US Army Corps of Engineers®

St. Louis District

Hydrodynamic Study of Vancill Towhead Reach on the Middle Mississippi River

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Contents

Figures and Tables

Figures

Tables

1 Introduction

1.1 Background

In September 2012 the United States Army Corps of Engineers, St. Louis District (USACE) conducted a Hydraulic Sediment Response (HSR) model study of the Middle Mississippi River at Vancill Towhead, River Miles 72.0-65.0, to develop and evaluate alternatives to address a repetitive dredging problem. The Vancill Towhead study area is located between Cape Girardeau County, Missouri and Union County, Illinois, approximately 100 miles south of St. Louis, Missouri. For a general project location please see Figure 1.Project Location.Figure 1.

The result of the model study was a recommended alternative to help reduce the need for repetitive channel maintenance dredging necessary to maintain the authorized safe and dependable navigation channel in this reach, commonly referred to as Grand Tower Phase 5. Three of the new structures in the recommended alternative were S-Dike Structures. This configuration of river training structure has never been constructed before. The S-Dike was designed to increase navigation channel depths while also providing diverse environmental habitats in the area around the structures. For more information on the HSR model study and S-Dike Structures please see http://mvs-wc.mvs.usace.army.mil/arec/Reports_HSR_Model.html, Technical report M62, Vancill Towhead HSR Model River Miles 72.0-65.0 Hydraulic Sediment Response Model Investigation.

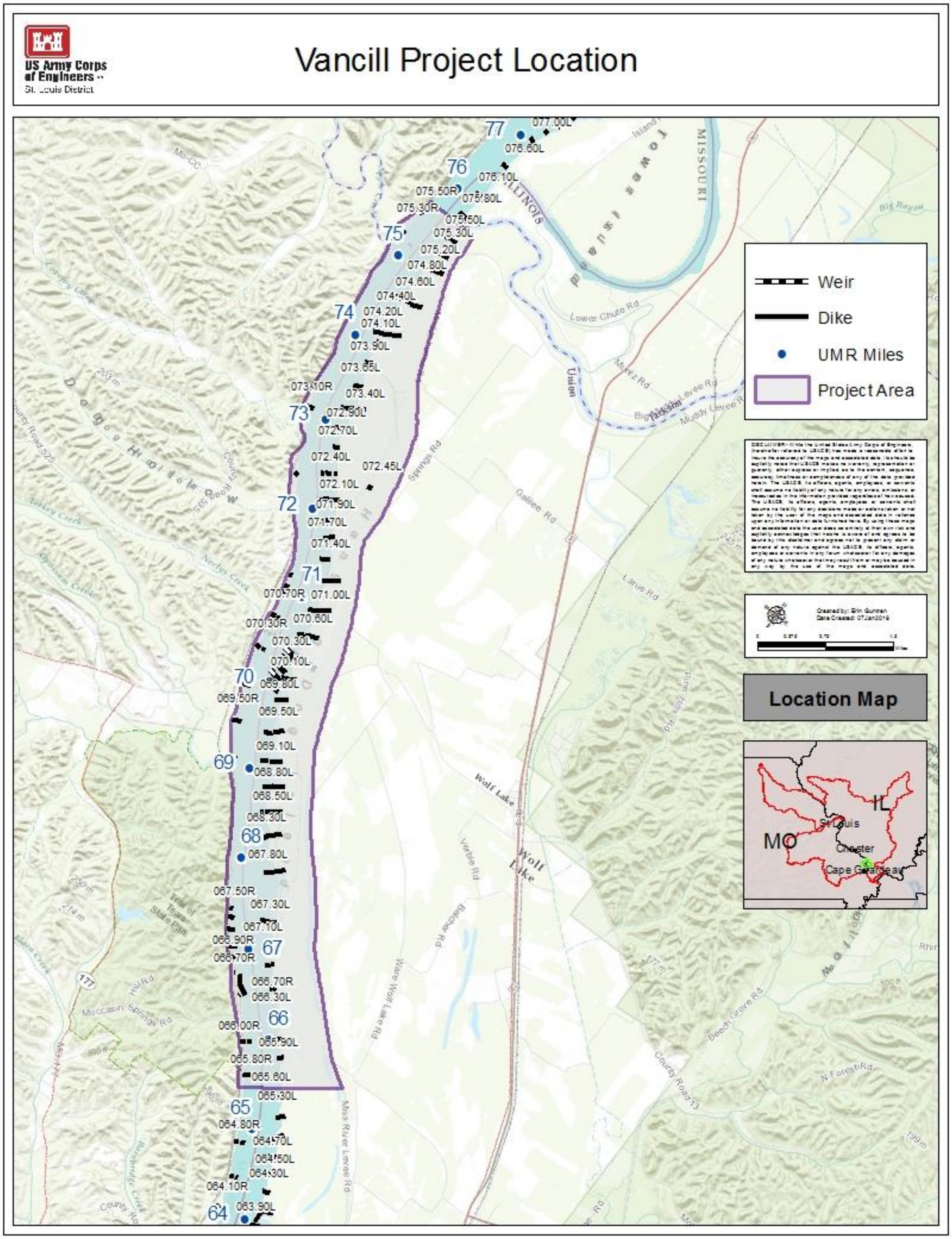
At a public hearing on the Grand Tower Phase 5 Draft Environmental Assessment (EA) in Grand Tower, Illinois on February 19th, 2014, the public raised concerns about the proposed S-Dikes at Middle Mississippi River Miles 68.10, 67.80, and 67.50 because this shape of river training structure had not been used before. To address this concern, the St. Louis District initiated a 2D numerical model study to investigate the recommended alternative's, including the new S-Dikes, effect on the water surface elevation for the 1 percent annual chance exceedance event. The results of this study will be incorporated into the appropriate National Environmental Policy Act (NEPA) documentation for Grand Tower Phase 5.

1.2 Approach

The model study utilized Adaptive Hydraulics (AdH) Version 4.5. AdH is a finite element modeling package that evaluates two-dimensional shallow water calculations. Adh was designed to solve water problems within riverine systems and estuaries. AdH works in conjunction with Surface Water Modeling System (SMS). SMS is used for mesh generation and visualization of results calculated in AdH.

AdH model development and calibration are discussed in Chapter 2. The model results and conclusions for the model study are included in Chapter 3.

Figure 1.Project Location.



2 AdH Model Development

2.1 Geometry

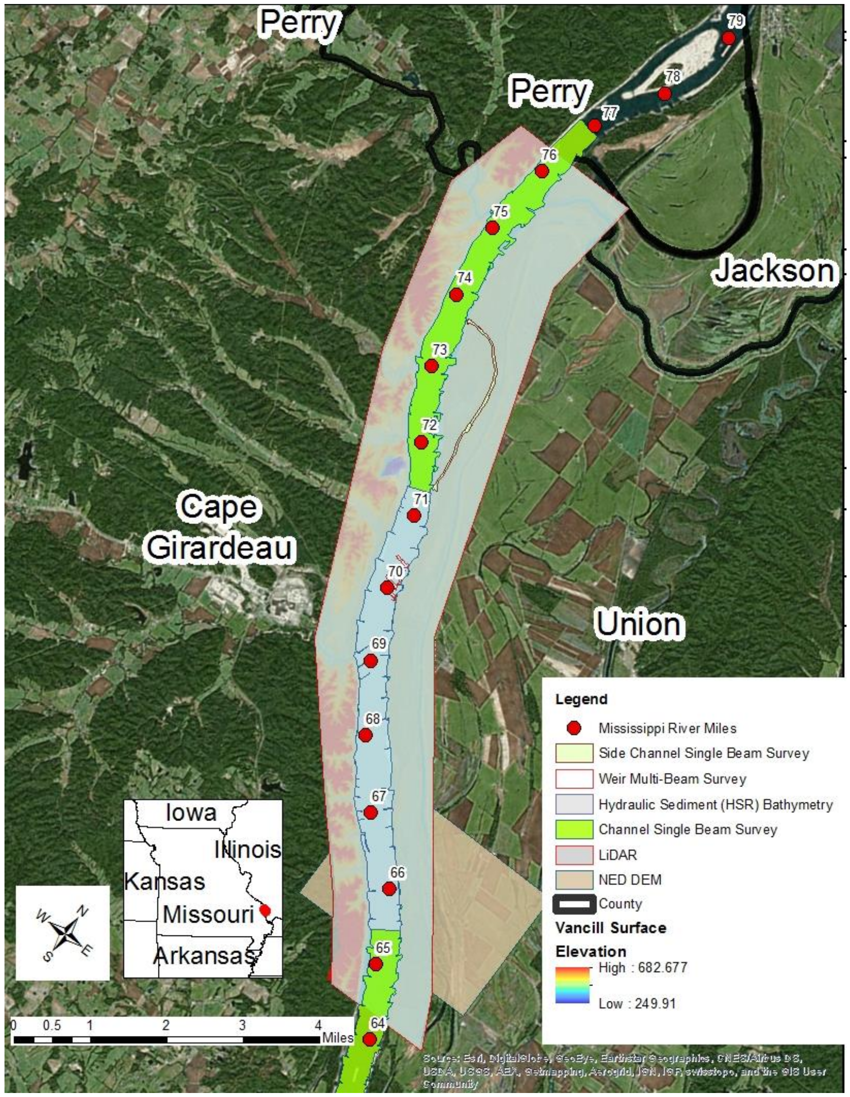
The elevation data used to create the AdH computational mesh was compiled using several datasets that covered both above and below the waterline. The sources include a combination of Light Detection and Ranging surveys (LiDAR), National Elevation Dataset (NED), and hydrographic surveys which consisted of single beam and multi-beam survey data. HSR base condition and recommended alternative bathymetry was also supplied for the study area. LiDAR and NED data is collected above the water surface. Hydrographic or bathymetric surveys are used to collect elevation data below the water surface. Table 1 lists the elevation datasets used to create the mesh.

Table 1. Source of Elevation Datasets

Survey	Survey Type	Vertical Datum	Date
Crawford Chute Side Channel Survey	Multi Beam Hydrographic Survey	(NGVD29)	March-2011
Structure Survey	Multi Beam Hydrographic Survey	(NGVD29)	January-2012
Hydraulic Sediment Response Model Base Condition	HSR Bed Scan	(NAVD88)	
Hydraulic Sediment Response Model Recommended Alternative	HSR Bed Scan	(NAVD88)	
Main Channel Survey	Single Beam Hydrographic Survey	(NGVD29)	April-2015
Upper Mississippi River LiDAR	LiDAR	(NAVD88)	December-2012
National Elevation Data Set	DEM	(NGVD29)	April-2015

Data in NGVD29 was converted to NAVD88 using a datum shift of -0.5 feet. The surveys were merged together to create a single elevation dataset representing all areas above and below the waterline within the numerical model mesh domain. The data was merged such that HSR and more accurate elevation data has priority over less accurate data. The order in which the data was merged was: HSR Bathymetry, Multi-beam hydrographic survey, Single beam hydrographic survey, LiDAR, and NED. The merged elevation data is show in Figure 2

Figure 2. Merged Elevation Data.



USACE has employed Hydraulic Sediment Response (HSR) modeling, formerly called Micro Modeling (Davinroy, 1994, Gaines 2002) since 1994 to address a variety of problems related to shoaling and scour on inland waterways in the United States (Davinroy 1999). Modeled waterways include the Mississippi, Atchafalaya, White, Missouri, Ohio, Brazos, and Kaskaskia Rivers. The small-scale physical models use synthetic bed material to simulate bed response, and use various materials to represent fixed boundary features such as banks, islands, dike structures, rock, and consolidated clay formations. Design alternatives have been developed from model output to solve problems such as repetitive maintenance dredging, side channel restoration, and other navigation related issues.

2.1.1 Base Condition

The base condition geometry is based on the HSR replication effort that produce a geometry that closely matched the actual field conditions in the area. For more information on model replication please see HSR model study please see Technical report M62, Vancill Towhead HSR Model River Miles 72.0-65.0 Hydraulic Sediment Response Model Investigation.

2.1.2 Proposed Construction Alternative

Several alternatives were investigated during the HSR modeling effort. The HSR model recommended alternative was the most desirable because of its ability to solve the dredging problem at Vancill Towhead while avoiding and minimizing negative environmental impacts. This alternative also alleviates sediment deposition at the boat ramp along the Right Descending Bank (RDB) at RM 66.65, while having no significant impacts on the navigation channel. Bathymetry results show that the thalweg between RM 68.00 and RM 67.00 was directed along the RDB by three S-Dikes. The thalweg depths increased in the main channel and more scour occurred near Dike 66.70R and the boat ramp.

The goal to improve the environmental diversity at Vancill Towhead involved increasing the flow and sediment transport through the side channel. However, the location of the side channel entrance being so far away from the thalweg made the task nearly impossible. Therefore the approach taken in the recommended alternative created a secondary side channel with river training structures. Overall, this alternative would eliminate the repetitive dredging, maintain the navigation channel and enhance the environmental diversity near Vancill Towhead.

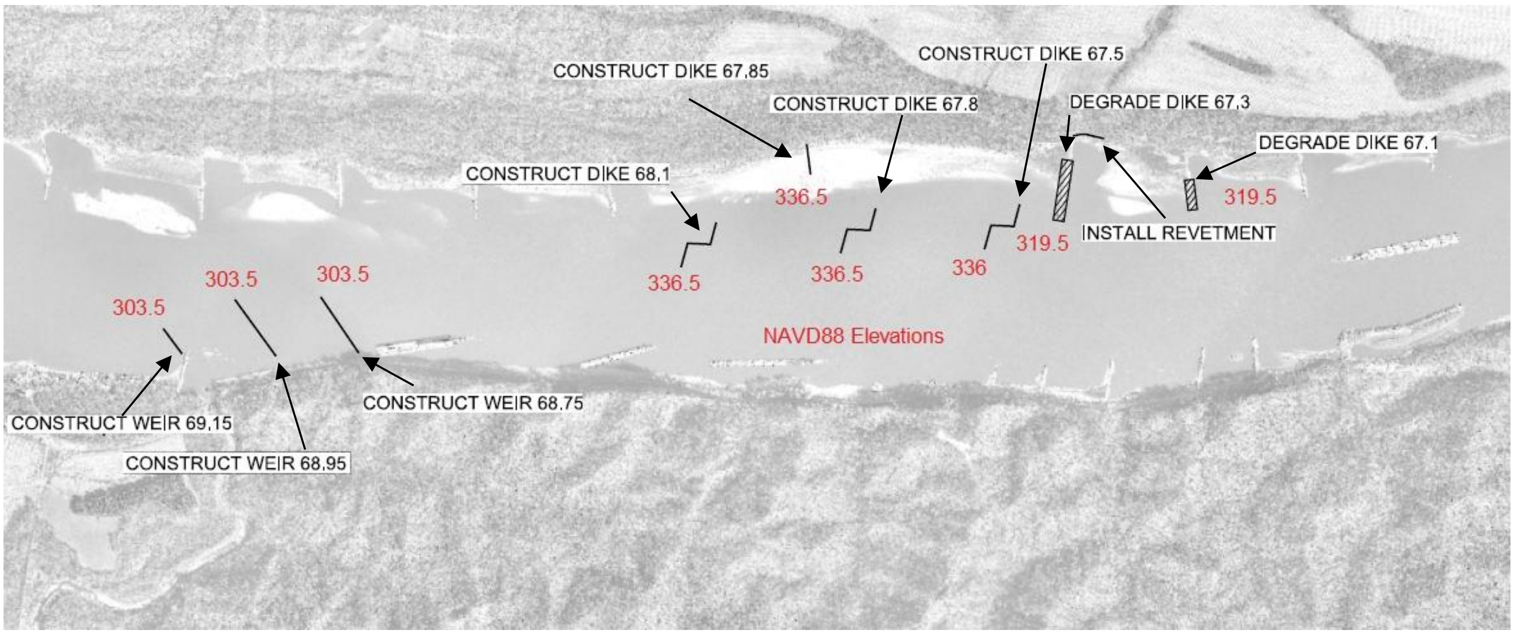
For more information on HSR recommended alternative and other alternatives investigated during the HSR effort, please see Technical report M62.

Construction plans were created based on the recommended alternative with some slight design changes such as revetment location changes which will not affect channel bathymetry. The proposed construction alternative includes the following features and is shown in Figure 3.

- Construct Weir 69.15R
- Construct Weir 68.95R
- Construct Weir 68.75R
- Construct Diverter Dike 68.10L (S-Dike)

- Construct Diverter Dike 67.80L (S-Dike)
- Construct Diverter Dike 67.50L (S-Dike)
- Repair Dike 67.80L
- Degrade Dike 67.30L
- Degrade Dike 67.10L
- Install Revetment downstream of dike 67.3L

Figure 3. Proposed Construction Alternative



2.2 Calibration

2.2.1 Discharge Data and Water-surface Elevation Data

2.2.1.1 Establishing Initial Boundary Conditions Utilizing HEC-RAS

Discharge data and water-surface elevation data was obtained from a calibrated unsteady HEC-RAS version 4.1 model of the Mississippi River. The following description was taken from the HEC-RAS 4.1 User Manual Forward. "The U.S. Army Corps of Engineers' River Analysis System (HEC-RAS) software allows you to perform one-dimensional steady and unsteady flow river hydraulics calculations." The HEC-RAS model was used to develop continuous discharge and water surface elevation boundary conditions for the AdH model and water surface elevations at cross section locations through the study reach.

