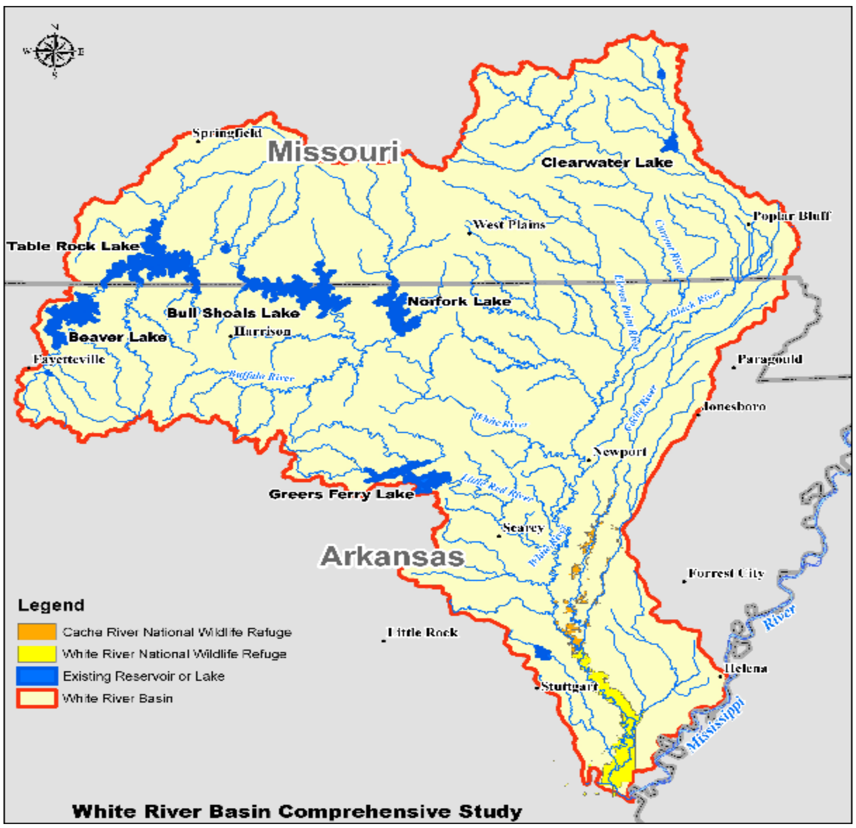
Final Report

White River Basin Comprehensive Study: Development of Unsteady-State Model



Prepared for
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1. Introduction

1.1 Study Authorization

The White River Basin Comprehensive Study is being carried out under the Corps of Engineers' General Investigations (GI) Program. This Section 905(b) Analysis was prepared as an initial response to Section 729 of the Water Resources Development Act (WRDA) of 1986, as modified by Section 202 of WRDA 2000, which reads as follows: "SEC 202 WATERSHED RIVER BASIN ASSESSMENTS. Section 729 of the Water Resources Development Act of 1986 (100 Stat. 4164) is amended to read as SEC. 729 WATERSHED AND RIVER BASIN ASSESSMENTS. The Secretary may assess the water resources needs of river basins and watersheds of the United States, including needs relating to:

(1) Ecosystem protection and restoration;
(2) Flood damage reduction;
(3) Navigation and ports;
(4) Watershed protection;
(5) Water supply; and
(6) Drought preparedness.

1.2 Study Narrative and Purpose

The general purpose of the White River Basin Comprehensive Study is to determine if there is a federal interest in providing solutions to a full spectrum of water resources related problems and opportunities in the White River Basin (Figure 1) for ecosystem restoration, navigation, flood damage reduction, agricultural and municipal water supply, waste water treatment, aquifer protection, water quality improvement, water fowl management, and aquatic and wildlife habitat restoration. The White River Basin is a large and comprehensive watershed that extends across portions of the states of Arkansas and Missouri. Existing water problems and potential future water related problems need to be identified and examined in a comprehensive manner. The interrelationships of the problems and potential solutions to all of the significant resources in the basin have also required assessment by using the proper methodology associated with newly developed techniques that fully cover the dimension of the problems. All studies authorized under the White River Basin Comprehensive Study as described above were to assess water and related land management needs in the White River Basin, and to develop a comprehensive plan for the environmentally sustainable development of water resources within the Basin.

This study was one of the projects under the White River Basin Comprehensive Study to exploit in both short and long-term flow simulations and to support specific White River projects, such as navigation, flood damage reduction, feedlot runoff, levee protection, wetland delineation, ecosystem restoration, recreation, critical aquifer protection, and agricultural water supply. One effective strategy to describe full flow conditions for those projects is to develop conceptual hydraulic models for determination of flows in the channel and on the floodplain.

A number of conceptual hydraulic models on the White River were developed in the 1980's and 1990's for navigation, dredging, channel improvement, flood damage reduction, levee protection, wetland protection, ecosystem restoration and protection, recreation, critical aquifer protection, and agricultural water supply issues. A disadvantage of those models was they were limited to a traditional standard-step-backwater approach with steady-state flow conditions or constant frequency flows. With the lack of dynamic water simulation, they were unable to address real-time flow simulations. Since those models contained general geometric data based on the 1980's hydrographic survey data, those models were limited in accurately estimating flow lines across the channel and on the floodplain because the data were out-of-date and less reliable. In particular, over the last two decades, the meandering of the White River has altered channel geometry considerably. As a result, the previous models are not well-suited to accurately simulate current flow conditions.

Another disadvantage of those steady-state hydraulic models was that the models were not able to describe channel storage, routing, and water interface between the channel and the floodplain. To express the wide range of dynamic changes in the river system, there was an urgent need to develop a dynamic unsteady-state model for the White River. This model should specifically represent the various flow regimes in the channel and over the floodplain under time-dependent circumstances.

1.3 Study Objectives

The specific objectives of this study include: (1) develop the framework of a one-dimensional unsteady-state hydraulic model; (2) collect data to support flow analysis for the unsteady-state model; (3) develop cross sections for the unsteady-state hydraulic model using HEC-GeoRAS model; (4) determine the roughness parameters for model's calibrations; (5) calibrate and verify the model; (5) conduct a sensitivity analysis; and (6) apply the model to specific projects in the White River Basin.

1.4 Study Area

The White River Basin has a drainage area of approximately 27,765 square miles, of which 10,622 square miles are in the southern part of Missouri and the remaining 17,143 square miles are in northern and eastern Arkansas. There are 5 large Corps multi-purpose lakes /reservoirs in the upper Whiter River Basin, i.e., Beaver, Table Rock, Bull Shoals, Norfork, and Greers Ferry. The operation of those reservoirs would become more complicated during the dry or wet season because it could either increase or decrease the discharges on the White River.

The lower portion of the White River Basin is a significant migratory waterfowl wintering area, including several Federal wildlife refuges and state management areas that comprise one of the largest remaining areas of bottomland hardwood forest in the Mississippi Valley. The White River Basin also consists of over 150 miles of flood control levees along the White River that may impact flood control, floodplain protection, channel navigation, environmental restoration and protection, and recreation.

For this study, the major modeling area comprises the main stem or the channel of the White River from the confluence of the Mississippi River and the White River (RM 0.0) to Newport (RM 258.94), Arkansas (Figure 2). The floodplain on both the right and left banks, stretching at least 3 to 5 miles from each bank of the main channel, is also considered in the model.

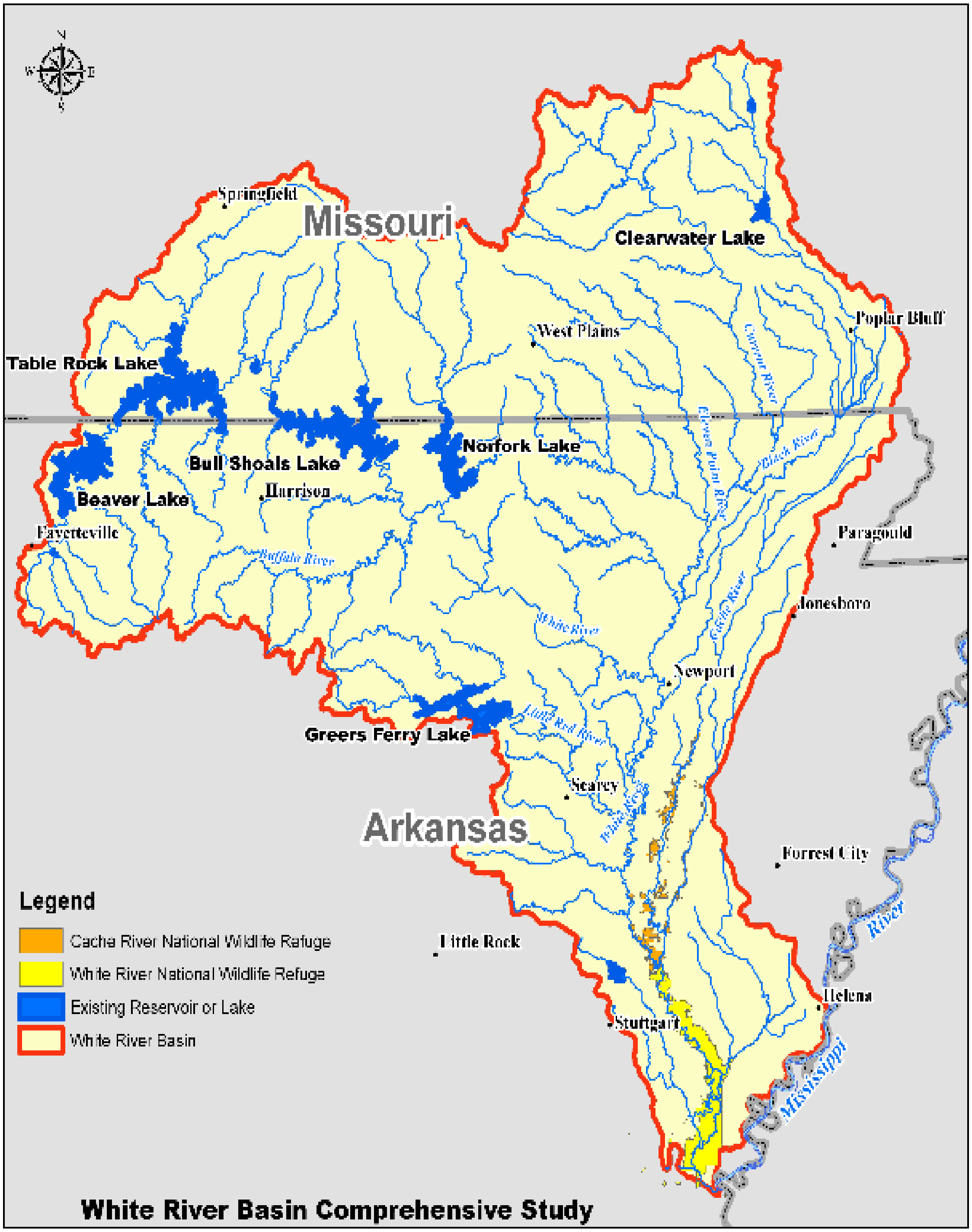

Figure 1. Comprehensive Study Area of the White River Basin

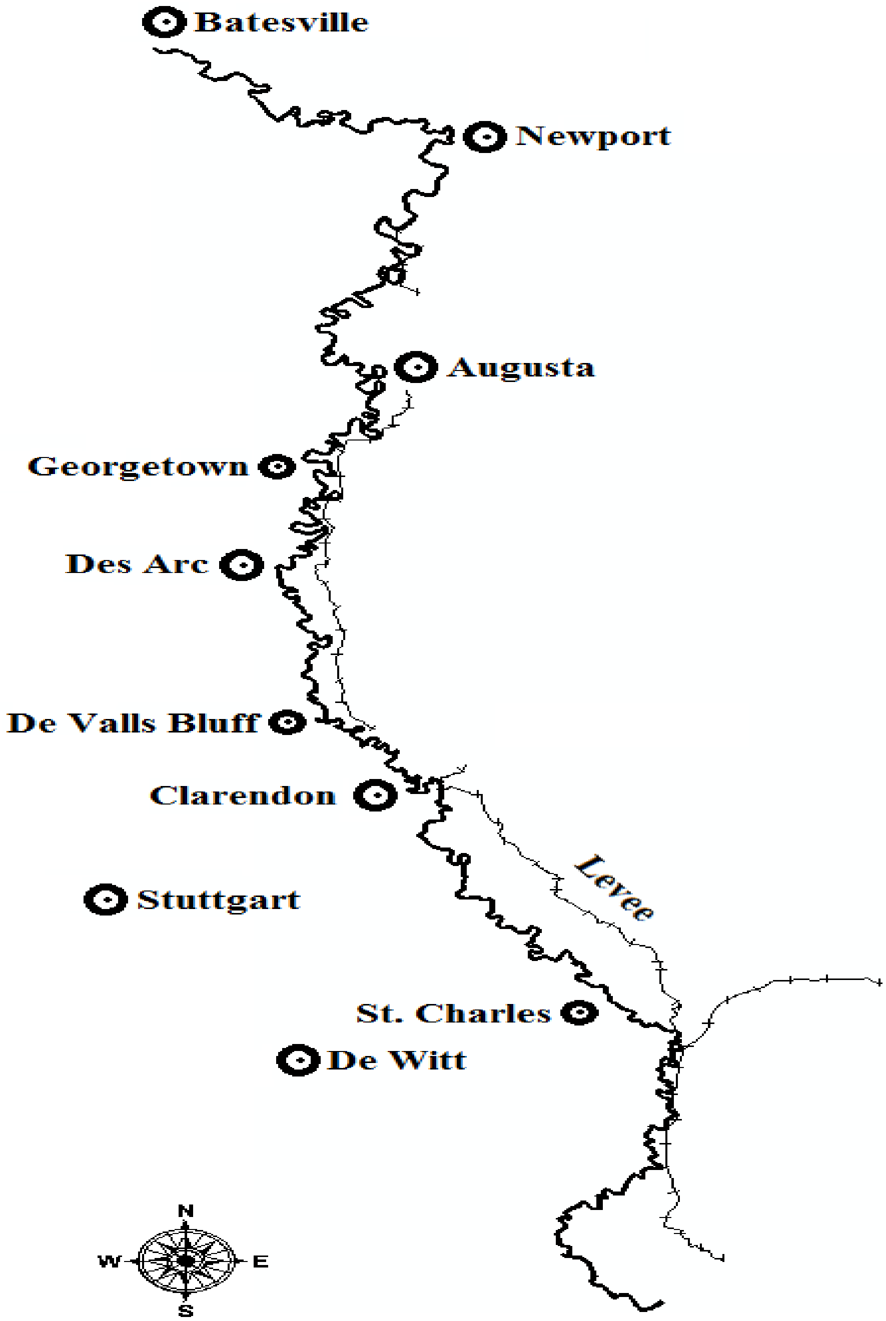

Figure 2. Study Area of the Unsteady-State Model on the White River

Levees along the White River and its tributaries were also included in the model to adequately simulate conditions up to the 100 year frequency flood. Therefore, this model covers various flow events including 1.01, 2, 5, 10, 25, 50, and 100 year frequency flows, which represent as annual percent chance of exceedance.

2. Methodology and Procedure

2.1 Field Study

Field trips to observe unstable channel, channel incision, bank erosion, and high-low water marks took place in the summer of 2008 and in the fall of 2009. Photos of those sites were taken during the field trips by using a Ricoh 500SE Global Positioning System (GPS)-ready digital camera, which provides photos with integrated GPS technology and high resolution pictures. The camera is capable of receiving NMEA data streams from external GPS devices via its on-board Bluetooth(R) radio. With the specific geo-reference, all photos were able to position on ArcMap, ESRI's Geographic Information Systems. As those photos were added to channel alignment files, such as river center, overbanks, flow lines, levees, and river conditions on ArcMap, it was easily to identify unstable sites, erosion, roughness of the channel and overbank, floodplain geomorphology, and wetlands. Additional information related to those sites was further compiled to support a field hydrographic survey, unsteady-state model development, model calibration, model verification, and model sensitivity study. An example of the photos added to ArcMap is shown in Figure 3.

2.2 Channel Geometric Data Collection

Geometric data collection throughout the entire channel and floodplain was the major task to support the channel schematic system in the unsteady-state model. For this study, an integration approach was carried out to combine channel geometric data and land elevation data. In the field, the hydrographic survey was limited to the main channel of the White River. Overland elevation data were obtained from the state of Arkansas and the U.S.G.S. digital elevation models (DEM). The hydrographic survey data and the overland elevation data were then merged following the procedures as described below:

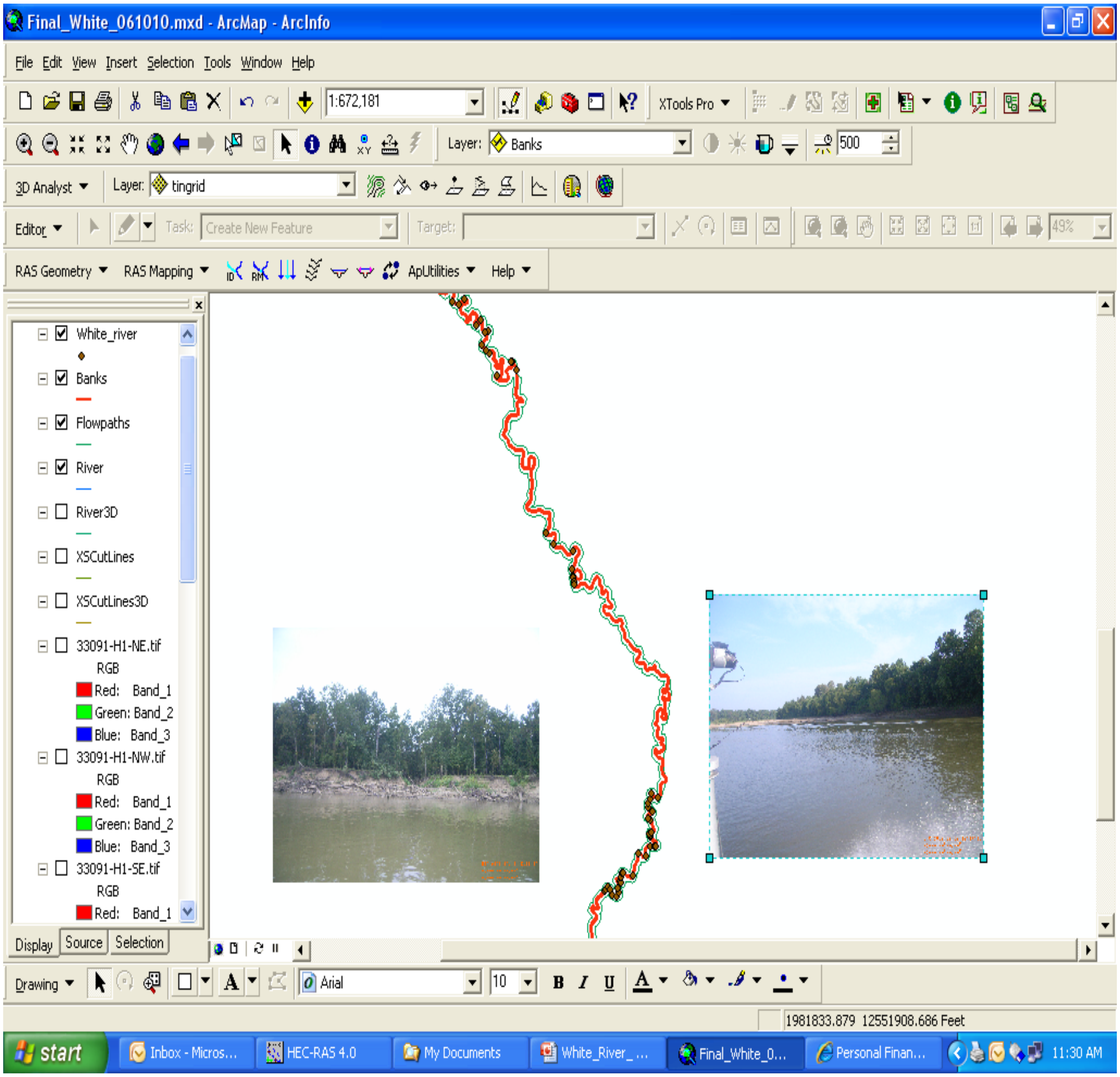

Figure 3. Photo Examples Taken from Field Trips

Starting in the spring of 2008 and ending in the summer of 2009, the hydrographic survey was performed from the confluence of the Mississippi River and the White River to Newport, Arkansas by boat. The hydrographic survey equipment on the boat was mounted in the cabin of a 24-foot tri-hull aluminum vessel equipped with twin inboard motors. The hydrographic system contained on the survey vessel consisted of a GPS receiver with a built-in radio and an antenna, a dual frequency depth sounder with single or multi-beam sonar, a helmsman display for navigation, a plotter, a computer, and hydrographic system software for collecting the underwater data. Power to the equipment was supplied by an on-board generator. To obtain the maximum radio transmission range, several known datum points near and higher above the water surface or close to the gage stations were selected.

The hydrographic survey started with establishing the control points along the river. The crew then drove the boat across the river channel following a systematic grid system. The survey was conducted on the White River by collecting data every 200 ft across the channel and at a distance of 20-30 ft on each cross section line. If the water was too shallow or distance was too close to the banks, the survey boat would stop and move to the next survey position.

According to the Corps Memphis District River Reference Plane, the Low Water Reference Plane (LWRP) was the primary reference system for the hydrographic survey. The survey measured the distance from the water surface to the bottom of the channel. The value reported as a Z value was the third dimension of a 3-D Cartesian coordinate system. X and Y coordinates (or horizontal and vertical coordinates) of each point associated with a Z value were simultaneously read from a Global Positioning System (or GPS) during the hydrographic survey. However, X and Y coordinates were reported as the North American Datum, 1983 Reference Plane. To handle data consistently throughout the channel and to be consistent with river gages along the White River, all data were converted to the 1929 National Geodetic Vertical Datum (NGVD) elevation for the channel and the 1983 the North American Datum for the overland. This conversion was performed within ArcMap's Geographic Information Systems.

Daily hydrographic survey data were obtained from the field. The data were saved and added into ArcMap. Upstream and downstream gage locations and stage elevations at the same date were also collected and positioned on ArcMap. The elevation of each survey point corresponding to the upstream and downstream gage stations was interpolated. Finally, hydrographic survey data of all points on the White River were merged into one file. Using 3-D Analyst Tools, the feature points of the White River channel were converted into a RASTER DEM. Figures 4 and 5 show the results of this merge.

Data on the floodplain or overbanks were obtained from existing elevation models, such as the Arkansas State 5-meter digital elevation model and the U.S.G.S 10-meter digital elevation model (DEM). However, those DEMs only represent the overland elevations. The elevation of the water surface was measured with the data collected from those DEMs were different and not the underlying channel geometry. The hydrographic survey data was required to provide additional data to support the unsteady-state model. To combine the hydrographic survey data with the overland elevation models, ArcMap data management tools in 3D Analyst Tools was used in this study. The channel DEM and overland DEM were united using MOSAIC in ArcMap. The final combined DEM of the entire White River Basin was used to produce the geometric data in the unsteady-state model.

