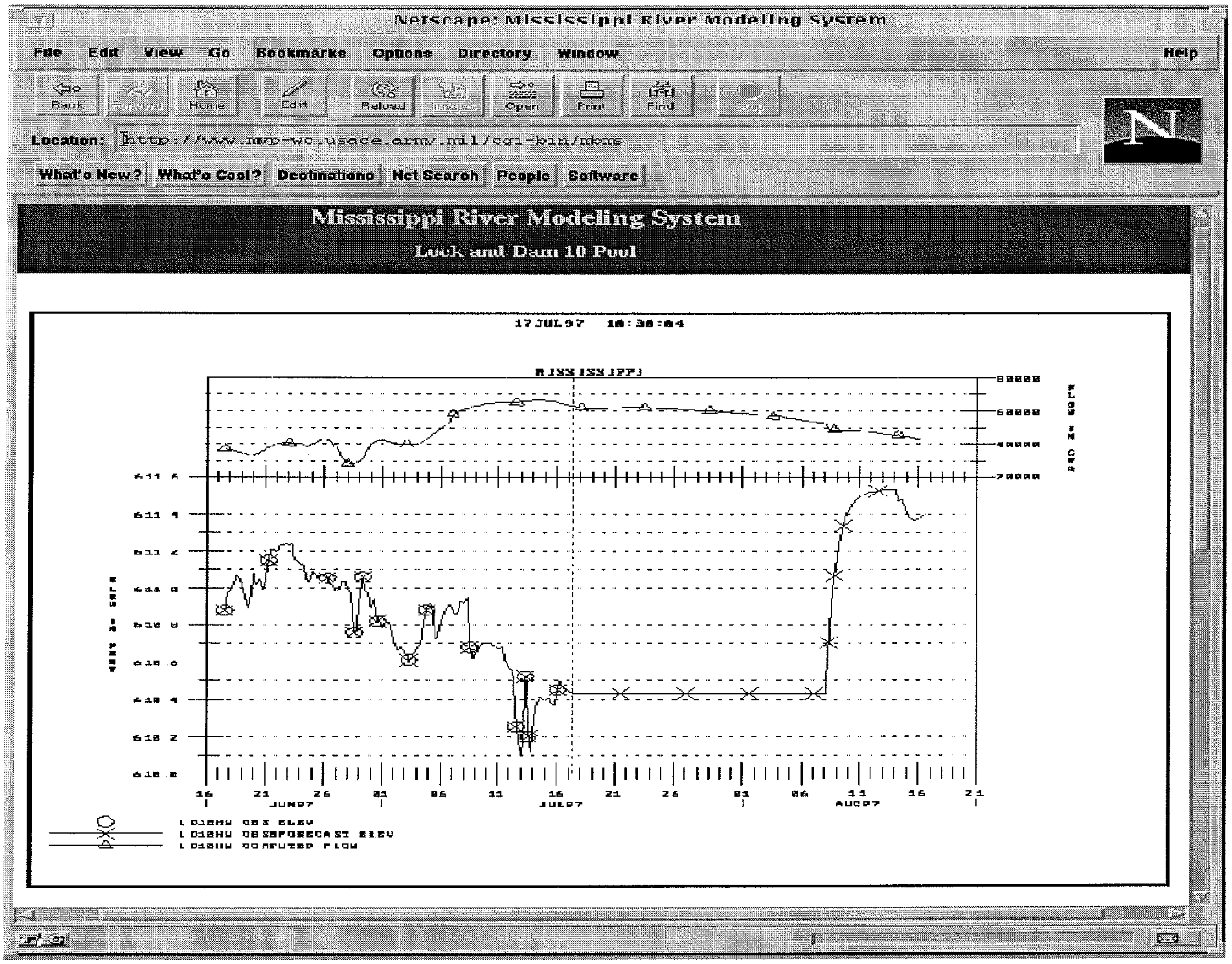


Figure MVP-11. 1997 Results for Location LNSI4.

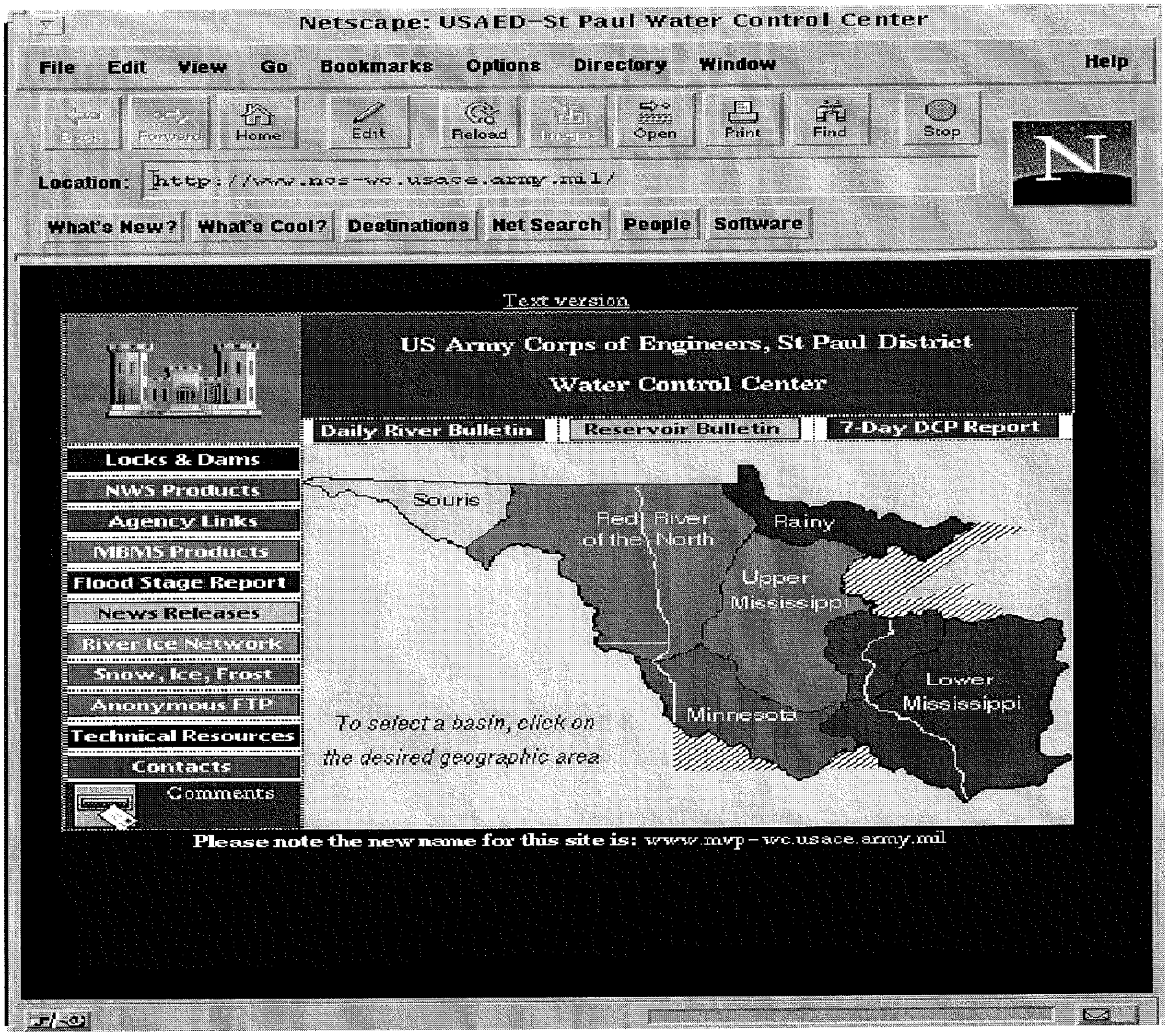

Netscape: Mississippi River Modeling System

Location: http://www.mvp-wc.usace.army.mil/cgi-bin/mbms

Mississippi River Modeling System

Lock and Dam 10 Pool

Figure MVP-12. 1997 Results for Lock and Dam 10 Pool



US Army Corps of Engineers, St Paul District

Water Control Center

To select a basin, click on the desired geographic area

Please note the new name for this site is: www.mvp-wc.usace.army.mil

Figure MVP-13. Availability of MBMS on the St. Paul District Web Site.

References

Barkau, 1994."Rating Curve Calibration." Addendum to the UNET manual, presented at a training class in UNET model calibration in Vicksburg Mississippi, September 1994.

Barkau, 1995."Null Internal Boundary Condition." Addendum to the UNET manual presented at a Mississippi River Work Group meeting at the Hydrologic Engineering Center, Corps of Engineers, September 1995.

Barkau, 1995. "UNET; Unsteady Flow through a Full Network of Open Channels." Hydrologic Engineering Center, Corps of Engineers, Davis, California.

Barkau, 1996. "Simulation of Navigation Dams." Addendum to the UNET manual, presented to the Hydrologic Engineering Center, Corps of Engineers, May 1996.

Department of the Army St. Paul District, Corps of Engineers 1975,"Mississippi River Nine Foot Channel Navigation Project Reservoir Regulation Manual Appendix SAF, St. Anthony Falls Upper Lock and Lower Lock and Dam." St. Paul District, Corps of Engineers.

Department of the Army St. Paul District, Corps of Engineers 1983,"Mississippi River Nine Foot Channel Navigation Project Reservoir Regulation Manual Appendix 1, Locks & Dam No.1." St. Paul District, Corps of Engineers.

Department of the Army St. Paul District, Corps of Engineers 1973,"Mississippi River Nine Foot Channel Navigation Project Reservoir Regulation Manual Appendix 2, Locks & Dam No.2." St. Paul District, Corps of Engineers

Department of the Army St. Paul District, Corps of Engineers 1974,"Mississippi River Nine Foot Channel Navigation Project Reservoir Regulation Manual Appendix 3, Locks & Dam No.3." St. Paul District, Corps of Engineers

Department of the Army St. Paul District, Corps of Engineers 1969,"Mississippi River Nine Foot Channel Navigation Project Reservoir Regulation Manual Appendix 4, Locks & Dam No.4." St. Paul District, Corps of Engineers

Department of the Army St. Paul District, Corps of Engineers 1970,"Mississippi River Nine Foot Channel Navigation Project Reservoir Regulation Manual Appendix 5, Locks & Dam No.5." St. Paul District, Corps of Engineers

Department of the Army St. Paul District, Corps of Engineers 1970,"Mississippi River Nine Foot Channel Navigation Project Reservoir Regulation Manual Appendix 5A, Locks & Dam No.5A." St. Paul District, Corps of Engineers

Department of the Army St. Paul District, Corps of Engineers 1970,"Mississippi River Nine Foot Channel Navigation Project Reservoir Regulation Manual Appendix 6, Locks & Dam No.6." St. Paul District, Corps of Engineers

Department of the Army St. Paul District, Corps of Engineers 1971,"Mississippi River Nine Foot Channel Navigation Project Reservoir Regulation Manual Appendix 7, Locks & Dam No.7." St. Paul District, Corps of Engineers

Department of the Army St. Paul District, Corps of Engineers 1971,"Mississippi River Nine Foot Channel Navigation Project Reservoir Regulation Manual Appendix 8, Locks & Dam No.8." St. Paul District, Corps of Engineers

Department of the Army St. Paul District, Corps of Engineers 1972,"Mississippi River Nine Foot Channel Navigation Project Reservoir Regulation Manual Appendix 9, Locks & Dam No.9." St. Paul District, Corps of Engineers

Department of the Army St. Paul District, Corps of Engineers 1972,"Mississippi River Nine Foot Channel Navigation Project Reservoir Regulation Manual Appendix 10, Locks & Dam No.10." St. Paul District, Corps of Engineers

Hydrologic Engineering Center, 1996."HEC-DSS Users Guide and Utility Manuals, User's Manual." Hydrologic Engineering Center, Corps of Engineers, Davis California.

Rock Island District

(MVR)

TABLE OF CONTENTS

MISSISSIPPI RIVER

ILLINOIS RIVER

MISSISSIPPI RIVER UNET REAL-TIME FORECAST MODEL

Rock Island District

MISSISSIPPI RIVER

1. Geographic Extent

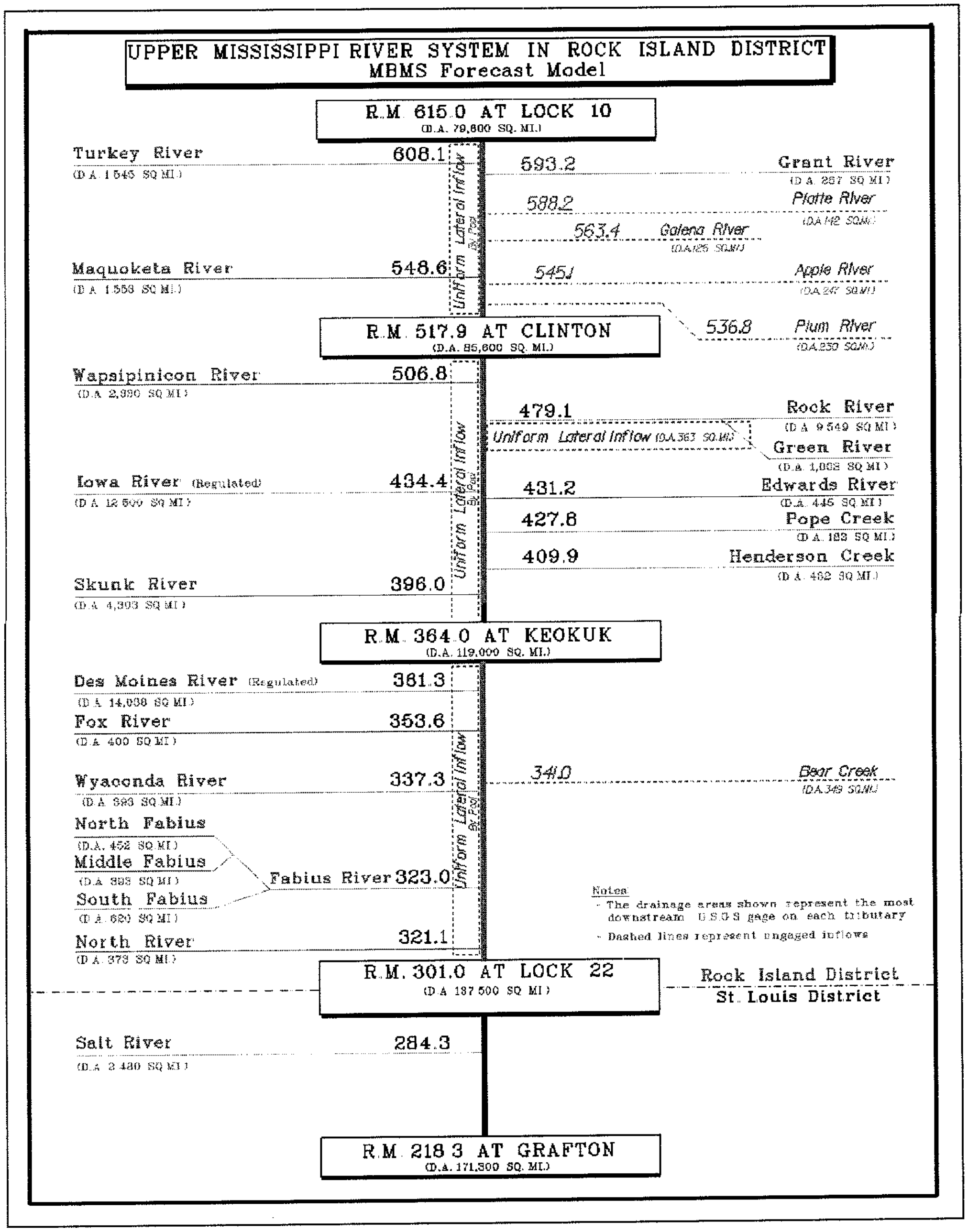


Figure MVR-1. Schematic of the Rock Island District Mississippi River MBMS Model.

The Mississippi River UNET model extends from Lock and Dam (L&D) 10 at Guttenberg, IA (R.M. 615.0), downstream to Grafton, Illinois (R.M. 218.3). As the Rock Island District ends downstream at L&D 22 at Saverton, MO, (R.M. 301.2), the 83 river miles of the UNET model from Saverton, MO to Grafton, IL were obtained from the St. Louis District. This portion of the St. Louis model was included to provide a true dynamic solution at L&D 22. Figure MVR-1 shows a schematic of the Mississippi River MBMS model.

2. Hydrologic/Geographic Description of the Area

2.1 Physical Characteristics. The Mississippi River rises in the lake and forest country of north-central Minnesota, near Itasca, Minn., and flows north, east and then south through timbered landscape to Minneapolis-St. Paul. At this point it leaves the northern woodlands and lakes and meanders southward past fertile prairies and many villages and cities. Along the way, tributaries that drain lands to the east and to the west join the Mississippi River and add to its flow. From its headwaters to the confluence with the Ohio River, the Mississippi River is 1,366 miles in length, of which 314 miles are in the Rock Island District. The boundary between the Rock Island and St. Louis Districts is located about nine miles downstream from Hannibal, Mo. The drainage area upstream from this boundary is about 137,500 square miles. The Rock Island District covers 78,300 square miles with 58,300 square miles draining directly to the Mississippi River within the District. The remaining 20,000 square miles drain to the Illinois River.

2.2 Climate. The climate within the Rock Island District is generally of the continental type, which varies somewhat from the northern to the southern extremities. Southern Minnesota, the southwest corner of Wisconsin, Iowa and northern Illinois have cold, humid winters and hot summers. Missouri and southern Illinois have warm, temperate, climates with hot summers and comparatively mild winters.

2.2 Precipitation. The annual precipitation generally increases from about 28 inches in the northwest reaches of the basin to about 36 inches to Hannibal, Mo. The eastern side of the Rock Island District generally receives more precipitation than the western side. The basin as a whole has an annual average precipitation of approximately 32 inches, or about 1,700 acre-feet of water per square mile.

2.3 Hydrology. Nearly all surface water runoff in the Upper Mississippi River basin is supplied by precipitation falling within its boundaries, with only minor amounts contributed through municipal and industrial withdrawals of water and diversion from Lake Michigan (3,200 cfs) and from subsurface aquifers whose sources are outside the basin. The average annual precipitation over the basin is 31.7 inches. Of this amount, an estimated 24.2 inches return to the atmosphere by means of evaporation and transpiration. The remaining 7.5 inches pass out of the basin as surface water runoff via the Mississippi River.

Runoff is subject to seasonal variations of temperature and precipitation. The months of highest runoff are generally March through June, roughly paralleling the monthly precipitation pattern. The average monthly flows then generally taper off, except for a widespread increase in late summer or early fall, reaching minimum values during the winter months. The March and April flows in the northern half of the basin are augmented by the melting of snow which has accumulated during the winter months. Monthly flows in the southern portion of the basin are relatively high during the winter months compared to the northern parts because annual precipitation is more evenly distributed and temperatures are more moderate.

3. Drainage System

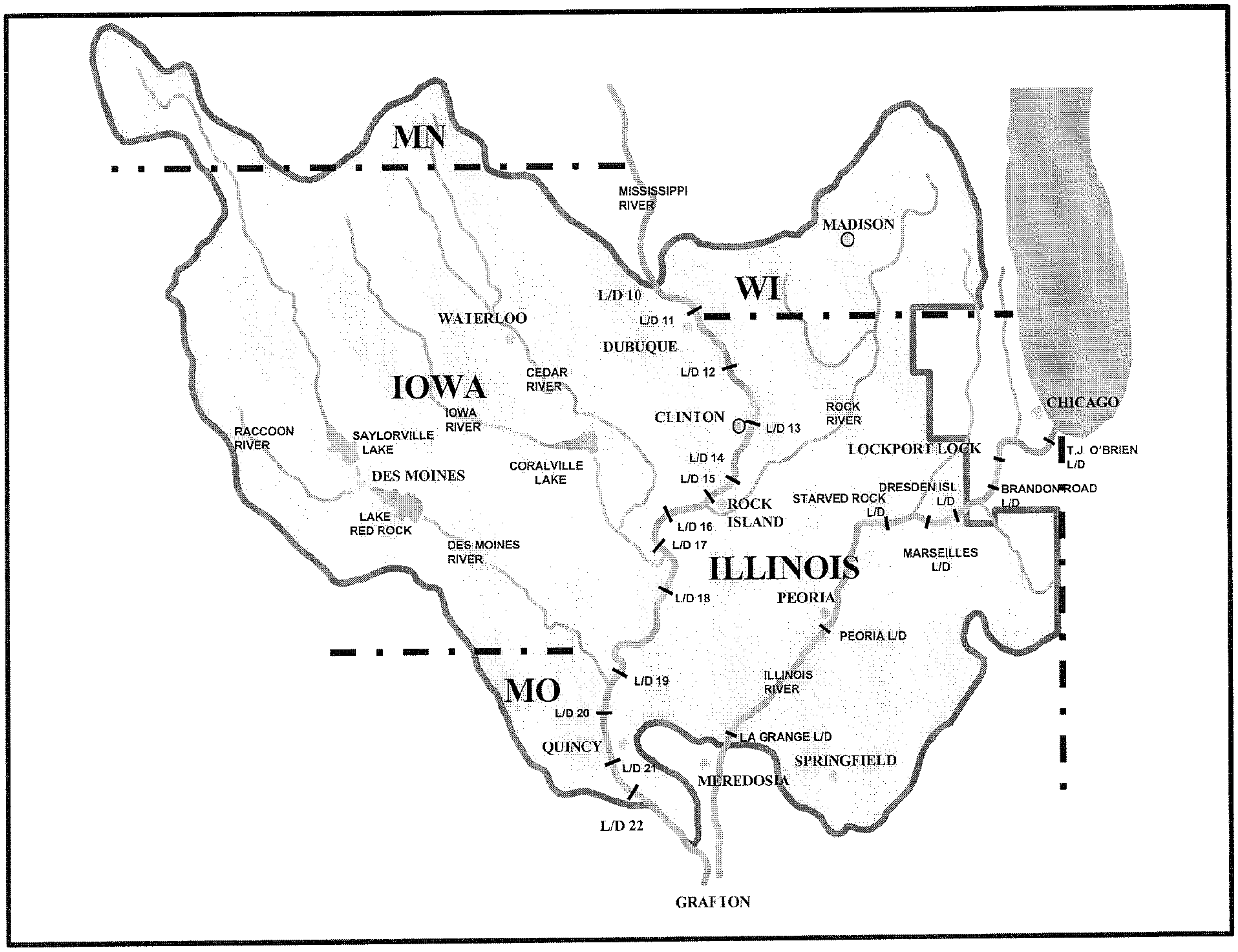


Figure MVR-2. Boundary Map of the Rock Island District.

3.1 Mississippi River. The Mississippi River within the Rock Island District ranges in drainage area from 79,200 square miles at its upstream boundary near Guttenberg, Iowa, to 137,500 square miles, near Saverton, Missouri, its downstream boundary. Along these 314.0 miles of river, the average slope of the river along this reach is 0.5 feet per mile except in the vicinity of Rock Island, Illinois where prior to construction of the navigation locks and dams, the slope of the river was 1.5 feet per mile. Topography is generally characterized by high bluffs and rolling hills, which descend to a wide, flat, floodplain adjacent to the river. Many small ungaged tributary streams as well as major rivers flow into the river along this reach. Figure MVR-2 is a boundary map of the Rock Island District. Drainage areas of the Mississippi River's locks and dams, gages and tributaries are listed in Tables MVR-3 and MVR-4. The three largest tributaries to the Mississippi River in the Rock Island District are the Rock, Iowa and Des Moines Rivers.

3.2 Rock River. Headwaters of the Rock River originate in the lake region of Fond du Lac County in Southeastern Wisconsin. The general direction of flow is south-southwest to the confluence with the Mississippi River at river mile (R.M.) 479.1 below Rock Island, Illinois.

The drainage area is 10,915 square miles at the mouth. The topography varies from flat and gently rolling farmland to steep uncultivated forest.

3.3 Iowa River. The Iowa River has a drainage area of 12,500 square miles, of which its major tributary, the Cedar River, contributes 7,870 square miles. The average slope of the Iowa River is 1.9 feet per mile while the Cedar is slightly steeper with an average slope of 2.6 feet per mile. Both basins are long and narrow and roughly parallel one another with flow following a southeast path. The Cedar River joins the Iowa River 29.6 miles upstream from the confluence with the Mississippi River at Columbus Junction, Iowa. The Iowa River enters the Mississippi River at R.M. 434.4. Both basins are characterized by gently rolling topography and well-drained soils. The Iowa River flow is partially controlled by the Coralville Reservoir, which protects the city of Iowa City, Iowa.

The Coralville Lake project is located on the Iowa River upstream from Iowa City in Johnson County and is a part of the general comprehensive plan for flood control and other purposes in the Upper Mississippi River region. Construction began on this project in July 1949, and it was completed and put into operation in October 1958. The dam controls runoff from 3,115 square miles and provides protection to downstream reaches including the operation for the Mississippi River flood stages. The normal conservation pool at the dam is 683.0 feet National Geodetic Vertical Datum (NGVD) with 42,200 acre-feet of storage. The flood control storage pool (elevation 712.0 feet) provides an additional 419,000 acre-feet of storage.

3.4 Des Moines River. The Des Moines River Basin extends across central Iowa to the southeastern part of the state. The watershed has an area of 14,470 square miles. Des Moines, Ottumwa and Fort Dodge are the largest population centers. This basin contains 9.4 million acres of land and 42,000 acres of lake surface. The Des Moines River has numerous tributaries, many of which are very short with small drainage areas. Its major tributary is the Raccoon River, which enters the Des Moines River in the city of Des Moines.

The Des Moines River Basin has an average width of 40 miles and extends 360 miles from its headwaters north of Slayton, Minn., to its confluence with the Mississippi River below Keokuk, Iowa at R.M. 361.3. Downstream of its confluence with the Raccoon River near Des Moines, Iowa, the river valley changes both in direction and character. North of this point, the valley topography is shallow, with steep walls and a narrow flood plain. South of this point the river flows southeasterly in a broader, more mature flood plain in which the valley becomes wider and deeper with rounded bluffs. Two reservoirs partially control upstream flow on the Des Moines River. Saylorville Reservoir, 214 miles upstream of the mouth, protects the City of Des Moines, Iowa. Red Rock reservoir, 143 miles above the mouth, provides flood protection for the downstream cities.

Saylorville Lake is located on the Des Moines River about 11 miles upstream from the City of Des Moines. The principal purpose of the Saylorville Project is to furnish needed additional storage to supplement the flood control capacity of the downstream Red Rock Dam and Lake Red Rock and to provide flood protection to the City of Des Moines. The permanent conservation pool forms a lake with storage of about 90,000 acre-feet and extends some 17 miles upstream from the dam.

The Saylorville Reservoir has a total capacity of 676,000 acre-feet at full flood control pool elevation 890 feet and covers about 16,700 acres. The conservation pool was raised from 833 to 836 feet in 1983 to provide a water supply for the City of Des Moines and the Iowa Southern Utilities near Ottumwa, Iowa. The Saylorville Project has been in operation since April 1977.

The Red Rock Dam and the Lake Red Rock Project on the Des Moines River started operations in 1968 approximately 60 miles downstream from the City of Des Moines. The drainage area above the dam site is 12,323 square miles. A permanent lake of 265,500 acre feet storage area is formed behind the dam. With the flood control pool full (elevation 780.0 feet), the reservoir storage is 1,484,900 acre-feet above the conservation pool of 742 feet NGVD. Flood protection is provided to 36,000 acres of agricultural lands in the Des Moines River basin and to the Cities and Towns of Ottumwa, Eldon, Eddyville, Keosauqua and Farmington.

4. Key Locations.

4.1 Gages. Stage gages are located at an average of 12 miles along the mainstem of the Mississippi River in the Rock Island District. U.S.G.S. flow gages are located along the mainstem at Clinton, IA and Keokuk, IA (L&D 19 Tailwater). Most stage data is available in near real-time via Data Collection Platforms (DCP) and satellite transmission to the District Office. Real-time flow data is available at the dams as computed by structural ratings for normal flows and tailwater ratings for high flows. Table MVR-1 lists the Mississippi River mainstem gages in the district. In addition to the tail gage, each Navigation dam also has a pool gage. Because the pool stages are highly controlled, the tailwater stage gives better indication of the current river status.

Table MVR-1. Mississippi River Stage Gages in the Rock Island District.

Mississippi River Gages	River Mile	Gage Zero (Ft. MSL)	Flood Stage (ft.)	Drainage Area (sq. mi.)	Years of Record	Real-time Stage Data Available
Dam 10 Tailwater	614.9	600.0	15	79200	67	YES
Cassville, WI	606.3	596.29		80900	16	NO
Dam 11 Tail	583	588.2	16	81600	67	YES
Dubuque, IA	579	585.47	17	81600	124	YES
Dam 12 Tail	556.7	580.2	17	82400	66	YES
Sabula, IA	535	572.27		85000	22	NO
Dam 13 Tail	522.5	568.7	16	85500	61	YES
Clinton, IA	518	566.29		85600	24	NO
Camanche, IA	511.8	563.21	17	85700	63	YES
Princeton, IA	502.1	563.56		88300	10	NO
Dam 14 Tail	493.3	557.08	11	88400	63	YES
Dam 15 Tail	482.9	542.5	15	88500	102	YES
Fairport, IA	463.5	535.16	14	99300	90	YES
Dam 16 Tail	457.2	533.79	15	99400	66	YES
Muscatine, IA	453.3	530.74	16	99450	102	YES
Dam 17 Tail	437.1	526.57	14	99600	71	YES
Keithsburg, IL	428	523.19	14	112870	102	YES
Dam 18 Tail	410.5	518.52	10	113600	66	YES
Burlington, IA	403.1	511.45	15	114000	27	YES
Fort Madison, IA	383.9	0	528	118500	112	YES
Dam 19 Tail	364.3	477.83	16	119000	102	YES
Gregory Landing, MO	352.9	572.71	15	134000	71	YES
Dam 20 Tail	343.2	468.5	14	134300	89	YES
La Grange, MO	336	469.6		134800	27	NO
Quincy, IL	327.9	458.59	17	135000	56	YES
Dam 21 Tail	324.9	457.8	17	135000	66	YES
Hannibal, MO	309.9	449.43	16	137200	124	YES
Dam 22 Tail	301.2	446.1	16	137500	66	YES

4.2 Tributaries. Table MVR-2 lists eighteen gaged tributaries which add flow to the Mississippi River in the Rock Island District. Each tributary is gaged with at least one rated gage, operated and maintained by the U.S.G.S. The three forks of the Fabius River combine below each of their respective gages to enter the Mississippi through one channel. The Green River is a gaged tributary to the Rock River downstream of the U.S.G.S. gage at Joslin, IL.

Table MVR-2. Gaged Tributaries of the Mississippi River in the Rock Island District.

Mississippi River Tributaries	Station Name	River Mile	Drainage Area at Gage	Drainage Area at Mouth	Years of Record	Real-time Flow Data Available
Turkey River	Garber	608.1	1545	1648	89	YES
Grant River	Burton	593.2	267	316	68	YES
Platte River	Rockville	588.2	142	334	68	NO
Maquoketa River	Maquoketa	548.6	1553	1879	89	YES
Apple River	Hanover	545.1	247	262	68	NO
Wapsipinicon River	De Witt	506.8	2330	2540	68	YES
Rock River	Joslin	479.1	9549	10915	63	YES
Green River	Geneseo	Trib. To Rock	1003		67	YES
Iowa River	Wapello	434.4	12500	12500	88	YES
Edwards River	New Boston	431.2	445	450	68	YES
Pope Creek	Keithsburg	427.8	183	200	70	YES
Henderson Creek	Oquawka	409.9	432	604	63	YES
Skunk River	Augusta	396	4303	4355	89	YES
Des Moines River	Keosauqua	361.3	14038	14470	99	YES
Fox River	Wayland	353.6	400	502	80	YES
Bear Creek	Marcelline	341	349	400	57	NO
Wyaconda River	Canton	337.3	393	458	70	YES
Middle Fabius River	Monticello	323.0	393	1570	57	YES
South Fabius River	Taylor	323.0	620		67	YES
North Fabius River	Monticello	323.0	452		80	YES
North River	Palmyra	321.1	373	397	67	YES

5. Key Locations – Structures

5.1 Levees. Levees protect the majority of the Mississippi River floodplain along the lower half of the Rock Island District. Levee in the district protect areas as small as a few acres to areas greater than 40,000 acres. Levees are designed and operated for purposes related to Environmental Management, Agriculture, and Local Flood Protection. The Environmental Management levees are usually the lowest in elevation and designed and operated to overtop at a specified stage and location. Agricultural and Local Flood Protection levees are generally designed to protect for higher stages and are historically flood fought to protect against all flood events. Table MVR-3 lists the levees currently modeled in the Mississippi River MBMS.

Table MVR-3. Modeled Levee Systems in the Rock Island District.

Mississippi River Modeled Levee Districts	Location (River Mile)	Protected Area (Acres)	Levee Type	Level of Protection (Year)
Green Island	545.8-548.5	6576	Agricultural	10
Drury	451-459	5050	Agricultural	50
Bay Island	434.2-447.9	24630	Agricultural	50
Lake Odessa	434.8-441	6413	Environmental	
Keithsburg	427.4-428	100	Agricultural	10
Oquawka	415-417.2	32	Urban	
Henderson #3	411.8-414.8	2380	Agricultural	10
Henderson #1	403.2-412.3	8330	Agricultural	50
Henderson #2	401-403.2	7870	Agricultural	50
Green Bay	386.6-388.8	13690	Agricultural	50
Des Moines-Mississippi	358.6-359.8	12716	Agricultural	50
Mississippi-Fox	354.3-355.9	11032	Agricultural	35
Hunt-Lima	341.9-358	31000	Agricultural	50
Gregory	347.8-354.4	9268	Agricultural	50
Canton	341.6-343.2	510	Urban	50
Indian Grave Upper	336.9-339.9	12399	Agricultural	50
Indian Grave Lower	330-335.6	6814	Agricultural	50
Union Township	331.5-335.3	3857	Agricultural	25
Fabius	324-327.5	14955	Agricultural	50
South Quincy	317.8-325.4	5800	Agricultural	500
Marion County	321.3-323.3	4170	Agricultural	50
South River	312.1-318.2	10200	Agricultural	50
Sny Upper Section	297.2-311.4	42070	Agricultural	50

5.2 Navigation Locks and Dams. A total of 13 locks and 12 dams are located along the Mississippi River within the Rock Island District. There are two locks at Rock Island, IL. Each dam creates on of a series of "steps" which river vessels climb or descend as they travel upstream or downstream. Each dam controls the level of its pool and the locks lift or lower vessels from one pool to the next. Within each pool, portions of the channel were excavated to maintain a minimum 400-foot width and 9-foot depth. The first pool formed in the District was by Lock and Dam 19, created in 1913. Pool 19 is the longest pool of the entire 9-foot navigation system and has the second highest head differential (38.2 feet at flat pool). On the Mississippi River, Dam 19 is the only non-government owned and operated dam of the system. Hydropower is generated at this facility under private ownership.

During high water, when the pool stage can no longer be controlled due to the stage of the tailwater, the dam gates are all raised up above the water surface, creating a free-flowing condition. This occurs periodically at all dams except Dam 19, where the head differential is too large for the tailwater to affect the pool stage.

Ten of the twelve dams have control points at the dam. When the control point is at the dam, the gates are operated to maintain a specified stage within a total tolerance of 0.5 ft. Dam 16 is controlled as a hinge point pool to maintain a specified stage at Fairport, IA. Dam 20 is operated with a wider tolerance to maintain a specified stage at Gregory Landing and to compensate for fluctuations in discharges from the hydropower dam at L&D 19.

Each dam, except Dam 19, is made up of roller gates, tainter gates, or a combination of the two. Roller gates at the dams may be either submersible or non-submersible, depending on the specific location. Submersible gates allow for the passage of floating debris and ice. Dam 19 consists of 119 lift gates proportionate with it's 119,000 square miles of drainage area. Table MVR-4 provides information for the Navigation Dams along the Mississippi within the district.

Table MVR-4. Navigation Dam Information for the Rock Island District.

Dam Number	River Mile	No. and Type of gates	Total Dam Gate Width	Earthen Dike Width and Type	Control Point
11	583.0	16 (3 sub. rollers, 13 sub. tainters)	1080	3540 ft. non-overflow	At Dam
12	556.7	10 (3 sub. rollers, 7 sub. tainters)	750	6320 ft. non-overflow, 1200 ft. overflow	At Dam
13	522.5	13 (3 sub. rollers, 10 sub. tainters)	940	11360 ft non-overflow, 1650 ft. overflow	At Dam
14	493.3	17 (4 sub. rollers, 13 non-sub. tainters)	1180	1357 ft. non-overflow	At Dam
15	482.9	11 (2 sub. rollers, 9 non-sub. rollers)	1100	415 ft. non-overflow	At Dam
16	457.2	19 (4 non-sub. rollers, 12 non-sub. tainters, 3 sub. tainters)	920	726 ft. non-overflow, 1700 ft. overflow	Fairport, IA
17	437.1	11 (3 sub. rollers, 8 sub. tainters)	810	720 ft. non-overflow, 1555 ft. overflow	At Dam
18	410.5	17 (3 sub. rollers, 14 sub. tainters)	1140	3470 ft. non-overflow, 2200 ft. overflow	At Dam

19	364.2	119 lift gates	3808	None	At Dam
20	343.2	43 (3 non-sub. rollers, 6 sub. tainters, 34 non-sub. tainters)	1780	150 ft. non-overflow	Gregory Landing, MO
21	324.9	13 (3 sub. rollers, 10 sub. tainters)	940	494 ft. non-overflow, 1400 ft. overflow	At Dam
22	301.2	13 (3 sub. rollers, 9 non-sub. tainters, 1 sub. tainters)	900	460 ft. non-overflow, 1600 ft. overflow	At Dam

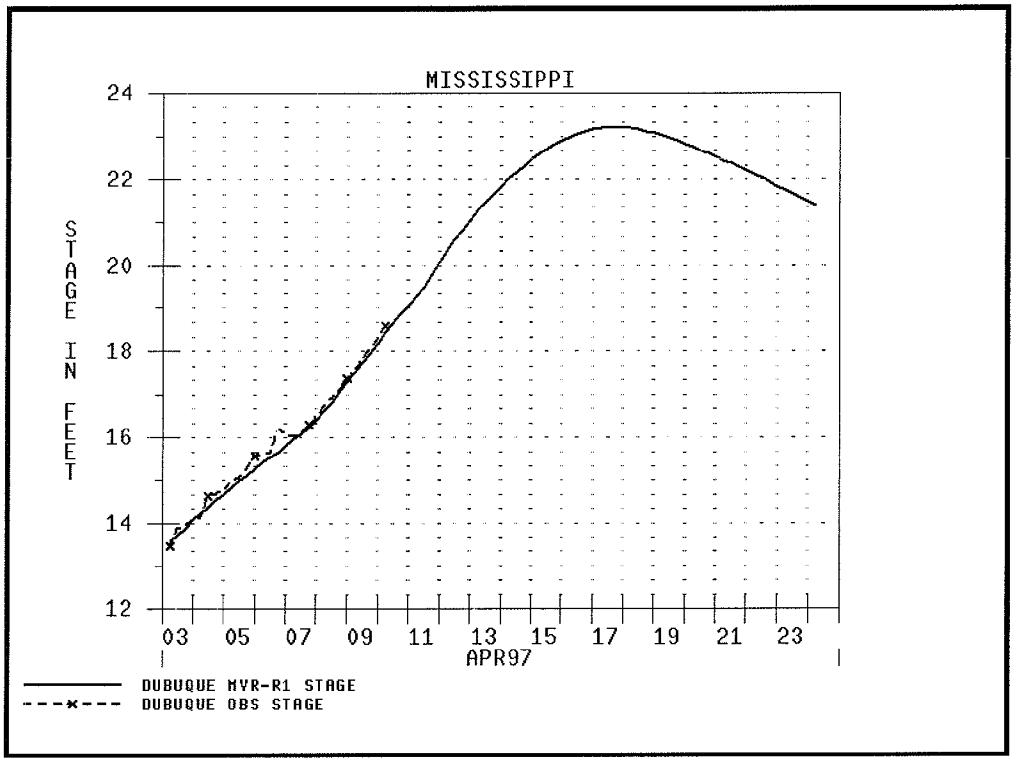
6. Calibration. The basic model calibration for the current Mississippi River portion of MVR's MBMS model was accomplished during the 1995 FPMA Study. Two flood events and one non-flood event were simulated for the purpose of model calibration. The 1986 flood was chosen to represent an event in which no levees were breached. The 1993 flood was calibrated to reproduce an event in which levees overtopped. Additionally, the 1996 water year was reproduced to adjust the model for normal and low flow conditions. In addition to the basic channel roughness calibration with Manning's *n*-values, the UNET automated calibration technique was used. In the automated calibration technique, best-fit rating curves of observed stages versus computed discharges at mainstem gaging stations are used by UNET to adjust conveyance, varying by flow, for each model reach. No additional discharge-conveyance or conveyance-change factors are used in the current Mississippi River MBMS. Also, the tributaries are not calibrated for stage reproduction.

7. Operational Experiences. The Mississippi River MBMS was tested during the spring flood event of 1997. Record snowfall in Wisconsin and Minnesota and subsequent snowmelt created the second highest recorded flood stage in Dubuque, Iowa and third highest in the Quad Cities (Davenport IA, Moline Il, Rock Island IL, and Bettendorf IA). The majority of flow for this event came down the Mississippi River through L&D 10 in St. Paul District. The accuracy of St. Paul's forecast and the calibration of the MBMS were the key factors to good forecasts in the Rock Island District. Most tributaries were low or recessing throughout the flood event. Within MVR, only the regulation of reservoirs on the Des Moines River affected the flood wave on the Mississippi.

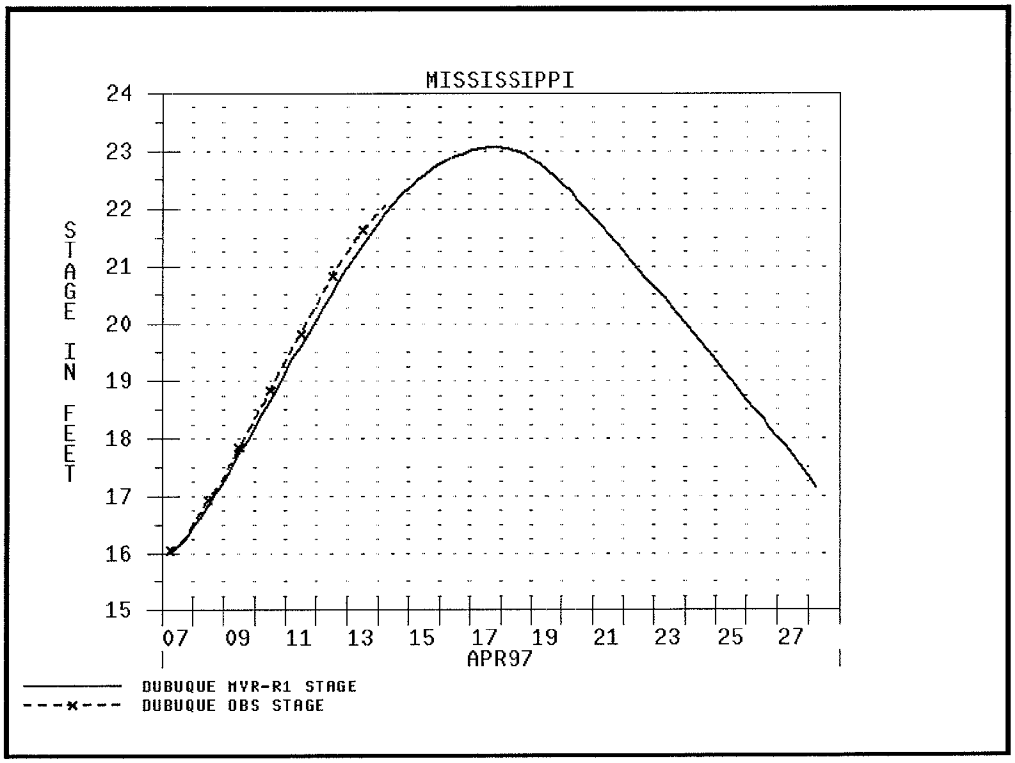
Water control personnel ran the MBMS daily from April 10 to May 6 1997. Computed flow hydrographs were received from the St. Paul District through ftp. Because the MBMS was not fully operational at that time, the discharge hydrograph at L&D 10 could not be entered directly into the MBMS as an internal boundary condition. The forecaster entered that data by hand. This was the hardest task for the flood event, as tributaries were fairly insignificant and all the levees held. This was a nearly perfect chance to check the calibration of the UNET model. Very little error could be attributed to poor estimation of ungaged flow in the district.

The real proof of the accuracy of the MBMS model is in its ability to accurately forecast the flood crests, in both stage and time. Four gages along the Mississippi are chosen to show the results of the daily forecasts. The gages include Dubuque, Iowa (R.M. 579.3), Muscatine, Iowa (R.M. 453.3), Burlington, Iowa (R.M. 403.1), and Quincy, Illinois (R.M. 327.9). Plates MVR-3 to MVR-18 trace the progress of the forecast, as the flood event passed downstream. For each station four hydrographs are shown. These four hydrographs represent MBMS stage forecasts before, near and after the observed flood crest passed the gage. The MBMS forecasted gages at Dubuque and Burlington well for all four forecasts. The forecasts at Muscatine were very good after an error in gage location was corrected in the model. The April 14 forecast illustrates this error. The unusual progression of stage at Quincy is attributable to the reservoir regulation on the Des Moines River. Better forecasts of the Des Moines River at the downstream gage would have created better forecasts on the Mississippi River. Des Moines River forecasts may be enhanced with the hydrologic model, now under development.

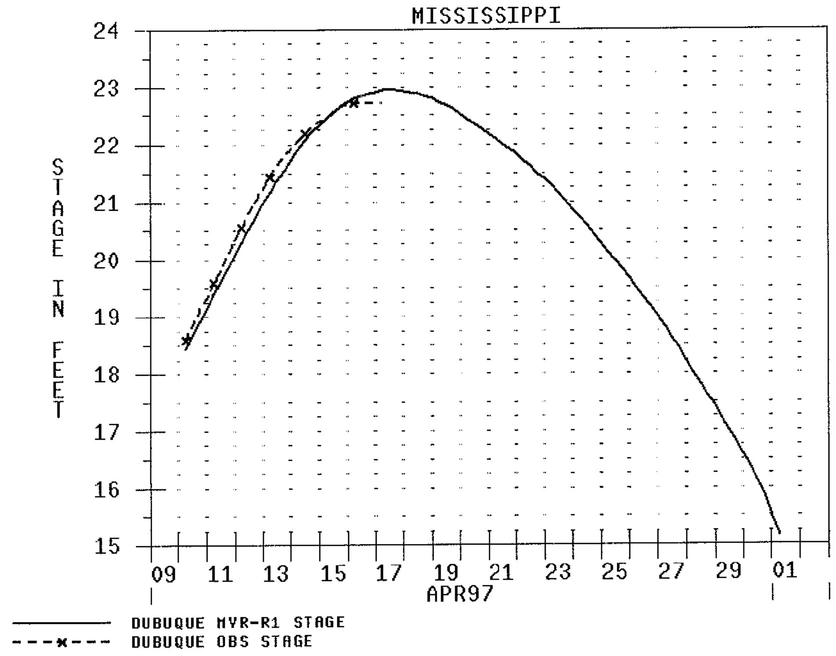
The MBMS system was run entirely by water control staff in Rock Island with very little assistance from model developers. This bodes well for the setup and logic of the MBMS, as well as the stability and reliability of the UNET model.



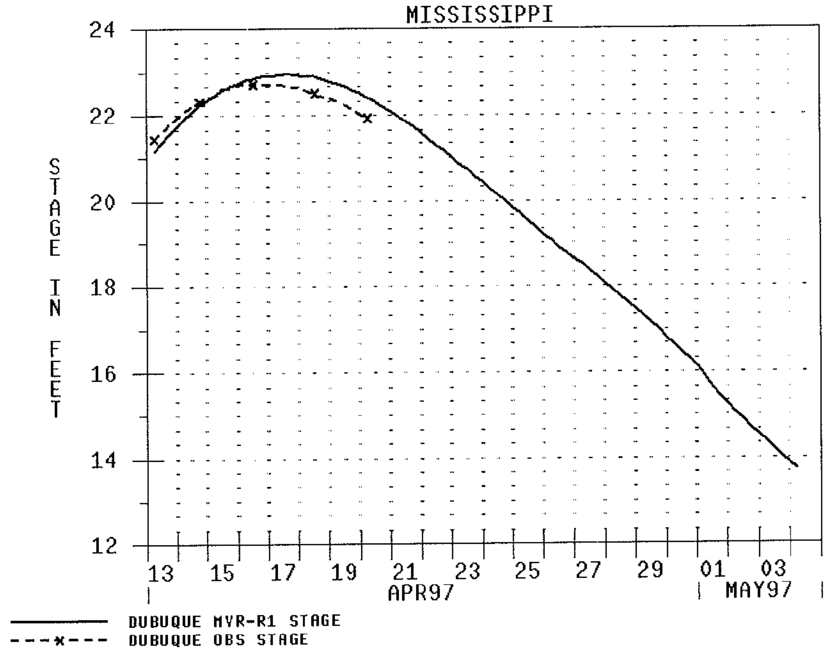
MVR-3. MBMS Forecast for Apr. 10, 97 for Dubuque, IA (six days before observed crest)



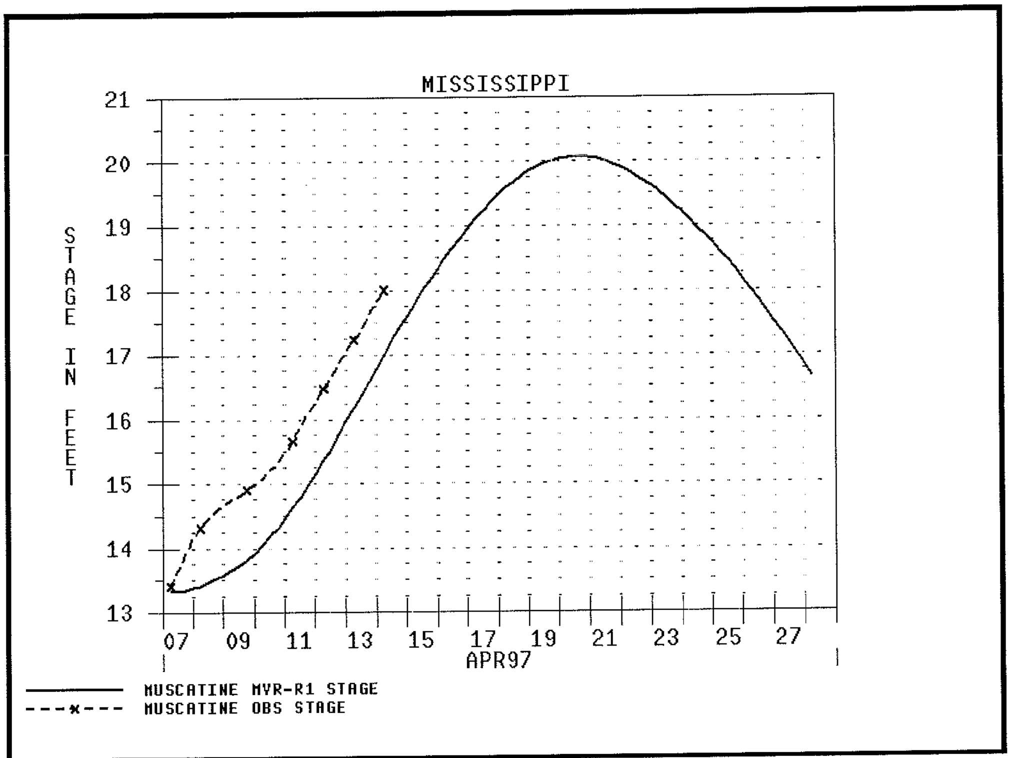
MVR-4. MBMS Forecast for Apr. 14, 97 for Dubuque, IA (two days before observed crest)



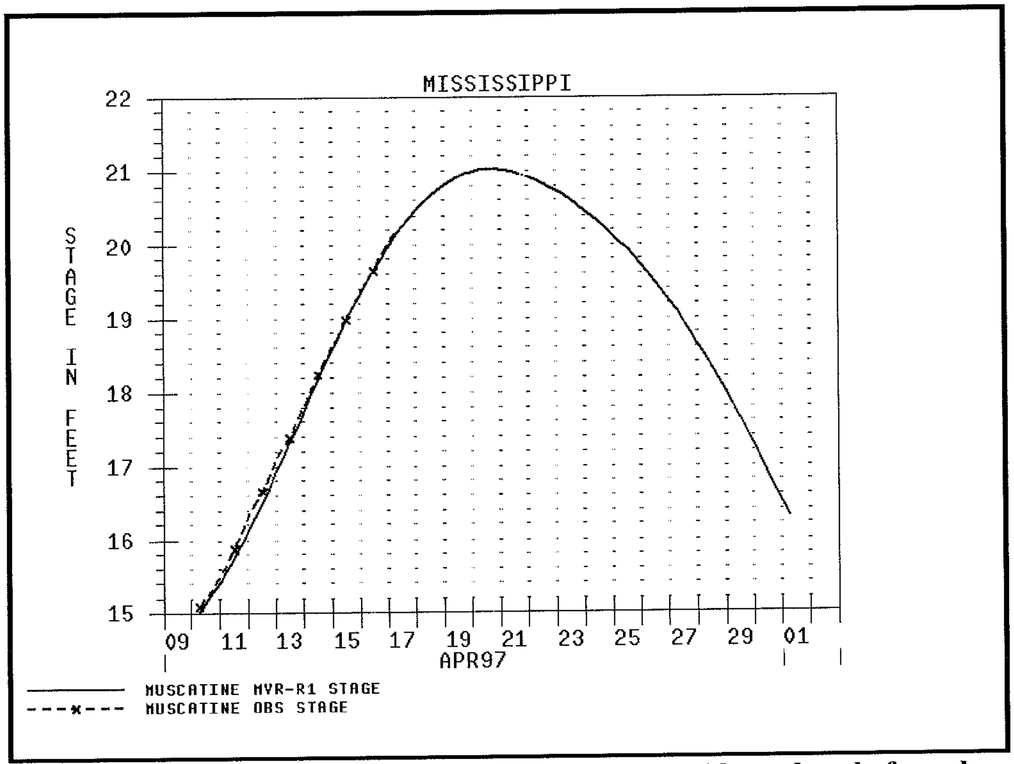
MVR-5. MBMS Forecast for Apr. 17, 97 for Dubuque, IA (one day after observed crest)



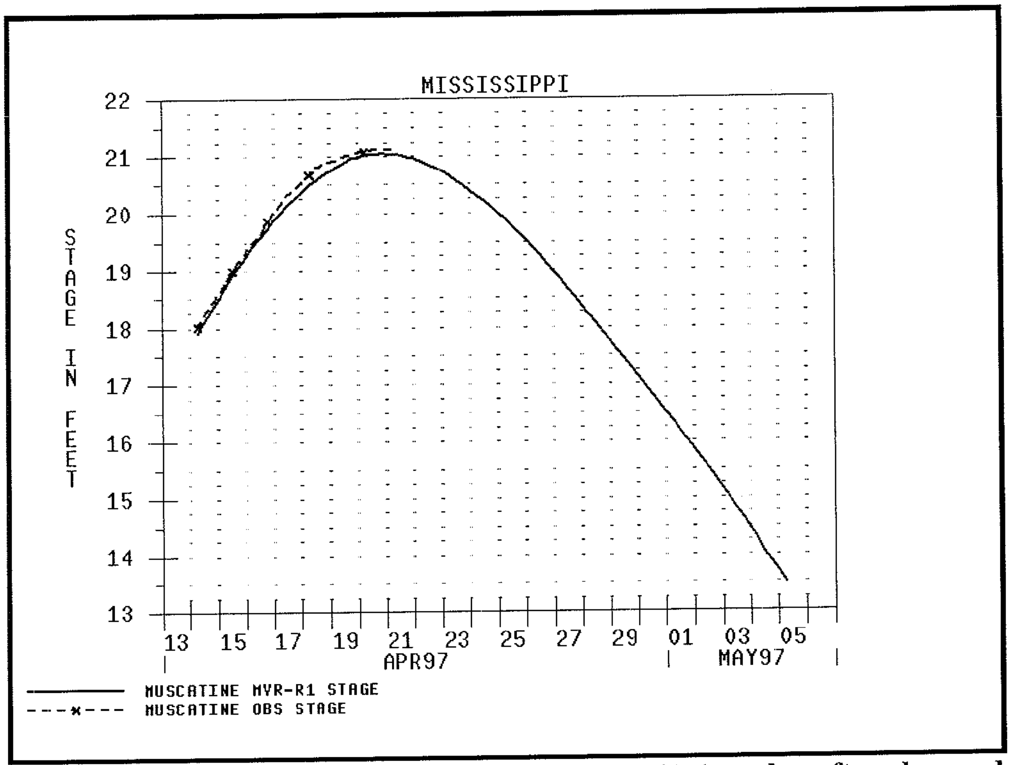
MVR-6. MBMS Forecast for Apr. 20, 97 for Dubuque, IA (four days after observed crest)



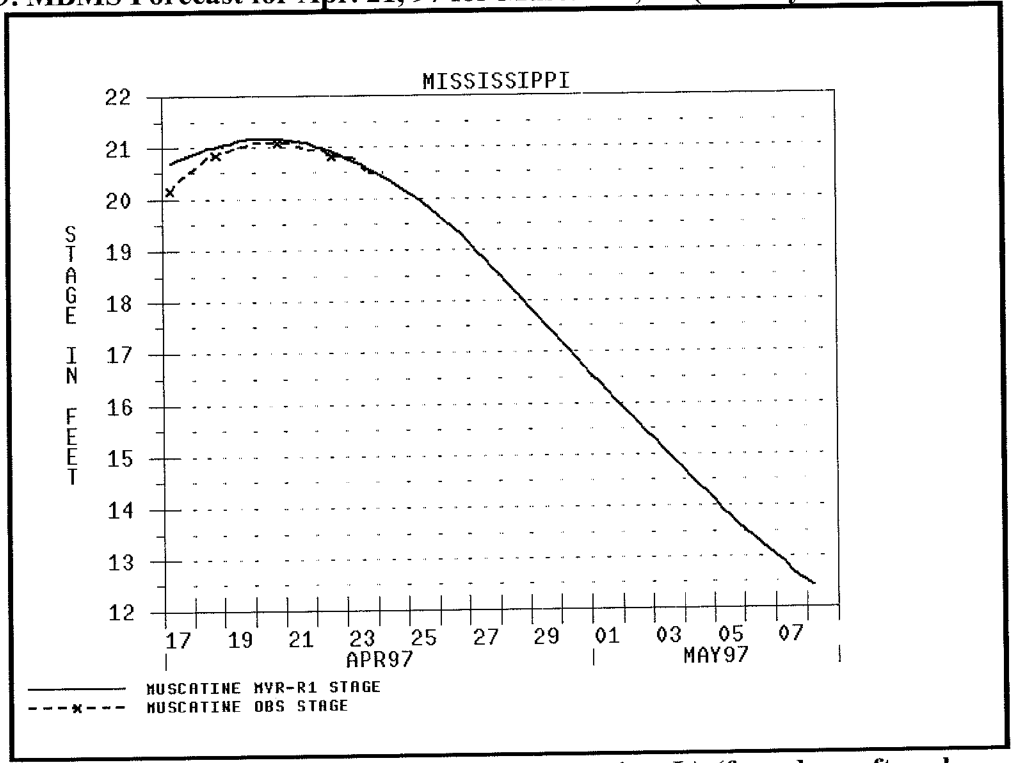
MVR-7. MBMS Forecast for Apr. 14, 97 for Muscatine, IA (six days before observed crest)