For the Vancill Towhead study the HEC-RAS model included the reach between the gage at Chester, Illinois and the gage at Thebes, Illinois (RM 109.90-43.70). On the Upper Mississippi River, river mile 0 is at the confluence of the Ohio River and increases in distance upstream from there. The gage at Chester provided the upstream flow boundary condition data and the gage at Thebes provided the downstream stage boundary condition data. Stage data from the Chester gage and the other three gages between the Chester gage and the Thebes gage (see Table 2) were used for model calibration.

Table 2. Gage Locations.

Gage Description	Gage Longitude	Gage Latitude
Chester River Mile 109.9	89°50'08"	37°54'13"
Grand Tower River Mile 82.06	89°30'45"	37°39'29"
Moccasin Springs River Mile 66.30	89°27'24"	37°27'01"
Cape Girardeau River Mile 52.1	98°31'05"	37°18'07"
Thebes Rive Mile 43.70	89°28'03"	37°12'59"

2.2.1.2 HEC-RAS Model Calibration

The HEC-RAS model was calibrated to observed field data for several years and a large range of flows. The comparison of observed elevations to HEC-RAS model elevations can be found in figures 4, 5, 6, and 7. The comparisons to the field data and HEC-RAS model plot very close to each other well with-in acceptable range for model calibration.

Figure 4. Chester Elevation Gage HEC-RAS Model compared to Field Data.

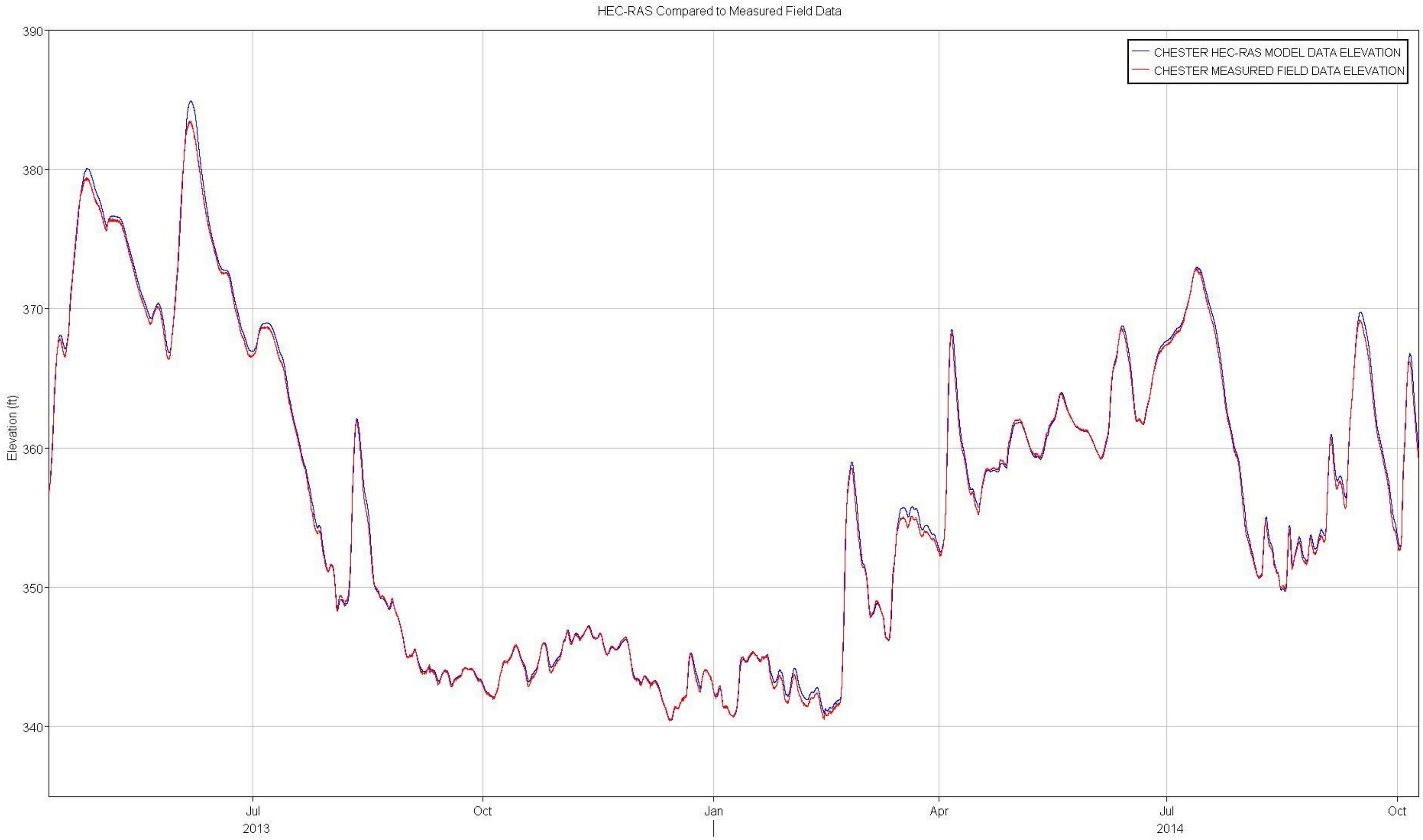


Figure 5. Grand Tower Elevation Gage HEC-RAS Model compared to Field Data.

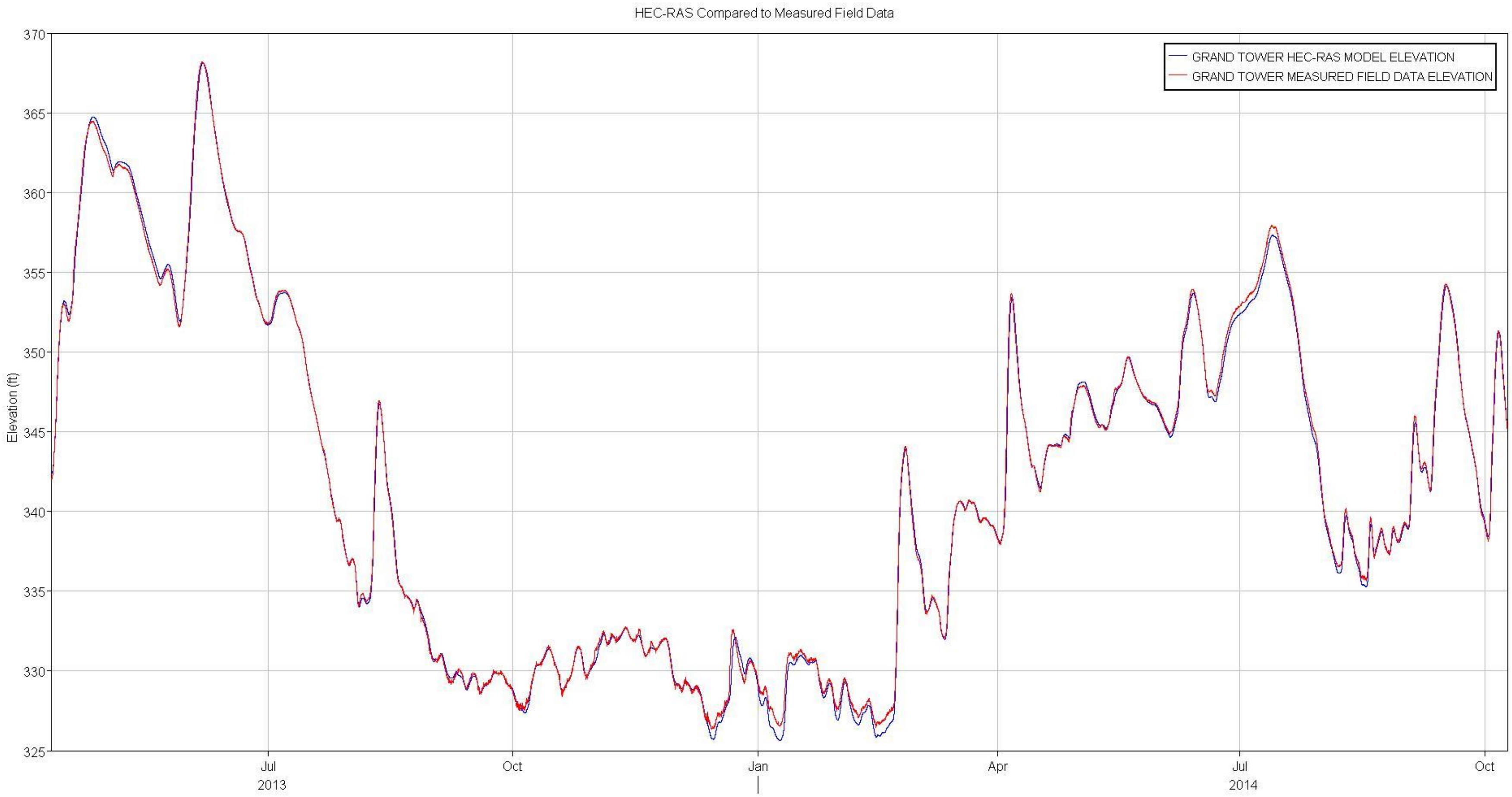


Figure 6. Moccasin Springs Elevation Gage HEC-RAS Model compared to Field Data.

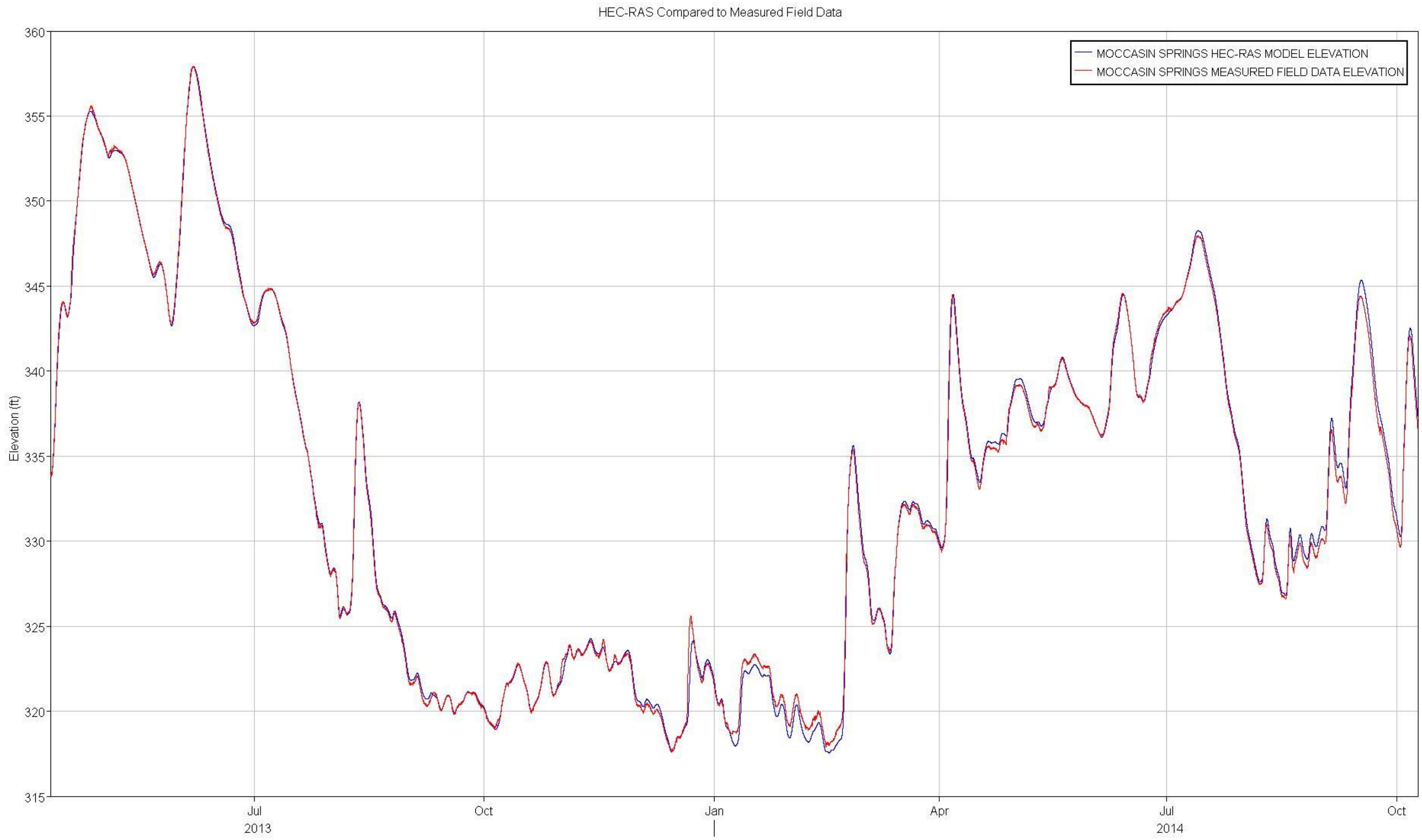
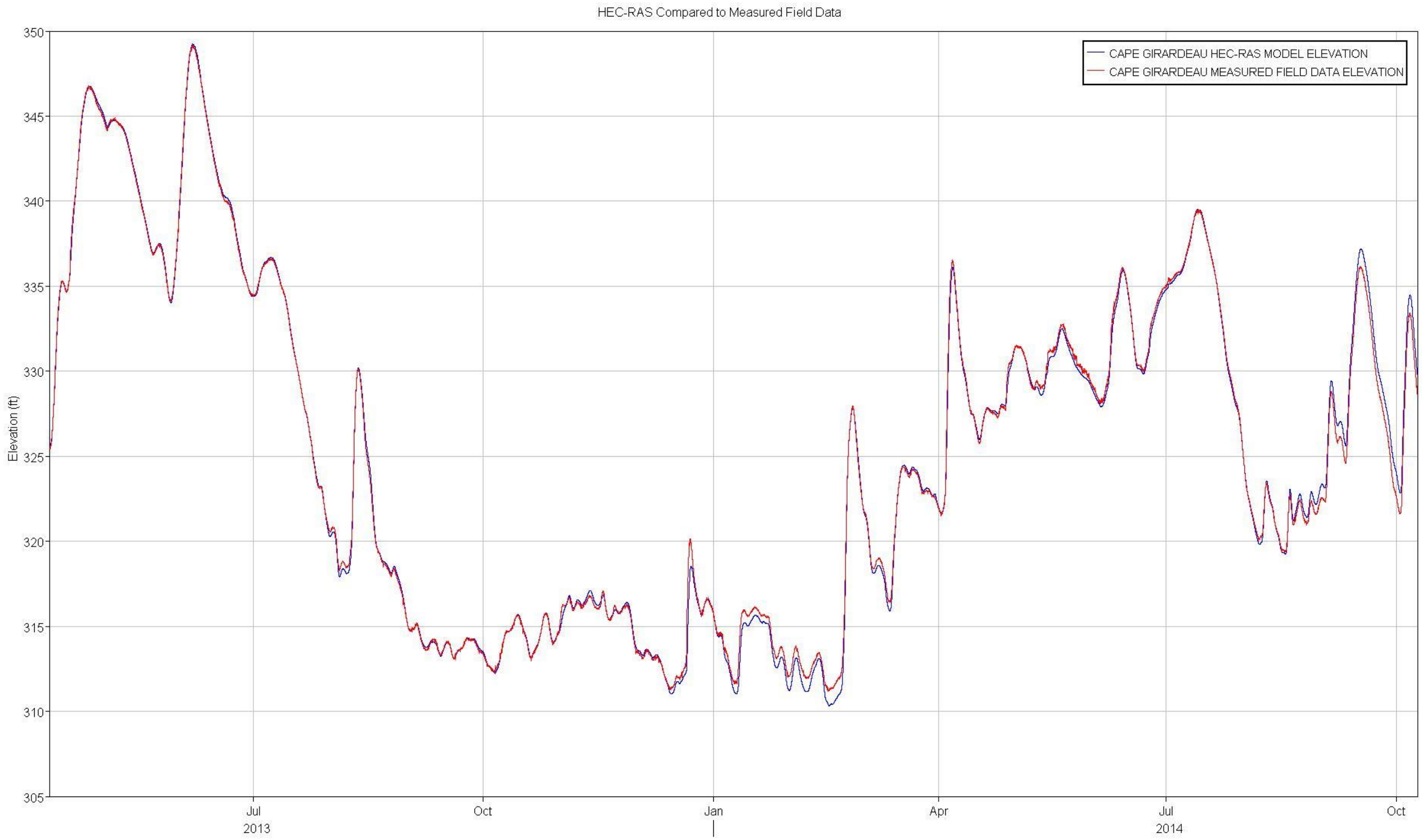


Figure 7. Cape Girardeau Elevation Gage HEC-RAS Model compared to Field Data.



2.2.1.3 Flow and Stage Boundary Conditions

The calibrated Mississippi River HEC-RAS model provided flow and elevation hydrographs. The flow boundary was located at RM 75.65 with the elevation boundary located at RM 65.40. Figure 8 and Figure 9 contain the flow and elevation boundary conditions.

Figure 8. Flow Boundary Conditions RM 75.65.

