USE OF VELOCITY DATA TO CALIBRATE AND VALIDATE TWO-DIMENSIONAL HYDRODYNAMIC MODELS

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Abstract: Calibration and validation of two-dimensional numerical hydrodynamic models often are limited to matching water-surface elevations and producing reasonable flow fields. With the advancement of acoustic Doppler current profilers (ADCPs), it is now cost effective to collect detailed field data and calibrate and validate models to match measured velocity fields. The U.S. Geological Survey (USGS), Kentucky District has used a combination of water-surface elevations and measured velocity fields to calibrate two models of the Ohio River. Calibrated models that adequately matched water-surface elevations did not necessarily guarantee an adequate match of the measured flow field.

The model calibration and validation process for both models included matching water-surface elevations, and ADCP velocity direction and magnitude profiles at cross sections throughout the study reach. The ability to compare the model to measured velocity data improved the overall calibration of the models from what would have been possible with only water-surface-elevation data.

INTRODUCTION

General: Flow models typically are calibrated and verified with water-surface elevations at a few locations in a model domain. It is rare that model simulated velocities are verified with measured data. To demonstrate the use of acoustic Doppler current profiler (ADCP) velocity data as well as measured water-surface elevations to calibrate and validate two-dimensional flow models, two models prepared by the US Geological Survey as part of the Ohio River Sanitation Commission (ORSANCO) study and the Olmsted Locks and Dam study are presented.

ORSANCO Study: The USGS, as part of an ORSANCO water-quality project, developed and field validated a two-dimensional RMA-2 model for a 40-mile study reach near Louisville, Ky (Ohio River miles 590-630). A separate ORSANCO contractor planned to use the modeled velocities to provide the advective component of a simple water-quality model to evaluate wet-weather water-quality problems and control measures for large river communities. Because of the hydrodynamic complexities induced by McAlpine Locks and Dam (Ohio River mile 607), the model was split into two segments; an upstream river reach that extended from dam upstream to the upper terminus of the study reach (Ohio River mile 590) and a downstream reach that extended from the dam downstream to a lower terminus at Ohio River mile 636. Floodplains were not included in the model simulations because low-flow periods spanning the recreational contact period from May through September were emphasized in this study.

<u>Olmsted Locks and Dam Study</u>: The knowledge and experience gained from the ORSANCO modeling efforts were transferable to a study on a 9.5-mile reach of the Ohio River near the U.S. Army Corps of Engineers (COE) Olmsted Locks and Dam project at Ohio River mile 964.4. The purpose of the Olmsted model was to provide the hydrodynamics input for a two-dimensional sediment transport model capable of estimating the effects that the phased in-the-wet construction sequence of the Olmsted Locks and Dam would have on sediment-transport patterns in the reach, and in particular at a mussel bed located downstream of the dam construction site.

FIELD DATA COLLECTION AND INTERPRETATION

<u>General</u>: At least two data sets are required to adequately calibrate and validate a numerical model. The general procedure used to calibrate and validate the RMA-2 models was to first collect field data that allowed the development of the computational mesh. The models then were calibrated to the water-surface elevations and velocities observed in the field for the initial flow. An additional one or two flow conditions then were simulated without changing the computational mesh or model parameters, and the simulated water-surface elevations and velocities were compared with those measured in the field to validate the model.

To document the changes in river stage during a hydraulic survey, the water-surface elevations were surveyed in the morning and then again in the afternoon. The average water-surface elevation was used to determine a water-surface slope corresponding to the average discharge measured during the survey.

<u>ORSANCO Study</u>: Water-surface elevations, channel bathymetry, and detailed water-velocity measurements were collected at two different flow conditions (36,000 and 390,000 ft^3/s). Water-surface elevations were measured at 10 locations (4 upstream and 6 downstream) along the study reach concurrent with both hydraulic surveys. Detailed water-velocity measurements and channel bathymetry data were collected at 30 cross sections (12 upstream and 18 downstream) spaced approximate 1.5 mi apart, during each of the hydraulic surveys (fig. 1). In addition, a detailed bathymetric survey of the upstream reach was completed to complement the hydrographic surveys available from the COE.

Water Surface Elevations: Water-surface elevations at 7 of the 10 locations throughout the reach (fig 1) were surveyed with a total station and the remaining three locations were USGS gaging stations.