2.3 Flow and Stage Analysis

Flow and stage data that provide upstream and downstream boundary conditions are needed to produce an accurate unsteady-state model. The model also needs the frequency flows to calibrate the model under the steady-state condition. There were two approaches to obtain flow and stage data in this study; one was the real-time gage data measured in the field and the other was the data from a synthetic hydrologic model, called the Supermodel. There are eleven real-time gage stations in the lower White River basin operated by the U.S. Army Corps of Engineers, Memphis District and the U.S. Geological Survey. These gage stations are Hudson Landing, Benzal, St. Charles, Aberdeen, Clarendon, Devalls Bluff, Des Arc, Georgetown, Augusta, Newport and Batesville. Only daily real-time stage and discharge data at Clarendon (RM 100.05), Georgetown (RM 169.52), Augusta (RM 204.34), and Newport (RM 258.94) were

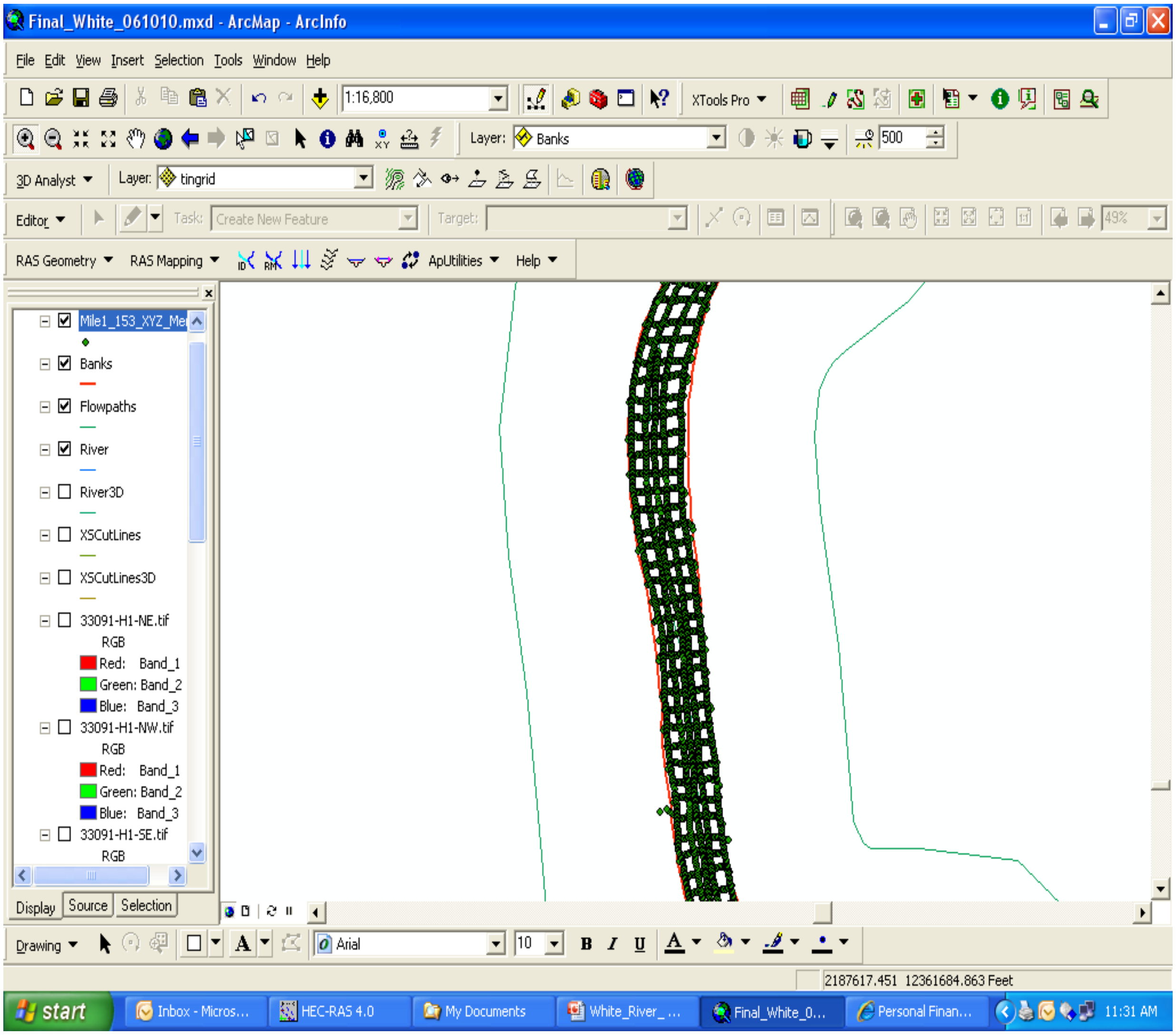

Figure 4. Data Merge from Hydrographic Survey on River Mile 0.0 to 30

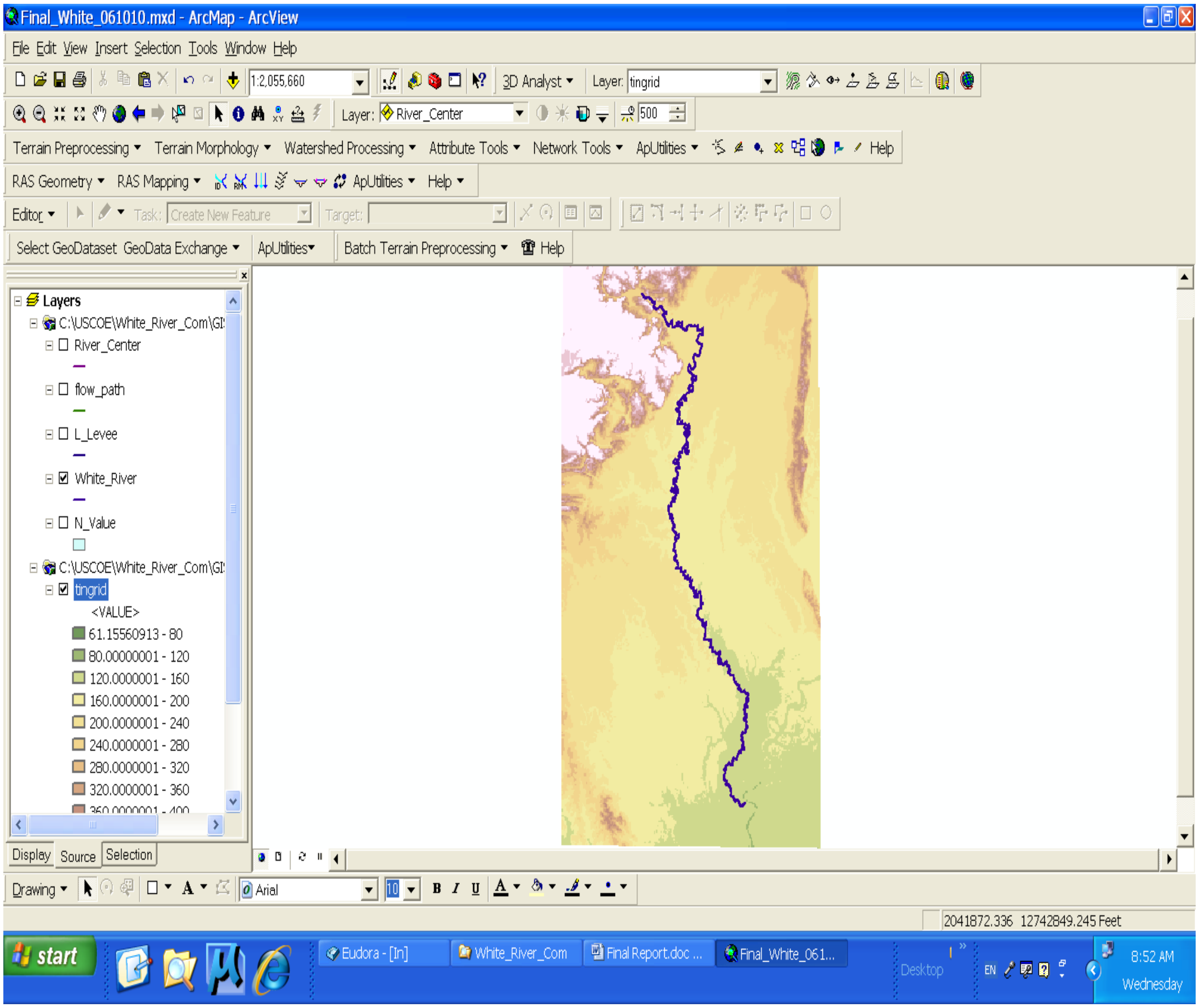

Figure 5. Mosaic Digital Elevation Model on the White River

collected and used for the model's upstream boundary and downstream boundary, model calibration, and model verification.

Since 1965, Beaver, Taneyacome, Table Rock, Bull Shoals, Norfork, and Greers Ferry lakes/reservoirs were built on the upper White River. The reservoir operation that is regulated by the Corps of Engineers and h Southwestern Power Administration (Southwestern) as affected discharge flows and the stages on the White River system. The Supermodel (USACE, 2005) was designed to simulate the regulation of multi-reservoir operation on a daily basis and to calculate the discharge and the stage at the control points according to rules related to flood control, hydropower water demand, stream flow into and out of the system, and flows required by irrigation, recreation, and fish and wildlife purposes. The Supermodel was originated by the U.S. Army Corps of Engineers, Little Rock District and Southwestern Division in Dallas, Texas. For this study, the flow and stage data from major control points including Clarendon, Georgetown, Augusta, and Newport were collected from the Supermodel during 1965 to 2009 as well.

Prior to conducting flow analysis, the Supermodel data and the real-time gage data were compared and verified. Rating curves at those control points were plotted and compared. As shown in Appendix A, a comparison of rating curves developed from collected measurements and computed from the Supermodel are similar, indicating that the flows and stages of those two data sets reasonably agree with each other. In Figures 6 and 7, the historic real-time data and the Supermodel data at Clarendon show a similar pattern. The flows are typically lower in the summer season and higher in the late spring and early winter.

The discharge data of the real-time gage readings and the Supermodel data on the White River were used for the frequency analysis. The Corps has established standard methods to estimate flow duration for stream flow gage stations using "Bulletin 17B: Guidelines for Determining Flood Flow Frequency" issued by the Water Resources Council (U.S.G.S., 1982). The guidelines provide a complete detailed procedure for flood flow frequency analysis. The Pearson Type III distribution with log transformation of flow data is recommended as the basic distribution for the annual flow analysis. A flow-frequency curve is a graphical representation of the percentage versus time that stream flow for a given time step is equaled or exceeded during a specified period at a stream site. Flow-frequency curves usually are constructed by first ranking all of the daily discharges for the period of record at a gage station from largest to smallest, next selecting the maximum daily discharge as the annual maximum discharge, computing the probability for each value being equaled or exceeded, then plotting the discharges against their associated exceedance probabilities. For this study, flow-frequency analysis was done by use of the US Corps of Engineers' HEC-SSP software (Figure 8). Flow-duration statistics are points along a flow-frequency curve. For example, the 99-percent stream flow is equaled or exceeded 99 percent of the time, whereas the 10-percent stream flow is equaled or exceeded 10 percent of the time. The annual maximum discharges and stages from 1965 to 2009 were extracted from real gage readings and the Supermodel. 99%, 50%, 20%, 10%, 4%, 2%, and 1% represent the 1.01 year, 2 year, 5 year, 10 year, 25 year, 50 year, and 100 year frequency flows, respectively.

Table 1 compiles the results of the frequency analysis for Clarndon, Georgetown, Augusta, and Newport on the White River. It clearly shows the flow increases as the frequency increases on each gage station.

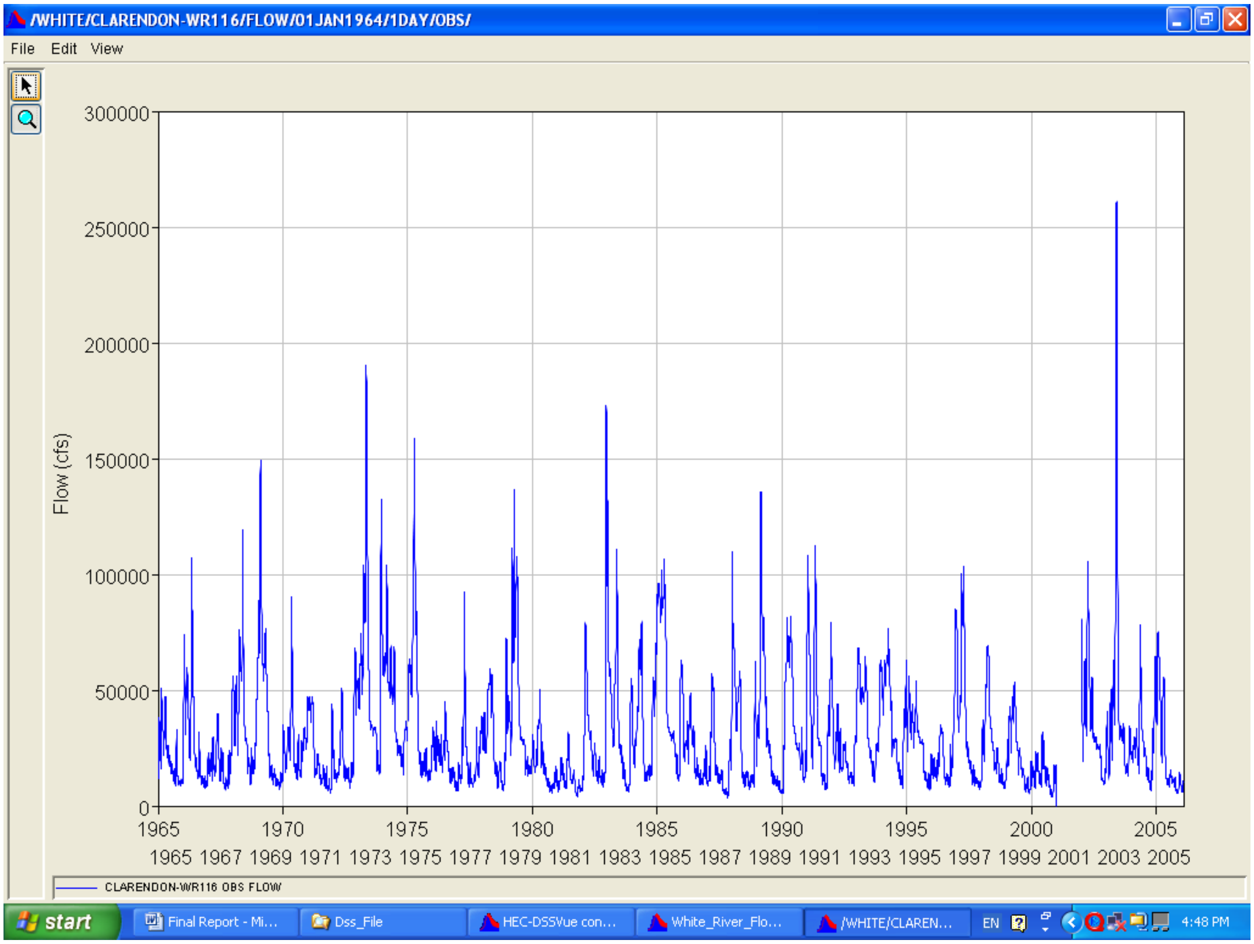

Figure 6. Discharge Flow Measurements at Clarendon Gage from 1965 to 2009

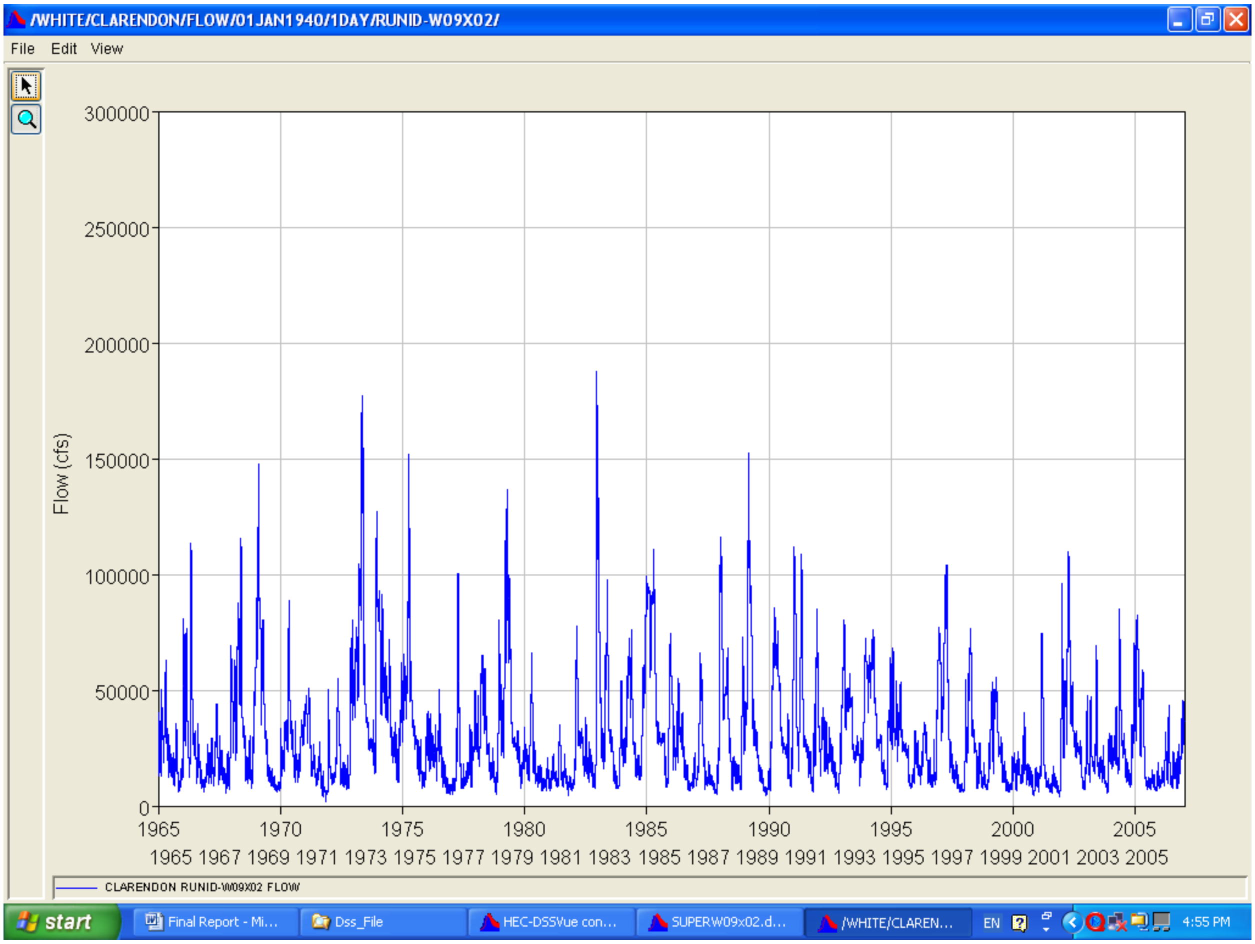

Figure 7. Supermodel Flows at Clarendon from 1965 to 2009

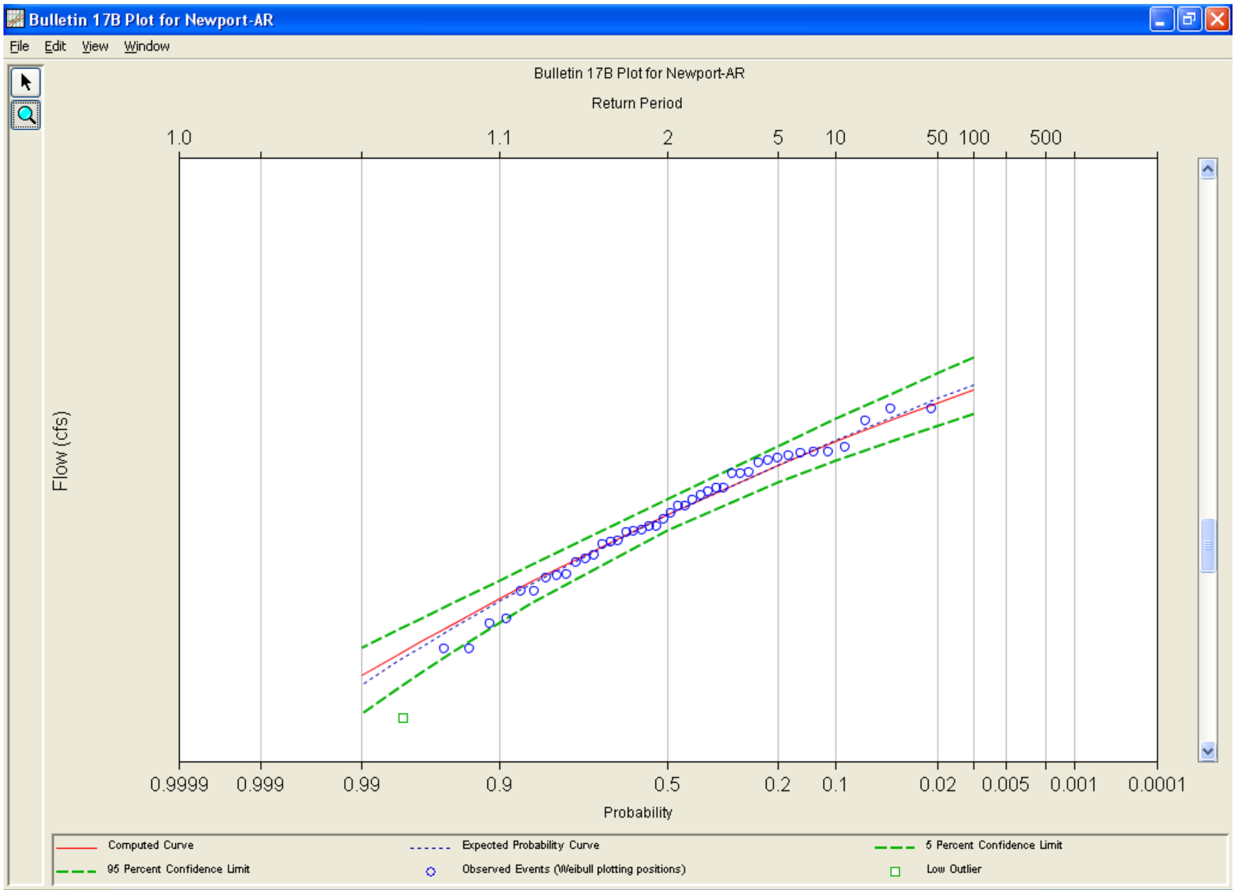

Figure 8. Frequency Analysis Plot using HEC-SSP for Newport, Arkansas

Table 1. Summary of Frequency Analysis for Clarendon, Georgetown, Augusta and Newport Gages on the White River

Reach	RS	1.01 yr	2 yr	5 yr	10 yr	25 yr	50 yr	100 yr
Newport	258.94	24000	77800	123000	162000	201000	220000	250000
Augusta	204.34	28600	79100	120000	150000	186000	220000	259000
Georgetown	169.04	30150	75400	115000	132000	166000	195000	227000
Clarendon	100.05	32500	78500	120000	147000	184000	213000	243000

The unsteady-state hydraulics model requires upstream and downstream boundary conditions. The upstream boundary conditions and the downstream boundary conditions for each reach connected to the river system are required to be either flow hydrographs or stage hydrographs. For this study, a flow hydrograph at Newport from 1965 to 2009 was used as the upstream boundary condition, which is represented as discharge (cfs) vs. time (days). The downstream boundary conditions are required at the downstream end for each reach. Four downstream boundary conditions are commonly used in unsteady-state model, including a stage hydrograph, a flow hydrograph, a rating curve, and a normal depth with a normal slope. The White River enters the Mississippi River at River Mile 599. The White River is influenced by the backwater effect produced by stages of the Mississippi River. As a result, a stage hydrograph (Figure 9) at River Mile 599 of the Mississippi River was selected for the model as the downstream boundary condition.

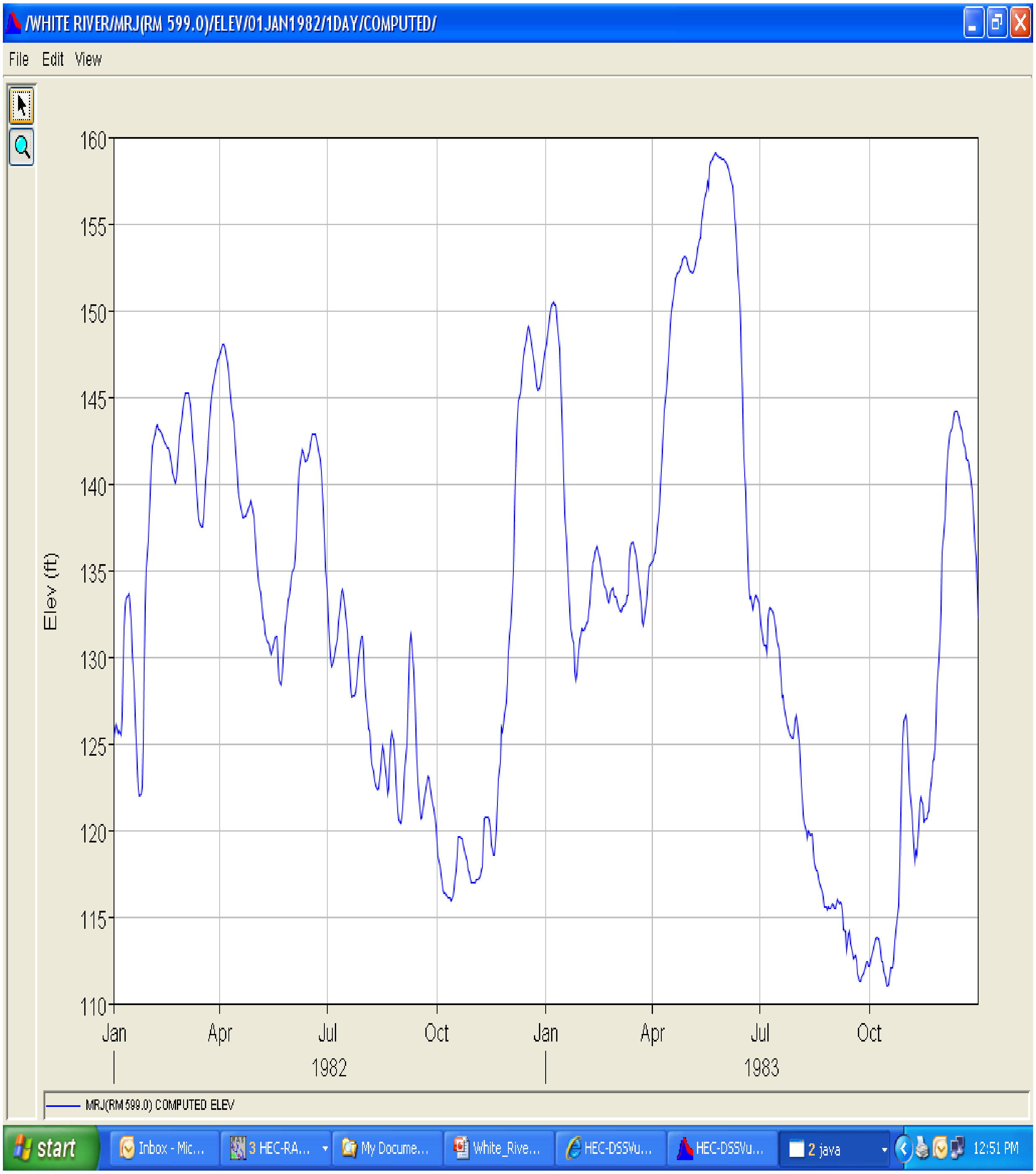

Figure 9. Stage Hydrograph at Mississippi River Mile 599 in 1982 and 1983

2.4 Development of Unsteady-State Model

HEC-RAS unsteady-state model is a one-dimensional flow model that has been used to simulate complex open channel systems. The model has been familiar to handle the flow interacted between the channel and the floodplain that has been considered as the movement flow in two-dimensional flow systems (Figure 10). Since the HEC-RAS model uses lateral flow or a storage area to represent the flow exchanges in the channel and its floodplain to reduce a two-dimensional flow problem to a one-dimensional flow condition. When the river is rising, water disperses laterally from the channel, inundating the floodplain and filling storage areas. The floodplain becomes a conveyance channel to deliver water downstream according to a short path in the channel. When the river stage is falling, the water moves toward the main channel from the overbank storage.