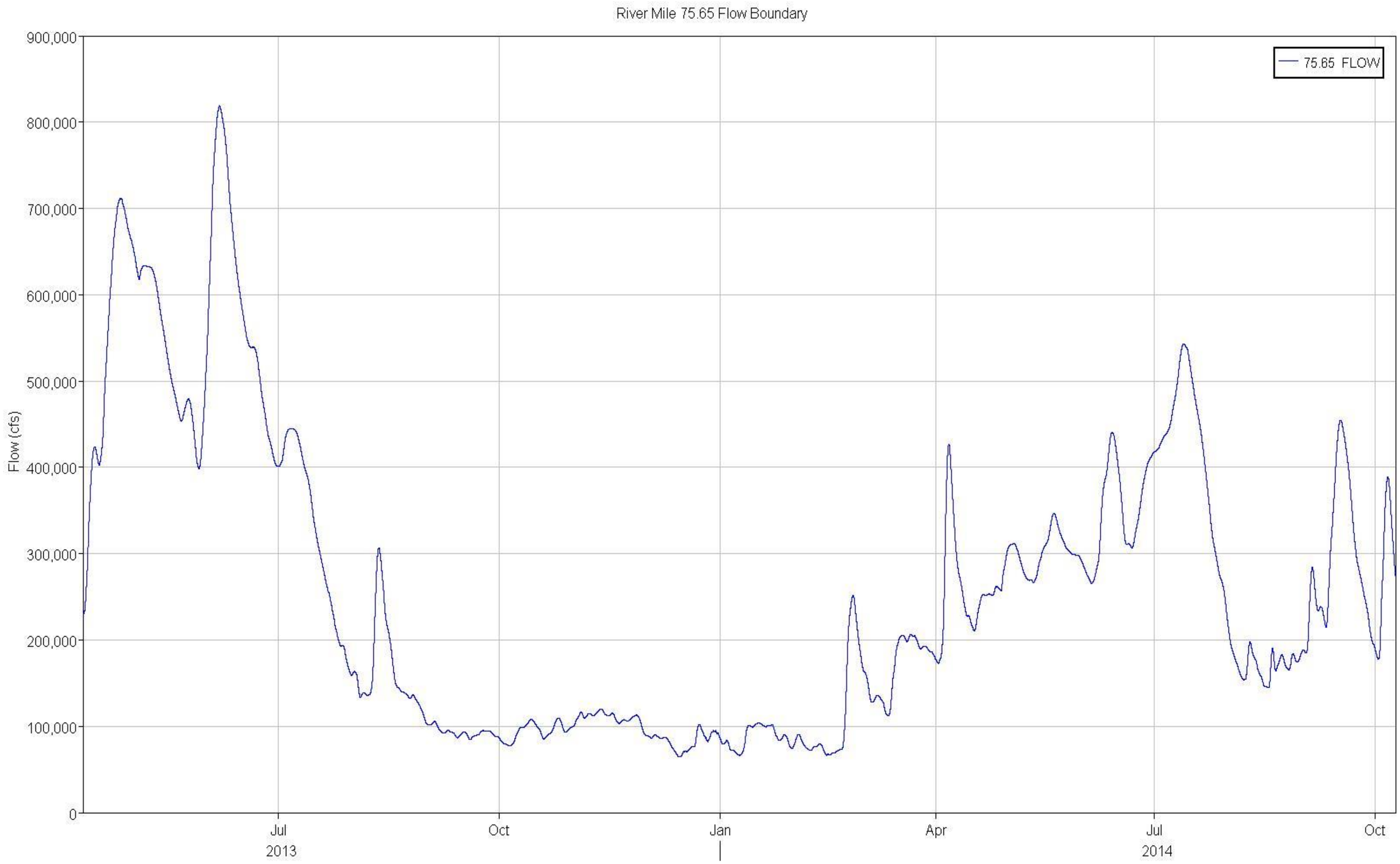
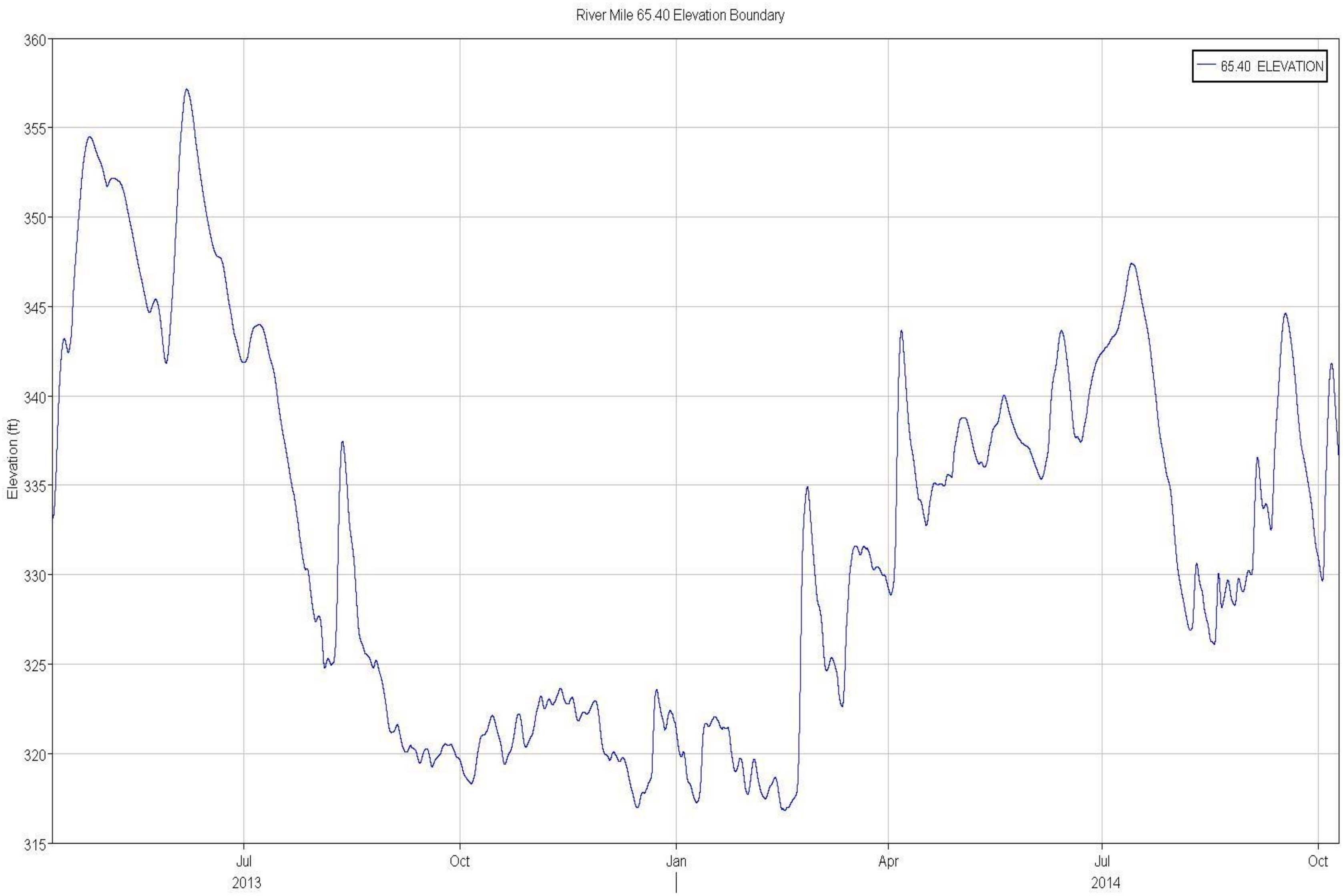


Figure 9. Elevation Boundary Conditions RM 65.40.



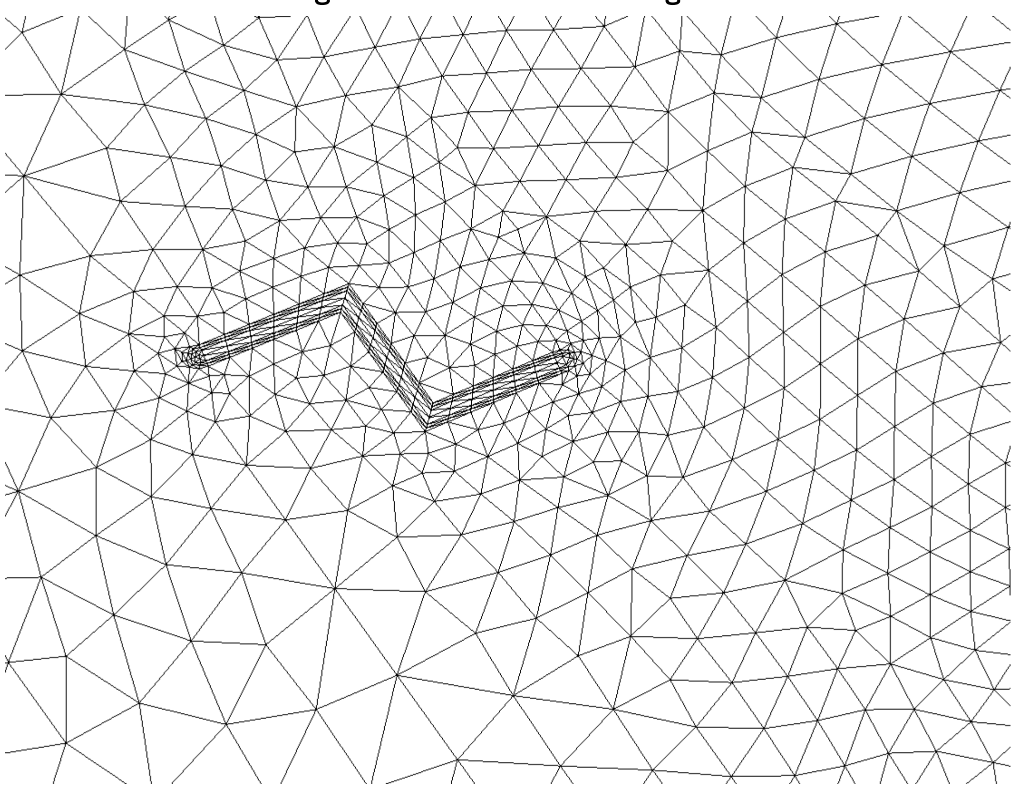
2.2.2 Initial AdH Setup Conditions

To develop an AdH model, three items are needed. These items include a numerical mesh file, boundary conditions (discussed above), and a hot start file.

2.2.2.1 Mesh Development

A numerical model mesh was created in order to utilize an AdH model. The mesh file was generated using SMS 11.2.3. The mesh is used to define the surface and extents of the area being evaluated. The extents of the mesh were from approximate river mile 65.4-75.65. The mesh is generated by using triangular elements and nodes at various spacing that would be overlaid over an elevation data set to create a surface mesh. The space between nodes were adjusted to change the size of the triangular elements, thus increasing detail as needed in areas such as the structures in the river. The upstream and downstream limits of the mesh were far enough away from the study area so effects of boundary conditions would be dissipated before reaching the study area. See Figure 10 for an example of triangular elements and nodes created in SMS to create the surface mesh.

Figure 10. Surface Mesh Triangles.



2.2.2.2 Hot Start Initial Conditions

The hot start initial condition is used for initial setup and stability of the model. The hot start establishes an initial depth of water and velocity when available. The hot start file used initial depth of water and was established for this study from HEC-RAS model profiles.

2.2.3 Modeling Properties

2.2.3.1 Bed Roughness

Three roughness types were used to define the roughness in the reach. The three factors were Unsubmerged Rigid Vegetation (URV), Equivalent Roughness Height (ERH), and Manning n values.

Unsubmerged Rigid Vegetation is used to compute a shear stress coefficient for computing shear stress through rigid, unsubmerged vegetation. URV takes into account bed roughness height, density, and diameter of the vegetation. This information was not available in the study area. But data was used from a similar density of trees from another location on the Mississippi River located near RM 183. The URV was used in areas with a heavy stand of trees.

Equivalent Roughness Height value is the average height of the roughness particles found on the bed or a given area. The ERH card was used for river training structures as well as the revetment.

The initial Manning's n values were obtained from Open-Channel Hydraulics, (Chow 1959). These values were taken from Chow and calibration was achieved by adjusting these values within an acceptable range.

The roughness values used in the model study can be seen below in Tables 3, 4, and 5.

Table 3. Equivalent Roughness Height

AdH Material	Roughness Height (ft)
Rock Bluff Line	1.15
Dikes	1.15
Weirs	1.15

Table 4. Unsubmerged Rigid Vegetation

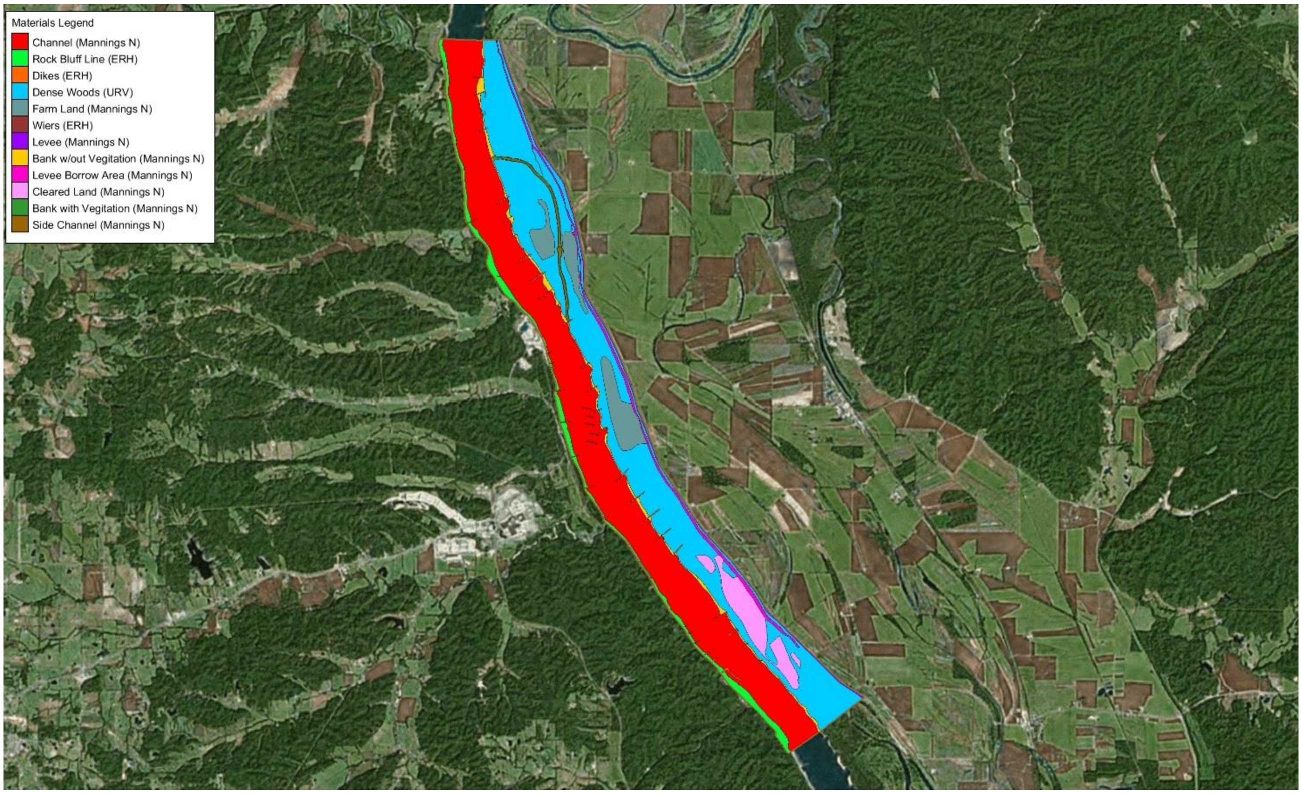
AdH Material	Roughness Height (ft)	Average Stem Diameter (ft)	Average Stem Density (trees/acre)
Dense Woods	0.16	1.71	29.4

Table 5. Manning's n Values

AdH Material	Roughness Coefficient
Channel	0.031
Levee	0.030
Bank with Vegetation	0.035
Bank without Vegetation	0.027
Levee Borrow Area	0.030
Cleared Land	0.035
Farm Land	0.032
Side Channel	0.030

The materials in the model were used to establish roughness parameters in the model domain. The material boundaries were set using 2014 aerial photography and elevation data. The aerial photograph was used to delineate areas with similar properties such as wooded area and farm land. The elevation data assisted in helping to delineate structures in the river that could not be seen by aerial photography. Figure 11 shows where the materials were used in the study area.

Figure 11. Bed Material Map.



2.2.3.2 Eddy Viscosity

The estimated Eddy Viscosity used in this study was the Smagorisnsky method, with a coefficient of 0.2. The Smagorinsky method was chosen because it is a common eddy viscosity method for rapidly changing velocity directions, such the changing velocities around the river training structures in the model.