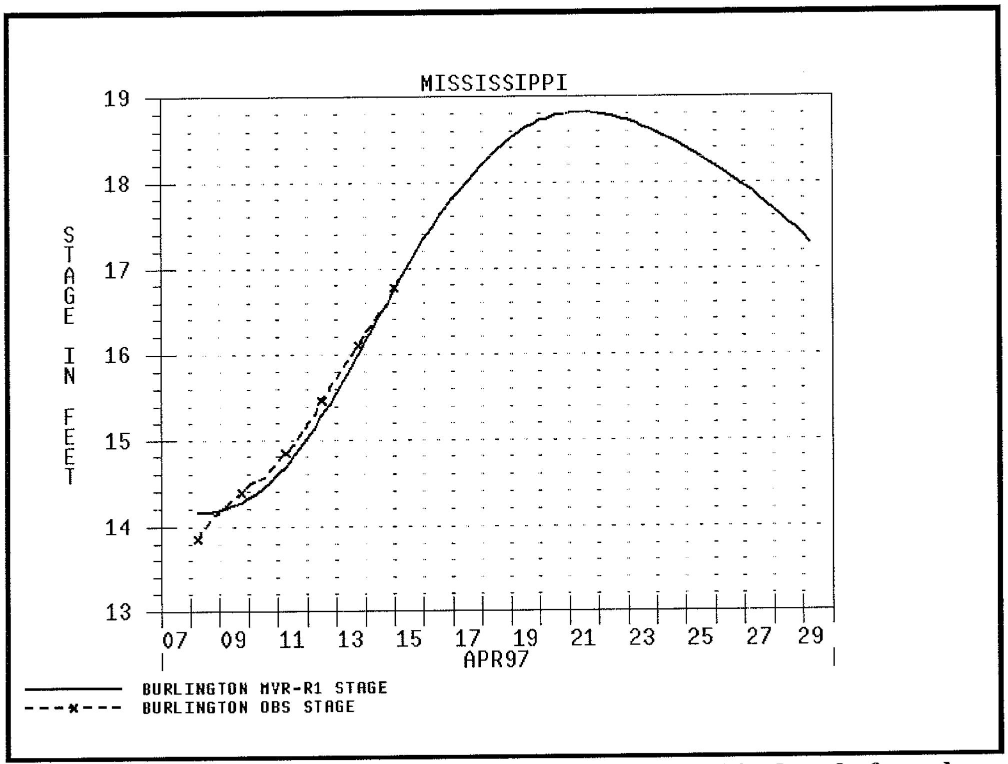
MVR-8. MBMS Forecast for Apr. 17, 97 for Muscatine, IA (three days before observed crest)



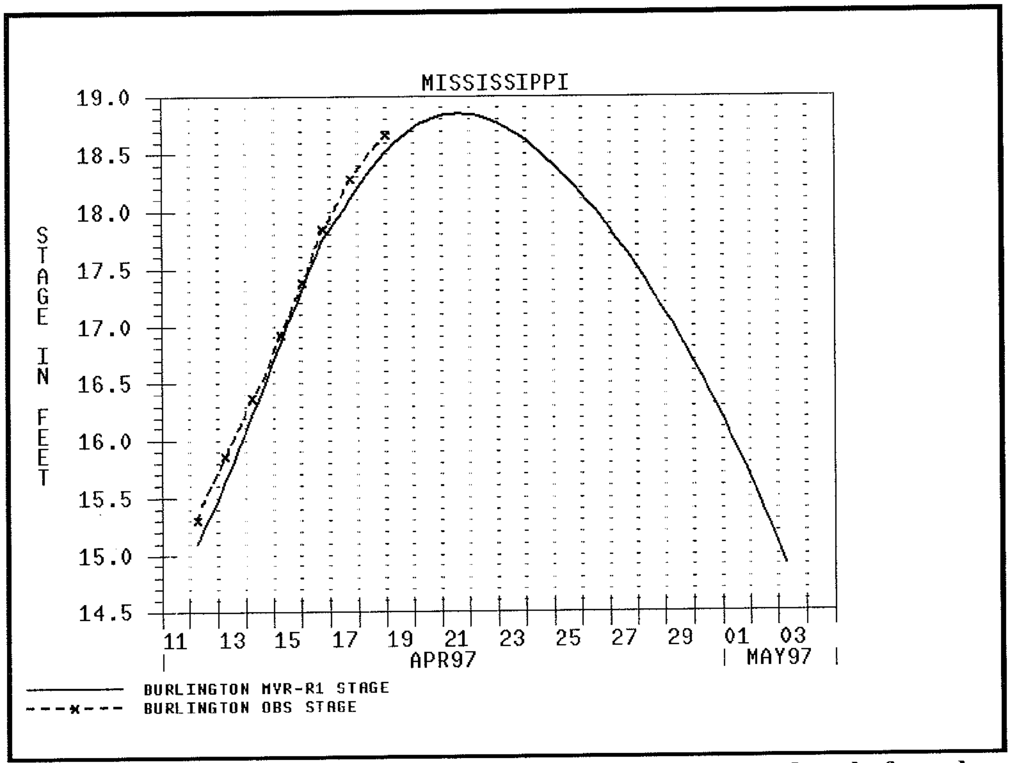
MVR-9. MBMS Forecast for Apr. 21, 97 for Muscatine, IA (one day after observed crest)



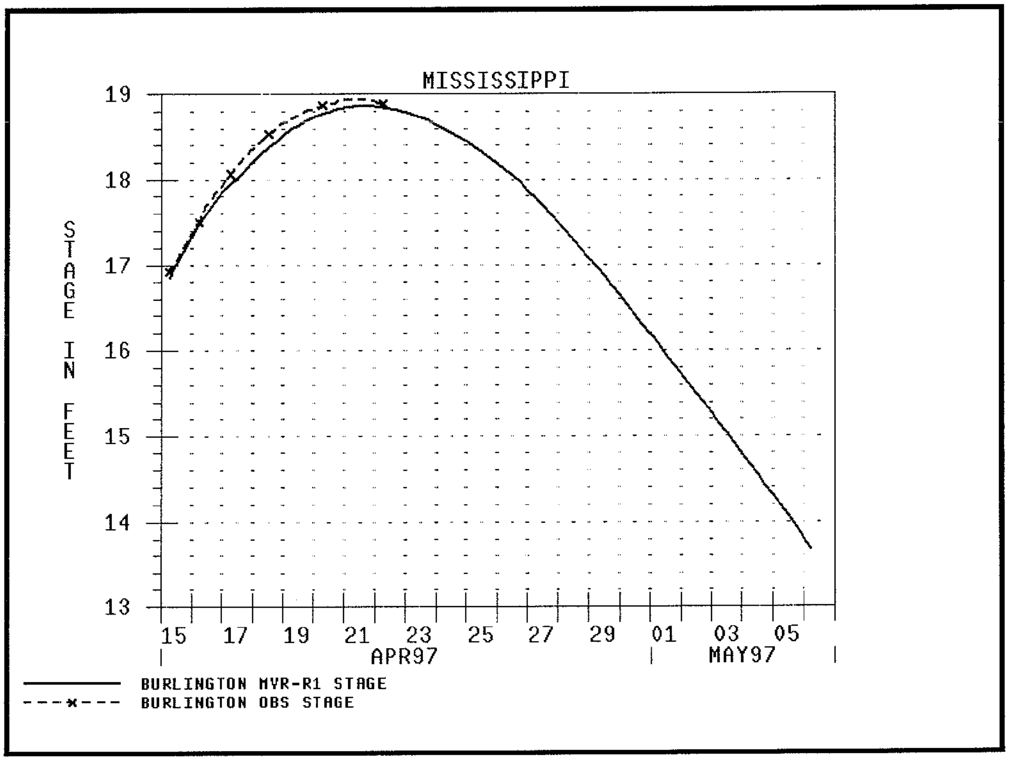
MVR-10. MBMS Forecast for Apr. 24, 97 for Muscatine, IA (four days after observed crest)



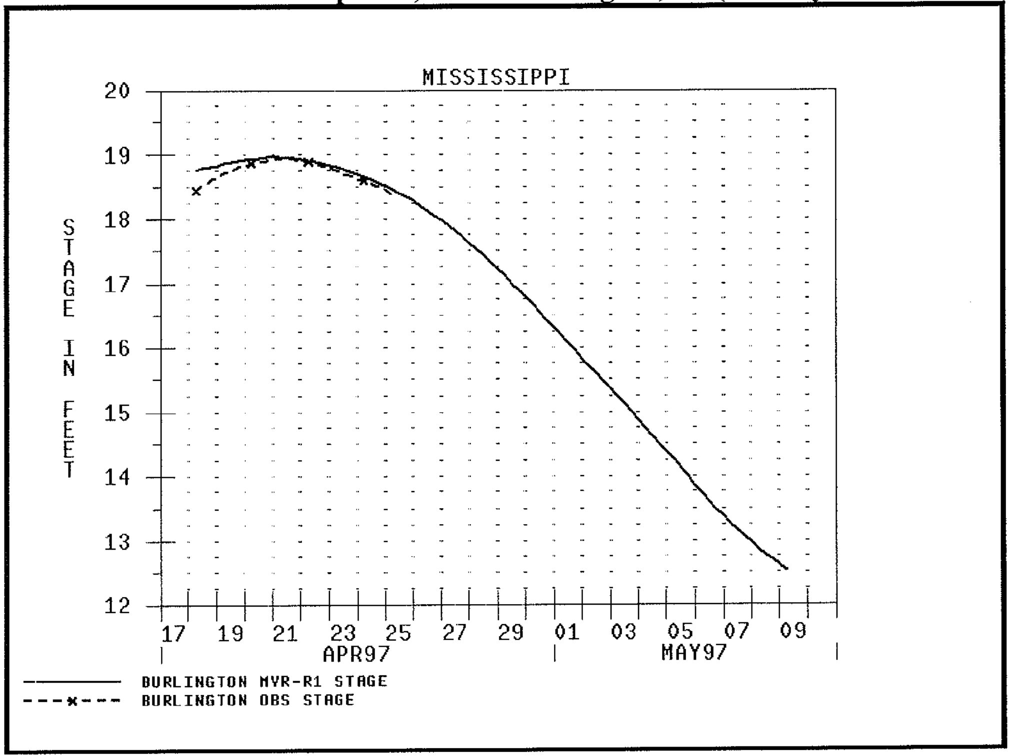
MVR-11. MBMS Forecast for Apr. 15, 97 for Burlington, IA (six days before observed crest)



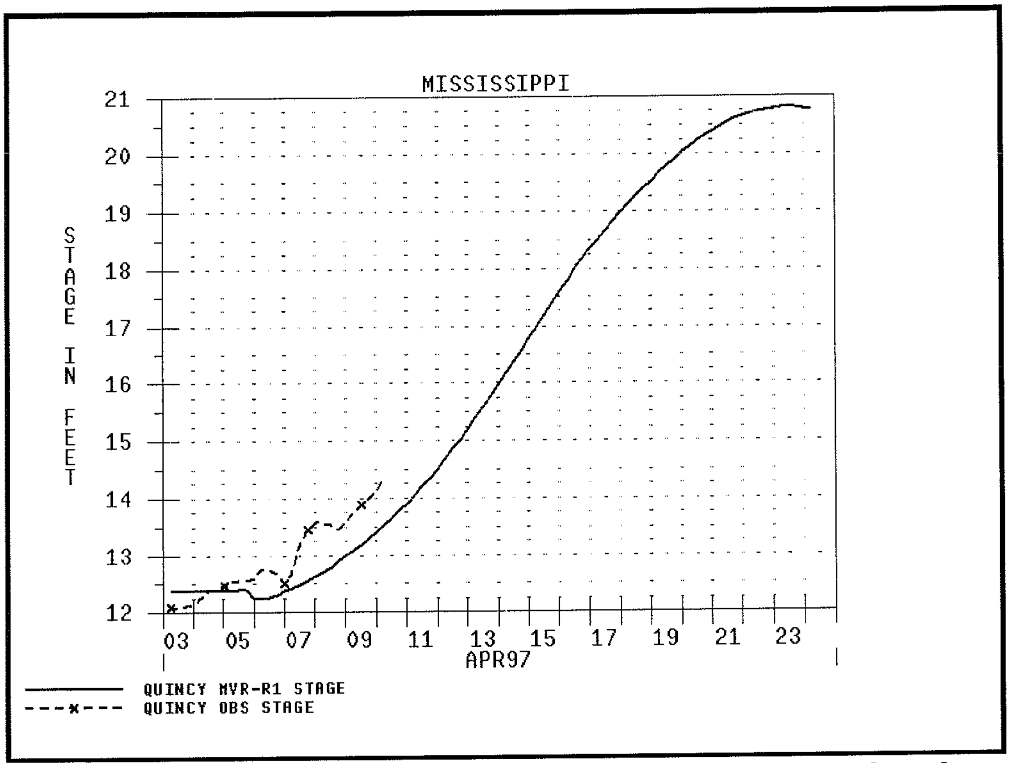
MVR-12. MBMS Forecast for Apr. 19, 97 for Burlington, IA (two days before observed crest)



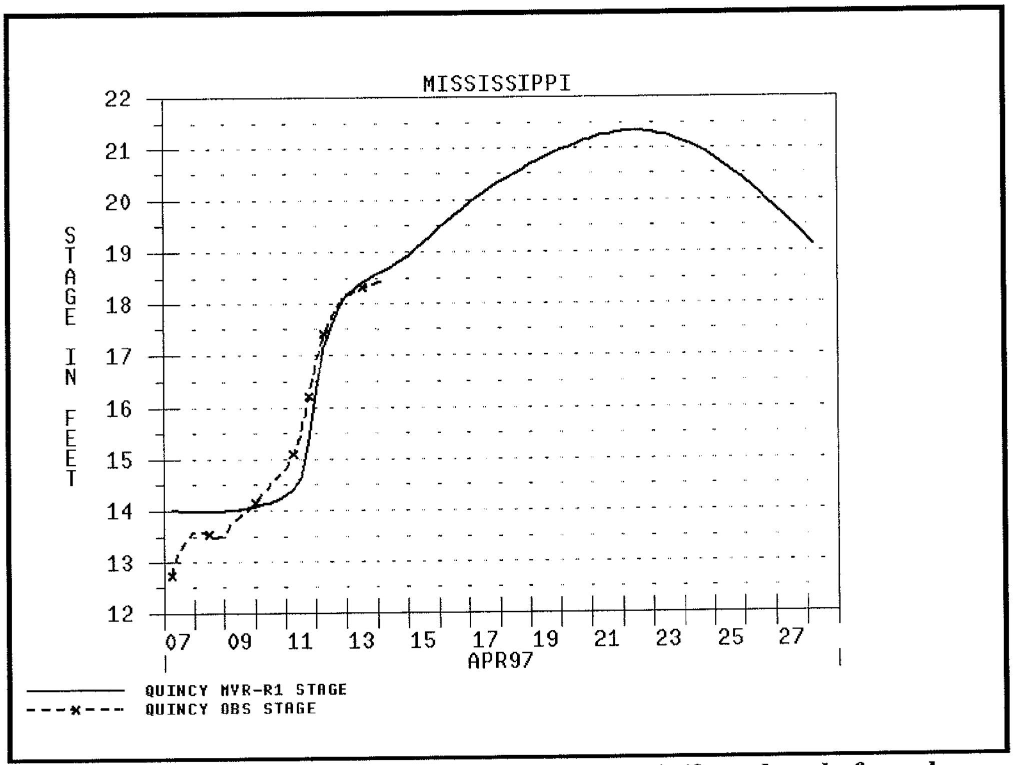
MVR-13. MBMS Forecast for Apr. 22, 97 for Burlington, IA (one day after observed crest)



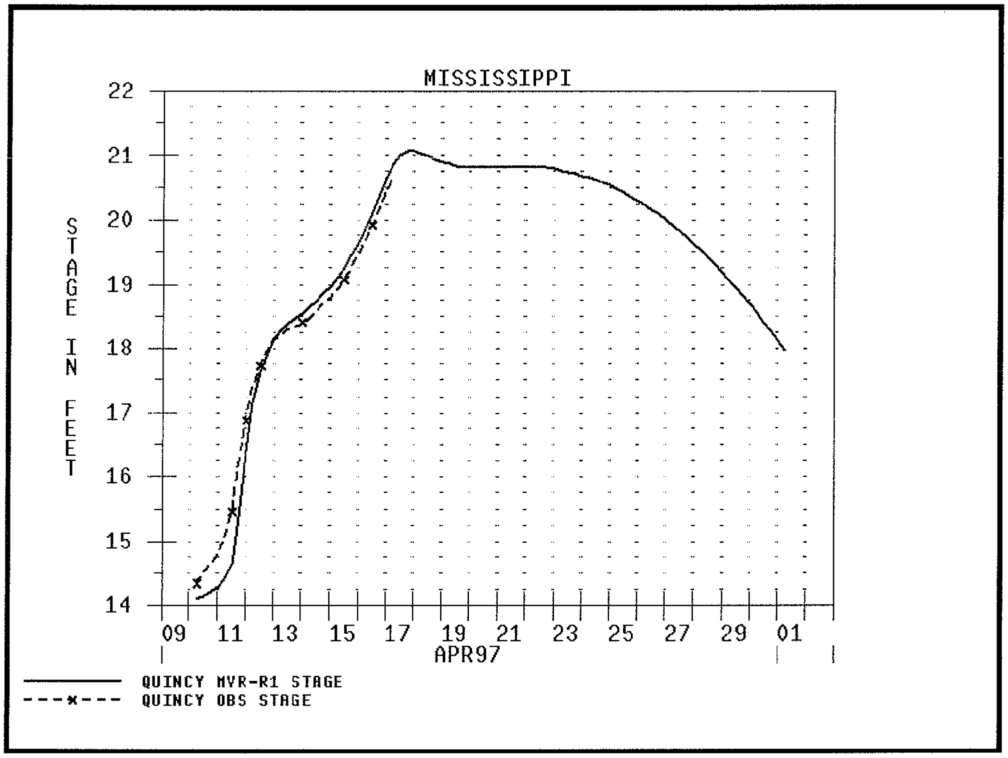
MVR-14. MBMS Forecast for Apr. 25, 97 for Burlington, IA (four days after observed crest)



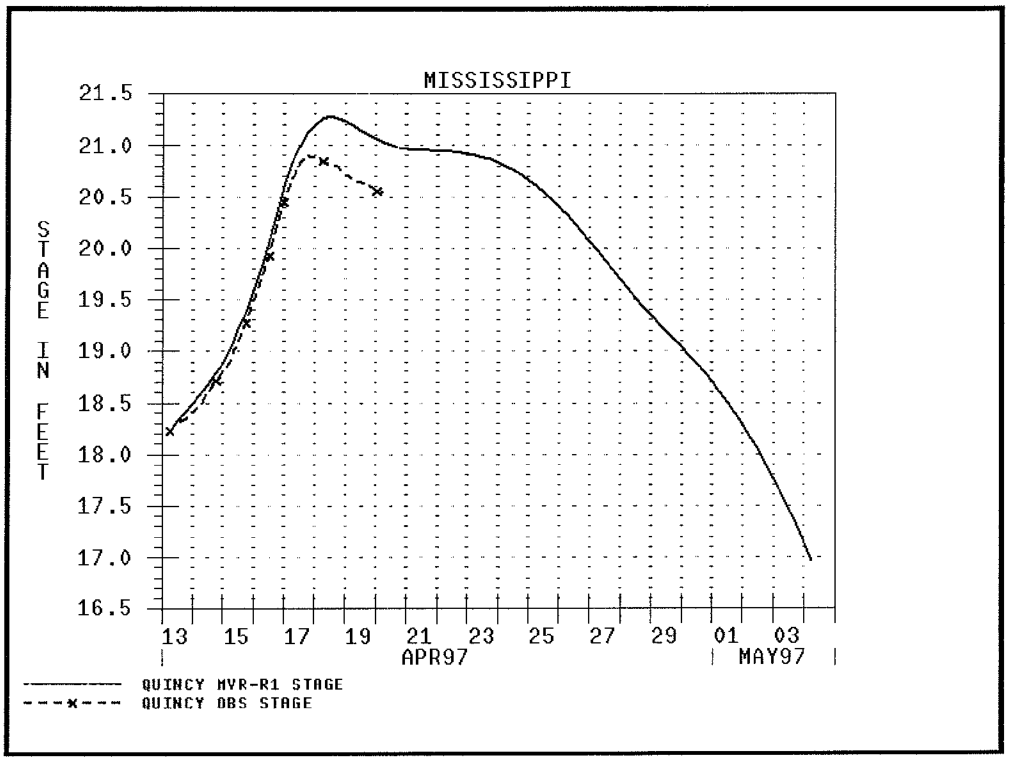
MVR-15. MBMS Forecast for Apr. 10, 97 for Quincy, IL (eight days before observed crest)



MVR-16. MBMS Forecast for Apr. 14, 97 for Quincy, IL (four days before observed crest)



MVR-17. MBMS Forecast for Apr. 17, 97 for Quincy, IL (one day before observed crest)



MVR-18. MBMS Forecast for Apr. 20, 97 for Quincy, IL (two days after observed crest)

ILLINOIS RIVER

1. Geographic Extent. The Illinois River basin covers 28,906 square miles, including the 673 square miles of the Lake Michigan basin that now drains into the Waterway. It extends from the vicinities of Milwaukee, Wisconsin, and South Bend, Indiana, to the Mississippi River. The average natural slope of the river is about one foot per mile above the "Great Bend" near Hennepin and about 0.1 foot per mile below. The Illinois Waterway is 327 miles long and provides a navigation link between the Mississippi River at Grafton, Illinois, RM 0.0 and Lake Michigan at Chicago. The Illinois River originates at the confluence of the Des Plaines River and the Kankakee River near Channahon, Illinois R.M. 273. From this point the river follows a generally west and southwest course through north central Illinois to its confluence with the Mississippi River near Grafton, Illinois, R.M. 0.0. Numerous backwater areas and lakes parallel the main channel. Downstream of R.M. 202 extensive levee systems have been built to protect agricultural areas in the wide floodplain. Drainage areas of the Illinois River's locks and dams and tributaries are listed on Figure MVR-19

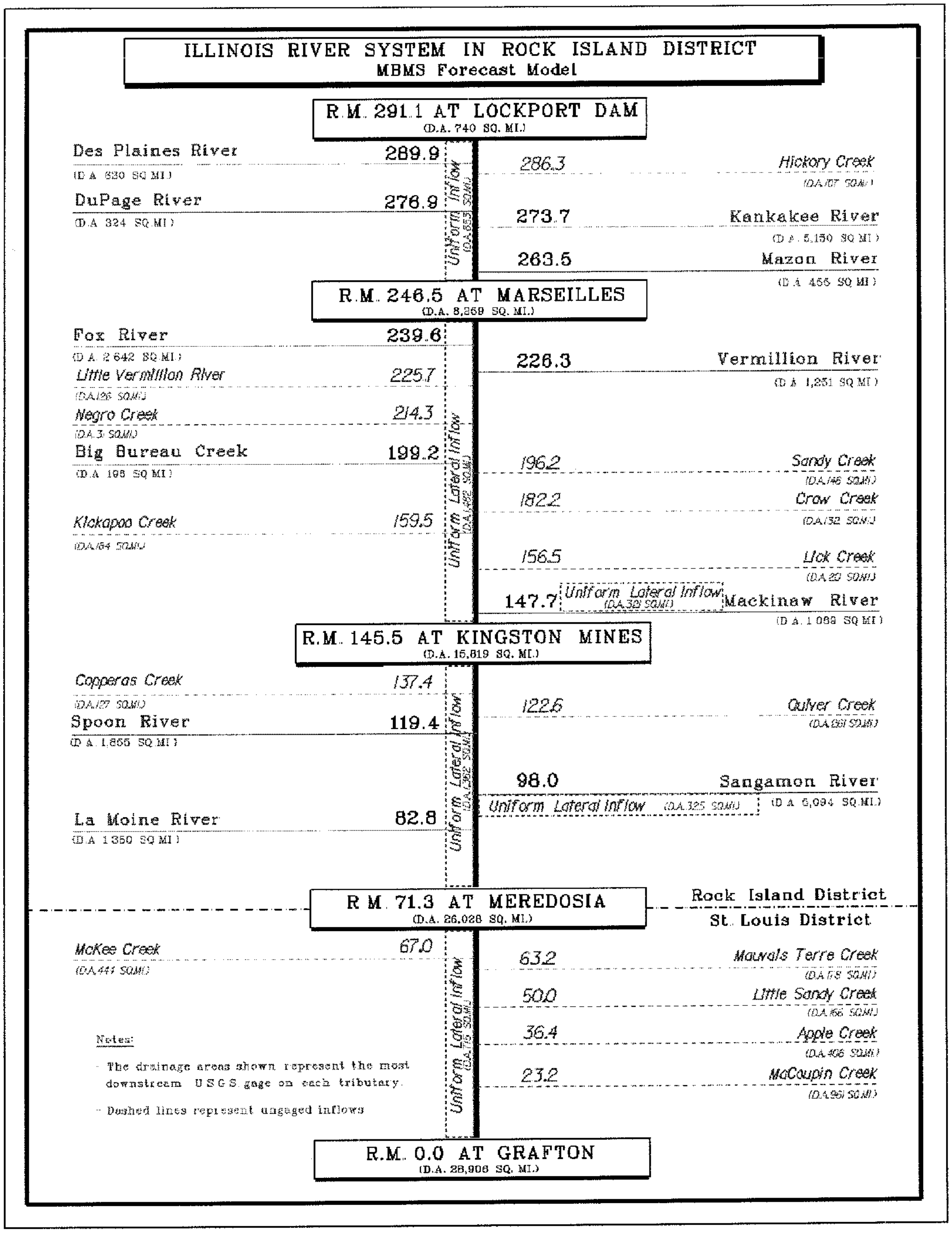


Figure MVR-19. Schematic of the MVR Illinois River MBMS Model.

2. Model Geometry. The MBMS covers the Illinois River from Lockport L&D, R.M. 291.0 to Grafton, Illinois, R.M. 0.0. The Rock Island District ends at New LaGrange L&D, R.M. 80.2. The remainder of the river is in the St. Louis District. This portion of the model is included in the Rock Island model to provide a true dynamic solution of stage and flow at Meredosia, Illinois, R.M. 70.8, the pass off point to the St. Louis District MBMS. Figure MVR-19 shows a schematic of the Illinois River MBMS model.

Cross sections for the Illinois River were coded in 1990 from the most recent hydrographic surveys, dated between 1975 and 1989. Cross section extensions into the overbank were taken from USGS 7.5 minute quadrangle maps and aerial mosaic maps.

Fifteen levee districts are coded as storage cells in the model. Downstream conveyance within each levee district is disregarded, as it is not significant to the total river conveyance, after overtopping. These storage areas act as sinks to remove flow from or add flow to the river as the hydrograph rises and falls. Most levee districts will act solely as storage areas, eliminating and later contributing flow to Illinois River. Levee districts are included in the model, but rarely have Illinois River levees been overtopped. Modeled Levee districts are listed on Table MVR-5.

Two tributaries of the Illinois River are modeled as UNET routing reaches to better represent the timing of inflows to the Illinois River. The Mackinaw is represented as a series of top widths from the mouth to the gage at Congerville, 58 miles upstream. The Sangamon has regular UNET cross sections form the mouth to the gage at Oakford, 26 miles upstream. The remainder of the tributaries, twenty-three in all, are represented as point inflows to the river geometry.

Table MVR-5. Drainage and Levee Districts.

Levee District	River Mile	Bank	Failure Elevation (feet, NGVD)	Area (arce)
Hennepin	202.4 – 207.0	L	460	2900
East Peoria	159.4 – 162.9	L	460	800
Pekin & LaMarsh	149.7 – 155.1	R	458	3010
Spring Lake	134.0 – 147.7	L	455	13120
Banner Special	138.1 – 143.8	R	455.6	4561
East Liverpool	128.4 – 132.5	R	455	2885
Liverpool	126.5 – 128	R	455	2885
Thompson Lake	120.9 – 125.9	R	453.7	5498
Lacy	119.9 - 119.6	R	456.0	10406
Seahorn	111.0 - 111.8	R	452.0	2000
Big Lake	102.8 – 108.2	R	451.0	3401
Kelly Lake	100.3 – 102.7	R	451.0	1045
Coal Creek	85.0-92.0	R	454.7	6794
South Beardstown	79.0-88.1	L	453.8	10516
Crane Creek	83.9-84.9	R	450.0	5417
Muscooten Bay	88.1-93.7	L	444.0	17000

3. Hydrologic Data Sources. The upstream boundary for the Illinois River is stage at Lockport L&D. The downstream boundary is stage at Grafton, Illinois. The pass-off point to St. Louis District is flow at Meredosia, Illinois.

Twenty-five tributaries provide inflow in the Illinois River MBMS model. Most are represented as point inflows. Two tributaries, the Sangamon and Mackinaw, are modeled as routing reaches from the most downstream real-time gage to the mouth. Of all the tributaries, only eleven have real-time gages. Flows for the remainder are estimated using drainage area ratios of the index gage at Princeton, Illinois on Big Bureau Creek.

Twenty-six percent of the Illinois River Basin above Meredosia is ungaged. Ungaged inflow along the Illinois River, not accounted for as estimated point inflows, is modeled as uniform lateral inflow in four reaches. These are Lockport to Marseilles, Marseilles to Kingston Mines, Kingston Mines to Meredosia, and Meredosia to Grafton. Each of these ungaged areas is estimated using a drainage area ratio of the index gage hydrograph. Tributary inflows are summarized in Table MVR-6 and uniform lateral inflows in Table MVR-7.

Table MVR-6. Tributary Inflows.

River	Method	Gage
Illinois	Point	Lockport (740 sq miles)
Des Plaines	Point	Riverside (603 sq. miles)
Du Page	Point	Shorewood (324 sq. miles)
Kankakee	Point	Wilmington (5,150 sq. miles)
Mazon	Point	Coal City (455 sq. miles)
Fox	Point	Dayton (2,642 sq. miles)
Vermillion	Point	Leonore (1,251 sq. miles)
Little Vermillion	Point	0.64 x Big Bureau at Princeton
Negro Creek	Point	0.16 x Big Bureau at Princeton
Big Bureau	Point	Princeton (196 sq. miles)
Sandy Creek	Point	0.75 x Big Bureau at Princeton
Crow Creek	Point	0.23 x Vermillion at Pontiac
Kickapoo	Point	0.31 x Vermillion at Pontiac
Lick Creek	Point	0.03 x Vermillion at Pontiac
Mackinaw	Routed	Congerville (767 sq. miles)
Copperas Creek	Point	0.19 x LaMoine at Colmar
Quiver Creek	Point	0.39 x LaMoine at Colmar
Spoon	Point	Seville (1,636 sq. miles)
Sangamon	Routed	Oakford (5,093 sq. miles)
LaMoine	Point	Ripley (1,293 sq. miles)
McKee Creek	Point	0.68 x LaMoine at Colmar
Mauvaise Creek	Point	0.27 x LaMoine at Colmar
Sandy Creek	Point	0.25 x LaMoine at Colmar
Apple Creek	Point	0.61 x LaMoine at Colmar
Macoupin Creek	Point	1.46 x LaMoine at Colmar

Table MVR-7. Uniform Lateral Inflows.

Area	Gage
Brandon Road to Marseilles	6.67 x Big Bureau Creek at Princeton
Congerville to mouth on Mackinaw	0.55 x Vermillion at Pontiac
Kingston Mines to Sangamon River	1.6 x LaMoine at Colmar
Along Sangamon	0.49 x LaMoine at Colmar
Meredosia to Grafton	1.09 x LaMoine at Colmar

4. Calibration. The unsteady flow model was calibrated to reproduce the 1982 flood and then verified against periods in 1973, 1974, 1979, and 1985. These floods were selected for model calibration for the following reasons: 1) data availability -- there is a vast amount of stage and flow data on hand for these flood events 2) flood event diversity -- the 1982 flood was a December flood (14 day duration above flood stage of 448.0 at Kingston Mines) caused by tributary flooding; the 1979 flood was a spring mainstem flood (60 day duration); and 3) non-snow melt events -- both the 1982 and 1979 floods rainfall events typical to the Illinois River Basin.

There are two facets in the calibration of an unsteady flow model: adjustment of discharge and adjustment of stage. Discharge is a function of reach length and storage. Stage calibration is obtained through a variation of Manning's *n* values via conveyance change factors. No automated calibration techniques were used for this model.

5. Real-Time Experiences. The flood of spring 1995 gave the Illinois River UNET model its first test at real-time simulation. Heavy rainfalls in the basin created predictions of record stages along the Illinois River near Beardstown, Illinois. Since these expected flows and stages were beyond the range of experience of our river forecasters, the UNET model was given the opportunity to predict these stages and crest timing.

A real-time version of the Illinois River UNET model was quickly developed by altering the existing frequency UNET model, stripping it of all the hydrographs not available in real-time and replacing them with estimated hydrographs from nearby index stations. The downstream boundary at Grafton was obtained daily from the St. Louis district.

With many of the tributary inflows not available in real-time the model, reproduction of observed stages was initially not very good. All of the inconsistencies that arose in the modeling effort were attributed to inaccuracies in inflows. The model parameter, QRATIO, was used to adjust ungaged inflows such that the computed mainstem river stage would better match the observed. After several iterations with the model, computed hydrographs were within one foot of the peak. While this reproduction was sufficient at the time, much better reproduction is expected of the MBMS.

Illinois River MBMS testing has shown some problems in reproduction of observed flows and stages for all flow conditions. At twenty-six percent of the total basin, the ungaged area has a tremendous impact on the model. With all ungaged inflow currently tied to the only remaining index gage, erroneous inflows are common during large precipitation events. More Data Collection Platforms (DCP) may be needed for some of the ungaged tributaries along the Illinois River.

Table MVR-8 shows the ungaged areas of the Illinois model.

Table MVR-8. Illinois River Tributary Drainage Areas.

ILLINOIS RIVER / TRIBUTARY DRAINAGE AREAS			D.A	D.A	D.A	CUM.	UNGAGED
			(sq. mi.)	(sq. mi.)	(sq. mi.)	GAGED	D.A.
STATE	RIVER AND LOCATION	River Mile	@ Mouth	@ Gage	@ L&D	D.A	above L & D
IL	**ILLINOIS RIVER AT LOCKPORT**	290.9			740	740	
IL	**DES PLAINES RIVER AT RIVERSIDE***	289.9	2111	630			
IL	Hickory Cr. at Joliet	286.3	109				
IL	**BRANDON ROAD LOCK & DAM**	286.0			1506	1370	136
IL	**DU PAGE RIVER AT SHOREWOOD***	276.9	376	324			
IL	**KANKAKEE RIVER AT WILMINGTON***	273.7	5165	5150			
IL	**DRESDEN ISLAND LOCK & DAM**	271.5			7278	6844	434
IL	Aux Sable Creek	268.1	187				
IL	**MAZON RIVER NEAR COAL CITY***	263.5	524	455			
IL	Nettle Creek	262.7	74.1				
IL	Waupecan Creek	260.7	57.1				
IL	Bills Run	260.1	14.3				
IL	Hog Run	254.3	18.3				
IL	**MARSEILLES DAM***	247.0			8259	7733	526
IL	**FOX RIVER AT DAYTON***	239.6	2658	2642			
IL	Covel Creek	236.3	74.6				
IL	**STARVED ROCK LOCK & DAM**	231.0			11056	10901	155
IL	**VERMILION RIVER NEAR LEONORE***	225.7		1251			
IL	Cedar Creek	220.7	27.7				
IL	Spring Creek	218.6	50.9				
IL	Negro Creek	214.3	29.9				
IL	Allfork Creek	214.0	24.7				
IL	Coffee Creek	207.0	7.3				
IL	**BIG BUREAU CREEK***	199.2	486	196			
IL	Sandy Creek	196.2					
IL	Crow Creek	191.6	81.7				
IL	Gimlet Creeek	189.1	5.8				

IL	Strawn Creek	185.5	12.2				
IL	Crow Creek	182.2	130				
IL	Senachwine Creek	181.6	89.3				
IL	Snag Creek	181.1	33.3				
IL	Richland Creek	180.4	44.9				

ILLINOIS RIVER / TRIBUTARY DRAINAGE AREAS			D.A	D.A	D.A	CUM.	UNGAGED
			(sq. mi.)	(sq. mi.)	(sq. mi.)	GAGED	D.A.
STATE	RIVER AND LOCATION	River Mile	@ Mouth	@ Gage	@ L&D	D.A	above L & D
IL	Partridge Creek	177.3	27.1				
IL	Tenmile Creek	166.2	17.2				
IL	Farm Creek	162	61.3				
IL	Kickapoo Creek	159.5	306				
IL	**PEORIA LOCK & DAM**	157.8			14554	12503	2051
IL	Lick Creek @ North Pekin	156.4	19.2				
IL	Lost Creek	151	16.5				
IL	LaMarsh Creek	149.7	40.2				
IL	**MACKINAW RIVER NEAR CONGERVILLE***	147.7	1136	767			
IL	Little LaMarsh Creek	147.2	8.1				
IL	Copperas Creek	137.4	127				
IL	Duck Cr. near Liverpool	131.7	20.5				
IL	Buckheart Creek	128.2	20.6				
IL	Big Sister creek	126.3	28.4				
IL	Quiver Creek	122.6	261				
IL	**SPOON RIVER AT SEVILLE***	119.4	1855	1636			
IL	Otter Cr	111.8	126				
IL	Elm creek	102.7	9.2				
IL	**SANGAMON RIVER NEAR OAKFORD***	98	5419	5094			
IL	Sugar Creek near Ray	94.2	162				
IL	Coal Creek	84.9					
IL	**LAMOINE RIVER AT RIPLEY***	83.5	1350	1293			
IL	**LA GRANGE LOCK & DAM**	80.2			25648	23344	2304
IL	Little Creek	78.8					

IL	Indian Creek	78.7	286				
IL	Camp Creek	75.7					
IL	**ILLINOIS RIVER AT MEREDOSIA**	71.3		26028		25648	380
	CUM. UNGAGED ABOVE MEREDOSIA						5986
	PERCENTAGE UNGAGED						23%
*** GAGED TRIBUTARIES**							

REFERENCES

Floods of June 13-14, 1981, and December 2-12, 1982, In Illinois, Water-Resources Investigations Report 91-4062, U.S. Geological Survey, 1991.

Floods of September 26 – October 4, 1986, and August 14-17, 1987, In Illinois, Water-Resources Investigation Report 92-4149, U.S. Geological Survey, 1993.

FPMA, Floodplain Management Assessment, Appendix A, Hydraulic Modeling, U.S. Army Corps of Engineers, June 1995.

Post Flood Report 1979, Illinois River Basin, U.S. Army Corps of Engineers, Chicago District, 1979.

Post-Flood Report, The Great Flood of 1993, Upper Mississippi River Basin, Appendix B, U.S. Army corps of Engineers, Rock Island District, September, 1994.

UNET, One-Dimensional Unsteady Flow Through a Full Network of Open Channels, Hydrologic Engineering Center, Davis, California, April 2001.

Omaha District

(NWO)

TABLE OF CONTENTS

MISSISSIPPI RIVER REAL-TIME FORECAST MODEL

Omaha District

1. Geographic Coverage. The Omaha District portion of the Mississippi Basin unsteady flow forecasting system extends from Gavins Point Dam to Rulo, NE. The Omaha District model includes 313 miles of the Missouri River and 211 miles of tributaries. The Missouri River drainage area increases from 279,500 square miles to 414,900 square miles within the Omaha District model limits. Shown below is a schematic of the modeled area. The schematic illustrates the Missouri River gaging stations on the mainstem, tributaries that are included as routing reaches, lateral inflows to the model, and the river mile location of hydrologic features. In order to provide an accurate downstream boundary, the forecast model includes geographic data between Rulo, NE and St. Joseph, MO which adds an additional Missouri River length of 49.9 miles to the forecast model. All features pertaining to the Rulo to St. Joseph reach are described within the Kansas City District section of the MBMS report.

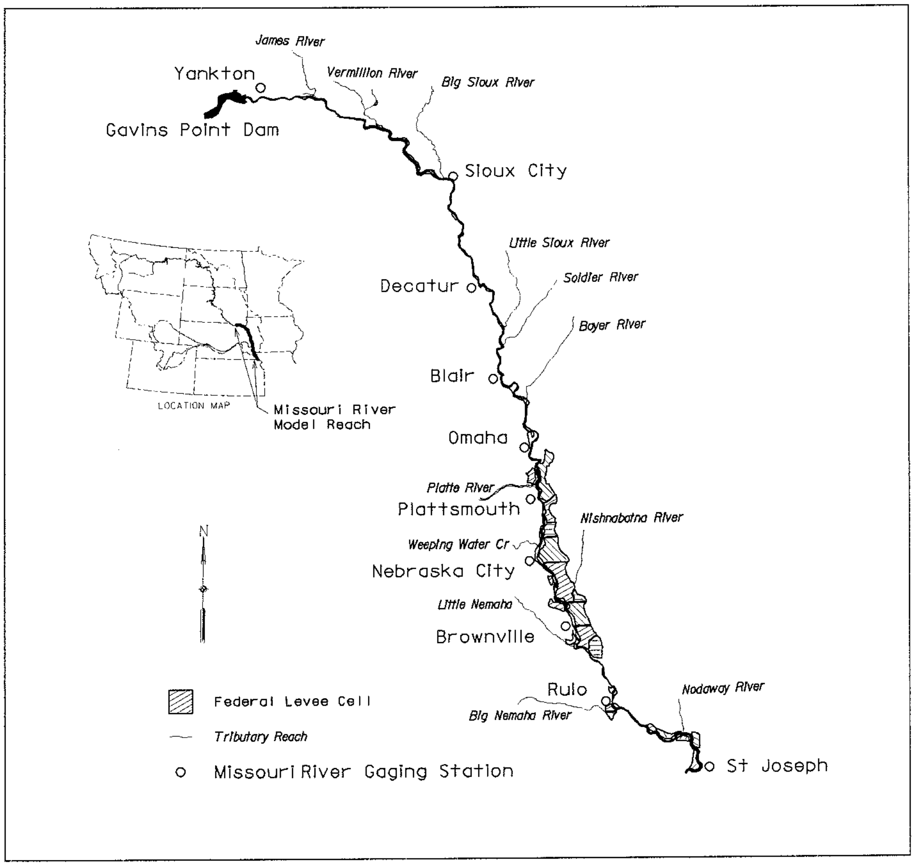


Figure NWO-1. Schematic of the Omaha District MBMS Model.

2. Hydrologic/Geographic Description of the Area. The Missouri River originates in the northern Rocky Mountains along the continental divide and flows south and east to join the Mississippi River near St. Louis, Missouri. At 2,315 miles (1960 mileage), it is the longest river in the United States. The Omaha District encompasses approximately 414,900 square miles of the drainage basin upstream of Rulo, NE to the river headwaters in the Rocky Mountains. The Missouri River basin contains numerous reservoirs and impoundments constructed by different interests for flood control, irrigation, power production, recreation, and water supply.

2.1 Missouri River Mainstem Dams. The most significant flood control projects constructed within the basin are the six main stem Missouri River Dams. The six dams, which were completed by 1964, provide flood protection by controlling runoff from the upper-most 279,000 square miles of the drainage basin. The reservoir system has a total combined capacity in excess of 73 million acre-feet of which more than 16 million acre-feet is for flood control. Gavins Point Dam, located near Yankton, SD at river mile 811.1, forms Lewis and Clark Lake and is the most downstream of the projects.

2.2 Navigation and Bank Stabilization. There were seven acts of Congress which provided for the construction, operation and maintenance of a navigation channel and bank stabilization works on the Missouri River. The most recent was authorized in 1945 and provided for bank stabilization combined with a 9-foot deep, and not less than 300 feet wide, navigation channel. The authorized project for the Missouri River extends from its confluence with the Mississippi River at St Louis, MO to Sioux City, IA for a total distance of 734.2 river miles. This project was accomplished through revetment of banks, construction of permeable dikes, cutoff of oxbows, closing minor channels, removal of snags, and dredging. In order to achieve the project objectives of bank stabilization and navigation, the river planform was shaped into a series of smoothly curved bends of the appropriate radii and channel width. Stabilization of the bank along the concave alignment of the design curve was accomplished with pile and stone fill revetments. Dikes were constructed along the convex bank, approximately perpendicular to the flow. These dikes were designed to prevent bank erosion and to promote accretion, forcing the channel to develop and maintain itself along the design alignment. In areas where the natural river channel did not conform to the design alignment, canals were excavated and natural channels blocked in order to force the river to flow along the design alignment.

2.3 Levee System. The Missouri River levee system was authorized by the Flood Control Acts of 1941 and 1944 to provide protection to agricultural lands and communities along the Missouri River from Sioux City, IA to the mouth at St. Louis, MO. The levees were designed to operate in accord with the six main stem dams. The extent of the levee system within the Omaha District consists of levee units on both banks from near Omaha, NE to near Rulo, NE. Although many federal levees were proposed north of Omaha, NE along the Missouri River, few have been built due to the significant contribution of the main stem dams in this reach and channel degradation that has occurred following dam closure. The majority of the area planned for protection by federal levees north of Omaha, NE is protected by private or non-federal levees with varying degrees of protection.

3. Drainage system. Missouri River forecast model limits within the Omaha District proceeds from Gavins Point Dam, at river mile 811.1, downstream to Rulo, NE, at river mile 498.0. Rulo, NE, corresponds with the Omaha District boundary with Kansas City District. The forecast model extends downstream of Rulo, NE to St. Joseph, MO at river mile 448.2 to provide an accurate downstream boundary condition.

3.1 Missouri River. The Missouri River is channelized through most of the model reach to river mile 734.2. Average channel width is about 600 feet. Upstream of the channelized section, the width varies widely with many islands and flow splits. Average Missouri channel gradient varies from 0.8 to 1.2 feet/mile. Total valley width usually averages 5-10 miles between the bluffs. The Missouri River generally follows the right (west) bluff line.

3.2 Tributaries. The Platte River, which enters the Missouri River downstream of Omaha, NE at river mile 594.8, is the largest tributary within the model reach and has a drainage area of 85,800 sq. miles. The Platte River is also a major contributor of coarse grained sediment. Other major tributaries include the James River, the Big Sioux River, and the Nishnabotna River. Refer to Figure NWO-1 for an illustration of significant tributaries. Major tributaries were included as separate routing reaches within the forecast model. Routing of the tributary flows from the gaging station location to their confluence with the Missouri River was found to increase the simulation accuracy. Tributary modeling efforts were of limited detail and intended for flow routing only. As a result of the coarse cross section data, computed stage information on the tributaries may not be accurate.

4. Key Locations – Gages. Gage data is required by the flood forecast model at all tributary and Missouri River gaging station locations. Discharge and stage hydrographs for the Missouri River and tributaries are required for inflow, boundary conditions, calibration, and verification. Historic hydrologic data was obtained from the USGS' Automated Data Processing System (ADAPS) which is part of the National Water Information System (NWIS). For real time operation, the forecast model employs hourly data extracted from the Missouri River database maintained by the Reservoir Control Center. The database includes hourly flow and stage data for the USGS's gaging stations that have data collection platforms (DCPs). Model inflow data also includes an estimation of ungaged flow within each Missouri River reach. Ungaged flows are estimated using the null internal boundary condition (Barkau, 1995). USGS and COE streamflow gages with their locations, gage identification numbers and other pertinent data are shown in Table NWO-1 for the tributaries and Table NWO-2 for the mainstem Missouri River.

Table NWO-1
Tributary Stream Gaging Stations

Tributary Gage and Location	USGS Gage ID	River Mile of Confluence
Gavins Point Dam Flow Release	----	811.1
James River at Scotland, SD	06478500	797.7
Vermillion River nr Vermillion, SD	06479010	772.2
Big Sioux River at Akron, IA	06485500	734.2
Perry Creek at Sioux City, IA	06600000	732.1
Floyd River at James, IA	06600500	731.3
Monona Harrison Ditch at Turin, IA	06602400	670.0
Little Sioux River nr Turin, IA	06607500	669.2
Soldier River at Pisgah, IA	06608500	664.0
Boyer River at Logan, IA	06609500	635.2
Papillion Creek at Fort Crook, NE	Corps Gage	596.6
Platte River at Louisville, NE	06805500	594.8
Weeping Water Creek at Union, NE	06806500	568.6
Nishnabotna River above Hamburg, IA	06810000	542.0
Little Nemaha River at Auburn, NE	06811500	527.8
Big Nemaha River at Fall City, NE	06815000	494.8
Nodaway River at Graham, MO	06817700	463.0

Table NWO-2
Missouri River Gaging Station Locations

Missouri River Gage Location	USGS Gage ID	Gage Datum	River Mile Location

Yankton, SD - 5.2 Miles D/S of Gavins Point Dam	06467500	1139.7	805.8
Gayville, SD - 3.8 Miles S.W. of Gayville	Corps Stage Gage	1100	796.0
Maskell, SD - 3.0 Miles N.E. of Maskell	Corps Stage Gage	1100	775.6
Ponca, Ne - Right Bank of Missouri River	Corps Stage Gage	1080	751.0
Sioux City, IA - 1.9 Miles D/S of Big Sioux River	06486000	1056.98	732.2
Decatur, NE - 0.1 Miles U/S of Hwy 175	06601200	1010	691.0
Blair, NE	Corps Stage Gage	977.28	648.3
Omaha, NE - 0.1 Miles D/S of I-480	06610000	948.24	615.9
Plattsmouth, NE - 3.2 Miles D/S of Platte River	Corps Stage Gage	928.31	591.5
Nebraska City, NE – 2.0 Miles U/S of Hwy 2	06807000	905.36	562.6
Brownville, NE - 6.8 Miles D/S of Nishnabotna River	Corps Stage Gage	860	535.2
Rulo, NE - D/S Hwy 159 and 3.2 Miles U/S of Big Nemaha River	06813500	837.23	498.1
St. Joseph, MO	06818000	788.2	448.2

5. Key Locations - Structures. Pertinent structures that impact hydraulics and flood routing within the reach include the mainstem dams, levees, and navigation structures. Federal levees are included within the forecast model as storage cells. Regulation of mainstem dams is reflected within the model by Gavins Point Dam inflow. Navigation structures are reflected in the cross section geometry and model calibration of roughness values.

5.1 Federal Levees. The Missouri River levee system was authorized by the Flood Control Acts of 1941 and 1944 to provide protection to agricultural lands and communities along the Missouri River from Sioux City, IA to the mouth at St. Louis, MO. Missouri River levees were designed to operate in conjunction with the six mainstem dams to reduce flood damages as part of the Pick-Sloan plan. The majority of the area upstream of Omaha, NE, is protected by private or non-federal levees with varying degrees of protection. Downstream of Omaha, federal levee protection is not continuous and the level of protection varies. A notable area without any federal levees is the left bank in the Rulo area between river miles 515.2 and 482.2. Federal levees were constructed in the 1950's and are usually set-back from the river bank a distance of 500 to1500 feet. Federal levees cover the left bank from river mile 515.2 to river mile 619.7. Levees on the right bank are intermittent since the river there is often near the bluff. Total federal levee length is approximately 191 miles in the reach from Omaha, NE (RM 615.9) to Rulo, NE (RM 498.1). The 191 levee miles may be subdivided as 133.5 miles along the mainstem Missouri River and 57.5 miles of levee tiebacks. All federal levees were included as storage areas within the forecast model. Table NWO-3 summarizes pertinent levee details.

Table NWO-3
Missouri River Levee Summary

Levee Unit (Year Completed)	Design Discharge[3] (cfs)	Location (River Miles).	River Length (Miles)
R-520 (1960)	310,000	501.0-505.5	4.5
L-536 (1951)	306,000	515.5-522.2	6.7
R-548 (1951)	304,000	527.9-534.6	6.7
L-550 (1951)	305,000	522.2-543.5	21.3
R-562 (1949)	300,000	541.6-549.0	7.4
L-575 (1949)	295,000	543.5-575.7	30.2
R-573 (1949)	295,000	552.3-558.0	5.7
L-594 (1964)	295,000	573.7-580.3	6.6
L-601 (1966)	295,000	580.3-588.0	7.7
[1]L-611-614 (1986)	295,000	588.0-594.8	6.8
[2]L-611-614 (1986)	250,000	594.8-605.7	10.9
R-613 (1971)	250,000	595.2-596.6	1.4
R-616 (1986)	250,000	595.6-601.5	4.9
L-624 (1950)	250,000	605.7-607.9	2.2
L-627 (1950)	250,000	607.9-613.9	6.0

Council Bluffs (1950)	250,000	613.9-619.7	5.8
Omaha (1950)	250,000	611.6-624.9	13.3

[1] Represents the portion of levee L-611-614 downstream of the Platte River.
[2] Represents the portion of levee L-611-614 upstream of the Platte River.
[3] Refers to the original design discharge. Channel changes such as aggradation have altered levee capacity.

5.2 Private Levees. Following levee construction and chute closure, deposited sediment filled many areas riverward of the federal levees. Farming of these areas became extensive. To prevent crop damages caused by normal high flows on the Missouri River, farmers constructed secondary levees at or near the river bank. Many of the secondary private levees tie directly into the federal levees. Private levees have also been constructed along the river bank in areas where federal levees were not constructed. The left bank reach from river mile 515.5 to river mile 498.1 near Rulo, NE is protected solely by private levees. Private levee topography is included within the forecast model cross section data. In contrast to federal levees, private levees were not included as separate levee cells. Private levees are included within the cross section geometry and affect bank stations and flow area.

6. Digital Terrain Data. Updated cross sections were extracted along the Missouri River for the forecast model. Missouri River valley digital terrain models (dtms) were assembled from 1999 aerial photography combined with hydrographic surveys. Hydrographic survey data was collected in 1994 between Rulo, NE, and Ponca, NE (river mile 498 to 752). Hydrographic survey data from Ponca to Gavins Point Dam was collected in 1995 (river mile 752 to 811). Dtm construction, including the insertion of hydrographic survey data, was performed by the survey contractor.

6.1 Tributary River Sections. Cross section geometry was included in the forecast model for all major tributaries for the reach from the confluence with the Missouri River upstream to the USGS gaging station location. Most tributary gaging stations are located approximately 10-15 river miles upstream of the confluence with the Missouri River. Tributary cross section data were taken from USGS 7.5 minute quadrangle topographic maps or the best available topographic information. Tributary cross section spacing varied from 5,000 to 20,000 feet. The assembled cross section data for each tributary is suitable for flow routing only. Accurate stage computation on the tributaries is not possible with the coarse data employed in the forecast model.

6.2. Missouri River Sections. New Missouri River sections were used in construction of the forecast model. Cross section location was limited to the location of hydrographic survey data. Extension of the cross section across the valley was drawn using existing USGS 1:24000 scale quadrangle maps. Flow paths, reach lengths, and bank station locations were also determined from the quadrangle maps. Using Arcview and digital images of the quadrangle maps and hydrographic survey location, shape files were created for the cross section locations, reach lengths, and bank stations. The shape files were submitted to the contractor. The contractor extracted the geo-referenced cross sections and provided the results in a .geo file suitable for importing into HEC-RAS. Cross sections were extracted from the dtm model at an interval of roughly 2000 feet. The total number of cross sections is in excess of 800 through the modeled reach. A number of editing steps were performed within HEC-RAS prior to incorporating the new sections within the forecast model. These steps were:

1. Import the .geo files into HEC-RAS and assemble into a single model.
2. Check HEC-RAS reach lengths compared to actual measurements.
3. Adjust bank station location within the section.
4. Correct the river mile cross section identifier to correspond with the 1960 river miles.
5. Add new cross sections at the bridge locations.
6. Add effective flow area encroachments.
7. Insert the horizontal roughness variation for each cross section.
8. Run a steady-flow simulation in RAS, and calibrate the model to observed water surface profiles.
9. Run RAS2UNET to translate the cross section data from RAS to UNET format.

Further editing was required within UNET to complete forecast model assembly. The UNET editing steps consist of the following:

1. Insert tributary routing reaches within the Missouri river section data.
2. Extract levee information from the dtm model to describe stage-storage information and overtopping elevations for each levee cell and provide levee connection UNET data.
3. Insert KR card rating curves at all gage station locations.
4. Calibrate the UNET model.
5. Insert finished UNET model files into the forecast platform.

7. Calibration Procedure. Calibration of the UNET model was performed for historical events. During real-time forecasting operation, the determined calibration factors may require revision to maintain model accuracy. Calibration efforts employed Manning's *n* value discharge/conveyance relationships and an automated calibration feature found in UNET on a reach by reach basis. Model calibration was performed for 3 different flow periods and included the summer months of 1993, 1997, and 1998. The selected flows periods include high flows and normal navigation flows.

7.1 HEC-RAS Calibration. Initial calibration was performed with the HEC-RAS model. Initial horizontal roughness values were assigned based on material type using aerial photographs. The initial Manning's roughness values were calibrated to recent measured steady water surface profiles. All measured profiles were for within channel flows in the normal operating flow range during the navigation season.

7.2 UNET Calibration. Calibration of the UNET model was an iterative process performed in several stages. Calibration efforts focused on reproducing observed stage hydrographs at gaging stations along the Missouri River and verifying with discharge measurements. Calibration was performed using conveyance change and discharge-conveyance relationships within the bc file for separate reaches within the model. The conveyance change relationship applies a constant factor to the cross section conveyance and storage determined by csect. The discharge-conveyance relationship applies a factor to cross section conveyance which may be varied according to flow rate. Once the model is nearly calibrated, the automated calibration is performed by pairing observed stages at the stream gages on the Missouri River with routed flow and fits a fifth order polynomial to the paired data to create a rating curve and write it to DSS. Since for each flow, a water surface elevation is produced at each cross-section, this procedure develops a relationship between elevation and factor at each cross-section. Using a KR record in the csect file at each stream gage location, this relationship is then applied to the ordinates in the cross section tables.

The model calibration is refined by adjusting the developed rating curves (KR records) to correct for deficiencies. The conveyance change and discharge conveyance relationship can also be used in conjunction with the rating curves to finalize the model calibration. Therefore, final calibration is a combination of the effects of all the parameters employed in both the csect and bc files.

7.2.1 Base Calibration. For base calibration, the model was calibrated to reproduce rating curves at the principal gaging stations along the Mississippi River. The rating curve calibration technique is described in the report "Rating Curve Calibration" (Barkau 1994). Calibration of computed model stages was performed employing stage hydrographs at Missouri River gaging stations located at Yankton, SD, Sioux City, IA, Decatur, NE, Omaha, NE, Nebraska City, NE, and Rulo, NE. Calibration of tributary routing reaches was not performed. Stage calibration was performed on a system wide basis for the entire hydrograph.

7.2.2 UNET Model Flow Calibration. While the UNET model was calibrated to observed stage hydrographs, discharges still need to be verified to assure model accuracy. The computed discharge hydrographs from the UNET model were compared to observed discharge hydrographs and actual USGS discharge measurements taken at the gaging stations. Discharge measurements are taken at least once a week on the mainstem Missouri River. The results show that the computed discharges for the UNET model were nearly the same as the discharge measurements.