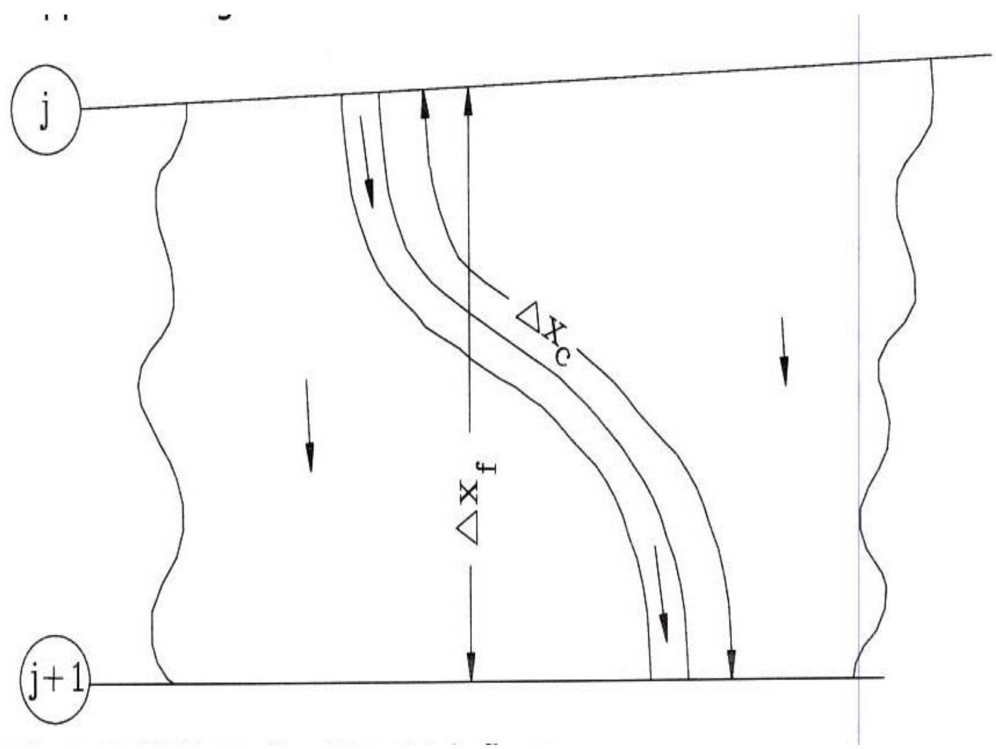

Figure 10. Schematic Model Concepts in HEC-RAS Model for Unsteady-State Model

In the HEC-RAS unsteady-state model, the primary direction of flow is oriented along the channel. This two-dimensional flow field can often be accurately approximated by a one-dimensional representation. Flow in the overbank can be modeled as a separate channel flowing through the basin. For a large system like the White River, the channel is widely spread over the floodplain under high flow conditions. The channel is also confined by levees and plateaus. The assumption of the unsteady- state model is to divide the system into channel and floodplain with its continuity and momentum equations. To simplify the channel and floodplain problem, it assumes a horizontal water surface at each cross section normal to the direction flow. The exchange of momentum between the channel and the floodplain is considered negligible. To represent the continuity and the momentum equations of the combined channel and floodplain, the following equations are the unsteady-state flow equations within the HEC-RAS model.

$$\frac{\partial A}{\partial t}+\frac{\partial(\Phi Q)}{\partial x_c}+\frac{\partial[(1-\Phi)Q]}{\partial x_f}=0$$

$$\frac{\partial Q}{\partial t}+\frac{\partial(\Phi^2 Q^2/A_c)}{\partial x_c}+\frac{\partial((1-\Phi)^2 Q^2/A_f)}{\partial x_f}+gA_c\left[\frac{\partial Z}{\partial x_c}+S_{fc}\right]+gA_f\left[\frac{\partial z}{\partial x_f}+S_{ff}\right]=0$$

(1) & (2)

Where: the subscripts c and f refer to the channel and the floodplain, respectively. A is Area, t is simulation time, Q is flow rate, Φ is a flow ratio between the channel and the floodplain, x is the simulation distance, Z is the potential energy, and S is the energy slope. Using implicit finite differences and the Newton-Raphson iteration, the model can estimate the water elevation (or stage), given input flows and cross section data.

The flow capacity in a river system, such as the White River is related to the function of upstream flow conditions and downstream backwater effects. The White River Basin is a common dendritic drainage system, which was considered to be a simpler modeling problem than other type of drainage systems. In this modeling work, the focus was on the main channel and overbanks of the White River. All tributaries, such as the Little Red River, Cache River, Little Black River, were excluded in this model. In addition, the upper White River contains five operational lakes/reservoirs that may complicate flow characteristics in the model and discharge. Those reservoir operations were not considered in the model.

The basic data requirements for developing an unsteady-state model include: geometric data, unsteady-state flow data, and simulation scheme selection. The main objective of the model is to determine water surface elevations at selected locations (or gage stations) for a given set of flow conditions, i.e., either a steady-state condition or an unsteady-state condition. The geometric data is presented in a logical framework to establish the connectivity of the river system schematic for unsteady-state model simulation. Types of information needed to describe the system include river reach designation, cross section geometry, overbank, hydraulic structure characteristics, reach lengths of channel and overbanks, and the roughness of the channel and overbanks. The basic geometry data of the White River, such as flow center line, left bank line, right bank line, and cross-section locality was digitized in HEC-GeoRAS according to the 2006 aerial photo alignment. Each line contains a specific geo-reference related to MOSAIC DEM. A positive flow condition was established as moving in the direction from upstream to downstream. The river mile was created on the channel center line using the Split option in ArcMap editor. Since the White River is a very dynamic system, the channel length is constantly changing. This change is river length affects river mile distance from mouth to any established location from one time to anther. The digitized river mile at gage location at other sites on the U.S.G.S. quad maps differs from the corresponding river mile designation. For this unsteady-state model, the river mile was based on the digitized river mile, instead of U.S.G.S. quad's river mile.

A total of 230 cross section locations were selected and created for the model. During the selection process, U.S.G.S. quad maps and Corps' aerial photos were used to support this selection. In general, the location of the cross section was chosen at locations where channel shapes, land/channel slopes, land uses, hydraulic structures, or discharges change. The alignment of the cross section is oriented to be perpendicular to the direction of flow. The spacing between cross sections was based on the maintaining a conveyance ratio between 0.7 and 1.4, although this was not possible for all section. Some locations had the limitation to apply this rule because the curvature of the channel is very high and causes a conveyance ratio greater than 1.4 or less than 0.7. To accommodate the maximum flow on the White River, the cross sections were extended across the entire floodplain or to levee or to high plateau. The cross sections for the unsteady-state model of the White River in HEC-RAS model are shown in Figure 11.

The station versus the elevation data pairs for each cross section were automatically extracted from the MOSAIC DEM in HEC-GeoRAS when the cross section alignment was determined. However, the HEC-RAS model limits the 500 number of station versus elevation data pairs to each cross section. To ensure the cross section in the model met this limitation, the cross section point filter in HEC-RAS was used. The criterion was to reduce station versus the elevation data points and to maintain the same cross section area. The results of this modification for a few cross sections are shown in Figures 12, 13, 14, 15 and 16.

The cross section data points were verified using 3D Analysis Toolbox in ArcMap. After each cross section location is selected for the reasons noted previously, the alignment of each cross section can be reproduced by tracing the cross section within ArcMap. Using 3D- Create Profile Graphic option, each cross section data point was automatically obtained by the 3D profile creator. Because both HEC-GeoRAS and ArcMap-GIS function similarly, a cross section plot determined independently using each software program should compare favorably at a common location. The results from the 3D profile creator were exported to plot using Excel. A comparison of both methods at RM 98.48 of the White River, located at the south side of Clarendon, is shown in Figure 17.

Other schematic data that are required for the unsteady-state model, including downstream reach lengths, bank stations, ineffective areas, bridges (hydraulic structures), roughness coefficients and contraction/expansion coefficients. The downstream reach lengths and the bank stations were automatically extracted from HEC-GeoRAS. Left bank and right bank stations were also read from HEC-GeoRAS. The data were finally exported to the HEC-RAS model through an sdf file. A schematic of the created cross sections and an example cross section in HEC-RAS are shown in Figure 18. Bank station and reach length data obtained from the HEC-GeoRAS model are presented in Appendix B.

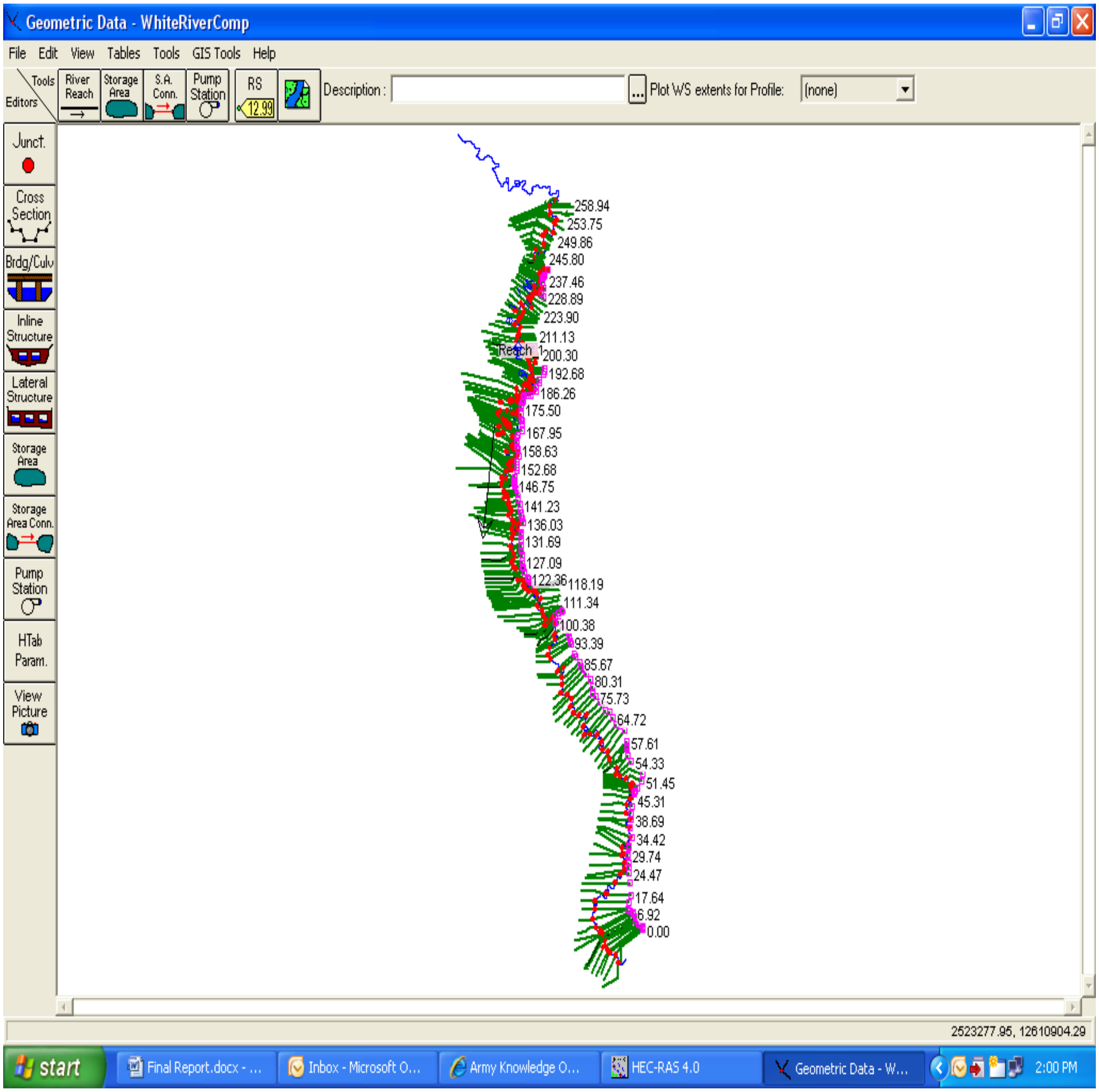

Figure 11. Cross Sections for the Unsteady State Model on the White River

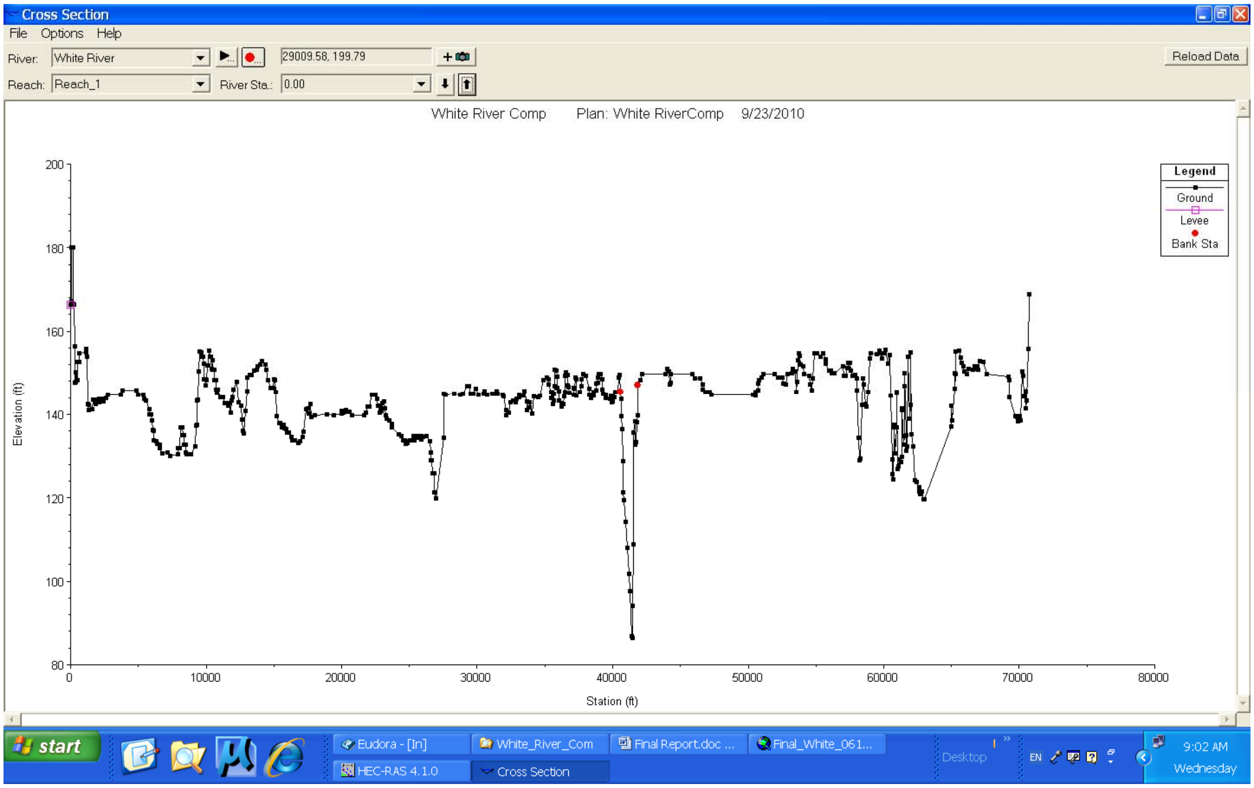

Figure 12. Cross Section at the Confluence of the Mississippi River and the White River