The following was taken from the section 4.5.4 of the AdH version 4.5 user's manual describing the Smagorinsky Method. The Smagorinsky formulation was used to compute the eddy viscosity. This option utilizes the area of the element as the length scale, A, and a user specified coefficient, C. The algorithm is given below.

$$v_t = C^2 A \left[\left(\frac{\partial u}{\partial x} \right)^2 + \left(\frac{\partial v}{\partial y} \right)^2 + \frac{1}{2} \left(\frac{\partial u}{\partial y} + \frac{\partial v}{\partial x} \right) \right]^{0.5}$$

Lilly (1967) analytically derived the value of C to be between 0.16 and 0.20. The C value of 0.20 is a standard value used in the AdH modeling software. Sensitivity of the model to this parameter was checked using both values. Resulting water surface elevations and velocity fields were similar and varied by an extremely small margin.

2.2.3.3 Computation Environment

The numerical modeling was executed on the ERDC High-Performance Computing (HPC) Cray XE6 (Garnet) parallel processing supercomputer, in conjunction with the US Air Force Research Laboratory (AFRL) HPC SGI Ice X (Spirit). The numerical model was computed with both HPC platforms due to time restrictions and long wait times. It was verified that model results remained the same on both HPC platforms. The model was executed using 256 parallel processors on Garnet and 128 parallel processors on Spirit. A time step of 300 seconds was used, allowing the model to reduce the time step for stability and accuracy as needed.

2.2.4 Calibration Results

2.2.4.1 AdH Calibration

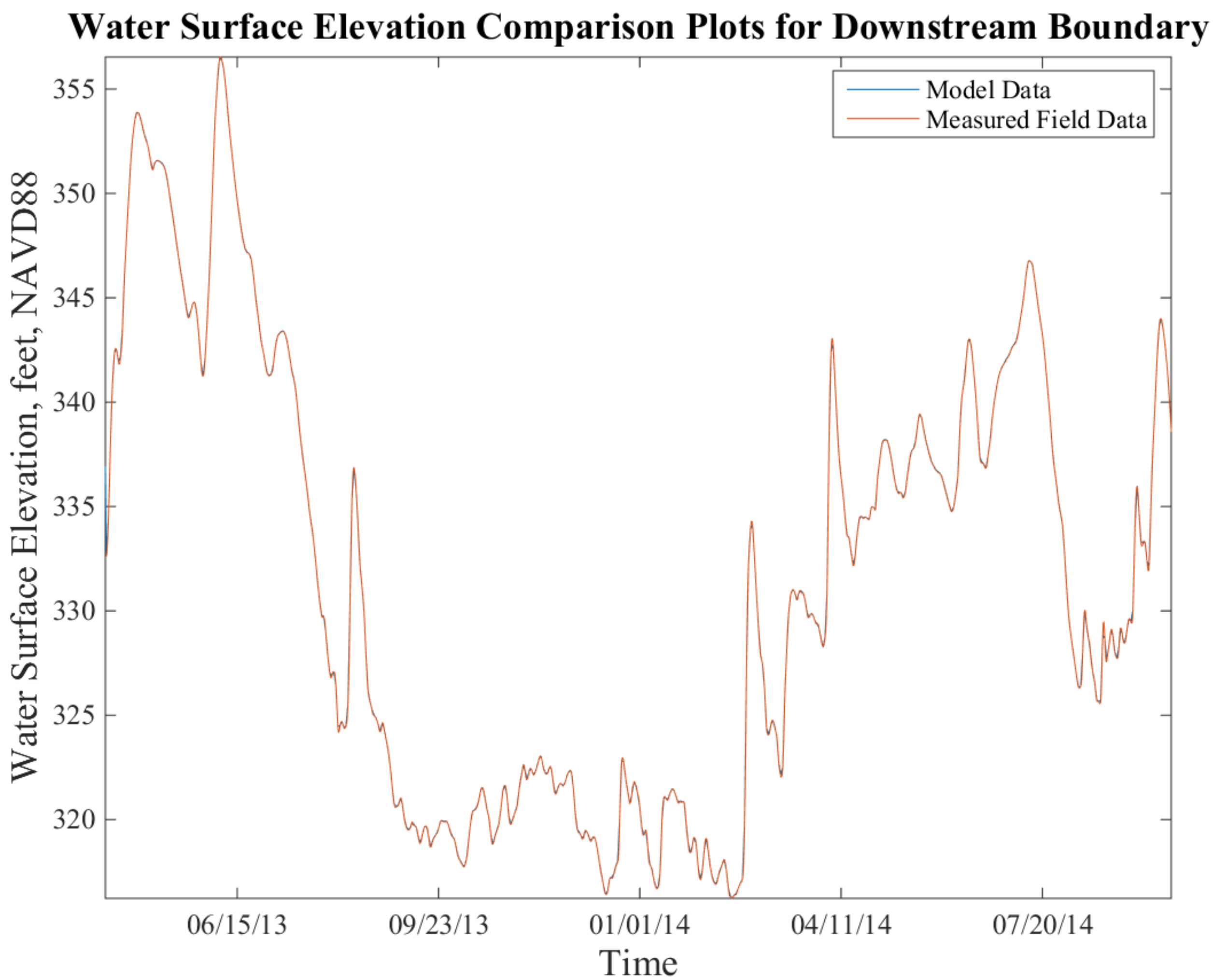
The output from the calibrated HEC-RAS model was used for the boundary conditions for the 2D model. The 2D model was calibrated using the mesh created using the base condition geometry described in 2.1. The 2D model was run by making small adjustments to the Manning's n values in the channel to achieve water surface elevations that closely match those from the HEC-RAS model. The adjustments to the n-values were still within the range of acceptable use for a river channel of this type. The elevations were compared at specific locations from the HEC-RAS model, as well as the Moccasin Springs gage data. This data was used for calibration and verification of the 2D AdH model. Plots displaying the results of the calibration can be found in figures 12 – 27.

The plots in figures 12, 14, 16, 18, 20, 22, 24, and 26 compare the water surface elevation (WSE) of the 2D AdH model and the HEC-RAS model, with respect to time. The plots show that the computed WSEs match well, especially with flows in which the structures are submerged. For this study, it was important higher flows and elevations matched closely because the effects of structures on WSEs during flood events was the greatest concern expressed by the public.

The plots in figures 13, 15, 17, 19, 21, 23, 25, and 27 compare the water surface elevations of the 2D AdH model (located on the y-axis) and the HEC-RAS model (located on the x-axis). This plot is an additional method to show the model calibration, by seeing how closely the points fell on the diagonal line in the plot. These figures also show that the AdH model results match the HEC-RAS model results more closely for higher stage conditions. A perfect match between the models would be represented by all points landing on the diagonal line.

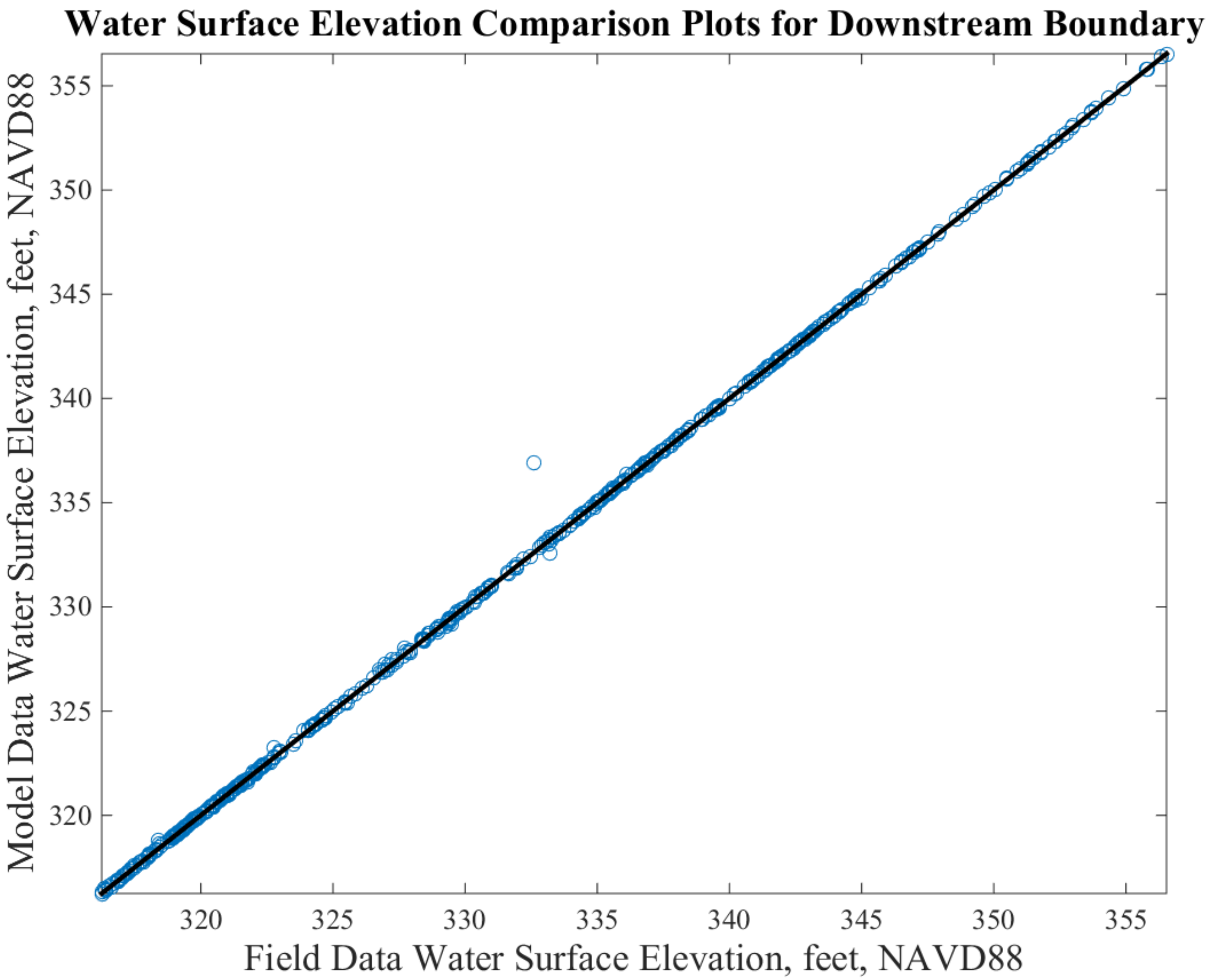
In figure 13, the data between the AdH model and HEC-RAS model match exactly. This is because figure 12 is comparing the downstream elevation boundary. Note that the HEC-RAS model values are labeled Measured Field Data in all of these figures.

Figure 12. Downstream Boundary Water surface elevation comparison



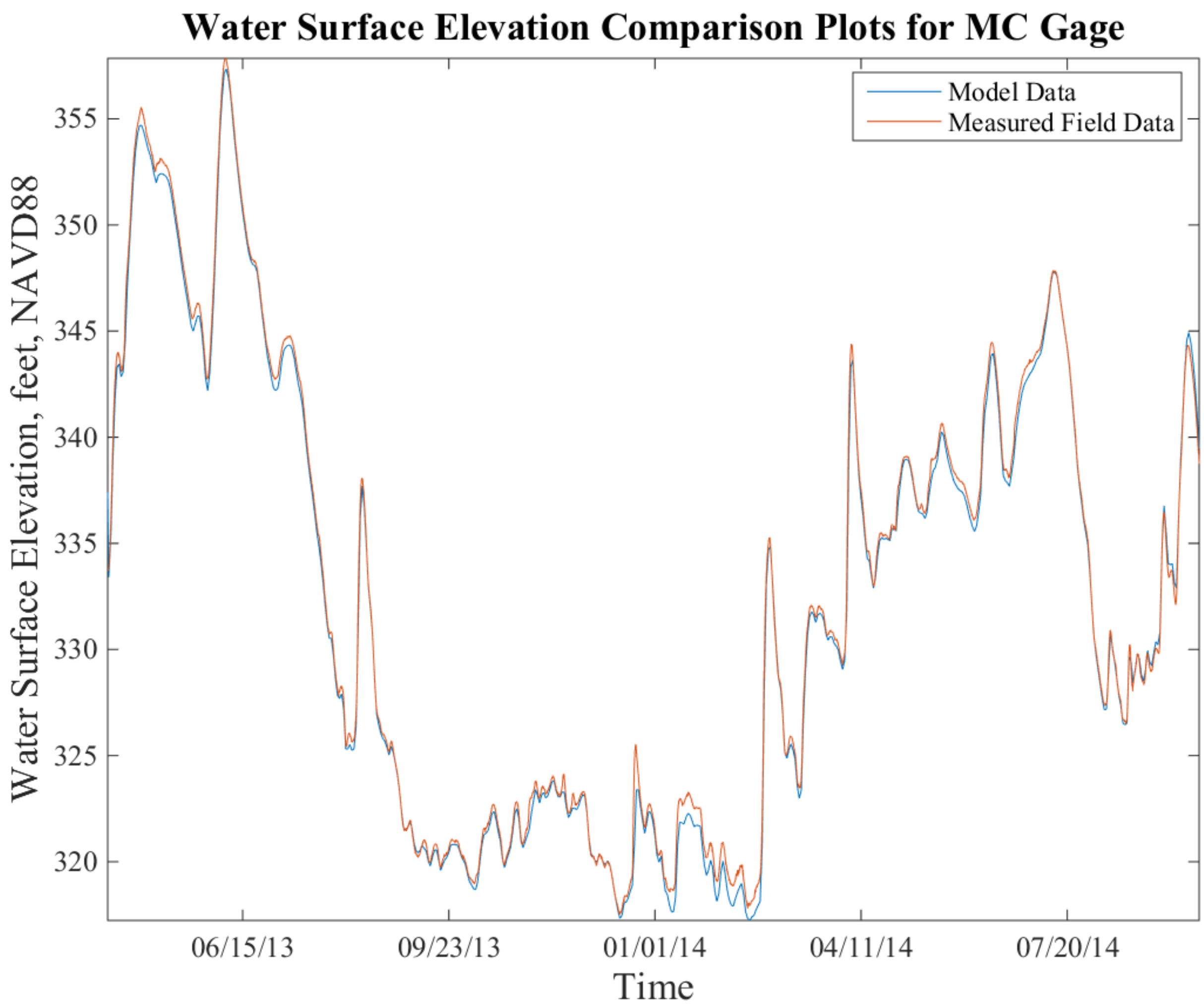
Note that the HEC-RAS model values are labeled Measured Field Data in figure. The AdH data is the model data represented in the plot.

Figure 13. Downstream Boundary Box Plot



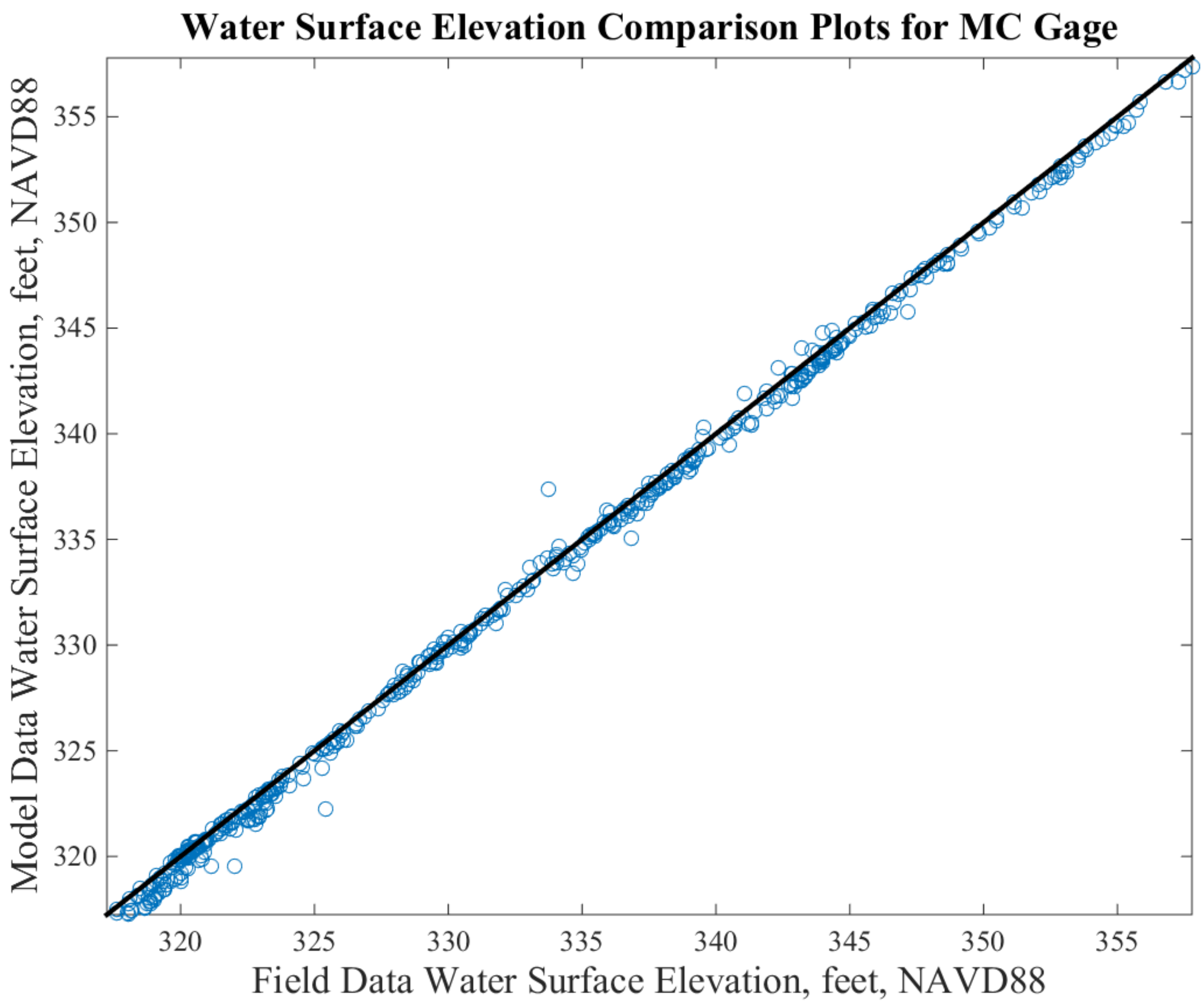
Note: the outlier at approximately model elevation 337 is caused by initial conditions and does not affect the results of the remainder of the model simulation.