The 40-mi study section of the Ohio River includes a total of four USGS stream gages—two each in both the upstream and downstream reaches (fig.1). Both upstream gages—one located on the Second Street Bridge (number 03293548) and the other at Indiana Pass (number 03293550) — are located near river mile 604 and are used by the COE, Louisville District in maintaining the McAlpine normal pool elevation. The Second Street Bridge station was only active during the later portion of the study and was not used in the model calibration. The McAlpine tailwater and Kosmosdale gaging stations (numbers 03294500 and 03294600, respectively) are located within the downstream reach.

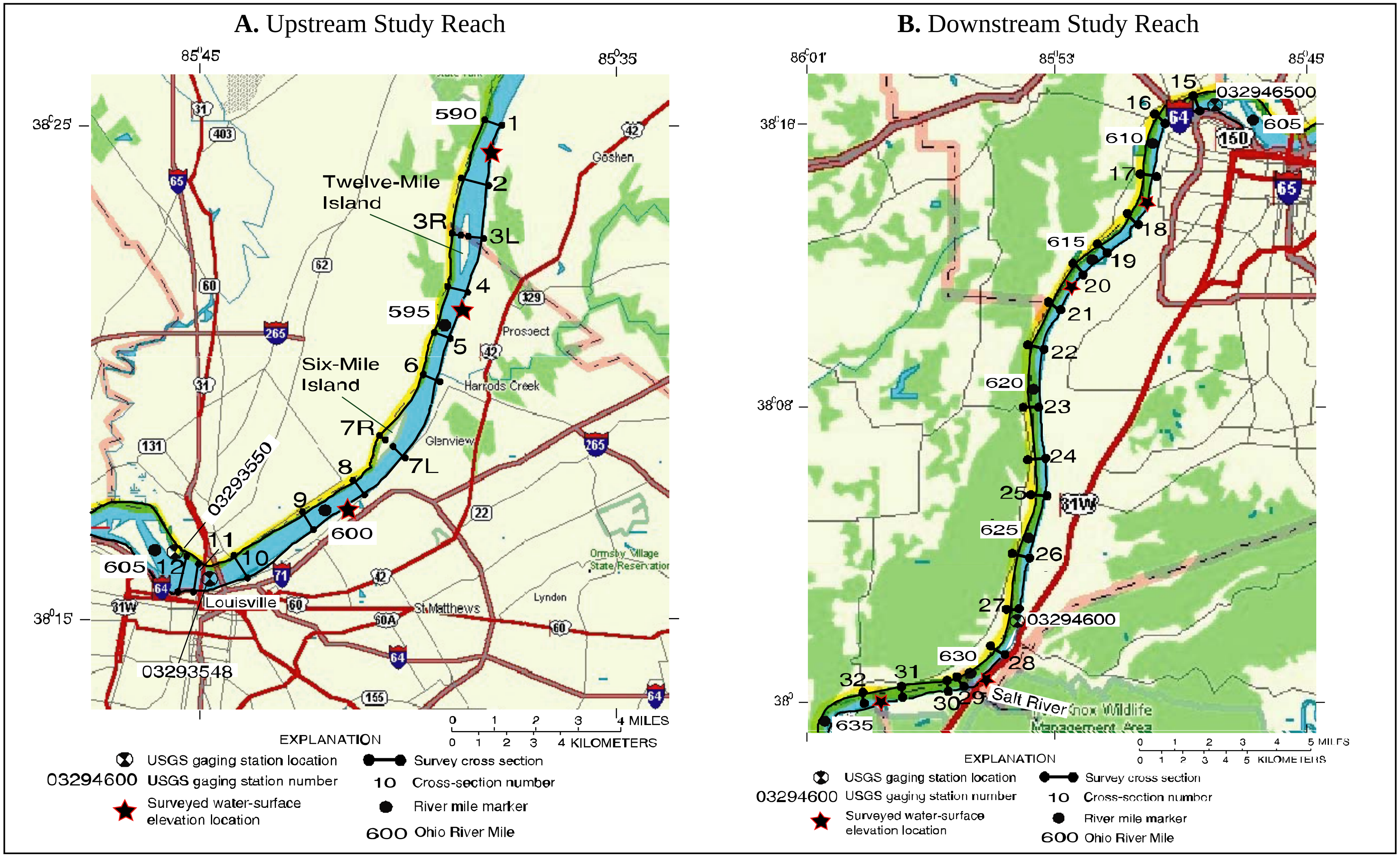


Figure 1. – Location of hydrographic survey cross sections, surveyed water-surface elevation stations, and U.S. Geological Survey (USGS) gaging stations in the ORSANCO Ohio River study reach near Louisville, Kentucky.