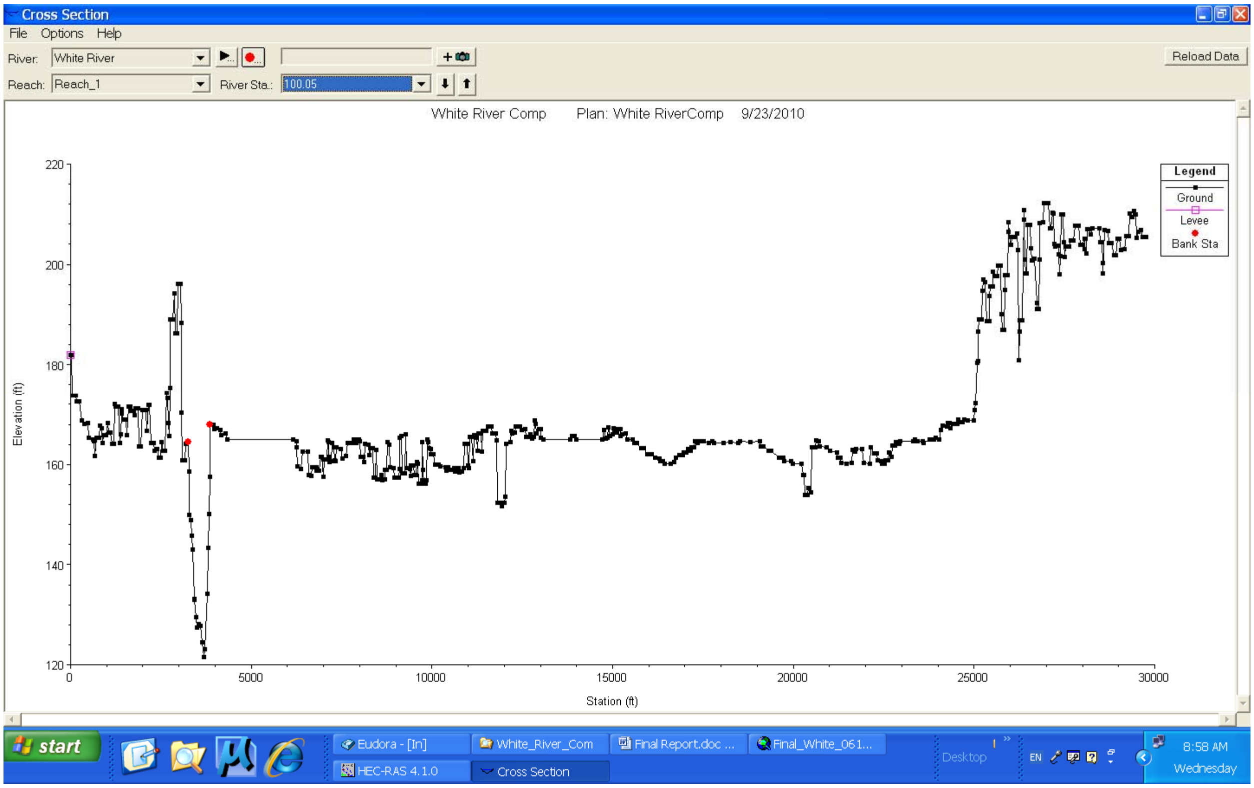

Figure 13. Cross Section at Clarendon on the White River

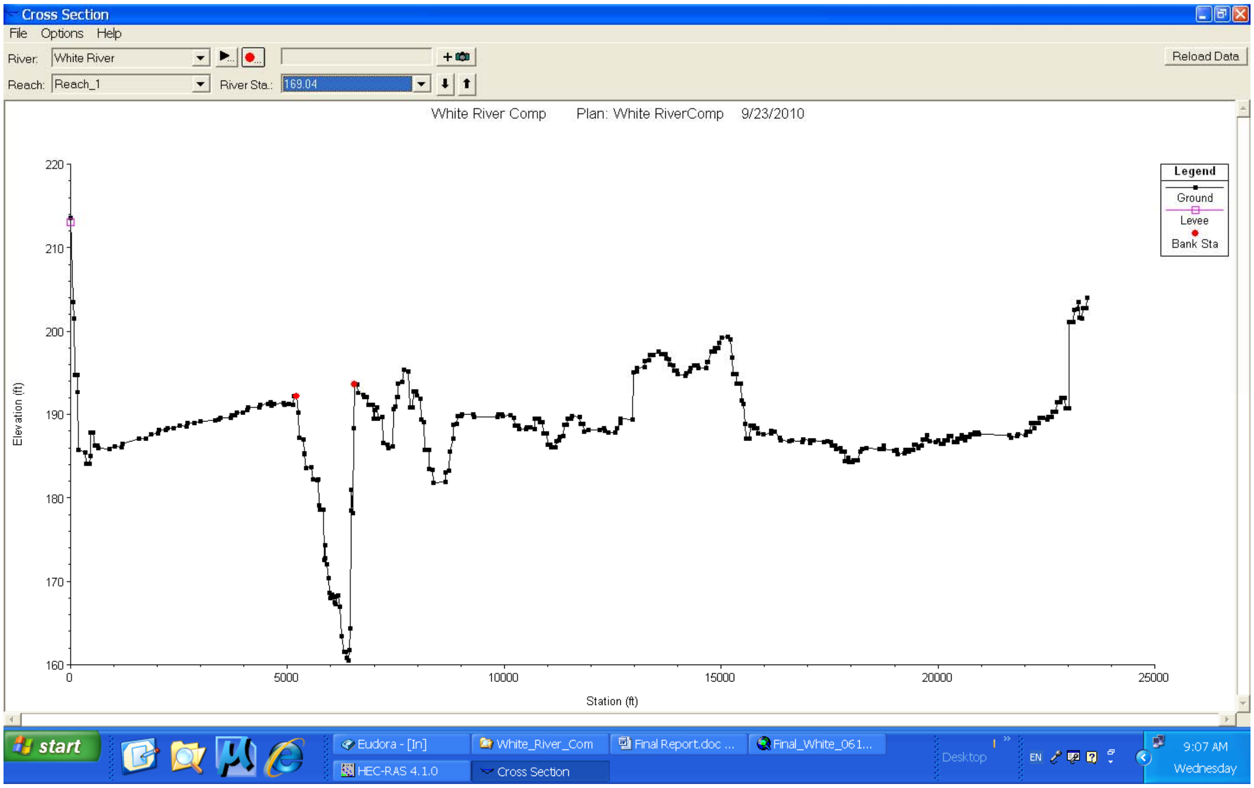

Figure 14. Cross Section at Georgetown on the White River

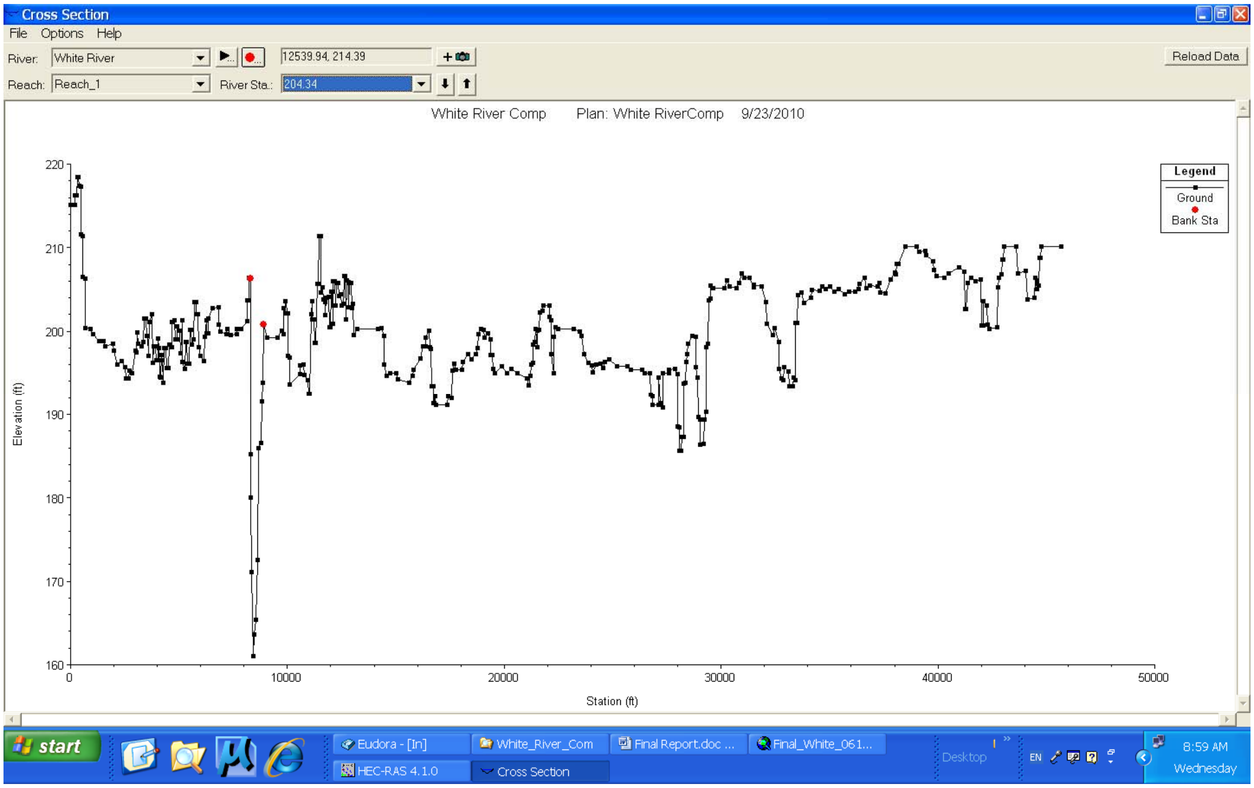

Figure 15. Cross Section at Augusta on the White River

Figure 16. Cross Section at Newport on the White River

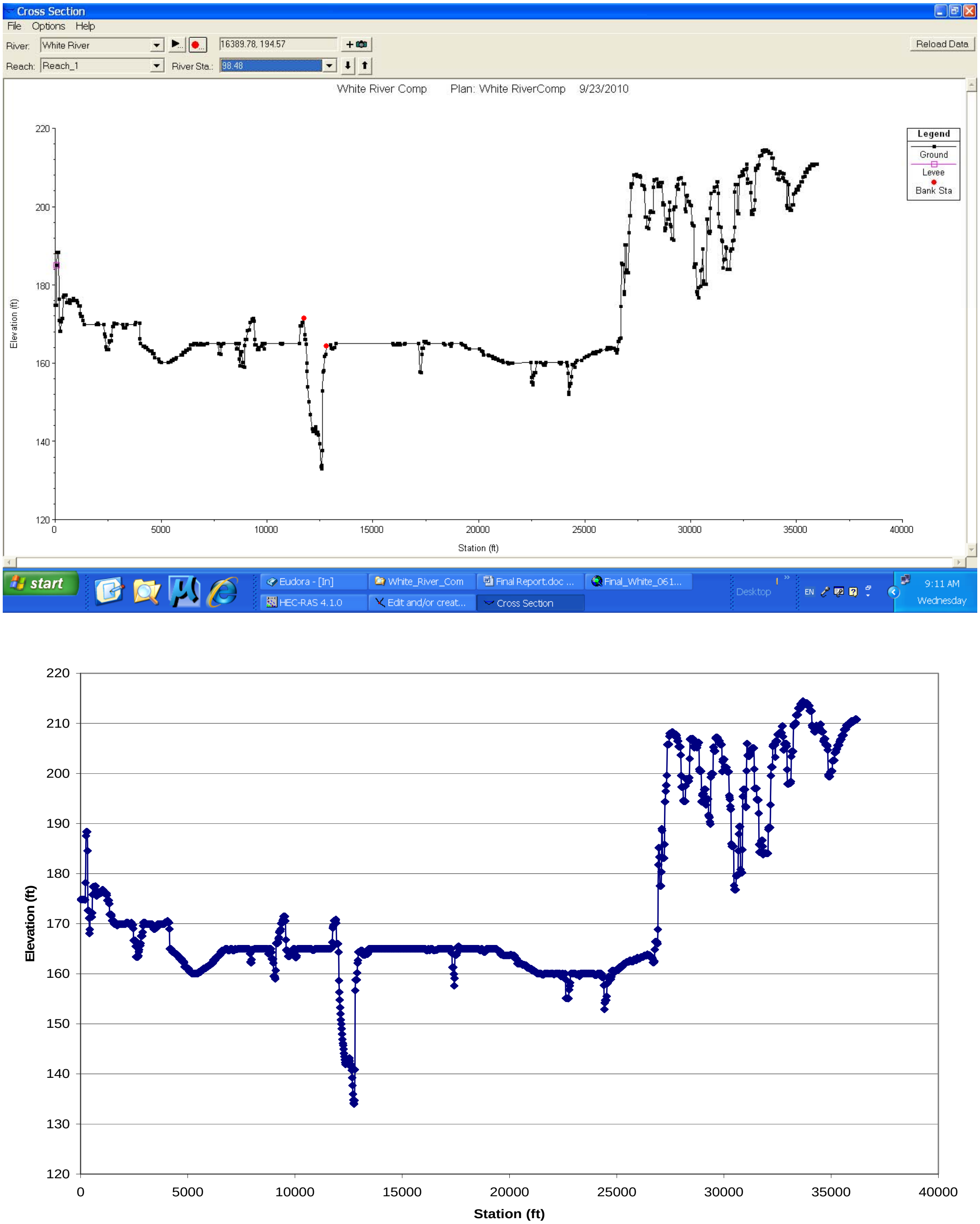

Figure 17. Comparison of a Section from HEC-GeoRAS and ArcMap's 3D Profile Creator

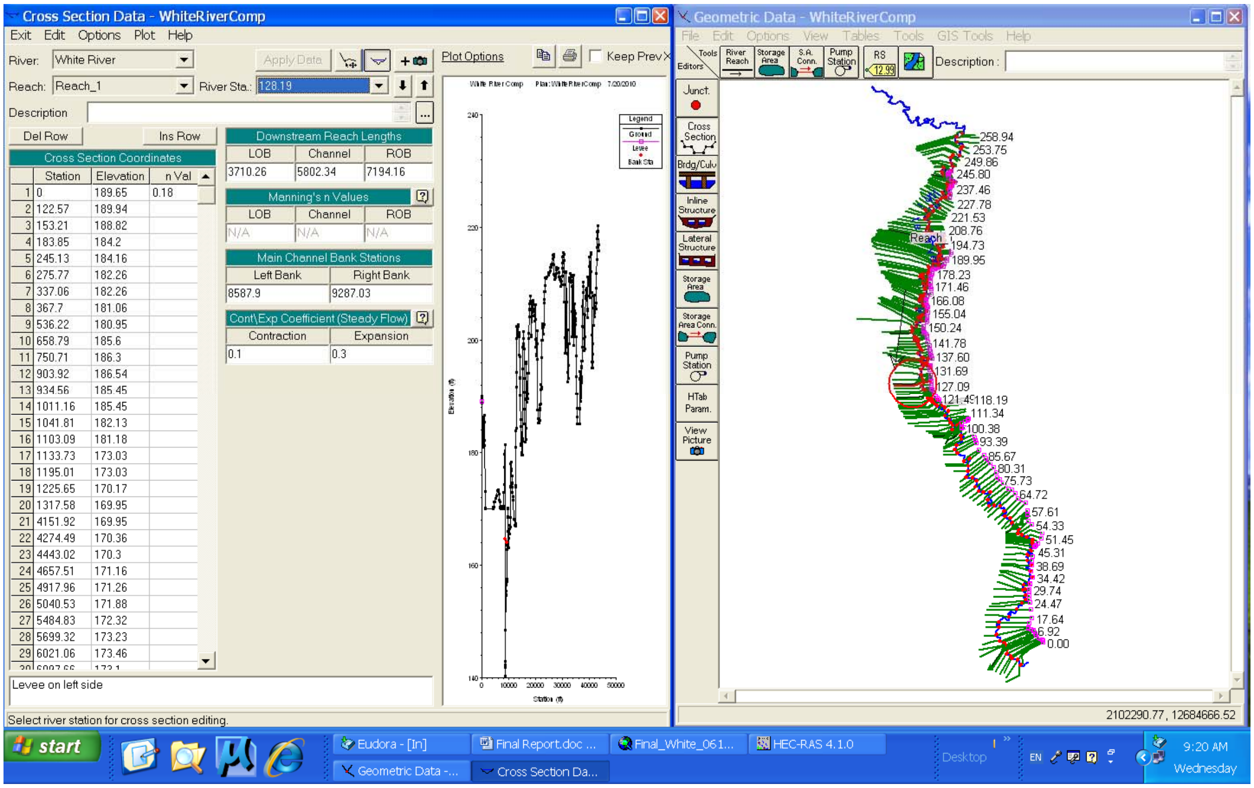

Figure 18. Example of Imported Cross Section from HEC-GeoRAS Model

Although main channel bank stations were automatically extracted from the HEC-GeoRAS model, these locations were sometimes modified to more accurately reflect the appropriate channel and overbank boundary. The need for modification of the locations of the bank station was necessary since the MOSAIC DEM, from which the bank station data was extracted based on U.S.G.S. quad maps and Corps aerial photos, were produced from data collected at different times. From the dynamic nature of the White River, banks have moved from one period to the next, resulting in an incorrect estimation of the actual bank line (Figure 5). To correct this discrepancy, the bank stations were determined from the 1.01 to 2 year bank full flow line following the procedures as described below: Once the imported bank stations were plotted on the HEC-RAS geometric data plate, the right and the left bank stations were easily identified as being either too high or too low. In comparison to the bank full flow line, an iteration process was conducted using the proceeded to run the steady-state White River model with a 1.01 to 2 year flows. Using revised left and right bank stations, the process was completed and the final left and right bank stations were established when they were close to the bank full line. The left and the right bank elevation close to the flow line were selected as the final stations. The results before and after this justification are shown in Figure 19.

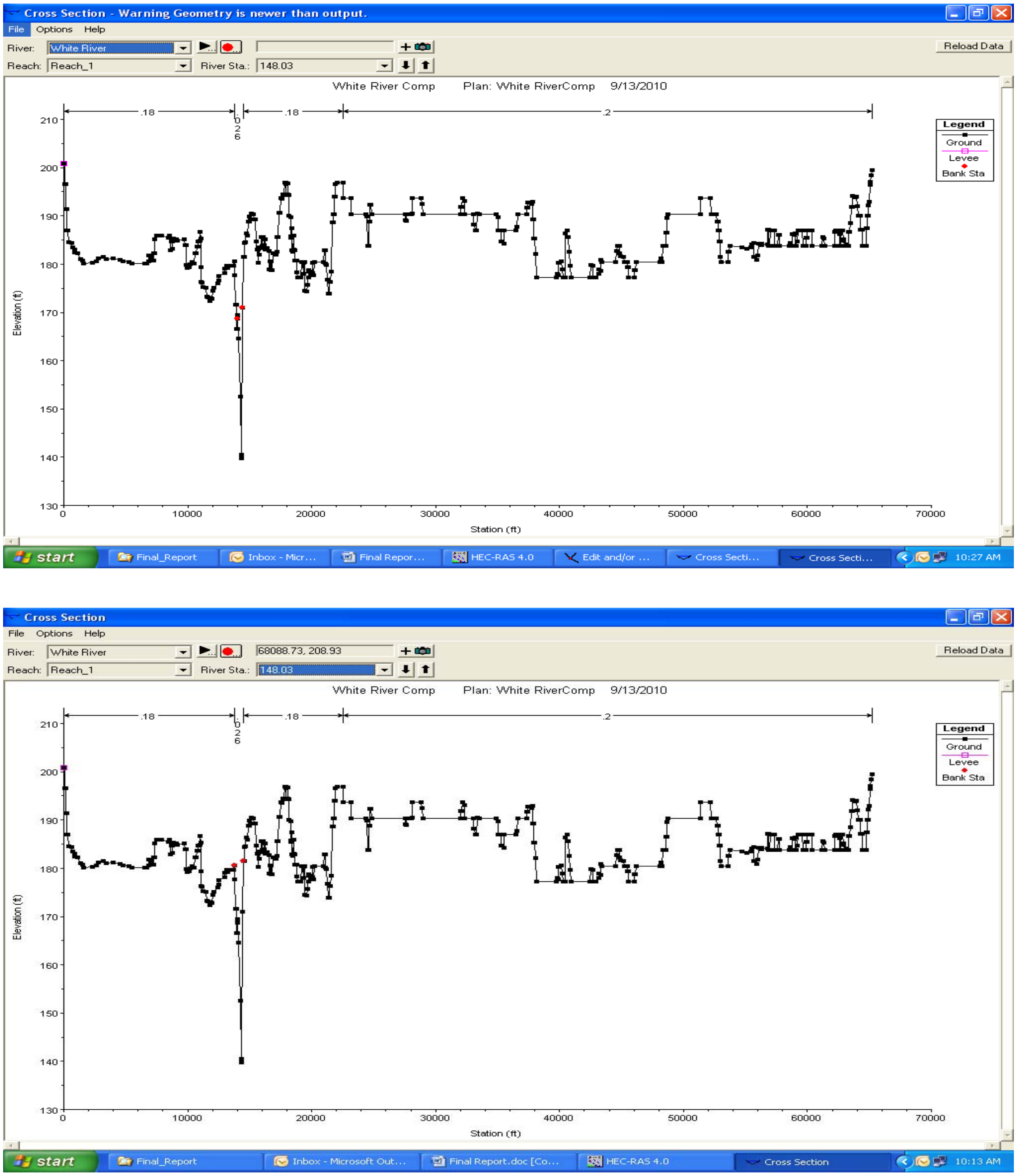

Figure 19. Example of Bank Station Locations between HEC-GeoRAS and HEC-RAS

There are three major levee sections along the White River, i.e., below Clarendon, between Clarendon and Georgetown, and below Augusta. Levee locations and elevations were identified in the model. The crest of the levee was determined from the Arkansas State 5-m DEM and the U.S.G.S quad maps. A model assumption was that water could not extend beyond the levee crest unless overtopped. Figure 2, Figure 20, and Appendix C show levee locations and elevations of the White River from the Geometric Data Editor Window (in pink square) and ArcMap's GIS.

Hydraulic structures, such as bridges, culverts, and in-line gates, have been considered in the model due to energy losses that can significantly affect water surface elevations. In this study, bridges are the only structure considered in the model. There are two energy losses associated with any bridge: one part of the energy loss is the contraction and expansion of flows as a flow approaches and leaves the bridge and the other part of the energy loss is at the bridge itself. The HEC-RAS model allows the model to compute the energy losses by using the option of the bridge geometry. In general, the bridge option in the geometric data requires four cross sections to count for all energy losses due to the bridge structure and the flow through the bridge opening.

Once cross sections were created in the model, nine bridges located at Benzal, Clarendon, Des Arc, Devalls Bluff, Georgetown, Augusta, and Newport on the White River were added into the model. For each bridge, two sections represented bridge deck/roadway; one section was located sufficiently on the downstream side so that the flow was not affected by the bridge, and the other section was located on the upstream side to account for bridge approach losses. A typical deck/roadway with 20-40 feet and an actual 40-60 ft width of bridge were assigned to a bridge. Actual pier location, width, and elevation were included into the bridge model geometry for the unsteady-state simulation. An example of a typical HEC-RAS bridge plot is shown in Figure 21.

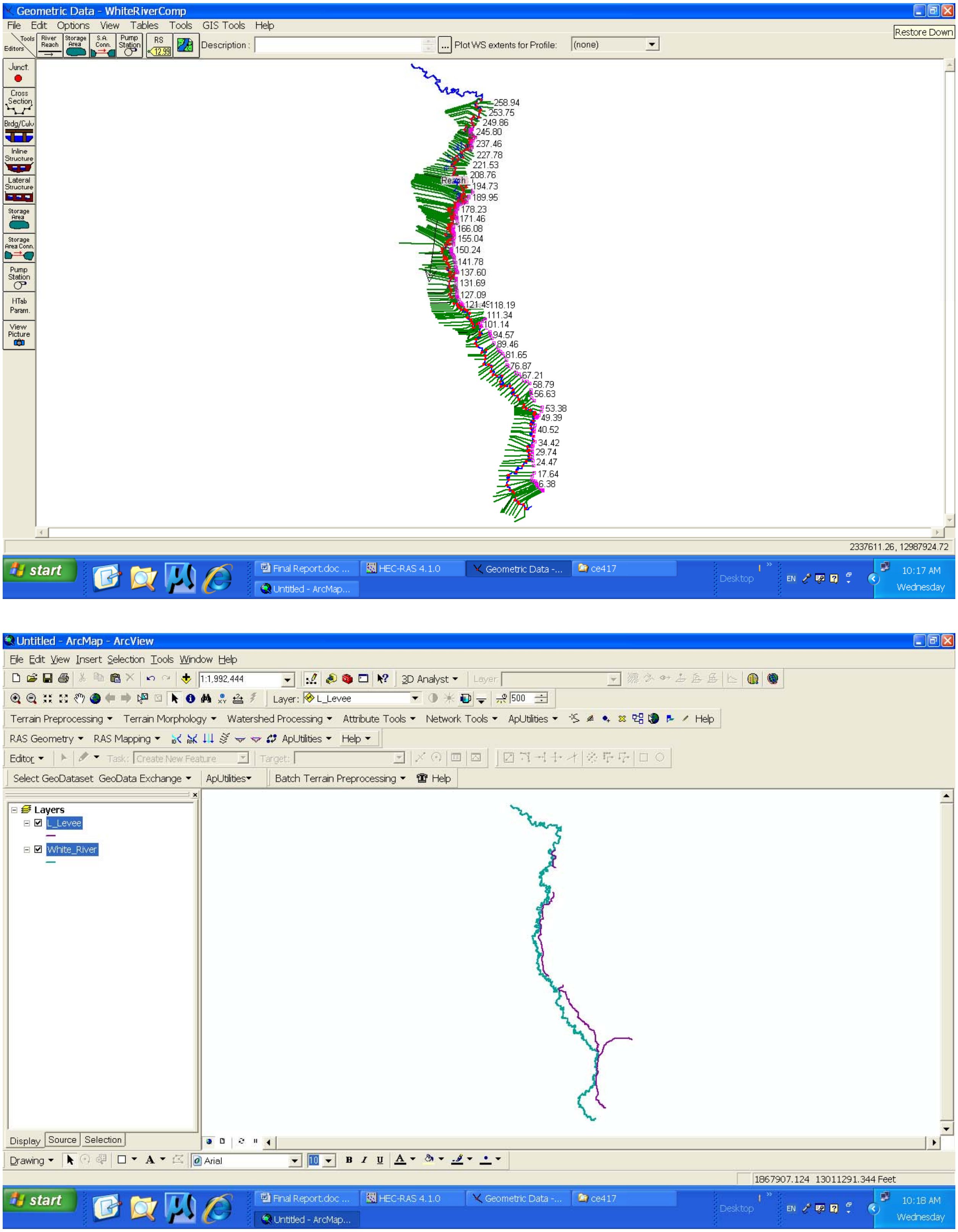

Figure 20. Levee Systems Built in the Hec-RAS Model

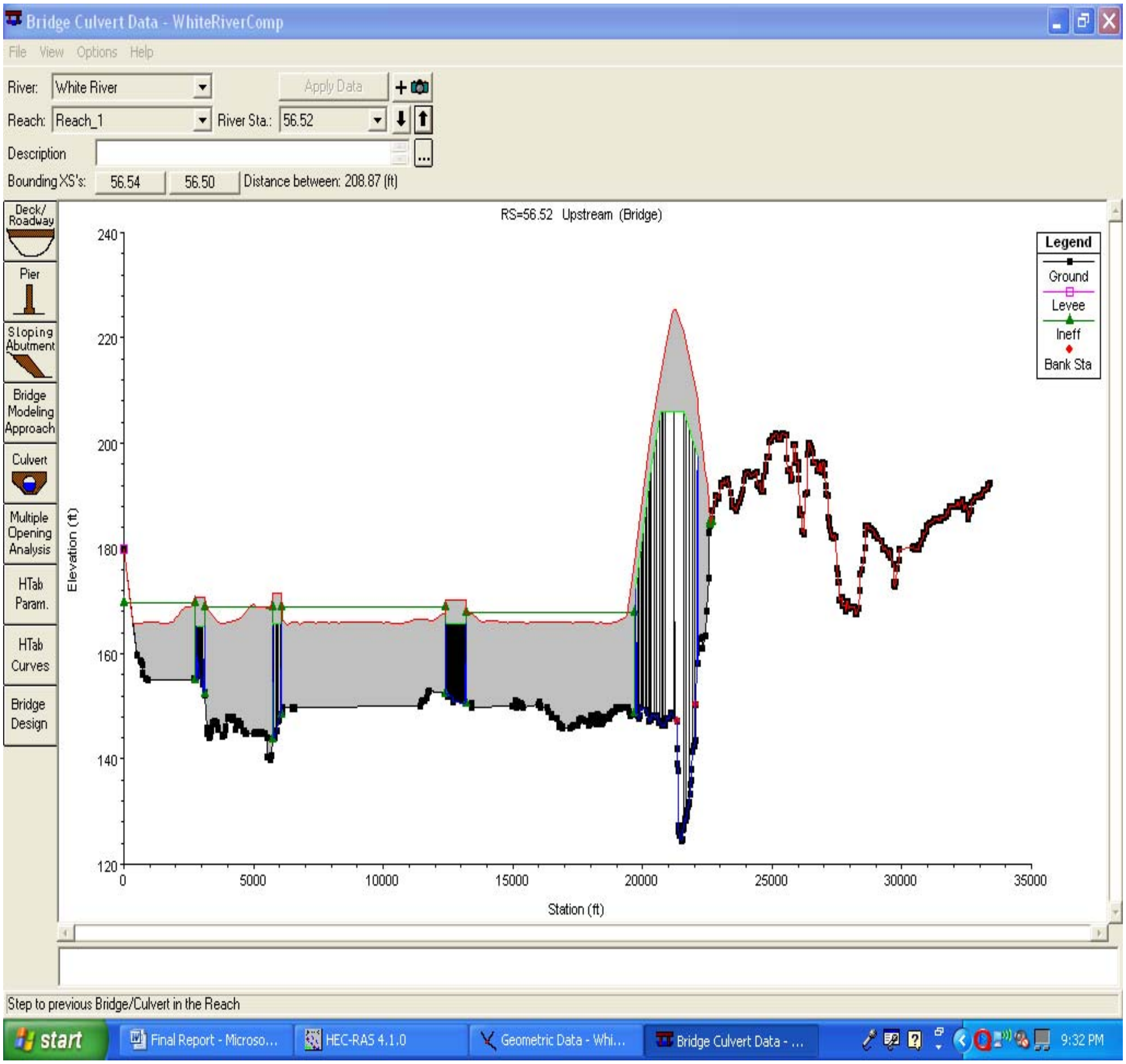

Figure 21. Plot of St. Charles Highway Bridge Built in the Unsteady-State Model

An ineffective area is defined as an area within a cross section where the flow would not actively be conveyed. The areas include ponds, storage areas, area above and below hydraulic structures, and areas behind levees. Two methods were used to identify ineffective area in the HEC-RAS model: one was to define station vs. elevation; and the other was to establish blocked ineffective flow area. Based on particular station and elevation at bridges and low storage areas on the White River, the first option was used to account for ineffective area. The block ineffective areas were only used for a non-conveyance flowing area. This was determined by field observations and model calibration. Typical ineffective area in the HEC-RAS model is shown in Figure 22.

Selection of the proper roughness coefficients for the unsteady-state model in HEC-RAS is a very important step to ensure the accuracy of the model. Typical Manning coefficients vary from 0.02-0.035 in a channel and 0.08-0.2 on a floodplain. The value is highly related to: channel bottom and side slope roughness, vegetation, channel shape, soil condition, scour and deposition, flow discharge, and water temperature. The initial Manning coefficient was selected for this study based on the U.S.G.S. Water Supply: Manning n Reference (1849), Open Channel Hydraulics by Chow (1959), and field observation. Because the Manning coefficient is a very sensitive parameter in the model, the value should be calibrated to observed gage data. For this unsteady-state model, the initial Manning coefficients in the channel and on the overbank ranged from 0.025-0.035 and 0.08-0.2, respectively. Four major gage data locations, Clarendon, Georgetown, Augusta, and Newport, were used for model calibration (as described in the Model Calibration Section).

Contraction and expansion coefficients were determined the steady-state model calibration. For a river system, changes in cross section from one location to the next location are relatively small. For this reason, contraction and expansion coefficients used in the steady-state model were 0.1 and 0.3, respectively.

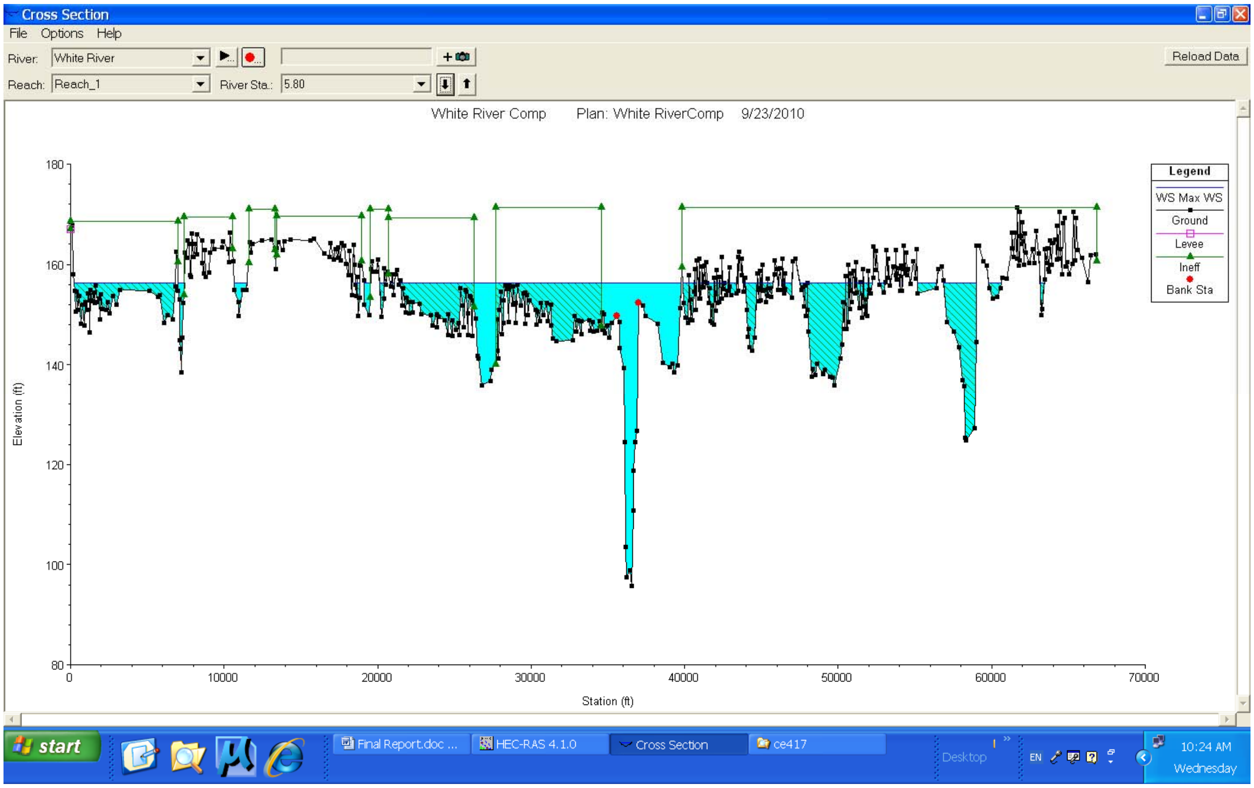

Figure 22. Ineffective Areas in the Unsteady State Model

2.5 Flow Analysis Data

Two types of flow analysis data were required in this study: one was frequency flows for the steady-state condition and the other was time-series flow data for the unsteady-state condition. The steady-state condition was primarily for calibration purposes to establish the Manning's n values by comparing with actual field gage measurements. The frequency flow data in Table 1 were an input data requirement for model calibration. An ineration process was conducted by varing Manning's n values and comparing resultant model stage values with actual gage measurements.