7.2.3 Ungaged Inflow. To account for ungaged flows, the null interior boundary function was applied. The null interior boundary condition is a tool for estimating the ungaged lateral inflow in a river system. Using the observed stage hydrographs, the river routing reach is divided into two routing reaches, usually at the location of a streamflow gage. Flow is routed from the upstream reach to the downstream reach. This flow does not include the ungaged flow. Next, to determine the flow at the downstream location with the ungaged included, the flow upstream based on a stage boundary condition is computed from the hydrodynamics and the geometry reach downstream. The ungaged inflow hydrograph is estimated by subtracting the routed hydrograph from the computed hydrograph and lagging the ungaged hydrograph backward in time and inserted in the model as a uniform lateral inflow. Ungaged inflow between the gaging stations is distributed according to drainage area. The ungaged drainage area is summarized within Table NWO-4.

Table NOW-4. Drainage Area Accounting

River Mile	Missouri River Location	Gaged Tributary Inflow	Total Drainage (sq. miles)	Trib. Drain. Area (sq. miles)
811.1	Gavins Point Dam		279,500	
797.7		James River at Scotland, SD		20,942
772.2		Vermillion River nr Vermillion, SD		2,302
734.2		Big Sioux River at Akron, IA		8,424
811.1-734.2		Ungaged, Gavins to Sioux City		3,432
732.3	Sioux City, IA		314,600	
732.1		Perry Creek at Sioux City, IA		65
731.3		Floyd River at James, IA		886
734.2-691.0		Ungaged, Sioux City to Decatur		649
691	Decatur, NE		316,200	
670		Monona Harrison Ditch at Turin, IA		900
669.2		Little Sioux River nr Turin, IA		1,526
664		Soldier River at Pisgah, IA		407
635.2		Boyer River at Logan, IA		871
691.0-615.9		Ungaged, Decatur to Omaha		2,896
615.9	Omaha, NE		322,800	
596.6		Papillion Creek at Fort Crook, NE		402
594.8		Platte River at Louisville, NE		85,800
568.6		Weeping Water Creek at Union, NE		241

615.9-562.6		Ungaged, Omaha to Nebraska City		757
562.6	Nebraska City, NE		410,000	
542		Nishnabotna River above Hamburg, IA		2,806
527.8		Little Nemaha River at Auburn, NE		793
		Ungaged, Nebraska City to Rulo		1,301
498.1	Rulo, NE		414,900	
494.8		Big Nemaha River at Fall City, NE		1,340
463		Nodaway River at Graham, MO		1,380
498.1-448.2		Ungaged, Rulo to St. Joseph		2,680
448.2	St Joseph, MO		420,300	

7.3 Fine Tuning. Operation of the forecast model will require revision to the calibration parameters in order to maintain model accuracy. Model calibration may be revised by a number of methods. The simplest method is to modify the Conveyance-Change factors which are located within the .bc file. An alternative method is to modify the rating curve calibration employed by Csect which is specified on the KR card.

7.3.1 Modify KR Card. Modification to the KR card allows variable corrections when the model stage error varies with discharge. If the model is calibrated correctly at a flow of 40,000 cfs but is 1.0 feet high at 60,000 cfs, then the KR rating curve should be modified by reducing the 60,000 cfs stage by one foot but leaving the 40,000 cfs stage at the current value. Following any KR card modification, a new Csect binary geometry file must be created in order for the changes to be incorporated. KR cards employed within the Csect files are stored within a Dss file. The KR card employed within the Csect file may be modifed using the graphic edit option within Dsplay or via text editing using Dssutl.

7.3.2 Modify Discharge Conveyance. Within the .bc files, additional modification to the model calibration is possible with the discharge conveyance factor. For each separate calibration reach, a table of discharge and conveyance change factors was entered. A conveyance change factor for discharge Q_i is

$$F_i = \frac{K_{new}}{K_{old}}$$

where: F_i = conveyance change factor for discharge i.
K_{new} = new conveyance value.
K_{old} = old conveyance value.

For each river discharge Q_i, the conveyance property is multiplied by F_i, thereby adjusting the calibration of the model. An example of a conveyance change specified within the bc file is:

```
REACH=15
CONVEYANCE CHANGE FACTORS
591.5 568.63  1  21 0.95 0.95  -0.85  -0.85 0 0
```

The format of the conveyance change factors is explained within the UNET Manual. Briefly, the factors are:

Reach=15	The reach specifies the location within the Csect file
591.5 568.83	These numbers specify the river mile range that the factors are applied over
1 21	These numbers specify the Csect table values which are modified
0.95 0.95	These numbers specify factors applied to the channel and overbank. Edit these values to modify the conveyance relationship. (e.g. changing from .95 to 1.05 means more conveyance at the same stage).
-0.85 -0.85	These numbers specify factors applied to the channel and overbank storage area. Changing these factors will affect model timing (e.g. reducing storage with a negative value decreases storage and speeds travel time).
0 0	Not used values.

7.3.3 Modify Seasonal Conveyance. Within the .bc files, a second modification to the model calibration is possible with the seasonal conveyance correction factor. Discharge conveyance factors are specified at numerous locations within the bc file. An example of a seasonal conveyance change specified within the bc file is:

```
REACH=7
SEASONAL CONVEYANCE CORRECTION
734.35  669.1  7
 01JAN  1.10
 05MAY 1.05
 15JUN 1.0
 15AUG 1.02
 10OCT 1.05
 01NOV 1.10
 31DEC 1.10
```

Refer to the UNET manual for a description of values to modify.

7.4 Calibration Results. Final parameters in the calibrated UNET model included a time step of 3.0 hours, Manning's *n* values ranging from 0.019 to 0.023 for the channel and 0.045 to 0.060 for the overbank, and a theta value of 0.6. Conveyance change calibration factors were generally in the range of 0.8 to 1.2 throughout the model.

A final calibration of the UNET model for all flow events was accomplished. However, several problems arose during calibration to flow events for separate years. When calibrating to each event separately, a final calibration of less than 0.5 feet was possible. However, when the model was calibrated to one event and then another event was configured with the same calibration factors, the model did not calibrate as well, being off as much as 1.0 foot for periods of the stage hydrograph. The discharge conveyance factors could then be changed to cause a better calibration, but then the calibration of the first event was not as good. Rating curves were not altered for the individual year calibration. The calibrated discharge conveyance factor variation was small for each of the events. Final calibration factors were weighted to give the best calibration for the more recent events at comparable flows. An example illustrating calibrated results is shown in Figure NWO-2.

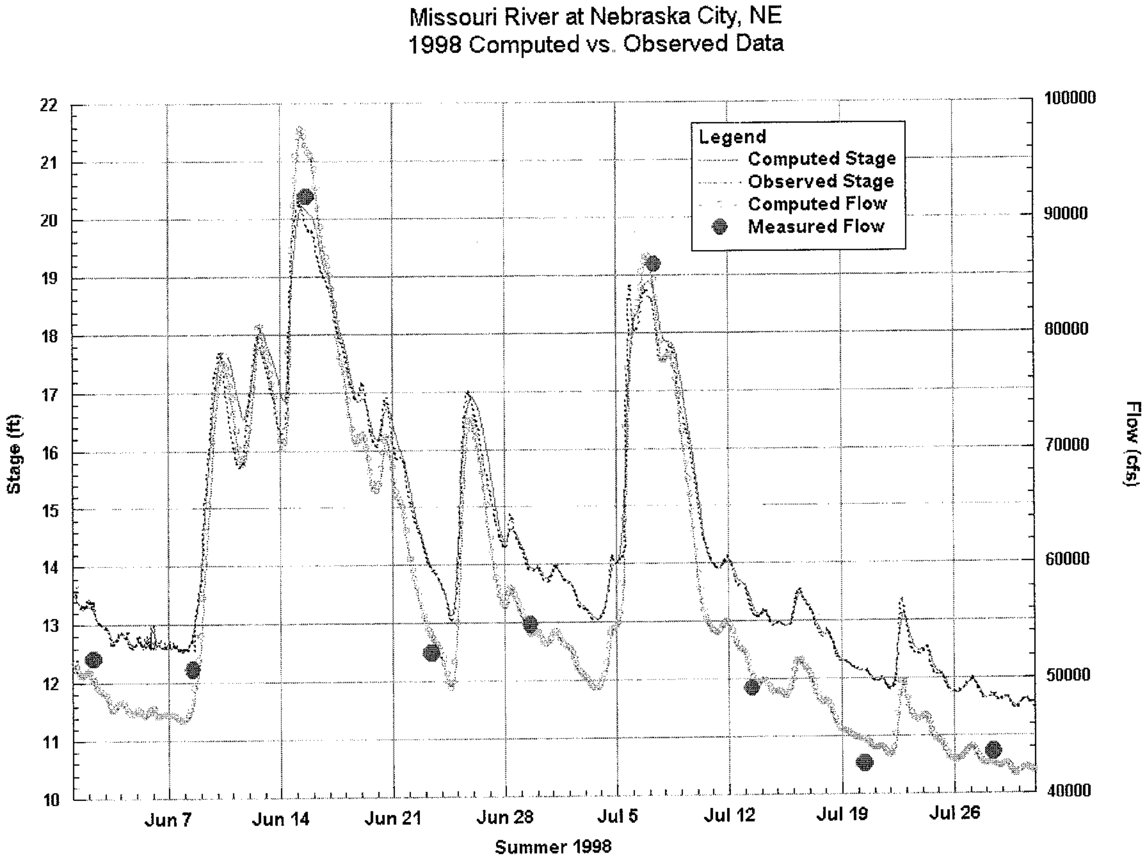
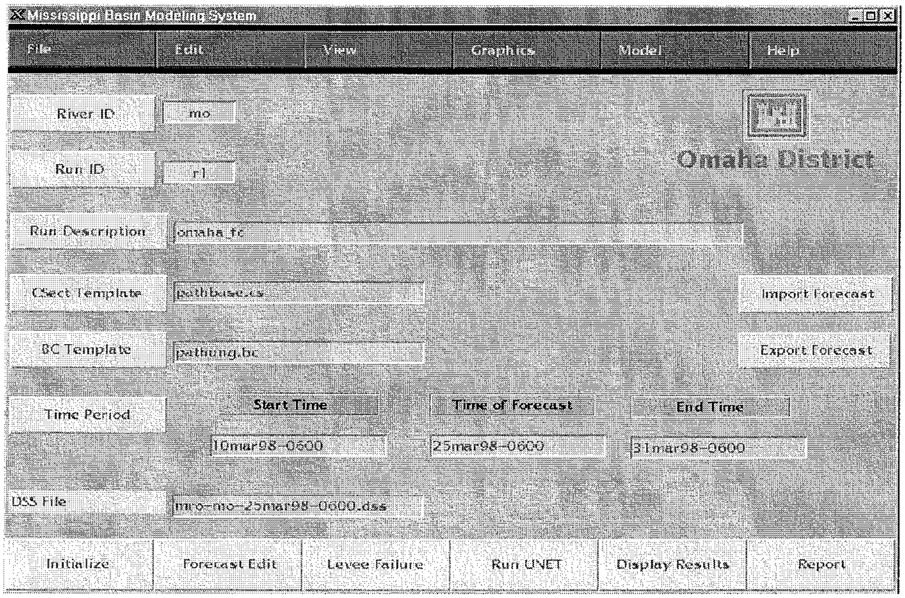


Figure NWO-2. Calibrated Results

8. Operational Procedures and Experience. The calibrated UNET model is available for operation in the forecast mode. Operation of the forecast model is facilitated with the use of the MBMS graphical user interface (GUI). Forecast operation is performed with updated inflow data from the DCP gaging stations for the desired forecast period. For forecast operation, model inflow hydrographs must be extended for the forecast period. The transition of the UNET model to a forecast model for use with the GUI required no additional UNET model development. The GUI provides an interface which couples operation of the UNET model with forecasting inflow data and processing UNET model results. By using the GUI, the forecaster can efficiently develop stage and flow forecasts for the desired period. GUI operation does not require detailed UNET model knowledge. The GUI provides for consistent file management, UNET model simulation, easy selection of historical and forecast time window, model result review, and report generation. A users manual that describes forecast model GUI operation has been prepared to assist with daily operation (RCC, 1998). An example of the forecast model GUI input screen is shown in Figure NWO-3.

Figure NWO-3. Example GUI Screen



River ID: mo

Run ID: r1

Run Description: omaha_fc

CSect Template: pathbase.cs

BC Template: pathung.bc

Time Period: Start Time 10mar98-0600; Time of Forecast 25mar98-0600; End Time 31mar98-0600

DSS File: mro-mo-25mar98-0600.dss

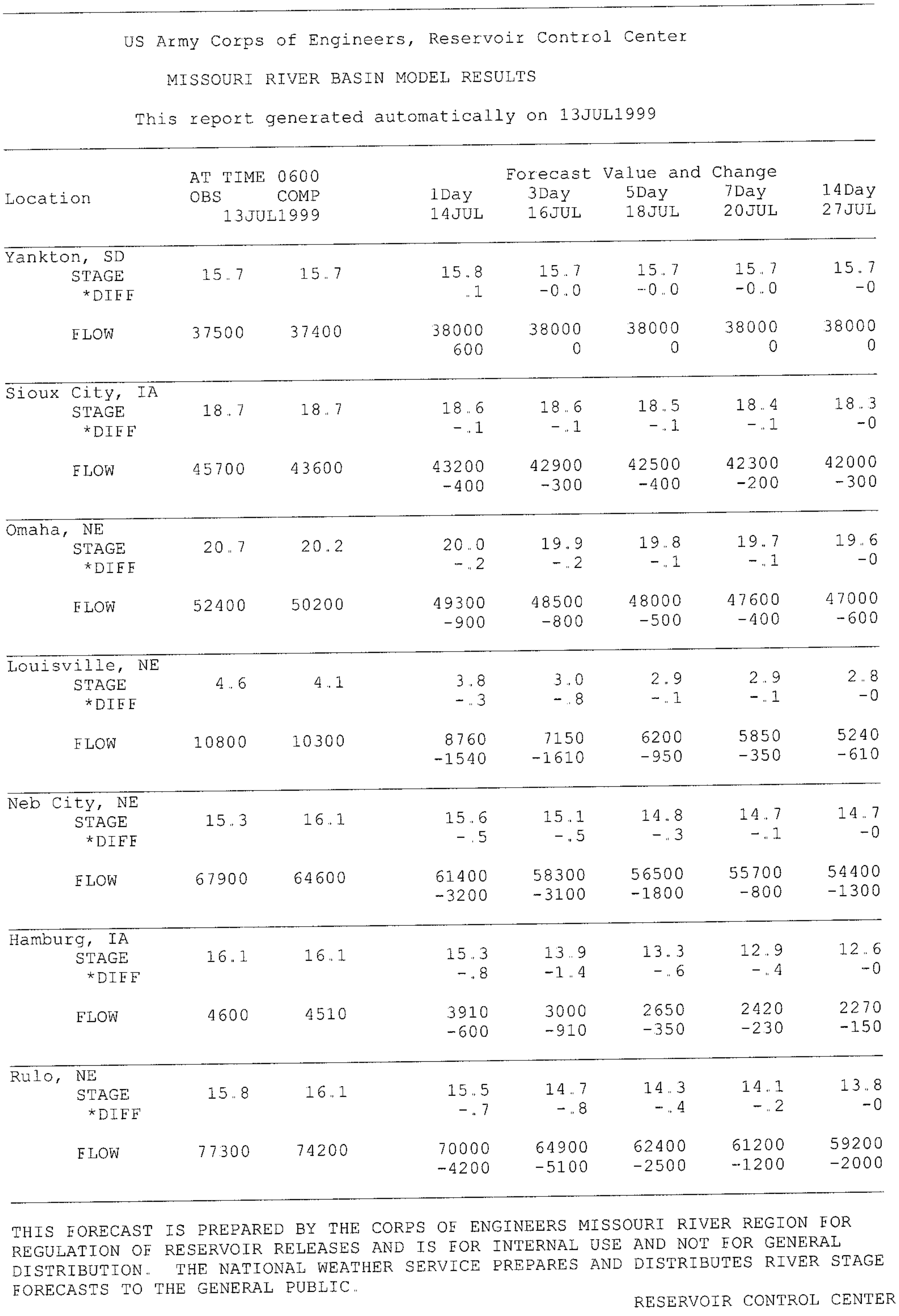
8.1 Forecast Operation. The initial step in forecast operation is the extraction of data by the GUI. The forecaster updates the UNET model data base to the current time of forecast by extracting data from the real-time DCP database at all required gaging station locations. Ungaged inflows are simulated by executing the UNET model employing the null internal boundary condition. The forecaster may edit all inflow hydrographs for the forecast period as desired. Current forecast model operation does not include use of any hydrologic models to forecast inflow data. Inflow data may be forecasted by extending current values or estimating a change in inflow based on upstream data, weather forecasts, and other available information. Levee failure data may be edited to reflect current conditions. Once forecasted inflows are determined, the UNET model is executed for the forecast period. A list of the steps required to perform the forecast are as follows:

Forecast Model Steps To Forecast the Upper Missouri River:

Start the GUI and select the Missouri Reach (check River ID, Run ID, and Run Description).
Set Time Period.
Initialize to build the working dss file for the model period.
Verify the extracted flow and stage data and edit forecast period data as required.
Run the unet model with the null boundary condition files to compute ungaged inflows.
Edit ungaged inflows computed by the model. Repeat steps 6 and 7 if necessary.
Specify any levee failures that are known to have occurred.
Run the unet model with the forecast files to compute the forecast period flow and stage.
Display and review results. Modify calibration or forecast inflows and re-run as required.
Run the report to tabulate results.
Export data to provide computed St. Joseph flow results to be used in lower reach modeling.

8.2 Forecast Results. The GUI also contains routines for presentation of forecast model results. Computed hydrographs may be reviewed at all gaging station locations. Levee failure data is also available for review. By comparing to observed stage and measured discharge data, the forecaster may adjust model calibration parameters as required to reflect seasonal changes in river conveyance. A report generator is available to summarize UNET model results in the format desired. An example of output generated by the GUI report is as follows:

Figure NWO-4. Example GUI Report.



```
          US Army Corps of Engineers, Reservoir Control Center

              MISSOURI RIVER BASIN MODEL RESULTS

           This report generated automatically on 13JUL1999

                AT TIME 0600                   Forecast Value and Change
Location        OBS      COMP        1Day      3Day      5Day      7Day      14Day
                   13JUL1999         14JUL     16JUL     18JUL     20JUL     27JUL

Yankton, SD
      STAGE     15.7     15.7        15.8      15.7      15.7      15.7      15.7
       *DIFF                           .1      -0.0      -0.0      -0.0        -0

      FLOW      37500    37400      38000     38000     38000     38000     38000
                                      600         0         0         0         0

Sioux City, IA
      STAGE     18.7     18.7        18.6      18.6      18.5      18.4      18.3
       *DIFF                          -.1       -.1       -.1       -.1        -0

      FLOW      45700    43600      43200     42900     42500     42300     42000
                                     -400      -300      -400      -200      -300

Omaha, NE
      STAGE     20.7     20.2        20.0      19.9      19.8      19.7      19.6
       *DIFF                          -.2       -.2       -.1       -.1        -0

      FLOW      52400    50200      49300     48500     48000     47600     47000
                                     -900      -800      -500      -400      -600

Louisville, NE
      STAGE      4.6      4.1         3.8       3.0       2.9       2.9       2.8
       *DIFF                          -.3       -.8       -.1       -.1        -0

      FLOW      10800    10300       8760      7150      6200      5850      5240
                                    -1540     -1610      -950      -350      -610

Neb City, NE
      STAGE     15.3     16.1        15.6      15.1      14.8      14.7      14.7
       *DIFF                          -.5       -.5       -.3       -.1        -0

      FLOW      67900    64600      61400     58300     56500     55700     54400
                                    -3200     -3100     -1800      -800     -1300

Hamburg, IA
      STAGE     16.1     16.1        15.3      13.9      13.3      12.9      12.6
       *DIFF                          -.8      -1.4       -.6       -.4        -0

      FLOW      4600     4510        3910      3000      2650      2420      2270
                                     -600      -910      -350      -230      -150

Rulo, NE
      STAGE     15.8     16.1        15.5      14.7      14.3      14.1      13.8
       *DIFF                          -.7       -.8       -.4       -.2        -0

      FLOW      77300    74200      70000     64900     62400     61200     59200
                                    -4200     -5100     -2500     -1200     -2000

THIS FORECAST IS PREPARED BY THE CORPS OF ENGINEERS MISSOURI RIVER REGION FOR
REGULATION OF RESERVOIR RELEASES AND IS FOR INTERNAL USE AND NOT FOR GENERAL
DISTRIBUTION.  THE NATIONAL WEATHER SERVICE PREPARES AND DISTRIBUTES RIVER STAGE
FORECASTS TO THE GENERAL PUBLIC.
                                                        RESERVOIR CONTROL CENTER
```

References

Barkau, 1994, Rating Curve Calibration.
Hydrologic Engineering Center, September 1992, UNET, One-Dimensional Unsteady Flow Through a Full Network of Open Channels.
Reservoir Control Center, December 1998, Forecast Model Users Guide.

Kansas City District

(NWK)

TABLE OF CONTENTS

MISSISSIPPI RIVER REAL-TIME FORECAST MODEL
Kansas City District

1. Geographic Coverage. The Kansas City District portion of the Mississippi River Basin unsteady flow forecasting system is the Missouri River Basin from the Missouri River's confluence with the Mississippi River to Rulo, NE. The Missouri River Basin drains 74 percent of the upper Mississippi River Basin. The Kansas City District model includes 498 river miles (RM) of the Missouri River and 360 RM of tributaries. The total drainage area of the Missouri River Basin is 525,400 square miles. The Missouri River drainage area within the Kansas City District model limits is 110,500 square miles. Shown in Figure NWK-1 is a schematic of the

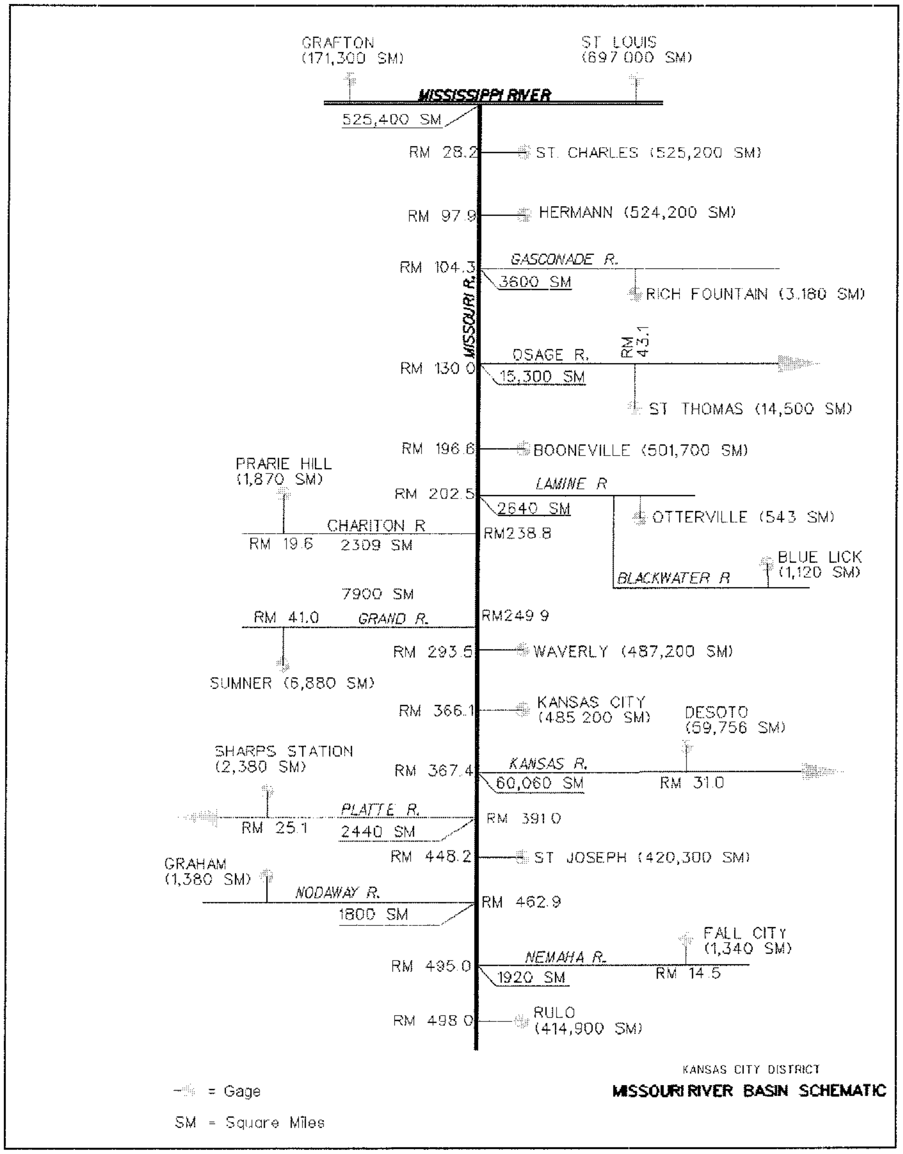


Figure NWK-1.

Missouri River modeled area. The schematic illustrates the Missouri River gaging stations on the mainstem with the river mile location and basin drainage areas at those gages, and the tributaries that are included as routing reaches in the model with their gaging stations and basin drainage areas.

2. Hydrologic/Geographic Description of the Area. The Missouri River originates in the northern Rocky Mountains along the continental divide and flows south and east to join the Mississippi River at a point approximately 15 miles upstream of St. Louis, Missouri. At 2,315 miles (1960 mileage), it is the longest river in the United States. The Kansas City District encompasses approximately 110,500 square miles of the drainage basin from Rulo, NE downstream to the mouth of the river. The Missouri River basin contains numerous reservoirs and impoundments constructed by different interests for flood control, irrigation, power production, recreation, and water supply.

From Rulo to Kansas City, the Missouri River flows through the dissected till plains of the central lowlands. Downstream of Kansas City, the river flows along the northern border of the Osage Plains and the Ozark Plateau to a point near St. Charles, Missouri, where it re-enters the central lowlands to join the Mississippi River (Reference No. 18). The Missouri River contributes 42 percent of the long-term average annual flow of the Mississippi River at St. Louis and is the major contributor of sediment in the upper Mississippi River Basin (Reference No. 17).

Between Rulo, Nebraska, and the mouth at St. Louis, the Missouri River has a total fall of about 451 feet and the average slope varies from 0.8 to 1.0 foot per mile. The river within this reach contains approximately 865 miles of bankline in Missouri, 140 miles in Kansas, and eight miles in Nebraska. The fringe area along the river is covered with willows and other trees. The floodplains are comparatively wide and for the most part are under cultivation (Reference No. 20). The width of the floodplain varies from a maximum of approximately thirteen miles to a minimum of approximately 1.5 miles. The actual flow way decreases to less than 0.5 mile in reaches with urban levees at St. Joseph, Kansas City, and St. Charles.

2.1. Lower Missouri River Basin Reservoirs. The Missouri River Basin contains numerous reservoirs and impoundments. The Corps of Engineers has constructed six mainstem Missouri River Dams which are all located upstream of Rulo, Nebraska, and are within the boundaries of the Omaha District. All reservoirs within the Kansas City District are constructed on tributaries of the Missouri River. These include eighteen multiple-purpose lake projects constructed by the Corps (see Table NWK-1) and eleven lake projects constructed by the Bureau of Reclamation (Bureau). The eleven Bureau lake projects are all on the Republican and Smoky Hill Rivers in the Kansas River Basin (see Table NWK-2). The Bureau operates these lake projects primarily for the storage and distribution of water for irrigation, while the Kansas City District is responsible for the flood control operation of the Bureau's lakes as part of the lower Missouri River flood control system (Reference No. 18).

Table NWK-1.
Kansas City District Corps of Engineers Lakes & Reservoirs

River Basin	Project
Kansas	Harlan County Milford Wilson Kanopolis Tuttle Creek Perry Clinton
Platte	Smithville
Little Blue	Blue Springs Longview
Chariton	Rathbun
Little Chariton	Long Branch
Osage	Melvern Pomona Hillsdale Stockton Pomme de Terre Harry S. Truman

Table NWK-2.
Bureau of Reclamation Reservoir Projects

River Basin	Project
Republican	Bonny Swanson Enders Hugh Butler Harry Strunk Keith Sebelius Lovewell
Smoky Hill	Webster Kirwin Waconda Cedar Bluff

3. Drainage system.

3.1. Tributaries. Major tributaries of the Missouri River are included as separate routing reaches in the UNET forecast model. Routing of the tributary flows from the gaging station location to their confluence with the Missouri River was found to increase the simulation accuracy. Tributary modeling efforts were of limited detail and intended for flow routing only. As a result of the coarse cross section data, computed stage information on the tributaries may not be accurate. Tributaries are modeled from the last downstream USGS gaging station on each tributary to the confluence with the Missouri River. Major tributaries of the Missouri River which are modeled are the Big Nemaha, Nodaway, Platte, Kansas, Big Blue, Little Blue, Grand, Chariton, Little Chariton, Blackwater/Lamine, Osage, and Gasconade Rivers. A schematic of the Missouri River and its significant tributaries included in the Kansas City District's Missouri River UNET model is illustrated in Figure NWK-1. Also in this figure are the locations of the gages on the tributaries and on the mainstem.

3.1.1. Big Nemaha River - RM 494.9. The Big Nemaha River is a right bank tributary of the Missouri River that drains 1920 square miles in southeastern Nebraska and northeastern Kansas, of which 1315 square miles lie in Nebraska. The topography of the basin consists of gently rolling to steeply rolling hills drained by a dendritic stream pattern. The major streams of the basin have wide flat floodplains which are generally poorly drained. Stream valley soils consist of alluvial and colluvial materials which are easily eroded.

Basin elevations range from about 840 feet N.G.V.D. at the mouth of the Big Nemaha River to a maximum of 1535 feet N.G.V.D. Stream slopes vary from 2 feet per mile in the lower reaches to over 20 feet per mile on some tributaries of the Big Nemaha River. Extensive channel modifications have increased stream slopes and caused channels to deepen and widen progressively upstream. Stream flow in the basin is due almost solely to runoff from precipitation and consequently shows frequent and wide fluctuation. There no major impoundments in the Big Nemaha River basin. (Reference No. 5).

3.1.2. Nodaway River - RM 463.0. The Nodaway River is a left bank tributary of the Missouri River that rises in the low, flat divide of southwest Iowa between the Missouri and Mississippi River basins. It flows southwesterly through Iowa, and then southerly through the northwest corner of Missouri to its confluence with the Missouri River. The main stem of the Nodaway River is a little over 61 miles from its mouth to the confluence of West Nodaway and East Nodaway Rivers. Continuing upstream on Middle Nodaway to its headwaters results in a total river length of about 130 miles.

Channel slopes vary from a relatively flat two feet per mile in Missouri to six feet per mile in the upper reaches of Iowa. The average channel slope is four feet per mile. The Nodaway River is considered to be a small stream with a relatively low average discharge of 524 cfs despite its relatively large drainage area of 1780 square miles. Approximately 67%, or 1200 square miles, of the drainage basin lie in Iowa. There are no major impoundments in the Nodaway River basin. (Reference No. 14).

3.1.3. Platte River - RM 391.1. The Platte River is a left bank tributary of the Missouri River that rises in the low, flat divide of southwest Iowa. It flows in a generally southerly direction through Iowa and Missouri. The main stem of the Platte River is formed by the confluence of the East Platte and West Platte Rivers in Iowa and is approximately 170 miles in length from the confluence to the mouth. River slope for the Platte River ranges from one to three feet per mile in Missouri and increases in the upper reaches in Iowa.

The Platte River basin drains an area of 2440 square miles, of which 32% is in Missouri and 68% is in Iowa. The basin lies generally north and south with approximate dimensions of 130 miles in length and 27 miles in maximum width. The topography of the basin consists of rolling or gently undulating glacial plains divided by deeply eroded valleys. The major impoundment in the basin is a Corps reservoir, Smithville Lake, which is on the Little Platte River, a major tributary of the Platte River. (Reference No. 16).

3.1.4. Kansas River - RM 367.5. The Kansas River is a right bank tributary of the Missouri River that is formed at the confluence of the Smoky Hill and Republican Rivers near Junction City, Kansas. From this junction the river flows eastward for about 170 miles to its confluence with the Missouri River at Kansas City. Locally, the main stem Kansas River is also known as the Kaw River. The floodplain of the Kansas River from Junction City downstream varies in width from approximately 1.5 to 5.0 miles and averages approximately two miles in width. The channel, which is generally 800 to 850 feet wide, meanders in this floodplain.

The entire Kansas River drainage basin lies within the Interior Plains region and is approximately 480 miles long and 140 miles wide. Elevation of the river varies from 750 feet N.G.V.D. at the mouth to approximately 5500 feet N.G.V.D. at the extreme western end of the basin. Channel slopes west of Concordia, Kansas, are approximately 12 feet per mile. The average channel slope downstream of Topeka, Kansas, is approximately 1.7 feet per mile.

The Kansas River basin constitutes approximately one-tenth of the drainage area of the Missouri River and drains the northern half of Kansas, much of southern Nebraska, and a part of northeastern Colorado. The total drainage area of the Kansas River basin is 60,060 square miles of which 15% is in Colorado, 28% is in Nebraska, and 57% is in Kansas. The Kansas River basin contains numerous major impoundments including seven Corps reservoirs and eleven Bureau of Reclamation reservoirs. (Reference Nos. 4, 23, & 25).

3.1.5. Big Blue River - RM 358.0. The Big Blue River is a right bank tributary of the Missouri River which is formed by the confluence of Coffee Creek and Wolf Creek in west-central Kansas and flows north-northeasterly into Missouri to its mouth in the eastern Kansas City urban area. The Big Blue River is 43.8 miles long and drains a basin that encompasses a total area of 272 square miles. Approximately 56% of the basin lies in Kansas and 44% lies in Missouri.

The Big Blue River basin measures approximately 31 miles in length and 17 miles at its maximum width. The topography of the basin is predominately rolling to gently undulating with fairly steep slopes adjacent to the larger streams. There are numerous channel improvement projects scattered throughout the length of the Big Blue River. The river channel slope ranges from 3 to 12 feet per mile with an average of 5 feet per mile. There are no major impoundments in the basin. (Reference No. 9).

3.1.6. Little Blue River - RM 339.5. The Little Blue River is a right bank tributary of the Missouri River which rises in west-central Missouri and flows in a generally northeasterly direction to join the Missouri River about 20 miles downstream of Kansas City. The main stem of the river is about 50 miles in length. The Little Blue River basin lies along the southeastern edge of the Kansas City metropolitan area and drains an area of 224 square miles. The basin is approximately 33 miles long, with a maximum width of 13 miles.

The topography of the basin is predominately rolling to gently undulating. The streams of the upper basin originate in steep terrain and limestone outcrops, and have well-incised channels. The slope of the lower basin averages 2 to 3 feet per mile, and steepens rather abruptly to 13 or more feet per mile in the upper reaches. Major impoundments in the basin include two Corps reservoirs and Lake Jacomo, a Jackson County (Missouri) public recreation lake. (Reference Nos. 8 & 13).

3.1.7. Grand River - RM 250.0. The Grand River is a left bank tributary of the Missouri River that rises in the low, flat divide of south-central Iowa and flows generally in a south-southeasterly direction. The topography of the Grand River basin ranges from rolling to gently undulating glacial plains divided by deeply eroded valleys. The Grand River basin drains an area of 7900 square miles, of which 78 percent is in Missouri and 22 percent is in Iowa. The main stem of the Grand River is about 210 miles in length, which includes the West Fork as part of the main stem. The slope of the river ranges from 1.0 to 2.0 feet per mile up to mile 148, with an average slope of 1.5 feet per mile.

Tributaries of the Grand River include the Thompson River with its major tributary the Weldon River, and numerous small tributaries, many of which are intermittent in character. The Grand River has undergone extensive channel modifications which were primarily projects of local drainage districts and other private interests. There are no major impoundments in the basin. (Reference No. 12).

3.1.8. Chariton River - RM 238.8. The Chariton River is a left bank tributary of the Missouri River that rises in the low, flat divide of south-central Iowa. It flows southeasterly through Iowa and then southerly through Missouri to join the Missouri River after flowing through a four-mile cutoff. Beginning in 1949, this flood control cutoff diverted the Chariton River directly into the Missouri River at a point approximately 12 miles upstream from its natural mouth. This cutoff separated the Chariton River from its tributary, the Little Chariton River, which is now an independent basin and tributary of the Missouri River.

The Chariton River is approximately 170 miles long and drains an area of 2390 square miles of which 925 square miles lie in Iowa and 1465 square miles lie in Missouri. The river slope is fairly uniform ranging from 1.5 to 2.5 feet per mile with an average of approximately 2 feet per mile. The river has been substantially channelized. Originally the Chariton River meandered a distance of over 200 miles from the Missouri-Iowa border to its mouth. That distance is now approximately 95 miles.

The Chariton River basin is long and narrow and extends nearly due north from the mouth to the Missouri-Iowa state line. The maximum length of the basin is about 140 miles and the maximum width is about 25 miles. The topography of the Chariton river basin is typical of the area consisting of rolling or gently undulating glacial plains divided by deeply eroded valleys. The only major impoundment in the basin is Rathbun Lake which is a Corps reservoir located in the upper basin in Iowa, approximately 140 river miles above the mouth of the Chariton River. (Reference Nos. 7 & 10).

3.1.9. Little Chariton River - RM 227.3. The Little Chariton River is a left bank tributary of the Missouri River which drains an area of approximately 691 square miles in north-central Missouri. The Little Chariton River was originally a part of the Chariton River basin. In 1949 a flood control cutoff on the Chariton River was constructed which started above the mouth of the Little Chariton and diverted the Chariton directly into the Missouri River. This made the Little Chariton River an independent basin draining directly into the Missouri River. The Little Chariton River is formed by the confluence of Middle Fork and East Fork at a point 17 miles above its mouth, and it flows into the Missouri River through the old, natural Chariton River channel.

The Little Chariton River basin is approximately 60 miles long with a maximum width of approximately 20 miles. The basin lies to the east of the Chariton River basin, and is entirely within the state of Missouri. The basin has a rolling topography with surface deposits of glacial till and loess overlying bedrock of Pennsylvanian Age. The Little Chariton River basin has two major impoundments -- Thomas Hill Reservoir on Middle Fork which is privately owned and Long Branch Lake on East Fork which is a Corps reservoir. (Reference Nos. 3 & 7).

3.1.10. Blackwater/Lamine River - RM 202.5. The Lamine River, with its major tributary, the Blackwater River, is a right bank tributary of the Missouri River, draining an area of 2640 square miles in west-central Missouri. The Lamine River, flowing in a northerly direction, is joined about ten miles upstream from its mouth by the Blackwater River, flowing in an easterly direction. The mouth of the Lamine is about five miles upstream from Boonville, Missouri. There are no major impoundments in the Blackwater/Lamine River basin.

The Lamine River originates in the southeastern part of the joint basin at the confluence of Flat Creek and Richland Creek, and meanders 64 river miles before reaching the Missouri River. Together with Flat Creek, its length is about 102 miles. Exclusive of the Blackwater basin, the Lamine River drains an area of 1090 square miles. The Lamine River channel slopes vary from about seven feet per mile in the upper basin to about two feet per mile along the lower main stem. The steeper channel slopes of the Lamine River permit faster discharge of flood flows than on the Blackwater River. The pronounced topographic relief contributes to quick runoff, resulting in frequent severe flood peaks of relatively short duration.

The Blackwater River and its tributaries drain 1550 square miles of the north and west part of the joint basin. The Blackwater River is 104 miles long and its chief tributaries are Salt Fork and Davis Creek. The Blackwater River channel slopes vary from about five feet per mile in the upper basin to about one foot per mile in the central and lower reaches. Topographic relief is not pronounced and runoff occurs at a comparatively moderate rate. (Reference no. 22).

3.1.11. Osage River - RM 130.2. The Osage River is a right bank tributary of the Missouri River which rises in east-central Kansas and flows eastward through west-central Missouri to join the Missouri River near Jefferson City, Missouri. The upper Osage River, which is in Kansas and Missouri, is called the Marais des Cygnes River. That portion of the river which is named the Osage River is entirely in Missouri and is formed by the confluence of the Little Osage and Marais des Cygnes Rivers. The Osage River is 262 miles long and the Marais des Cygnes River is 254 miles long. These two rivers combine for a total length of 516 miles and drain an area of 15,300 square miles, of which 28% is in Kansas and 72% is in Missouri.

The Osage-Marais des Cygnes River basin is approximately 250 miles long from west to east and has a maximum width of 100 miles. Headwater elevations reach 1450 feet N.V.G.D. and valley lands near the mouth of the Osage River lie at 520 feet N.G.V.D. River slopes of the Marais des Cygnes River average more that two feet per mile. River slopes of the Osage River average approximately 1.4 feet per mile.

The western part of the basin is in the Osage Plains area and is characterized by gently rolling uplands. The eastern part of the basin enters the Ozark Highlands Region and is rugged and hilly with deep, narrow valleys. Major impoundments in the Osage-Marais des Cygnes River basin are the Lake of the Ozarks, which is a hydroelectric power project of the Union Electric Company of Missouri and has a normal power-pool area of 60,000 acres, and six Corps reservoirs including Harry S. Truman Reservoir, which has a full flood-control pool area of 209,300 acres. (Reference Nos. 6 & 15).

3.1.12. Gasconade River - RM 104.5. The Gasconade River is a right bank tributary of the Missouri River that rises in south-central Missouri and follows a northeasterly course. The river is about 265 miles long and drains an area of 3600 square miles south of the Missouri River. The channel slope ranges from 0.8 to 6.2 feet per mile, with an average of 2.5 feet per mile. The average discharge volume over the period of record is 2490 cfs. The drainage area is mostly Ozark Plateau region with steep hillsides and ridges covered with timber. The Gasconade River is extremely meandering in character and flows through small alluvial valleys. The basin has many springs which contribute to stream flow. There are no major impoundments in the basin. (Reference No. 11).

3.2. Missouri River. Kansas City District's Missouri River UNET forecast model begins at the upstream boundary which is the gage at Rulo, NE, at RM 498.1, and ends at the downstream boundary which is the gage at St. Charles, MO, at RM 28.2. The upstream boundary at Rulo, NE, corresponds with the boundary between the Kansas City District and the Omaha District. The downstream boundary is at the St. Charles gage since this is the last gage on the Missouri River. The last 28.2 RM of the Missouri River are modeled in the St. Louis forecast model as part of the Missouri River tributary inflow reach to the Mississippi River.

3.2.1. Navigation and Bank Stabilization. There were seven acts of Congress which provided for the construction, operation and maintenance of a navigation channel and bank stabilization works on the Missouri River. The most recent was authorized in 1945 and provided for bank stabilization combined with a 9-foot deep, and not less than 300 feet wide, navigation channel. The authorized project for the Missouri River extends from its confluence with the Mississippi River at St Louis, MO to Sioux City, IA for a total distance of 734.2 river miles. This project was accomplished through revetment of banks, construction of permeable dikes, cutoff of oxbows, closing minor channels, removal of snags, and dredging. In order to achieve the project objectives of bank stabilization and navigation, the river planform was shaped into a series of smoothly curved bends of the appropriate radii and channel width. Stabilization of the bank along the concave alignment of the design curve was accomplished with pile and stone fill revetments. Dikes were constructed along the convex bank, approximately perpendicular to the flow. These dikes were designed to prevent bank erosion and to promote accretion, forcing the channel to develop and maintain itself along the design alignment. In areas where the natural river channel did not conform to the design alignment, canals were excavated and natural channels blocked in order to force the river to flow along the design alignment.

4. Key Locations – Stream Gages. Gage data is required by the UNET forecast model at all tributary and Missouri River stream gage station locations. Discharge and stage hydrographs for the Missouri River and tributaries are required for inflow, boundary conditions, estimation of ungaged inflow, calibration, and verification. Historic hydrologic data is available from the USGS Automated Data Processing System (ADAPS) which is part of the National Water Information System (NWIS). For real time operation, the forecast model employs hourly data extracted from the Missouri River database maintained by the Missouri River Reservoir Control Center in Omaha, Nebraska. The database includes hourly flow and stage data for the USGS stream gaging stations that have data collection platforms (DCPs). USGS streamflow gages with their locations, gage identification numbers, and other pertinent data are listed in Table NWK-3 for Missouri River tributaries and in Table NWK-4 for the mainstem Missouri River.

Table NWK-3.
Tributary USGS Stream Gaging Stations

Tributary	Station	Tributary River Miles	USGS Station Number	Missouri River RM at Confluence
Big Nemaha River	Falls City, NE	14.5	06815000	494.9
Nodaway River	Graham, MO	28.0	06817700	463.0
Platte River	Sharps Station, MO	25.1	06821190	391.1
Kansas River	DeSoto, KS	31.0	06892350	367.5
Blue River	near Kansas City, MO at Bannister Road	23.2	06893500	358.0
Little Blue River	Lake City, MO	10.5	06894000	339.5
Grand River	Sumner, MO	41.0	06902000	250.0
Chariton River	Prairie Hill, MO	19.6	06905500	238.8
East Fork Little Chariton River	Huntsville, MO	42.1	06906300	227.3
Lamine/ Blackwater River	Blue Lick, MO	30.3	06908000	202.5
Osage River	St. Thomas, MO	43.1 (34.5 since Oct. 1996)	06926500 (06926510)	130.2
Gasconade River	Rich Fountain, MO	51.3	06934000	104.5

Table NWK-4.
Missouri River Mainstem USGS Stream Gaging Stations

Station	River Mile Location	USGS Station Number	Gage Datum (ft above sea level)
Rulo, NE	498.0	06813500	837.2
St. Joseph, MO	448.2	06818000	788.2
Kansas City, MO	366.1	06893000	706.4
Waverly, MO	293.5	06895500	646.0
Boonville, MO	196.6	06909000	565.4
Hermann, MO	97.9	06934500	481.6
St. Charles, MO	28.2	06935965	413.5

5. Key Locations - Structures. Pertinent structures that impact hydraulics and flood routing within Kansas City's UNET forecast model include levees and navigation structures, specifically dikes. Levees are included within the forecast model as storage cells. Dike structures are reflected in the cross section geometry and model calibration of roughness values.

5.1. Levees. The Missouri River Levee System (MRLS) was authorized by the Flood Control Acts of 1941 and 1944 to provide protection to agricultural lands and communities along the Missouri River from Sioux City, IA to the mouth at St. Louis, MO. The MRLS levees were designed to operate in conjunction with the six mainstem dams, which are located in the Omaha District, to reduce flood damages as part of the Pick-Sloan Plan. The extent of the Federal levee system within the Kansas City District consists mainly of levee units on both banks from Rulo, NE, to Kansas City, MO. Although many Federal levees were proposed downstream of Kansas City, MO along the Missouri River, only a few have been built. The majority of the area planned for protection by Federal levees downstream of Kansas City, MO is protected by private or non-Federal levees with varying degrees of level of protection.

5.1.1. Federal Levees. Construction of the Federal levees began in the 1950's. The Kansas City District has constructed seventeen Federal levees along the Missouri River as part of the MRLS. All but four of the completed MRLS units are upstream of Kansas City. These units protect mostly agricultural lands plus some small towns. A combination of urban and agricultural land is protected in the St. Joseph, Missouri/Elwood, Kansas area by MRLS Levee Units R471-460 and L455. Flood protection in the Kansas City, Kansas/Missouri urban area is provided by seven Federal levee units constructed by the Kansas City District along the Missouri and Kansas Rivers. The units along the Missouri River are the Fairfax/Jersey Creek, Central Industrial District (CID), and East Bottoms Levee Units along the right bank, and the North Kansas City and Birmingham Levee Units along the left bank. Federal levees are included in the UNET forecast model as storage cells. Table NWK-5 lists Federal levees and pertinent information.

Table NWK-5.
Missouri River Federal Levees

Levee Unit	Design Discharge [1] (cfs)	Location along the Missouri River (U/S RM - D/S RM)
R-513	309,000	497.5 - 495
R-500	319,000	484.5 - 480
L-497	319,000	482.8 - 476.2
L-488	322,000	476 - 465.2
R-482	325,000	468 - 458
L-476	325,000	460.7 - 454
R-471-460 [3]	325,000	456.5 - 441.8
L-455 [3]	325,000	445.6 - 437.5
L-448-443	325,000	437.5 - 428
R-440	429,000	431 - 424.3
L-408	270,000	401.3 - 391.5
L-400	348,000	391 - 385
Fairfax-Jersey Creek [2]	460,000	374 - 367.5
North Kansas City [2]	540,000	370.5 - 363.5
Central Industrial District (CID) [2]	540,000	367.4 - 365.7
East Bottoms [2]	540,000	365.7 - 357.5
Birmingham [2]	540,000	360.3 - 353.5
R-351	436,000	350 - 339.7
L-246	400,000	250 - 239
Chariton River Main Stem	476,000	238.8 - 227.3
New Haven	529,000	82 - 82.5

[1] Refers to the original design discharge. Basin evolution and channel changes, such as aggradation, may have altered levee capacity.
[2] Kansas City urban levees.
[3] St. Joseph, Missouri/Elwood, Kansas area levees.

5.1.2. Non-Federal or Private Levees. Non-Federal levees are private levees which are funded and constructed by locally organized levee districts, or which are constructed and owned by one or more individual landowners. Within the Kansas City District, the Missouri River is almost totally leveed from the mouth upstream to Rulo, NE, by Federal and non-Federal levees. Non-Federal levees protect the majority of the agricultural lands from the mouth to Kansas City. However, three non-Federal levees downstream of Kansas City protect urban areas on the lower end of the river. They are the Chesterfield-Monarch, Riverport, and Earth City Levee Districts, and they are located downstream from RM 45. Upstream of Kansas City, non-Federal levees fill in where there are unprotected areas around the MRLS units. There are approximately one hundred non-Federal levee systems modeled as storage cells in the Missouri River UNET forecast model. Many of these levee systems are aggregates of several levee and drainage districts where the levees are contiguous along the river.

Non-Federal levees along the Missouri River were devastated by the 1993 Flood. Approximately 99 percent of all non-Federal levees were breached from Brownsville, Nebraska, to the mouth, which is a distance of 535 river miles. At the peak of the flood, all non-Federal agricultural levees in the lower reach of the river were completely inundated and the floodplain functioned as if the levees did not exist. Levees are included within the UNET forecast model as storage cells. However, should the area behind the levees begin to convey flow as happened in the 1993 Flood, the UNET model discontinues using the area behind the levees as storage cells, joins the geometry of the floodplain (the area behind the levees) to that of the channel at each cross section, and the full cross sections from bluff to bluff actively convey flow.

5.1.3. UNET Modeling Procedure for Missouri River Levees. For the Kansas City UNET model, the Missouri River levees are modeled as systems. Where levee districts are contiguous, the levees are considered to be part of one levee system which encompasses one protected area. The minimum protected area of a levee system is considered to be 100 acres. This means that levee districts are aggregated into systems such that the protected area per levee system is greater than 100 acres. Levee properties, such as top of levee elevation, surface area encompassed by the levee, and upstream and downstream river mile, were determined for each individual levee system. These properties were used to build the UNET levee parameter file, called the "include" file, which the program references during a run.

During large flood events on the Missouri River, agricultural levees are overtopped and there is significant overbank flow. One method of handling levees in UNET simulates levee systems as storage cells defined by surface area and height of levee above the ground elevation. Levees are breached based upon a time at which the breach begins or on river stage versus top of levee elevation. However, this methodology is inadequate for modeling multiple levee system breaches along the Missouri River such as occurred in the 1993 Flood. To overcome this problem, a unique levee algorithm was developed and programmed for UNET. This new UNET levee algorithm simulates the unique hydraulics of the Missouri River levee system that evolves during large flood events.

The behavior and breaching of levees along the Missouri River during the 1993 Flood were studied and used in developing the new levee algorithm. The Missouri River levees were breached early in the 1993 Flood event, and subsequently the protected area behind the levees filled with water from the river. During the final crest, the levees degraded and the floodplain behind the levees actively conveyed flow. The Missouri River functioned under two different geometric conditions: one in which levees constrained the flow to the channel, but provided storage behind the levees; and the second in which the levees no longer constrained the flow, and the overbank actively conveyed flow as if the levees did not exist (Reference No. 1).

With the new levee algorithm, levees are modeled in UNET in the following manner: When a levee breaches and the leveed area subsequently fills, the flow through the breach section depends on the elevation of the river and the elevation of the water in storage behind the levee. The water surface inside the levee interior is assumed to be horizontal. When the river discharge exceeds a specified flow, or when the river elevation exceeds a specified elevation, then the levee storage cross-sectional area and conveyance are added to the river cross-sections and the program routes flow through the channel and the entire width of the floodplain. The point at which the model changes from storage routing to floodplain routing is usually specified by flow. UNET uses elevation only if a flow is not specified. When the flow falls below a specified discharge, or the river falls below a specified elevation, the levee storage cross-sectional area and conveyance are subtracted from the cross-sections and the river once again interacts with the levee through the breach.

5.2. Dikes. The Missouri River Bank Stabilization and Navigation Project between Sioux City, Iowa, and the mouth, traverses the 498.1 river miles within the Kansas City District, plus 233.9 river miles in the Omaha District. This project entails the use of bank revetments and dikes to achieve a free-flowing navigation channel. A dike field is a system of rock embankments or timber structures that protrude from the bank. The dikes block the flow along the bank, concentrating the flow along the opposite bank, deepening the channel. The slack water areas behind the dikes eventually fill with sediment, burying the dike and forming a narrower but deeper river channel. Dikes are generally located on the point bars on the inside of a river bend. Figure NWK-2 shows a typical dike field along the Missouri River.

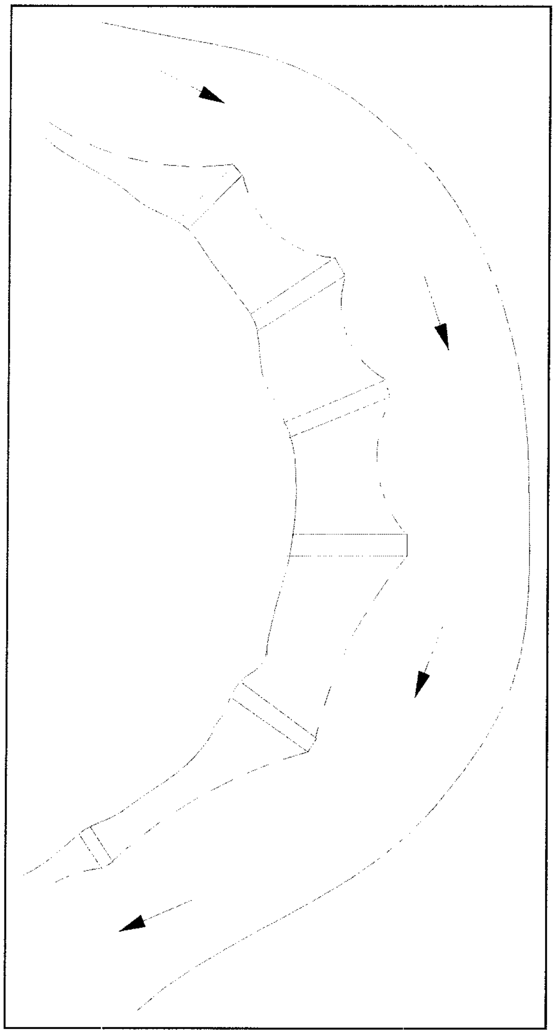


Figure NWK-2. A dike field on the inside of the river bend. The dike field narrows the river to a design topwidth. The slack water area blocked by the dikes fills with sediment and a new bank line eventually develops.

5.2.1. Description of a Typical Dike on the Missouri River. A typical dike on the right bank of the river is shown in Figure NWK-3. The dike field creates a channel with a design width at a low flow water surface elevation profile which is called the construction reference plane (CRP) on the Missouri River. The target topwidth, TWCH, extends from the opposite bank to the end of the dike. The dike can have two steps - a lower step and an upper step. The lower step has a set width with a crest elevation defined by a distance below the CRP, ZSTEP = ZCRP - DZLOW. The width of the upper step is the remaining distance from the bank. The crest elevation of the upper step is an increment, DZSTEP, above the lower step, ZDIKE = ZSTEP + DZSTEP.

The following parameters define a dike field in the UNET program:

ZCRP = the elevation of the CRP at a cross-section.
TWCH = the design topwidth of the contracted channel cross-section.
TWSTEP = the topwidth of the lower step.
DZLOW = distance between the CRP and the lower step.
ZSTEP = ZCRP - DZLOW = elevation of the lower step.
DZSTEP = elevation difference between the lower step and the upper step.
ZDIKE = ZSTEP + DZSTEP = elevation of the upper step

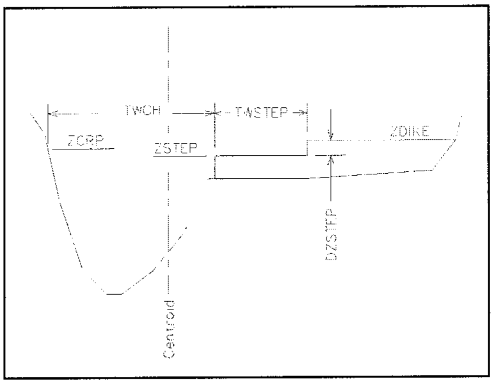


Figure NWK-3. Dike on the right side of the channel. The dike is positioned on the right side because the centroid of the channel is within the left 40% of the channel

5.2.2. UNET Modeling Procedure for Simulation of a Dike Field. A dike field is defined as a system of structures that contract the low flow cross-section to the design width of the channel. The model is one-dimensional; therefore, the effect of each individual dike cannot be simulated. Rather, the cross-sections are contracted to simulate the contraction of the dike field. The area blocked by the dike field can be modeled as storage area or as a dead area which is deducted from the cross-section. The storage area simulates the condition where the area behind the dike has not as yet filled with sediment and the area stores water. When the water exceeds the top of the dike, the storage area is assumed to return to active flow area, since the submerged dike field has little impact on the conveyance of high flow. The added form roughness of the dike is part of the calibration of the model. The dead area simulates the condition when the area behind the dike has been filled with sediment and the area has been lost for all river stages.

The dike field may be positioned either on the left or the right bank. The modeler can specify the bank or the modeler can allow the program to choose the appropriate bank. The program always attempts to place the dike field on the point bar opposite the channel. The program uses the centroid of the area about the left bank station to locate the dike. The following rules apply:

1. If the centroid is located within the left 40% of the cross section topwidth, the dike is located on the right bank (Figure NWK-3).
2. If the centroid is located within the right 40% of the cross section topwidth, the dike field is located on the left bank.
3. If the centroid is located within the middle 20% of the topwidth, then the dike field is located on the side opposite the minimum elevation.

Rules 1 and 2 apply to a pool cross-section where point bar is on the right and the left sides respectively. The 40% limit is based on the UNET program developer's judgment. Rule 3 applies to a crossing cross-section, where the area is uniformly distributed, and assumes that the appropriate location of the dike filed is on the side opposite the invert.