Figure 14. Moccasin Springs Gage Water surface elevation comparison



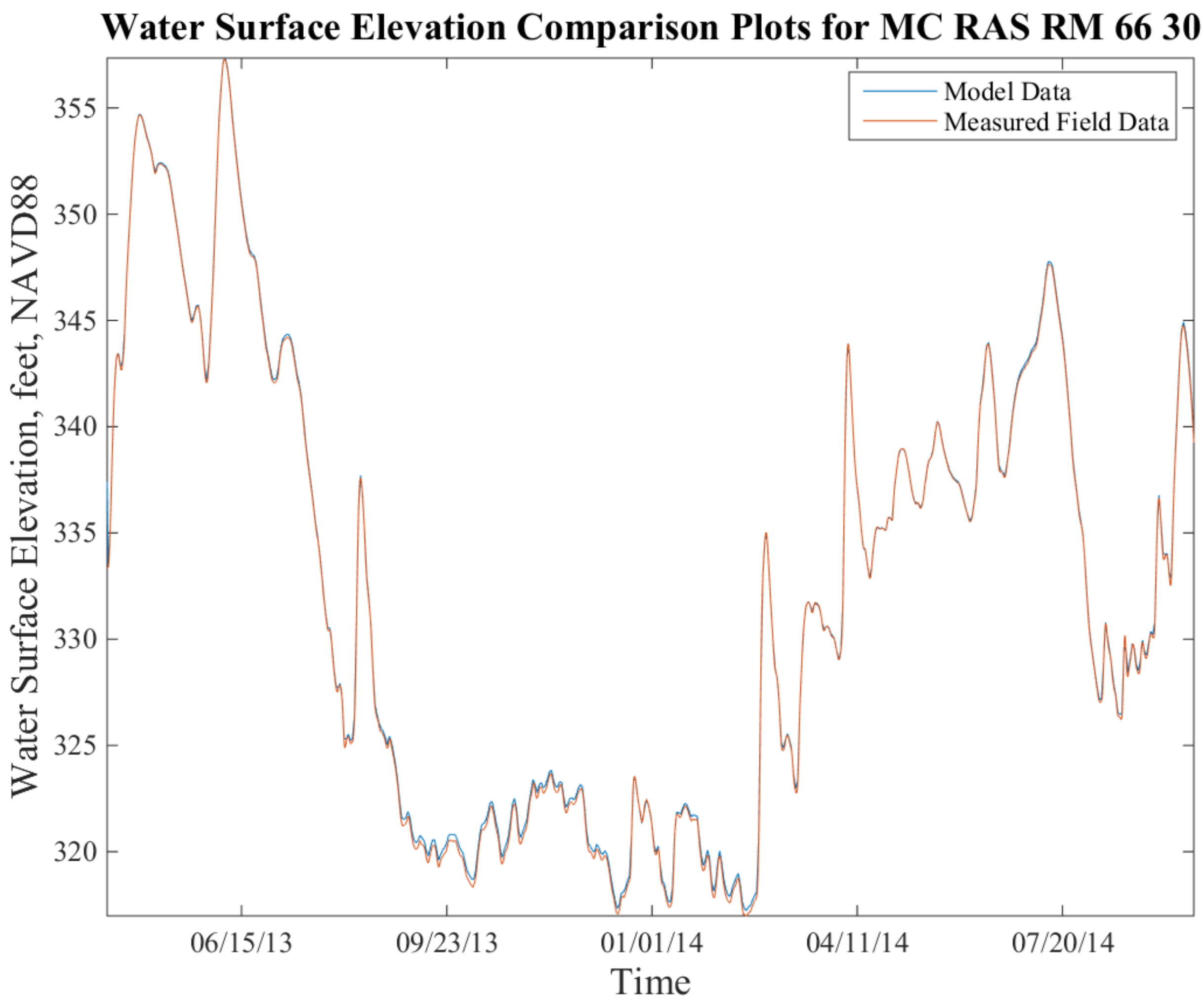
Note that the HEC-RAS model values are labeled Measured Field Data in figure. The AdH data is the model data represented in the plot.

Figure 15. Moccasin Springs Gage Box Plot



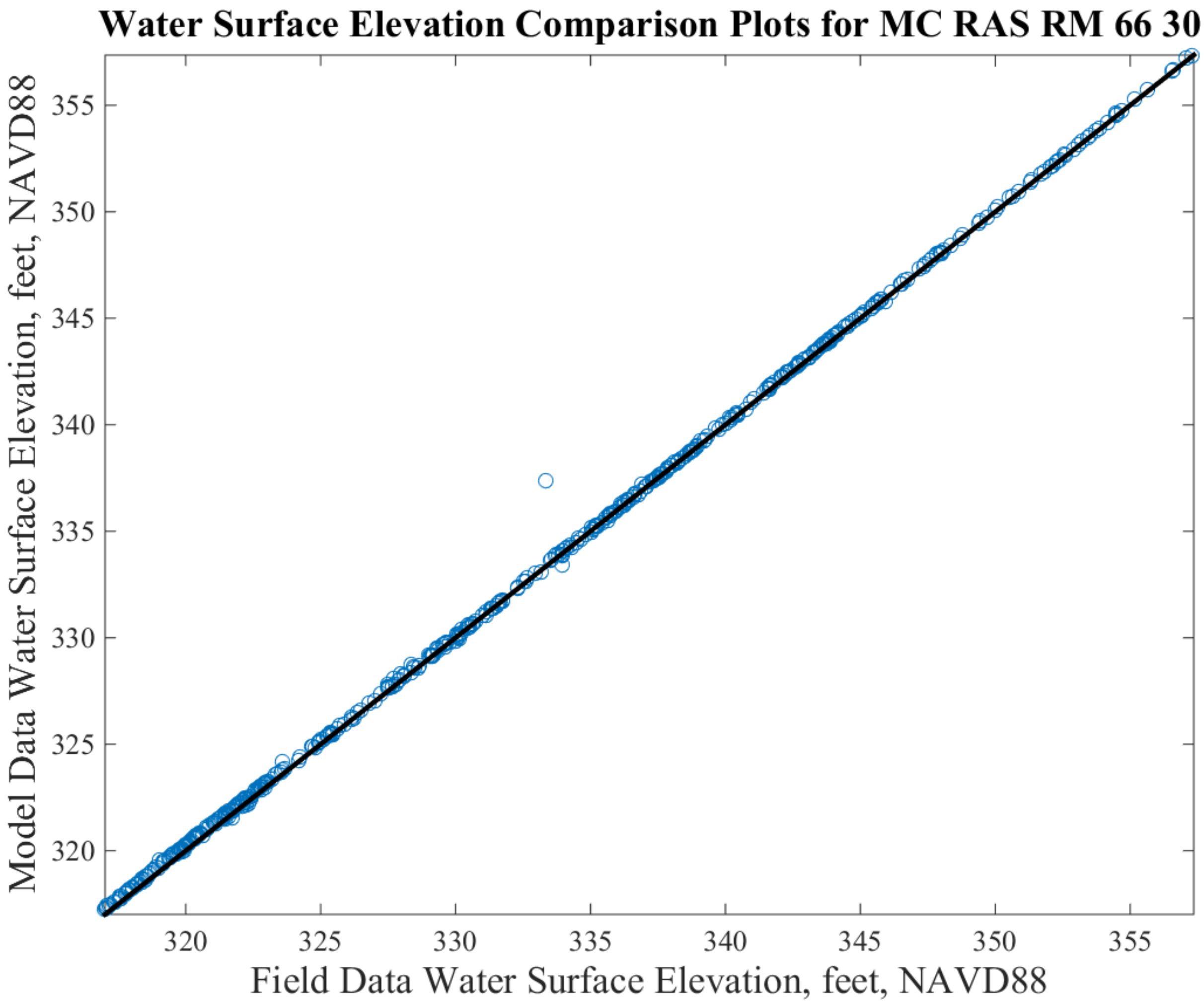
Note: the outlier at approximately model elevation 337 is caused by initial conditions and does not affect the results of the remainder of the model simulation.

Figure 16. River Mile 66.30 Water surface elevation comparison



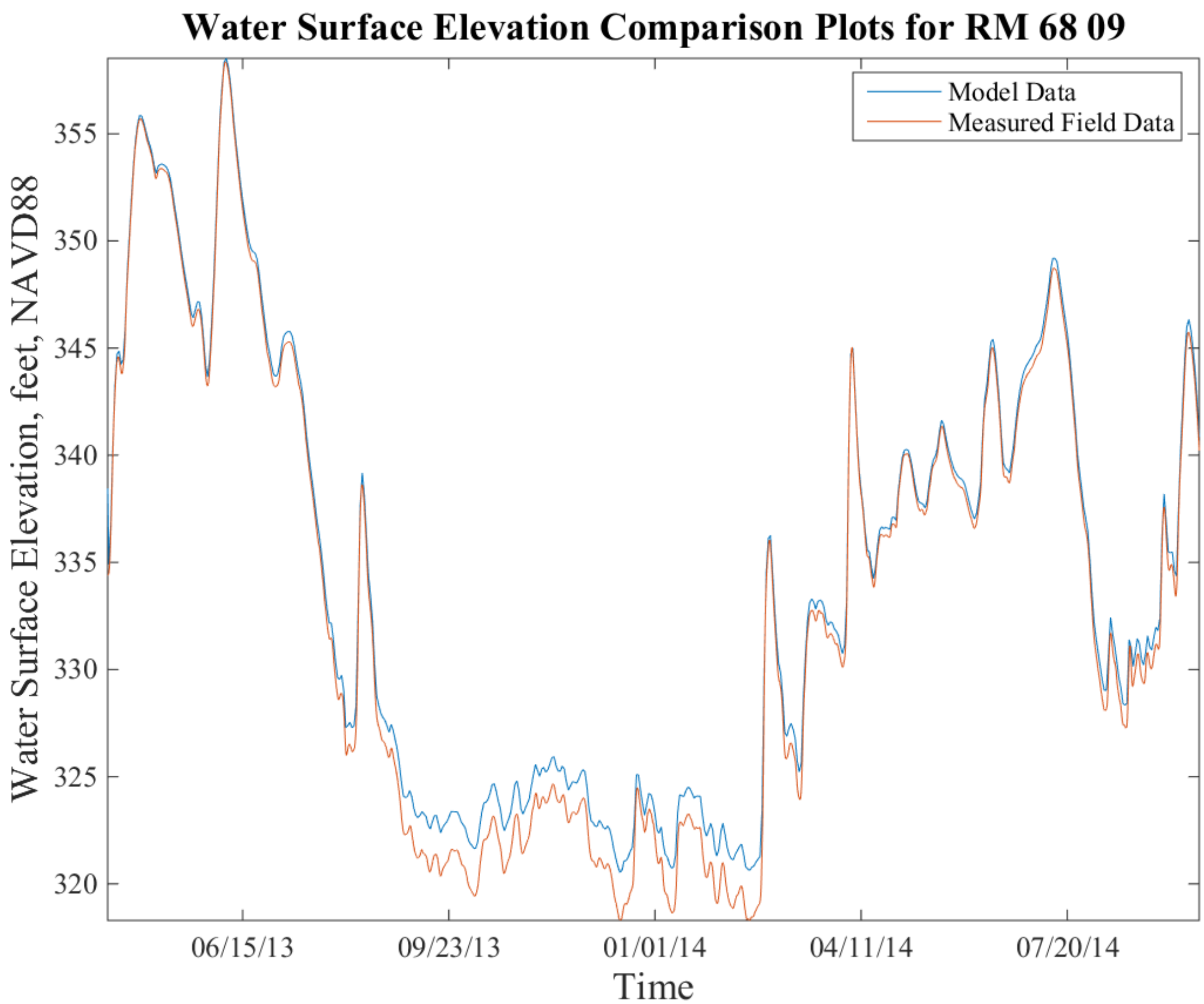
Note that the HEC-RAS model values are labeled Measured Field Data in figure. The AdH data is the model data represented in the plot.

Figure 17. River Mile 66.30 Box Plot



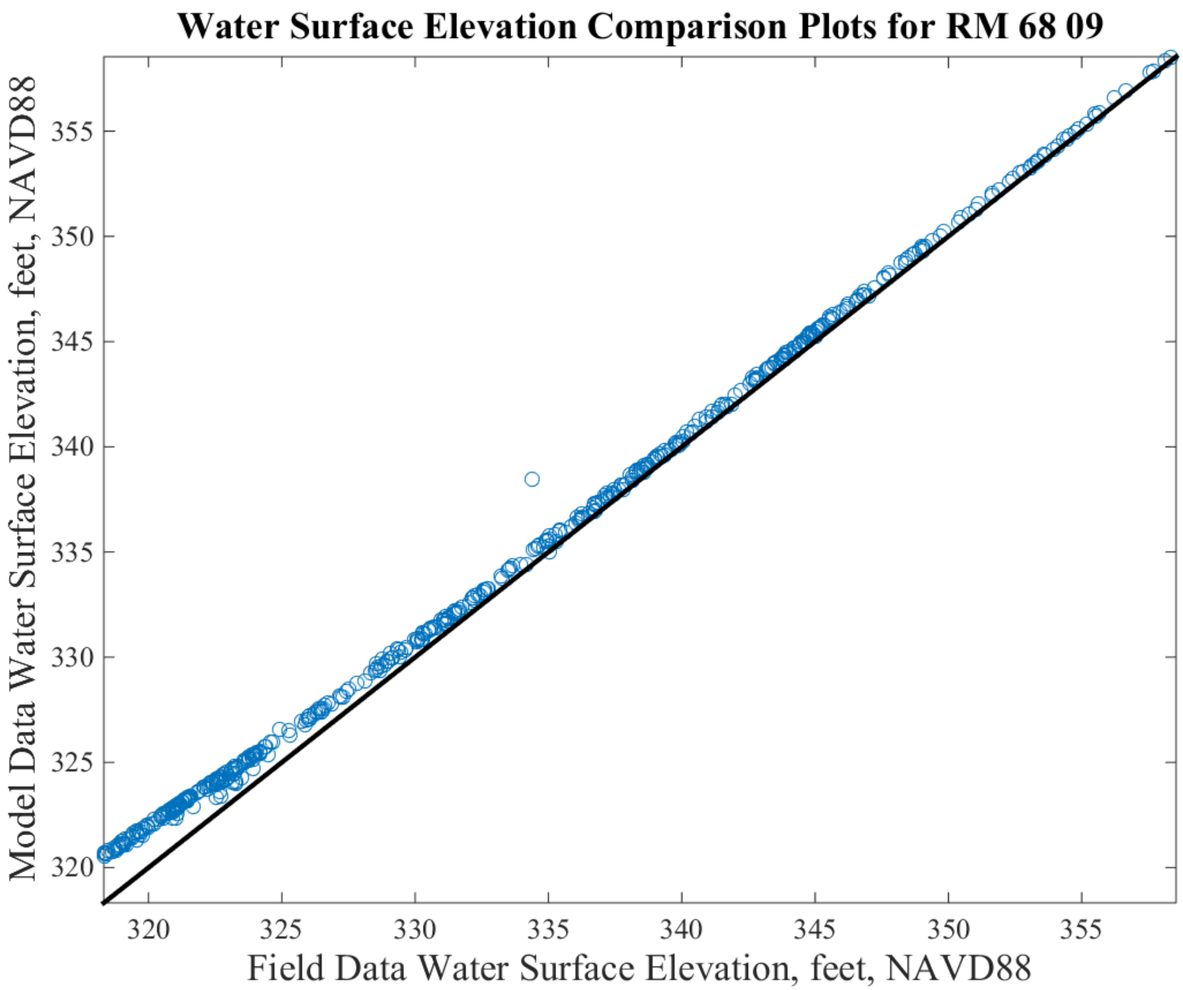
Note: the outlier at approximately model elevation 338 is caused by initial conditions and does not affect the results of the remainder of the model simulation.