Velocity and Discharge: Water-velocity and discharge data were collected from a moving boat. The horizontal position of the boat was measured using a differentially corrected global positioning system (DGPS) receiver. The DGPS receiver used is the study receives its differential corrections from a commercial service's communications satellite. The manufacturer specifies the unit to be accurate to 3.3 ft at two standard deviations; tests and prior use of this unit indicate that typically about 80 percent of the data are within 3.3 ft of the true location.

Recent advances in velocity-measurement technology allow three-dimensional velocities to be collected from a moving boat using an ADCP (Oberg and Mueller, 1994; Mueller, 1996). All velocities were measured with an ADCP. The ADCP allows three-dimensional velocities to be measured from approximately 3 ft beneath the water surface to within 6 percent of the total depth to the bottom. Established methods were used to estimate the discharge in the unmeasured top and bottom portions of the profile (Simpson and Oltmann, 1991). Cross-sectional average velocities were computed by dividing the measured discharge by the measured cross-sectional area. In addition, depth-averaged velocities were computed for subsections of the flow in each cross section; however, these discrete depth-averaged velocities were computed as an average of the measured velocity and did not account for the velocity in the unmeasured portions of the water column. Analysis of this method showed that depth averaged velocities should be within 5 percent of the mean that would result if the entire water column could have been measured. In order to compensate for the slight changes in river discharge (typically less than 10 percent) during the survey, all of the collected discharge measurements were averaged to produce a flow rate that was representative of the entire survey period.

Olmsted Locks and Dam Study: Water-surface elevations, channel bathymetry, and detailed water-velocity measurements were collected at three different flow conditions (72,200, 350,000 and 750,000 ft^3/s). Water-surface elevations were determined at three locations along the study reach concurrent with all three hydraulic surveys. Detailed water-velocity measurements and channel bathymetry data were collected at 15 cross sections (fig. 2), spaced approximately 2,000 ft apart, during each of the hydraulic surveys in accordance with methods described in the ORSANCO study. Field data processing methods also were similar to those of the ORSANCO study.

DISCUSSION OF CALIBRATION AND VALIDATION

ORSANCO Study: Data from the low-flow (36,000 ft^3/s) hydraulic survey were used to calibrate the model and data from the high-flow (390,000 ft^3/s) survey were used to validate the model. The calibration and validation process consisted of comparing the simulated water-surface elevations at the 10 water-surface elevation stations and 30 cross-sectional velocity profiles with those surveyed in the field. A Manning's roughness coefficient (n) was assigned to each element and iteratively adjusted until the model adequately simulated the surveyed water-surface elevations. Initially, a Manning's roughness coefficient (n) of 0.025 at all elements provided the best fit with the water-surface elevations for both low- and high-flow conditions.