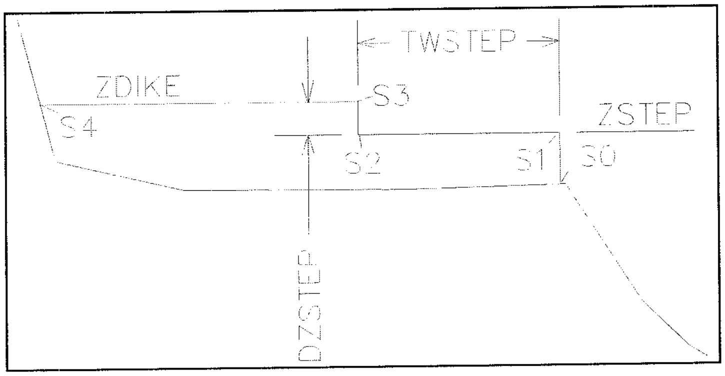


Figure NWK-4. The dike is defined by five points, S0 through S4.

The effect of the dike field can be modeled by entering five points into a cross-section (Figure NWK-4). The five points are as follows:

1. Point S0 is at the end of the dike at the intersection of the ground and the dike.
2. Point S1 is at the end of the dike at the bottom of the lower step.
3. Point S2 is at the inner limit of the lower step.
4. Point S3 is at the inner limit of the upper step.
5. Point S4 is at the intersection of the upper step with the bank line.

The DK record, or card, is used to insert the effect of the dike field into a cross-section. In the geometry file, the DK record is inserted before the X1 record of a cross-section. Based on the information on the DK record, the UNET program performs the following actions. Points S1 through S4 are entered into the dike cross-section and all cross-section points between S1 and S4 are brought up to the appropriate elevations, either ZDIKE or ZSTEP. The minimum width of the dike field is the width of the lower step. If the width of the channel is insufficient to insert the lower step, the dike field is not inserted.

6. Digital Terrain Data. In order to update the geometry of the UNET forecast model, new mapping data was acquired and assembled to develop new Missouri River cross sections. Digital terrain models (DTMs), which cover the Missouri River floodplain from bluff to bluff, were produced from a combination of 1995 and 1998/9 aerial photography. Source of the 1995 aerial photography is the United States Geological Survey (USGS). Source of the 1998/9 aerial photography is the contractor, Horizons, Inc. DTMs with soundings were produced by merging the DTMs with 1998 hydrographic survey data. Kansas City District performed the 1998 hydrographic survey of the Missouri River and supplied this data to the contractor, Bohannan Huston, Inc. Bohannan Huston produced the DTMs with soundings.

6.1. Missouri River Cross Sections. Locations of the Missouri River cross sections were laid out by Kansas City District using the ArcView program with USGS 1:24,000 scale quadrangle digital maps and USGS 1:100,000 scale digital maps. Cross sections were laid out based on the geomorphology of the channel, attempting to capture locations of features such as pools and crossings. Based on this procedure, the cross sections averaged approximately 0.7 to 0.8 miles apart in rural areas. In urban areas, cross sections were laid out to be 0.2 to 0.3 miles apart. For bridges, four cross sections were laid out -- two upstream and two downstream of each bridge. ArcView shape files were created of the cross section locations. The shape files were supplied to Bohannan Huston. With this cross section location information and the DTMs with soundings, Bohannan Huston produced geo-referenced cross sections in *.geo files which are compatible with the HEC-RAS program.

The *.geo files were imported into HEC-RAS and were edited using options available in RAS. After accomplishing all the editing possible within RAS, the RAS files were translated into UNET geometry files with the HEC program RAS2UNET. Using a text editor with the UNET geometry files, additional editing of the cross sections was accomplished and a complete UNET *.cs file incorporating the tributary reaches was assembled for the entire Kansas City District reach of the Missouri River from Rulo, NE, to the mouth.

6.1.1. HEC-RAS Editing Steps.

1. Import *.geo files into HEC-RAS
2. Check that cross section layout and direction of flow is from upstream to downstream
3. Check that cross section orientation is from left to right looking downstream
4. Check validity of spikes in the data points and eliminate as needed
5. Check for correct locations in the cross sections of major land surface features such as lakes, chutes, islands, etc.
6. Correct river station name at each cross section to correspond with the 1960 river miles
7. Extend or shorten cross sections as needed
8. Correct as needed channel and overbank reach lengths compared to actual measurements
9. Adjust bank station locations to be located at the top of the high banks
10. Check for correct location and configuration of levees
11. Check top of levee elevations
12. Check bridge cross section locations
13. Locate effective flow area encroachment stations at the top of levees

6.1.2. UNET Geometry *.cs File Editing Steps.

1. Insert tributary routing reaches from the existing Missouri River UNET geometry file into the new UNET geometry file
2. Insert observed hydrograph records, output hydrograph records, roughness values, dike records, upstream and downstream boundary records, etc. as needed, and using information from the existing UNET geometry file
3. Add natural levee data on the X3 records at every cross section

6.2 Tributary River Cross Sections. Cross section geometry is included in the UNET forecast model for all tributaries which have USGS gaging stations. These gaging stations supply the inflow data needed to run the UNET forecast model. Each tributary is modeled from its confluence with the Missouri River upstream to the USGS gaging station location. Tributary gaging stations are located from 10 to 50 river miles upstream of the confluence with the Missouri River. Tributary cross section data were developed from USGS 7.5 minute series quadrangle topographic maps. The distance between cross sections on tributaries varies from approximately 5.0 miles to 0.5 miles. The assembled cross section data for each tributary is suitable for flow routing only. Accurate stage computation on the tributaries is not possible with the coarse data employed in the development of the tributary cross sections.

7. Calibration Procedure. The Kansas City District's Missouri River UNET forecast model was calibrated to reproduce observed stages at river gages for the 1986, 1993, and 1994 water year flows. During real-time forecasting operation, calibration factors may require revision to maintain model accuracy. Calibration factors include Manning's *n*, development of rating curves at gaging stations, estimation of ungaged inflow, and fine tuning which includes conveyance change factors, discharge-conveyance change factors, and seasonal conveyance change factors.

7.1. Calibration Strategy. The primary factor for adjusting the UNET model is Manning's *n*, which is an estimate of the friction force of the boundaries on the flowing water. For large rivers, Manning's *n* varies with depth, because the relative size of the roughness elements, such as the dunes in the river bed, the height of vegetation, etc., declines with increasing depth. The object of the calibration process is to determine the variation of Manning's *n* with depth. The effect of the friction force from downstream is shown in the rating curve (stage versus flow) at a gaging station; hence, the variation of Manning's *n* with depth is represented in that relationship.

The Missouri River system is gaged by USGS streamflow gaging stations (see Table NWK-4) and by stage stations. Stage data is always available at streamflow stations. Because flow is unavailable at the stage stations, the model must first be calibrated to reproduce stage at the streamflow determination stations, and then calibrated at the stage stations. The calibration procedure steps are as follows:

1. Develop rating curves at the USGS streamflow gaging stations using observed discharge and observed stage.
2. Calibrate the model by adjusting the rating curves to reproduce stage at the USGS streamflow gaging stations.
3. Estimate ungaged inflow throughout the model using the null interior boundary condition (NIBC) procedure.
4. Develop rating curves at the stage gages using computed discharge and observed stage.
5. Calibrate the model by adjusting the rating curves to reproduce stage at the stage gages.
6. Fine tune the calibration of the entire model using the conveyance change factors which are located in the boundary conditions (*.bc) file.

7.2. Rating Curve Calibration. The rating curve calibration technique is described in the report "Rating Curve Calibration" written by Dr. Robert L. Barkau in 1994, and updated in 2000 in Dr. Barkau's report "Calibration Using Rating Curves". For the initial rating curve calibration, the UNET model was calibrated to reproduce rating curves at the principal gaging stations along the Missouri River as listed in Table NWK-4. Secondary rating curve calibration, as described in Step 4 in the previous paragraph, occurs at the stage gages. Stage gages are located at Atchison, KS (RM 422.6); Napoleon, MO (RM 328.7); Glasgow, MO (RM 226.3); and Jefferson City, MO (RM143.9). It should be noted that calibration of tributary routing reaches was not performed. The UNET model is designed for forecasting on the Missouri River only and the tributaries are modeled for routing inflow to the mainstem.

7.3. Ungaged Inflow. The NIBC procedure for estimating ungaged lateral inflows is described in the report "The Estimation of Ungaged Inflow Using the Null Internal Boundary Condition" written by Dr. Robert L. Barkau in 1995, and updated in 2000 in Dr. Barkau's report "The Null Internal Boundary Condition". The NIBC is a tool for estimating ungaged lateral inflow in a river system. The technique optimizes ungaged inflow to reproduce either a stage hydrograph or a flow hydrograph at the NIBC station. In the Missouri River UNET forecast model, NIBC stations are located at the USGS gaging stations except for the last downstream gage at St. Charles. When optimizing the stage hydrograph, the reproduction of flow is secondary, being dependent on the calibration of the model. Likewise, when optimizing the flow hydrograph, the reproduction of stage is secondary, being dependent on the calibration of the model. Optimizing stage is generally used for a flood forecast model, where stage accuracy is the primary goal. The ungaged inflow compensates for all the errors in the measurement of stage and flow, and for systematic changes in roughness and geometry, that may not be included in the model. Hence, the ungaged inflow compensates for all that is not known, understood, or anticipated.

The Missouri River UNET forecast model is optimized to stage using the NIBC technique. First, the river is divided into routing reaches. The routing reach divisions occur at the locations of USGS streamflow gages. NIBC stations are inserted to separate the routing reaches at each gage. The observed stage hydrograph is used as the upstream boundary for each routing reach. Flow is computed from this boundary condition and is routed through the reach to the adjoining downstream reach. The routed flow hydrograph at the NIBC station from the upstream reach does not include ungaged inflow. To determine the flow hydrograph just downstream of the NIBC station, the flow is computed from the stage boundary condition used at the upstream end of the downstream reach. This computed flow is generated by the hydrodynamics and the geometry of the downstream reach, and includes the ungaged inflow. The ungaged inflow hydrograph for the reach upstream of the NIBC station is estimated by subtracting the routed flow hydrograph (upstream side of the NIBC station) from the computed flow hydrograph (downstream side of the NIBC station).

To use the ungaged inflow in the Kansas City District UNET forecast model, the ungaged flow hydrograph is lagged backward in time, usually one day. The ungaged flow is inserted in the model as point inflow and uniform lateral inflow between the gages at the upstream and downstream boundaries of the reach (i.e. the NIBC stations). Point inflow occurs at known ungaged tributaries and uniform inflow is the remainder. The inflow is normally distributed by drainage area. The backward lag is adjusted by distance. For example, if a one-day lag is assumed, the upper one-half of the reach has a lag of one day and the lower one-half of the reach has no lag. The Missouri River basin drainage areas downstream of Rulo, NE, are summarized in Table NWK-6.

Table NWK-6.
Missouri River Drainage Areas
Kansas City District

SITE	RIVER MILE	DA*	SITE	RIVER MILE	DA*
Mouth	0	525,400	Waverly Gage	293.5	487,200
St Charles	28.2	525,200	Crooked River (ds)	313.6	487,200
Hermann Gage	97.9	524,200	Crooked River (us)	313.6	486,700
Gasconade River (ds)	104.4	523,800	Fishing River (ds)	334	486,700
Gasconade River (us)	104.4	520,200	Fishing River (us)	334	485,900
Osage River (ds)	130	519,400	Little Blue River (ds)	339.5	485,900
Osage River (us)	130	504,100	Little Blue River (us)	339.5	485,600
Jefferson City	143.9	503,500	Big Blue River (ds)	358	485,600
Boonville Gage	196.6	501,700	Big Blue River (us)	358	485,200
Lamine River (ds)	202.5	501,700	Kansas City Gage	366.1	485,200
Lamine River (us)	202.5	500,600	Kansas River (ds)	366.4	485,200
Glasgow	226.3	499,600	Kansas River (us)	366.4	425,100
Little Chariton River (ds)	238.8	499,600	Platte River (ds)	391	423,500
Little Chariton River (us)	238.8	498,900	Platte River (us)	391	421,100
Chariton River (ds)	238.8	498,900	St Joseph Gage	448.2	420,300
Chariton River (us)	238.8	496,600	Nodaway River (ds)	462.9	420,100
Grand River (ds)	249.9	496,600	Nodaway River (us)	462.9	418,300
Grand River (us)	249.9	488,700	Big Nemaha River (ds)	494.9	416,800
Wakenda Creek (ds)	262.8	488,600	Big Nemaha River (us)	494.9	414,900
Wakenda Creek (us)	262.8	487,200	Rulo Gage	498.0	414,900

* DA = Drainage Area in square miles

From: *Missouri River Basin Condensed Tabulation of River Mileage and Drainage Areas – May 1965,* Revised by USGS 1976.

7.4. Fine Tuning. The fine tuning procedures for refining the calibration of the UNET model are described in the report "Fine Tuning" written by Dr. Robert L. Barkau in 2000. The final step in the basic calibration procedure is to fine tune the model using conveyance change factors. The basic calibration of the UNET model represents an average flow-conveyance structure that is representative of the entire calibration period, not a specific event. The calibration is static, whereas the roughness of the river is dynamic. Over time, moving water of a river works and reworks the granular bed material as the water surface elevation rises and falls with changing flow. The bed forms and the frictional resistance of the riverbed are continuously changing. Thus, the resistance varies with stage, flow, season, and the timing of the event. Therefore, to simulate a particular event, the average calibration must be fine tuned to reproduce the observed stage and flow.

7.4.1. Conveyance Change Factors. The UNET program has three conveyance change factor tools which can be used for fine-tuning the calibration of the model. These conveyance change factors are included in the boundary conditions file.

1. Discharge Conveyance Change Factors: This relationship adjusts conveyance with discharge over multiple cross-sections along the same river in a designated calibration reach. Different discharge conveyance change factors can be entered for each increment in a series of discharge increments for the calibration reach. This relationship is the primary tool for adjusting systematic errors in stage at the same discharge.

2. Seasonal Conveyance Change Factors: This relationship changes an overall conveyance multiplier with time, simulating seasonal shifts in roughness. The seasonal factor is applied to all the cross-sections in a calibration reach at all stages for the designated time period.

3. Conveyance Change Factors: These factors, one for the channel and one for the overbanks, adjust the conveyance for all stages at multiple cross-sections in a calibration reach. These factors simulate a systematic change in roughness – one that is apparent for all stages over the entire duration of the simulation in the designated reach.

8. Operational Procedures and Experience. The calibrated UNET model is available for operation in the forecast mode. Northwest Division, Missouri River Region, Reservoir Control Center (RCC) operates the Missouri River UNET forecast model for real-time forecasting of Missouri River flows and stages. The Missouri River forecast model is a combination of the Kansas City and Omaha UNET forecast models. All data and geometry files necessary to operate the Kansas City UNET model were forwarded to RCC for their testing and use.

Operation of the forecast model is facilitated through the use of the Mississippi Basin Modeling System (MBMS) graphical user interface (GUI). Forecast operation is performed with updated inflow data from the DCP gaging stations for the desired forecast period. For forecast operation, model inflow hydrographs must be extended for the forecast period. The transition of the UNET model to a forecast model for use with the GUI required no additional UNET model development. The GUI provides an interface which couples operation of the UNET model with forecasting inflow data and processing UNET model results. By using the GUI, the forecaster can efficiently develop stage and flow forecasts for the desired forecast period. GUI operation does not require detailed UNET model knowledge. The GUI provides for consistent file management, UNET model simulation, easy selection of historical and forecast time window, model results review, and report generation. A user's manual entitled "Forecast Model User's Guide, December 1998," has been prepared by RCC to describe the forecast model GUI operation and to assist with daily operation.

REFERENCES

1. Barkau, R. L. Impact of Levees on the Middle Mississippi River: A report prepared for the Strategic Assessment and Strategy Team, July 15, 1994.
2. Barkau, R. L. UNET: Unsteady Flow through a Full Network of Open Channels, February 24, 1992.
3. Department of the Army, Kansas City District, Corps of Engineers. Multiple-Purpose Project: Long Branch Reservoir, Little Chariton River Basin, East Fork Little Chariton River, Missouri; Design Memorandum No. 1, Hydrology, May 1968.
4. Department of the Army, Kansas City District, Corps of Engineers. Review Report: Kansas River navigation, Lawrence to mouth, May 1971.
5. Department of the Army, Kansas City District, Corps of Engineers. Review Report: Nemaha and Little Nemaha Rivers, Nebraska and Kansas, November 1973.
6. Department of the Army, Kansas City District, Corps of Engineers. Review Report on Osage River: Additional tributary reservoirs, Missouri and Kansas, September 1967.
7. Department of the Army. Chariton and Little Chariton Rivers and tributaries, Iowa and Missouri, 89th Congress, 1st Session, House Document No. 238, U. S. Government Printing Office, Washington, 1965.
8. Department of the Army. Little Blue River, vicinity of Kansas City, Missouri, 90th Congress, 1st Session, House Document No. 169, U. S. Government Printing Office, Washington, 1967.
9. Grumman Ecosystems Corporation. Report on Navigability of the Blue River in Missouri and Kansas: Navigability Report No. 1, Final Report, September 1975.
10. Grumman Ecosystems Corporation. Report on Navigability of the Chariton River in Missouri and Iowa: Navigability Report No. 5, Final Report, October 1975.
11. Grumman Ecosystems Corporation. Report on Navigability of the Gasconade River and Tributaries Big Piney River and Little Piney Creek in Missouri: Navigability Report No. 13, Final Report, December 1975.
12. Grumman Ecosystems Corporation. Report on Navigability of the Grand River and its Tributary Thompson River in Missouri and Iowa: Navigability Report No. 6, Final Report, October 1975.
13. Grumman Ecosystems Corporation. Report on Navigability of the Little Blue River in Missouri: Navigability Report No. 2, Final Report, October 1975.
14. Grumman Ecosystems Corporation. Report on Navigability of the Nodaway River in Missouri and Iowa: Navigability Report No. 3, Final Report, October 1975.
15. Grumman Ecosystems Corporation. Report on Navigability of the Osage River and the Marais des Cygnes River in Missouri and Kansas: Navigability Report No. 12, Final Report, December 1975.
16. Grumman Ecosystems Corporation. Report on Navigability of the Platte River and its Tributary, 102 River, in Missouri and Iowa: Navigability Report No. 4, Final Report, October 1975.
17. Interagency Floodplain Management Review Committee. Sharing the Challenge: Floodplain Management into the 21st Century, June 1994.
18. U. S. Army Corps of Engineers, Kansas City District. The Great Flood of 1993 Post-Flood Report: Lower Missouri River Basin, Omaha District, Appendix E, September 1994.
19. U. S. Army Corps of Engineers, Omaha District. The Great Flood of 1993 Post-Flood

Report: Lower Missouri River Basin, Appendix D, September 1994.

20. U. S. Army Engineer District, Kansas City, Corps of Engineers. Missouri River Basin, Kansas and Missouri: Design Memorandum No. 1A, Preliminary Master Plan, March 1964.
21. U. S. Army Engineer District, Kansas City, Corps of Engineers. Missouri River Restudy, Missouri River Backwater Computations, 1977 through 1979.
22. U. S. Army Engineer District, Kansas City, Corps of Engineers. Review of Report on the Lamine and Blackwater Rivers, Missouri, March 1960.
23. U. S. Army Engineer District, Kansas City, Corps of Engineers. Report on Flood Plain Information: Kansas River, Kansas, Junction City to the mouth, April 1965.
24. U. S. Army Corps of Engineers, Floodplain Management Assessment of the Upper Mississippi and Lower Missouri Rivers and Their Tributaries, Appendix A (Hydraulic Modeling), June 1995.
25. U. S. Department of the Interior, Bureau of Reclamation, Region 7 - Denver, Colorado. Report on the Kansas River Basin: Colorado - Nebraska - Kansas, September 1956.

St. Louis District

(MVS)

TABLE OF CONTENTS

MISSISSIPPI RIVER REAL-TIME FORECAST MODEL

St. Louis District

1.0 Geographic Coverage. The St. Louis District includes 300-miles of the Mississippi River, 80-miles of the Illinois River, 97-miles for the Missouri River main river and 182-mi. of tributaries that are simulated with the Mississippi Basin unsteady flow forecasting system. The district area involved is approximately 25,000 mi^2 . Shown in Figure MVS-1 is a schematic of the modeled area.

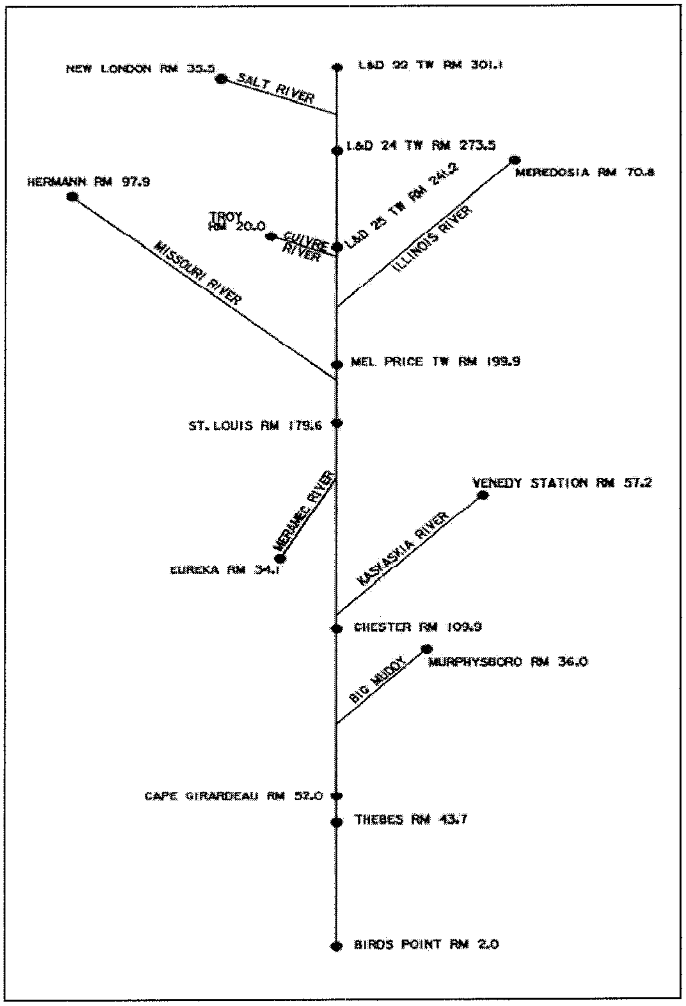


Figure MVS-1. Schematic of the St. Louis District MBMS Model.

2.0 Hydrologic/Geographic Description of the Area. The Mississippi River rises in the Lake Forest country of north central Minnesota near the Village of Bemidji, and flows north, east and then south through this timbered landscape to Minneapolis-St. Paul. At this point, it leaves the northern woodlands and lakes, and meanders southward past fertile prairies and many villages and cities. Along the way, tributaries that drain lands to the east and to the west join the Mississippi River and add to its flow. The Mississippi River flows 1,370 miles from its headwaters to the confluence with the Ohio River. Then it flows another 964 miles to the Gulf of Mexico.

3.0 Drainage system. The inflows into the UNET model from the upstream districts are at the Lock and Dam 22 TW gage for the Mississippi River, at the Meredosia gage for the Illinois River and the Hermann gage for the Missouri River. Their drainage areas are 138,200 mi^2 , 26,000 mi^2, and 524,200 mi^2 , respectively. The major tributaries of the Mississippi River that were modeled using UNET are as follows:

3.1 Salt River Basin. The Salt River Basin lies in northeastern Missouri and has a drainage area of approximately 2,934 square miles. One multiple purpose reservoir, Mark Twain Lake (Clarence Cannon Dam), has been constructed approximately 63 miles above the confluence of the Salt River with the Mississippi River. The watershed for the reservoir is 2,314 square miles, or about 79 percent of the total Salt River Basin. Along the main stream below the dam, the bottomlands vary in width from 2,000 feet to more than a mile.

3.2 Cuivre River Basin. The Cuivre River Basin is about 1,300 square miles in area and located in east central Missouri. The Cuivre River enters the Mississippi River (RM 236.5) at Cuivre Island immediately downstream from Lock and Dam 25, about 41.5 miles upstream from the confluence with the Missouri River. The basin is largely agricultural land with isolated small pockets of urban development. There are no major impoundments in the basin.

3.3 Illinois River Basin. The Illinois River Basin extends southwesterly across the northern half of the State of Illinois from Chicago to the Mississippi River at Grafton, Illinois, 38.4 miles above St. Louis, Missouri. It extends northerly to just west of Milwaukee, Wisconsin, and easterly to South Bend, Indiana. The total natural drainage area is about 28,906 square miles, with about 1,000 square miles in Wisconsin, 3,000 square miles in Indiana and 25,000 square miles in Illinois. The St. Louis District jurisdiction of the Illinois River is the lower 80 miles from the tailwater of the LaGrange L&D (R.M. 80.2) to the mouth.

The Illinois River is the largest tributary of the Mississippi River above the mouth of the Missouri River. It lies entirely within the State of Illinois and is formed by the confluence of the Kankakee and Des Plaines Rivers about midway between Chicago and La Salle, Illinois. From this point, the Illinois River flows in a southwesterly direction 273 miles to the Mississippi River. The average water surface slope through the St. Louis District reach is small and there is little or no evidence of erosion along the banks and stream bed. Throughout the greater part of the lower 80 miles, the river follows the base of the western bluff.

3.4 Missouri River Basin. The Missouri River basin is the largest of the nation's 18 major water resource regions, embracing 529,400 square miles within the United States, including all or parts of 10 states. The basin also includes 9,715 square miles in Canada. On the west are the Rocky Mountains, and on the east are the productive farmlands of the Missouri-Mississippi drainage areas. The Missouri River flows in a southeasterly direction 2,315 miles from its headwaters at Three Forks, Montana through six major main stem reservoirs to its confluence with the Mississippi about 15 miles above St. Louis, Missouri.

3.5 Meramec River Basin. The Meramec River Basin lies in the east central portion of the State of Missouri. The basin is bounded on the north by the Missouri River Basin; on the east by the Mississippi River; on the south by the St. Francis, Black, and Current Rivers; and on the west by the Gasconade River Basin. The drainage area of the entire watershed is about 3,980 square miles of which 3,788 square miles are upstream of the Eureka, Missouri stream gage. The watershed comprises all or portions of 15 counties and converges toward the metropolitan area of St. Louis. The drainage system consists of the Meramec River and its two principle tributaries, the Big River and the Bourbeuse River. The Meramec River Bain has no major reservoirs.

3.6 Kaskaskia River Basin. The Kaskaskia River Basin lies entirely in the State of Illinois. It is the second largest river basin in Illinois with a drainage area of 5,801 square miles. It extends from the center of Champaign County in a southwesterly direction to the Mississippi River near the City of Chester. Elevations range from about 730 feet at the headwaters to about 385 feet at the bluff line where it emerges into the Mississippi River floodplain. The basin has a median length of 175 miles, a maximum width of 55 miles and an average width of 33 miles. The topography of the basin is generally flat or gently rolling except for broken terrain near the streams.

The Kaskaskia River rises about 5 miles northwest of Urbana, in the east-central part of the State. It flows southwesterly for about 310 miles and empties into the Mississippi River above Chester, Illinois, 118 miles upstream of the mouth of the Ohio River. Multiple purpose reservoirs have been constructed at river mile 106.6 (Carlyle Lake) and river mile 221.8 (Lake Shelbyville).

3.7. Big Muddy River. The Big Muddy River Basin is located in southwest Illinois and drains an area of approximately 2,360 square miles. The river has a total length of 155 miles and empties into the Mississippi River at mile 75.5 above the Ohio River.

One multiple purpose reservoir, Rend Lake, has been constructed 103.7 miles above the mouth of the Big Muddy River. The lake is located in Franklin and Jefferson Counties, Ill., near Benton, Ill. The Big Muddy River basin above the Rend Lake Dam site has a length of about 32 miles, a maximum width of 20 miles, an average width of about 15 miles, and a drainage area of about 488 square miles.

4.0 Key Locations – Gages. There are five discharge gages on the Mississippi River in the SLD, although one (Louisiana) is stage only with occasional discharge measurements made. These sites were used to calibrate the model to recorded discharge data. In addition to the discharge gages, Mississippi River stage data is also available at 33 sites throughout the 300-mile reach of the Mississippi in the SLD that were used for stage calibration. One discharge gage is available on the Illinois River, with five additional stage gages sited on the 80-mile reach. On the Missouri River, the only discharge gage near the SLD boundary is at Hermann, MO with discharge data to 1928 and limited stage data prior to that date. Stage data is available at the St. Charles gage at river mile 28.2 for the Missouri River. Discharge and stage gages are shown on Tables MVS-1, MVS-2, and MVS-3.

Table MVS-1. Mississippi River USGS Discharge Gage Information.

RIVER	GAGE SITE	STATE	RIVER MILE	GAGE ZERO	FLOOD STAGE
MISSISSIPPI	LOUISIANA	MO	282.90	437.33	15.00
MISSISSIPPI	GRAFTON	ILL	218.60	403.79	18.00
MISSISSIPPI	ALTON	ILL	203.00	400.00	
MISSISSIPPI	ST. LOUIS	MO	179.60	379.94	30.00
MISSISSIPPI	CHESTER	ILL	109.90	341.05	27.00
MISSISSIPPI	THEBES	ILL	43.70	300.00	33.00
ILLINOIS	MEREDOSIA	ILL	70.80	418.00	14.00
ILLINOIS	VALLEY CITY	ILL	61.30	418.00	8.00
MISSOURI	HERMANN	MO	97.90	481.56	21.00

Table MVS-2. Mississippi River Pertinent Stage Gage Information.

RIVER	GAGE SITE	STATE	RIVER MILE	GAGE ZERO	FLOOD STAGE
MISSISSIPPI	L&D 22 (LOWER)	MO	301.20	446.10	12.00
MISSISSIPPI	MUNDYS LANDING	MO	293.00	441.85	14.00
MISSISSIPPI	LOUISIANA	MO	282.90	437.33	15.00
MISSISSIPPI	L&D 24 (UPPER)	MO	273.50	421.81	
MISSISSIPPI	L&D 24 (LOWER)	MO	273.20	421.81	446.81
MISSISSIPPI	RIP RAP LANDING	MO	265.00	426.03	17.00
MISSISSIPPI	MOSIER LANDING	MO	260.30	400.00	441.00
MISSISSIPPI	STERLING LANDING	MO	250.80	420.48	
MISSISSIPPI	L&D 25 (UPPER)	MO	241.50	407.00	
MISSISSIPPI	L&D 25 (LOWER)	MO	241.20	407.00	433.00
MISSISSIPPI	DIXON LANDING	ILL	228.30	410.62	16.00
MISSISSIPPI	GRAFTON	ILL	218.60	403.79	18.00
MISSISSIPPI	ALTON	ILL	203.00	400.00	

MISSISSIPPI	MELVIN PRICE L&D (UPPER)	ILL	201.10	359.48	
MISSISSIPPI	MELVIN PRICE L&D (LOWER)	ILL	200.50	395.48	416.48
MISSISSIPPI	HARTFORD	ILL	196.80	350.00	417.00
MISSISSIPPI	CHAIN OF ROCKS	MO	190.40	313.91	101.00
MISSISSIPPI	LOCKS 27 (UPPER)	ILL	185.30	350.00	
MISSISSIPPI	LOCKS 27 (LOWER)	ILL	185.10	350.00	
MISSISSIPPI	ST. LOUIS	MO	179.60	379.94	30.00
MISSISSIPPI	ENGINEERS DEPOT	MO	176.80	379.58	29.00
MISSISSIPPI	JEFFERSON BARRACKS	MO	168.70	377.69	26.00
MISSISSIPPI	WATER'S POINT	MO	158.50	370.39	27.00
MISSISSIPPI	SELMA	MO	145.80	0.00	390.00
MISSISSIPPI	BRICKEYS	MO	136.00	357.78	26.00
MISSISSIPPI	LITTLE ROCK LANDING	MO	125.50	213.79	163.00
MISSISSIPPI	CHESTER	ILL	109.90	341.05	27.00
MISSISSIPPI	BISHOP LANDING	MO	100.80	334.11	29.00
MISSISSIPPI	RED ROCK LANDING	MO	94.10	328.92	31.00
MISSISSIPPI	GRAND TOWER	ILL	81.90	321.93	28.00
MISSISSIPPI	MOCCASIN SPRINGS	MO	66.30	313.89	28.00
MISSISSIPPI	CAPE GIRARDEAU	MO	52.10	304.65	32.00
MISSISSIPPI	GRAYS POINT	MO	46.30	301.18	25.00
MISSISSIPPI	THEBES	ILL	43.70	300.00	33.00
MISSISSIPPI	COMMERCE	MO	39.50	301.83	24.00
MISSISSIPPI	PRICE LANDING	MO	28.20	299.75	24.00
MISSISSIPPI	THOMPSON LANDING	MO	20.20	280.00	319.00
MISSISSIPPI	BIRDS POINT	MO	2.00	274.53	38.00

Table MVS-3. Illinois and Missouri River Pertinent Stage Gage Information

RIVER	GAGE SITE	STATE	RIVER MILE	GAGE ZERO	FLOOD STAGE
ILLINOIS	MEREDOSIA	ILL	70.80	418.00	14.00
ILLINOIS	VALLEY CITY	ILL	61.30	418.00	8.00
ILLINOIS	FLORENCE	ILL	56.00	400.00	24.30
ILLINOIS	HARDIN	ILL	21.50	400.00	25.00
ILLINOIS	PEARL	ILL	43.20		424.00
MISSOURI	HERMANN	MO	97.90	481.56	21.00
MISSOURI	ST. CHARLES	MO	27.90	413.59	25.00

5.0 Key Locations - Structures. The St. Louis District is responsible for administering Federal water resource development programs in large portions of Missouri and Illinois. The District operates and maintains four locks and dams on its portion of the mainstem Mississippi River: Lock and Dam 24, Lock and Dam 25, Melvin Price Locks and Dam, Locks 27, and one lock and dam on the Kaskaskia River. The St. Louis District operates three multi-purpose reservoirs in the state of Illinois; Lake Shelbyville and Carlyle Lake on the Kaskaskia River, and Rend Lake on the Big Muddy River. The District operates Mark Twain Lake on the Salt River, and Wappapello Lake on the St. Francis River in the state of Missouri.

5.1 Navigation Dams. The navigation dams within the St. Louis District were constructed as components of the Mississippi River Nine-Foot Channel Navigation Project. As mandated by Congress, the dams are regulated for the sole purpose of creating pools to provide a nine-foot depth navigation channel. The Federal Government purchased land subjected to inundation as the result of the operation of the navigation dams before project operation began.

Strict water control guidelines are employed so as to provide adequate navigation depths, while preventing water from inundating land not purchased for the navigation pools. The mid-pool control point (hinge-point) method is used to regulate the pools within the St. Louis District. The river stage at the control point is maintained within the limits specified in the water control plan. In order to maintain the stage at the control point within the limits, the elevation held at a dam is varied depending upon the flow rate in the river. Medium- to high-flow conditions necessitate low elevations at a dam. Low-flow conditions necessitate high elevations at a dam. When flow conditions are such that the nine-foot depth occurs naturally, the gates are taken out of the water. When the gates are out of the water, open-river conditions exist. The rule curve that is used for Mel Price is depicted in Figure MVS-2. A list of the Navigation Dams for the Mississippi River that uses the hinge-point control is shown in Table MVS-4.

Table MVS-4. Navigation Dams.

Dam	Tailwater River Mile	Maximum Regulated Pool (Feet NGVD)	Hinge-Point Location	Hinge-Point River Mile
24	273.2	449.0	Louisiana	282.9
25	241.2	434.0	Mosier landing	260.3
Mel Price	199.9	419.0	Grafton	218.0

5.1.1 Lock & Dam 24. Lock and Dam 24 is located at river mile 273.4 on the Upper Mississippi River at Clarksville, Missouri. Dam 24 backs water up from river mile 273.4 to 301.2 during low and moderate river flow conditions, thus providing a nine-foot navigation channel.

Lock and Dam 24 is constructed of concrete, with steel gates. There are fifteen 80-foot by 25-foot tainter gates. These gates are used to regulate the water level upstream of the dam. The lock is on the Missouri side of the river and has dimensions of 600 feet by 110 feet. The adjoining overflow dike is constructed with a core of sheet pile cells covered with stone and slush concrete.

Navigation Pool 24 is regulated within the elevation limits of 445.5 and 449.0 feet National Geodetic Vertical Datum (NGVD) at the dam and within the stage limits of 11.5 and 12.2 feet at Louisiana, MO (river mile 282.9). During low to moderate flow periods (less than 154,000 cfs), the gates of the dam are lowered into the flowing water. The gates thus impede the flow and raise the water level on the upstream side of the dam. When the flow rate increases, the stage at Louisiana also tends to increase and will thus exceed the authorized limit unless the water level on the upstream side of the dam is lowered. The dam gates are raised to lower the water level. When the flow rate reaches 145,000 cfs, the water level on the upstream side of the dam is held at the minimum elevation (445.5 feet NGVD). The gates are further adjusted as necessary to maintain the pool level at the minimum elevation until the flow rate is such that the tailwater elevation is approximately the same as the pool elevation (approximately 154,000 cfs). As the flow rate continues to increase, the gates are lifted clear of the water and open-river conditions exist. For a flow rate in excess of 154,000 cfs, a minimum of a nine-foot channel exists naturally, and there is no need to maintain a pool with the dam.

5.1.2 Lock & Dam 25. Lock & Dam 25 is located at river mile 241.4 on the Upper Mississippi River at Cape Au Gris, Missouri. Dam 25 backs water up from river mile 241.4 to 273.2 on the Mississippi River during low and moderate river flow conditions, thus providing a nine-foot channel.

Lock and Dam 25 is constructed of concrete, with steel gates. There are fourteen 60 by 25-foot tainter gates and three 100 by 25-foot roller gates. These gates are used to regulate the water level upstream of the dam. The lock is on the Missouri side of the river and has dimensions of 600 feet by 110 feet.

Navigation Pool 25 is regulated within the elevation limits of 429.7 and 434.0 feet NGVD at the dam and 434.0 and 435.75 feet NGVD at Mosier Landing (river mile 260.3). During low to moderate flow periods (less than 135,000 cfs), the gates of the dam are lowered into the flowing water. The gates thus impede the flow and raise the water level on the upstream side of the dam. The water backed up maintains a nine-foot navigation channel. When the flow rate increases, the stage at Mosier Landing also tends to increase and will thus exceed the authorized limit, unless the water level on the upstream side of the dam is lowered. The dam gates are raised to lower the water level. When the flow rate reaches 95,000 cfs the water level on the upstream side of the dam is held at the minimum elevation (429.7 feet NGVD). The gates are further adjusted as necessary to maintain the pool level at the minimum elevation until the flow rate is such that the tailwater elevation is approximately the same as the pool elevation (approximately 135,000 cfs). As the flow rate continues to increase, the gates are lifted clear of the water and open-river conditions exist. For a flow rate in excess of 135,000 cfs, a nine-foot channel exists naturally, and there is no need to maintain a pool with the dam.

5.1.3 Melvin Price Locks & Dam. Melvin Price Locks and Dam is located at river mile 200.78 on the Upper Mississippi River. Melvin Price Dam backs water up from river mile 200.78 to 241.2 on the Mississippi River, and to river mile 80.1 on the Illinois River during low and moderate river flow conditions, providing a nine-foot deep navigation channel.

Melvin Price Locks and Dam is constructed of concrete, with steel gates. The project provides for one 1,200-foot main lock and one 600-foot auxiliary lock. The dam has nine 110 feet wide by 42 feet high tainter gates and an overflow dike. These gates are used to regulate the water level upstream of the dam.

Melvin Price Navigation Pool is regulated within the elevation limits of 412.5 and 419.0 feet NGVD at the dam and within the stage limits of 14.2 and 16.2 at Grafton, Illinois (river mile 218.0). During low to moderate flow periods (less than 210,000 cfs), the gates of the dam are lowered into the flowing water, thus impeding the flow and backing water up on the upstream side of the dam. When the flow rate increases, the stage at Grafton also tends to increase and will thus exceed the authorized limits, unless the water backed up at the dam is permitted to recede. The dam gates are raised to permit this recession. When the flow rates reaches 210,000 cfs, the backed-up water is held at the minimum elevation (412.5 feet NGVD) authorized for maintaining the nine-foot navigation channel. The gates are further adjusted as necessary to maintain the pool at the minimum elevation until the flow rate is such that the tailwater elevation is approximately the same as the pool level, approximately 210,000 cfs. As the flow rate continues to increase, the gates are lifted clear of the water and open-river conditions exist. At a flow rate in excess of 210,000 cfs, a minimum of a nine-foot channel exists naturally, and there is no need to maintain a pool with the dam. The rule curve that is used for Mel Price is depicted below.

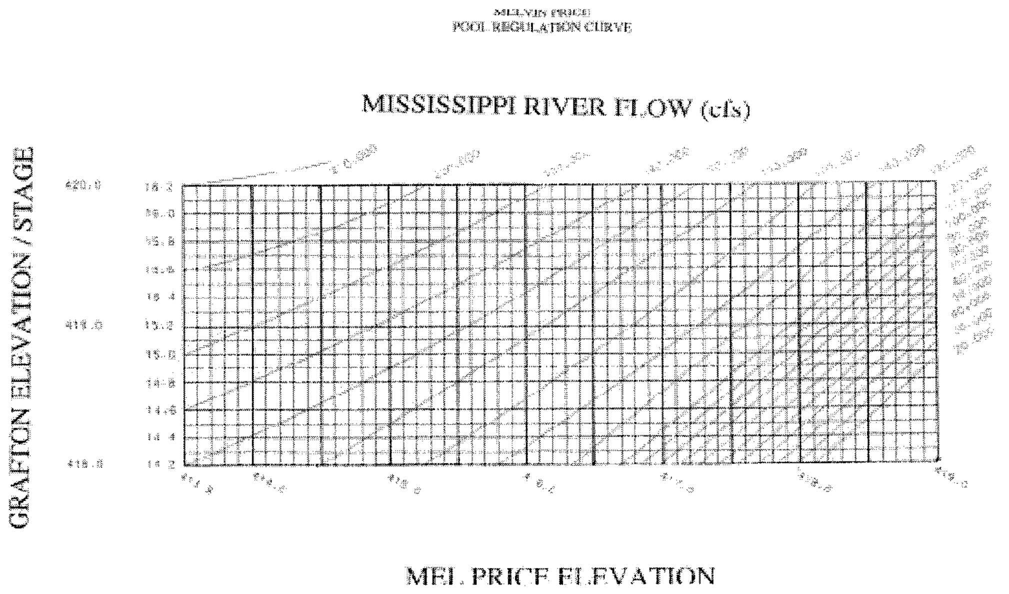


Figure MVS-2. Melvin Price Pool Regulation Curve.

5.1.4 Dam 27 - Low Water Dam. Dam 27 is an existing rock-filled structure located in the Mississippi River channel at river mile 190.3 above the mouth of the Ohio River. Construction of the dam was initiated in June 1960 and completed in August 1962. The dam consists of a broad-crested weir with a length of about 2,140 feet at crest elevation 395 ft. NGVD with a notch of 676 feet at crest elevation 391 feet NGVD. The notch was sized to pass the design minimum discharge of 25,000 cfs at pool elevation of 395 ft. NGVD. The purpose of Dam 27 is to maintain a tailwater elevation at Melvin Price to assure a minimum of 9-foot depth over the lower lock sill. All navigation now passes through the Chain of Rocks Canal and Lock 27.

5.2 Multi-Purpose Reservoirs. The operation of four reservoirs in the St. Louis District will affect the flows in the UNET forecasting model.

5.2.1 Mark Twain Lake. Mark Twain Lake is located on the Salt River about 63 miles upstream from the confluence with the Mississippi River. The authorized purposes of this project include flood reduction, hydroelectric power generation, water supply, fish and wildlife conservation, recreation, and water quality enhancement. Incidental navigation benefits on the Mississippi River occur as the result of releases from the lake during low-flow periods. The Mark Twain Lake watershed is comprised of 2,318 square miles, with an additional 29 square miles draining into the Reregulation Pool. The joint-use pool at the dam is between 567.2 and 606.0 feet National Geodetic Vertical Datum (NGVD), with 457,000 acre-feet of conservation storage. The flood-control pool at the dam is between 606.0 and 624.8 feet (NGVD), with 442,000 acre-feet of flood-control storage.

5.2.2 Lake Shelbyville. Lake Shelbyville is a multi-purpose reservoir located on the Kaskaskia River, one-half mile east and one-fourth mile north of the Town of Shelbyville, Illinois. The purposes of this reservoir are to provide flood reduction, to create recreational opportunities, to provide fish and wildlife conservation, to augment water supplies, to enhance water quality, and to augment flows for navigation. The drainage area of the lake is 1,054 square miles. The joint-use pool is between elevations 573.0 and 599.7 feet NGVD with 180,000 acre-feet of conservation storage. The flood-control pool is between elevations 599.7 and 626.5 feet NGVD with 474,000 acre-feet of flood-control storage.

5.2.3 Carlyle Lake. Carlyle Lake is a multi-purpose reservoir on the Kaskaskia River extending from the main dam at river mile 106.6 near Carlyle, Illinois, to river mile 160.0. The purposes of this project are to provide flood reduction, to create recreational opportunities, to augment water supplies, to enhance water quality, to augment flows for navigation on the Kaskaskia River, and to provide fish and wildlife conservation. The drainage area of the lake is 2,717 square miles. The joint-use pool is between elevations 429.5 and 445.0 feet NGVD with 233,000 acre-feet of conservation storage. The flood-control pool is between elevations 455.0 and 462.5 feet NGVD with 699,900 acre-feet of flood-control storage.

5.2.4 Rend Lake. Rend Lake is a multi-purpose reservoir located on the upper reaches of the Big Muddy River in southern Illinois. The dam is located on the Big Muddy River at River Mile 103.7 about 3 miles northwest of Benton, Illinois, and the reservoir at normal levels extends upstream approximately 13 miles. The purposes of this project are to provide flood reduction, to create recreational opportunities, to augment water supplies, to enhance water quality, and to provide fish and wildlife conservation. The drainage area of the lake is 488 square miles. The joint-use pool is between elevations 391.3 and 405.0 feet NGVD with 160,000 acre-feet of conservation storage. The flood-control pool is between elevations 405.0 and 410.0 feet NGVD with 109,000 acre-feet of flood-control storage. The flood control pool is limited to protecting the area downstream of the dam to floods not exceeding a 5-year frequency of occurrence. Two subimpoundments, one each on the Big Muddy and Casey Fork arms, are located in the upper reaches of the reservoir. They consist of compacted earth core and rock embankment with the crest elevation at 416.0 feet NGVD and overflow section at elevation 412.0 feet NGVD.

5.3 Levees. There are 39 federal and numerous non-federal and private levee districts within the St. Louis District boundary that provide limited flood protection to specific areas along the Mississippi River.

5.3.1 Federal Levees. Federal levees are those built and maintained by the Federal government. The standard Federal levees are designed for a 20-500 year+ flood event. The Mississippi River Federal agricultural levee systems, (Columbia, Harrisonville, Ft. Chartres, Stringtown, Prairie du Rocher, Kaskaskia Island, Bois Brule, Degognia, Grand Tower, Preston, Clear Creek and East Cape Drainage and Levee districts) are designed to the 50-year level of protection. The Illinois River Federal levee systems (Nutwood, Eldred and Spanky, Keach, Hartwell, Hillview, Big Swan, Scott County, Valley City, Mauvaise Terre, Willow Creek and McGee Creek Drainage and Levee districts) are designed to varying levels of protection from 20-100+ year. The urban Federal levee systems, (Wood River, East St. Louis, City of St. Louis, and Prairie du Pont Drainage and Levee districts) are designed to the 500 + year level of protection. The Cape Girardeau Federal urban levee is designed to the 200-year level of protection. Federal levees are constructed with a minimum five-foot-thick clay cap, or entirely of clay and have side slopes of 1V:3-4H. Crown widths on Federal levees vary from 10 to 20 feet. Federal levees also include seepage control measures where determined necessary.

5.3.2 Non-Federal and Private Levees. Non-Federal levees are constructed with non-Federal funds by an organized levee district. Private levees are levees constructed, owned and maintained by one or more individual landowners. The typical private levee is designed for a 5-20 year flood event. They are generally constructed of a mixture of soil materials with side slopes of 1V:2H. Private levees often have narrow crown widths of 4-5 feet and little or no seepage control. Private levees are also typically located closer to the river than federal levees.

Three private levees on the Missouri River are considered to be urban systems. Riverport and Earth City levee districts are designed to a 500-year + level of protection. The Chesterfield-Monarch levee district is designed to provide a 100-year level of protection.

Lists of the levees used in the UNET for the Mississippi and Illinois Rivers are shown in Tables MVS-5 and MVS-6.

Table MVS-5. Mississippi River Drainage and Levee Districts.

UNET Levee Definition (Name/District)	LEVEE D/s RM	LEVEE U/s RM	Bank	AREA (Acres)
Sny Middle (Rock Island District)	296.7	273	L	58740
Sny Lower (Rock Island District)	273	266	L	10900
Riverland	293.2	286	R	5878
Pettus-Burns-Prewitt-Jaegger P/L	272.3	270.8	R	400
Clarksville P/L	270.8	267.5	R	2340
Kissinger LD	267.5	265	R	2570
Busch – Goose Pasture P/L	265.6	263.8	R	410
Busch P/L	265.6	264.8	R	110
Goose Pasture P/L	265.5	263.8	R	300
Annada – Clarence Cannon	263.8	260.6	R	6800
Clarence Cannon NWR	263.8	260.6	R	3480
Annada	267 - 265	262.8 - 260.6	R	3320
Elsberry	260.6	251.3	R	23481
Kings Lake LD	251.3	246.2	R	3300
Sandy Creek	246	245.1	R	944
Foley	245.1	243.7	R	1214
Cap Au Gris	243.7	239.1	R	3491
Winfield	241.9	238.7	R	2826
Brevator-Schram	238.7	237	R	2121
Brevator	238.7	237	R	1841
Schram P/L	237.5	237	R	280
Old Monroe	237	236.5	R	900
Heitman P/L (Cuivre R)	236.3	235.5	R	300
Martsan-Portucheck	236.3	235.7	R	755
St. Peters (Agric)	230.5	229.5	R	300
St. Peters (Urban)	230.5	229.8	R	700
Consolidated N County LD	213.8	199.8	R	30000
Wood River LD	203	195	L	13700
Chouteau Island LD	193.3	189	L	2400
Gaberet/Cabrolet Island LD	189	185.8	L	800

Chouteau, Nameoki, & Venice LD	194.9	184	L	4800
St. Louis Flood Protection	187.4	176.4	R	3160
Metro-East Sanitary District	184	175.4	L	61645
Praire Du Pont-Fish Lake	175.4	166.3	L	12000
Columbia	166.3	156.3	L	14800
Harrisonville - Stringtown - Fort Chartres & Ivy Landing	156.3	130	L	46500
Harrisonville				27800
Stringtown				2800
Ft. Chartres & Ivy Landing				15900
Praire Du Roche/Modoc Includes Edgar Lake D&L	130	118	L	16000
City of Ste. Genevieve	125	122.5	R	505
Ste. Genevieve #2	122.5	115.5	R	7000
Bois Brule	111	94.3	R	26060
Degognia - Ground Tower	99.2	75.8	L	51000
Degognia & Fountain Bluff	99.2	84.2	L	36200
Grand Tower	81.8	75.8	L	14800
Big Five	75.5	46	L	51500
Preston	75.5	65.8	L	20500
Includes Miller Pond DD				4300
Clear Creek	65.8	57	L	18000
East Cape Girardeau	57	46	L	13000
Includes N. Alexandar County LD				3600
Cape Girardeau	52.4	52	R	140
Powers Island (Memphis District)	39	32.5	R	5740
Miller City/Len Small	39	21.2	L	8720

Table MVS-6. Illinois River Drainage and Levee Districts.

UNET Levee Definition (Name/District)	**LEVEE** D/s RM	**LEVEE** U/s RM	**Bank**	**AREA** (Acres)
McGee Creek D&L	75.2	67.2	R	12200
Meredosia & Willow Cr DL	71	67	L	4000
Coon Run	71	66.7	L	4600
Smith Lake P/L	67.2	67	L	1500
Oakes P/L	66.7	65.9	L	400
Mauvaise Terre D&L	67	63.3	L	4000
Robertson P/L	64	63.3	L	1000

Valley City DL	66.6	63	R	4900
Scott County DL	63	56.7	L	10500
Walnut Creek	56.5	56.1	L	500
Big Swan DL	56.7	50.1	L	12300
Hillview DL	50.1	43.1	L	12900
Village of Pearl P/L	43.3	43	R	1000
Hartwell DL	43.1	38.3	L	8900
Keach	38.3	32.7	L	8400
Bluffdale Farms	34	32	L	1000
Schaefer – Farrow P/L	32	30.7	L	800
Eldred - Spankey DL	32.7	23.6	L	11300
Nutwood DL	23.5	15.3	L	11300

6.0 Digital Terrain Data. Aerial photography, airborne GPS control, ground survey control, and aerotriangulation was used in development of digital terrain model (DTM) and digital elevation model (DEM) of the project area for the St. Louis District (Illinois River, Grafton, Illinois, river mile 0 to river mile 43.0 and the Mississippi River from the confluence of the Ohio River, river mile 0 to Dam 22 at Saverton, Missouri, river mile 301.2). The aerial Photography for the DTM was taken in March 1995 and November 1996 under the direction of the Scientific Assessment Team (SAST)). Two areas not covered by the SAST, St. Louis Harbor and the Thebes Gap, photography was taken in May and April 1998 respectively. The DTM data is composed of mass points and breaklines that adequately define elevated roads, railroads, levees (features that would impede flow) and other major topographic changes required for accurate DEM development. The DEM has a 15' posting and a vertical resolution of 1/10 ft. Both the DTM and DEM data collection utilized procedures that met U.S. ARMY CORPS OF ENGINEERS Class I Standards. The aerial mapping is based on surveyed ground control points. These surveyed ground control points are very accurate, but the aerial mapping of well-defined features between the ground control points can vary by as much as 0.67 feet 67% of the time in accordance with the ASPRS Class I mapping standards. Ground surface elevations developed by the aerial mapping will be accurate to within 1.33 feet. This level of accuracy is much better than that used for previous hydraulic models along these rivers and is considered very good for the purposes of hydraulic modeling.

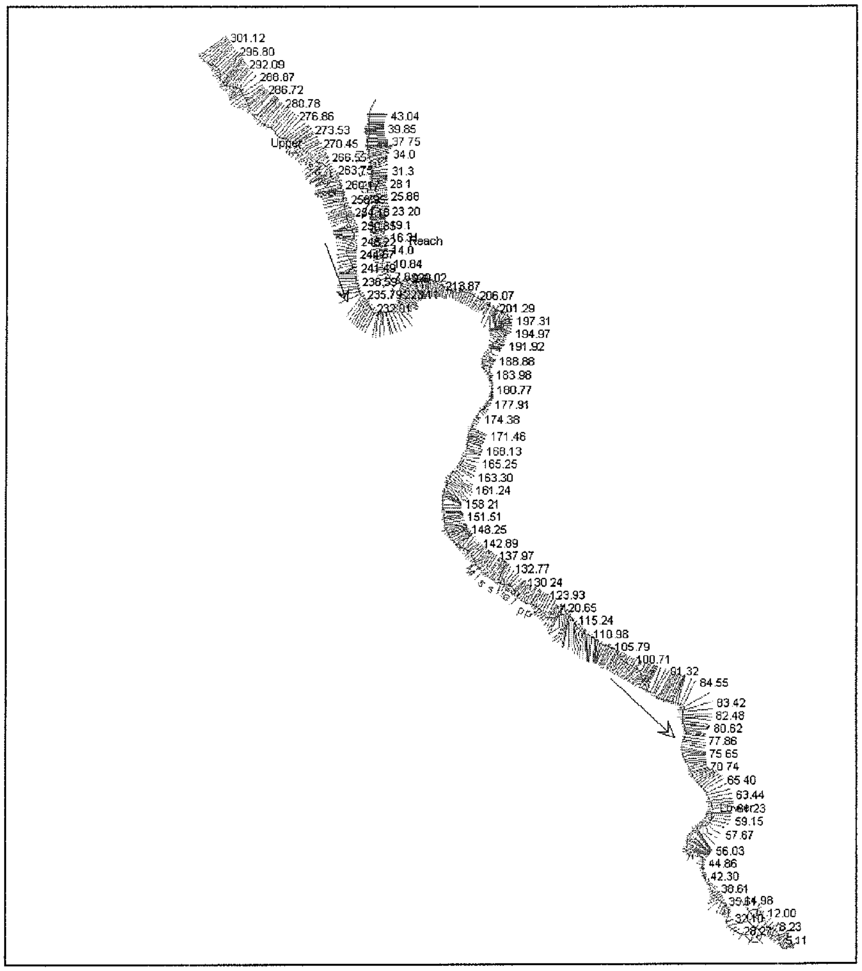
6.1 Verification of DTM Terrain Data. DTM's were verified using recent top-of-levee as built elevations and documented structural feature elevations (roadways, lock walls, etc.).

6.2 Merging of terrain and bathymetry. Hydrographic survey data taken in 1996 was combined with cross-sectional data cut from the DEM to produce a final cross-sections for use in the UNET model.

6.3 Geometry. The UNET model cross-section geometry was acquired from digital survey information of the Mississippi and Illinois River channel and floodplain using new profile generating software. Digital cross-sections were cut along the entire reach of the Mississippi River within the SLD from river mile 0.0 to 300.0 and along the Illinois River from the confluence through river mile 43.0. The previous UNET geometry information for the Illinois River from river mile 43 to 80 was used to complete the Illinois reach. The average distance between cross-sections was between 2000 to 3000 feet. The Digital terrain models (DTM) of the project area were merged with hydrographic survey data of the Mississippi and Illinois River and converted into triangulated irregular network (TIN) data sets. Electronically cut profiles through these TIN data sets generated cross-sections for the Mississippi and Illinois River. The cross-section profiles were imported into HEC-RAS. Cross-section reach lengths, bridge pier data, and Manning's *n* value data were added to the HEC-RAS geometry file. This information was converted into a UNET geometry file. Additional information on the geometry of levee and drainage districts, and crossover storage areas were added to the UNET geometry file. Figure MVS-3 is an illustration of a final UNET geometry file cross-section alignment.

6.4 Friction Values. Manning's *n* values for channel and overbank areas were estimated by skilled modelers. The *n* value is determined from the factors that affect the roughness of channels and flood plains. This *n* roughness value can vary from season to season, and change with depth of water. Channel *n* values for the main stem rivers varied from 0.02-0.04, while the overbank *n* values ranged from 0.035 to 0.15. Manning's *n* values were adjusted in the form of conveyance during the calibration process in UNET to better simulate actual river stages at gaging sites.

Figure MVS-3. Alignment of Cross Sections.



7.0 Calibration Procedure. The UNET model calibration is based upon stage calibration at more than 40 stage and discharge gages along the Mississippi, Illinois and Missouri Rivers. This total includes most discharge and staff gages operated by the USGS and Corps on the three rivers within or near the SLD boundaries. The results at Grafton, IL range from 3% for the high flow year to 10% for the low flow year and at St. Louis, MO range from 0.5% for the high flow year to 3% for the low flow year. Flows and stages at Chester and Thebes, IL gages were of similar accuracy. Figure 7.0 illustrate the actual vs. stages at the St. Louis gage but with a day-to-day forecasting mode, a better reproduction and forecast should be obtainable.