Time series flow data was needed to produced a real-time model simulation. To perform the unsteady-state flow simulation, the boundary conditions and the initial condition have to be established. The flow hydrograph from 1965 to 2009 at Newport was the upstream boundary condition. The downstream boundary condition was a stage hydrograph at the conflence of the White River and the Mississippi River (RM 599). The initial condition in the unsteady-state model was an initial flow at Newport required to produce an initial condition for model simulation.

2.6 Model Calibration

Model calibration consists of changing input variables to match field conditions. Under steady-state conditions, the model should be calibrated by adjusting the Manning's n value to obtain an agreement between the model results and the actual gage data for a specific flood event. In this case, the 1.01, 2, 5, 10, 25, 50, and 100 year frequency flows were used.

Model calibration processes involve both steady-state and unsteady-state calibrations. For the steady-state condition, the gage data collected from Clarendon, Georgetown, Augusta, and Newport were used to calibrate the HEC-RAS model. The Manning's n value was only one parameter that was calibrated to meet measured stage data for higher flow events that create higher stages. This can create difficulty in calibrating a model of a particular area for a large range of flow conditions. A good hydraulic model should be able to reproduce measured data for the full range of flow data. For this study, adjustment of Manning's n values was insufficient to adequately reproduce measured stages for the range of events considered. To produce the

White River model, inclusion of ineffective flow areas were needed. Manning's n values and ineffective areas were appropriately revised to produce an accurate reproduction of historic gage data. Table 2 and Figure 23 present a comparison between final model results and measured gage data. The final Manning's n values from this process are listed in Appendix D.

The following steps are recommended by the HEC-RAS to calibrate an unsteady-state HEC-RAS model (HEC-RAS, 2010):

1. Run a range of discharges in the Steady-State Flow mode, and calibrate Manning's n values to established rating curves at known water stages;
2. Select specific events to run in unsteady state flow model. Ensure each event goes from low flow to high blow and back to low flow;
3. Adjust Manning's n values to reproduce stage hydrographs;
4. Fine tune calibration for low to high stages using discharge roughness factors or seasonal roughness factors;
5. Verify the model calibration by running other flow events or long term periods that were not used in the calibration; and
6. Further adjustment deemed necessary from verification runs, make those adjustments and re-run all events.

Table 2. Comparison of Gage Measurement and Model Forecast for Frequency Flows

	Clarendon			Georgetown			Augusta			Newport		
Frequency	Gage	Model	Diff,	Gage	Model	Diff,	Gage	Model	Diff,	Gage	Model	Diff,
1	162.04	162.01	-0.03	181.64	181.61	-0.03	194.84	194.8	-0.04	205.74	206.08	0.34
2	167.87	167.7	-0.17	190.68	190.59	-0.09	202.03	201.88	-0.15	219.05	218.41	-0.64
5	170.75	170.25	-0.50	194.28	194.15	-0.13	204.38	204.06	-0.32	223.15	222.72	-0.43
10	172.05	171.58	-0.47	195.98	195.37	-0.61	205.59	205.14	-0.45	224.99	225.41	0.42
25	173.48	173.23	-0.25	198.08	197.65	-0.43	206.88	206.61	-0.27	226.79	22749	0.70
50	174.45	174.48	0.03	199.58	199.41	-0.17	207.57	207.82	0.25	227.79	227.57	-0.22
100	175.35	175.82	0.47	201.18	201.25	0.07	208.45	209.08	0.63	228.69	228.45	-0.24

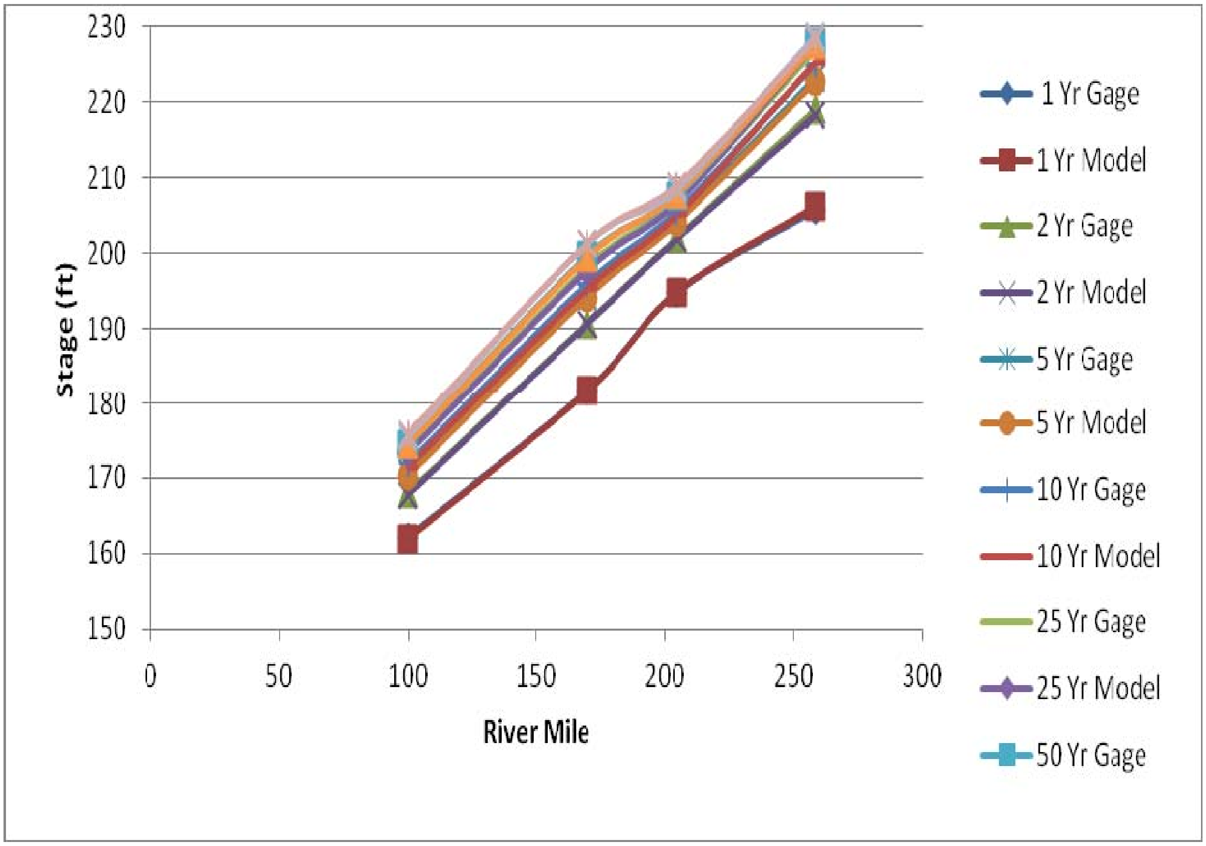

Figure 23. Plots of Gage Measurement and Model Forecast for Frequency Analysis

For the range of flood events along the White River at Clarendon, Georgetown, Augusta, and Newport, the stage differences between the model results and measured data were less than 1 ft. Within channel model results were less than 0.69 ft of actual stages for 1.01 and 2 year events. Model results for flood events that flows into the overbanks were within 0.75 ft of actual stages. The more accurate hydrographic survey data obtain for the channel required less calibration effort than the calibration effort required for events that included floodplain areas developed from U.S.G.S. DEMs. Several places were considered as ineffective areas included the upstream and downstream portions in the vicinity of bridges, low storage spots, areas behind levees, and valley sections. Among the flood events, the 10 percent and 20 percent annual chance exceedance of flood events produced the greatest differences between the model stages and measured stages due to less accurate digital elevation survey data on the floodplain.

After the Manning's n values were determined in the steady-state model, a special flow event was selected for the unsteady-state model calibration. Historical data in the White River Basin indicated an extreme flood event occurred in the basin 1982 following a drought in 1981. This period was selected for the unsteady-state calibration. The main task of this calibration was to determine discharge roughness factors and seasonal roughness factors appropriate for model results to closely compare with measured data.

The Manning's n values determined from the steady-state run were used to run the initial unsteady-state model. The model results with the Manning's n values in the steady-state were insufficiently as compared to actual stages. Therefore, seasonal roughness factors were considered to calibrate the unsteady-state model. The calibration proceeded from downstream to upstream, one section at a time. The seasonal roughness factors were modified until the model results closely matched the actual historic state data. Figure 24 shows the downstream boundary condition for the unsteady-state calibration at Clarendon for the 1982 flow event.

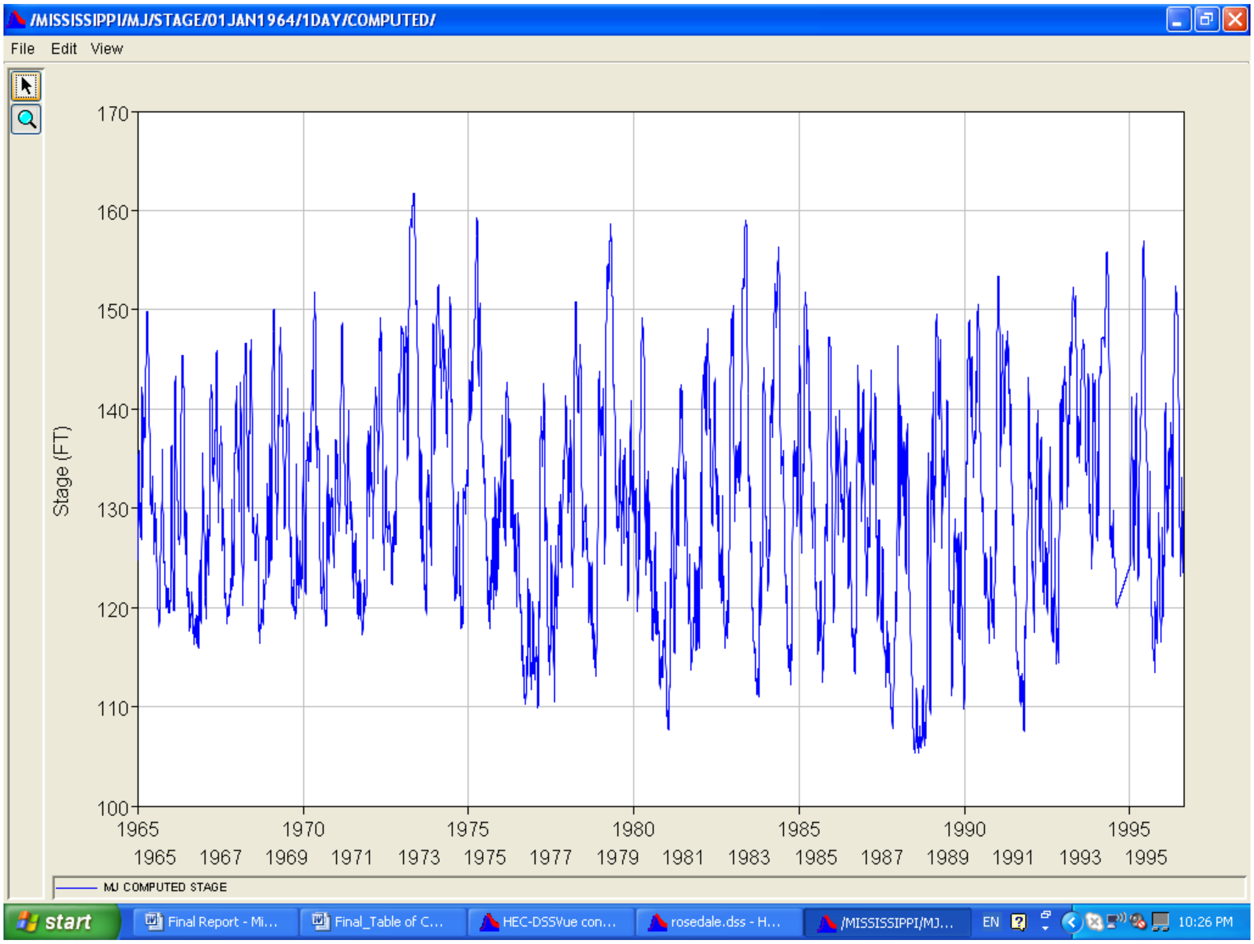

Figure 24. Stage Hydrograph at River Mile 599 of the Mississippi River

Among the four seasons, the flow dropped to lower part of the channel in the summer. The bed was much smoother during that time because the flows contained within the main channel, where the deposition of fine materials occurs. During the wet season, the flow easily overflows onto the floodplain where the Manning's n values were much higher than that within the channel. Based on a review of historical records, two wet seasons occur annually in early spring and in late fall. Historical data also suggest that the spring flood event typically has a higher peak flow magnitude than the flood in late fall, resulting in a higher flow line in the spring than in the late fall. Simulated peak stages and minimum stages were very close to corresponding 1982 measured stages. This indicates very little bias exists between the model and measured data. It also suggests that the model can adequately reproduce measured stages at each gage.

Calibration for the unsteady-state model continued similarly for the upstream gage stations including Clarendon, Georgetown, Augusta, and Newport. Using the same 1982 flood event, the calibration process only considered adjustment of seasonal roughness factors. In general, calibration of the seasonal roughness factors followed a similar pattern with rising in the spring, falling in the summer, and rising again in the late fall or early winter. The roughness factors ranges from 0.8- 1.3 (Appendix E). The lowest values were found in the late summer and the highest values were found in winter and early spring. The comparisons between the model and the measured data for Clarendon, Georgetown, Augusta, and Newport are listed in Figures 25, 26, 27 and 28. The results indicate that the differences between the simulation model and measured stage were within 2 ft discrepancy. Also, since Clarendon may be affected by the backwater effect from the Mississippi River, the simulation results suggested that the model appropriately accounted for this affect.

Figure 25. Comparison of 1982 Measured Stages and Unsteady-State Model Results at Clarendon

Blue Line: Field Measured Data

Red Line: Predicted Model

Figure 26. Comparison of 1982 Measured Stages and Unsteady-State Model Results at Georgetown

Blue Line: Field Measured Data

Red Line: Predicted Model

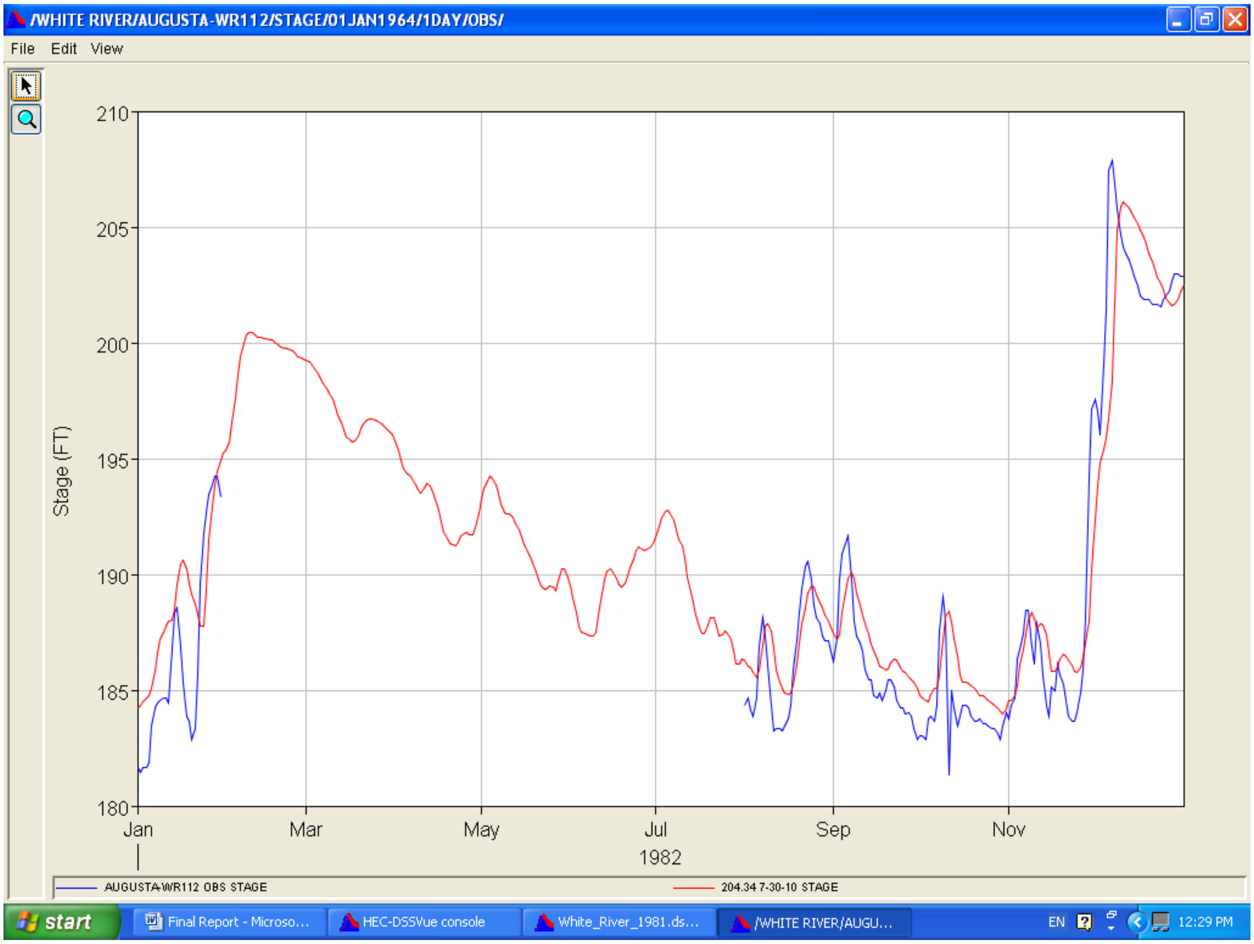

Figure 27. Comparison of 1982 Measured Stages and Unsteady-State Model Results at Augusta

Blue Line: Field Measured Data

Red Line: Predicted Model

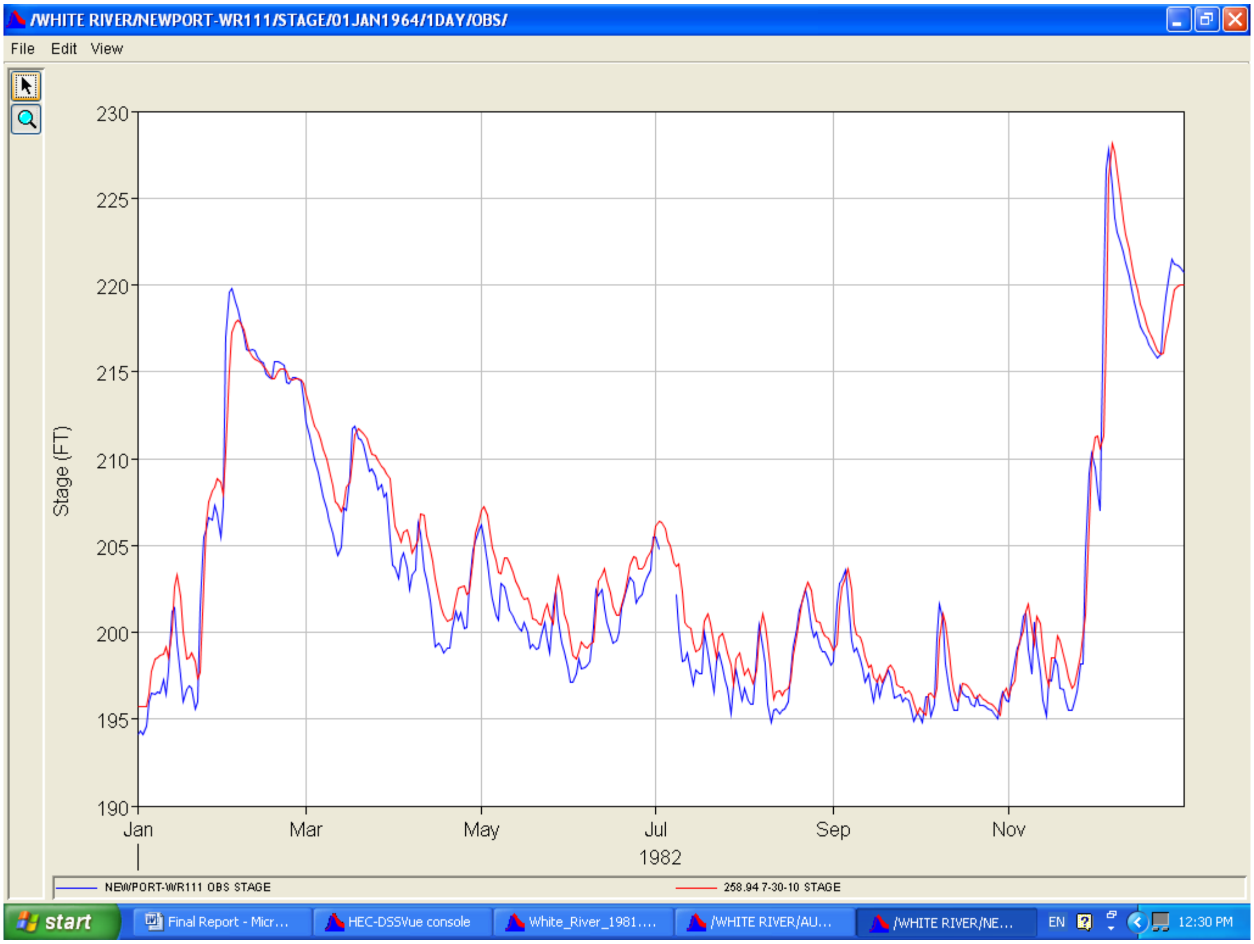

Figure 28. Comparison of 1982 Measured Stages and Unsteady-State Model Results at Newport

Blue Line: Field Measured Data

Red Line: Predicted Model

2.7 Model Verification

After the model was calibrated to produce results that closely agreed to measured stage for the 1982 flood event, the model was verified using historic flood events. The primary goal was to confirm that the model can be used to predict water surface elevation and be able to apply to other magnitudes. The verification process included floods from 1965 to 1995. The water surface elevations and measured stages were compared to confirm the quality of the model. As used for model calibration, four gage stations- Clarendon, Georgetown, Augusta, and Newport were again used for model verification. The results of model verification are shown in Figures 29, 30, 31, and 32.

The verification showed that the model results reproduced very closely to corresponding high water marks between the observed water surface elevation and measured stage data without further modification. The differences in annual peak and minimum stage readings between the model and measured data were less than 2 ft. It suggested that the model provides a high correlation to the data measured in the field. For the entire simulation period, the model can reproduce similar results as the field measurement during times of low flows that are confined to the main channel. The more inaccurate overbank topographical data used in the model produced results that were significantly different than historical stages particularly during high flow periods.