Figure 18. River Mile 68.09 Water surface elevation comparison



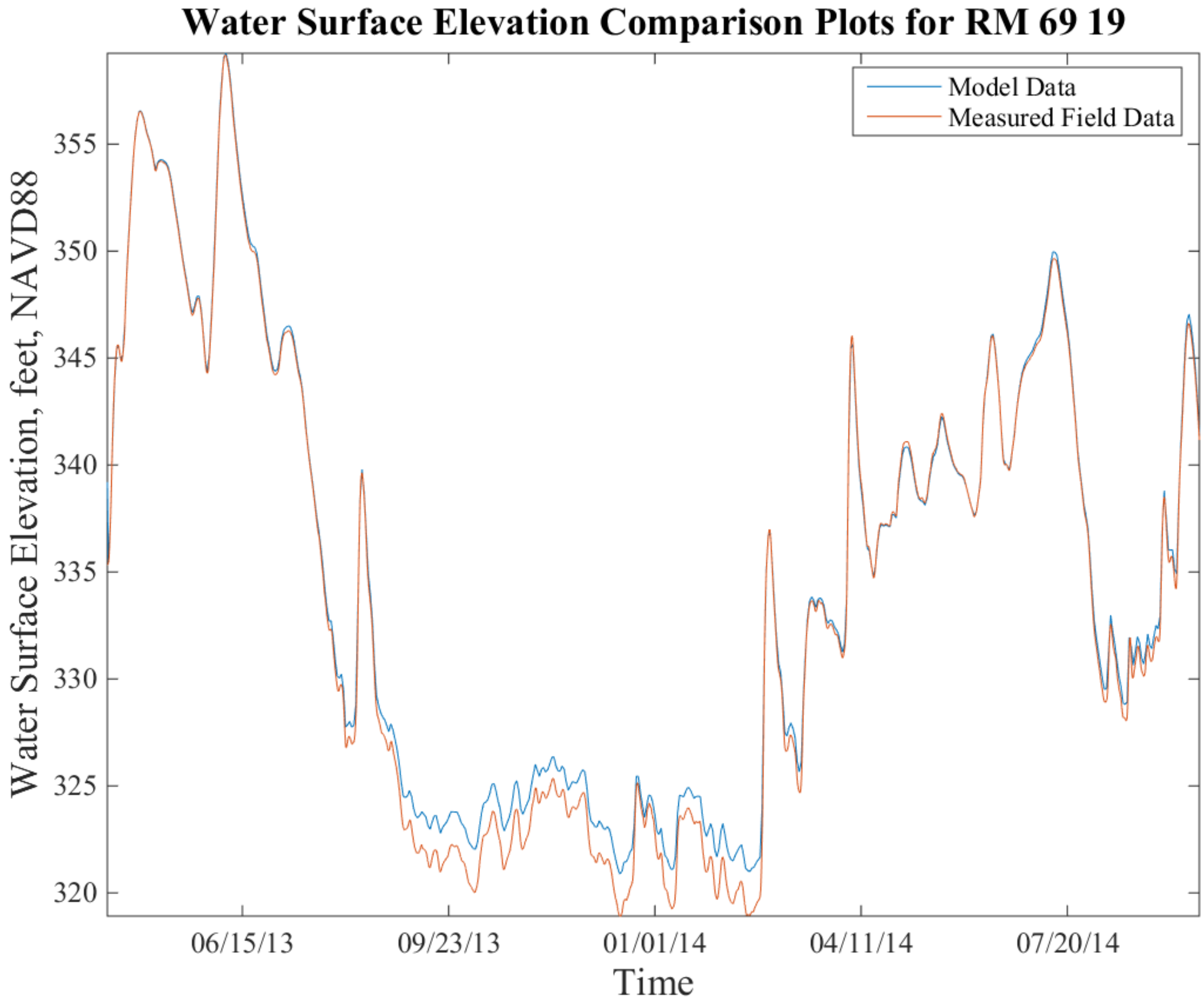
Note that the HEC-RAS model values are labeled Measured Field Data in figure. The AdH data is the model data represented in the plot. There is some divergence in the lower elevations of the model, however it does not have an effect on the higher elevations which is the focus of the study.

Figure 19. River Mile 68.09 Box Plot



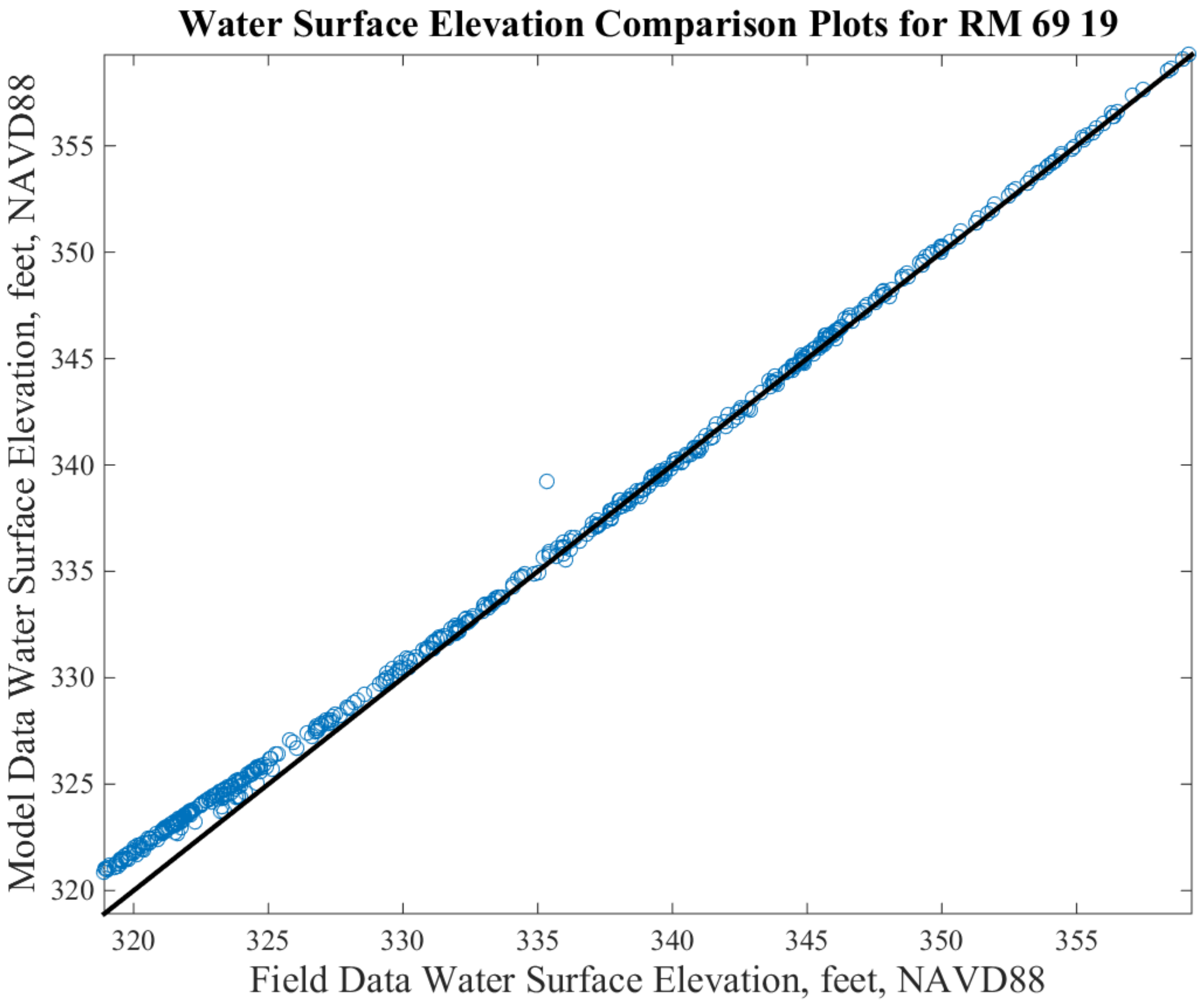
Note: the outlier at approximately model elevation 339 is caused by initial conditions and does not affect the results of the remainder of the model simulation. There is some divergence in the lower elevations of the model, however it does not have an effect on the higher elevations which is the focus of the study.

Figure 20. River Mile 69.19 Water surface elevation comparison



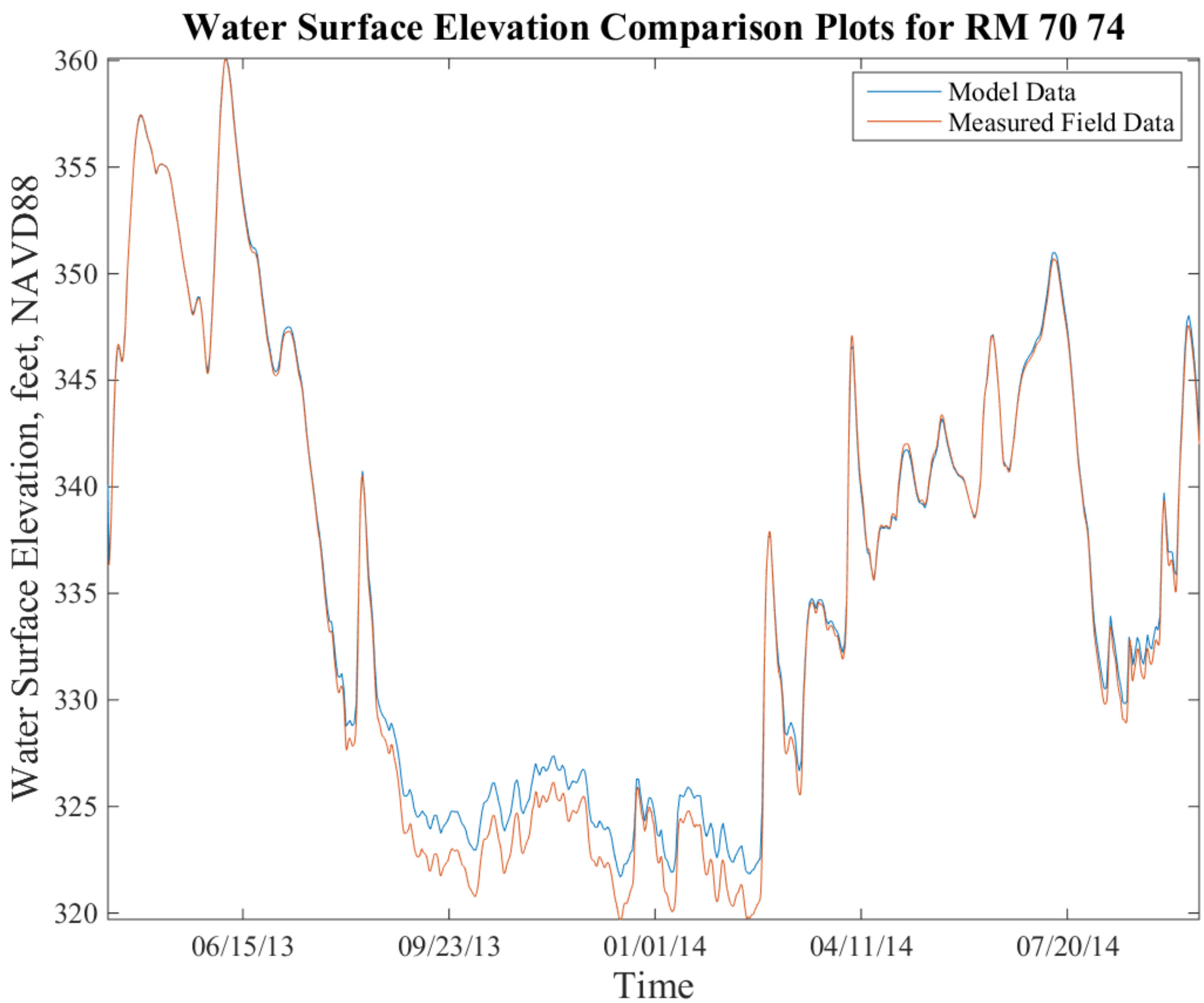
Note that the HEC-RAS model values are labeled Measured Field Data in figure. The AdH data is the model data represented in the plot. There is some divergence in the lower elevations of the model, however it does not have an effect on the higher elevations which is the focus of the study.

Figure 21. River Mile 69.19 Box Plot



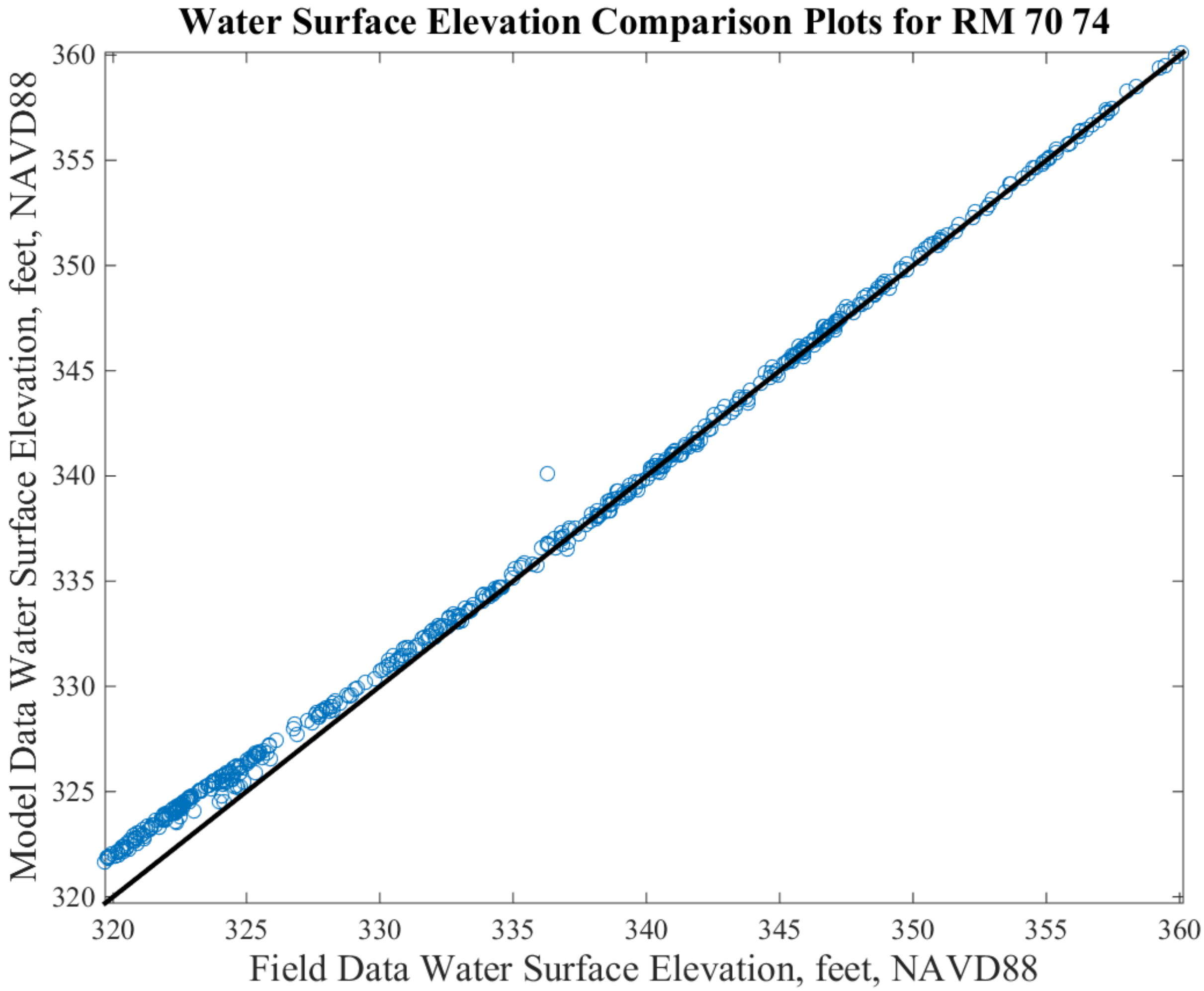
Note: the outlier at approximately model elevation 341 is caused by initial conditions and does not affect the results of the remainder of the model simulation. There is some divergence in the lower elevations of the model, however it does not have an effect on the higher elevations which is the focus of the study.