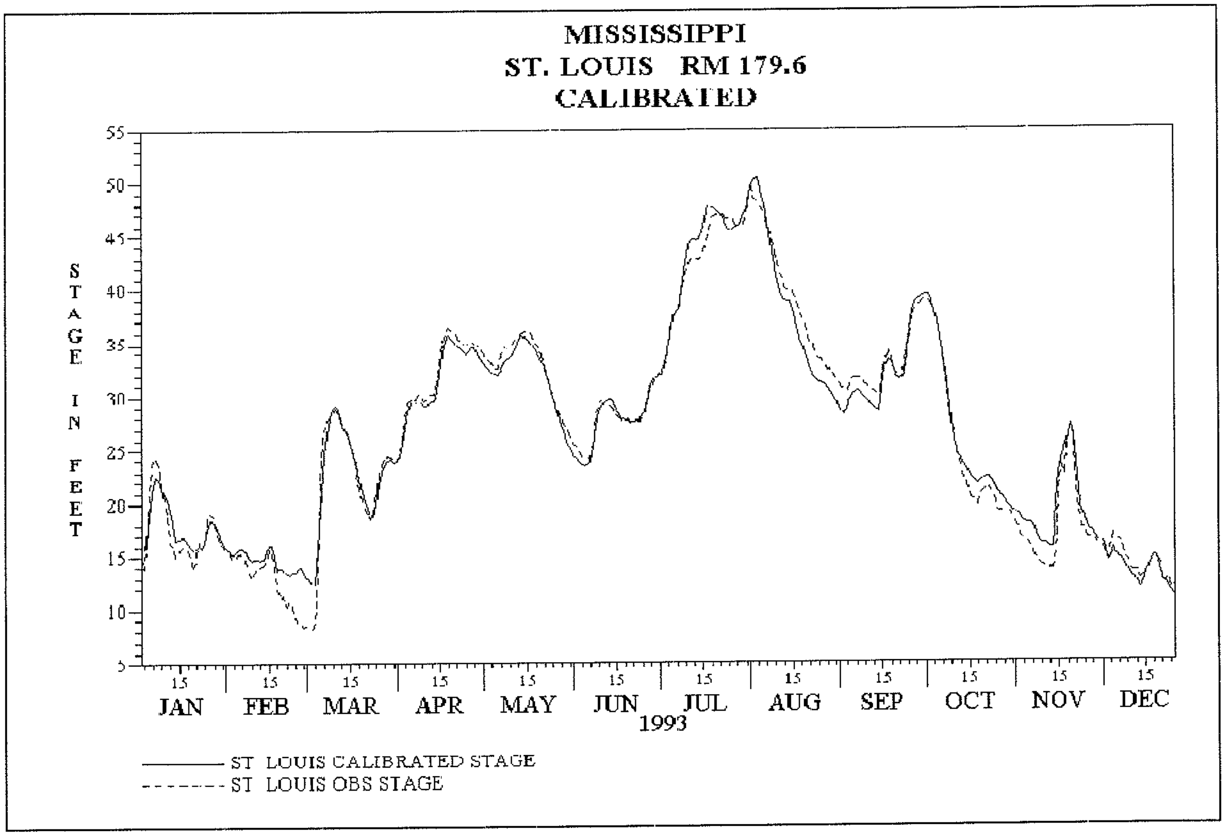


Figure MVS-4. 1993 Calibrated Flood

7.1 Base Calibration. For base calibration, the model was calibrated to reproduce rating curves at the principal gaging stations along the Mississippi, Illinois and the Missouri Rivers. The rating curve calibration technique is described in the report "Rating Curve Calibration" (Barkau 1994). Observed rating curves are entered at principal gaging stations. The program adjusts the conveyance of the cross-sections between the gaging stations so that the rating curve at the upstream stations is approximately reproduced by backwater calculations. Rating curves were made using the data from the years of 1988 and 1989 for draught events, and 1993 and 1995 for flood events. This calibration was done in the cross section file for UNET.

7.2 Primary Calibration. There are number of variables that can be adjusted in UNET to alter the response of the stage in reaction to the flow after the base calibration. Basically, the stage calibration involves increasing or decreasing the conveyance of the channel and overbank areas to raise or lower the stage for a given flow. The conveyance can be altered by making the channel and overbank areas smoother (increase the conveyance and lower the stage) or rougher (decrease the conveyance and raise the stage). The conveyance can be adjusted in small vertical increments based on rate of flow for any user defined reach or it can be adjusted more broadly for all flow rated for a reach. The user may subdivide the model into any number of reaches for this purpose, defining reaches by indicating the beginning and ending river miles of each reach. Since the river reacts differently to cold and warm water temperatures, there is a provision for varying the conveyance according to the time of the year. This seasonally conveyance adjustment can vary by reach. Generally, cold water temperatures in winter months tend to provide a smoother channel and less vegetation in the overbank areas, resulting in greater conveyance and lower stage for a given flow than in summer months.

7.3 Flow Calibration. The gaged areas represent approximately 98% of the inflow in the MBMS model for the St. Louis District. Because of the low percentage of ungaged areas, the Null Boundary Condition is not necessary. Runoff from the ungaged areas are estimated by the water control personnel, and are inserted into a utility program. This utility program writes the estimated local flows into a local DSS file that is read as uniform lateral inflow hydrographs in the MBMS model.

8.0 Operational Procedures and Experience. The St. Louis District's Water Control Data System (WCDS) comprises the hardware, software, and data collection system that supports the accomplishment of the water control mission. The WCDS is used as the data collection and dissemination mechanism for the MBMS. Within the WCDS, a DOMSAT Receive System (DRS) located in the district's Water Control office receives real-time hydro-met data from the GOES satellite. The DRS uses a turn-key multi-user system providing fully automated receipt, analysis, and storage of Data Collection Platform (DCP) message data. Redundancy of the DRS is provided through additional links to the Rock Island District (CEMVR) DRS and the Vicksburg District (CEMVK) DRS. DCPs are located at stream gaging stations throughout the St. Louis District. The MBMS model was developed to utilize the DCP data received from as many of the stream gages as possible.

The real-time data is stored in the district's WCDS HEC Data Storage System (HEC-DSS) master data base. The data is extracted to a local HEC-DSS data base for the MBMS model to be used as input data values for upstream and downstream boundary conditions, internal boundary conditions, and for graphical and tabular comparison of real-time data and model computed results at the gage locations.

In May 1996 the first use of the St. Louis UNET model for forecasting of an on-going flood event was made. The model's computed stages followed the observed fairly well. The shape of the stage hydrograph was good but the computed stages were 2-3 foot lower than the observed stages. Was this a rating curve shift? Were the flows correct? Flow at St. Louis is measured by the USGS about every other week. Using the preliminary flow measurement from the USGS for the St. Louis gage, the discharge value showed that a shift in the rating curve did occur. A shift adjustment then was made in the MBMS model. The calculated values, after the rating curve shift, followed the observed values within a foot. As the model was not being used for forecasting at that time no additional calibrations were made. After the peak stage passed, the model usage was discontinued. However, experiences from these working sessions helped shape the future development of the model.

With additional development of the GUI (graphical user interface) for the MBMS model, calibration refinements, lock and dam rule curve capabilities and software development, the MBMS model was ready for testing in February 1997. The model was used extensively from February 18 to May 14. Output was compared to that of the existing forecast model to evaluate accuracy. During this time, continual improvements were made to the data and software. The calculated stages from the model tracked the observed stages generally within one foot, but usually closer. The locks and dams were at open river during this period.

A special feature was added to the MBMS model because of the variable stage operation for a flow using the hinge-point control. An interactive routine was set up in the MBMS GUI to set pool stages according to the “Gate Edit Page”. The “Gate Edit Page” was extremely time consuming because of the computer language it was written in. Figure MVS-5 is a sample of the data page used in the MBMS model.

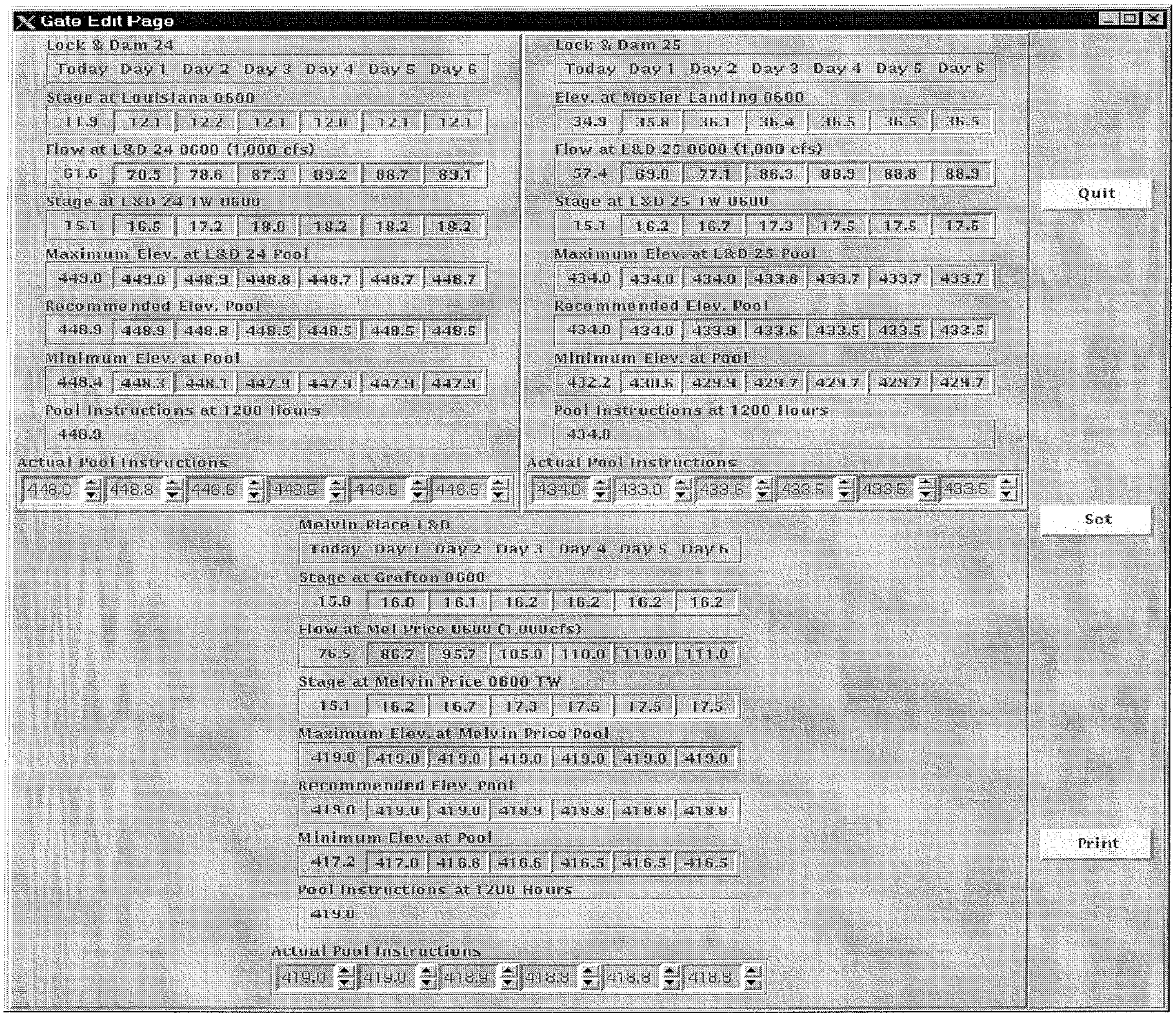
9.0 Interactions With Others. Upstream and downstream Corps' offices and the National Weather Service offices are key members of the forecasting model team. Continual communications between the offices are required to ensure smooth passage of forecast data information. The interactions between Corps offices and National Weather Service have always been critical.

Two upstream Corps offices pass data to the St. Louis District. The Rock Island District provides flow values at Lock & Dam 22 tailwater on the Mississippi River and at Meredosia, IL, on the Illinois River. Northwestern Division passes flow values at Hermann, MO, on the Missouri River.

The National Weather Service transmits their 7-day flow forecast data daily to the St. Louis District. This data includes the forecast flows for the Mississippi River, Missouri River, and Illinois River gages and local drainage areas required for the forecasting model.

The results of the St. Louis District forecast model is needed at the Thebes, Illinois gage on the Mississippi River by the Great Lakes and Ohio River Division and by the Mississippi Valley Division for an unsteady flow boundary condition input.

The communication link from Corps' offices can be achieved with a telephone call, from the internet, or through the file transfer system. The MBMS model uses the file transfer system to deliver the files to all offices that are identified. This file transfer system is activated by using the **Import Forecast** or **Export Forecast** button in the MBMS model GUI.



Lock & Dam 24

	Today	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6
Stage at Louisiana 0600	11.9	12.1	12.2	12.1	12.0	12.1	12.1
Flow at L&D 24 0600 (1,000 cfs)	61.6	70.5	78.6	87.3	89.2	88.7	89.1
Stage at L&D 24 TW 0600	15.1	16.5	17.2	18.0	18.2	18.2	18.2
Maximum Elev. at L&D 24 Pool	449.0	449.0	448.9	448.8	448.7	448.7	448.7
Recommended Elev. Pool	448.9	448.9	448.8	448.5	448.5	448.5	448.5
Minimum Elev. at Pool	448.4	448.3	448.1	447.9	447.9	447.9	447.9

Pool Instructions at 1200 Hours: 448.9

Actual Pool Instructions: 448.0, 448.8, 448.6, 448.5, 448.5, 448.5

Lock & Dam 25

	Today	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6
Elev. at Mosier Landing 0600	34.9	35.8	36.1	36.4	36.5	36.5	36.5
Flow at L&D 25 0600 (1,000 cfs)	57.4	69.0	77.1	86.3	88.9	88.8	88.9
Stage at L&D 25 TW 0600	15.1	16.2	16.7	17.3	17.5	17.5	17.5
Maximum Elev. at L&D 25 Pool	434.0	434.0	434.0	433.8	433.7	433.7	433.7
Recommended Elev. Pool	434.0	434.0	433.9	433.6	433.5	433.5	433.5
Minimum Elev. at Pool	432.2	430.6	429.9	429.7	429.7	429.7	429.7

Pool Instructions at 1200 Hours: 434.0

Actual Pool Instructions: 434.0, 433.0, 433.6, 433.5, 433.5, 433.5

Melvin Price L&D

	Today	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6
Stage at Grafton 0600	15.8	16.0	16.1	16.2	16.2	16.2	16.2
Flow at Mel Price 0600 (1,000cfs)	76.5	86.7	95.7	105.0	110.0	110.0	111.0
Stage at Melvin Price 0600 TW	15.1	16.2	16.7	17.3	17.5	17.5	17.5
Maximum Elev. at Melvin Price Pool	419.0	419.0	419.0	419.0	419.0	419.0	419.0
Recommended Elev. Pool	419.0	419.0	419.0	418.9	418.8	418.8	418.8
Minimum Elev. at Pool	417.2	417.0	416.8	416.6	416.5	416.5	416.5

Pool Instructions at 1200 Hours: 419.0

Actual Pool Instructions: 419.0, 419.0, 418.9, 418.8, 418.8, 418.8

Figure MVS-5. Gate Edit Page.

9.1 Inundated area determination and mapping. Inundation mapping was performed on the Mississippi River reach from L&D 24 to L&D 25. The procedure for inundation mapping was created by CRREL. Three sets of information were required for inundation mapping. HEC-RAS data files with GIS coordinates were used to locate the cross section lines. The calibrated UNET model output in DSS was used to calculate stages at each cross section for the year of 1993. Closed polygons were used to define each levee system in this area, and were activated when the levees overtopped in the simulation. Daily simulation for this reach of river verified observed data. Observed data consisted of gage data and aerial photos during this period.

10. References.

1. Barkau, R. L. Impact of Levees on the Middle Mississippi River: A report prepared for the Strategic Assessment and Strategy Team, July 15, 1994.

2. Barkau, R. L. UNET: Unsteady Flow through a Full Network of Open Channels, February 24, 1992.

3. Scientific Assessment and Strategy Team, Science For Floodplain Management Into The 21st Century, Washington, D.C., June 1994.

4. U. S. Army Corps of Engineers, St. Louis District. The Great Flood of 1993 Post-Flood Report: Lower Missouri River Basin, St. Louis District, Appendix C, September 1994.

5. U. S. Army Corps of Engineers, Flood Plain Management Assessment, Appendix A, St. Louis District, June 1995.

6. U. S. Army Engineer , Master Water Control Manual, Missouri River, Reservoir Regulation Studies, Long Range Study Model, Volume 2, Missouri River Division, July 1994.

7. U. S. Army Engineer , Master Water Control Manual, Missouri River, Mississippi River Studies, Volume 13, Missouri River Division, August 1998.

8. Department of Interior, Guide for Selecting Manning's Roughness Coefficients for Natural Channels and Flood Plains, U.S. Geological Survey, Denver, CO., 1989.

Mississippi Valley Division

(MVD)

TABLE OF CONTENTS

MISSISSIPPI RIVER REAL-TIME FORECAST MODEL

Mississippi Valley Division

1. Geographic Coverage. The Mississippi Valley Division's forecast model includes 986 miles of main stem Mississippi River, 257 miles of Red and Atchafalaya Rivers, 109 miles of tributaries, including the lower 7 miles of the Ohio, and 102 miles of floodways and diversion channels that are simulated with the Mississippi Basin unsteady flow forecasting system. The drainage area involved is 1,246,000 square miles. A schematic of the modeled area is shown on Figure MVD-1.

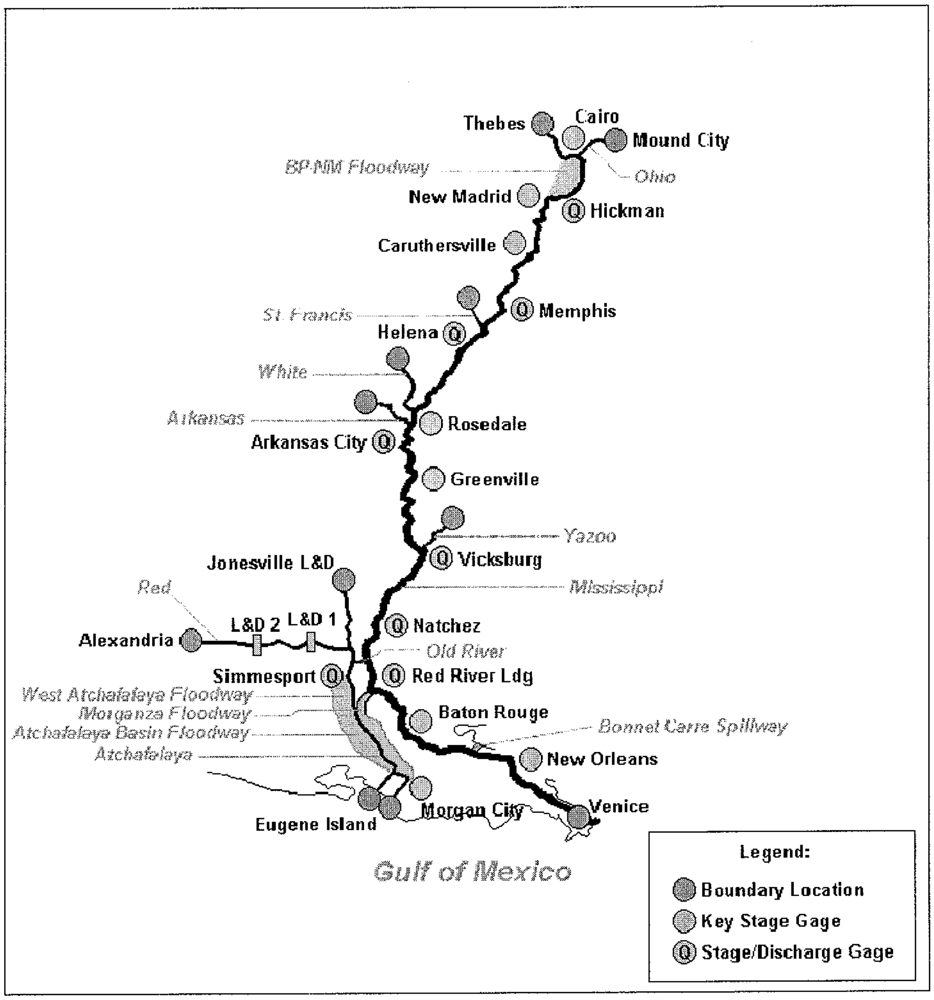


Figure MVD-1. Schematic of the Mississippi Valley Division MBMS Model.

2. Hydrologic/Geographic Description of the Area. The Lower Mississippi/Atchafalaya River model, as shown on Figure 1, extends from Thebes, Illinois (RM 43.7), on the middle Mississippi River, and near Mound City, Illinois (RM 973.0), on the Ohio River, to Venice, Louisiana (RM 10.7), on the lower Mississippi River near the Gulf of Mexico; and from Alexandria, Louisiana (RM 88.6), on the Red River, and Jonesville Lock and Dam, Louisiana (RM 25.1), on the Black River to the Gulf of Mexico via the Atchafalaya River and its two outlets. The model also includes portions of four other tributaries to the Mississippi: St. Francis River, which enters the Mississippi at RM 672.4; White River, which enters the Mississippi at RM 599.0; Arkansas River, which enters the Mississippi at RM 581.4; and the Yazoo River, which enters the Mississippi at RM 437.6. Descriptions of the Mississippi River Basin and its tributary basins included in the model are found in Section 2.2.

2.1. River Mileage. Locations on the Mississippi River are in 1962 river miles and the Atchafalaya River in 1963 river miles. The direction in which the river miles increase or decrease vary with the reach as follows:

<u>Mississippi River from Thebes, Illinois, (RM 43.7) to the mouth of the Ohio (RM 0.0)</u>: The river mile increases in the upstream direction and is measured from the mouth of the Ohio River.

<u>Ohio River from L&D 52 TW (RM 938.9) to the mouth of the Ohio (RM 980.0)</u>: The river mile increases in the downstream direction and is measured from Pittsburgh, Pennsylvania.

<u>Lower Mississippi River from the mouth of the Ohio (RM 953.8) to Venice, Louisiana, (RM 10.7)</u>: The river mile increases in the upstream direction and is measured from near the head of passes where the Mississippi River ends and the water flows to the Gulf through various outlets or passes. The Head of Passes gage is located at RM -0.6, or 0.6 miles below the head of many passes that convey the Mississippi River flow to the Gulf of Mexico. The model terminates at RM 10.7 near the Venice gage. The passes were included in the earlier phase of the model development but were later excluded because the ill-defined nature of the area geometry made calibration difficult and there was no apparent advantage in including the passes in the model.

<u>St. Francis River</u>: The river mile increases in the upstream direction and is measured from the mouth of the St. Francis River.

<u>White River</u>: The river mile increases in the upstream direction and is measured from the mouth of the White River.

<u>Arkansas River</u>: The river mile increases in the upstream direction and is measured from the mouth of the Arkansas River.

<u>Yazoo River</u>: The river mile increases in the upstream direction and is in 1970 river miles above Vicksburg, Mississippi.

<u>Bonnet Carre Spillway</u>: The river mile increases in the downstream direction and is measured from the Mississippi River.

Red River: The river mile increases in the upstream direction and is measured in 1967 river miles from the confluence of the Old River and the Mississippi River.

Black River: The river mile increases in the upstream direction and is measured from the mouth of the Black River.

Old River: The river mile increases in the downstream direction and is measured from the head of the channel, which is at mile 312.0 (1962 river mile) on the Mississippi River.

Atchafalaya River: The river mile increases in the downstream direction and is measured in 1963 river miles from the head of the river, which is at the confluence of the Red and the lower Old Rivers.

Morganza Floodway: The river mile increases in the upstream direction and is measured from the downstream end of the floodway, which is just north of the head of the Whiskey Bay Pilot Channel.

2.2. Basin Descriptions.

2.2.1. Mississippi River Basin. The Mississippi River and its tributaries drain a total of 1,246,000 square miles, which is 41 percent of the land area of the continental United States. About 13,000 square miles of this drainage area lie in two Canadian provinces; the remainder is within the geographical boundaries of the United States and covers all or part of 31 states. The drainage basin is bounded on the west by the Rocky Mountains, which exceed an elevation of 10,000 feet at many points. Between the Rockies and the Mississippi River is the Great Plains, which vary in elevation up to 4,000 feet. From the Great Plains, the land slopes eastward to the Mississippi River. The Appalachian Mountain chain forms the eastern divide of the watershed. From these mountains, the Appalachian Plateau extends westward at elevations varying from 2,000 to 4,000 feet. In contrast to the east and west divides, the northern divide is comparatively ill-defined and varies in elevation from less than 1,000 feet to more than 2,000 feet.

The Mississippi River rises in northern Minnesota and flows in a southerly direction for 2,430 miles into the Gulf of Mexico. The Missouri River enters the Mississippi River at RM 1,159 above head of Passes, Louisiana; the Ohio at RM 964; and the White-Arkansas at RM 583. At RM 314.5, some of the flow leaves the Mississippi River through the Old River Control Structures and passes to the Gulf of Mexico through the Atchafalaya River Basin. The alluvial valley of the Mississippi River extends from Cape Girardeau, Missouri, 50 miles above Cairo, to the Gulf of Mexico. This valley caries in width from 20 miles at Natchez, Mississippi, to 80 miles at Greenville, Mississippi, and has an average width of 45 miles.

2.2.2. Ohio River Basin. The Ohio River is formed at Pittsburgh, Pennsylvania, at the junction of the Allegheny and Monongahela Rivers. The Allegheny River has its source in northwestern Pennsylvania, then flows northward into southwestern New York and southward again into west Pennsylvania. The Monongahela River has its source at the confluence of the Tygart and West Fork Rivers near Fairmont, West Virginia, and then flows northwest through north central Pennsylvania. From Pittsburgh, the Ohio flows generally southwest by west, 981 miles to its junction with the Mississippi River at Cairo, Illinois. The parent stream is joined by a number of major tributaries in its course: Little Kanawha, Kanawha, Guyandotte, Big Sandy, Licking, Kentucky, Salt, Green, Cumberland, and Tennessee from the south, and Beaver, Muskingham, Hocking, Sciotto, Little Miami, Great Miami, and Wabash from the north.

The topography of the Ohio River basin varies from flat and rolling plains to rugged mountains. The basin elevation falls from over 600 feet in the Great Smoky Mountains to about elevation 310 feet at Cairo, Illinois. The ridged terrain of the Appalachian Mountains and plateau from southwestern New York to North Carolina dominates the eastern portion of the basin. The ridges are sharp, the slopes steep, and the valleys narrow. The area extending westward from the Appalachians and south of the Ohio River has considerable relief, with most of the streams enclosed in deep canyons and narrow valleys; however, portions of the area in central and western Kentucky and Tennessee have rolling plains and hills suitable for agriculture. North of the Ohio River offers broad valleys and minor relief extending westward covering northwest Pennsylvania, central and southwest Ohio, central Indiana, and southeast Illinois.

The drainage area of the Ohio Basin comprises approximately 204,000 square miles, which includes portions of states of New York, Pennsylvania, Maryland, Virginia, North Carolina, Ohio, West Virginia, Tennessee, Georgia, Alabama, Mississippi, Indiana, Illinois, and Kentucky. This area represents about 6 percent of the total area of the 48 contiguous states and nearly 5 percent of the land east of the Mississippi River. The Ohio River enters the Mississippi at RM 953.8.

2.2.3 Mainstem Lower Mississippi River - Cairo, Illinois, to Gulf of Mexico. The Lower Mississippi is considered to begin at Cairo, Illinois, at the confluence of the Ohio and Mississippi Rivers. It travels southward a distance of 953.8 miles to Head of Passes, Louisiana. At that point, the river separates into several passes to the Gulf of Mexico, the principal one being the Southwest Pass, approximately 20 miles long.

2.2.4. St. Francis River Basin. The St. Francis River rises in the rugged Ozark Hills region of southeastern Missouri. It flows southeasterly 475 miles to enter the Mississippi River near Helena, Arkansas, draining an area of 8,400 square miles. Its principle tributaries are the L'Anguille, Tyronza, and Little Rivers, and Blackfish Bayou. The St. Francis River empties into the Mississippi River 284 miles downstream of the Ohio River and 672 miles upstream of Head of Passes.

2.2.5. White River Basin. The White River rises in the "Boston Mountain" region of northwestern Arkansas. From there, it flows northeast to the Missouri-Arkansas state line and then easterly along the line to RM 447. It then runs in a southeasterly direction to its mouth on the Mississippi River. The White River is 686 miles long and drains 27,765 square miles. Principle tributaries are the Little Red, Cache, Kings, James, Buffalo, North Fork, and Black Rivers, Bayou De View, and Big Creek. It empties into the Mississippi River 357 miles downstream of the Ohio River and 600 miles upstream of Head of Passes, Louisiana.

2.2.6. Arkansas River Basin. The Arkansas River rises in the Rocky Mountains near Leadville, Colorado, and flows southeastward for 1,459 miles through the states of Colorado, Kansas, Oklahoma, and Arkansas. Its major tributaries are the North Canadian, Canadian, Cimarron, Salt Fork, Verdigris, and Grand Rivers. The entire basin includes a total of 160,645 square miles of area and joins the Mississippi River at a point about 582 miles above Head of Passes, Louisiana.

2.2.7. Yazoo River Basin. The Yazoo River Basin covers an area of 13,355 square miles and occupies approximately the northwest quarter of the state of Mississippi. The western boundary of the area is formed by the east bank Mississippi River levee to the vicinity of Vicksburg, Mississippi, where the boundary becomes the east top bank of the Mississippi River. The area is bordered on the north by the divides of the Wolf and Hatchie River Basins. The divides of the Tombigbee and Big Black River Basins form the eastern and southern boundaries, respectively.

The physical characteristics of the basin divide it into two distinct areas, usually referred to as the Delta and Hill sections. The delta section lies in the alluvial valley of the Mississippi River and occupies the western half of the basin. The terrain of this area is relatively flat, with an average slope from north to south of 0.5 foot per mile. The hill section lies in the eastern half of the basin and has topography varying from gently rolling to rugged hills. Elevations in this section range from 100 feet, NGVD, near Yazoo City, Mississippi, to over 600 feet on the highest hills in the basin's northeast corner. The Yazoo River enters the Mississippi 437.2 miles above Head of Passes, Louisiana.

2.2.8. Big Black River Basin. The Big Black is located entirely in the state of Mississippi. The basin is 155 miles long and averages about 22 miles in width, thus constituting a long narrow basin with a total drainage area of approximately 3,400 square miles. It rises in Webster County and flows about 270 miles in a southwesterly direction to its confluence with the Mississippi River approximately 27 miles below Vicksburg and 408.5 miles above Head of Passes, Louisiana.

2.2.9. Red River Basin. The Red River rises in the high plains area of west Texas south of Amarillo, Texas. The river basin traverses an east-southeast directional pattern and drains portions of the states of New Mexico, Texas, Oklahoma, Arkansas and northern Louisiana, encompassing an approximate total of 67,600 square miles. A 3 to 5 miles wide alluvial valley characterizes that portion of the river above Alexandria, Louisiana. Below Alexandria, the river enters a backwater area (not to be confused with the Red River Backwater Project area).

2.2.10. Atchafalaya River Basin. The Atchafalaya River is formed at the confluence of the Red and Old Rivers. The joining of the Ouachita and Tensas Rivers forms the Black River, which joins the Red River at RM 34.0. The Atchafalaya River Basin is a complex system of guide levees and floodway levees. The drainage from the Red and Old Rivers enters the basin from the north, with the West Atchafalaya Basin Floodway lying parallel to and on the west side of the channel. The Morganza Floodway lies on the east side of the basin and is used to divert a portion of the flood flow of the Mississippi River through the Atchafalaya Basin to the Gulf of Mexico.

3. Drainage system. The main artery of the Lower Mississippi/Atchafalaya River model has its upstream boundary on the middle Mississippi River at Thebes, Illinois, at RM 43.7. The drainage area at Thebes is 713,200 square miles and includes approximately 143,000 square miles of the upper Mississippi River Basin above the confluence with the Illinois, approximately 29,000 square miles of the Illinois River Basin, and approximately 530,000 square miles of the Missouri River Basin. The main artery of the model has its downstream boundary on the lower Mississippi River at Venice, Louisiana, at RM 10.7, where the drainage area is 1,125,970 square miles. Major tributaries modeled include the lower 7 miles of the Ohio from Mound City, Illinois, at RM 973.0 to the mouth at RM 980.0, with total drainage area of approximately 204,000 square miles; the lower 10.0 miles of the St. Francis, from RM 10.0 to the mouth, with a total drainage area of approximately 8,500 square miles; the lower 10.0 miles of the White from Benzal, Arkansas, at RM 10.2 to the mouth, with a total drainage area of approximately 28,000 square miles; the lower 40.1 miles of the Arkansas, from Dam 2 at RM 40.1 to the mouth, with a total drainage area of 160,000 square miles; and the lower 16.7 miles of the Yazoo, from Redwood, Mississippi, at RM 16.7 to the mouth, with a total drainage area of 13,600 square miles. The model also includes portions of the Red and Black Rivers which combine to form the Atchafalaya River that runs southward and somewhat parallel to the Mississippi and empties into the Gulf of Mexico. This portion of the model has its upstream boundary on the Red River at Alexandria, Louisiana, at RM 104.9 with a drainage area of approximately 68,000 square miles. The model includes the lower 25.0 miles of the Black River from Jonesville L&D, Louisiana, at RM 25.0, with a drainage area of approximately 24,000 square miles, to the mouth, joining the Red at RM 37.1. The Old River Control Structures divert portion of the Mississippi River flow at RM 313.4. The flows from the Red and the Black combine with the Old River flow at just upstream of Simmesport, Louisiana, on the Atchafalaya River. The total drainage area of the model, including the Mississippi portion and the Atchafalaya portion, is approximately 1,246,000 square miles.

4. Key Locations – Gages. Table MVD-1 contains the list of stage and discharge gaging stations within the modeled area. The river mile, drainage area, and the zero of the gage are shown for each gaging station. An "X" in the "DCP" column indicates that the gage is equipped with a Data Collection Platform (DCP) and that the stage data at that location is collected automatically via satellite. An "X" in the "Q-Meas" column indicates that discharge measurements are taken (at varying frequencies) and daily discharges computed, unless otherwise noted, at that station.

Table MVD-1. Stream Gages

Stream	Station	RM	DA	Zero	DCP	Q-Meas
Mississippi	Thebes	43.7	713,200	300.00	X	X
Mississippi	Commerce	39.5	713,269	301.83	X	
Mississippi	Price Landing	28.2	713,308	299.75	X	
Mississippi	Thompson Landing	20.2	713,348	280.00	X	
Mississippi	Birds Point	2.0	713,397	274.53	X	
Mississippi	Cairo	953.8	713,400	270.47	X	
Mississippi	Wickliffe	951.5	917,400	269.12		
Mississippi	Columbus	937.2	917,900	266.38		
Mississippi	Hickman	922.0	918,500	264.73	X	X
Mississippi	Phillippy	905.7		254.71		
Mississippi	New Madrid	889.0	919,200	255.48	X	
Mississippi	Tiptonville	872.4		245.14	X	
Mississippi	Caruthersville	846.4	919,400	235.49	X	
Mississippi	Cottonwood Point	832.7	919,500	230.18		
Mississippi	Mouth of Obion	819.1	924,000	218.33		
Mississippi	Osceola	783.5		209.43	X	
Mississippi	Fulton	778.2	924,300	208.61		
Mississippi	Richardsons	769.0		205.35		
Mississippi	Mouth of Sycamore Chute	740.5	927,900	181.92		
Mississippi	Memphis (C of E)	735.9	928,700	183.91	X	X
Mississippi	Memphis (W.B.)	734.7	928,700	183.91		
Mississippi	Hulbert	727.6		180.09		
Mississippi	Memphis (Tenn Chute)	725.6		178.05		
Mississippi	Memphis (Ensley)	725.6		178.05		
Mississippi	Star Landing	707.4		168.38		
Mississippi	Mhoon Landing	687.5	929,200	161.22		
Mississippi	Helena	663.1	937,700	141.70	X	X
Mississippi	Friar Point	652.5	937,700	138.62		
Mississippi	Fair Landing	632.5	937,800	132.20		
Mississippi	Rosedale	592.1	965,800	108.33		
Mississippi	Arkansas City	554.1	1,104,360	96.66	X	X
Mississippi	Greenville	531.1	1,104,460	74.92	X	
Mississippi	Lake Providence	487.2	1,104,560	69.71		
Mississippi	Vicksburg (canal)	437.6	1,118,060	46.23		
Mississippi	Vicksburg	435.7	1,118,160	46.23	X	X
Mississippi	St. Joseph	396.4	1,122,660	33.12		
Mississippi	Natchez	363.3	1,123,160	17.28	X	X
Old	Inflow Channel	314.6	1,124,700	0.00	X	
Old	Outflow Channel	314.6	1,124,700	0.00	X	X
Mississippi	Knox Landing	313.7	1,124,700	0.00	X	

Mississippi	Tarbert Landing	306.3	1,124,900	0.00		X
Mississippi	Red River Landing	302.4	1,125,000	0.00	X	
Mississippi	Bayou Sara	265.4	1,125,400	0.00		
Mississippi	Baton Rouge	228.4	1,125,810	0.00	X	
Mississippi	Donaldsonville	175.4	1,125,860	0.00		
Mississippi	College Point	157.4	1,125,870	0.00		
Mississippi	Reserve	138.7	1,125,880	0.00	X	
Mississippi	Bonnet Carre	128.0	1,125,890	0.00	X	
Mississippi	New Orleans	102.8	1,125,910	0.00	X	
Mississippi	Harvey Lock	98.3	1,125,920	0.00		
Mississippi	IHNC Lock	92.7	1,125,920	0.00		
Mississippi	Chalmette	91.0	1,125,920	0.00		
Mississippi	Algiers Lock	88.3	N/A	0.00		
Mississippi	Braithwaite	76.6	N/A	0.00		
Mississippi	Alliance	62.5	N/A	0.00		
Mississippi	W Pt A La Hache	48.7	1,125,940	0.00		
Mississippi	Port Sulphur	39.3	N/A	0.00		
Mississippi	Empire	29.5	1,125,960	0.00		
Mississippi	Venice	10.7	1,125,965	0.00	X	
Mississippi	Head of Passes	-0.6	1,125,970	0.00		
Red	Alexandria	104.9	67,500	44.26	X	X
Red	L&D 2 HW	89.7	N/A	0.00	X	
Red	L&D 2 TW	89.3	N/A	0.00	X	X*
Red	Moncla	67.7	67,625	23.90	X	
Red	L&D 1 HW	43.5	N/A	0.00	X	
Red	L&D 1 TW	43.5	N/A	0.00	X	X*
Black	Jonesville L&D TW	25.0	24,200	0.00		
Black	Acme	0.1	24,237	0.00	X	X*
Atchafalaya	Barbre landing	N/A	N/A	0.00		
Atchafalaya	Simmesport	4.9	87,570	0.00	X	X
Atchafalaya	Melville	29.5	N/A	0.00	X	
Atchafalaya	Krotz Springs	41.3	N/A	0.00		
Atchafalaya	Butte La Rose	64.8	N/A	0.00		
Wax Lake Outlet	Calumet	111.4	N/A	0.00		
Lower Atchafalaya	Morgan City	117.7	N/A	0.00	X	
Lower Atchafalaya	Sweet Bay Lake	129.5	N/A	0.00		
Atchafalaya Bay	Eugene Island	N/A	N/A	0.00	X	

*Daily flows not computed

5. Key Locations - Structures. Table MVD-2 contains a list of floodways and diversion structures, as well as locks and dams, that are included in the model. A detailed description of each follows the table.

Table MVD-2. Floodways and Diversion Structures

Floodway/Structure	River Mile	Pool Elevation (Ft., NGVD)
Birds Point-New Madrid Floodway	953	N/A
Old River Control Structure	314	N/A
Morganza Control Structure and Floodway	280	N/A
Bonnet Carre Control Structure and Spillway	128	N/A
West Atchafalaya Floodway		N/A
Atchafalaya Basin Floodway		N/A
L&D 2, Red River Waterway	87.0	64.0
L&D 1, Red River Waterway	43.8	40.0
Jonesville L&D, Black River	25.0	34.0

5.1. Birds Point-New Madrid Floodway. This floodway is located immediately downstream from Cairo, Illinois, on the west bank of the Mississippi River. The floodway varies in width from 3 to 10 miles and has a length of about 33 miles. The floodway provides about 7 feet of stage lowering in the vicinity of Cairo during the project flood with smaller reductions above Cairo and through the floodway reach. The floodway is provided with fuseplug levees that are 10 miles long at the upper end and 5 miles long at the lower end. These fuseplug sections are designed to be artificially crevassed during flows approaching the magnitude of the project flood. The floodway was operated in 1937 by overtopping and natural crevassing of the fuseplug, followed by explosive crevasses made at selected locations. During the project flood, this floodway will carry 550,000 cfs. The fuseplug requires timely crevassing to ensure its design effect during a flood approaching project flood magnitude.

5.2. Old River Control Structures. The Old River Control Structures, consisting of a low sill structure and an overbank structure, were authorized in 1954 to prevent the Atchafalaya River from becoming the main stem of the Mississippi River and were completed in 1962. The Auxiliary Structure was added in 1986 and Sidney A. Murray, Jr., Hydroelectric Station in 1990. The structures were designed to duplicate, as near as practicable, the diversion of flow and sediment from the main stem under 1950 conditions, which was determined to be approximately 30 percent of the total latitude flow (combined flow in the Red River and Mississippi River above the control structures) passing down the Atchafalaya River on an annual basis. Since its completion, the Overbank Structure has passed flows in 1973, 1974, 1975, and 1983. During the project flood, the total design flow through the structures is 620,000 cfs. Ten miles south of Old River, a navigation channel and lock were constructed to provide for navigation between the Mississippi River and the Atchafalaya and Red Rivers.

5.3. Morganza Floodway. About 29 miles south of Old River, the flood control plan provides for a major diversion of flow from the main stem into the Atchafalaya Basin through the Morganza Floodway. It was designed to divert 600,000 cfs from the Mississippi River through a control structure that is 3,900 feet long and containing 125 bays. It can be operated either before or after Bonnet Carre to prevent the flow passing New Orleans, Louisiana, from exceeding 1,250,000 cfs. The floodway was used only once, in 1973.

5.4. Bonnet Carre Spillway. About 30 miles above New Orleans, the Bonnet Carre Spillway diverts excess floodwaters from the Mississippi River into Lake Pontchartrain. It has a design capacity of 250,000 cfs and is operated to keep the main stem flow below the floodway from exceeding 1,250,000 cfs, which is the safe carrying capacity of the Mississippi River at New Orleans, Louisiana. The structure is about 7,000 feet long and contains 350 bays. The Bonnet Carre Spillway was operated in 1937, 1945, 1950, 1973, 1975, 1983, and 1997.

5.5. West Atchafalaya Floodway. The West Atchafalaya Floodway extends along the west side of the Atchafalaya River. A 7.9-mile fuseplug section of the levee is located at the head of the floodway, while the lower end discharges into the Atchafalaya Basin Floodway near the latitude of Krotz Springs, Louisiana. The West Atchafalaya Floodway is a highly developed agricultural area. The floodway is placed into operation when a fuseplug section is overtopped or when the levee along the west bank of the Atchafalaya River is overtopped. During the project flood, the floodway is designed to pass a maximum of about 250,000 cfs. This floodway would be the last feature of the flood control system to be used during a project flood and has never been used.

5.6. Atchafalaya Basin Floodway. The Atchafalaya Basin Floodway is formed near the latitude of Krotz Springs, Louisiana, with the combining of the Atchafalaya River, the Morganza Floodway, and the West Atchafalaya Floodway. Roughly 63 miles in length and 15 miles in width, the floodway empties into the Gulf of Mexico through Wax Lake Outlet and the Lower Atchafalaya River. During the project flood, the floodway will pass 1,500,000 cfs.

5.7. Lock and Dam No. 2, Red River Waterway. Located on the Red River at RM 87.0, this 84-foot-by-685-foot lock with a 348-foot wide dam maintains a normal pool of 64.0 feet to provide a 9-foot navigation. Open river navigation begins at a flow of 95,000 cfs.

5.8. Lock and Dam No.1, Red River Waterway. Located on the Red River at RM 43.8, this 84-foot-by-685-foot lock with a 630-foot wide dam maintains a normal pool of 40.0 feet to provide a 9-foot navigation. Open river navigation begins at a flow of 72,000 cfs.

5.9. Jonesville Lock and Dam, Black River. Located on the Black River at RM 25.0, this 84-foot-by-600-foot lock with 282-foot wide dam maintains a normal pool of 34.0 feet to provide a 9-foot navigation. Open river navigation begins at a flow of 62,000 cfs.

6. Digital Terrain Data. The Mississippi Valley Division office and its development of the MBMS model did not involve data acquisition under a mapping contract. Memphis, Vicksburg, and New Orleans Districts developed the cross sections used in this model for their respective reaches of the Mississippi, Red, and Atchafalaya Rivers and tributaries for their own use in backwater computations. Most of the geometric data contained in the Lower Mississippi/Atchafalaya River model were obtained from the 1992 hydrographic survey.

7. Calibration Procedure.

7.1. Data Assemblage. The forecasting model was tailored to make the maximum use of the tributary forecast inflows generated and furnished daily to this office by the Lower Mississippi River Forecast Center (LMRFC) in Slidell, Louisiana. Table 3 below contains the list of 47 locations at which 6-hour observed and forecast flow values are furnished by the LMRFC in SHEF-coded format. At this time, flows at 13 of the 47 locations are being used in the Lower Mississippi/Atchafalaya River MBMS model, as indicated in the last column of Table 3. Flows at additional locations will be added to the forecast model as the model is expanded in the future. The LMRFC began furnishing the data to this office in early 1997. Since the LMRFC did not archive their flow data, the historical flow data for the locations shown in Table MVD-3 (as computed by the LMRFC) is only available since 28 January 1997.

Table MVD-3. Forecast Flows Furnished by LMRFC

ID	Stream	Location	Used in the MBMS Model?
MURI2	Big Muddy	Murphysboro	
CPGM7LCL	Mississippi	Cape Girardeau Local	
PAHK2LCL	Ohio	Paducah Local	
CIRI2LCL	Ohio	Cairo Local	
9WCKLCL	Mississippi	Wickliffe Local	Yes
NMDM7LCL	Mississippi	New Madrid Local	Yes
BOGT1	Obion	Bogota Flow	
DYET1	NF Forked Deer	Dyersburg Flow	
HLST1	SF Forked Deer	Halls Flow	
9OBT1TLI	Mississippi	Obion Total Inflow	Yes
RLTT1	Hatchie	Rialto Flow	
GERT1	Wolf	Germantown	
MEMT1TLI	Mississippi	Memphis Total Inflow	Yes
MSNA4	St. Francis	Madison Flow	
HEEA4TLI	Mississippi	Helena Total Inflow	Yes
CLDA4	White	Clarendon Flow	Yes
9RDA4TLI	Mississippi	Rosedale Total Inflow	Yes
ARSA4LCL	Mississippi	Arkansas City Local	Yes
YZOM6	Yazoo	Yazoo City Flow	
ANGM6	Big Sunflower	Anguilla Flow	
VCKM6TLI	Mississippi	Vicksburg Total Inflow	Yes
BOVM6	Big Black	Bovina Flow	
NTZM6TLI	Mississippi	Natchez Total Inflow	Yes
RSAM6	Homochitto	Rosetta Flow	
RRLL1TLI	Mississippi	Red River Ldg Total Inflow	
BTRL1LCL	Mississippi	Baton Rouge Local	Yes
AEXL1	Red	Alexandria Flow	Yes
JNEL1	Black	Jonesville Flow	Yes
BRKI2	Ohio	Computed L&D 52 Flow	
THBI2	Mississippi	Thebes Flow	
9WCK2	Mississippi	Computed Wickliffe Flow	
FLTA4	Red	Fulton Flow	
TXTT2	Sulphur	Wright Patman Flow	
SBFA4TLI	Red	Spring Bank Total Inflow	

DIXL1	12-Mile Bayou	Dixie Flow	
CRLL1	Cross lake below Dam	Cross Lake Flow	
SVPL1TLI	Red	Shreveport Total Inflow	
LBUL1	Bayou Dorcheat	Lake Bistineau Flow	
SLGL1	Red Chute Bayou	Sligo Flow	
CSHL1TLI	Red	Coushatta Total Inflow	
LENL1	Bayou Pierre	Lake End	
GRETLI	Red	Grand Ecore Total Inflow	
9SLL1	Saline Bayou	Saline Lake Dam Flow	
9CLL1	Black Lake Bayou	Clarence Flow	
AEXTLI	Red	Alexandria Total Inflow	
RRBL1TLI	Red	L&D 2 Total Inflow	
RRAL1TLI	Red	L&D 1 Total Inflow	
JACM6LCL	Pearl	Jackson Local Flow	

7.2. Flow Accounting. Flow measurements are taken at 13 locations within the modeled area, as listed in Table MVD-4. Frequency of measurements varies by location, ranging from once per month at several of the locations to as often as twice per week at Simmesport, Louisiana. At most of these locations, with the exceptions being L&D 2, L&D 1, and Delhoste on the Red River, daily flows are computed by the respective District offices and published in their annual gage book publications.

Table MVD-4. Discharge Gaging Stations

Stream	Station	River Mile	Approximate Frequency of Measurement
Mississippi	Thebes	43.7	2 per month
Mississippi	Hickman	922.0	2 per month
Mississippi	Memphis	734.4	2 per month
Mississippi	Helena	663.1	1 per month
Mississippi	Arkansas City	554.1	3 per month
Mississippi	Vicksburg	435.7	7 per month
Mississippi	Natchez	363.3	3 per month
Mississippi	Red River Landing	302.4	6 per month
Red	Alexandria	104.9	2 per month
Red	L&D 2	89.3	1 per month
Red	L&D 1	43.5	1 per month
Red	Delhoste	33.4	1 per month
Atchafalaya	Simmesport	4.9	2 per week

One of the steps in the calibration process was to force the model to replicate the daily flows computed by the Districts for the 8 of the 13 gaging stations (non-boundary stations where daily flows are computed by the Districts) for the calibration year 2000. This was accomplished by first routing the flows at the 4 upstream boundary locations – Mississippi River at Thebes, Illinois; Ohio River at Mound City, Illinois; Red River at Alexandria, Louisiana; and Black River at Jonesville, Louisiana – plus tributary flows at 13 locations furnished by the LMRFC, as discussed in Section 7.1, through the model, and then sequentially (from upstream to downstream) computing the difference between the published flow and the routed flow and introducing the differential flow hydrograph into the model at a cross-section immediately upstream of the discharge gaging station as a point-source inflow. Subsequent model run with the differential flow, then, would produce a routed hydrograph nearly identical to the published flow at that particular location. The first location at which this corrective differential flow was computed and introduced into the model was at Hickman. The process was repeated 7 more times, moving in the downstream location one discharge gaging station at a time, to compute the corrective differential flows at Memphis, Helena, Arkansas City, Vicksburg, Natchez, Red River Landing, and Simmesport.

7.3. Base Calibration. For the base calibration, the model was calibrated to reproduce rating curves at principal gaging stations along the Mississippi, Red, and Atchafalaya Rivers for the calendar year 2000. Average rating curves for the calendar year 1997 were entered at the 13 discharge-gaging stations as the initial estimates of rating curves at those locations. The RATINGC program was used to develop the best-fit average rating curves at each gaging station from discharge measurements and the corresponding observed stages. These rating curves are referenced in the KR cards in the cross-section (CS) file, which is the input file for the geometry program. The geometry program adjusts the conveyance of the cross-sections between the gaging stations so that the rating curve at the upstream station is approximately reproduced by backwater calculations.

To calibrate the Lower Mississippi/Atchafalaya River System model, the following procedure was used:

1) Estimate rating curves at all discharge-rating stations within the model boundaries, as listed in Table MVD-3, for calendar year 1997. Figure MVD-2 shows the 1997 rating curve and the scatter diagram at Vicksburg as an example.

2) Estimate rating curves at the dams from stages and measured flows for calendar year 1997. Figure MVD-3 shows the rating curve and the scatter diagram at Red River Waterway L&D 1.

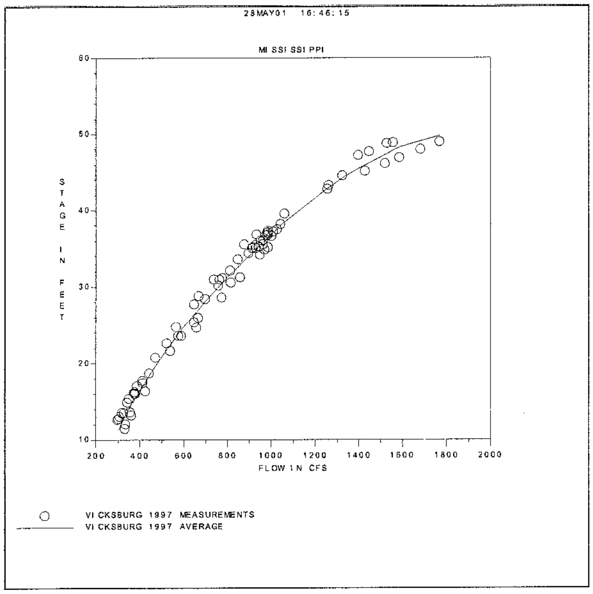


Figure MVD-2. 1997 Vicksburg Rating Curve

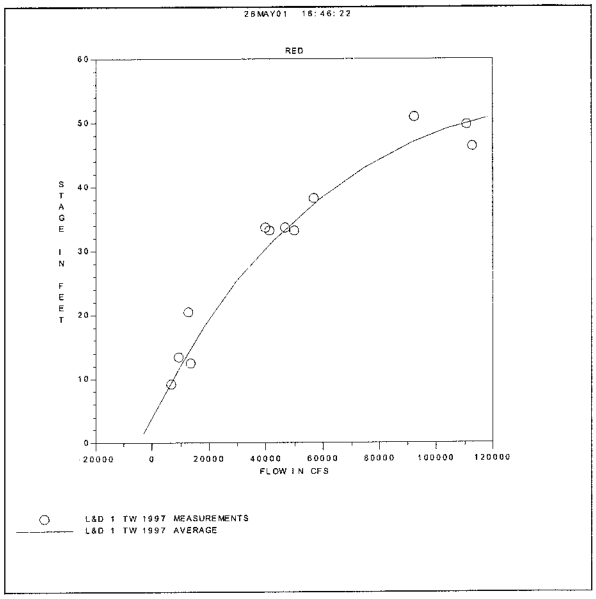


Figure MVD-3. 1997 L&D 1 Rating Curve

3) Simulate calendar year 2000.

4) Adjust the rating curves Thebes, Hickman, Memphis, Helena, Arkansas City, Vicksburg, Natchez, Red River Landing, Alexandria, Simmesport, L&D 2, and L&D 1 to reproduce the 2000 observed stages at these locations.

5) Estimate rating curves for other interior stream gages using routed flows and 2000 observed daily stages.

6) Simulate calendar year 2000.

7) Adjust the rating curves to achieve a better fit of observed stages.

8) Repeat steps 6 and 7 until 2000 observed stages are satisfactorily replicated at all gaging stations.

7.4. Fine Tuning. To fine-tune the system, the model reaches were partitioned into sub-reaches with each sub-reach containing a table of discharge versus conveyance change factors. A conveyance change factor for discharge Qi is

$$F_i = \frac{K_{new}}{K_{old}}$$

where: F_i = conveyance change factor for discharge i.
K_{new} = new conveyance value.
K_{old} = old conveyance value.

If the river discharge is Q_i, the conveyance property is multiplied by F_i, thereby adjusting the calibration of the model.

7.5. Seasonal Conveyance Correction Factor. Seasonal Conveyance Correction Factors were used to account for seasonal variation in conveyance characteristics. The seasonal variation in water temperature has a significant impact on conveyance characteristics and, hence, on stages along the Lower Mississippi and Atchafalaya Rivers. Figures MVD-4 and MVD-5 show plots of measured water temperatures in 1991 calendar year at Memphis, Tennessee, and at Helena, Arkansas, gages on the Mississippi River, while Figures MVD-6 and MVD-7 show similar plots for 1993.

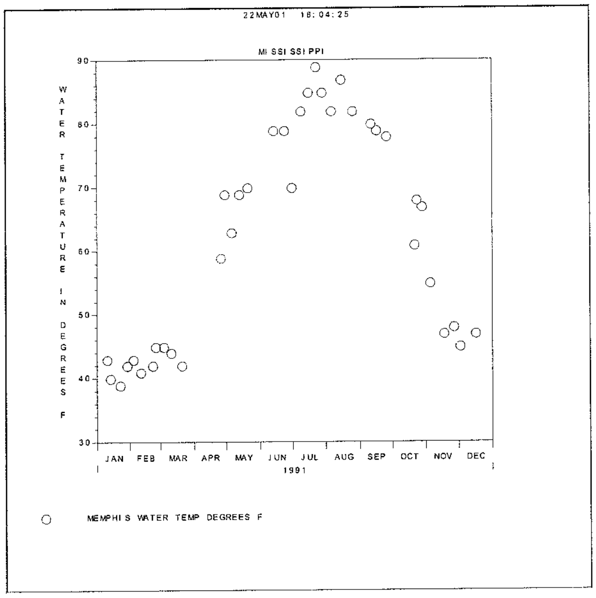


Figure MVD-4. 1991 Water Temperature at Memphis

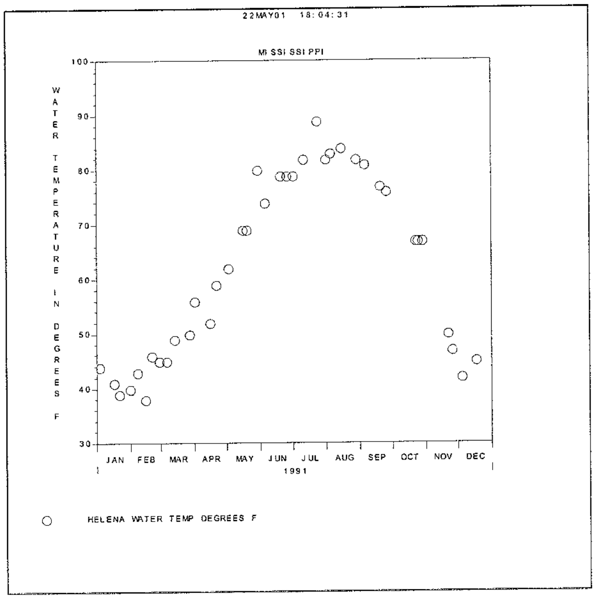


Figure MVD-5. 1991 Water Temperature at Helena

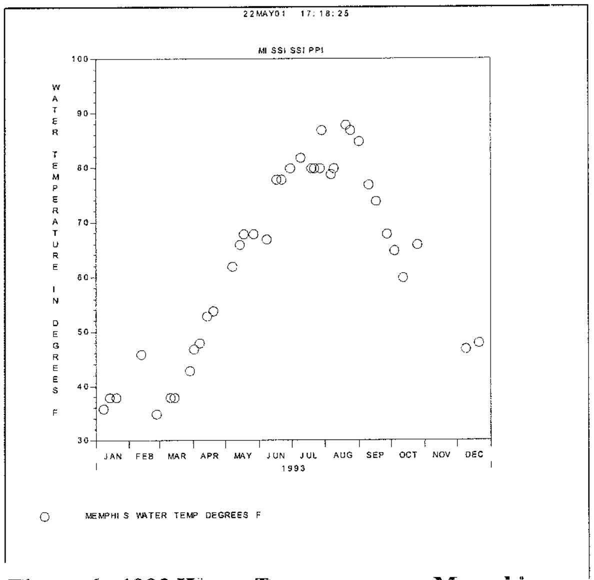


Figure MVD-6. 1993 Water Temperature at Memphis

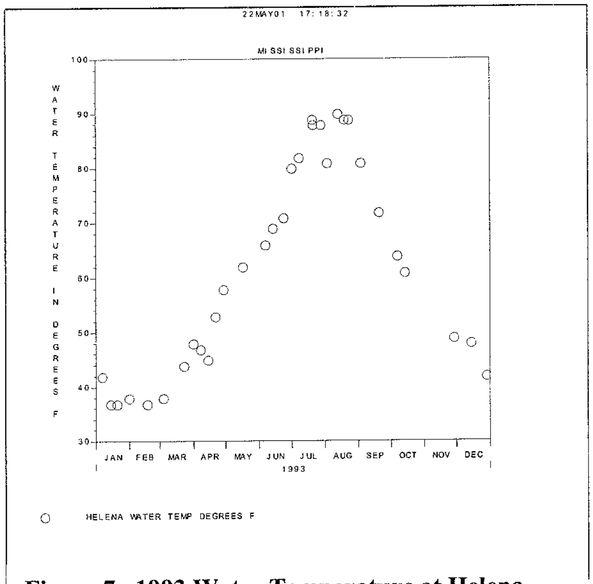


Figure 7. 1993 Water Temperature at Helena

Figure MVD-7. 1993 Water Temperature at Helena

consistent pattern from year to year. The seasonal change in water temperature impacts channel bed forms which in turn impacts the channel resistance to flow. Cold water tends to smooth the bed-forms and less resistance to flow. Therefore, during cold winter months, a given discharge will pass at a lower stage than during the warm summer months. Generally, it was found during the calibration process that a gradual 10 percent reduction in the summer conveyance factors from the winter conveyance factors yielded reasonable calibration results. Table MVD-5 contains typical seasonal conveyance adjustment factors used in the model, patterned to reflect the seasonal changes in water temperature shown on Figures MVD-4 through MVD-7.