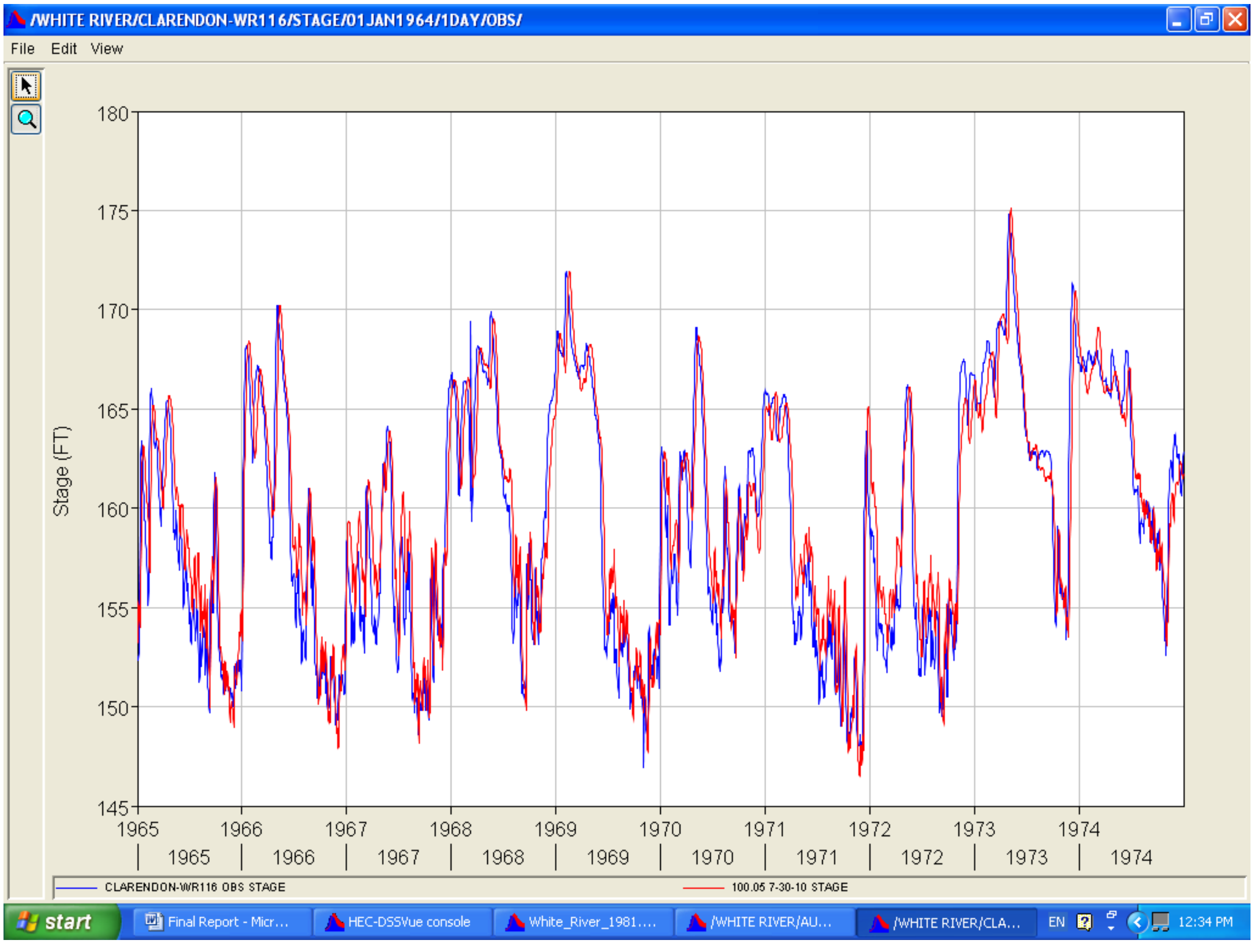

Figure 29. Model Verification between Gage Measurement and the Model at Clarendon during 1965-1975

Blue Line: Field Measured Data

Red Line: Predicted Model

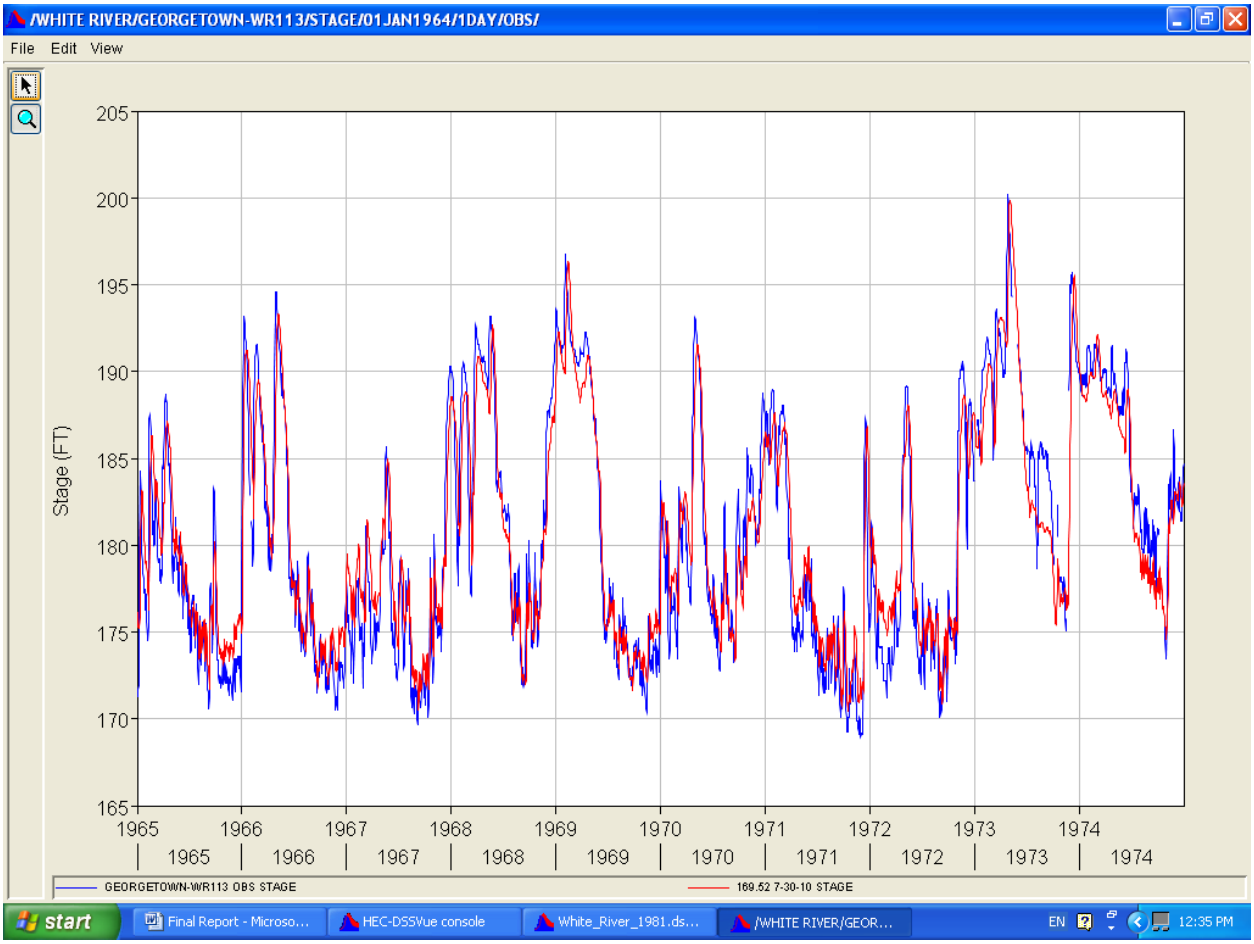

Figure 30. Model Verification between Gage Measurement and the Model at Georgetown during 1965-1975

Blue Line: Field Measured Data

Red Line: Predicted Model

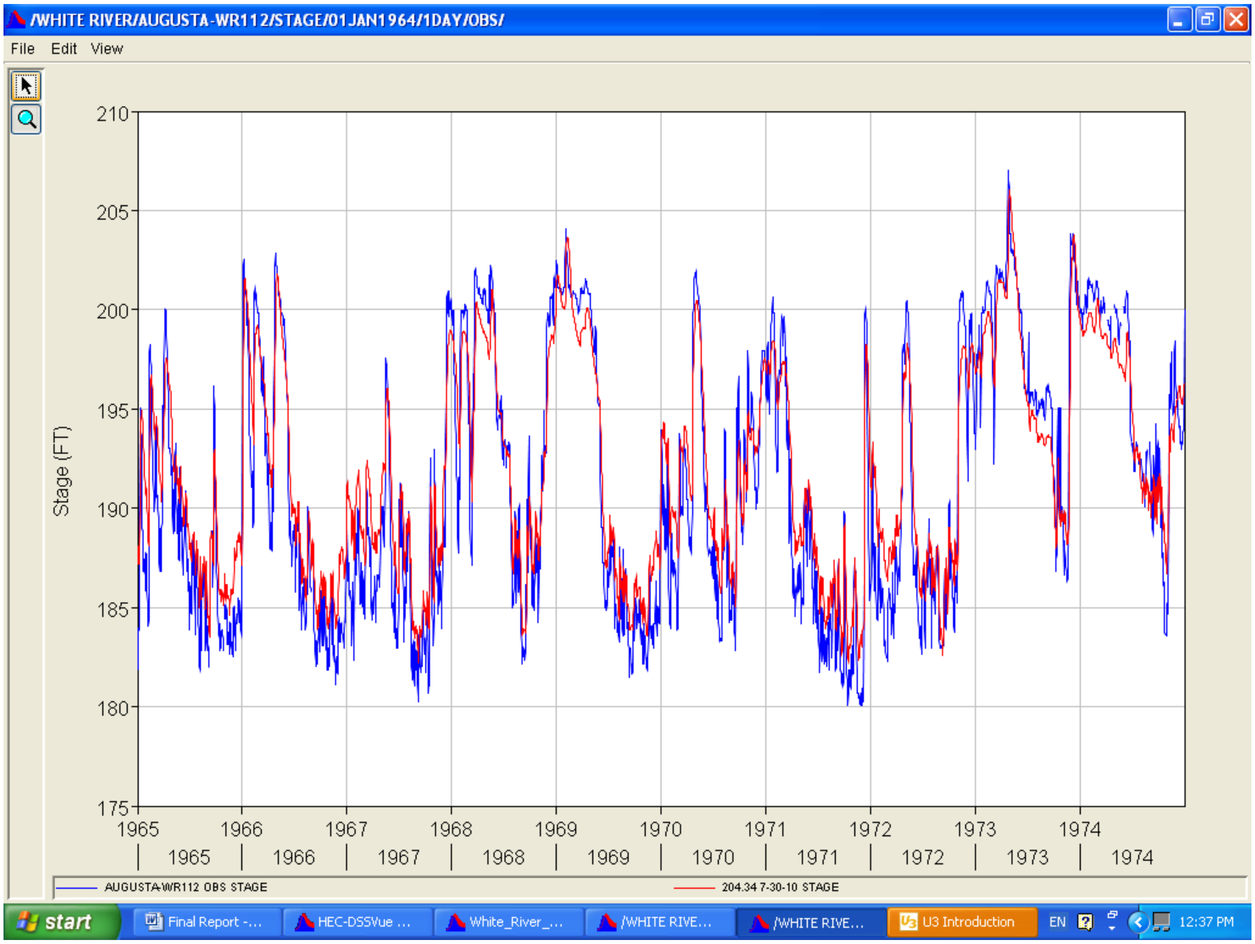

Figure 31. Model Verification between Gage Measurement and the Model at Augusta during 1965-1975

Blue Line: Field Measured Data

Red Line: Predicted Model

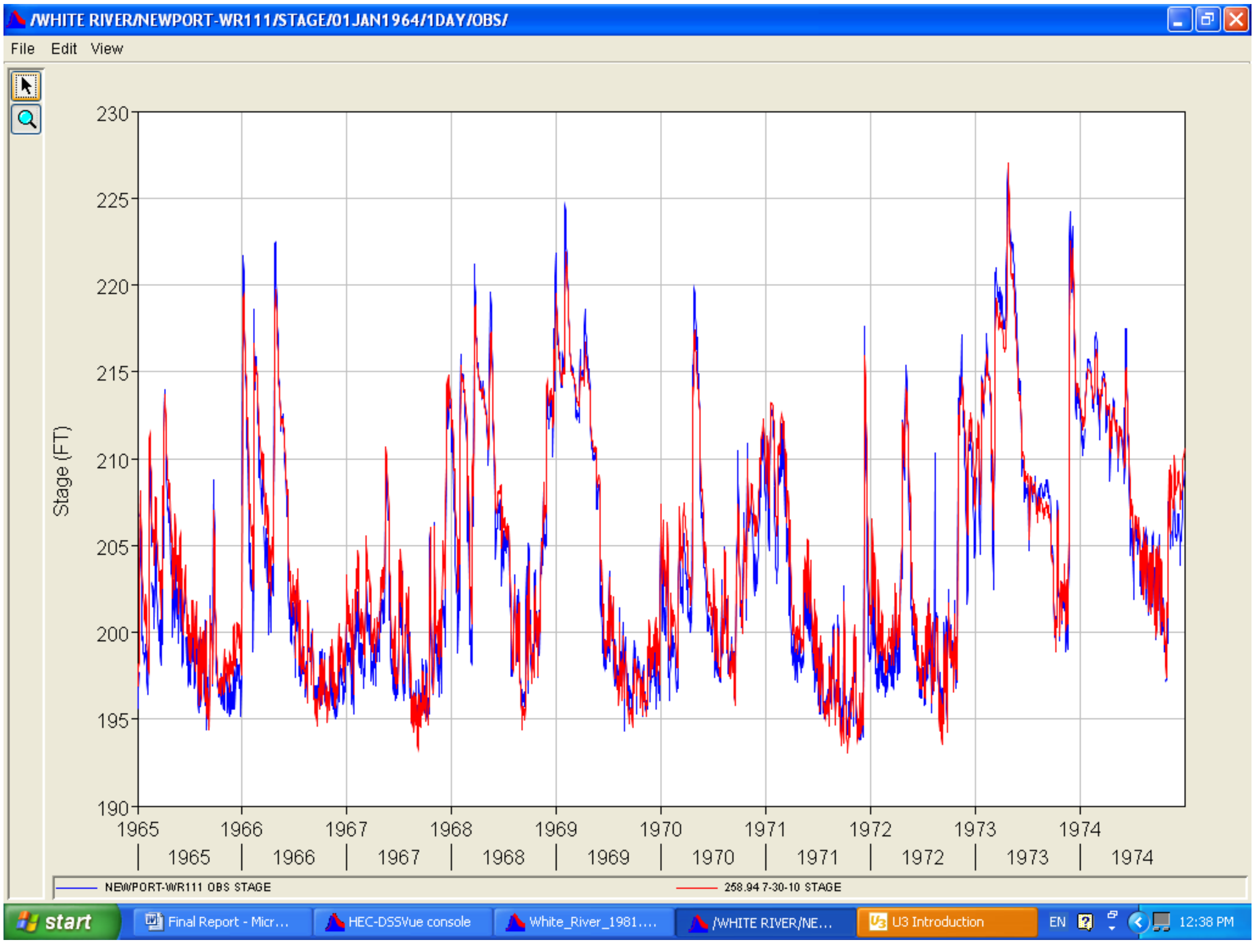

Figure 32. Model Verification between Gage Measurement and the Model at Newport during 1965-1975

Blue Line: Field Measured Data

Red Line: Predicted Model

2.8 Sensitivity Analysis

The Manning's roughness coefficients used in the flow capacity analysis were determined during the model calibration. Using historic flood events in the 1970's, 1980's, and 1990's to verify the model, the model provides a high correlation between the model and measured stages in the field. The Manning's roughness coefficients in the model were consistent with the normal values recommended by the HEC-RAS User's Manual (USACE, 2010) ranging from 0.025-0.035 in the channel and 0.05-0.2 in the overbanks. The seasonal roughness factors range from 0.8-1.3 over the dry and wet seasons.

A sensitivity analysis of the Manning's roughness values was conducted. According to the Manning equation for open channel flow, a higher roughness coefficient would result in slower flow velocities that could result in higher water surface elevations along the channel by reducing the channel conveyance. On the other hand, a lower roughness value would increase the flow velocity. For a prismatic channel, the flow capacity would increase as well. The backwater effect from the Mississippi River may also alter the conveyance in the main channel of the White River. The roughness values of a channel are affected by changes in vegetation, bottom material, channel sedimentation/erosion, and other factors.

The sensitivity analysis was conducted for this study for two cases: (1) increasing the calibrated Manning's roughness values by 0.01 and decreasing the calibrated roughness values by 0.01 in the channel; and (2) increasing and decreasing the Manning's roughness values by 0.05 on the overbanks. The test with increased roughness values represented the dense vegetative and hydraulically rougher channel conditions than currently exist, which would yield a more conservative (smaller) estimate of the in-channel flow capacity. The test with decreased roughness values represented less vegetative, clean and hydraulically smoother channel conditions, which would yield a larger in-channel flow capacity. The same rational can be applied to the change in overbank roughness values. The flow capacities predicted with the larger and smaller roughness values are summarized in Tables 3(a) and 3(b) for the channel, and in Tables 4(a) and (b) for the overbanks.

Table 3(a). Sensitivity Study by Increasing the Manning's n Values of 0.01 in the Channel

	Clarendon			Georgetown			Augusta			Newport		
Frequency	Gage	Model	Diff,	Gage	Model	Diff,	Gage	Model	Diff,	Gage	Model	Diff,
1	162.04	163.35	1.31	181.64	184.57	2.93	194.84	196.9	2.06	205.74	209.35	3.61
2	167.87	168.47	0.60	190.68	192.52	1.84	202.03	202.68	0.65	219.05	220.74	1.69
5	170.75	170.89	0.14	194.28	195.92	1.64	204.38	204.38	0.00	223.15	224.78	1.63
10	172.05	172.19	0.14	195.98	197.21	1.23	205.59	205.69	0.10	224.99	227.23	2.24
25	173.48	173.79	0.31	198.08	199.54	1.46	206.88	207.14	0.26	226.79	227.93	1.14
50	174.45	175.04	0.59	199.58	201.36	1.78	207.57	208.49	0.92	227.79	228.45	0.66
100	175.35	176.33	0.98	201.18	203.19	2.01	208.45	209.7	1.25	228.69	229.57	0.88

Table 3(b). Sensitivity Study by Decreasing the Manning's n Values of 0.01 in the Channel

	Clarendon			Georgetown			Augusta			Newport		
Frequency	Gage	Model	Diff,	Gage	Model	Diff,	Gage	Model	Diff,	Gage	Model	Diff,
1	162.04	159.87	-2.17	181.64	177.66	-3.98	194.84	191.41	-3.43	205.74	201.31	-4.43
2	167.87	166.38	-1.49	190.68	186.74	-3.94	202.03	200.33	-1.70	219.05	213.75	-5.30
5	170.75	169.19	-1.56	194.28	191.02	-3.26	204.38	203.09	-1.29	223.15	218.82	-4.33
10	172.05	170.58	-1.47	195.98	192.28	-3.70	205.59	204.43	-1.16	224.99	221.75	-3.24
25	173.48	172.33	-1.15	198.08	194.49	-3.59	206.88	205.64	-1.24	226.79	224.16	-2.63
50	174.45	173.61	-0.84	199.58	196.2	-3.38	207.57	206.89	-0.68	227.79	225.22	-2.57
100	175.35	175.02	-0.33	201.18	197.97	-3.21	208.45	208.12	-0.33	228.69	226.8	-1.89

Table 4(a). Sensitivity Study by Increasing the Manning's n Values of 0.05 for the Overbanks

	Clarendon			Georgetown			Augusta			Newport		
Frequency	Gage	Model	Diff,	Gage	Model	Diff,	Gage	Model	Diff,	Gage	Model	Diff,
1	162.04	162.18	0.14	181.64	181.66	0.02	194.84	194.85	0.01	205.74	206.11	0.37
2	167.87	168.4	0.53	190.68	190.93	0.25	202.03	202.2	0.17	219.05	219.59	0.50
5	170.75	171.3	0.55	194.28	194.71	0.43	204.38	204.67	0.29	223.15	223.17	0.02
10	172.05	172.83	0.78	195.98	196.06	0.08	205.59	205.63	0.04	224.99	226.12	1.13
25	173.48	174.75	1.27	198.08	198.55	0.47	206.88	207.17	0.29	226.79	227.59	0.80
50	174.45	176.25	1.80	199.58	200.47	0.89	207.57	208.59	1.02	227.79	228.13	0.34
100	175.35	177.68	2.33	201.18	202.44	1.26	208.45	209.92	1.47	228.69	229.3	0.61

Table 4(b). Sensitivity Study by Increasing the Manning's n Values of 0.05 for the Overbanks

	Clarendon			Georgetown			Augusta			Newport		
Frequency	Gage	Model	Diff,	Gage	Model	Diff,	Gage	Model	Diff,	Gage	Model	Diff,
1	162.04	161.65	-0.39	181.64	181.52	-0.12	194.84	194.65	-0.19	205.74	206.01	0.27
2	167.87	166.42	-1.45	190.68	190.08	-0.60	202.03	201.41	-0.62	219.05	217.98	-1.07
5	170.75	168.49	-2.26	194.28	193.4	-0.88	204.38	203.69	-0.69	223.15	222.01	-1.14
10	172.05	169.49	-2.56	195.98	194.47	-1.51	205.59	204.62	-0.97	224.99	224.48	-0.51
25	173.48	170.75	-2.73	198.08	196.48	-1.60	206.88	205.71	-1.17	226.79	226.55	-0.24
50	174.45	171.71	-2.74	199.58	198.05	-1.53	207.57	206.82	-0.75	227.79	227.25	-0.54
100	175.35	172.76	-2.59	201.18	199.66	-1.52	208.45	207.95	-0.50	228.69	227.55	-1.14

3. Conclusions and Suggestions

3.1 **Conclusions of the Study**

Through authorization of the White River Basin Comprehensive Study, a one-dimensional unsteady-state model was developed for the White River Basin using the HEC-GeoRAS model. The study area includes its junction with the Mississippi River to Newport, Arkansas. It also covers the floodplain extended 3 to 5 miles from both sides of the river. To develop the model, field data, hydrographic surveys and the existing digital elevation models of the overbanks were collected. The model was built in the HEC-GeoRAS environment, which was operated under ESRI's ArcMap. The geometric data, including cross sections, reach length, and bank stations were automatically extracted from a synthetic digital elevation model in the HEC-GeoRAS. As the geometric data were imported to the HEC-RAS model, the schematic system of the river was developed. The geometric data fairly accurate described the current White River system. The data also indicate that the White River is an unstable channel system. When tributaries, such as Cache River, Little River, or Back River join together with the White River, the bed elevations were suddenly changed.

A flow frequency analysis that used measured gage data and Supermodel data was conducted. Prior to using the data, the data set were verified and plotted. The plots as rating curves indicate that both data sets were consistent and very similar in pattern and magnitudes, which concluded either data set could used for the frequency analysis and for the model simulations. The frequency analysis was conducted for both the measured gage data and Supermodel data from 2005 to 2009 using HEC-SSP software program. A range from of 24,000 to 378,000 cfs flow for the 99 percent annual chance exceedance was determined from Clarendon to Newport. Despite the difference between measured data and Supermodel data, the biases were still within 95% confidence level.

The computed frequency flows at Clarendon, Georgetown, Augusta, and Newport were selected for the model calibration before the model verification. The initial stage of the calibration was to determine Manning's n values for the steady-state model. Roughness values were varied until model results closely compared with measured stages. The final Manning's n values were reasonable as suggested publications produced by the U.S.G.S. and Chow. Overall, there was less than a one ft difference found between the model stage results and the measured stages for all frequency flows at Clarendon, Georgetown, Augusta, and Newport. The greatest difference in stages between model and measured data occurred for 10 percent and 20 percent annual chance exceedance events. Less accurate overbank data is likely responsible for the differences for he high flow events.

The Manning's n values went through a series of modifications during calibration of the unsteady-state since seasonal roughness factors were applied to the model. The roughness on the channel varies as sediment and debris deposit on the channel bottom. The deeper the channel, the higher soil compaction would occur that will decrease the Manning's n values. During the low flows seasons, the Manning's n values are lower than the average composite Manning's n values. Due to cyclically recurring changes in roughness in the White River system, the decision to use seasonally adjusted values on the Manning's n values were invaluable in achieving a robust mode, capable of accurately reproducing and predicting wide range of condition on the White River.

The versatility of the model was further demonstrated during the verification process. Simulations of several major floods in the 1970's, 1980's, and 1990's were produced a less than 2 ft difference between the peak and the lowest values.

3.2 **Suggestions**

The model simulated a one-dimensional unsteady-flow for the White River from the confluence with the Mississippi River to Newport, Arkansas. A few suggestions drawn from this study are:

- Missing flow and stage data affected the frequency analysis, model calibration, and model verification. To ensure the accuracy of the model, historic data are required to validate again. Missing data should be estimated prior to further verify the model.
- The model closely reproduced stages during the simulation. To verify the predictive capability of the model, additional data should be collected in the field.
- To further refine the overbank geometry and improve the model performance, more accurate digital elevation data should be collected.

- Low flows occurred in the channel during the dry seasons that need more justification for the seasonal factors. Although the seasonal factors were within the ranges, more efforts would provide more accurate results.

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3. U.S. Army Corps of Engineers, Hydrologic Engineering Center. "UNET: One-Dimensional Unsteady Flow through a Full Network of Open Channels." May 1993.

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5. U.S. Army Corps of Engineers, Southwestern Dallas Texas Division, "Regulation Simulation and Analysis of Simulation for a Multi-Purpose Reservoir System", August 2005.

6. U.S. Department of the Interior, Geological Survey, "Guidelines for Determining Flood Flow Frequency: Bulletin#17B of the Hydrology Subcommittee." March 1982.

7. U.S. Army Corps of Engineers, Hydrologic Engineering Center. "HEC-RAS River Analysis System User's Manual (V. 4.1)." January 2010.