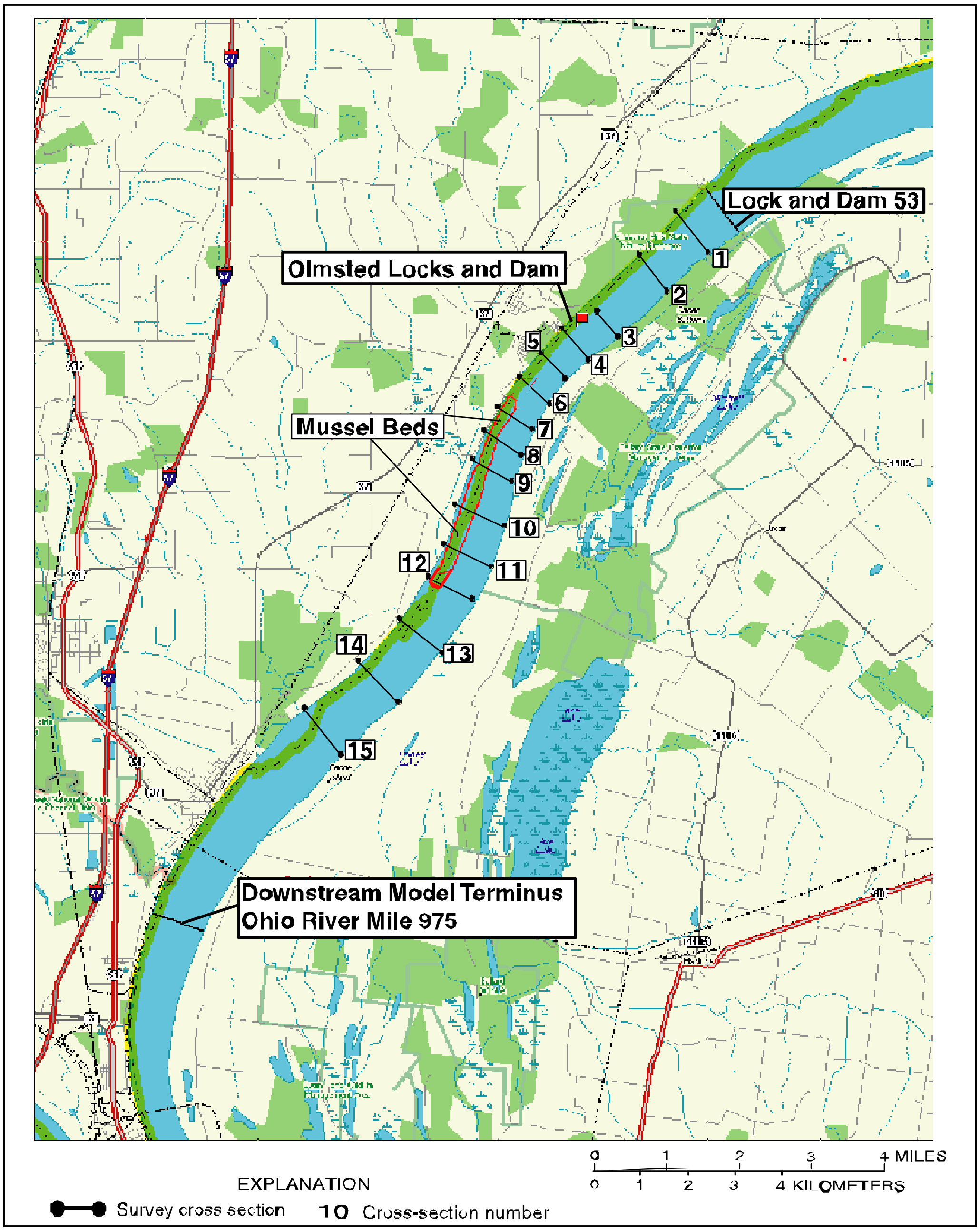


Figure 2. Olmsted Locks and Dam study reach with location of hydrographic -survey cross-sections near Olmsted, Illinois.

Inspection of the velocity profiles collected in the field showed that no-slip conditions along the riverbanks were required to obtain an accurate velocity distribution in the cross-section. To simulate the no-slip condition with RMA-2, the Manning's n value was increased to 0.035 for one row of elements along the outer boundary of the mesh. The calibrated Manning's n in the remainder of the channel was lowered to 0.024. This combination of Manning's n produced the best simulation of water-surface elevation (table 1 and 2), velocity magnitudes, and lateral velocity distribution for both low- and high-flow conditions.

Table 1. Summary of water-surface elevation calibration and validation for the upstream Ohio River reach, in downstream station order.
[WS, water surface; ft, feet; Elev, elevation]

	8/13/1998 Low Flow			2/16/00 High Flow		
Station	Field WS Elev (ft)	Model WS Elev (ft)	Difference (ft)	Field WS Elev (ft)	Model WS Elev (ft)	Difference (ft)
Harmony Landing	419.99	419.66	-0.33	427.59	427.68	0.09
Louisville Water Company	419.91	419.64	-.27	426.51	426.46	-.05
Cox's Park Well	419.86	419.62	-.24	425.19	425.04	-.15
Indiana Pass	419.60	419.60	0	423.88	423.90	.02