Table MVD-5. Typical Seasonal Conveyance Change Factors

Date	Conveyance Change Factor
01Jan	1.00
15 Mar	1.00
01 Jul	0.90
01 Sep	0.90
31 Dec	1.00

A factor of 0.9 results in 10 percent less conveyance than a factor of 1.0, thereby yielding a higher stage at a given discharge.

7.6. Calibration Results. Plates 1 through 46 show results of the calibration at 46 gaging stations along the Mississippi, Red, Black, and Atchafalaya Rivers for the calendar year 2000. As the Atchafalaya River approaches the Gulf, portion of the flow enters the Gulf through the Wax Lake Outlet and the remaining flow enters the Gulf through the Lower Atchafalaya River past Morgan City, LA. Figure MVD-8 shows the approximate percentage of the Atchafalaya River flow that passes down the Lower Atchafalaya River. The conveyance factors of the Wax Lake Outlet and the Lower Atchafalaya River were adjusted during the calibration process to achieve the distribution ratio shown in Figure MVD-8.

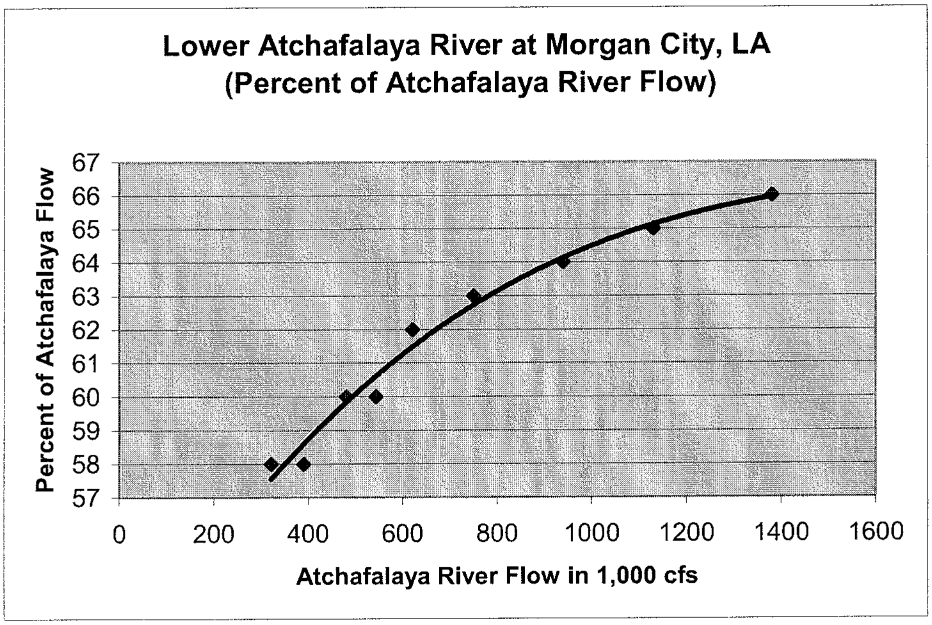


Figure MVD-8. Distribution of Atchafalaya River Flow

8. Operational Procedures and Experience.

The calibrated model of the Mississippi/Atchafalaya River system (cross section and boundary condition files) was transferred to the Sun workstation along with the master database containing all pertinent observed hydrologic data and the database containing rating curves. Pathnames imbedded in the cross section and boundary condition files were modified as necessary to accommodate workstation's file structure. Initial attempts to run the model through the MBMS interface failed due to some careless user errors. Some problems were related to file ownership and read/write/execute permission issues associated with some of the files. These errors, and the difficulties encountered in identifying the sources of these errors, point out the need for a user-friendly means of identifying for the user the possible/probable source of error as it occurs. The first successful near real-time run revealed a need for some minor adjustments in the calibration due to the fact that the model was calibrated to the calendar year 2000 event and the run was made in late August 2001.

One immediate concern was the quality of the real-time DCP data being reported during the past 2 or 3 weeks for the downstream model boundary on the Atchafalaya Bay at Eugene Island, LA, which were several feet higher than reasonable. That rendered the station useless as the downstream boundary; therefore, a constant stage of 1.0 foot is being specified for the entire routing period, for the time being, until the gage problem is rectified.

Another area of concern is the accuracy of the NWS supplied tributary inflows that drive the model to a great extent. That is not to say that the NWS inflows are suspected of being inaccurate, but no assessment has been made, thus far by this office, to evaluate whether or not there is a tendency for the inflows, once routed along the mainstem, to be either too high or too low as compared to the measured flows on the mainstem. At the moment, the model does not rely on the Null Internal Boundary option; however, its use will be considered after greater experience with the real-time use of the model.