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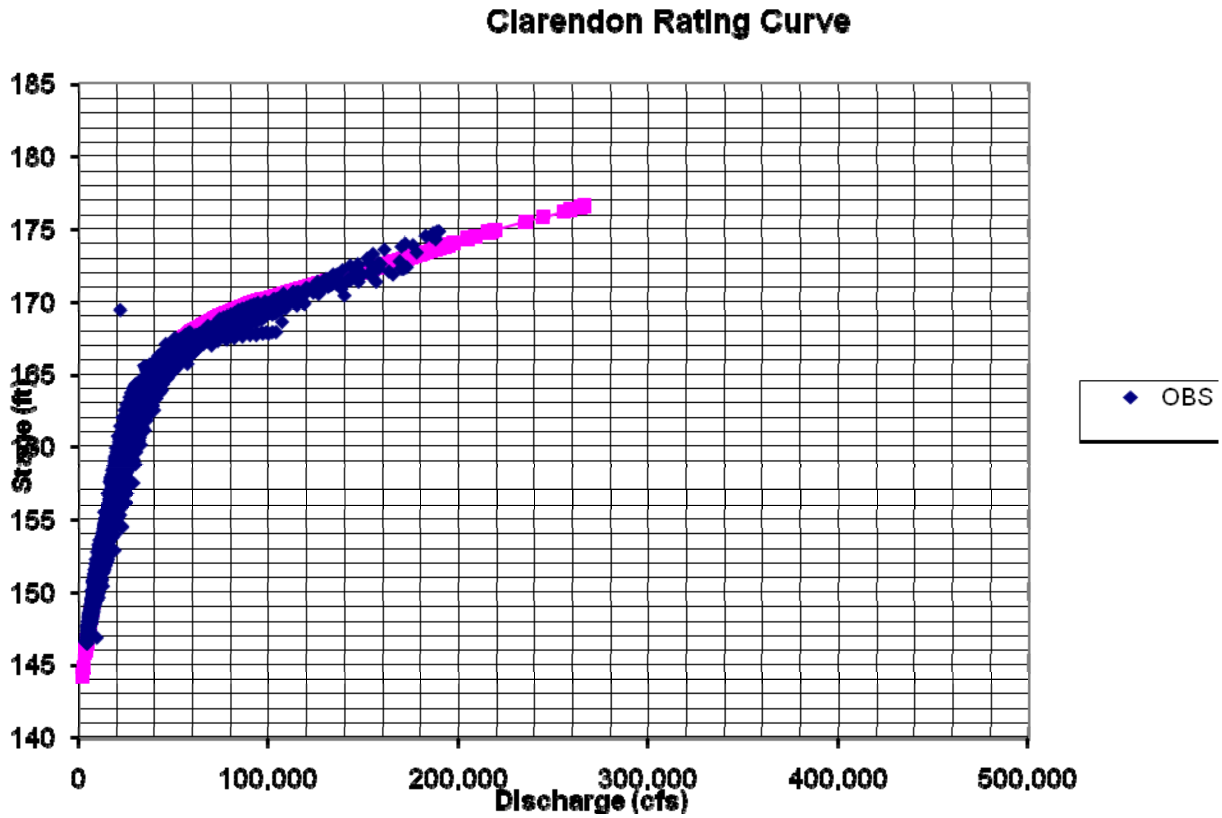
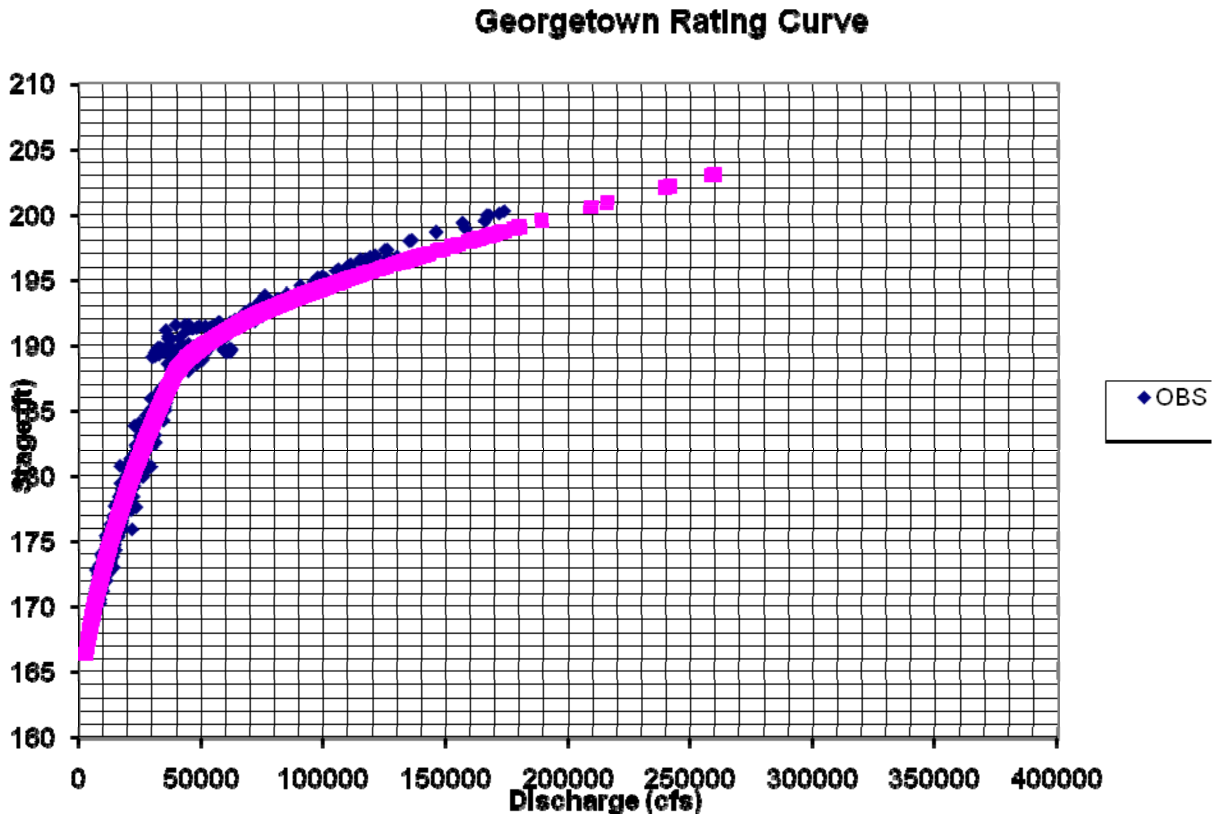
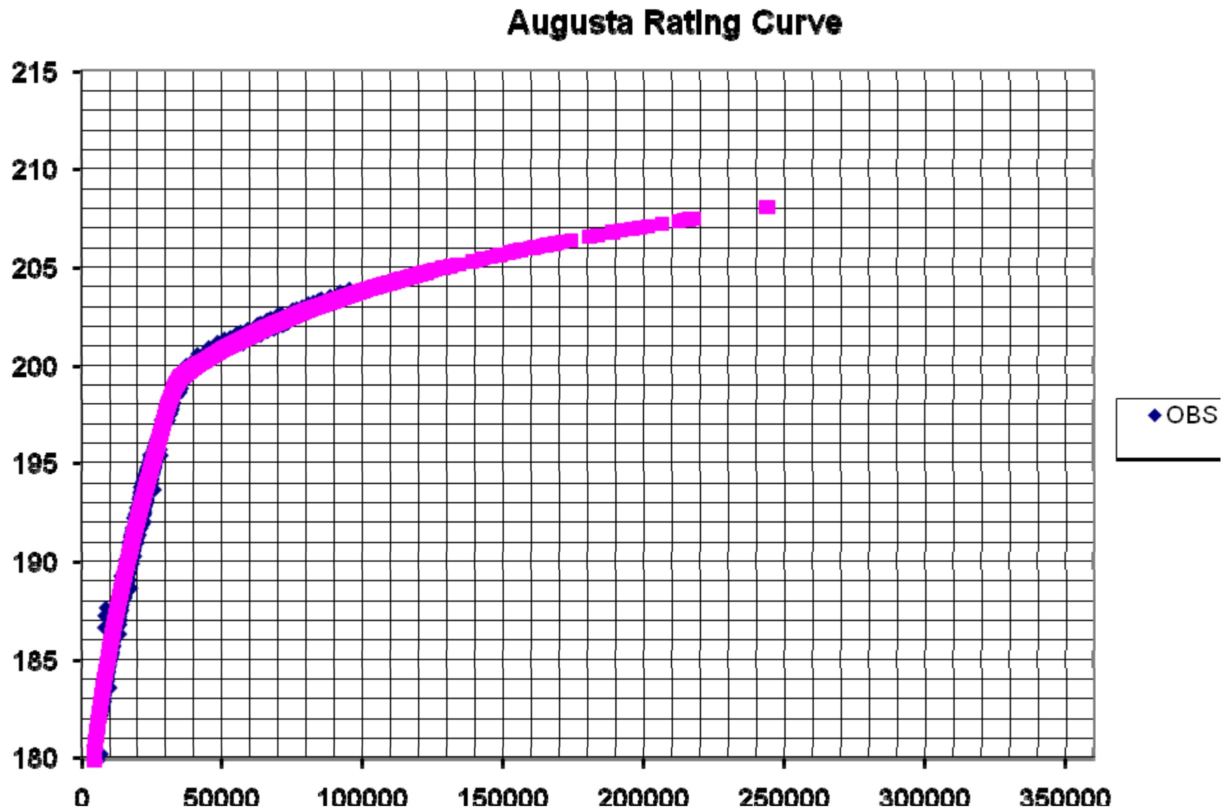
Appendix A

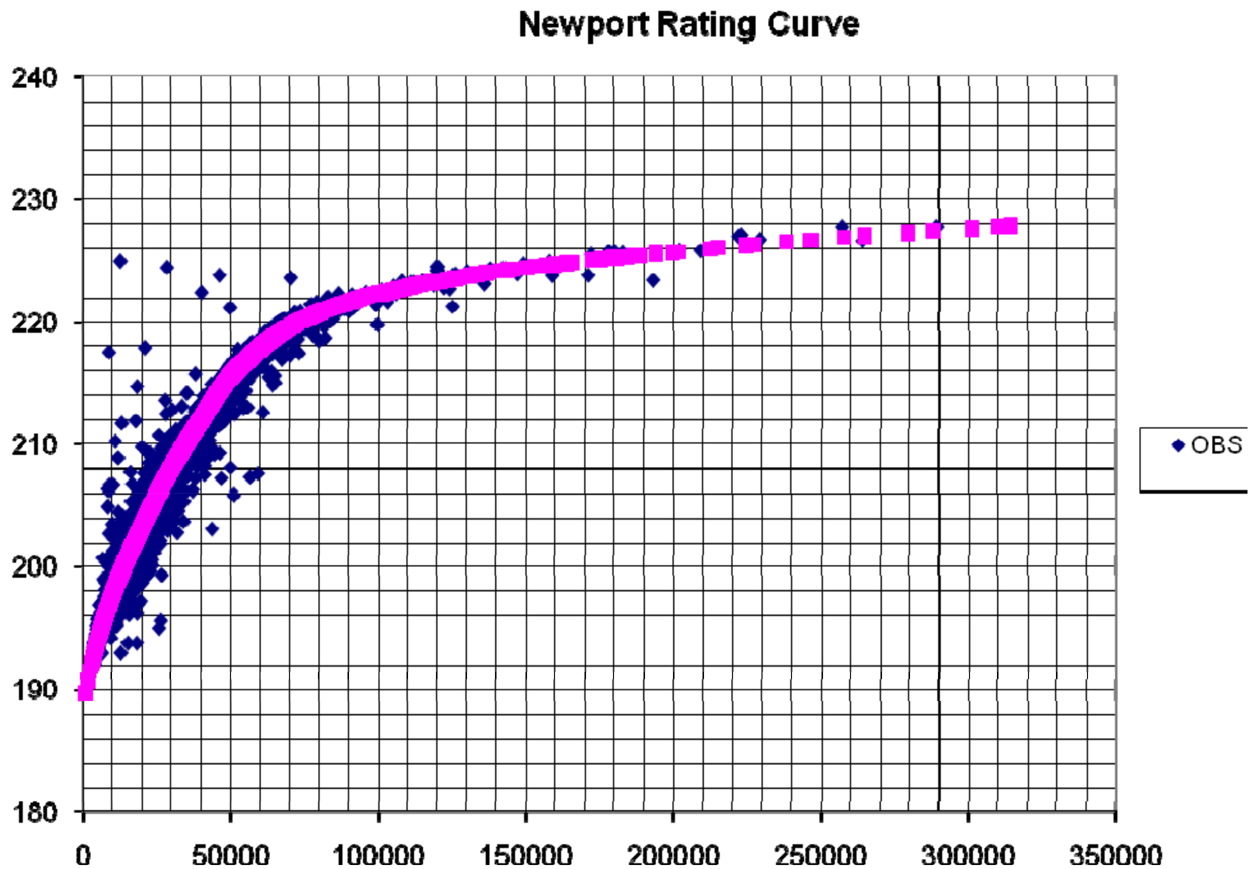
Comparison of Rating Curves between Gage Measured Data and Supermodel at Clarendon, Georgetown, Augusta, and Newport


Clarendon Rating Curve
Stage (ft)
185
180
175
170
165
160
155
150
145
140
0
100,000
200,000
300,000
400,000
500,000
Discharge (cfs)
OBS


Georgetown Rating Curve
210
205
200
195
190
185
180
175
170
165
160
Stage(ft)
0
50000
100000
150000
200000
250000
300000
350000
400000
Discharge (cfs)
OBS



Augusta Rating Curve
215
210
205
200
195
190
185
180
0
50000
100000
150000
200000
250000
300000
350000
OBS


Newport Rating Curve
240
230
220
210
200
190
180
0
50000
100000
150000
200000
250000
300000
350000
OBS

Appendix B

Bank Stations and Reach lengths

River Station	Left Bank Sta	Right Bank Sta	LOB Length	Channel Length	ROB Length
258.94	15974.48	17147.13	2439.9	10799.25	3193.53
256.89	26591.91	27469.3	9748.67	7295.27	4773
255.51	23936.54	25012.95	8441.71	9303.67	4985.18
253.75	5811.78	6700.59	4870.52	3554.22	6450.81
253.08	10592.74	11593.36	6559.34	7814.58	7114.72
251.6	2882.68	4491.26	5526.88	9146.88	3189.14
249.86	10125.38	11591.27	2784.33	4810.16	9305.82
248.95	7998.26	9693.81	3882.99	6111.11	6332.04
247.8	6442.57	7349.13	1897.62	4683.67	4261.35
246.91	2811.39	3661.34	9305.53	5876.86	6515.88
245.8	2230.06	3152.84	2236.98	2093.18	2652.84
245.4	2187.07	2801.62	709.04	10465.41	1243.65
243.42	11185.47	11600.28	445.27	5652.91	6466.53
242.35	9065.41	9648.23	685.26	5433.6	4612.4
241.32	5994.01	7175.36	3192.88	5073.95	6233.75
240.36	2342.45	3167.16	200	200	200
240.35	Bridge		Bridge		
240.34	2342.45	3401.65	2849.36	4767.03	4446.55
239.45	3000.01	4055.29	8053.36	5135.44	157.46
238.48	2476.85	3347.5	8720.88	5378.36	1451.52
237.46	3407.95	4098.55	443.72	9475.47	4977
235.67	8056.12	8933.72	1054.26	3619.25	2341.75
234.98	3350.58	4159.48	2876.35	4035.49	1825.65
234.22	3136.56	4021.38	5552.57	8788.74	1984.16
232.55	2135.59	3046.36	4428.74	5832.69	1351.38
231.45	3535.43	4876.67	3580.47	13529.2	4199.88
228.89	13723.92	14712.86	1324.31	5819.86	4055.55
227.78	11288.07	12664.39	5445.54	4524.42	3475.28
226.93	17314.82	17975.29	3635.28	4186.34	4140.99
226.14	15499.18	18701.94	7724.84	11784.76	4526.43
223.9	9576.18	10037.19	9205.04	12508.44	4544.78
221.53	19415.96	22863.43	4644	11214.5	5100.33
219.41	13402.28	14962.55	5017.08	12862.93	3022.49
216.97	20575.98	22231.43	2647.35	8692.16	5292.43
215.33	17766.11	18496.99	3083.21	2634.47	2018.97
214.83	19547.03	20281.79	1961.56	7901.16	7633.19
213.33	22336.82	23337.51	4704.38	6806.65	5914.77
212.04	13974.98	14890.98	5638.74	4819.73	3469.9
211.13	16300.15	17152.55	1395.49	4402.41	4593.65
210.3	17656.88	18876.99	2024.49	8125.28	4287.56
208.76	21242.43	22382.88	3905.52	8386.75	7245.79
207.17	18355.19	19281.03	6785	6777.52	2960.37
205.89	13716.84	14317.58	9068.93	8149.14	8589.12
204.34	8308.92	8896.59	355.53	3364.94	3496.7

203.73	10830.23	12460.99	200	200	200
203.72	Bridge		Bridge		
203.71	11011.43	12460.99	653.97	11319.39	3428.27
201.56	4543.43	5078.37	889.98	2929.26	339.21
201.01	2283.44	2899.79	4631.42	3734.28	187.37
200.3	2413.47	2940.79	210.53	6566.93	435.52
199.06	8173.98	8972.5	469	4485.91	3402.17
198.21	12273.33	13244.48	297.91	4919.37	4330.59
197.27	11809.09	12571.29	1968.67	11957.06	1096.68
195.01	3339.56	3903.03	3014.84	1473.54	1136.52
194.73	2100	2734.82	3652.75	3364.41	1586.04
194.09	2127.65	2604.12	5941.25	5906.56	2428.64
192.97	12772.68	13570.93	1748.34	1550.83	1466.46
192.68	13070.73	13915.83	3723.68	5486.23	5364.12
191.64	11991.34	12671.37	5298.77	8952.73	1577.18
189.95	10057.48	10526.66	1651.51	7179.32	1035.86
188.59	5011.15	6167.73	8090.43	5450.76	253.57
187.55	5585.36	6589.39	3053.8	6854.76	555.72
186.26	483.22	1328.84	7164.43	5881.86	507.49
185.14	1751.29	2470.8	2665.11	5014.48	538.24
184.19	7037.24	7899.78	404.29	3668.71	148.01
183.5	9710.49	10468.53	6185.4	4637.84	4326.85
182.62	9643.63	10591.29	502.18	1588.69	2310.64
182.32	8807.11	10055.84	7513.25	5423.58	2787.15
181.29	1009.26	3583.71	1994.76	4924.76	6238.53
180.36	5446.06	6205.2	1938.91	4188.26	4672.24
179.57	1849.08	3469.82	4416.73	7026.48	2379.7
178.23	3044.06	3985.04	2099.73	2259.02	3069.23
177.81	3436.69	4343.64	3123.43	6739.9	6219.6
176.53	9030.29	10188.97	1179.97	2817.09	2235.65
176	10424.91	11339.46	1191.45	2617.9	3612.46
175.5	10879.04	12094.97	2823.76	5247.7	3739.52
174.51	6515.46	9032.96	1049.81	5970.65	1805.2
173.38	1996.09	2835.82	3986.58	3851.83	4239.45
172.65	2060.61	3152.42	3827.67	6279	5708.89
171.46	3129.47	4914.84	867.87	5624.33	4779.16
170.39	9127.18	9747.18	1886.46	4590.67	5046.8
169.52	6573.86	8208.41	5714.15	2545.33	2741.92
169.04	5216.02	6543.24	7075.13	5732.68	3580.84
167.95	6770.21	7681.58	3356.17	4593.21	1754.66
167.08	4049.76	5335.97	3763.05	5296.75	3826.76
166.08	2248.59	2965.26	1680.51	8939.85	1239.24
164.39	10742.35	11291.07	227.47	5198.89	5037.27
163.4	6792.01	7501.26	1845.11	2017.81	2416.86
163.02	7419.76	8391.77	2625.33	5853.5	7611.45
161.91	3736.26	4493.28	2912.76	3617.42	9899.82
161.23	2253.15	3121.52	2311.23	13718.77	2611.22
158.63	12655.57	13864	1567.63	15418.39	7880.49

155.71	1726.96	2386.9	4600.16	3557.02	1158.85
155.04	1218.2	1809.6	4994.19	5287	4043.94
154.03	3444.33	4150.01	2902.75	3003.46	3078.48
153.47	5918.96	6950.83	2795.75	4148.54	2888.76
152.68	8594.43	9652.46	2050.94	6347.4	3543.19
151.48	4901.44	5474.21	7648.4	6535.42	3871.3
150.24	9090.16	10180.48	5745.45	6391.48	5962.34
149.03	8567.06	9537.9	1224.63	5294.11	5291.34
148.03	13746.76	14461.82	4430.36	4437.07	6340.74
147.19	12200.76	12965.76	2011.24	2531.86	3117.5
146.75	12021.45	12841.92	148.16	180.79	139.36
146.73	Bridge		Bridge		
146.71	12021.45	12841.92	6611.07	5120.89	5155.85
145.72	13331.99	14113.36	2645.52	4375.56	523.95
144.89	10723.01	11928.62	1131.22	6022.33	4932.33
143.75	14422.44	15206.32	1794.3	4770.1	4340.22
142.85	10541.06	11779.9	5688.32	5643.62	3246.64
141.78	9540.49	11508.22	3623.12	2890.02	2121.61
141.23	10917.27	12017.91	4656.43	4469.15	4363.57
140.39	7631.67	9084.53	5024.45	6224.14	4439.17
139.21	12910.24	13881.51	4912.69	6307.6	7469.84
138.01	9521.12	11159.52	2919.73	2195.24	1897
137.6	8892.78	10239.15	6791.82	8260.38	2082.4
136.03	3965.95	5323.09	6590.36	4635.6	765.16
135.16	3551.67	4270.46	2654.43	7943.4	2153.96
133.65	9653.1	10509.77	1974.53	5497.59	3595.9
132.61	6191.78	7316.89	5066.83	4849.54	4524.08
131.69	8949.62	10016.78	5485.96	6063.3	6467.91
130.54	9568.02	10715.58	2915.05	6334.62	7307.5
129.34	11681.07	12161.32	5307.39	3239.45	3198.18
128.73	7909.2	8898.5	160.01	161.48	162.09
128.72	Bridge		Bridge		
128.7	7909.2	8898.5	2975.94	2709.18	2206.1
128.19	8587.9	9587.46	3710.26	5802.34	7194.16
127.09	10659.78	11409.79	3248.2	4973.01	4922.51
126.15	9137.13	10212.17	3099.85	3242.48	3138.26
125.53	6710.83	7412.71	5121.55	4762.14	3585.66
124.65	8362.57	9113.15	250	250	250
124.64	Bridge		Bridge		
124.63	8362.57	9113.15	164.55	1493.77	1273.7
124.35	9663.22	10533.22	178.29	81.1	99.21
124.33	9731.65	10601.65	5092.25	3601.28	7720.17
123.65	9300.05	10364.67	4184.82	6792.37	1447.02
122.36	5031.56	5537.52	3201.96	4613.5	8492.73
121.49	7034.57	8121.96	7303.45	6581.33	2084.7
120.24	1951.4	2598.66	3674.08	6660.1	608.66
118.98	8027.15	8722.72	10350.88	4189.46	4683.69
118.19	37459.16	38423.54	3198.88	9449.35	3946.92

116.4	30190.42	31272.28	3747.48	9893.99	7284.28
114.53	24264.14	25037.31	7650.04	9268.73	2131.25
112.77	20188.4	21254.72	6496.74	7565.9	3896.32
111.34	23722.48	24495.33	7186.92	8281.51	7197.96
109.77	23321.49	23956.16	3659.59	5370.59	4895.42
108.75	21777.46	22623.71	3962.98	5720.79	3617.52
107.67	21464.13	22169.86	1290.13	17722.38	5193.98
104.31	24341.23	24791.16	3998.39	4240.09	2055.89
103.51	21489.87	21991.83	53773.9	6627.84	934.51
102.25	11524.71	12331.67	1902.2	5853.33	1219.48
101.14	1773.49	2508.64	4521.19	4059.97	744.03
100.38	165.03	840.14	201.79	201.6	385.82
100.36	Bridge		Bridge		
100.34	165.03	840.14	201.79	201.6	385.82
100.3	165.02	750.1	287.38	365.6	6369.12
100.23	217.06	821.71	301.03	372.1	1527.27
100.16	251.25	971.51	210.23	207.15	241.05
100.14	Bridge		Bridge		
100.12	251.25	971.51	521.14	378.48	658.97
100.05	3261.41	3869.65	8345.52	8297.32	6631.52
98.48	11763.94	12813.66	5777.83	9275.08	4108.06
96.72	14508.53	15322.69	7349.45	11360.19	9908.42
94.57	21489.92	22111.73	12618.34	6247.79	6483
93.39	25105.68	25991.08	3850.12	5097.04	6075.25
92.42	24113.3	24994.58	13642.12	15633.62	15034.96
89.46	21823.06	22770.62	3523.65	10813.18	4467.54
87.41	14251.37	15113.44	9499.06	9173.73	2327.08
85.67	21845.49	22970.49	5233.58	5558.45	5563.52
84.62	24219.07	25719.07	5416.3	7865.68	8968.15
83.13	30028.71	31378.96	8955.62	7810.04	8096.94
81.65	25860.45	26746.19	7634.06	7068.98	4570.95
80.31	25024.2	25876.34	6501.55	7529.2	8410.65
78.89	27707.1	28705.88	8041.42	10620.17	7676.88
76.87	24747.44	25825.1	6073.83	6056.02	6057.46
75.73	22574.39	23904.53	11093.15	11114.26	5940.67
73.62	17604.31	18473.9	8011.85	10718.5	10836.56
71.59	27170.78	28260.14	7057.29	16266.83	5551.01
68.51	28911.62	29625.71	11101.67	6855.58	6921.08
67.21	26516.82	27493.76	5734.38	13156.48	10418.93
64.72	21024.19	22234.06	8288.42	10669.93	12511.03
62.7	20365.71	21448.08	7739.08	13610.14	6174.41
60.12	26126.31	27522.5	7120.46	7059.17	6423.54
58.79	24097.57	25538.04	6299.19	6218	5411.22
57.61	21973.28	22780.46	4787.52	5143.14	5162.92
56.63	22554.84	23082.76	314.9	324.49	330.48
56.57	21820.17	22498.79	207.27	170.46	189.37
56.54	21320.19	22058.02	207.23	208.87	221.51
56.52	Bridge		Bridge		