Figure 22. River Mile 70.74 Water surface elevation comparison



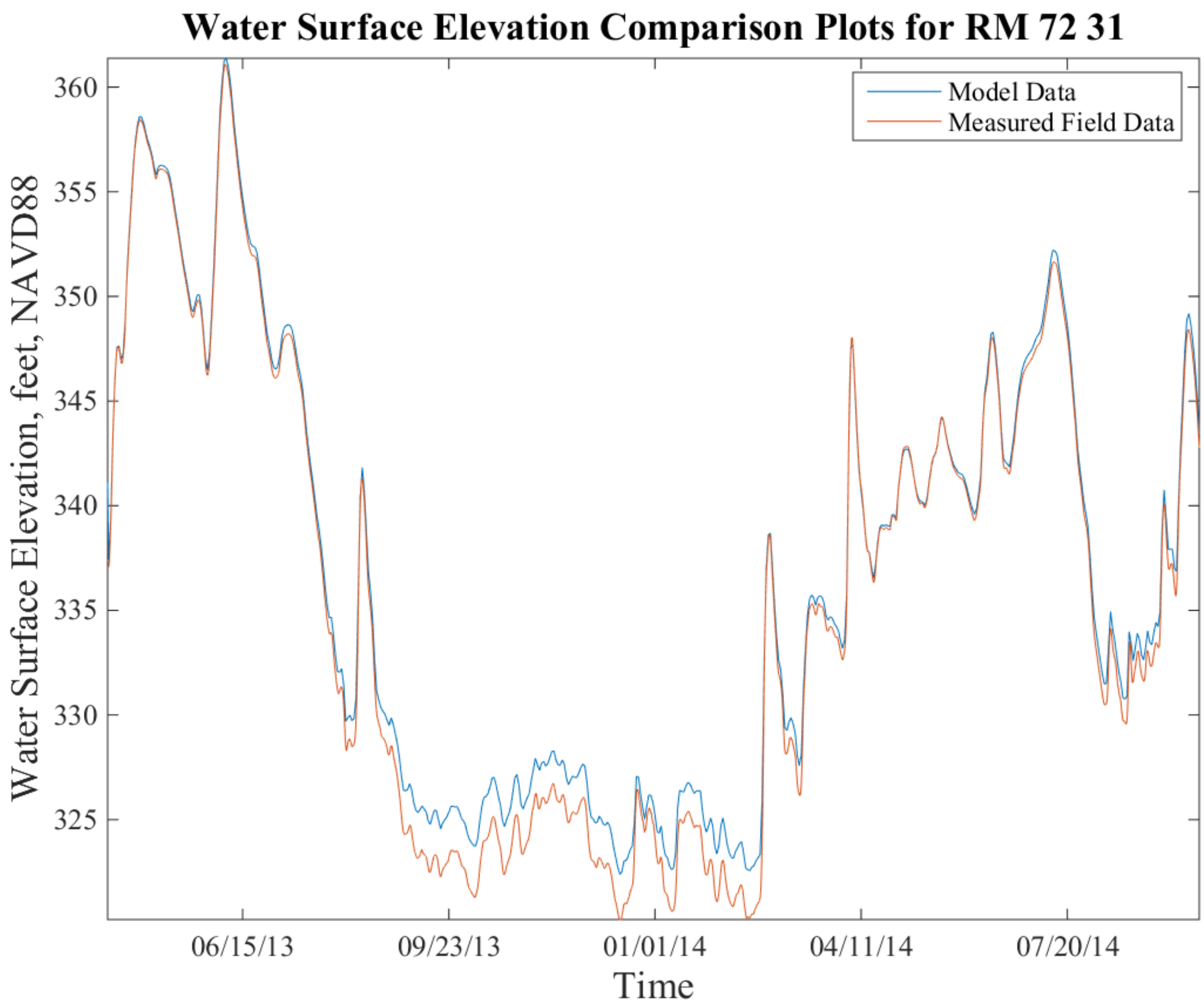
Note that the HEC-RAS model values are labeled Measured Field Data in figure. The AdH data is the model data represented in the plot. There is some divergence in the lower elevations of the model, however it does not have an effect on the higher elevations which is the focus of the study.

Figure 23. River Mile 70.74 Box Plot



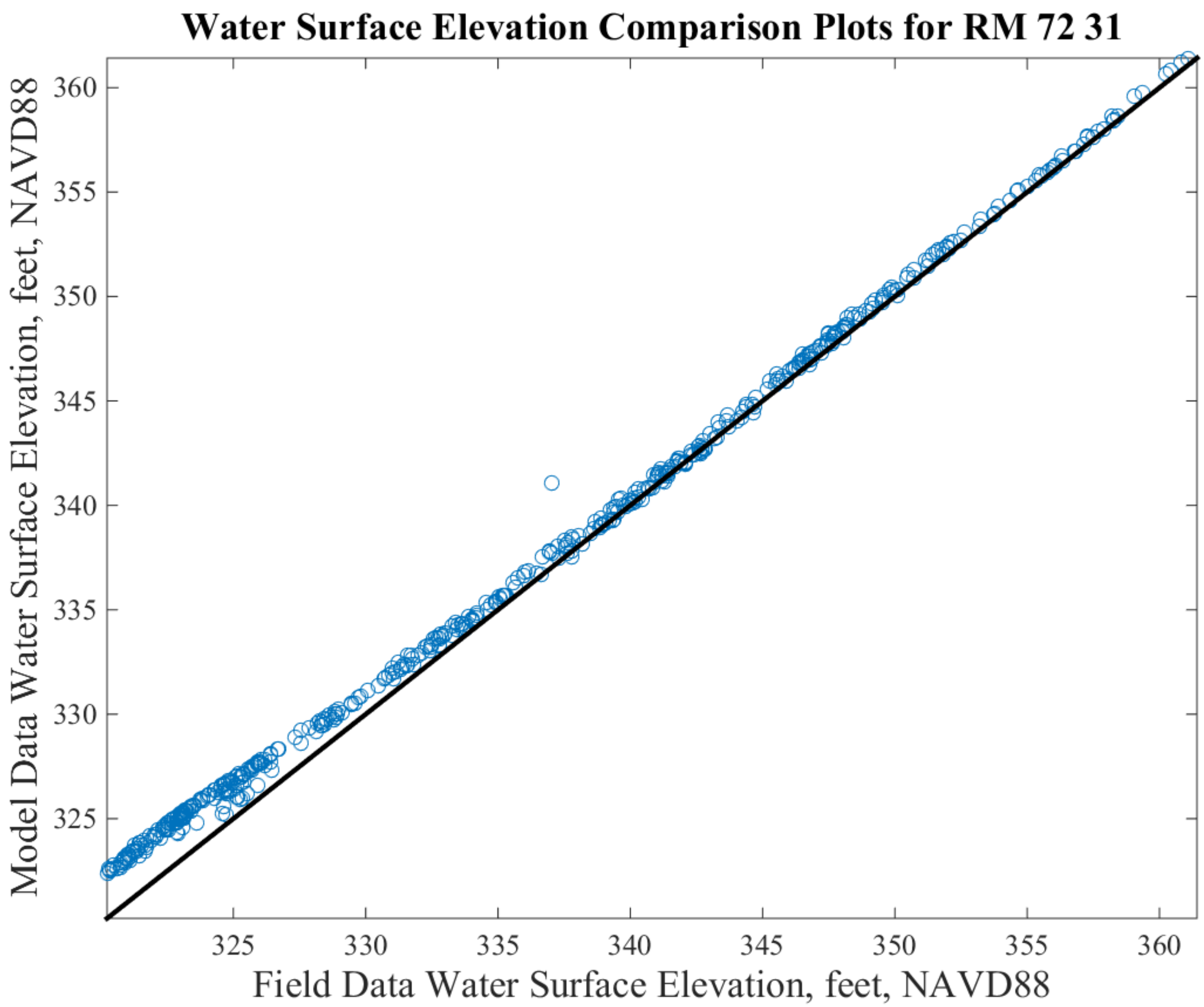
Note: the outlier at approximately model elevation 342 is caused by initial conditions and does not affect the results of the remainder of the model simulation. There is some divergence in the lower elevations of the model, however it does not have an effect on the higher elevations which is the focus of the study.

Figure 24.River Mile 72.31 Water surface elevation comparison



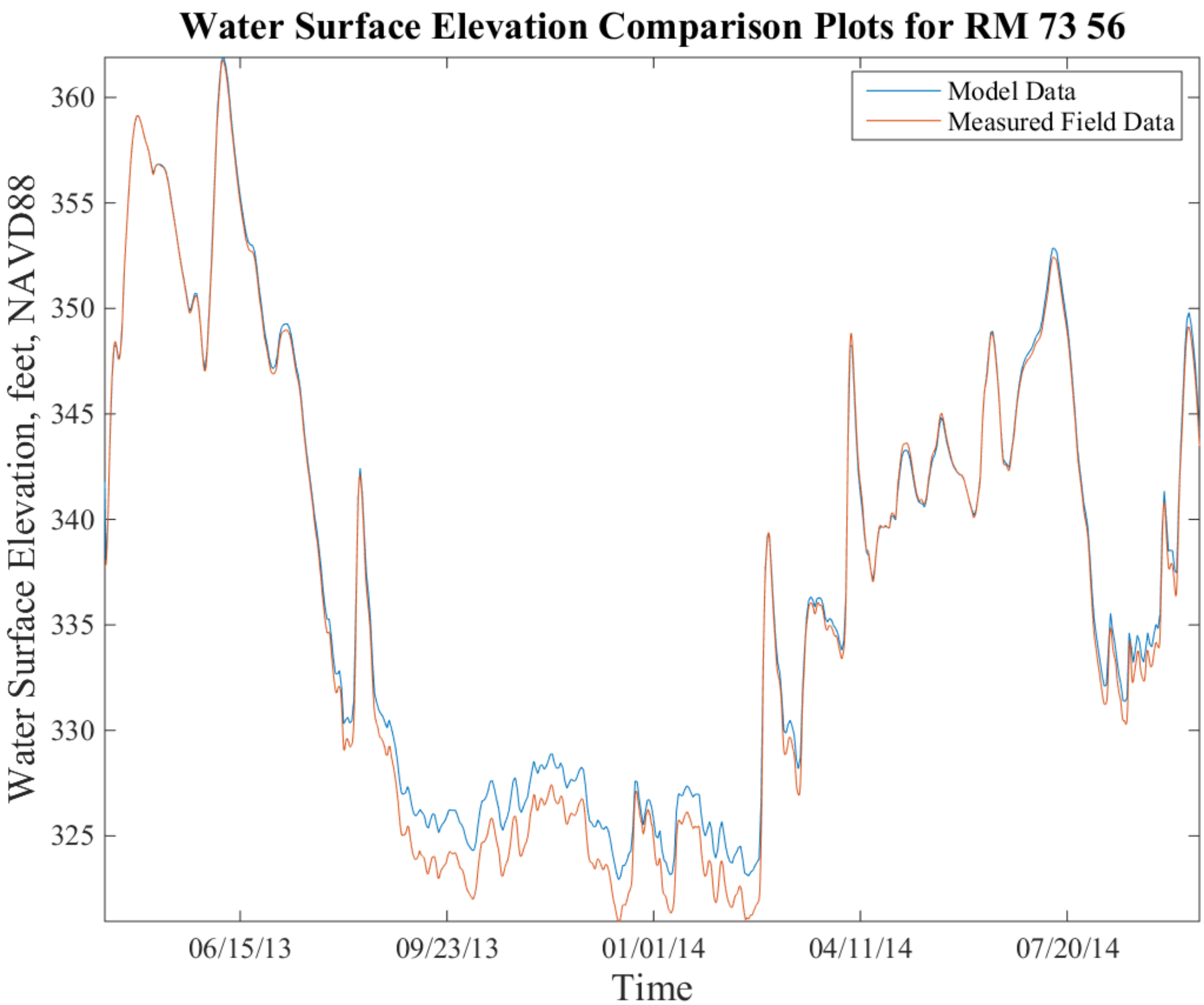
Note that the HEC-RAS model values are labeled Measured Field Data in figure. The AdH data is the model data represented in the plot. There is some divergence in the lower elevations of the model, however it does not have an effect on the higher elevations which is the focus of the study.

Figure 25. River Mile 72.31 Box Plot



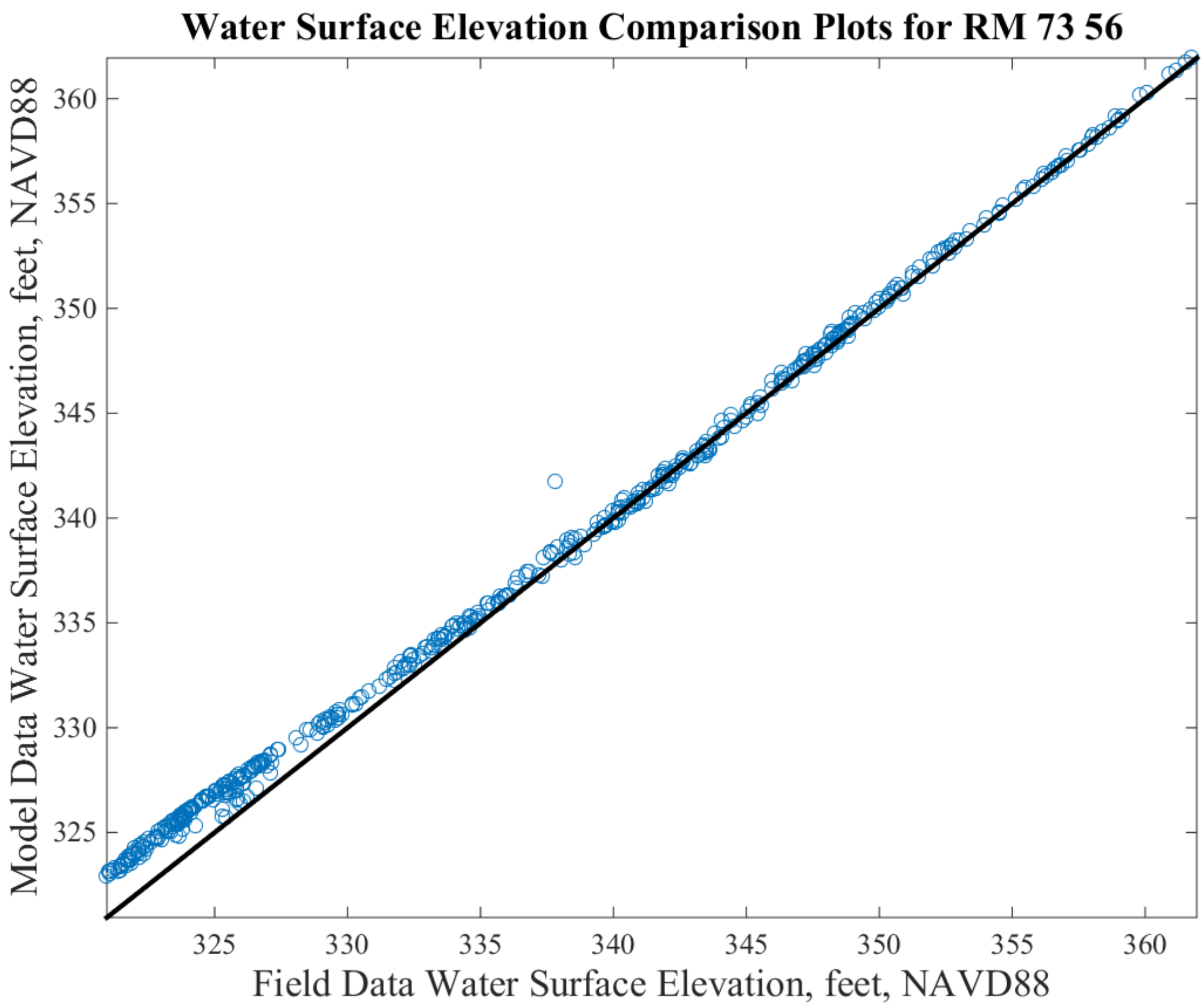
Note: the outlier at approximately model elevation 343 is caused by initial conditions and does not affect the results of the remainder of the model simulation. There is some divergence in the lower elevations of the model, however it does not have an effect on the higher elevations which is the focus of the study.

Figure 26. River Mile 73.56 Water surface elevation comparison



Note that the HEC-RAS model values are labeled Measured Field Data in figure. The AdH data is the model data represented in the plot. There is some divergence in the lower elevations of the model, however it does not have an effect on the higher elevations which is the focus of the study.

Figure 27. River Mile 73.56 Box Plot



Note: the outlier at approximately model elevation 343 is caused by initial conditions and does not affect the results of the remainder of the model simulation. There is some divergence in the lower elevations of the model, however it does not have an effect on the higher elevations which is the focus of the study.