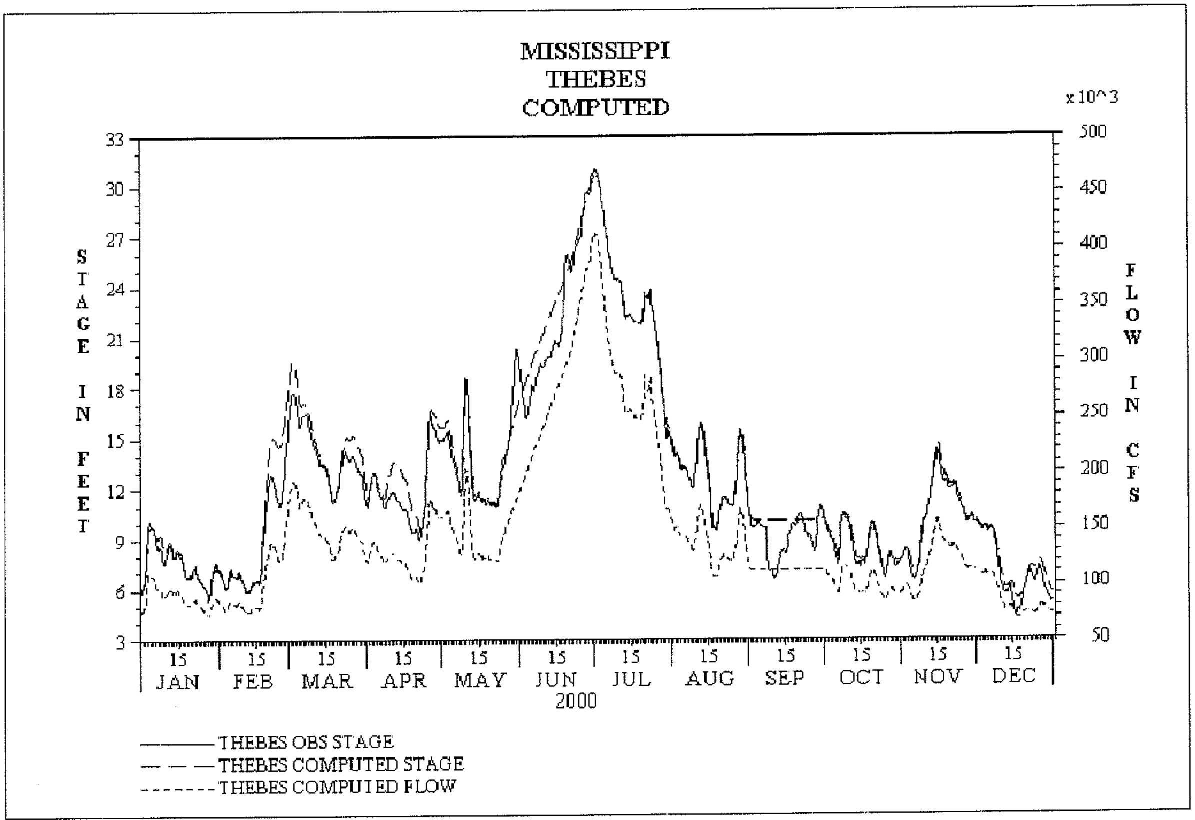


Plate 1. Mississippi River at Thebes, IL

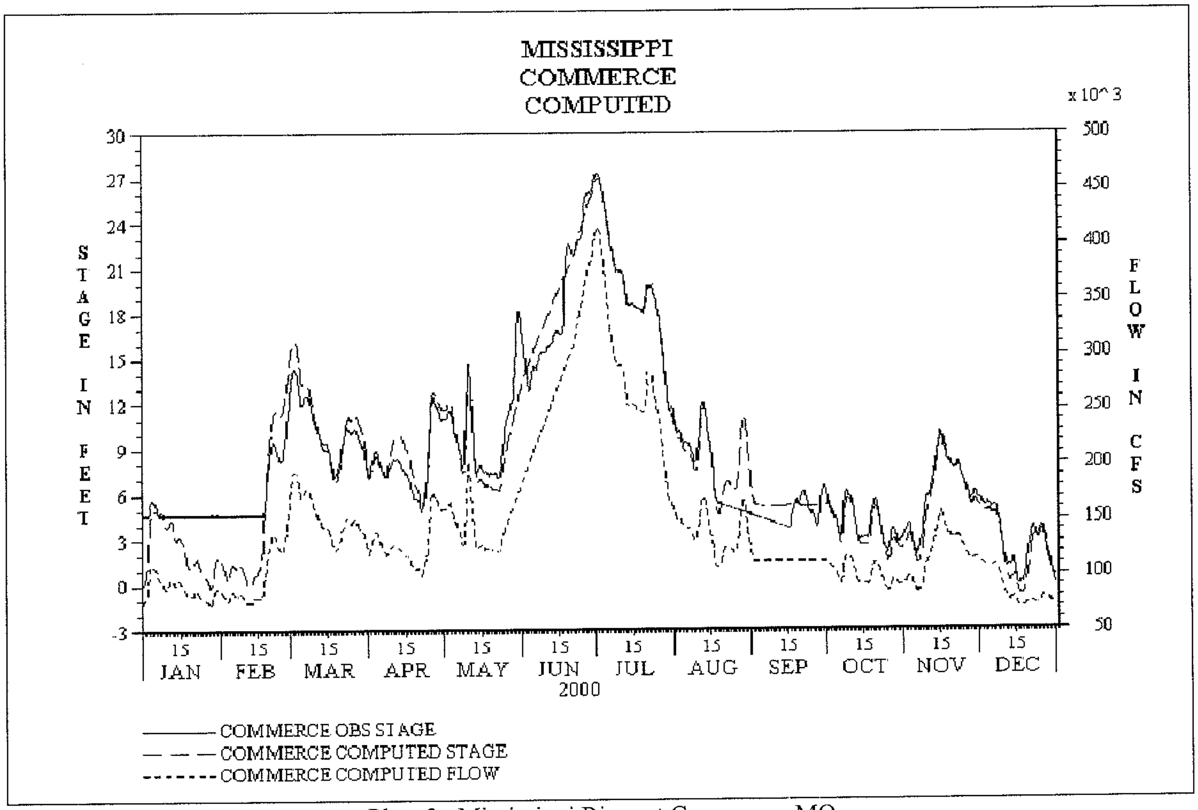


Plate 2. Mississippi River at Commerce, MO

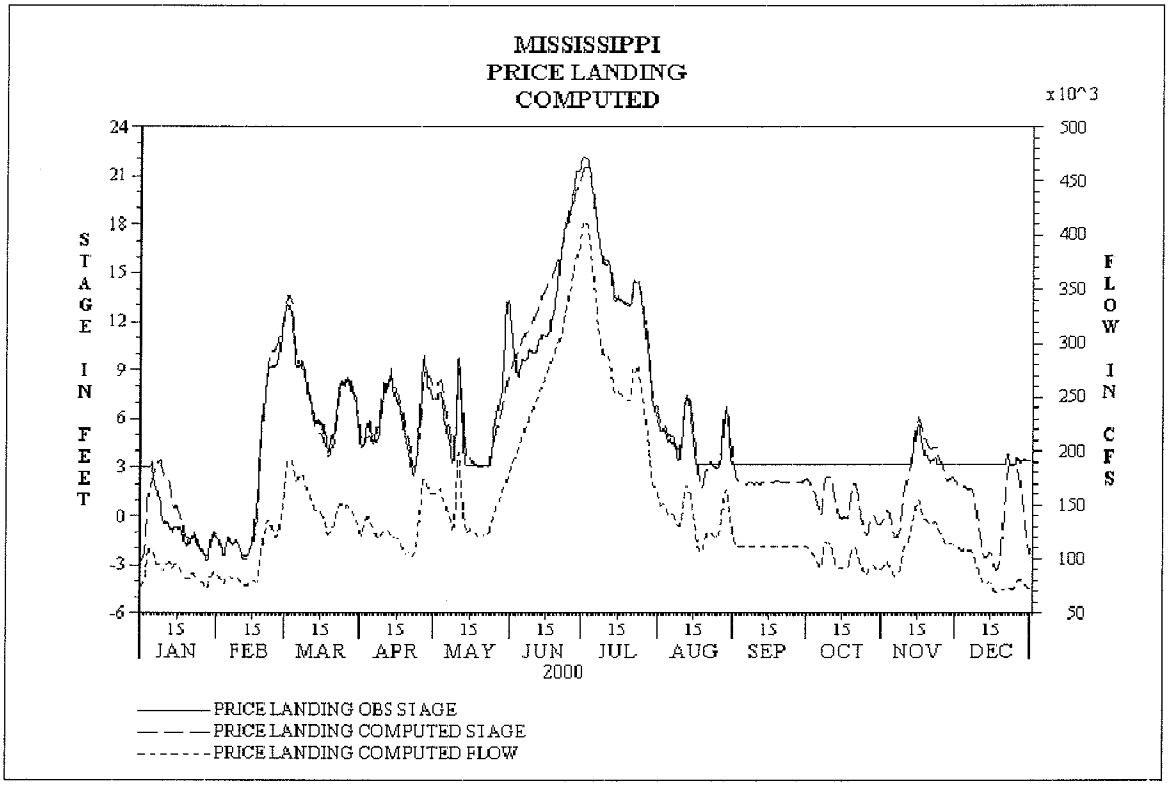


Plate 3. Mississippi River at Price Landing, MO

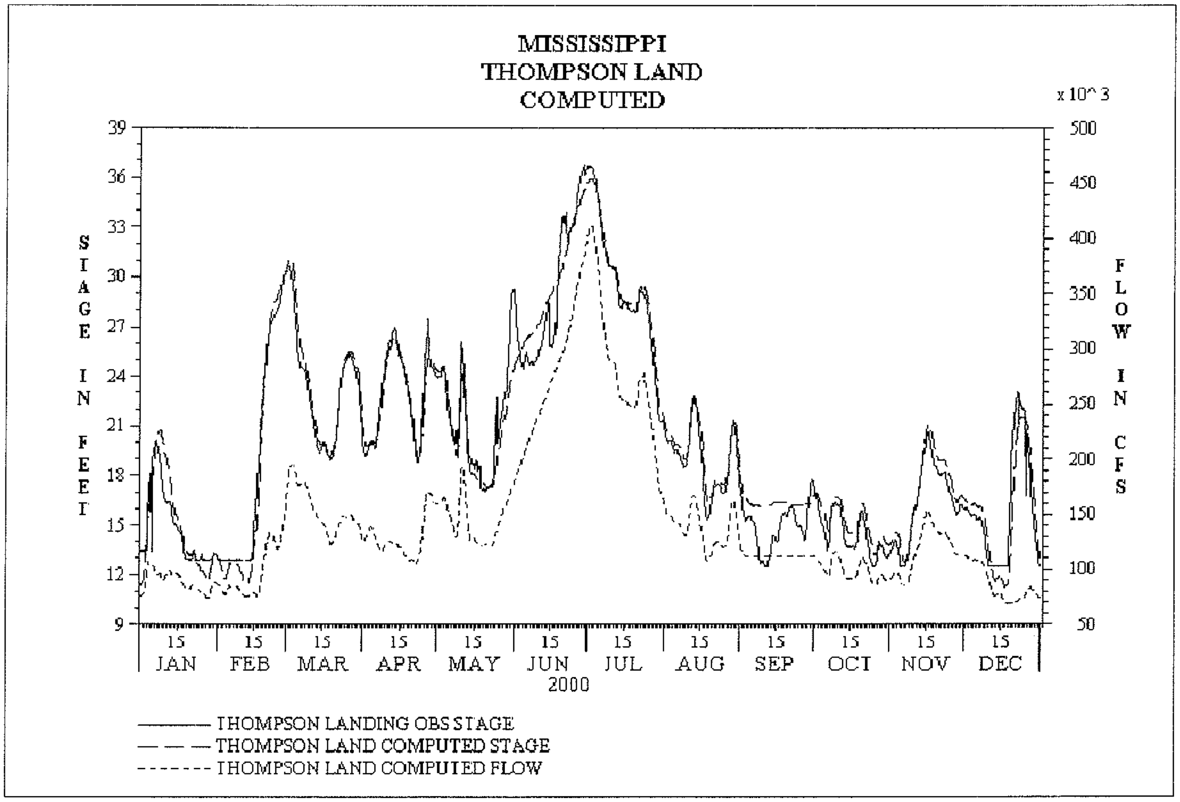


Plate 4 Mississippi River at Thompson, Landing, MO

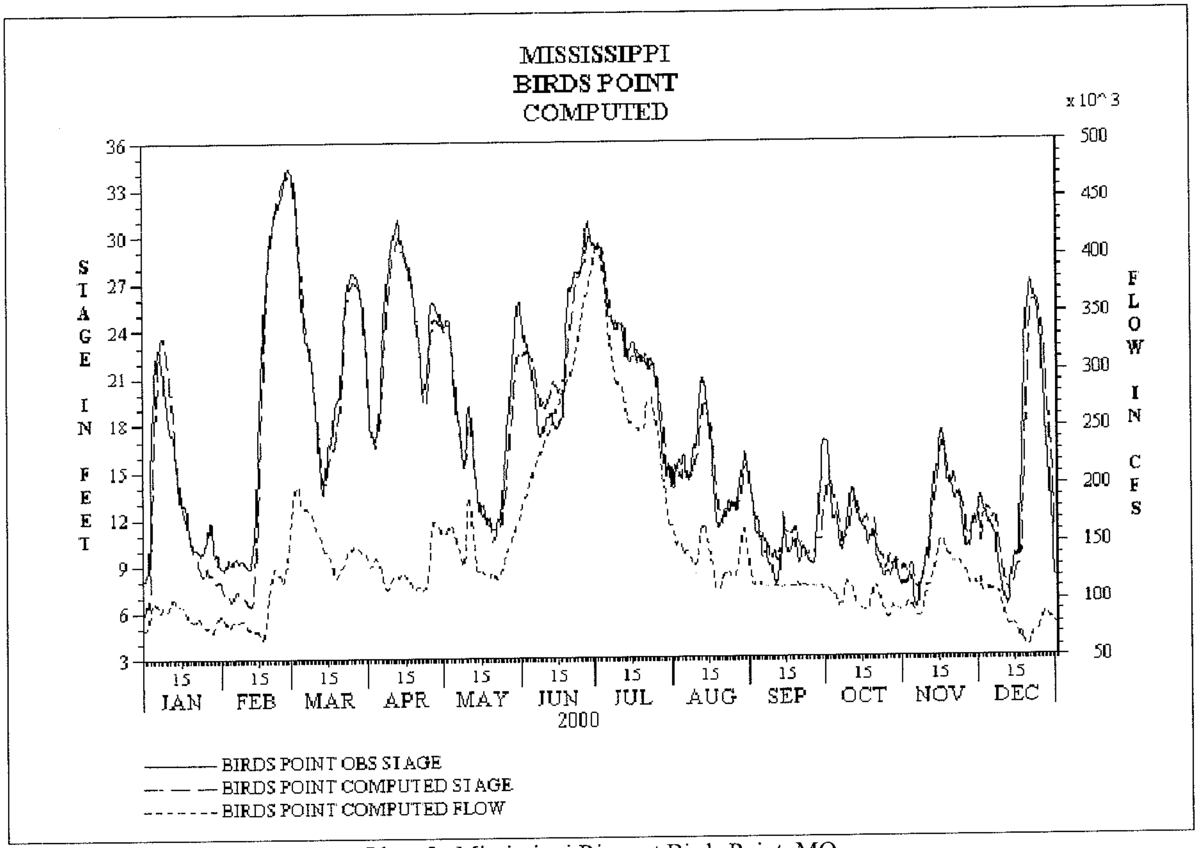


Plate 5 Mississippi River at Birds Point, MO

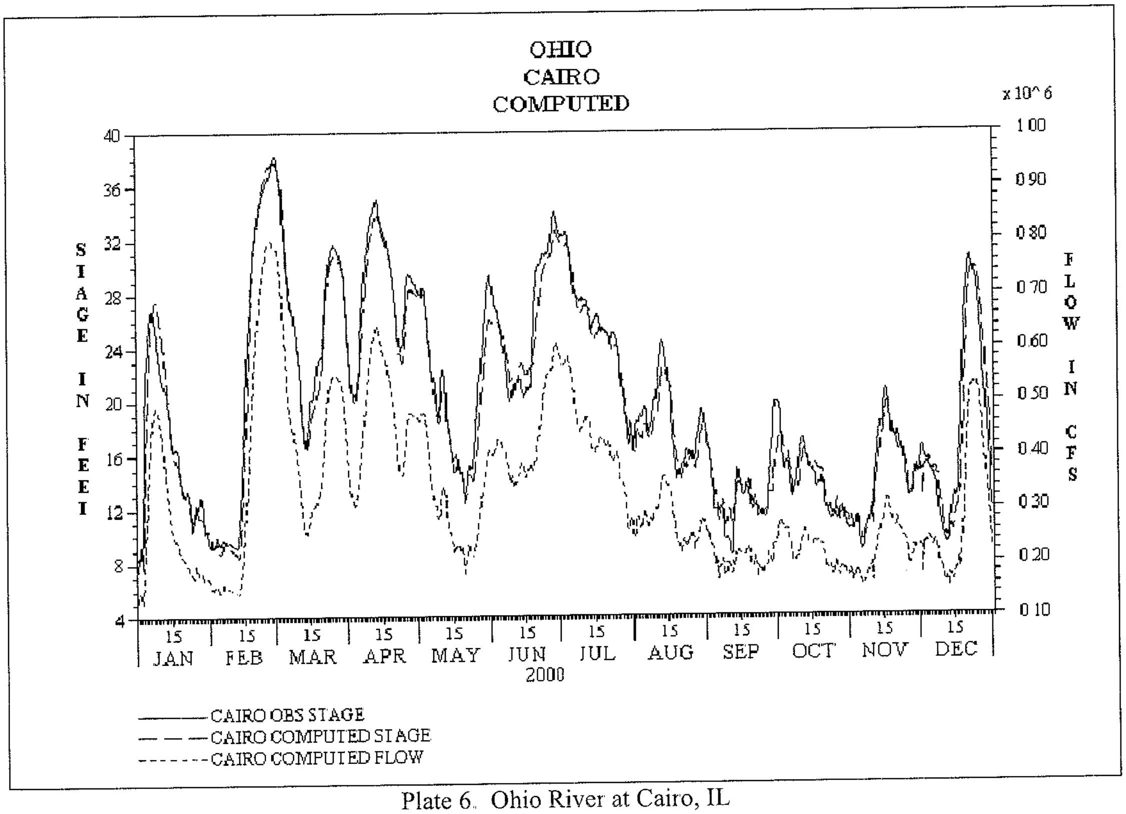


Plate 6. Ohio River at Cairo, IL

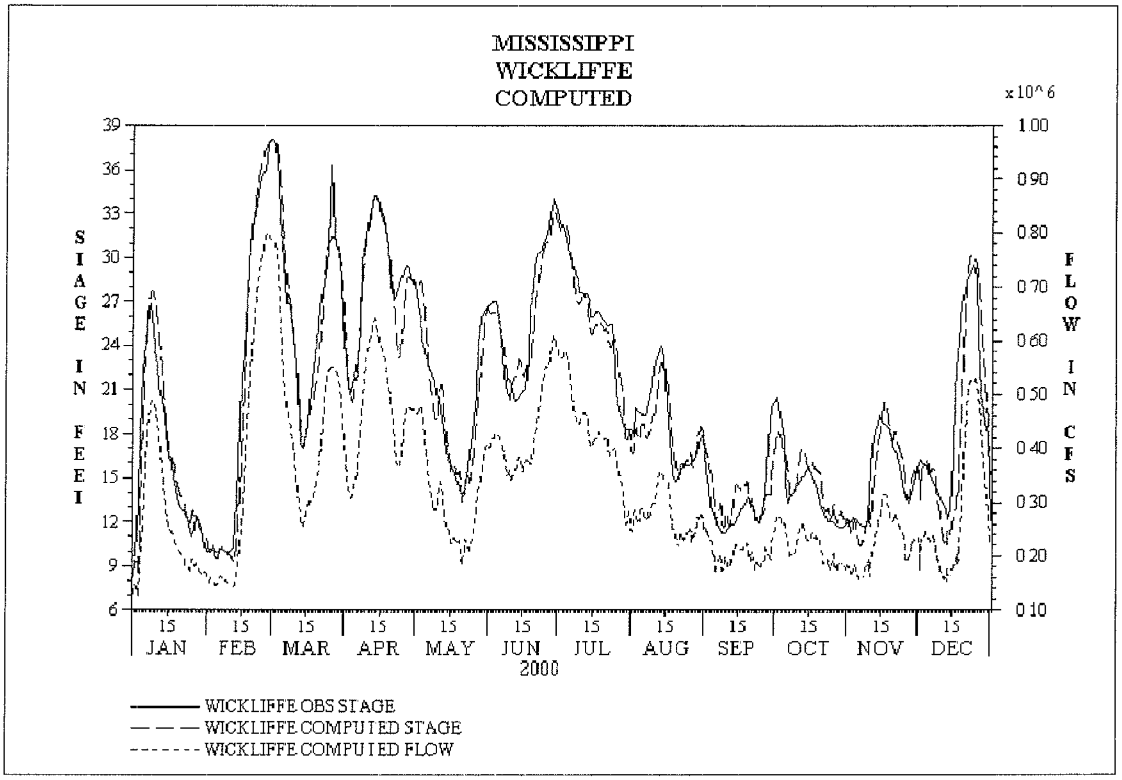


Plate 7. Mississippi River at Wickliffe, KY

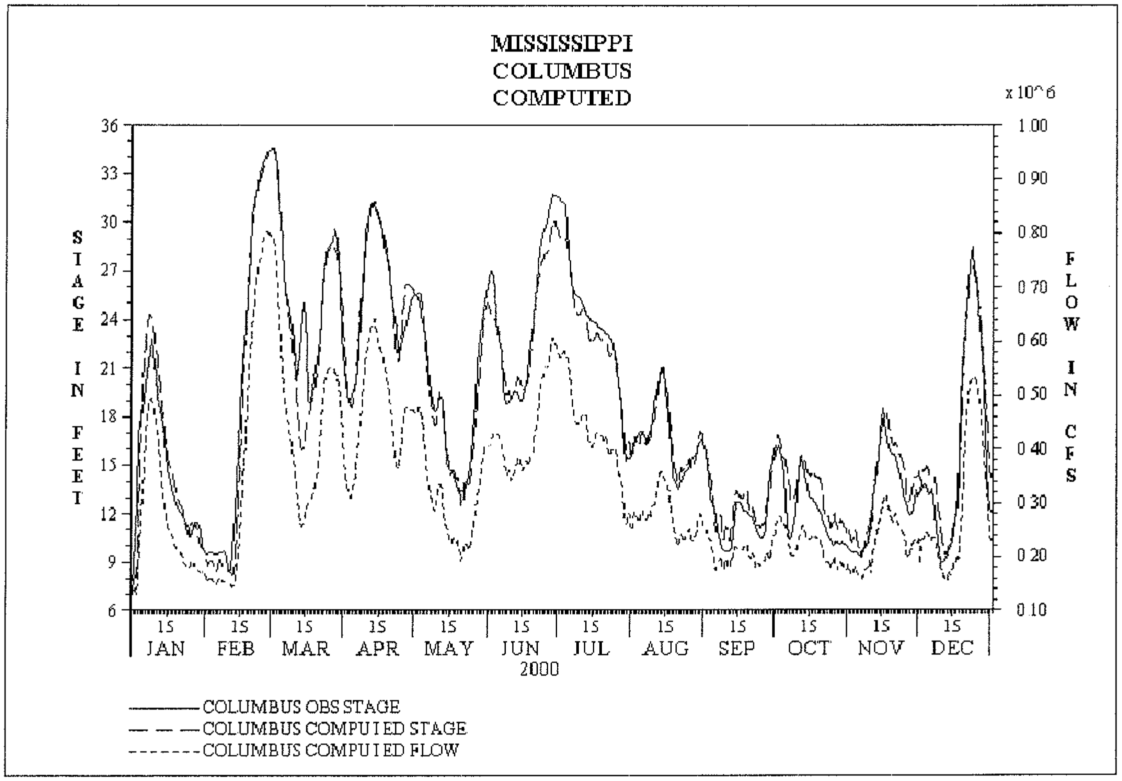


Plate 8. Mississippi River at Columbus, MO

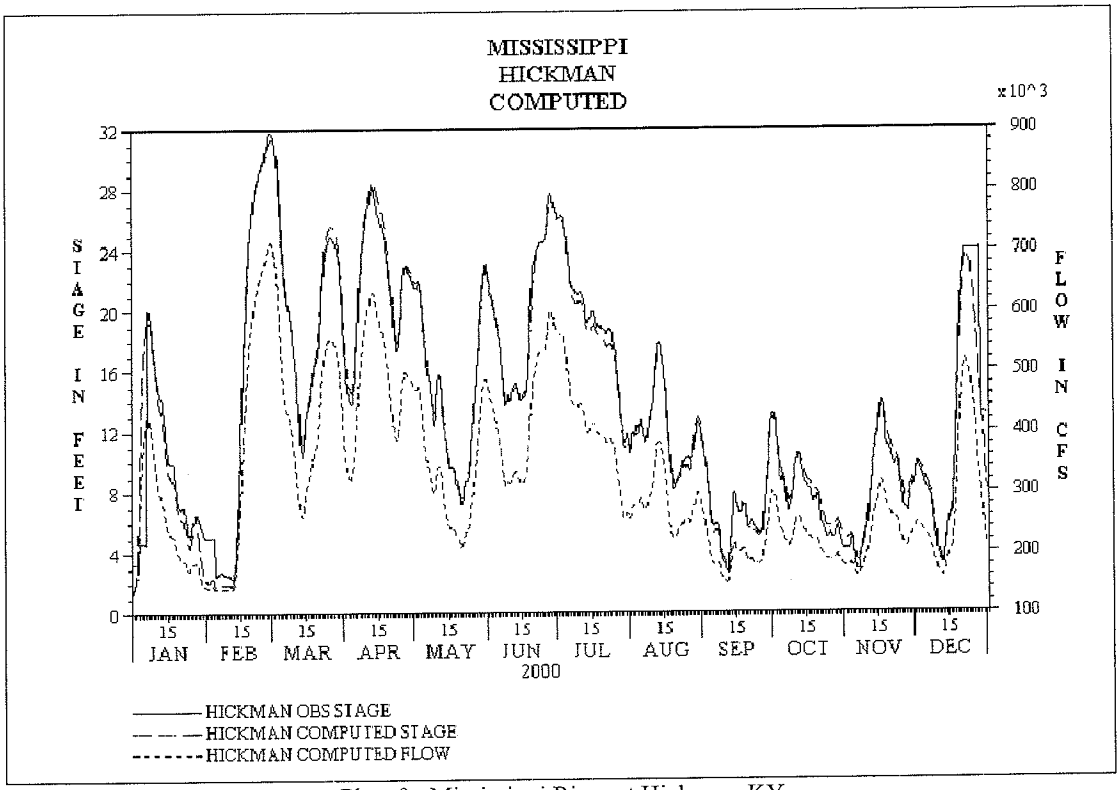


Plate 9. Mississippi River at Hickman, KY

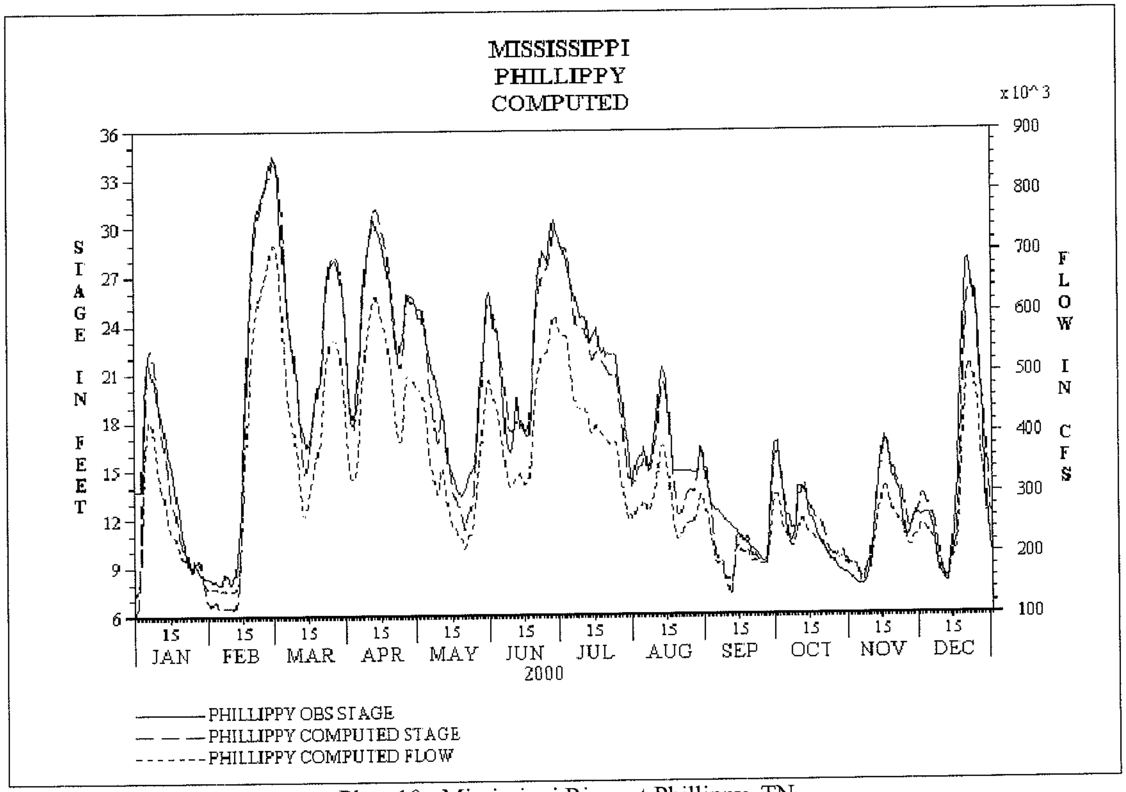


Plate 10. Mississippi River at Phillippy, TN

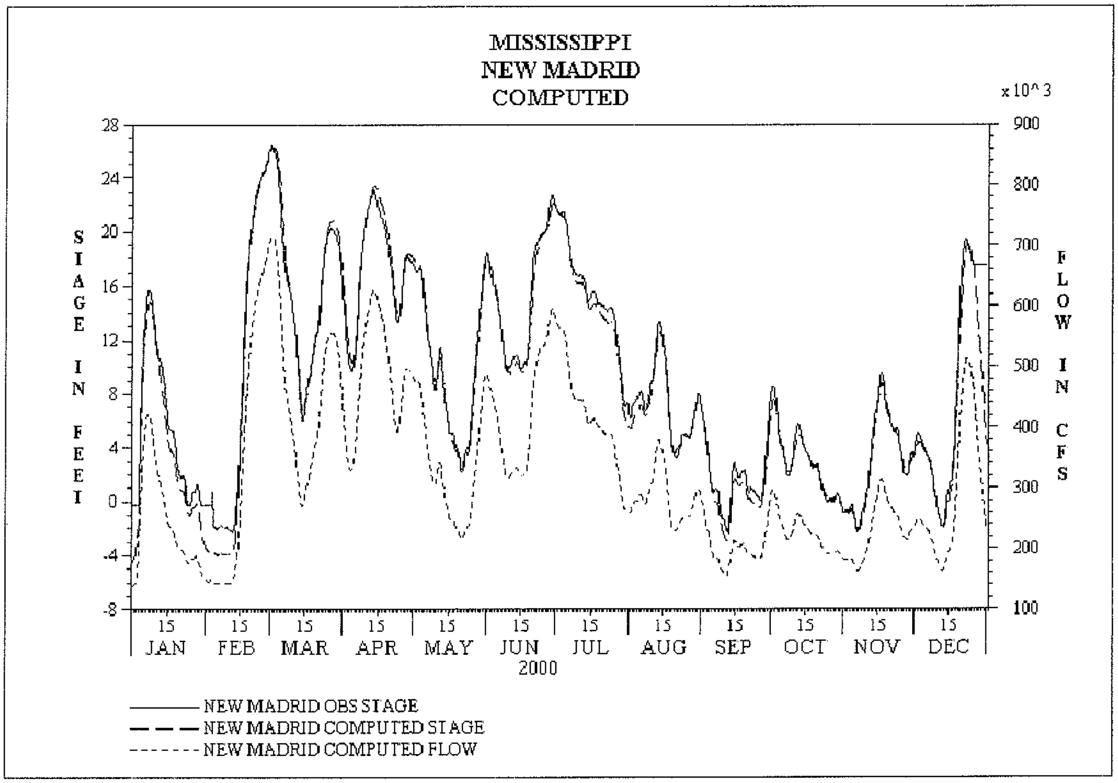


Plate 11. Mississippi River at New Madrid, MO

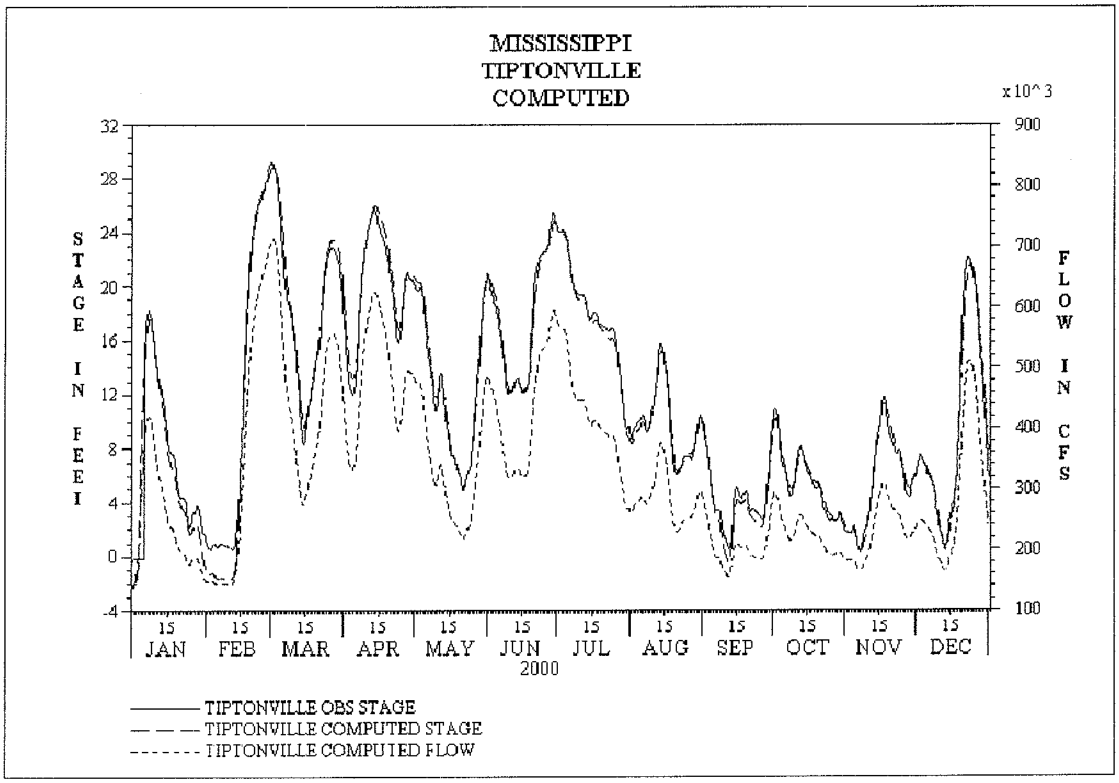


Plate 12. Mississippi River at Tiptonville, TN

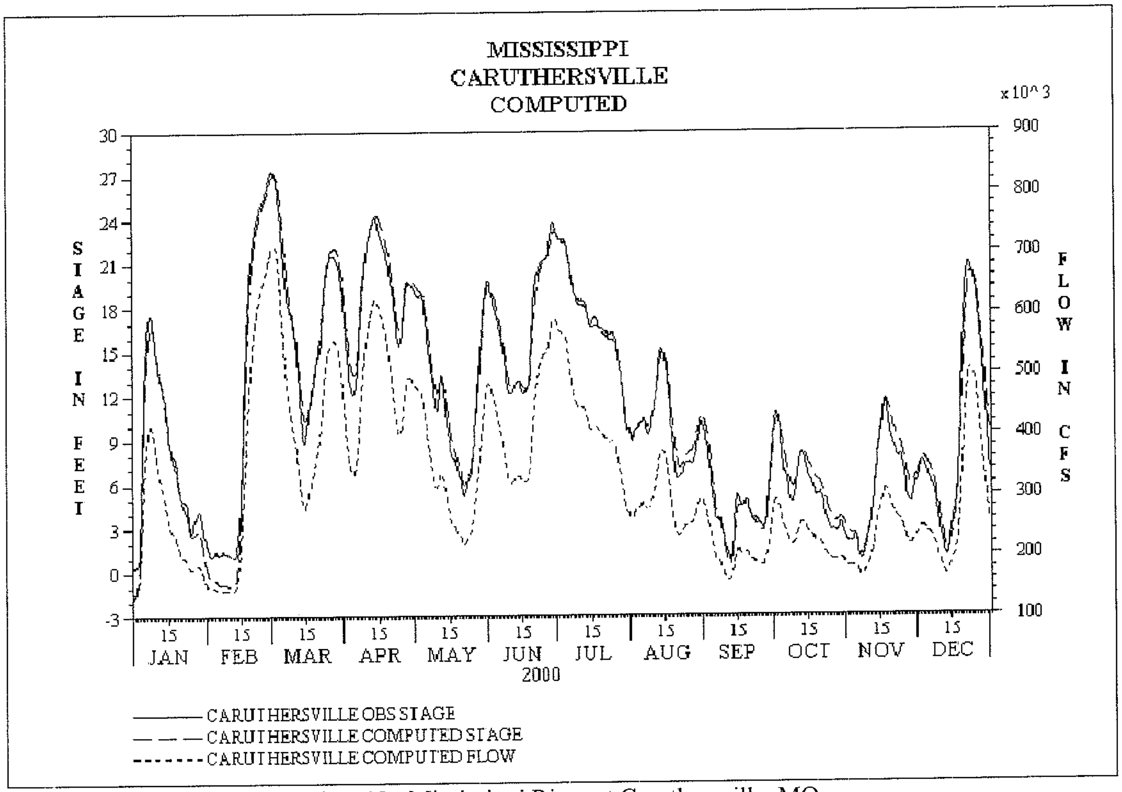


Plate 13. Mississippi River at Caruthersville, MO

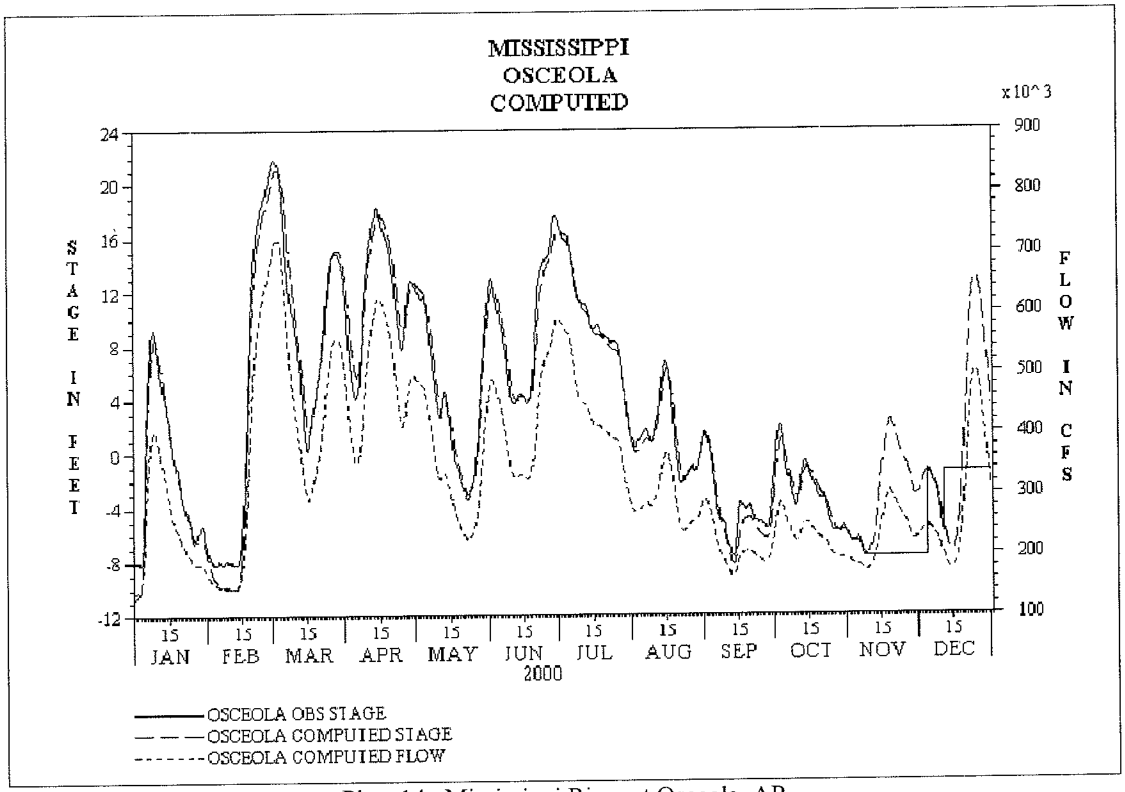


Plate 14. Mississippi River at Osceola, AR

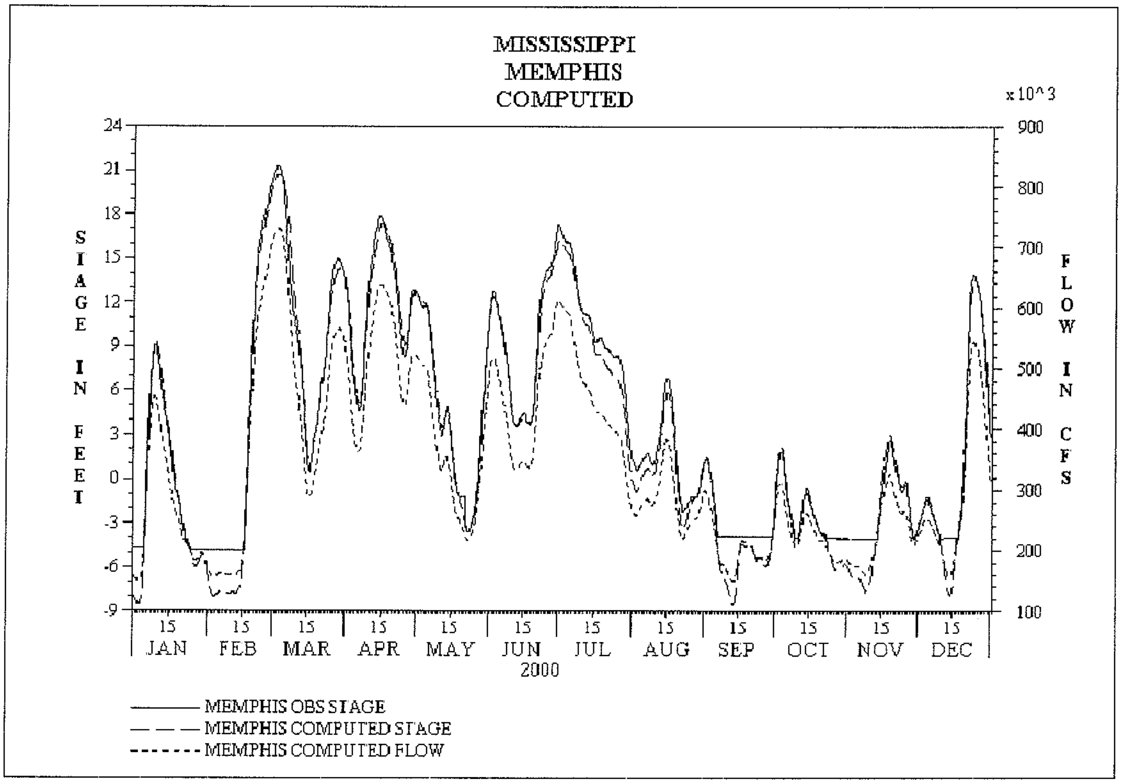


Plate 15. Mississippi River at Memphis, TN

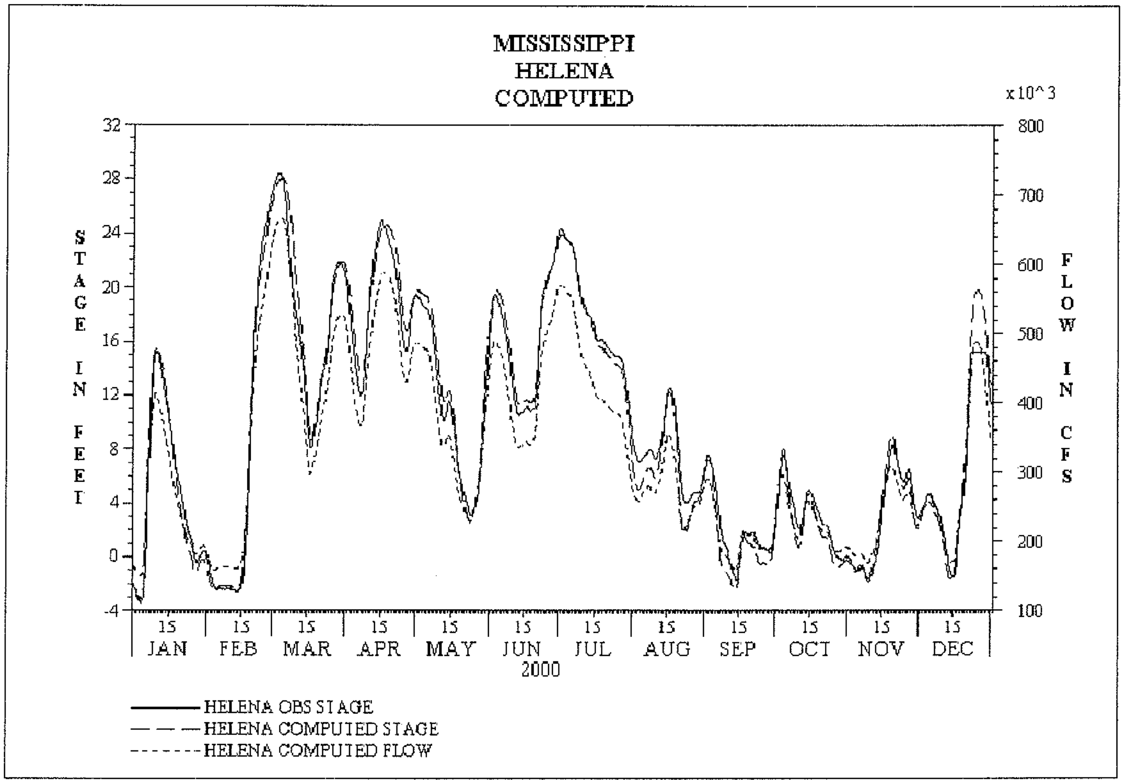


Plate 16. Mississippi River at Helena, AR

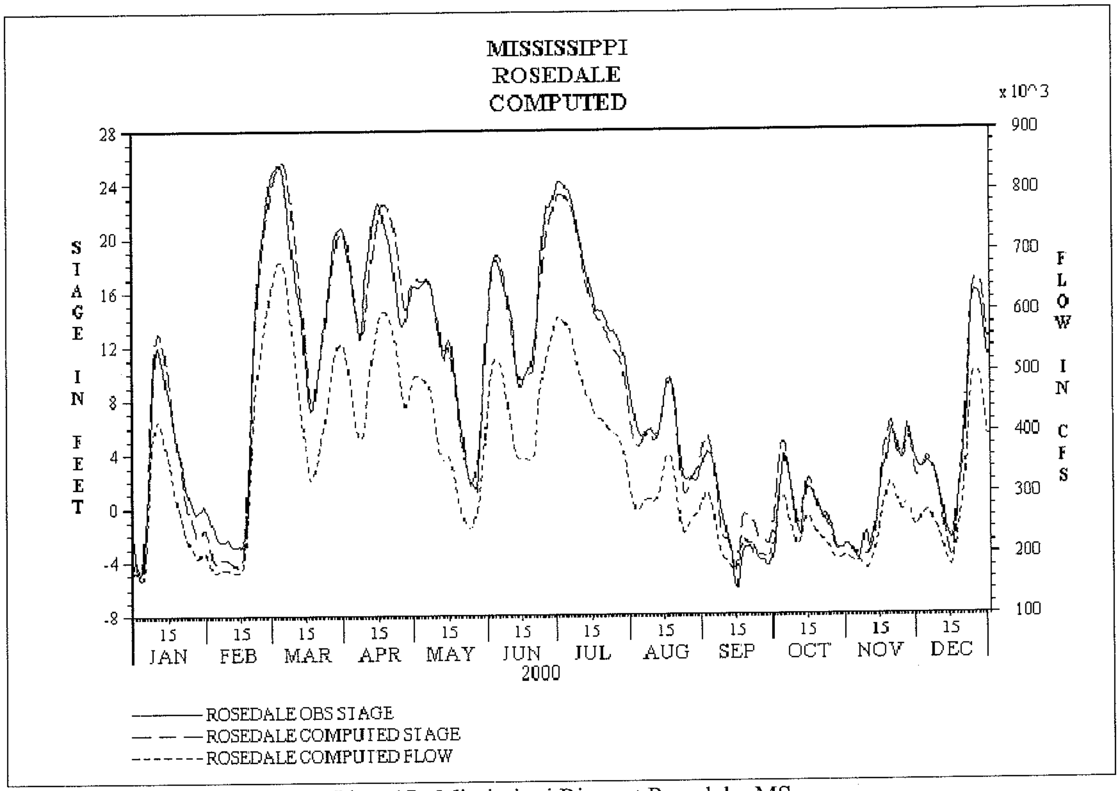


Plate 17. Mississippi River at Rosedale, MS

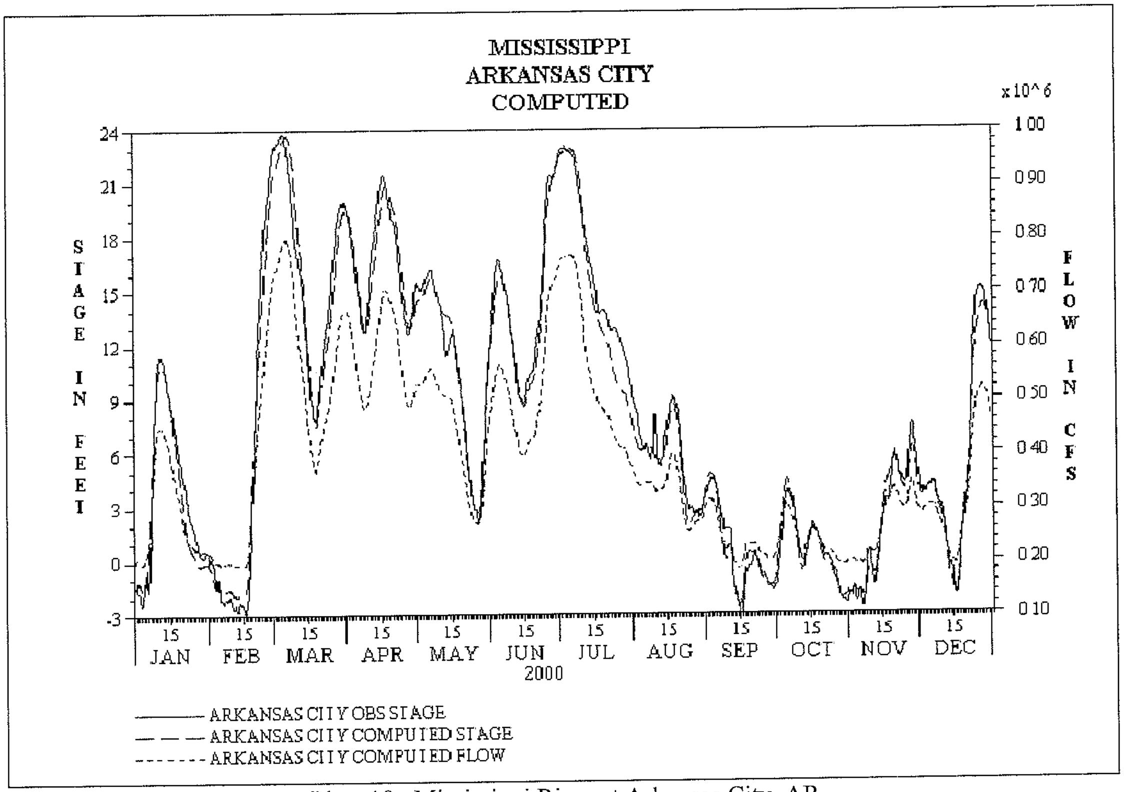


Plate 18. Mississippi River at Arkansas City, AR

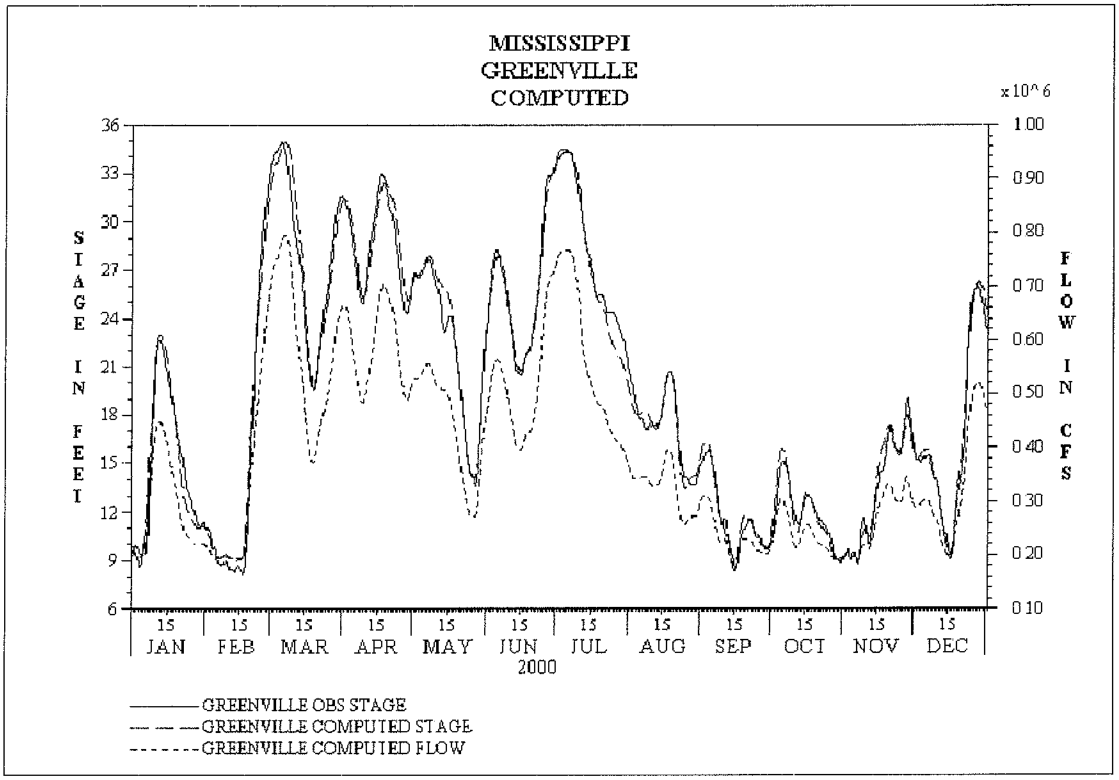


Plate 19. Mississippi River at Greenville, MS

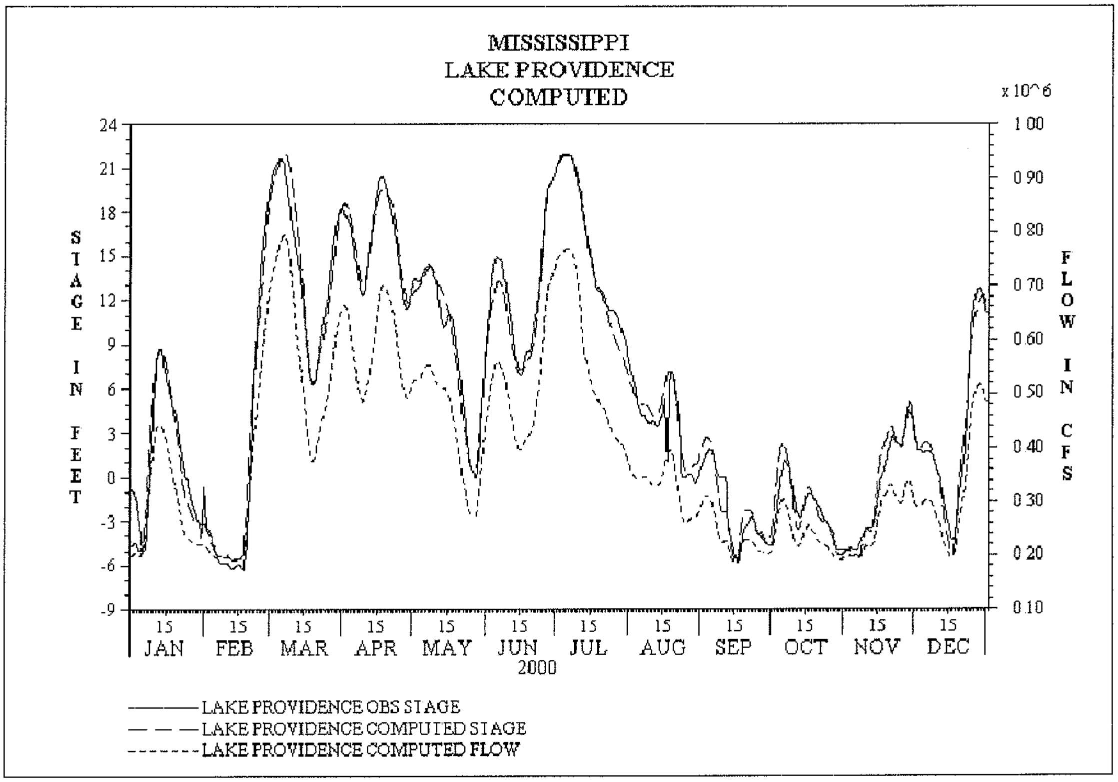


Plate 20. Mississippi River at Lake Providence, LA

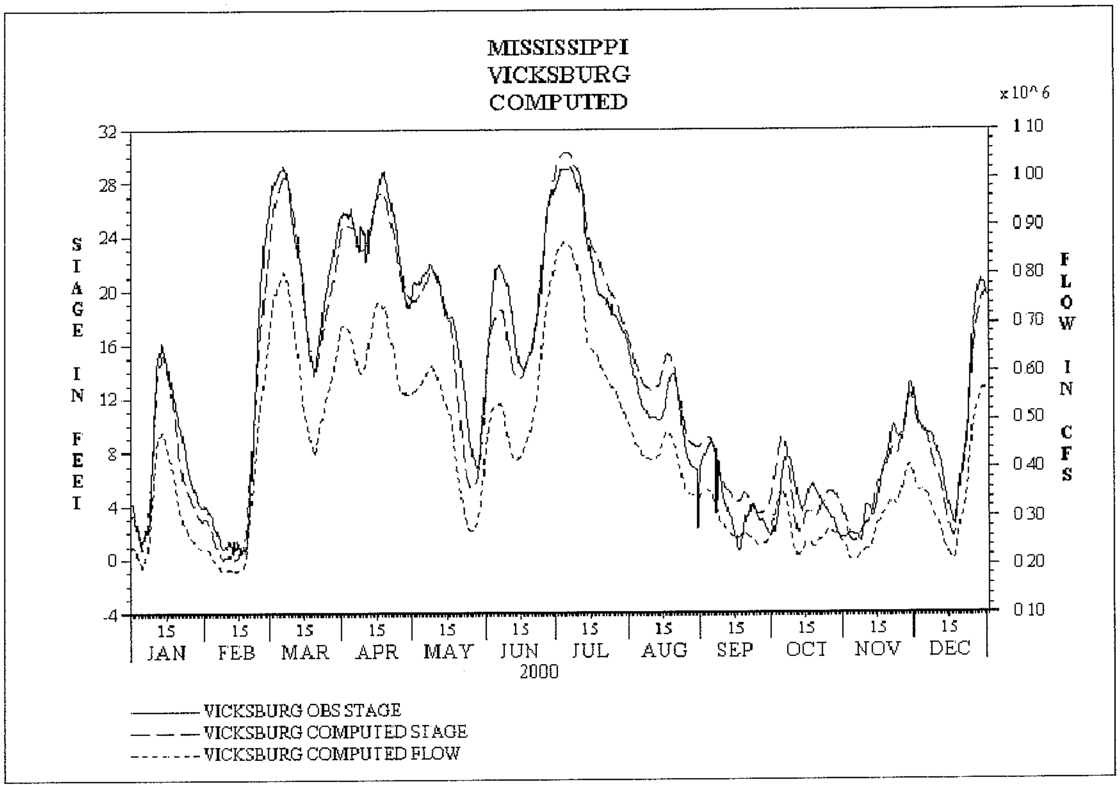


Plate 21. Mississippi River at Vicksburg, MS

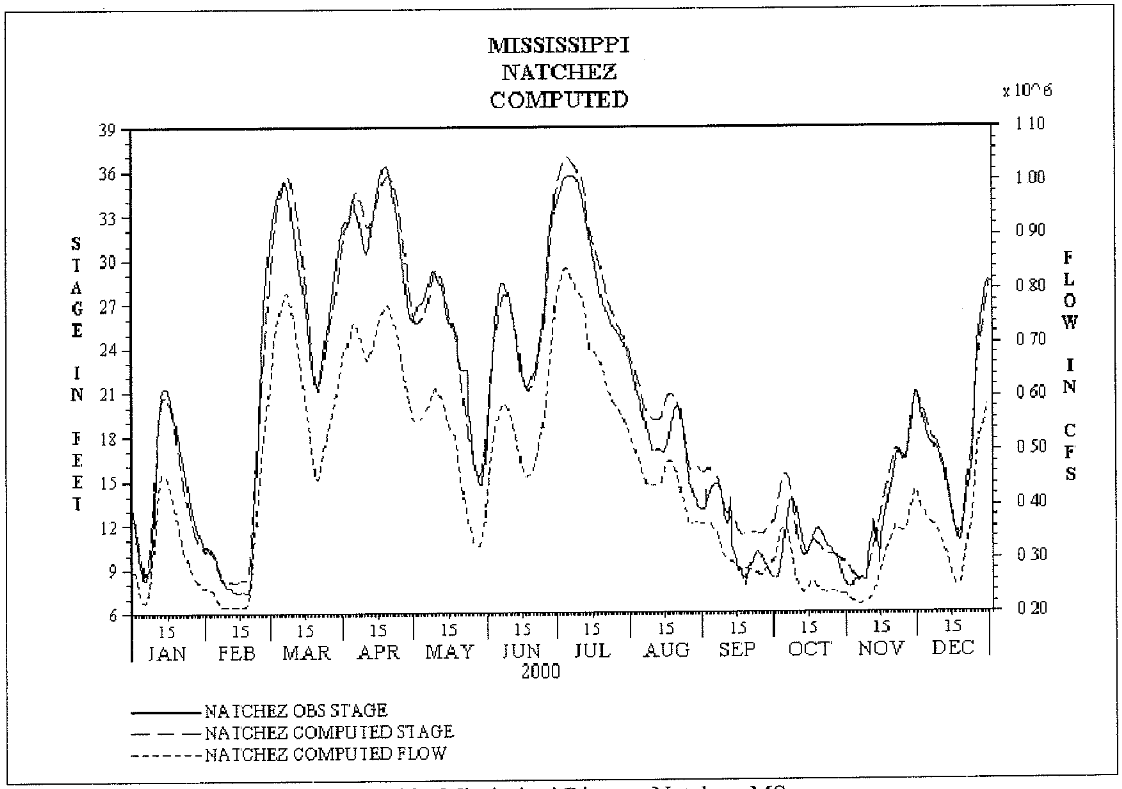


Plate 22. Mississippi River at Natchez, MS

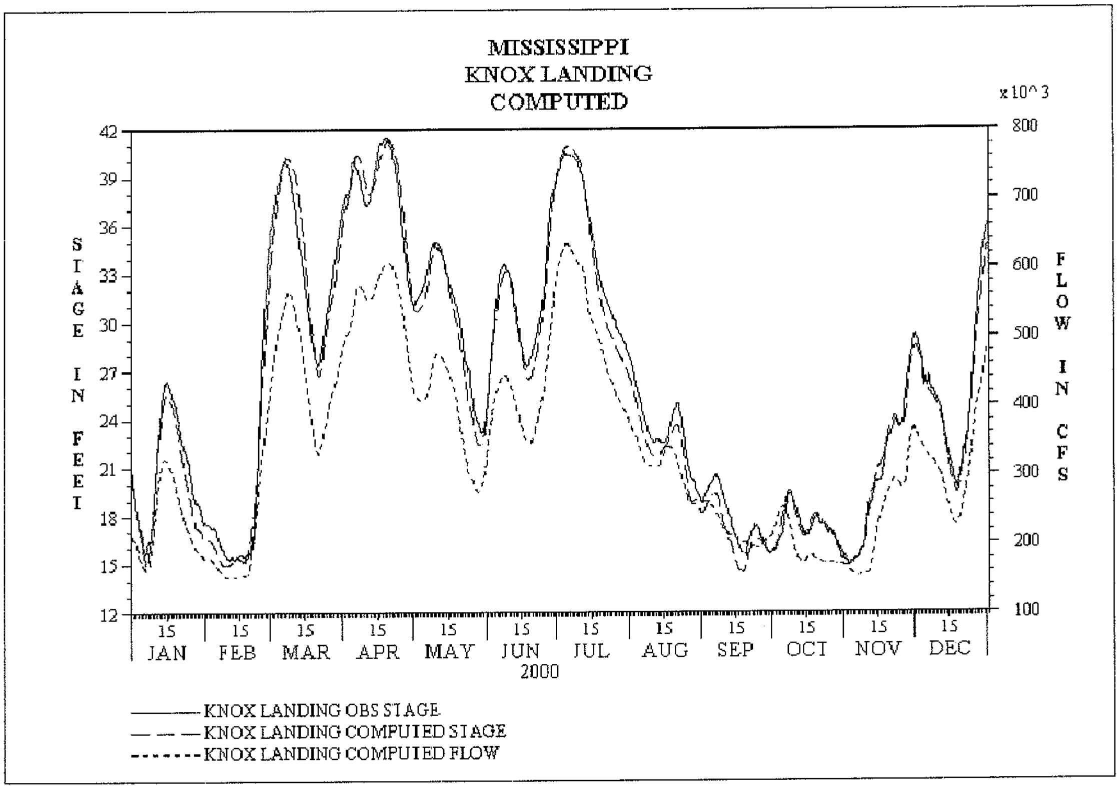


Plate 23. Mississippi River at Knox Landing, LA

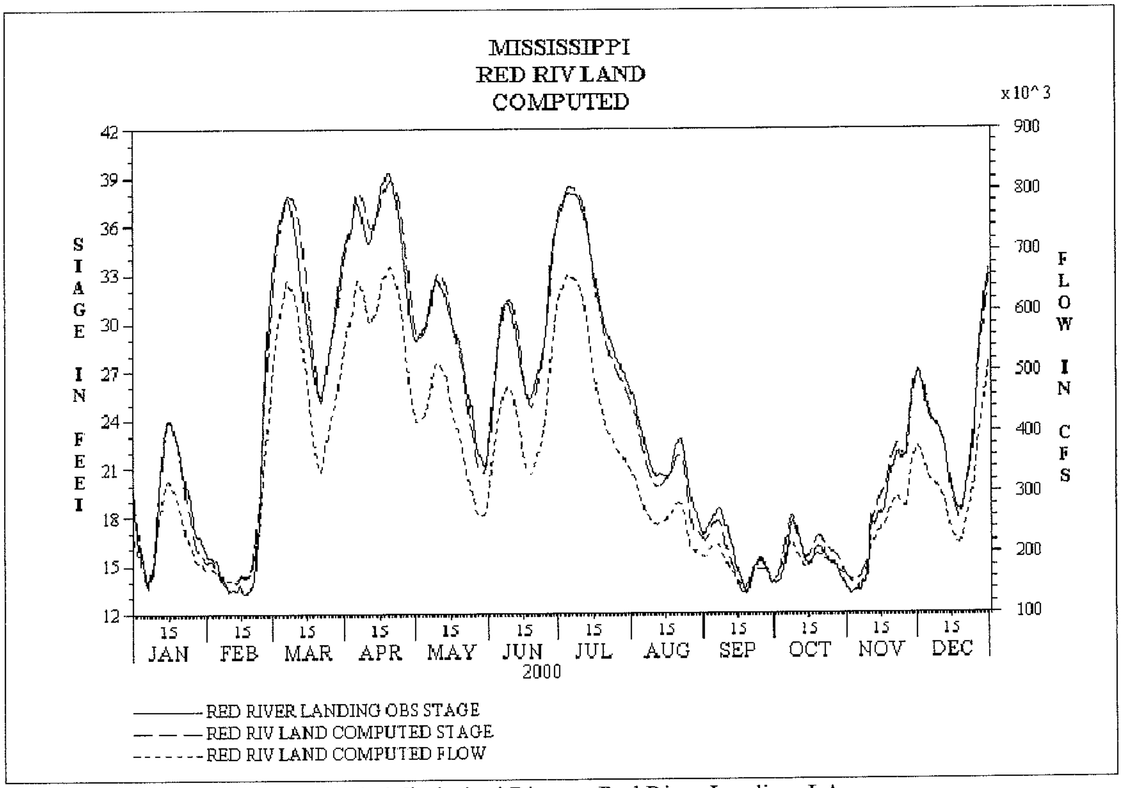


Plate 24. Mississippi River at Red River Landing, LA

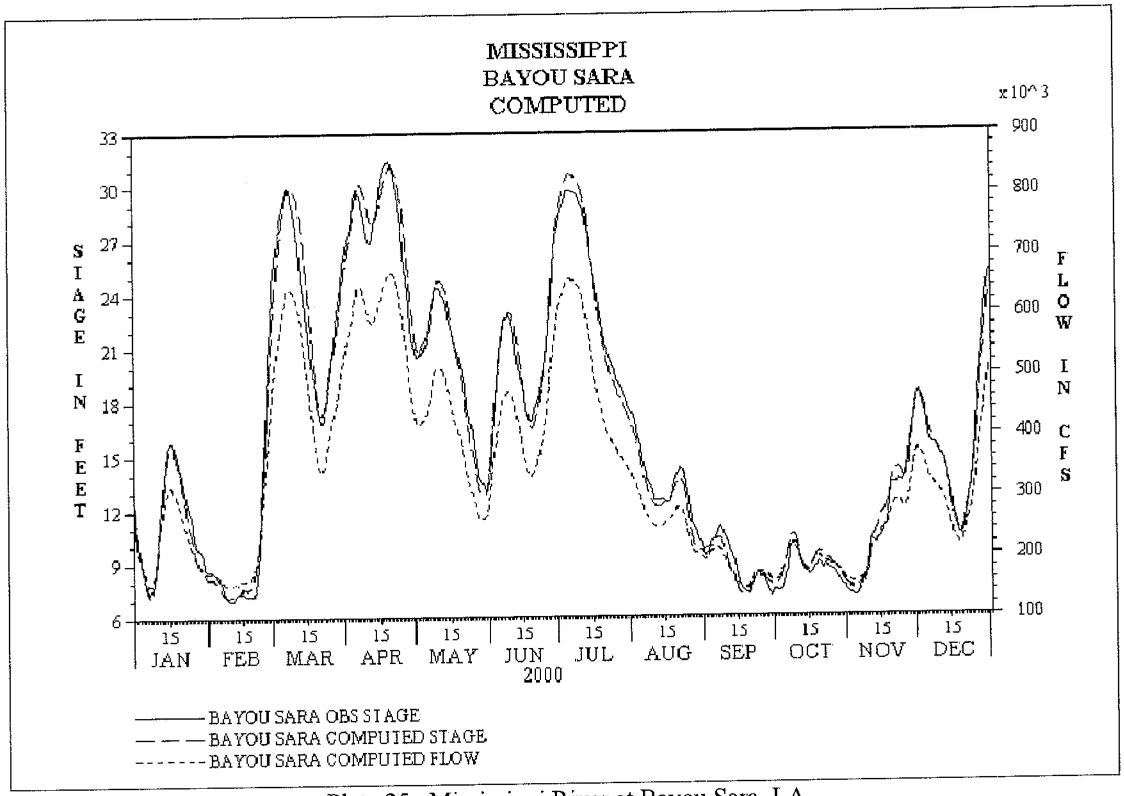


Plate 25. Mississippi River at Bayou Sara, LA

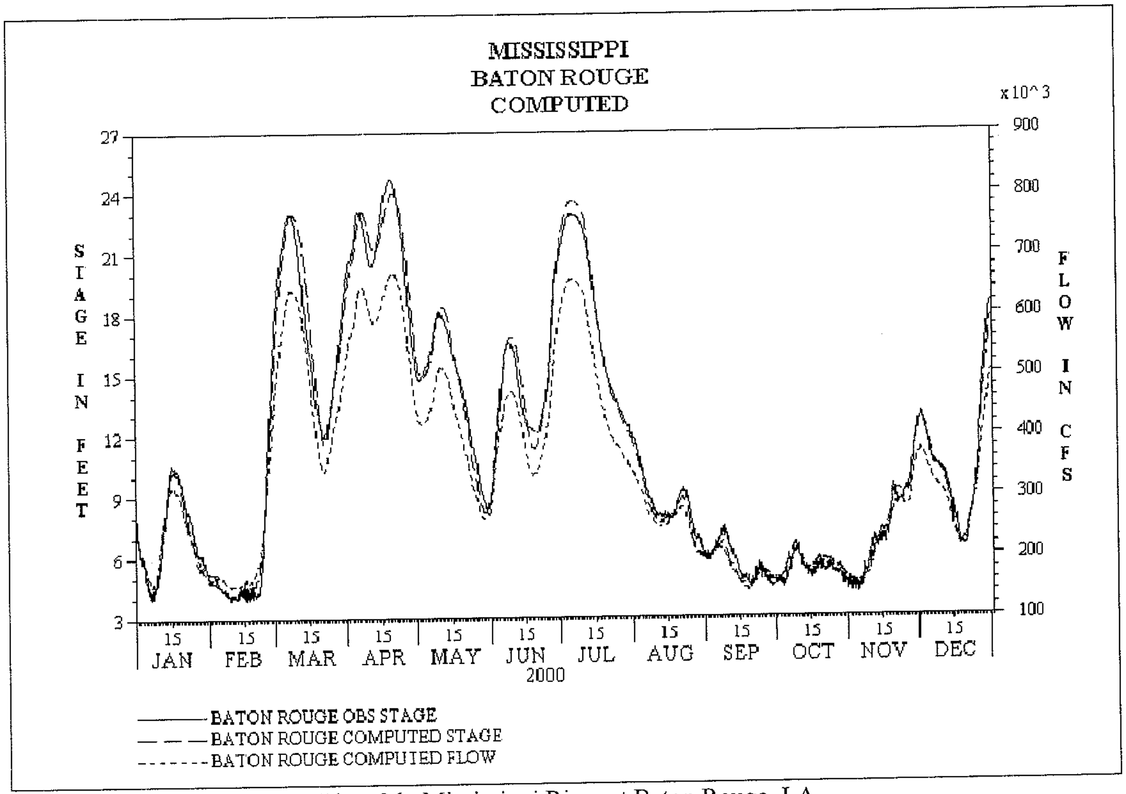


Plate 26. Mississippi River at Baton Rouge, LA

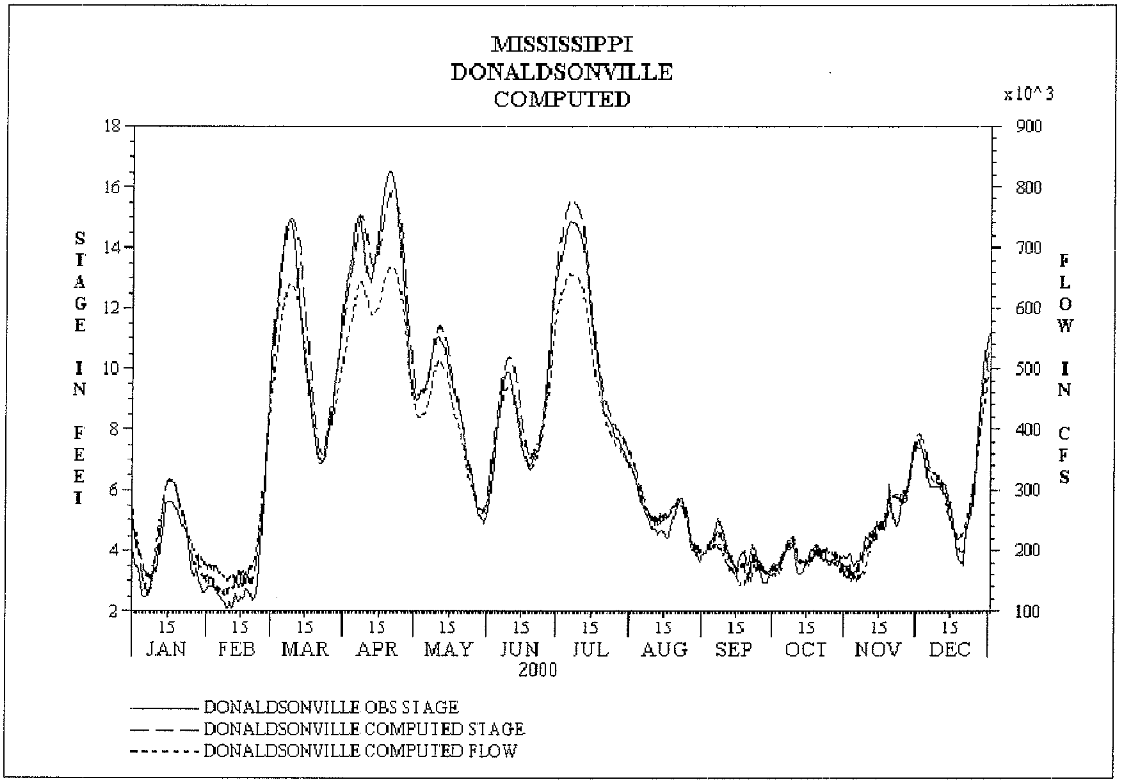


Plate 27. Mississippi River at Donaldsonville, LA

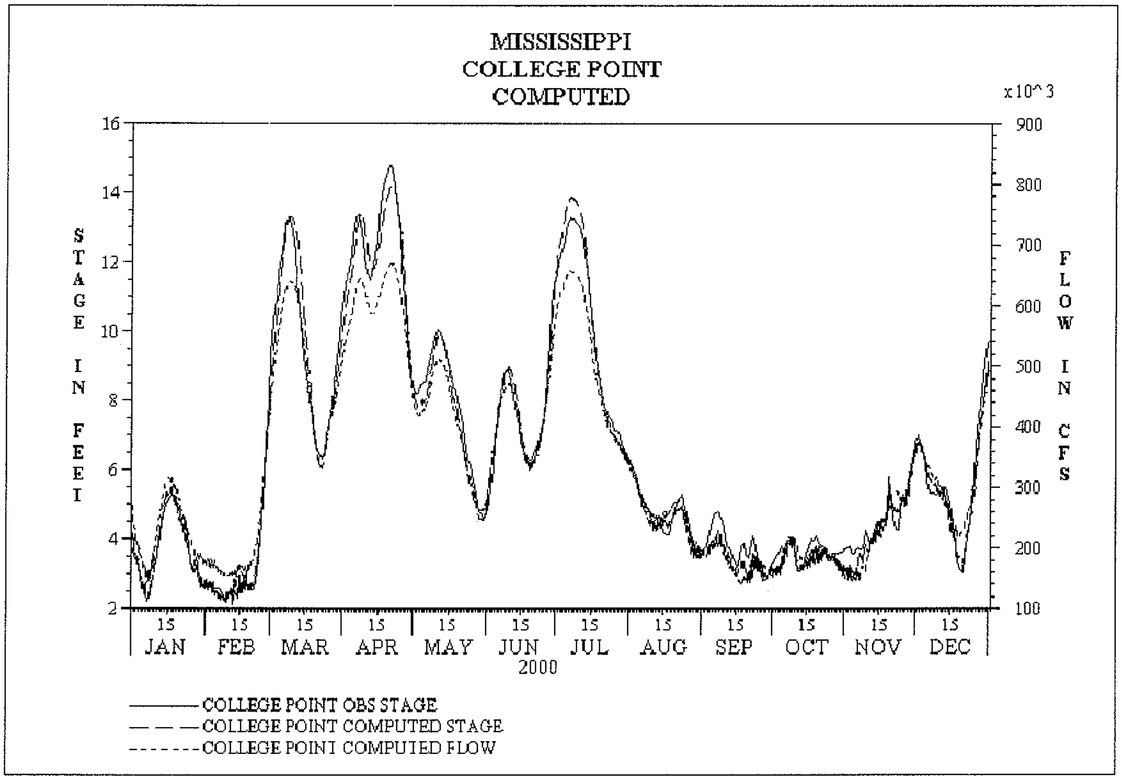


Plate 28. Mississippi River at College Point, LA

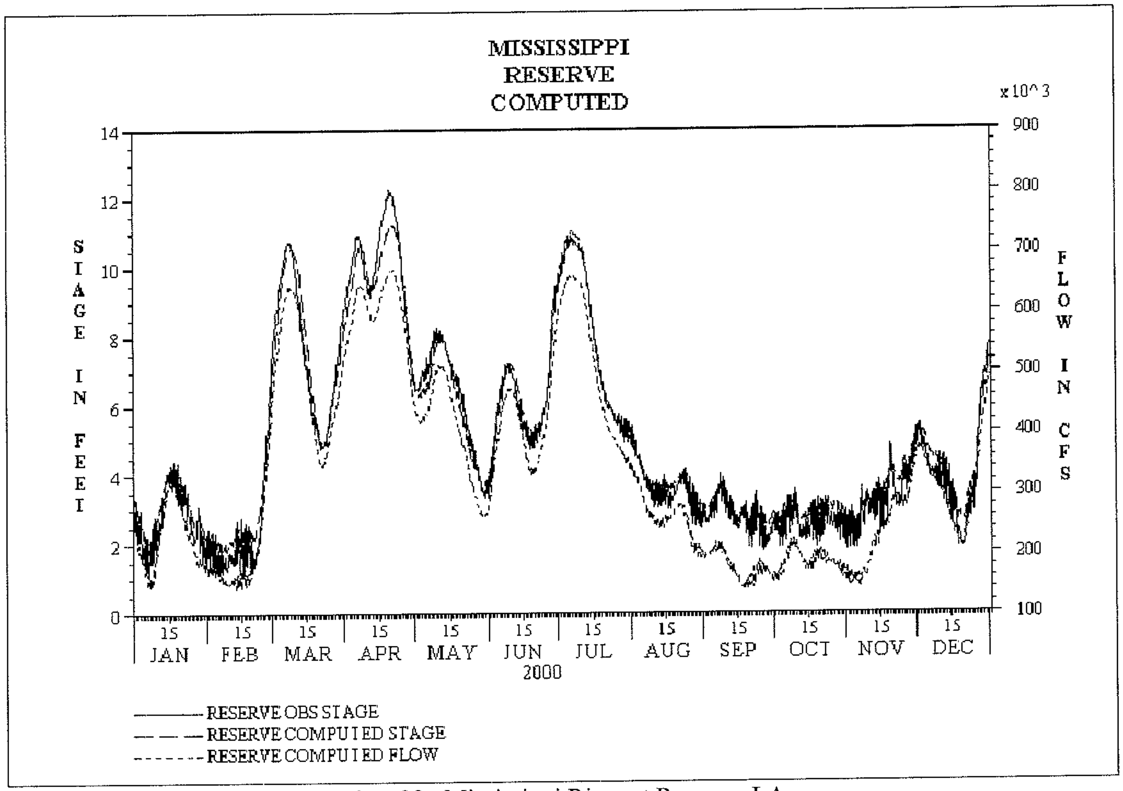


Plate 29. Mississippi River at Reserve, LA

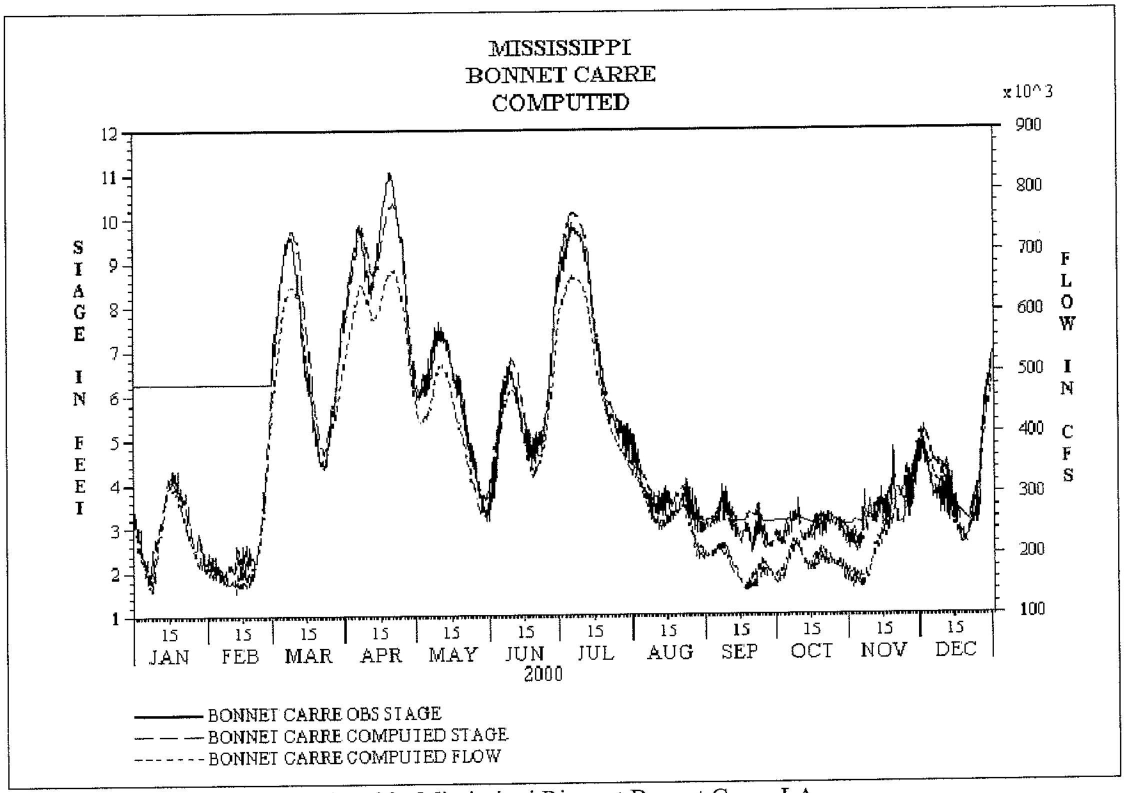


Plate 30. Mississippi River at Bonnet Carre, LA

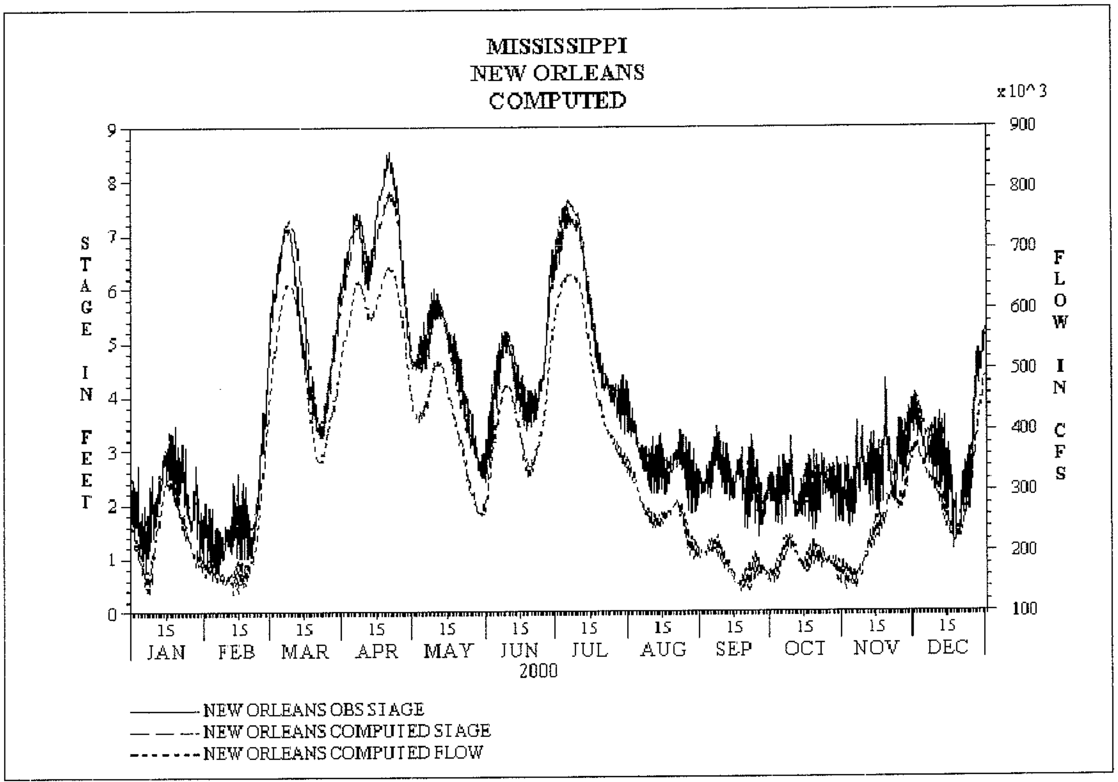


Plate 31 Mississippi River at New Orleans, LA

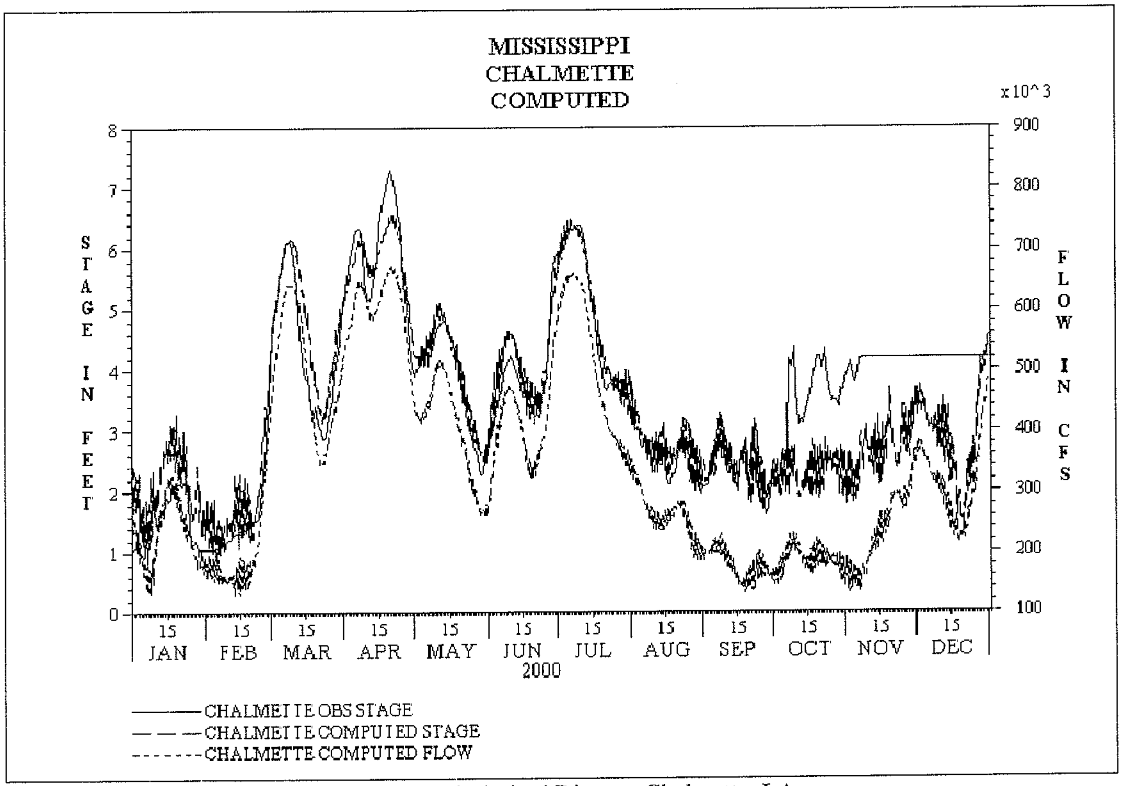


Plate 32. Mississippi River at Chalmette, LA

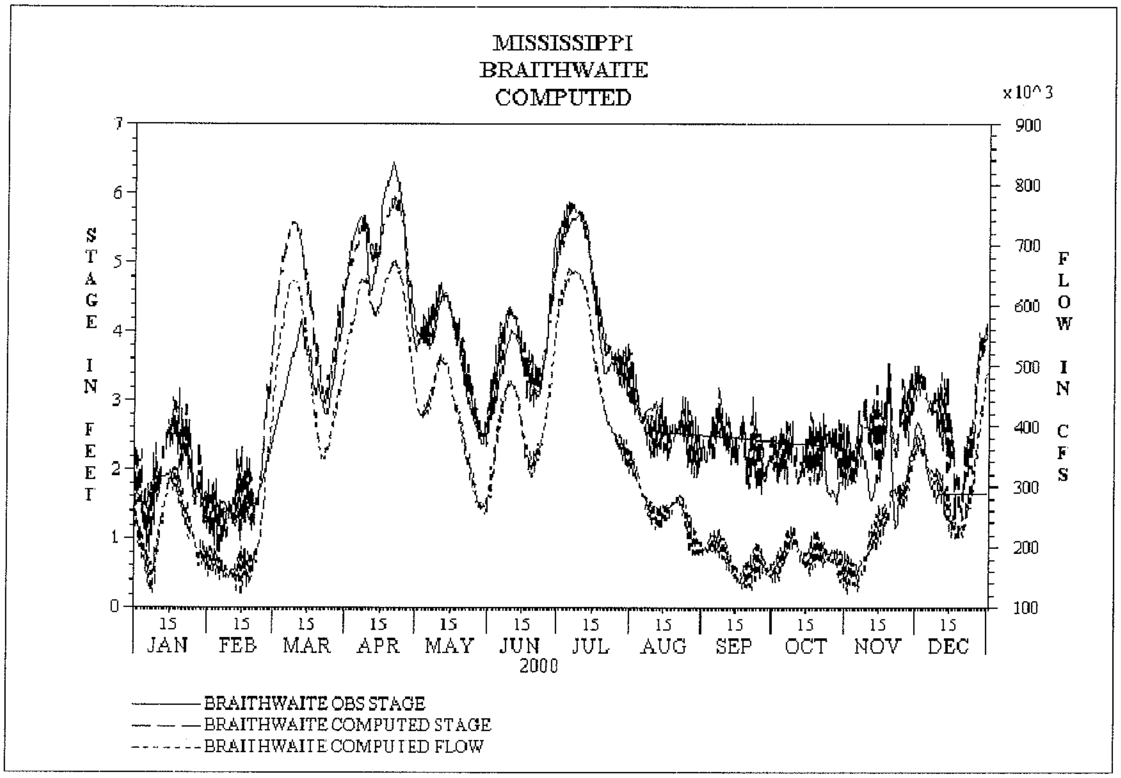


Plate 33. Mississippi River at Braithwaite, LA

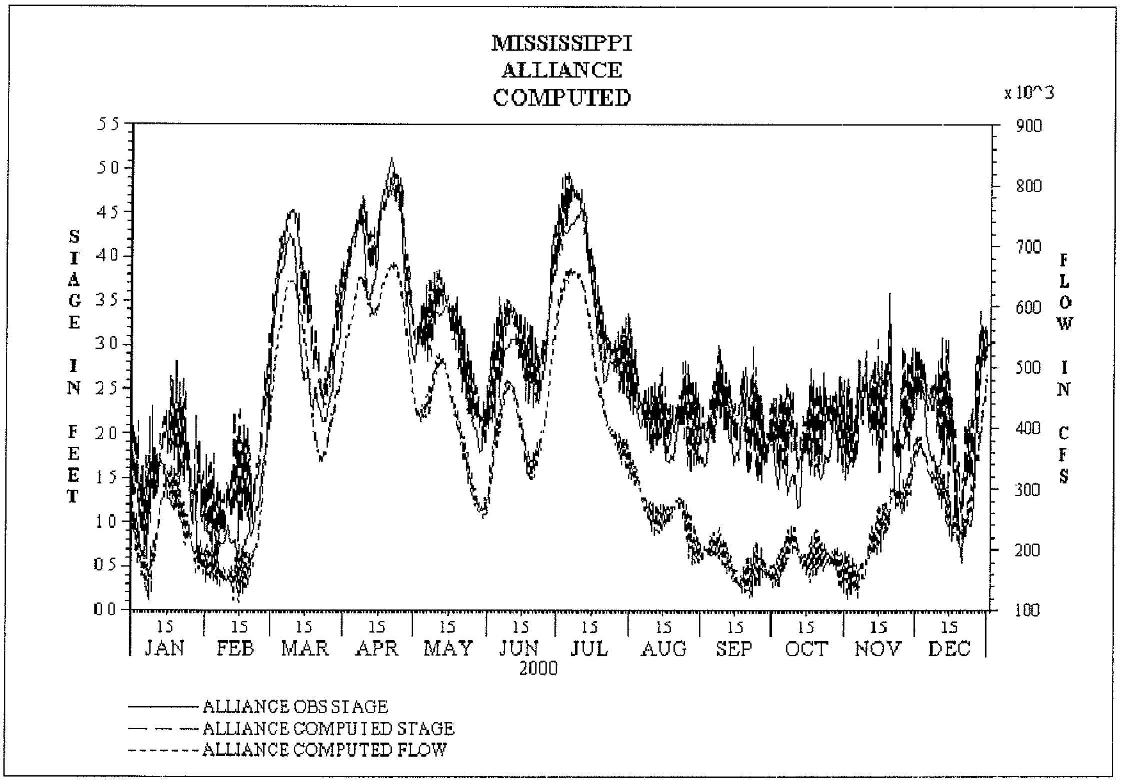


Plate 34. Mississippi River at Alliance, LA

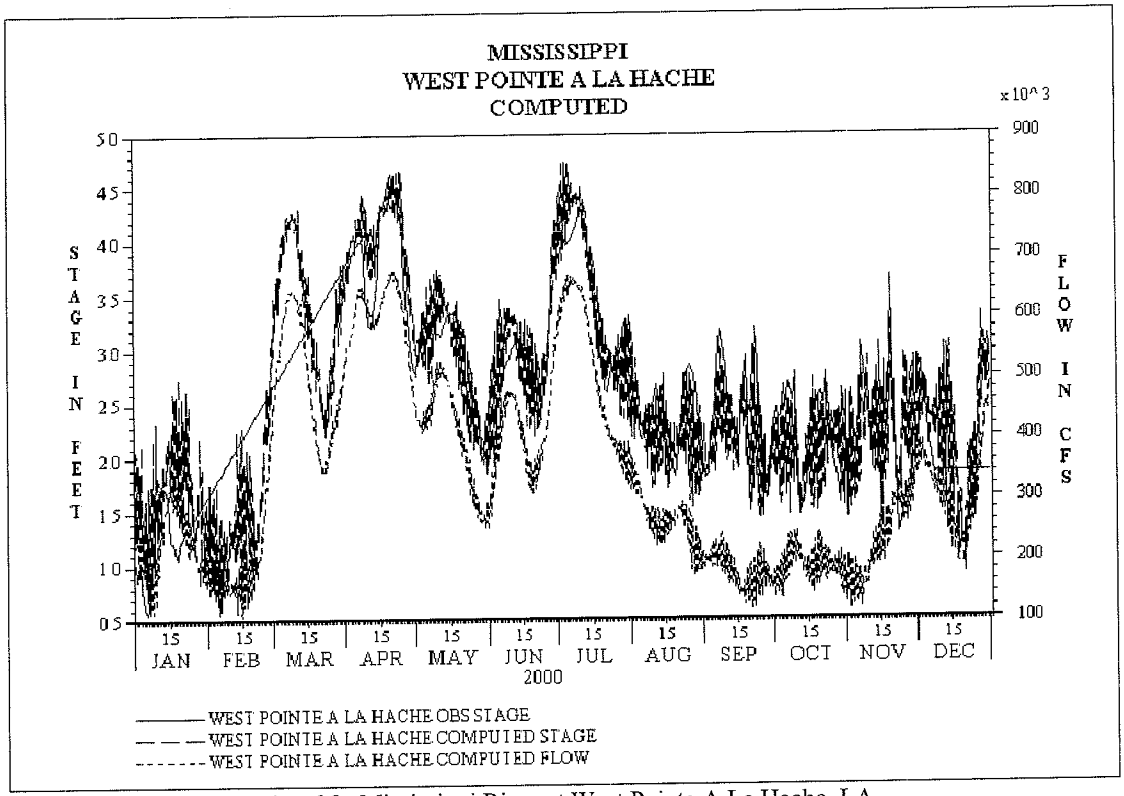


Plate 35. Mississippi River at West Pointe A La Hache, LA

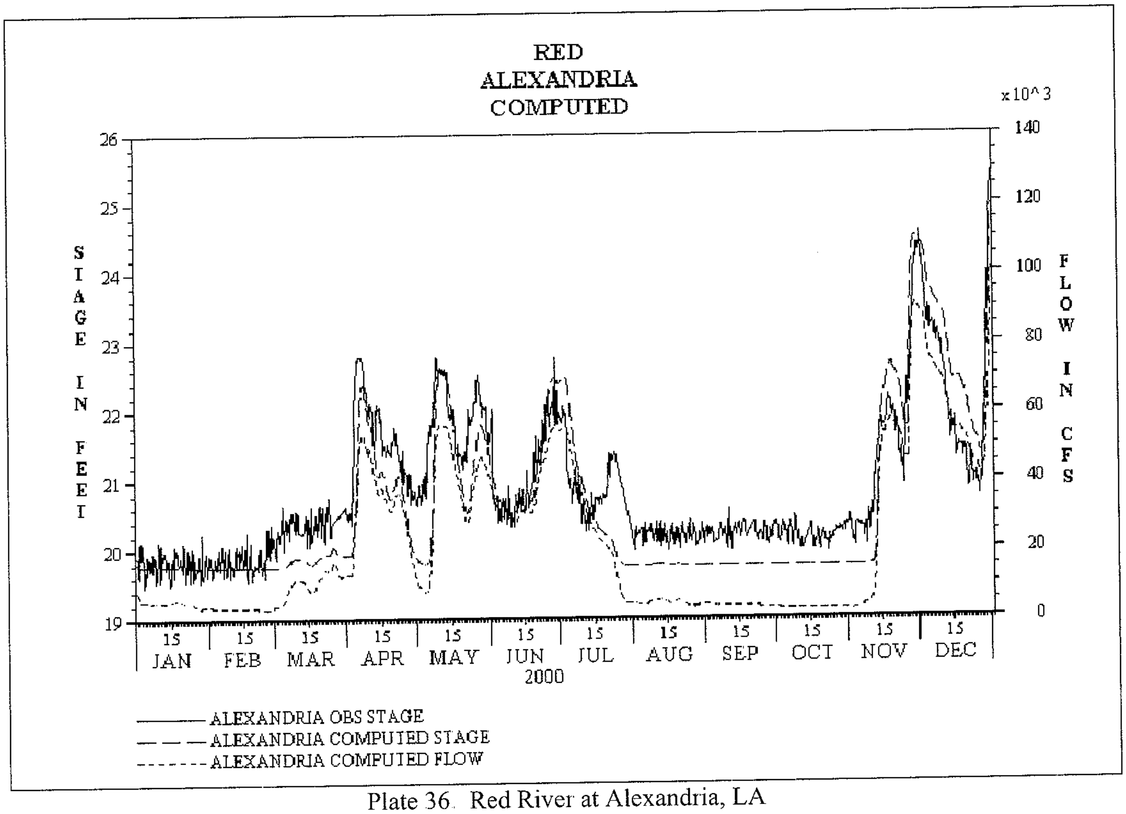


Plate 36. Red River at Alexandria, LA

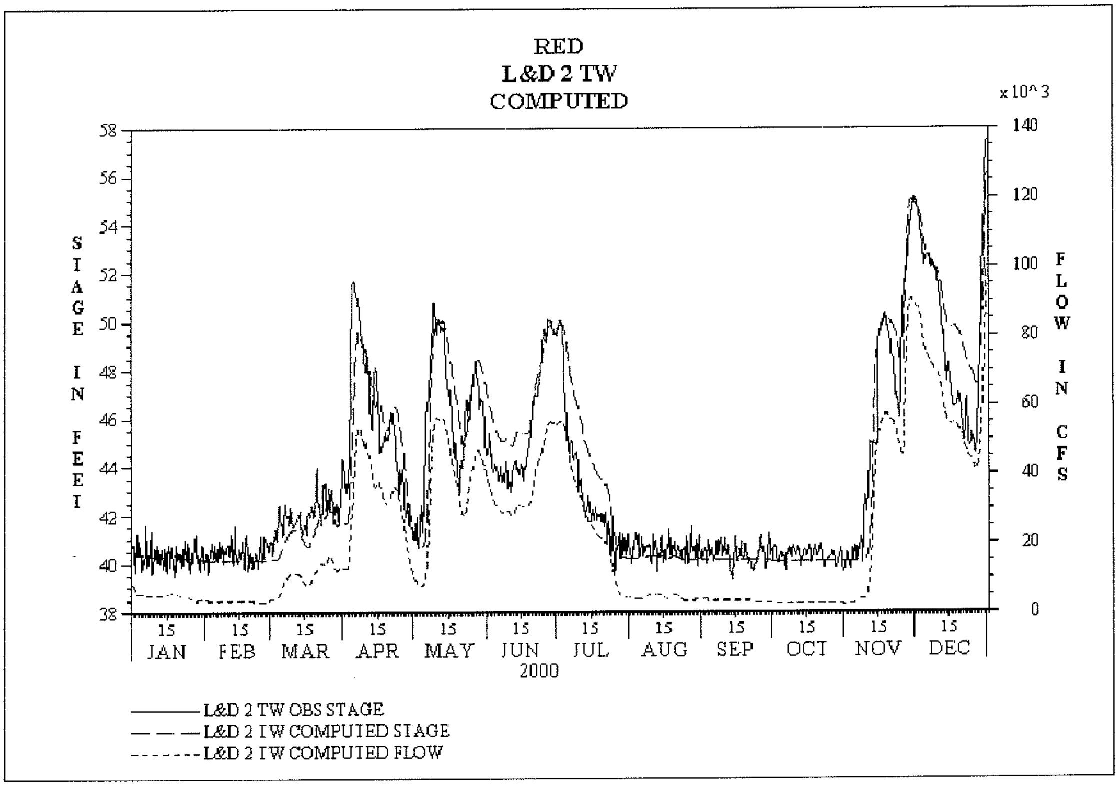


Plate 37. Red River at L&D 2 TW, LA

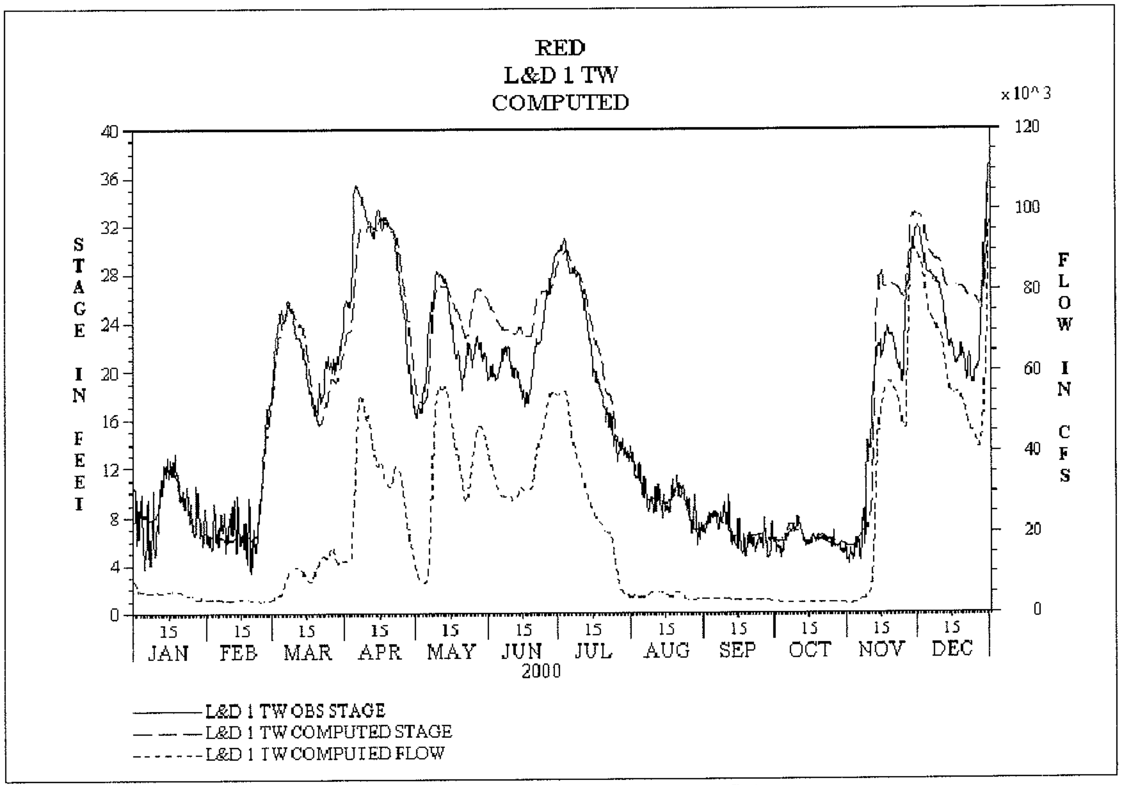


Plate 38. Red River at L&D 1 TW, LA

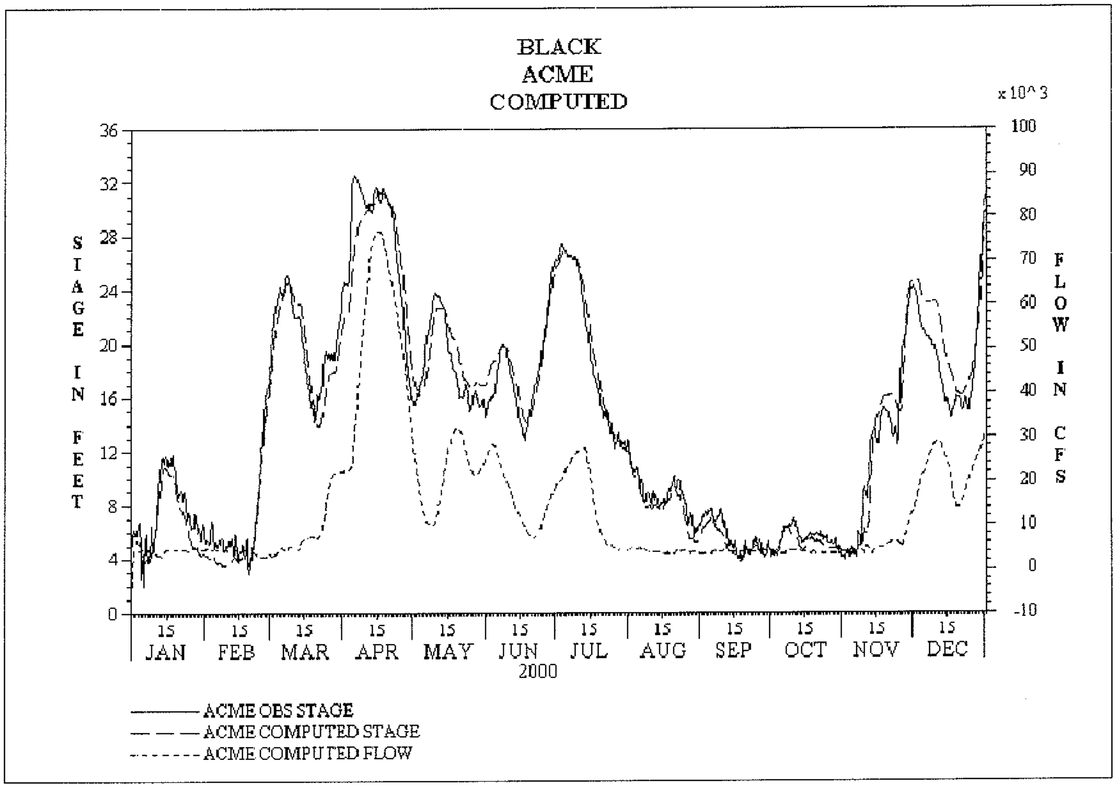


Plate 39. Black River at Acme, LA

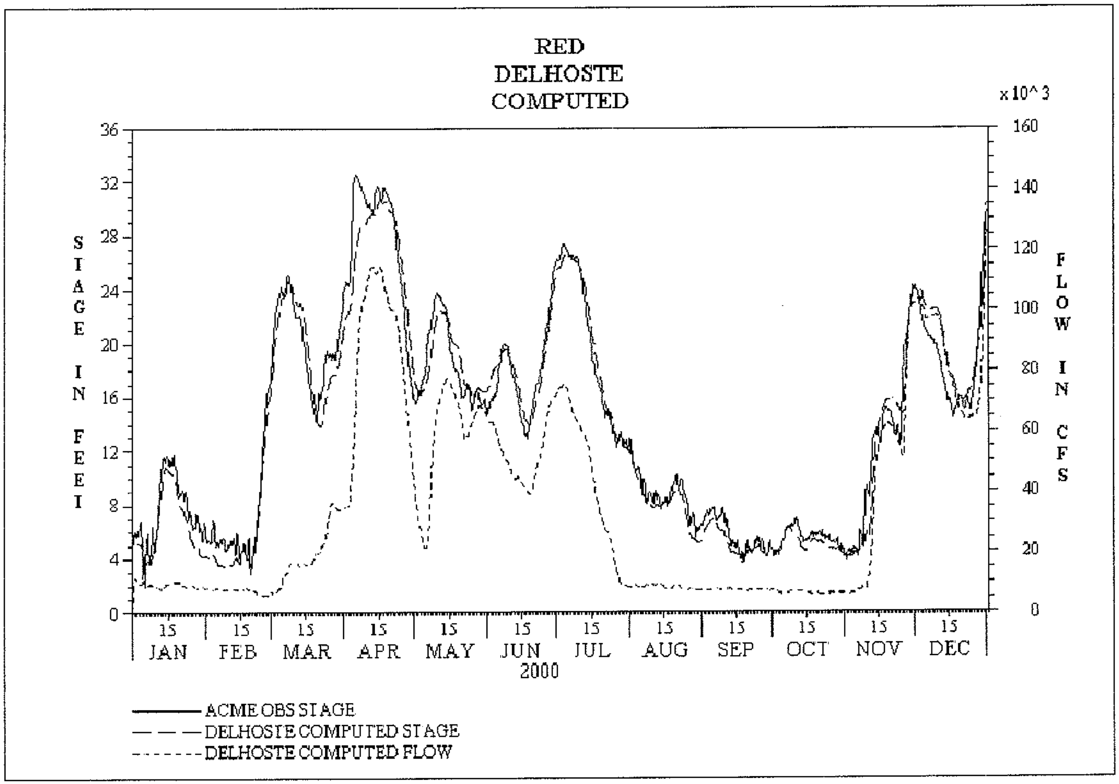


Plate 40 Red River at Delhoste, LA

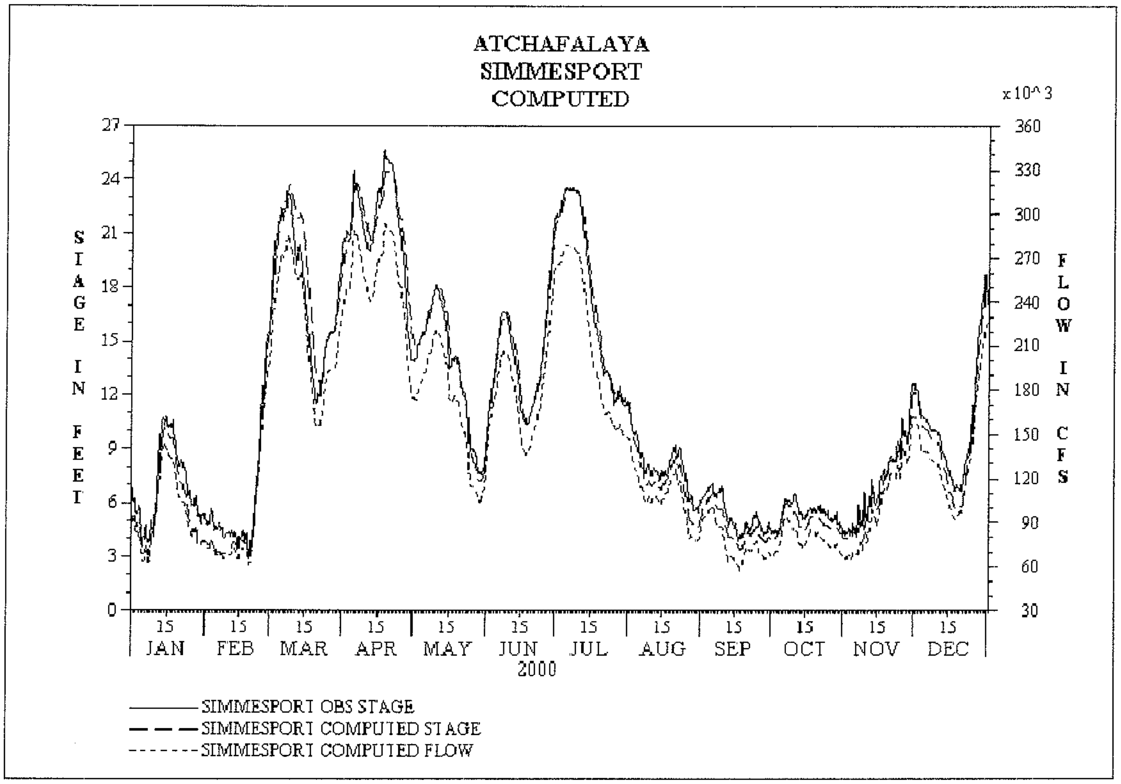


Plate 41. Atchafalaya River at Simmesport, LA

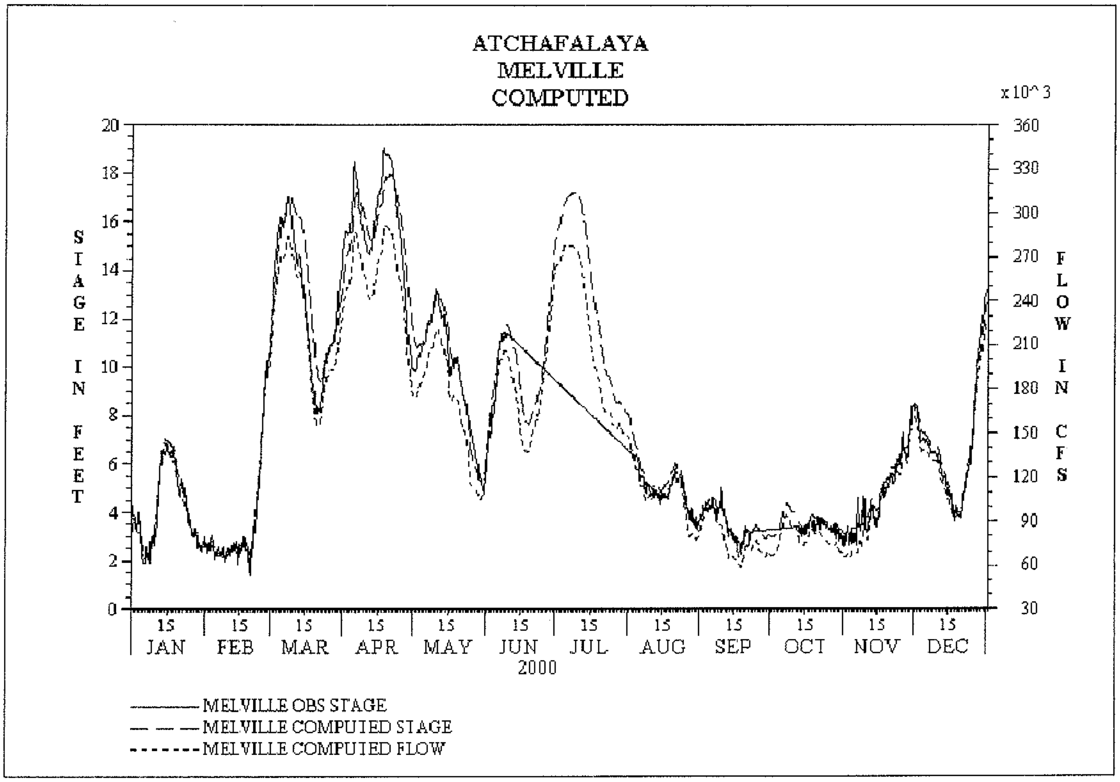


Plate 42. Atchafalaya River at Melville, LA

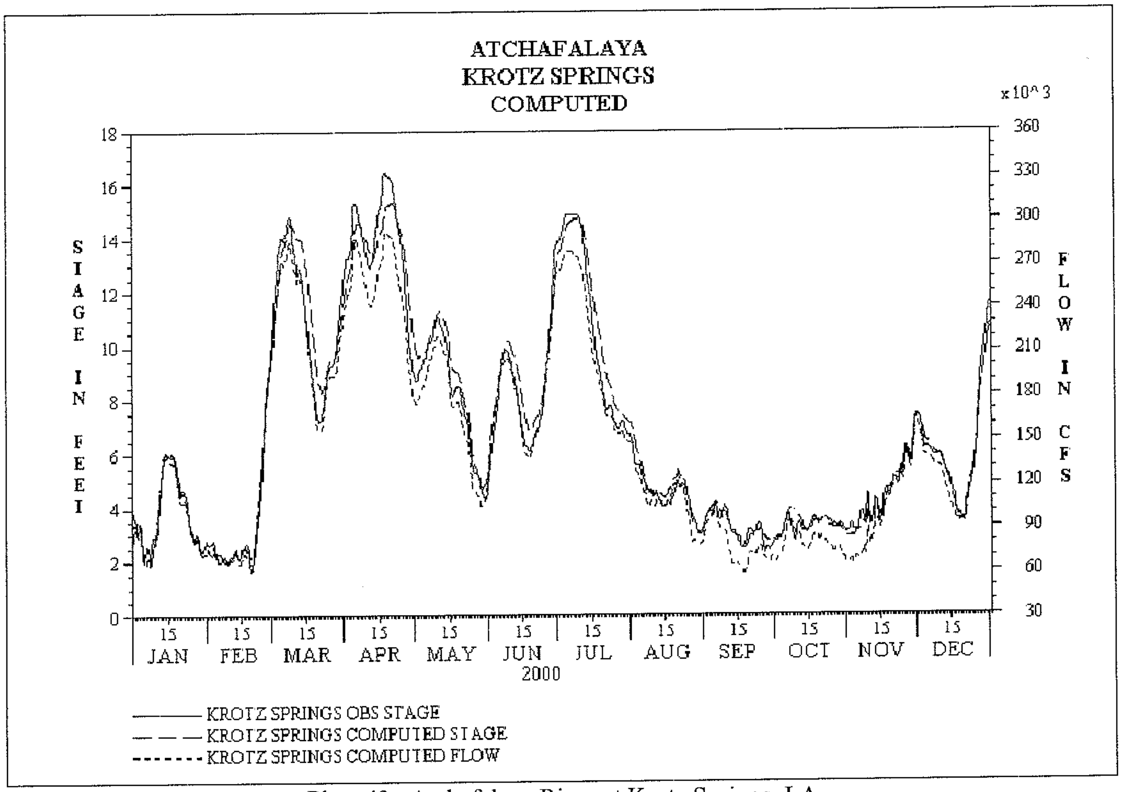


Plate 43. Atchafalaya River at Krotz Springs, LA

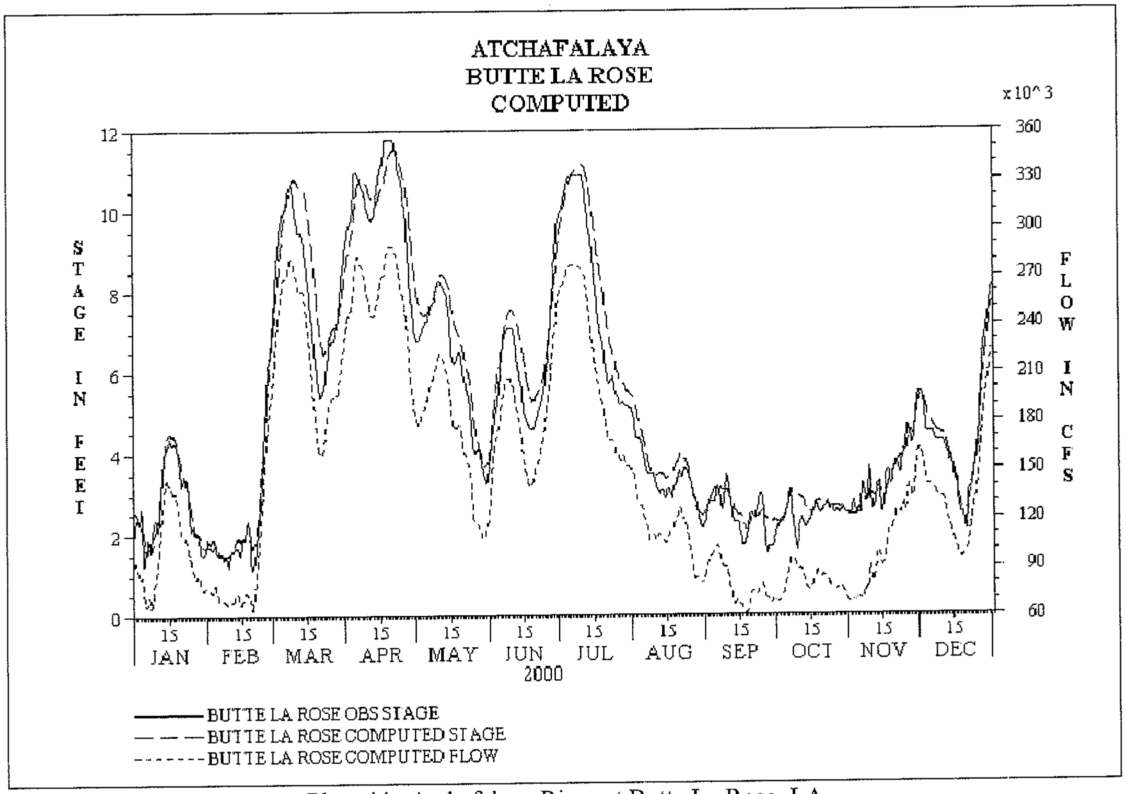


Plate 44. Atchafalaya River at Butte La Rose, LA

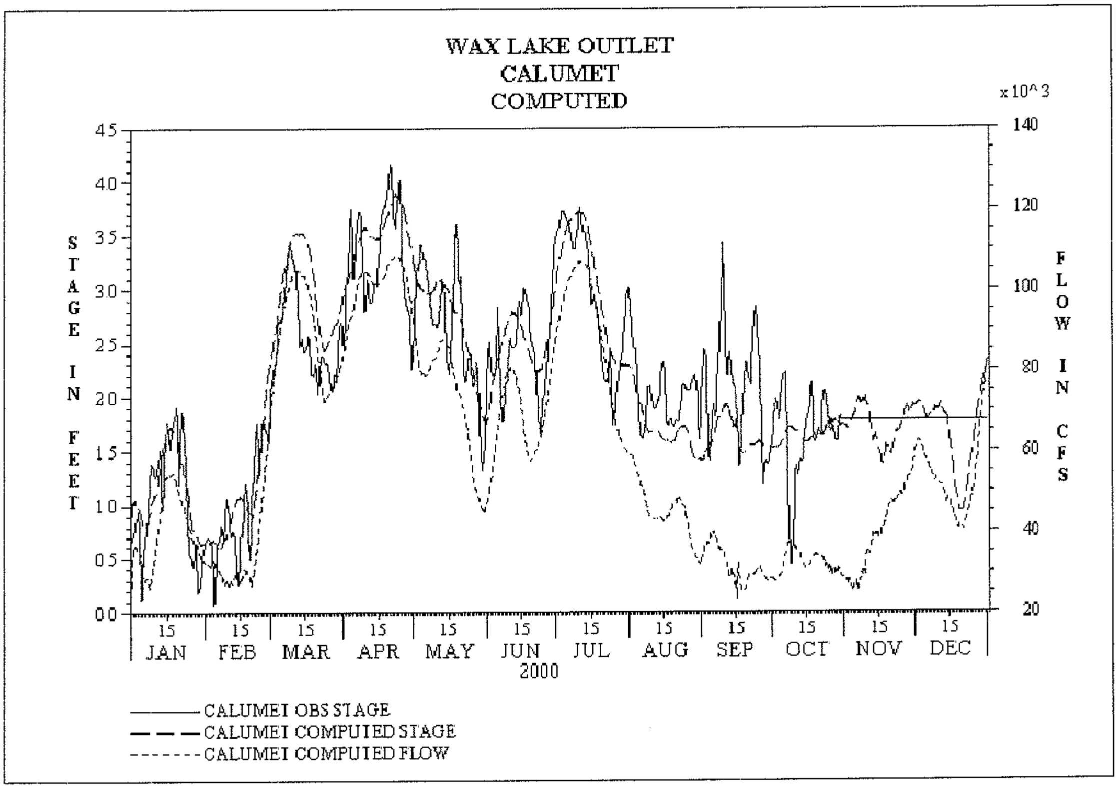


Plate 45. Atchafalaya River at Calumet, LA

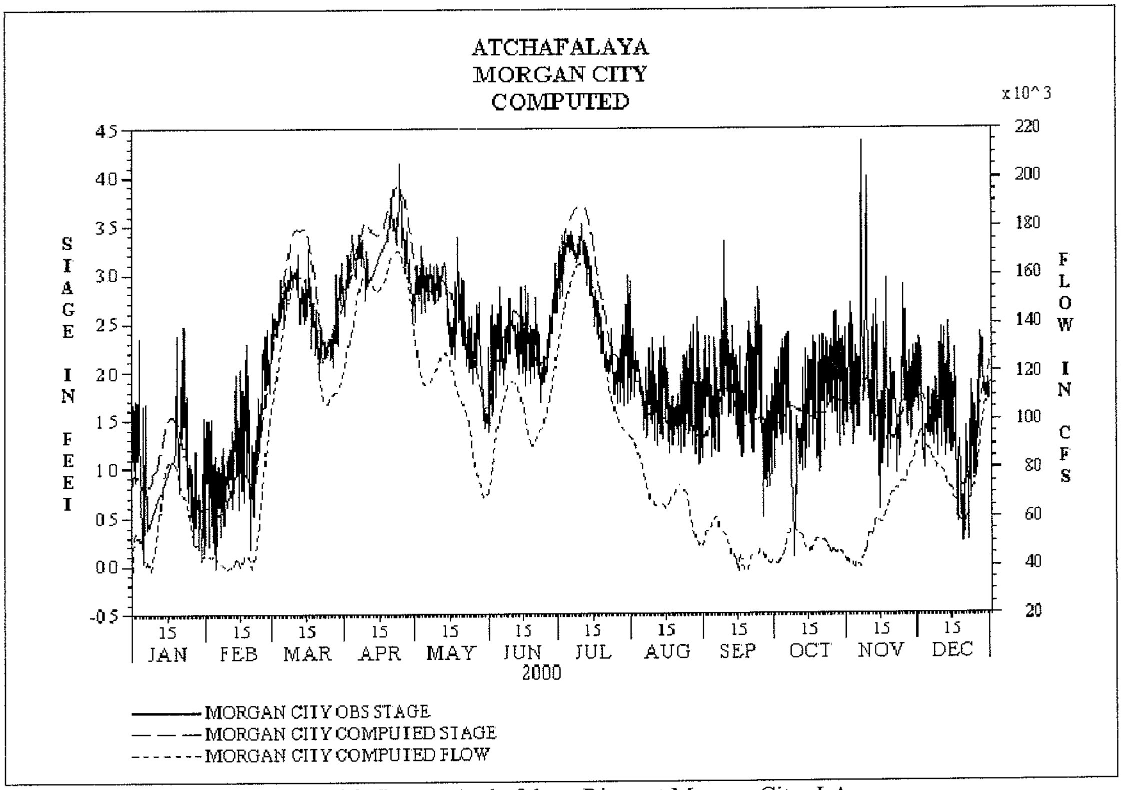


Plate 46. Lower Atchafalaya River at Morgan City, LA

Comparison of UNET-MBMS Results:
DEM Cross Sections versus Field Surveys and USGS Maps

TABLE OF CONTENTS

COMPARISON OF UNET-MBMS RESULTS: DEM CROSS SECTIONS VERSUS FIELD SURVEYS AND USGS MAPS[1]

EXECUTIVE SUMMARY

Following the Great Flood of 1993, Congress allocated funds to create digital elevation models (DEMs) of portions of the Mississippi, Missouri, and Illinois River floodplains that were impacted by that event. The Corps' Hydrologic Engineering Center (HEC) investigated the impact of the use of new digital terrain model data, compared to traditional cross-section data, on unsteady flow modeling results. The sample data investigated was prepared by the St. Louis District. The St. Louis District had used the state-of-the-art mapping data to update an existing hydraulic model that had been used for the Floodplain Management Assessment Study published in 1995. The old model geometry was based on hydrographic survey data and limited overbank surveys that had been conducted in the late 1970's.

Hydraulic properties (geometry and *n*-values) of the old and new cross sections were compared, showing that utilization of the DEM data produces a more detailed physical description of the floodplain. Plots comparing the old with the new cross sections, at approximately the same locations, displayed similarity in floodplain shape. Hydraulic features of the new cross sections better represent present-day river morphology.

The maximum computed water surface elevations obtained using the MBMS UNET unsteady flow model with both the old and new geometric data were compared. All other hydraulic variables such as boundary conditions, roughness, and period of record simulated were held constant to ensure that the modeling situations were comparable. The unsteady flow model results showed a trend toward increased computed maximum water surface elevations due solely to the increased sampling frequency of topographic data. Impacts of changed geometries on model results and subsequent model calibration are significant.

The UNET model geometry, updated with the new DEM technology, will produce a current model with standard cross section data files for use by all interested parties. The DEM technology better defined linear features of the floodplain such as roads, railroads, and levees. This technology provided improvements to the description of the floodplain hydraulic properties, compared with previous data. Finally, the DEM technology will provide improved methods for updating topographic information, producing inundation maps, and will consequently lead to a wider public acceptance of the model results.

---

[1] Prepared by Michael Gee, HEC and Dennis Stephens, MVS.

COMPARISON OF UNET-MBMS RESULTS: DEM CROSS SECTIONS VERSUS FIELD SURVEYS AND USGS MAPS[1]

1. Introduction. The report, Science for Floodplain Management Into the 21st Century (1), prepared by the Scientific Assessment and Strategy Team (SAST) to the Administration Floodplain Management Task Force recommended development of hydrologic and hydraulic models to define flood-response characteristics of river floodplains in the Upper Mississippi Basin. Two of that report's pertinent recommendations are:

> **Recommendation 5.1: The USGS, SCS, NBS, and USACE should initiate a scientific research program to conduct detailed geomorphic/hydrologic/topographic mapping of the lower Missouri River floodplain and selected upper and middle Mississippi River floodplains to develop an overall geomorphic physical process model stratigraphic framework and geotechnical database. The program would identify floodplain zones of variable flood risk and would include analysis of the age of floodplain zones, sedimentation rates, and the record of prehistoric large floods.**
>
> **Recommendation 8.6: Develop a standard set of cross sections that can be updated by local, state, and Federal input for the modeling of long river reaches. The availability of a standard set would reduce the cost of modeling and facilitate the development and calibration of a basin-wide model that could be used for planning, design, operations, and forecasting if necessary. The standard cross sections must be updated when there are changes in floodplain morphology and must be available through the clearinghouse.**

UNET (2,3) is a one-dimensional unsteady-flow hydraulic numerical model that is used by the Mississippi Basin Modeling System (MBMS) team offices to model the Mississippi and Missouri Rivers. UNET is able to simulate flow in a complex dynamic network of open channels with the capability to include off-channel storage, overbank storage areas and impacts of levee breaches. The UNET modeling system is suited for simulating long reaches of river experiencing the dynamic effects of levee breaches, backwater conditions, bed slopes of less than one foot per mile, and varying flow rates along the river. One of the fundamental inputs to UNET is a geometric description of the system, which contains cross-sectional river and floodplain data.

---

[1] Prepared by Michael Gee, HEC and Dennis Stephens, MVS.

1.1 Technical Background. Digital terrain models (DTMs) are essentially topographic maps in computer form. If sufficient detail is available in a DTM, it becomes possible to extract cross-section geometry for river hydraulics modeling from that DTM. Programs for this purpose have been developed by a number of agencies and companies. One of the advantages of constructing hydraulic models in this way is that it becomes easier to update the model data as new survey data become available. Furthermore, the same digital terrain model can be used in combination with the simulation results to produce maps of inundated areas.

A substantial quantity of DTM data is now available for river floodplains in the Mississippi basin. These DTMs come from two sources: 1) data compiled at the recommendation of the SAST team following the 1993 floods, and 2) photogrammetric surveys carried out in 1998 under the direction of the Corps of Engineers. The current effort is directed at generating a new set of cross sections for the Mississippi UNET forecasting model, based on these DTMs.

The primary channel geometry for the St. Louis District's Mississippi River model was gathered in the late 1970's. Data were gathered by limited field survey cross sections and USGS 7.5" series quadrangle maps. Slight changes were made to the model after the 1993 flood, but those cross sections still represent the pre-digital 1970's conditions. Some concerns about the UNET model results have arisen because of the age of the cross sections.

This report compares the present day digital channel geometry obtained from DTM's to the previous cross-sectional data as suggested by SAST Recommendations 5.1 and 8.6. This study will focus on the Middle Mississippi River from the mouth of the Ohio River (RM 0.0) to about river mile 171.5, eight miles south of downtown St. Louis.

2. Procedure

2.1 Preparation of Digital Elevation Models. In response to the SAST recommendation, Congress funded the preparation of the new digital elevation models (DEMs). The models were prepared for the United States Geological Survey (USGS) with the St. Louis District Corps of Engineers (USACE) administering the contracts. An independent contractor was selected to complete the photogrammetric mapping and related surveys needed in the preparation of the DEMs for portions of the Mississippi, Missouri, and Illinois Rivers.

All surveying and photogrammetric mapping work was referenced to NAD 83 (horizontal datum) and NGVD NAVD 88 (vertical datum). Surveys were performed to establish the horizontal and vertical locations of approximately 108 points, marked and labeled, that were used in controlling the stereoscopic models. Each airborne Global Positioning System (GPS) controlled coverage block contained four of these points. Photogrammetric control was accomplished with the combined use of airborne GPS control data for each photograph and supplemental ground survey control for selected points.

The three-dimensional Cartesian coordinates for mensurated photo control points were derived using fully analytical, simultaneous block aerotriangulation adjustment methods. When expressed as a ratio of the flying height, the root mean square (RMS) error for the control points was not more then 1:10,000 in horizontal (x and y) and 1:10,000 in elevation (z).

The DEMs contain all representative and specified hypsographic features visible or identifiable on, or interpretable from, the aerial photographs. One meter contour intervals were generated from the photography, except through densely wooded areas where the ground cannot be seen and where it was obscured by an overhanging bluff or ledge. In such ground-hidden places, data was not collected. Mass points and break lines were established to define flow and drainage patterns for ditches, swamps, sloughs, etc. Water limits and edges of roadways were also noted with the use of mass points and breaklines.

To obtain higher accuracy DEMs for selected linear features, the data collection specifications required an 0.5 foot RMS error for DEM posts with a vertical resolution in tenths of a foot. Selected linear features included the centerline of major obstructions to river flow including roads, railroads, and levees. The location data was collected for these areas using kinematic GPS surveys and added to the DEMs for selected areas for complete coverage.

Stereoplotter-derived DEMs were furnished in USGS format, 1:5000 horizontal scale, generated on a preset grid interval of five meter horizontal posts from a triangulated irregular network (TIN) data set along with a network of random points supplemented with break-line points as required to depict topographic features. Intermediate breaks, highs, lows, etc., were added independently. Contours were generated off-line using standard DEM/CADD (Computer-Aided Design and Drafting) software and plotted on paper map sheets to be used as a check of the accuracy of the DEMs.

2.2 InRoads Conversion and Cross Section Designation. Focusing on the DEM blocks for the Middle Mississippi River from the mouth of the Ohio River (RM 0.0) to about river mile 171.5, the USGS format data was imported into InRoads where it was converted to digital terrain model (DTM) format. Metric units were converted to English units and the Universal Transverse Mercators (UTM) were converted to Missouri state plane geo-reference.

The DTM blocks were combined to form approximately five to six mile sections of the Middle Mississippi River. Main channel geometry (from the 1996 USACE hydrographic surveys) was imported and united with its appropriate section. The new cross sections were matched to the locations of the old cross sections by physical features. Several additional cross sections were also designated to better define the changing channel morphology and structures. For each channel section, the designated cross sections were converted from DTM into HEC-2 format, while filtering the cross section data to 99 points maximum. Because InRoads is not capable of producing UNET geometric file format, HEC-2 format was used because of its close similarities to UNET geometric file format.