56.5	21320.19	22058.02	6237.6	6365.23	7706.43
55.3	14180.02	15101.62	3887.02	5090.75	2418.03
54.33	18144.22	18864.22	5054.23	5009.68	4860.05
53.38	24547.89	25215.26	8543.73	10221.39	2581.51
51.45	16842.98	18032.73	7864.77	8828.13	9672.96
49.77	6169.35	6934.43	2919.87	2046.87	4234.9
49.39	5091.72	5901.9	3570.35	1604.38	2346.63
49.08	3305.08	4719.42	1482.25	10015.55	4003.4
47.19	520.53	973.46	5075.75	9929.38	7348.11
45.31	2361.96	3021.46	6168.61	17431.19	5778.18
42	5395.62	6079.79	10263.4	7853.63	7631.64
40.52	4811.63	5578.47	4672.08	9664.68	8980.37
38.69	210.77	1114.09	6990.21	14160.11	5639.03
36	215.87	1171.87	8054.67	8355.83	9648.82
34.42	372.45	1148.38	7484.52	8484.83	12380.11
32.81	460.77	1300.03	1637.78	10217.5	5003.68
30.88	6518.33	7265.73	10733.62	6033.17	5508.29
29.74	4131.94	5097.07	1657.49	3215.69	2049.1
29.13	6373.67	6974.95	5982.89	7234.76	8404.4
27.76	3066.62	3998.64	5049.99	7259.46	8192.05
26.38	3620.06	4695.01	4824.68	10110.85	7119.5
24.47	8121.93	9468.05	16859.98	12983.34	6485.1
22.01	15257.78	16473.01	15967.93	23057.88	25536.52
17.64	25532.62	26928.53	18251.98	19165.13	9129.69
14.01	33811.8	34952.39	6946.87	11663.16	8502.51
11.8	33113.62	34148.62	8998.82	9676.92	9968.28
9.97	36020	37355.93	11247.65	9730.79	8991.9
8.13	37716.53	38757.19	3091.61	6392.01	8197.63
6.92	36523.07	37883.94	3440.04	2811.14	2163.99
6.38	34854.76	36992.03	3099.63	3100.79	3099.23
5.8	35568.85	36977.5	206.11	204.15	201.8
5.78	Bridge		Bridge		
5.76	35568.85	36977.5	206.11	204.15	201.8
5.72	35793.2	37006.97	2098.49	2101.85	2103.39
5.32	35274.61	36715.64	4996.76	5326.27	5900.06
4.31	38991.31	40857.88	5538.01	5591.24	5504.63
3.26	38397.64	39713.95	2535.93	3071.82	3576.36
2.67	39444.07	40598.54	6546.56	6931.7	7111.83
1.36	35845.11	36763.11	7945.1	7183.39	6840.27
0	40573.96	41876.97	6973.85	10491.49	15658.72

Appendix C

Levee Stations and Elevations

River Station	Left Sta	Left Elev	Right Sta	Right Elev
258.94				
256.89				
255.51				
253.75				
253.08				
251.6				
249.86				
248.95				
247.8				
246.91				
245.8				
245.4				
243.42				
242.35				
241.32				
240.36				
240.35	Bridge			
240.34				
239.45				
238.48	2296	226.91		
237.46	2957	224.45		
235.67	2928	225.6		
234.98	1895	219.59		
234.22	810	220.16		
232.55	1052	221.05		
231.45	526	212.46		
228.89	0	220.01		
227.78				
226.93				
226.14				
223.9				
221.53				
219.41				
216.97				
215.33				
214.83				
213.33				
212.04				
211.13				
210.3				
208.76				
207.17				
205.89				
204.34				

203.73	5045	214.24		
203.72	Bridge			
203.71	5045	209.74		
201.56				
201.01				
200.3				
199.06				
198.21				
197.27				
195.01				
194.73				
194.09				
192.97	0	210.18		
192.68	0	211		
191.64	0	211.53		
189.95	0	208		
188.59	0	208		
187.55	0	208		
186.26	0	207		
185.14	0	207		
184.19	0	207		
183.5	0	207		
182.62	0	206		
182.32	0	207		
181.29	0	207		
180.36	0	207.5		
179.57	0	208		
178.23	0	210		
177.81	0	206		
176.53	0	206		
176	0	206		
175.5	0	207.5		
174.51	0	209.5		
173.38				
172.65	0	206		
171.46	0	209		
170.39	0	207		
169.52	0	207.64		
169.04	0	213		
167.95	0	205.5		
167.08	0	204.39		
166.08	0	203		
164.39	0	203.18		
163.4				
163.02	0	203		
161.91	0	203		
161.23	0	203		
158.63	0	203		

155.71	0	203		
155.04	0	201		
154.03	0	201		
153.47	0	201		
152.68	0	202		
151.48	0	201		
150.24	0	201		
149.03	0	201		
148.03	0	200.79		
147.19	0	200.2		
146.75	0	200.56		
146.73	Bridge			
146.71	0	200.56		
145.72	0	200		
144.89	0	200		
143.75	0	199		
142.85	0	199.37		
141.78	0	198		
141.23	0	196		
140.39	0	196		
139.21	0	195		
138.01	0	195		
137.6	0	195		
136.03	0	199.52		
135.16	0	195		
133.65	0	195		
132.61	45.91	193.05		
131.69	0	198.43		
130.54				
129.34	0	197.06		
128.73	0	190		
128.72	Bridge			
128.7	0	190		
128.19	0	189		
127.09	0	189		
126.15	0	189		
125.53	0	186.54		
124.65	0	189.59		
124.64	Bridge			
124.63	0	189.59		
124.35	0	188.7		
124.33	0	188.91		
123.65	0	187.56		
122.36	0	185		
121.49	0	185		
120.24	0	185		
118.98	0	181.48		
118.19				

116.4				
114.53				
112.77				
111.34				
109.77				
108.75				
107.67	0	184.45		
104.31	0	186.05		
103.51	0	180.71		
102.25	0	181.53		
101.14	0	187.8		
100.38	0	187.89		
100.36	Bridge			
100.34	0	187.89		
100.3	0	191.97		
100.23	0	188.1		
100.16	0	186.57		
100.14	Bridge			
100.12	0	186.57		
100.05	0	181.95		
98.48	72.39	185.1		
96.72	0	180.08		
94.57	0	174.83		
93.39	0	174.83		
92.42	0	174.83		
89.46	0	175.16		
87.41	0	176.49		
85.67	0	175.16		
84.62	0	176.75		
83.13	0	177.78		
81.65	0	175.23		
80.31	0	174.78		
78.89	0	177.84		
76.87	0	174.94		
75.73	0	174.94		
73.62	0	174.94		
71.59	0	174.21		
68.51	0	174.16		
67.21	0	174.94		
64.72	0	174.91		
62.7	0	175.91		
60.12	0	180		
58.79	0	180		
57.61	0	180		
56.63	0	180		
56.57	0	180		
56.54	0	180		
56.52	Bridge			

56.5	0	180		
55.3	0	180		
54.33	0	180		
53.38	0	170.24		
51.45	0	175.41		
49.77	0	178.04		
49.39	39.44	176.14		
49.08	0	177.64		
47.19	30.42	176.9		
45.31	76.69	176.84		
42	0	174.2		
40.52	0	172.69		
38.69	105.29	174.67		
36	0	176.47		
34.42	0	172.19		
32.81	0	177.94		
30.88	291.09	173.51		
29.74	0	166.2		
29.13	0	176.06		
27.76	0	169.83		
26.38	0	167.81		
24.47	0	171.63		
22.01	45.01	168.67		
17.64	0	164.56		
14.01	0	169.42		
11.8	0	172.27		
9.97	0	171.88		
8.13	97.55	172.78		
6.92	0	169.6		
6.38	0	169.48		
5.8	0	166.94		
5.78	Bridge			
5.76	0	166.94		
5.72	0	172.87		
5.32	0	172.27		
4.31	0	171.07		
3.26	0	163.62		
2.67	0	167.89		
1.36	0	165.11		
0	0	166.44		

Appendix D

Manning’s n Values of Each Section

River Station	Frctn (n/K)	n #1	n #2	n #3	n #4	n #5	n #6	n #7	n #8	n #9	n #10	n #11
258.94	n	0.18	0.026	0.18	0.22							
256.89	n	0.18	0.026	0.18	0.22							
255.51	n	0.18	0.026	0.18	0.22							
253.75	n	0.18	0.026	0.18	0.22							
253.08	n	0.18	0.026	0.18	0.22							
251.6	n	0.18	0.026	0.18	0.22							
249.86	n	0.18	0.026	0.18	0.22							
248.95	n	0.18	0.026	0.18	0.22							
247.8	n	0.18	0.026	0.18	0.22							
246.91	n	0.18	0.026	0.18	0.22							
245.8	n	0.18	0.026	0.18	0.22							
245.4	n	0.18	0.026	0.18	0.22							
243.42	n	0.18	0.026	0.18	0.22							
242.35	n	0.18	0.026	0.18	0.22							
241.32	n	0.18	0.026	0.18	0.22							
240.36	n	0.18	0.026	0.18	0.22							
240.35	Bridge											
240.34	n	0.18	0.026	0.18	0.22							
239.45	n	0.18	0.026	0.18	0.22							
238.48	n	0.18	0.026	0.18	0.22							
237.46	n	0.18	0.026	0.18	0.22							
235.67	n	0.18	0.026	0.18	0.22							
234.98	n	0.18	0.026	0.18	0.22							
234.22	n	0.18	0.026	0.18	0.22							
232.55	n	0.18	0.026	0.18	0.22							
231.45	n	0.18	0.026	0.18	0.22							
228.89	n	0.18	0.026	0.18	0.22							
227.78	n	0.18	0.026	0.18	0.22							
226.93	n	0.18	0.026	0.18	0.22							
226.14	n	0.18	0.026	0.18	0.22							
223.9	n	0.18	0.026	0.18	0.22							
221.53	n	0.18	0.026	0.18	0.22							
219.41	n	0.18	0.026	0.18	0.22							
216.97	n	0.18	0.026	0.18	0.22							
215.33	n	0.18	0.026	0.18	0.22							
214.83	n	0.18	0.026	0.18	0.22							
213.33	n	0.18	0.026	0.18	0.22							
212.04	n	0.18	0.026	0.18	0.22							
211.13	n	0.18	0.026	0.18	0.22							
210.3	n	0.18	0.026	0.18	0.22							
208.76	n	0.18	0.026	0.18	0.22							
207.17	n	0.18	0.026	0.18	0.22							
205.89	n	0.18	0.026	0.18	0.035	0.22						
204.34	n	0.18	0.03	0.18	0.035	0.22	0.035	0.22				

203.73	n	0.18	0.03	0.18	0.035	0.22	0.035	0.22				
203.72	Bridge											
203.71	n	0.18	0.03	0.18	0.035	0.18	0.035	0.18				
201.56	n	0.18	0.03	0.08	0.18	0.035	0.18					
201.01	n	0.18	0.03	0.08	0.18	0.18						
200.3	n	0.18	0.03	0.08	0.18	0.18						
199.06	n	0.18	0.03	0.15	0.18							
198.21	n	0.18	0.03	0.15	0.035	0.18	0.035	0.18				
197.27	n	0.18	0.03	0.15	0.035	0.18	0.035	0.18				
195.01	n	0.18	0.03	0.15	0.035	0.18	0.035	0.18				
194.73	n	0.18	0.03	0.15	0.035	0.18	0.035	0.18				
194.09	n	0.18	0.03	0.15	0.035	0.18	0.035	0.18				
192.97	n	0.18	0.03	0.15	0.035	0.18	0.035	0.18				
192.68	n	0.18	0.03	0.15	0.18	0.035						
191.64	n	0.18	0.03	0.15	0.18	0.035	0.18	0.035	0.18			
189.95	n	0.18	0.03	0.15	0.035	0.18						
188.59	n	0.18	0.03	0.15	0.035	0.18	0.18					
187.55	n	0.18	0.03	0.15	0.035	0.18	0.035	0.18				
186.26	n	0.18	0.03	0.15	0.035	0.18	0.035					
185.14	n	0.18	0.03	0.15	0.035	0.18	0.035	0.035				
184.19	n	0.18	0.03	0.15	0.035	0.18	0.035					
183.5	n	0.18	0.03	0.15	0.035	0.18	0.035					
182.62	n	0.18	0.08	0.18	0.032	0.18						
182.32	n	0.18	0.03	0.18	0.035	0.18						
181.29	n	0.18	0.03	0.18	0.035	0.18						
180.36	n	0.18	0.03	0.18	0.035	0.18						
179.57	n	0.18	0.03	0.18	0.035	0.18	0.035	0.18	0.035	0.18	0.035	0.18
178.23	n	0.18	0.03	0.18	0.035	0.18	0.035	0.18	0.035	0.18		
177.81	n	0.18	0.03	0.18	0.035	0.18						
176.53	n	0.18	0.03	0.18	0.035	0.18						
176	n	0.18	0.03	0.18	0.035	0.18						
175.5	n	0.18	0.03	0.18	0.035							
174.51	n	0.18	0.03	0.18	0.035	0.18						
173.38	n	0.18	0.03	0.18	0.035	0.18	0.035	0.18	0.035			
172.65	n	0.18	0.03	0.18	0.035	0.18	0.2	0.035				
171.46	n	0.18	0.03	0.18	0.035							
170.39	n	0.18	0.03	0.18	0.035	0.18						
169.52	n	0.18	0.026	0.18	0.035	0.18	0.2					
169.04	n	0.18	0.026	0.18	0.2							
167.95	n	0.18	0.035	0.026	0.18	0.035						
167.08	n	0.18	0.026	0.18								
166.08	n	0.18	0.026	0.18								
164.39	n	0.18	0.026	0.18	0.18							
163.4	n	0.18	0.026	0.18	0.035	0.18						
163.02	n	0.18	0.026	0.18	0.2							
161.91	n	0.18	0.026	0.18	0.2							
161.23	n	0.18	0.026	0.18	0.035	0.18	0.2					
158.63	n	0.18	0.026	0.18	0.2							

155.71	n	0.18	0.026	0.18	0.2							
155.04	n	0.18	0.026	0.18	0.2							
154.03	n	0.18	0.026	0.18	0.2							
153.47	n	0.18	0.026	0.18	0.2							
152.68	n	0.18	0.026	0.18	0.2							
151.48	n	0.18	0.026	0.18	0.2							
150.24	n	0.18	0.026	0.18	0.2							
149.03	n	0.18	0.026	0.18	0.2							
148.03	n	0.18	0.026	0.18	0.2							
147.19	n	0.18	0.026	0.18	0.2							
146.75	n	0.18	0.026	0.18	0.2							
146.73	Bridge											
146.71	n	0.18	0.026	0.18	0.2							
145.72	n	0.18	0.026	0.18	0.035	0.2						
144.89	n	0.18	0.026	0.18	0.2							
143.75	n	0.18	0.026	0.18	0.2							
142.85	n	0.18	0.035	0.18	0.026	0.2	0.18					
141.78	n	0.18	0.035	0.18	0.026	0.2	0.18					
141.23	n	0.18	0.035	0.18	0.026	0.2	0.18					
140.39	n	0.18	0.026	0.18	0.18							
139.21	n	0.18	0.026	0.18	0.18	0.18	0.035	0.18				
138.01	n	0.18	0.026	0.18	0.035	0.18	0.035	0.18				
137.6	n	0.18	0.026	0.18	0.035	0.18	0.035	0.18				
136.03	n	0.18	0.026	0.18	0.18	0.035	0.18					
135.16	n	0.18	0.026	0.18	0.2							
133.65	n	0.18	0.026	0.18	0.035	0.2						
132.61	n	0.18	0.026	0.18	0.18							
131.69	n	0.18	0.026	0.18	0.035	0.18	0.035	0.18	0.035	0.2		
130.54	n	0.18	0.026	0.18	0.035	0.2						
129.34	n	0.18	0.026	0.18	0.035	0.18	0.035	0.2				
128.73	n	0.18	0.026	0.18	0.035	0.18	0.035	0.2				
128.72	Bridge											
128.7	n	0.18	0.026	0.18	0.035	0.18	0.035	0.18				
128.19	n	0.18	0.026	0.18	0.035	0.18	0.035	0.18				
127.09	n	0.18	0.026	0.18	0.2							
126.15	n	0.18	0.026	0.18	0.2							
125.53	n	0.18	0.026	0.18	0.2							
124.65	n	0.18	0.026	0.18	0.035	0.18	0.035	0.18				
124.64	Bridge											
124.63	n	0.18	0.026	0.18	0.035	0.18	0.035	0.18				
124.35	n	0.18	0.026	0.18	0.2							
124.33	n	0.18	0.026	0.18	0.2							
123.65	n	0.18	0.026	0.18	0.2							
122.36	n	0.18	0.026	0.18	0.2							
121.49	n	0.18	0.026	0.18	0.2							
120.24	n	0.18	0.026	0.18	0.2							
118.98	n	0.18	0.026	0.18	0.2							
118.19	n	0.18	0.026	0.18	0.2							

116.4	n	0.18	0.026	0.18	0.2							
114.53	n	0.18	0.026	0.18	0.035	0.2						
112.77	n	0.18	0.026	0.18	0.035	0.2						
111.34	n	0.18	0.035	0.18	0.035	0.18	0.026	0.18	0.035	0.2		
109.77	n	0.18	0.035	0.18	0.026	0.18	0.18					
108.75	n	0.18	0.035	0.18	0.035	0.026	0.2	0.18				
107.67	n	0.18	0.026	0.18	0.18							
104.31	n	0.18	0.026	0.18	0.035	0.035	0.18					
103.51	n	0.18	0.026	0.18	0.035	0.18						
102.25	n	0.18	0.026	0.18	0.035	0.18	0.035	0.18				
101.14	n	0.18	0.026	0.18	0.035	0.18	0.035	0.18				
100.38	n	0.18	0.026	0.18	0.035	0.18	0.08	0.18				
100.36	Bridge											
100.34	n	0.18	0.026	0.18	0.035	0.18	0.08	0.18				
100.3	n	0.18	0.026	0.18	0.035	0.18	0.035	0.18				
100.23	n	0.18	0.026	0.18	0.035	0.18	0.035	0.18				
100.16	n	0.18	0.026	0.18	0.035	0.18	0.035	0.18	0.035	0.18		
100.14	Bridge											
100.12	n	0.18	0.026	0.18	0.035	0.18	0.035	0.18	0.035	0.18		
100.05	n	0.1	0.033	0.1	0.035	0.1						
98.48	n	0.1	0.033	0.1	0.035	0.1						
96.72	n	0.1	0.033	0.1	0.035	0.1	0.035	0.1				
94.57	n	0.1	0.033	0.1	0.035	0.1						
93.39	n	0.1	0.033	0.1								
92.42	n	0.1	0.033	0.1								
89.46	n	0.1	0.033	0.1	0.035	0.1						
87.41	n	0.1	0.033	0.1	0.035	0.1						
85.67	n	0.1	0.035	0.1	0.033	0.1	0.035	0.1				
84.62	n	0.1	0.035	0.1	0.033	0.1						
83.13	n	0.1	0.035	0.1	0.035	0.1	0.035	0.1	0.033	0.1	0.035	0.1
81.65	n	0.1	0.035	0.1	0.035	0.1	0.035	0.1	0.033	0.1		
80.31	n	0.1	0.035	0.1	0.035	0.1	0.033	0.1				
78.89	n	0.1	0.035	0.1	0.033	0.1	0.03	0.1				
76.87	n	0.1	0.035	0.1	0.033	0.1						
75.73	n	0.1	0.035	0.1	0.033	0.1	0.035	0.1				
73.62	n	0.1	0.035	0.1	0.033	0.1	0.035	0.1				
71.59	n	0.1	0.035	0.1	0.033	0.1	0.035	0.1				
68.51	n	0.1	0.035	0.1	0.035	0.1	0.033	0.1				
67.21	n	0.1	0.035	0.1	0.035	0.1	0.035	0.1	0.033	0.1		
64.72	n	0.1	0.035	0.1	0.033	0.1	0.035	0.1				
62.7	n	0.1	0.035	0.1	0.033	0.1	0.035	0.1				
60.12	n	0.1	0.035	0.1	0.035	0.1	0.033	0.1				
58.79	n	0.1	0.035	0.1	0.035	0.1	0.033	0.1				
57.61	n	0.1	0.035	0.1	0.033	0.1	0.035	0.1	0.035			
56.63	n	0.1	0.035	0.1	0.035	0.1	0.035	0.033	0.1			
56.57	n	0.1	0.035	0.1	0.035	0.033	0.1					
56.54	n	0.1	0.035	0.1	0.033	0.1	0.035					
56.52	Bridge											

56.5	n	0.1	0.035	0.1	0.033	0.1	0.035					
55.3	n	0.1	0.035	0.1	0.033	0.1	0.035	0.1				
54.33	n	0.1	0.035	0.1	0.033	0.1	0.035	0.1				
53.38	n	0.1	0.035	0.1	0.033	0.1	0.035	0.1				
51.45	n	0.1	0.035	0.1	0.033	0.1	0.035	0.1				
49.77	n	0.1	0.033	0.1	0.035	0.1						
49.39	n	0.1	0.033	0.1	0.1	0.035	0.1	0.035	0.1			
49.08	n	0.1	0.033	0.1	0.035	0.1	0.035	0.1				
47.19	n	0.1	0.033	0.1	0.035	0.1	0.035	0.1	0.035	0.1		
45.31	n	0.1	0.033	0.1	0.035	0.1	0.035	0.1				
42	n	0.1	0.033	0.1	0.035	0.1						
40.52	n	0.1	0.033	0.1	0.035	0.1	0.035	0.1	0.035			
38.69	n	0.1	0.033	0.1	0.035	0.1	0.035	0.1				
36	n	0.1	0.033	0.1	0.035	0.1	0.035	0.1				
34.42	n	0.1	0.033	0.1	0.035	0.1	0.035	0.1				
32.81	n	0.1	0.033	0.1	0.035	0.1	0.035	0.1				
30.88	n	0.1	0.033	0.1	0.035	0.1						
29.74	n	0.1	0.033	0.1	0.035	0.1	0.035	0.1	0.035			
29.13	n	0.1	0.033	0.1	0.035	0.1						
27.76	n	0.1	0.033	0.1	0.1							
26.38	n	0.1	0.033	0.1	0.035	0.1	0.035	0.1				
24.47	n	0.1	0.035	0.1	0.033	0.1	0.035	0.1				
22.01	n	0.1	0.035	0.1	0.033	0.1	0.035	0.1				
17.64	n	0.1	0.035	0.1	0.033	0.1	0.035	0.1				
14.01	n	0.1	0.035	0.1	0.033	0.1	0.035	0.1				
11.8	n	0.1	0.035	0.1	0.033	0.1	0.035	0.1				
9.97	n	0.1	0.035	0.1	0.033	0.1	0.035	0.1				
8.13	n	0.1	0.035	0.1	0.033	0.1	0.035	0.1				
6.92	n	0.1	0.035	0.1	0.03	0.1	0.033	0.1				
6.38	n	0.1	0.035	0.1	0.03	0.1	0.033	0.1	0.035	0.1		
5.8	n	0.035	0.1	0.035	0.1	0.033	0.1	0.035	0.1	0.035	0.1	
5.78	Bridge											
5.76	n	0.035	0.1	0.035	0.1	0.033	0.1	0.035	0.1	0.035	0.1	
5.72	n	0.035	0.1	0.033	0.1	0.035	0.1					
5.32	n	0.1	0.035	0.1	0.033	0.1	0.035	0.1				
4.31	n	0.1	0.035	0.1	0.033	0.1	0.035	0.1				
3.26	n	0.1	0.035	0.1	0.033	0.1	0.035	0.1				
2.67	n	0.1	0.035	0.1	0.033	0.1	0.035	0.1				
1.36	n	0.1	0.035	0.1	0.035	0.1	0.033	0.1	0.035	0.1		
0	n	0.1	0.035	0.1	0.035	0.1	0.033	0.1	0.035	0.1		

Appendix E

Seasonal Factors of the Unsteady-State Model

Clarendon		Georgetown		Augusta		Newport	
Day	Seasonal Factors	Day	Seasonal Factors	Day	Seasonal Factors	Day	Seasonal Factors
1-Jan	1.15	1-Jan	1.3	1-Jan	1.2	1-Jan	1.3
1-Feb	1.1	1-Feb	1.3	18-Jan	1.3	1-Feb	1.2
1-Mar	1.1	1-Feb	1.2	25-Feb	1	1-Mar	1.2
1-Apr	1.1	1-Mar	1.3	1-Apr	1.2	1-Apr	1.3
1-May	1.2	1-May	1.3	1-May	1.2	1-May	1.2
1-Jun	1	1-Jun	1.2	1-Jun	0.8	1-Jun	1.1
1-Jul	1	1-Jul	1.1	1-Jul	0.8	1-Jul	1
1-Aug	1.1	1-Aug	1	1-Aug	0.8	1-Aug	1
1-Sep	0.9	1-Sep	0.9	1-Sep	0.8	1-Sep	0.9
1-Oct	0.9	1-Oct	0.9	1-Oct	0.8	1-Oct	0.9
1-Nov	0.9	1-Nov	0.9	20-Nov	0.8	20-Nov	0.9
1-Dec	0.8	25-Nov	1.1	10-Dec	1.3	10-Dec	1.3