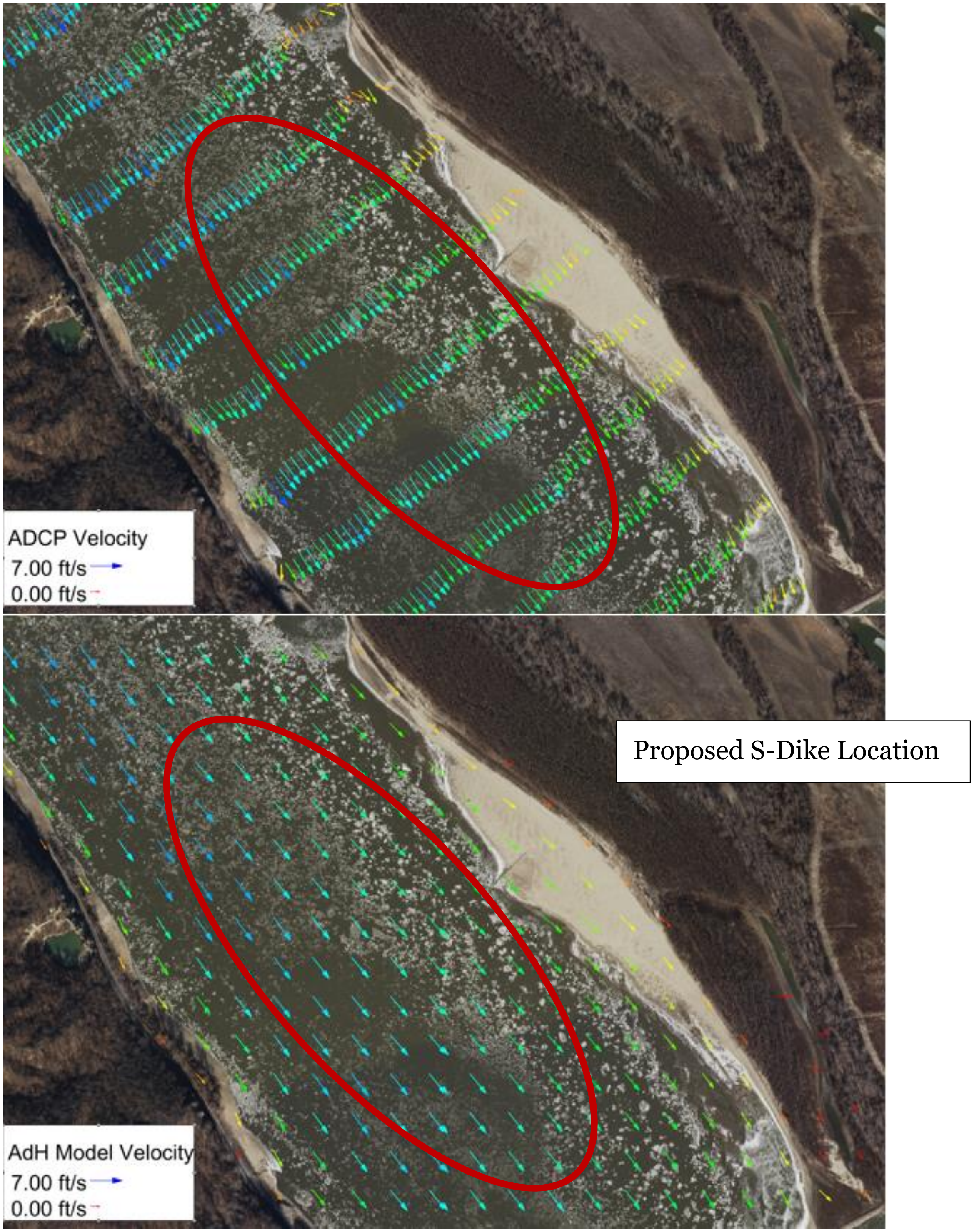
2.2.4.2 Acoustic Doppler Current Profiler (ADCP)

Velocity fields within the study area were measured using Acoustic Doppler Current Profiler (ADCP). ADCP is a hydroacoustic current meter that uses the Doppler effect of sound waves to measure water current velocities throughout the water column. Velocities collected using ADCP were compared to calculated velocities to verify model calibration. To make a direct comparison, since AdH is a two dimensional model, depth average velocities were calculated from the ADCP data.

The ADCP data was collected in the study area on May 29, 2015. The flow on the day that the ADCP data was collected was 308,000 cfs at the Upstream Boundary with a water surface elevation of 338.2 feet NAVD88 as the Downstream Boundary. The AdH model was run with these boundary conditions to provide a direct comparison which could be used to evaluate how well the calculated velocities matched those observed in the field.

The ADCP data is displayed using arrows to denote the direction of the velocity. The ADCP is a validation to the water surface elevation calibration of the AdH model. The AdH model closely matches the ADCP data in both magnitude and direction in both the channels and around the structures in the river. Figure 28 below shows ADCP compared to AdH model in the area where s-dike structures will be placed. Figure 29 shows ADCP compared to the AdH model around one of the existing dike structures.

Figure 28. ADCP (top) compared to AdH Model Velocity (bottom) in the Proposed S-Dike Construction location.



Note: Background Photo is for imagery purposes only. The photo does not represent the conditions on the day the ADCP was taken.

Figure 29. ADCP (top) compared to AdH Model Velocity (bottom) near current structure.

Note: Background Photo is for imagery purposes only. The photo does not represent the conditions on the day the ADCP was taken.

3 AdH Simulation of Proposed Construction Alternative

3.1 Modeling Simulation

The AdH models for the base condition and the proposed construction alternative were run using the same boundary conditions and model parameters (viscosity, Manning's n, ERH, and URV values). This was done to ensure that the only changes were the structure changes and bathymetry response. The two comparisons were run using steady flow simulations using 1% Annual Chance of Exceedance (ACE) discharge of 949,011 cfs at the upstream end and elevation of 360.89 ft at the downstream end. The 1 percent annual chance exceedance was selected based on the concern for WSE impacts during flooding events.

3.2 Results

The proposed structures in the Vancill Towhead reach have no impact on water surfaces for a 1% of annual chance of exceedance (ACE) discharge of 949,011 cfs. Throughout the study reach, including upstream and along the banklines, the difference in water surface elevation between the base condition and the proposed construction alternative did not exceed 0.05 feet which is the accepted standard for 'no rise' by permitting agencies. A few isolated local areas adjacent to the proposed structures showed an increase in water surface that exceeded 0.05 feet which did not propagate upstream, downstream or laterally. Figure 30 below shows the water surface elevation comparison. The results of this AdH model study are consistent with previous analyses on the impact of river training structures on flood levels (USACE 2014, Huizinga 2009, Watson et al. 2013).

Velocity magnitude for the base condition and the proposed construction alternative is shown in figures 31 and 32. The purpose of the proposed structures is to change the sediment transport within the reach. In the near term, the constriction from the S-dikes causes scour in the main channel and along the bankline side of the structures. This results in a deeper navigation channel and the development of a sustainable side channel. As equilibrium is reached within the reach and the resulting channel dimensions are achieved, the increased velocities in the main channel return to values consistent with the pre-construction scenario (shown in figure 32) (Watson et al. 2009). Previous studies have shown that the cross sectional area of the resulting channel geometry and channel conveyance are similar or greater than the pre-construction scenario (Little et al. 2015).

Figure 30. WSE difference of proposed construction alternative and base condition

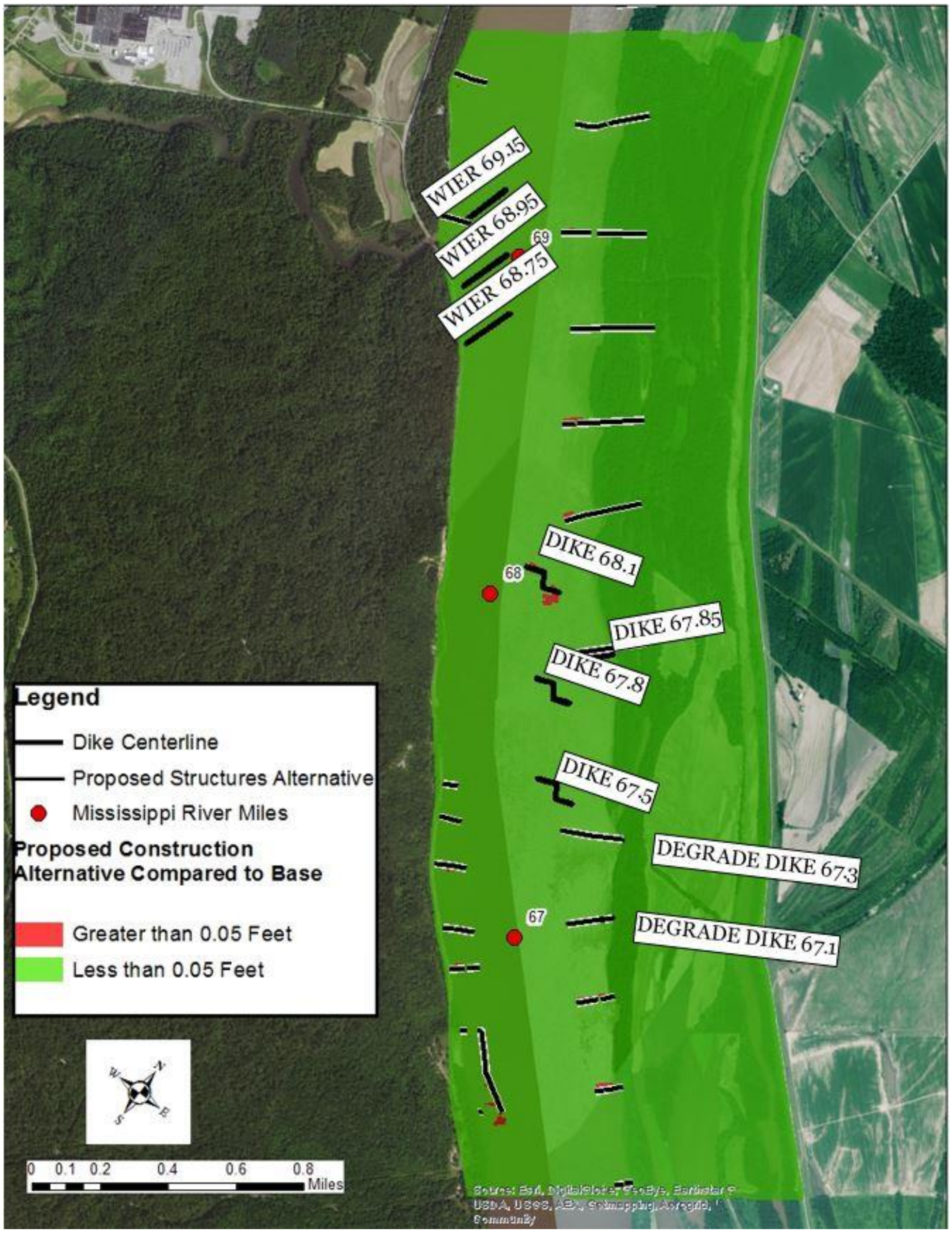


Figure 31. Base Condition Velocity.

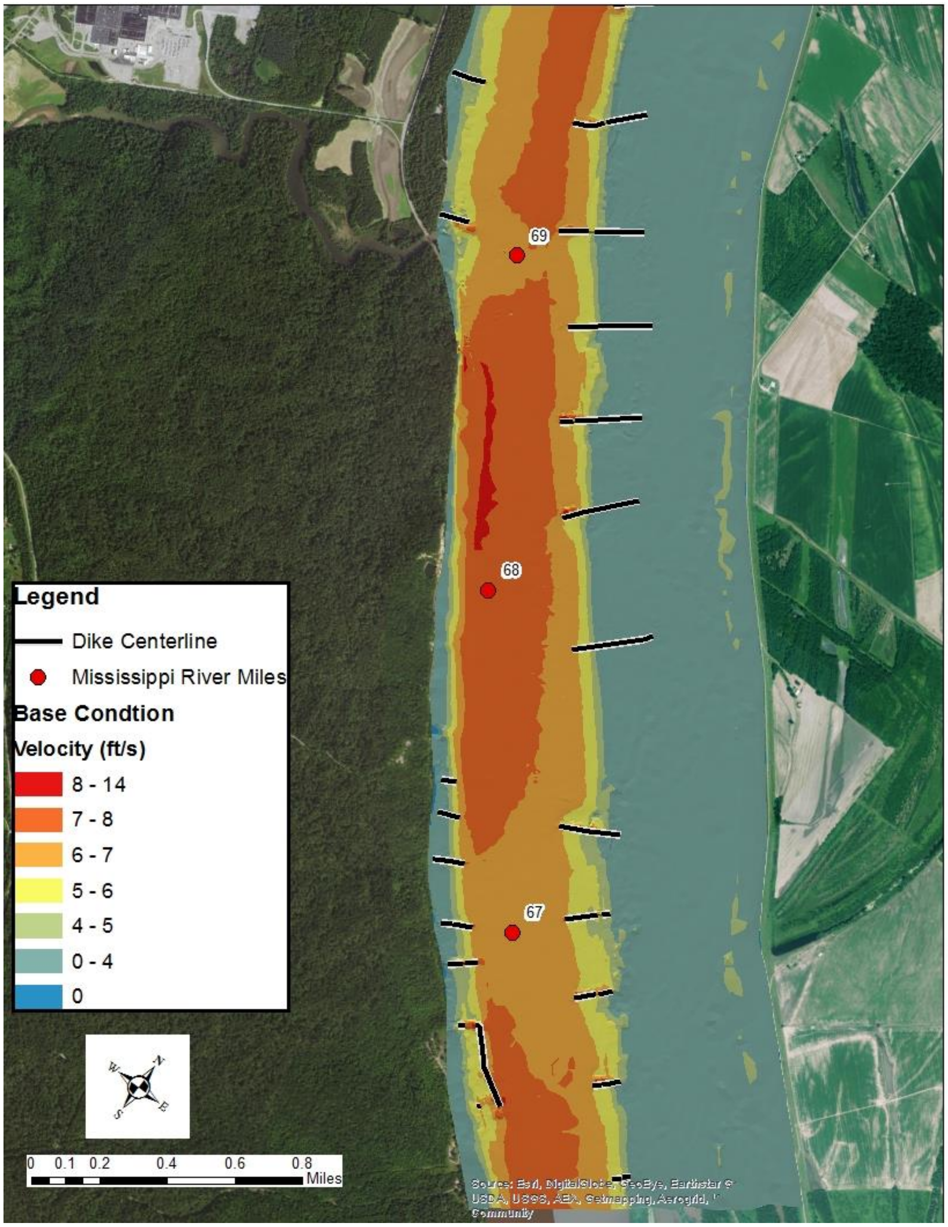
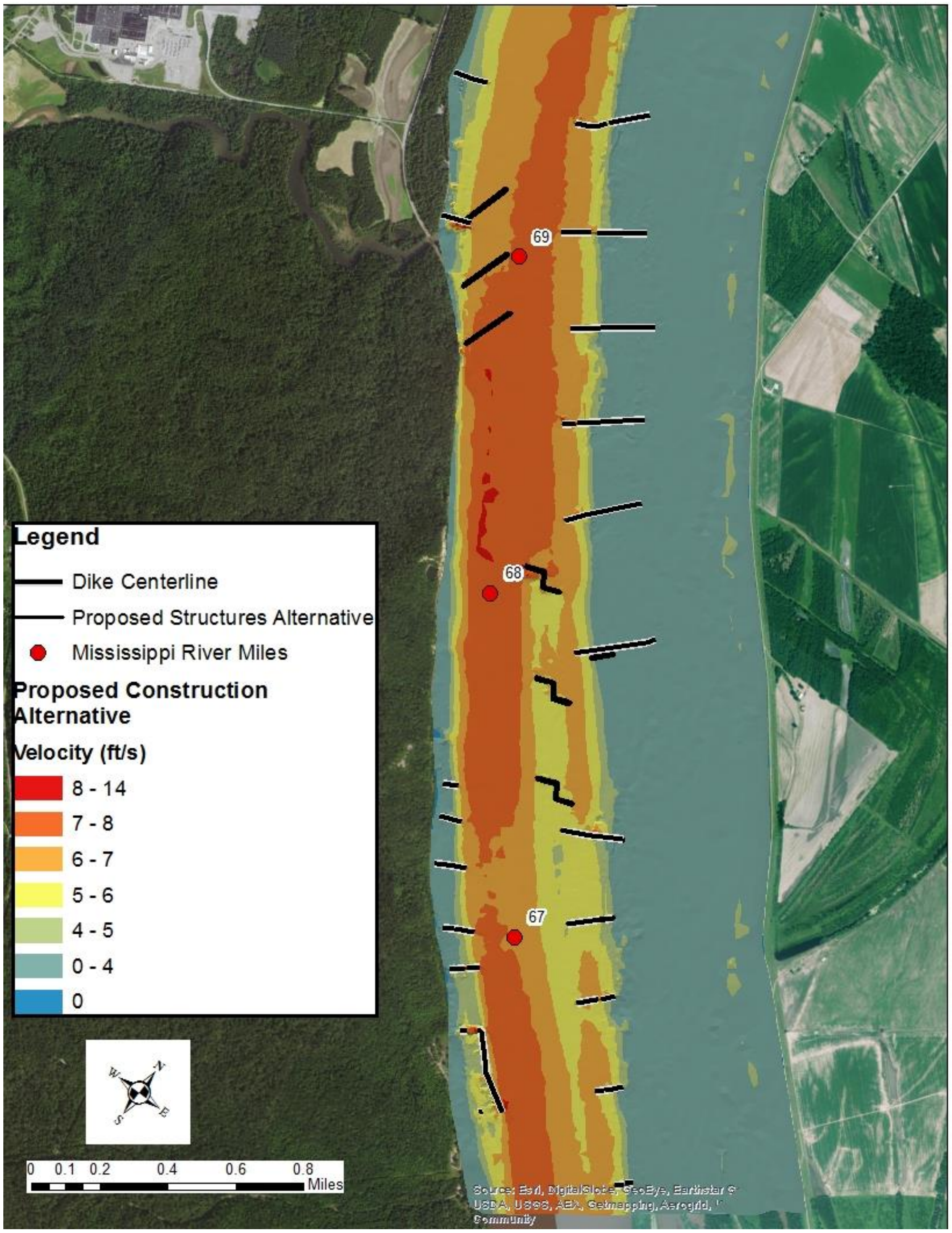


Figure 32. Proposed Construction Alternative Velocity.



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5 Acronyms

Name	Acronym
United States Army Corps of Engineers	USACE
Hydraulic Sediment Response	HSR
National Environmental Policy Act	NEPA
Adaptive Hydraulics	AdH
Surface Water Modeling System	SMS
River Mile	RM
Hydrologic Engineering Center River Analysis System	HEC-RAS
National Geodetic Vertical Datum of 1929	NGVD29
North American Vertical Datum of 1988	NAVD88
Light Detection and Ranging	LiDAR
National Elevation Dataset	NED
Right Descending Bank	RDB
Unsubmerged Rigid Vegetation	URV
Equivalent Roughness Height	ERH
2 Dimensional	2D
Water Surface Elevation	WSE
Engineering Research and Development Center	ERDC
High-Performance Computing	HPC

Air Force Research Laboratory	AFRL