2.3 Editing of Reach Lengths and Channel Geometry. A graphical HEC-2 edit module was used to adjust the new cross sections obtained by InRoads. (This step can now be performed using HEC-RAS.) Each cross section was inspected and identified with its respective section-cut on USGS 7.5" series quadrangle maps. Erroneous and missing data points were discarded or replaced with interpolated points. Some cross sections were altered to assure that left and right end stations extended well above the 1% annual chance flood elevation. Left and right overbank stations were selected and chute and slough bottom elevations were estimated. Areas of non-conveyance, such as creeks, standing ponds, and lakes, were removed from the active flow conveying portion of the cross sections using UNET channel encroachment options. With levee situations, UNET encroachment data were also used to identify areas of non-conveyance, whether to left or right of a levee station. Using USGS quadrangle and hydrographic survey maps, the distances between each section and its downstream section were manually measured for the main channel and overbank paths of flow.

2.4 Revision and Execution of UNET. The Middle Mississippi River UNET model, used in this study, extends on the Mississippi River from Grafton, Illinois (RM 218.3), to Birds Point, Illinois (RM 2.0). On the Missouri River, it extends from Hermann, Missouri (RM 97.9), to the mouth. On the Meramec River it extends from Eureka, Missouri (RM 34.1), to the mouth. On the Kaskaskia River, it extends from Venedy Station, Illinois (RM 57.2), to the mouth; and, on the Big Muddy River from Murphysboro, Illinois (RM 36.0), to the mouth. A schematic of the system embodied in the UNET Model is shown in Fig. 1.

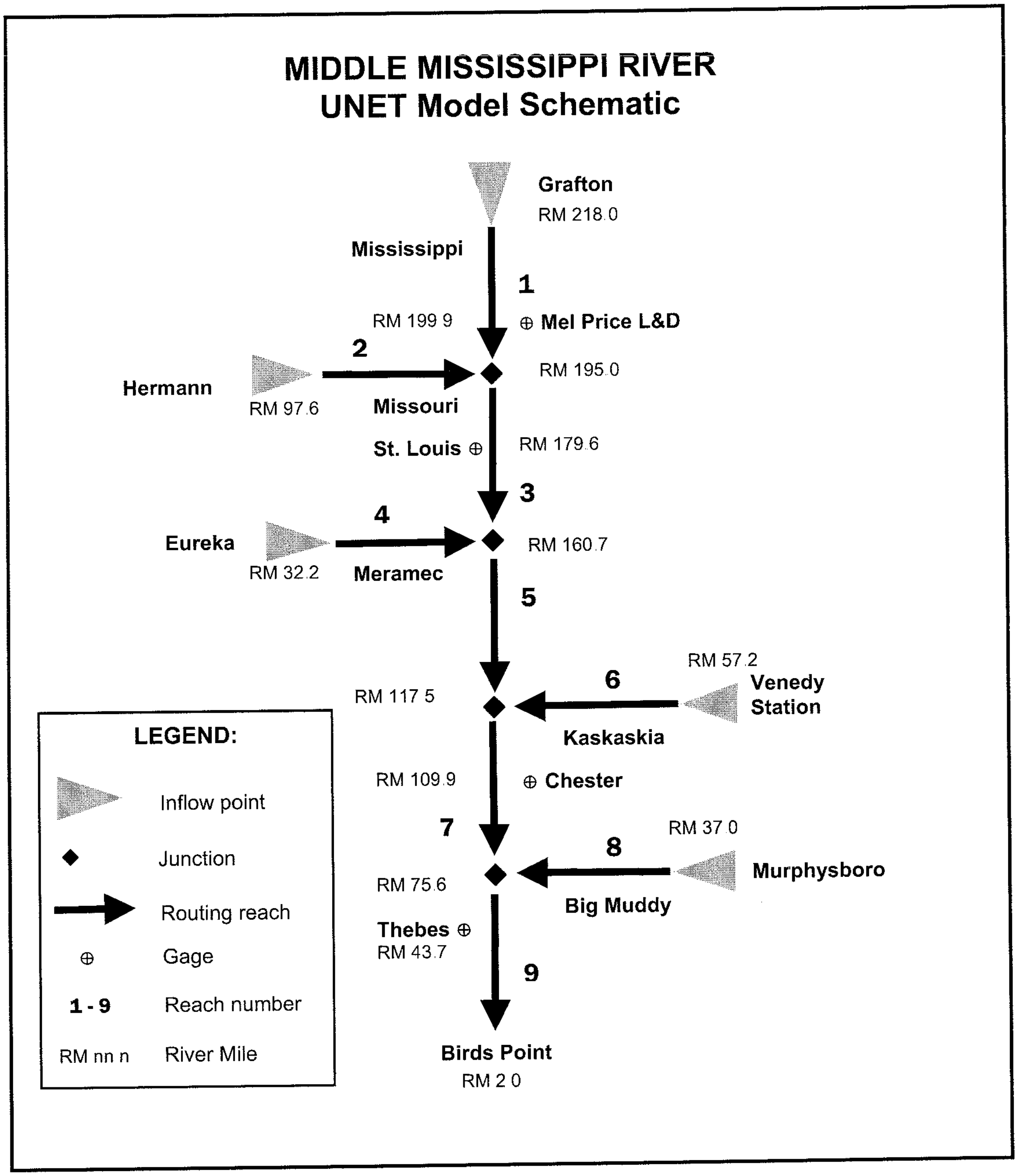


Figure 1. MVS UNET Schematic.

A new geometry input file for the UNET model was created using the old file as a template. The old geometry data for the four different river reaches was replaced with the new cross-sectional geometry, reach lengths, and encroachment data. The four revised reaches consisted of:

Reach 9 – Ohio River to Big Muddy River (RM 2.0 – RM 75.65)
Reach 7 – Big Muddy River to Kaskaskia River (RM 75.65 – RM 117.41)

Reach 5 – Kaskaskia River to Meramec River (RM 117.41 – RM 160.71)
Reach 3 – Meramec River to Missouri River (RM 160.71 – RM 195.0) (only partially updated to RM 171.46)

The time period used for comparison of the water surface computations was January 1, 1995 to January 2, 1996.

3. Calibration. The issues and procedures involved in the calibration of a UNET system application, particularly within the MBMS area, are complex. Typical Corps of Engineers applications of river hydraulics models such as HEC-2 and HEC-RAS utilize adjustments to Manning's *n* and cross section characteristics such as the channel/overbank separation for calibration. Historical applications of UNET also use these adjustments, which may be further adjusted several times (e.g., by the "Seasonal Conveyance Correction" factor) before the UNET unsteady flow solution is computed. Furthermore, UNET calibrations to observations may involve the adjustment of storage area characteristics, levee failure parameters, and adaptation of the software to model circumstances not previously encountered. An example is the "Elevation Controlled Gate" feature that was created by Dr. Barkau to reproduce the flow distributions observed during crossover flows between the Missouri and Mississippi Rivers in the Great Flood of 1993. Such software modifications will continue to be made. The documentation, computational components and data of any particular application should be closely reviewed and tested by user's of the UNET system.

The old model was calibrated using stage and discharge records for the drought years of 1988 and 1989, as well as the flood years of 1993 and 1995. Three calibration factors were applied to accomplish that calibration:

1. **Conveyance Change Factor** – used to adjust conveyance and storage between cross sections.
2. **Discharge-Conveyance Relation** – used to redefine a discharge versus conveyance rating curve between cross sections.
3. **Seasonal Conveyance Correction** – used to adjust conveyance on a seasonal basis.

These calibration factors are inserted by the user into the UNET data file (the .bc file). They are multiplied together with the CSECT-computed conveyance functions to produce the conveyance functions ultimately used in the unsteady flow computations.

The new and old geometry files used the same calibration factors during comparison of the computed maximum water surface elevations. The Manning's roughness coefficients and bridge cross sections were kept the same for both geometry conditions.

3.1 UNET Automatic Calibration (KR Feature). A close investigation by HEC of the data and computed results revealed that the impacts of the new geometry on UNET-computed water surface profiles were being masked by the use of KR records in the CSECT input files. The KR option enables computation and use of an additional, automatic, calibration factor that is applied to the cross section conveyance prior to the three factors mentioned above. (This is an undocumented UNET feature that is routinely used in MBMS forecasting models. Its use greatly facilitates the calibration and updating of real-time UNET forecasting models. Indeed, without such a capability, the application of UNET to day-to-day forecasting would be extremely cumbersome.) Existence of KR records in the data causes CSECT to apply an adjustment to the conveyance tables after they are printed and before the binary geometry file is prepared for use by UNET. Those adjustments bend the conveyance functions computed from the geometric data so that observed rating curves input to CSECT via DSS files are approximately matched in a steady-flow sense. This adjustment may be useful within the context of forecasting applications of UNET; however, the adjustments that are activated by the KR's are not obvious to the model user. When KR's are used, the conveyance-elevation functions output by CSECT for user evaluation are not those being used in the UNET computations. Thus, in this case, the conveyances for both old and new geometries were being adjusted to reproduce the same target objective function - an observed rating curve. In this instance the changes in the traditional conveyance due to the different geometries were, to a large degree, masked by the CSECT KR conveyance adjustments.

To isolate and evaluate the impacts of the geometric changes, the KR's were removed from the CSECT input files. An example of the computed profiles for Reach 3 is shown on Fig. 2. This illustrates, for example, that the difference in computed water surface elevation **due only to the change in geometry** is of the order of 2 ft. in this reach (compare NEW and OLD NOKR profiles.) The differences were up to 5 ft. in other reaches. The new data produces a higher water surface. These differences in computed profiles should not be generalized, however, because, in practice, the UNET data for both the "old" and "new" geometries would be calibrated to their appropriate corresponding flood events resulting in profiles similar to those shown as "OLD GEO" and "NEW GEO" (which were computed using the UNET automatic calibration function implemented via the CSECT KR records).

A comprehensive description and discussion of all the calibration options available in UNET, their interactions and their appropriate usages is beyond the scope of this report.

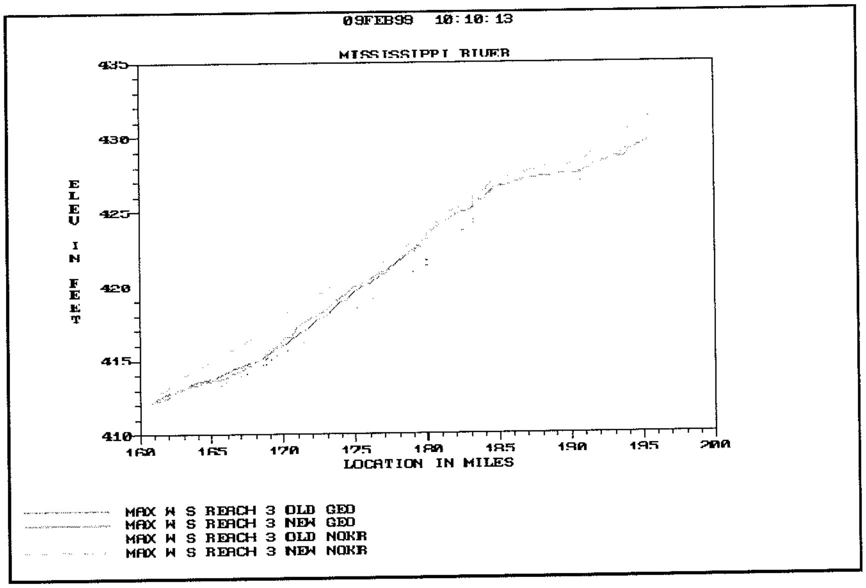


Figure 2. Example Water Surface Profiles with Old and New Geometry

4. Discussion of Results

4.1 Cross Section Geometry Comparison. The comparison of the cross sections generally shows no significant change in cross section shape, however the DEM data produced better definition of the section. (The locations selected for discussion below were also used in the St. Louis report (4), which evaluated the impacts of new topography under the operation of UNET automatic calibration.) For example, the plot of cross sections at RM 53.1 (Old) and RM 53.13 (New) in reach 9 shows higher resolution of the floodplain with the DEM data. Note the following computed maximum water surface elevations when examining Figures 3 and 4.

	Old data	**New data**
WSEL at Sec. 53.1	350.9 ft.	355.5 ft.
WSEL at Sec 40.1	343.0	345.1

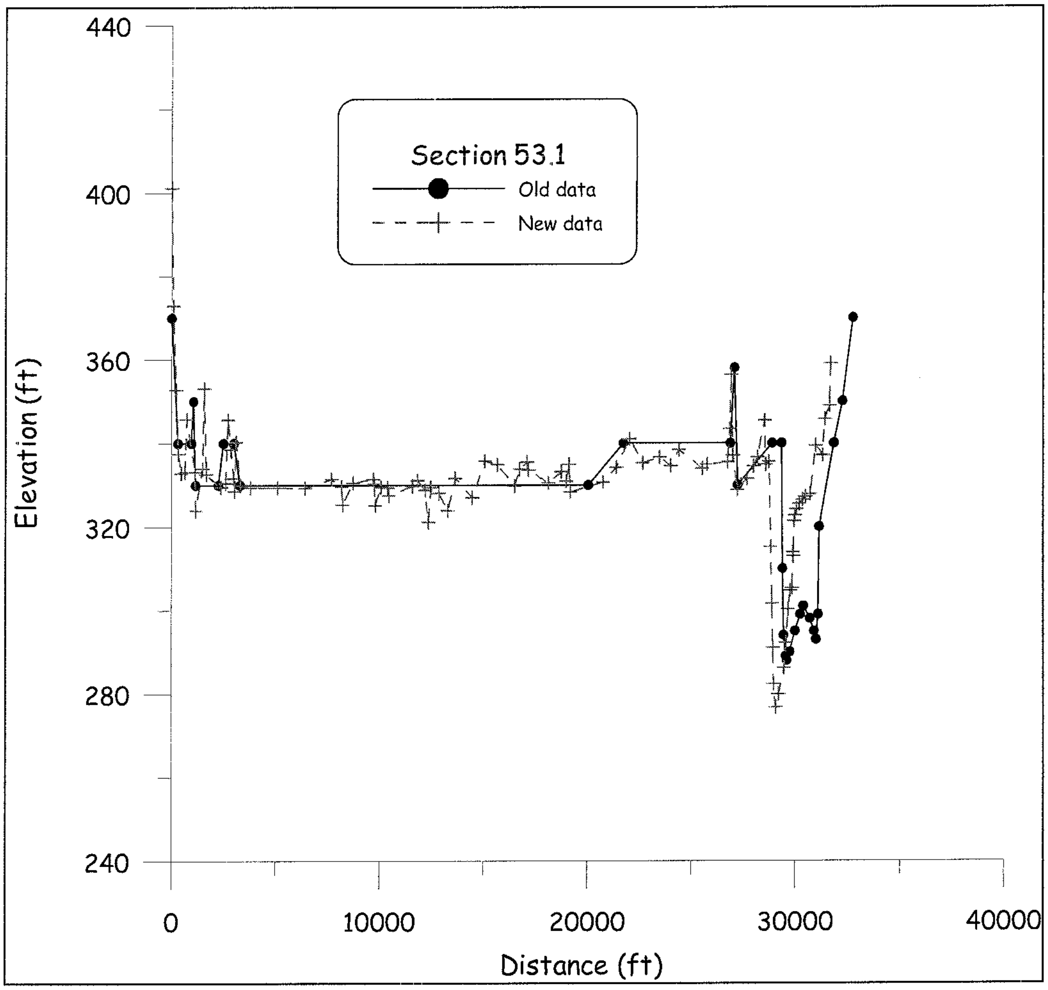


Figure 3. Cross Section 53.1

Occasionally, the cross sections exhibited noticeable differences. For example, the cross sections at RM 40.1 (Old) and 40.09 (New) show a significant difference in the left overbank which was not fully defined in the old survey. Lack of survey information as well as morphology changes are possible reasons for this disparity.

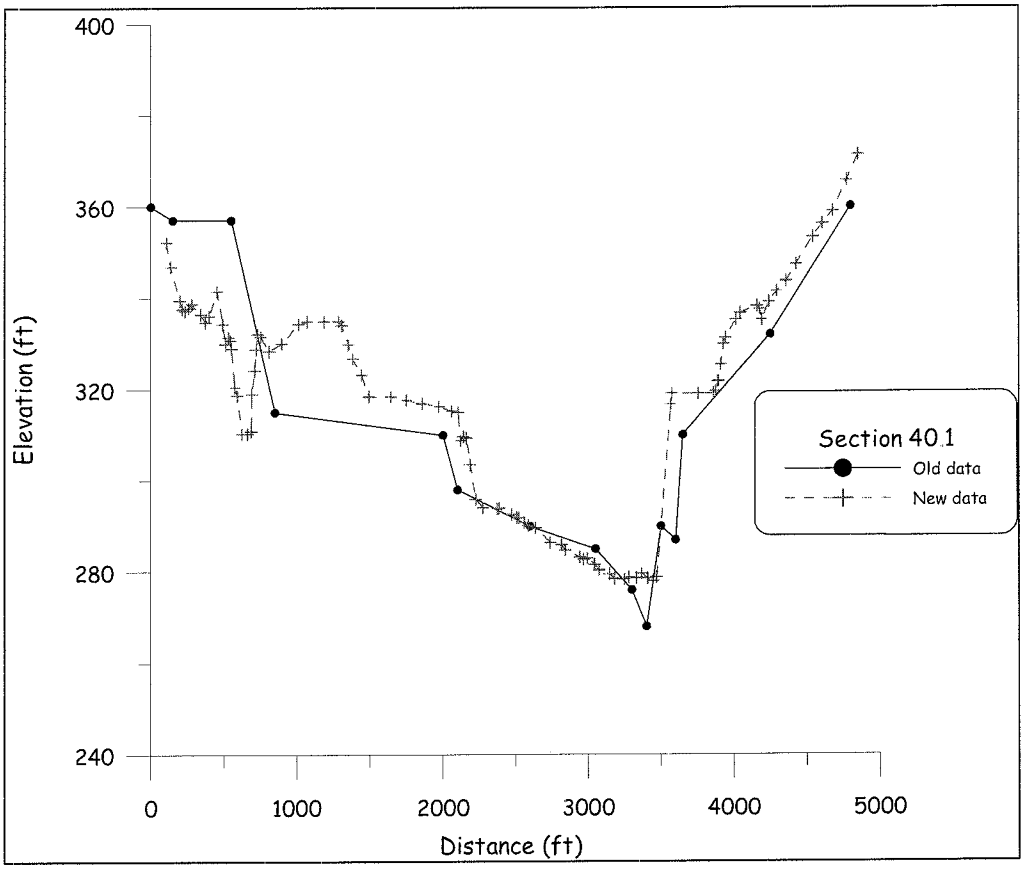


Figure 4. Cross Section 40.1

The computed water surface elevation at RM 40 is about 344 ft. Therefore, this difference in geometry (shape of the cross section) will affect the hydraulic computations at these water surface elevations.

These comparison plots demonstrate the following general characteristics of the DEM model:

1. The digital technology allows for fully defined sections yielding more detailed floodplain definition.
2. The linear features (roads, railroads, and levees) were more accurately defined.
3. The new cross sections have altered channel features that reflect present day morphology.
4. Associated with better and updated channel definition, the conveyance relations of the geometry model are improved.
5. In general, new overbank elevations are slightly higher. This is primarily due to changed floodplain morphology resulting from the 1993 flood.

4.2 Stage vs. Conveyance Comparison. Conveyance, a measure of the flow carrying capacity of a cross section, is defined as:

$$K = (1.49/n)AR^{2/3}$$

where:
n = Manning's roughness coefficient
A= Flow area (ft^2)
R= Hydraulic radius (ft)
= A/P
P= Wetted perimeter (ft)

The direct effect of the new geometry on hydraulic computations is evidenced in changed conveyance, as shown in Figures 5 and 6.

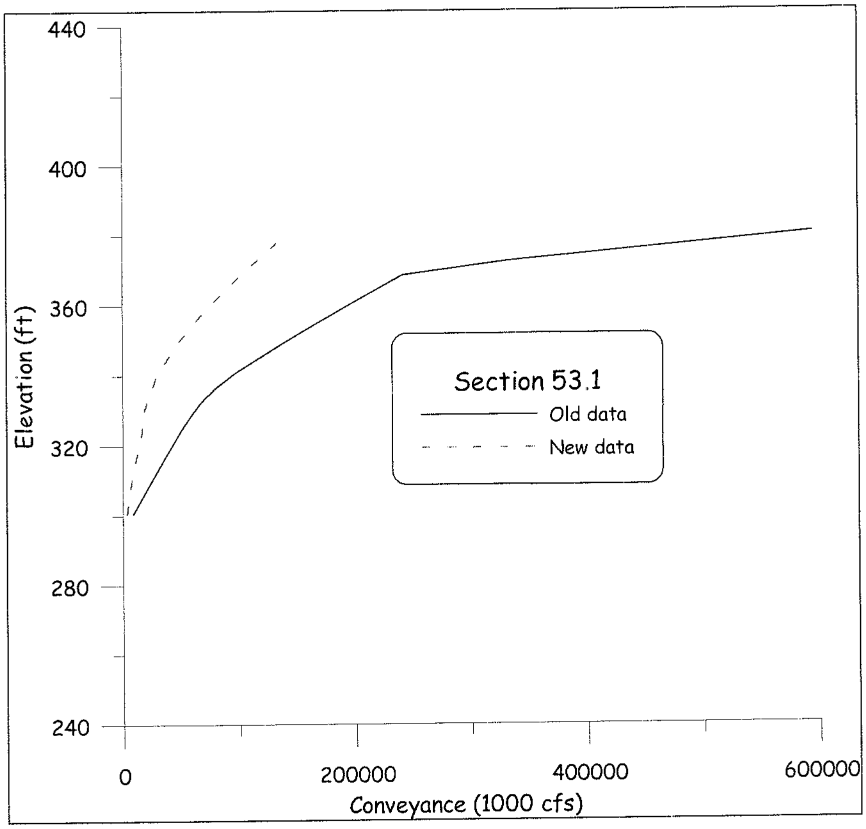


Figure 5. Conveyance - Cross Section 53.1

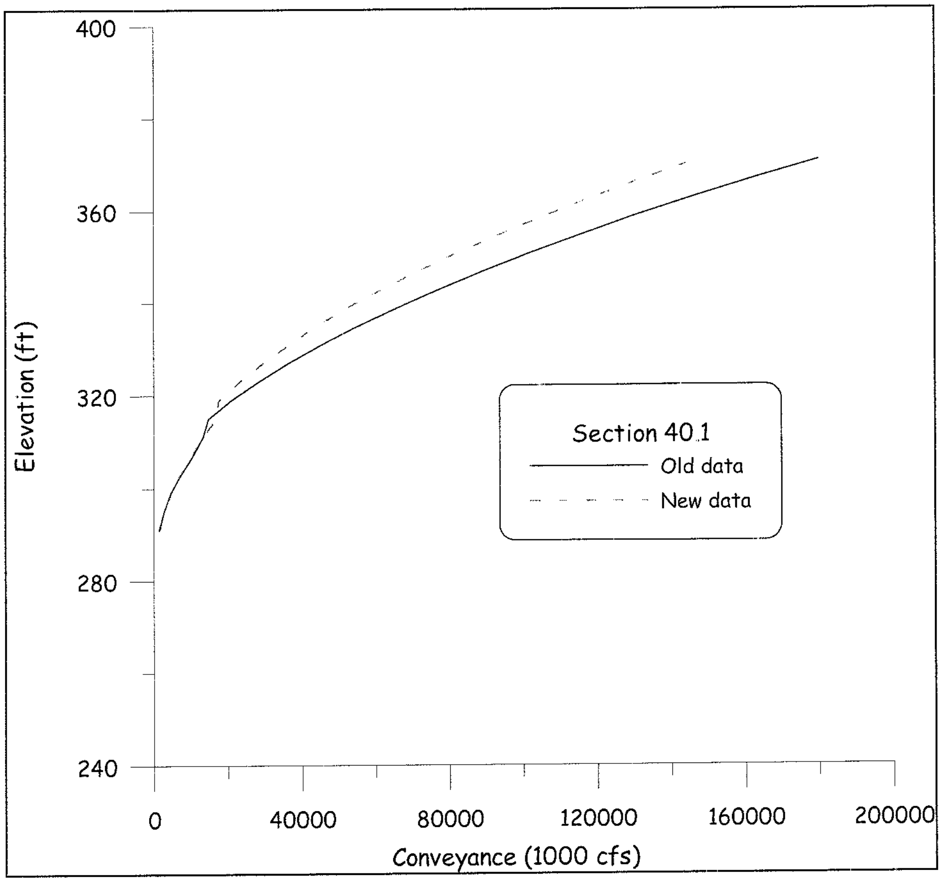


Figure 6. Conveyance - Cross Section 40.1

The conveyance values shown above for the selected cross sections do not incorporate any post-geometric processing conveyance modifications done by the CSECT module of the UNET system; such as would result from use of automatic calibration (KR option). These comparisons demonstrate that the conveyances for the new cross sections are substantially lower than those of the old. Indeed, at the elevation of the maximum computed water surface elevation for RM 53.1 (351 to 355 ft.) the conveyances differ by a factor of more than two. This difference is caused primarily by more ground points in the cross section data resulting in larger wetted perimeter (note that additional non-colinear ground points increase the wetted perimeter and, therefore, decrease the conveyance at any given elevation (refer to Fig. 3) and some changes in channel morphology. Manning's *n* values and channel station locations were <u>not</u> modified.

4.3 UNET Model Analysis Comparison. The computed results will differ substantially from the old results (see Fig. 2) **just due to the increased sampling frequency of the cross section ground points.** More ground points will result in larger wetted perimeter, less conveyance and higher computed water surface elevations. These differences may be masked by using automatic calibration features of UNET. While useful in forecasting applications, these features should be nullified when replacing geometry so that the focus can be on separating geometric influences from calibration adjustments.

4.4 A Protocol for Evaluating Worth of New DEM Data. The findings given herein relate to the influence of changed (new) geometry on hydraulic computations using UNET. The changes investigated herein were constrained to comparing results obtained from traditional field surveys and USGS topographic maps as the data source to those obtained using contemporary digital elevation technology, holding all other factors constant. To test whether the use of such new data produces "better" modeling results, the following protocol is suggested:

1. Calibrate UNET with "old" geometric data to a given set of objectives (events).
2. Use that calibrated UNET model to reproduce a newer, non-calibration event.
3. Calibrate UNET with "new" geometric data to the same set of objectives (events).
4. Use that calibrated UNET model to reproduce the event in (2).
5. Compare the errors (computed-observed) resulting from (2) to those from (4).

Implementing this protocol for testing the worth of DEM data was beyond the scope of this study.

5. Findings

This report documents the comparison of UNET-computed water surface profiles using 1970's floodplain cross sections with newly acquired DEM's. The data and calibration procedures were obtained from the St. Louis District. The comparison of the two data sets reported herein should only be applied to this data. The implications of the results, however, should be noted by all those replacing the old technology UNET cross sections with new technology digital topography.

Note also that, while use of DEM's facilitates the acquisition of more cross sections, this study only addressed increasing the resolution and accuracy of cross sections taken from the new DEM at the old locations. A more complete comparison could not be done because the old cross section data is not georeferenced.

Following are the findings of this study:

- The computed results may differ substantially from the old results (see Fig. 2) **just due to the increased sampling frequency of the cross section ground points.**
- The **computed water surfaces will be higher** with denser ground points due solely to increased wetted perimeter, all other factors being held constant.
- The **new geometry file accurately reflects the current floodplain morphology**.
- Associated with the floodplain morphology, the **hydraulic properties of the floodplain sections are improved.**
- The old geometry, obtained using quadrangle maps and limited cross sections surveys, yields acceptable results with UNET calibration, but the new geometry file leads to a more defensible position of the model results; therefore, **wider public and private acceptance can be expected.**
- Production and use of **inundation maps** is a direct and substantial benefit of using DEM's.
- A **better floodplain feature recognition** also results from the new digital data; these features will be evidenced in inundation mapping of the computed results.
- The influence of **automatic calibration algorithms** must be isolated from the evaluation of the impact of new digital terrain information on computed UNET results as the impacts of the new geometry on UNET-computed water surface profiles can be masked by the auto-calibration.

In conclusion, the new floodplain cross sections enhance the efforts of floodplain management through better management of data and presentation of results. Addition of DEM technology may significantly improve public acceptance of the hydraulic results. The new Middle Mississippi UNET model along with DEM technology has the ability to assist Federal, State and local authorities in improving floodplain emergency management measures.

References

1. Kelmelis, J. A., ed., *Science for Floodplain Management into the 21st Century*, U.S. Geological Survey, 500 National Center, Reston, VA 20192, 1997.
2. HEC, "Mississippi Basin Modeling System Development and Application," PR-36, April 1998.
3. U.S. Army Corps of Engineers, Hydrologic Engineering Center (HEC), "UNET One-Dimensional Unsteady Flow Through a Full Network of Open Channels," User's Manual, CPD-66, Ver. 4.0, April 2001.
4. U.S. Army Corps of Engineers, St. Louis District, "Comparison of Unsteady State Hydraulic Results using Digital Elevation Model (DEM) Cross Sections versus Field Surveys and USGS Maps Taken in the 1970's," Dec. 1998.