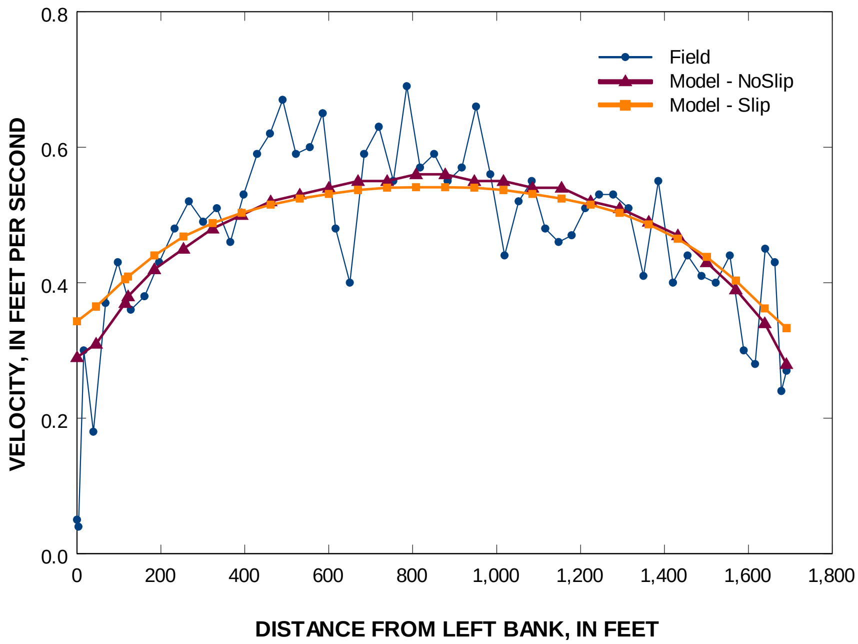
Table 2. Summary of water-surface elevation calibration and validation for the downstream Ohio River reach, in downstream station order.
[WS, water surface; ft, feet; TW, tailwater; Elev, elevation]

	5/19/2000 Low Flow			2/17/2000 High Flow		
Station	Field WS Elev (ft)	Model WS Elev (ft)	Difference (ft)	Field WS Elev (ft)	Model WS Elev (ft)	Difference (ft)
McAlpine TW	385.20	384.90	-0.30	416.18	416.13	-0.05
Shawnee Well	384.75	384.50	-.25	415.10	415.21	.11
RR-22 Well	384.68	384.20	-.48	413.65	413.83	.18
Kosmosdale	383.85	383.50	-.35	410.10	410.12	.02
West Point	383.54	383.40	-.14	409.70	409.50	-.20

The simulated velocity magnitudes and distributions in the upstream reach compared well with the field measurements. A comparison of the model and field-velocity profiles for cross-section number 5, which is 13 mi upstream from McAlpine Locks and Dam, is shown in figure 3. The shapes of the field- and model-velocity distributions are similar, and the model velocity magnitudes were within 0.1 ft/s of the average field values.

Comparison of the simulated velocity magnitudes and distributions, in the downstream reach, with field measured values indicate good agreement for the low-flow simulation but less favorable agreement for the high-flow simulation. Examples of the agreement between the low-flow simulated velocities and the field-measured velocities are shown in figure 4. The maximum difference at low flow was about 0.25 ft/s. For the high-flow condition, the simulated velocities were consistently greater than the measured velocities, despite excellent agreement in the water-surface elevations.

A. Low-flow velocity profile comparison



B. High-flow velocity profile comparison

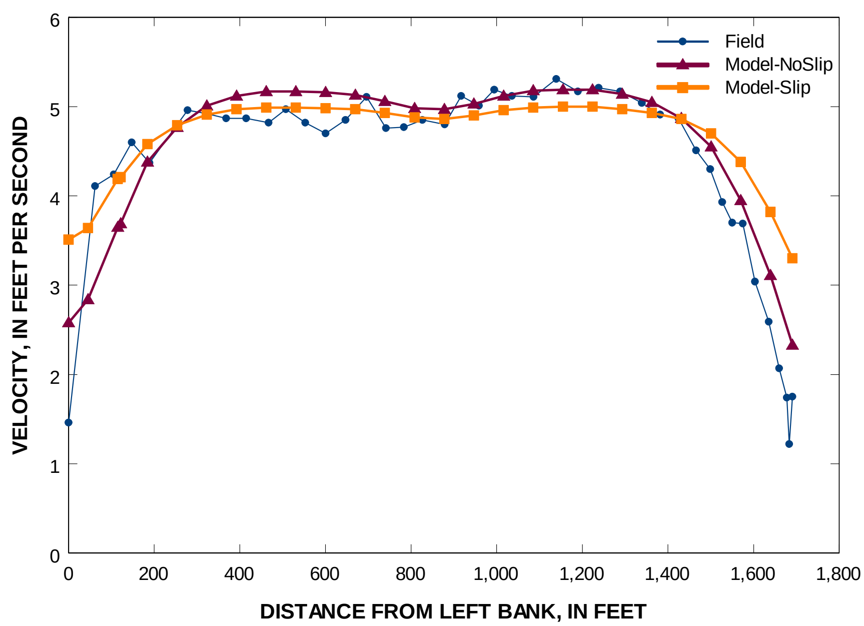
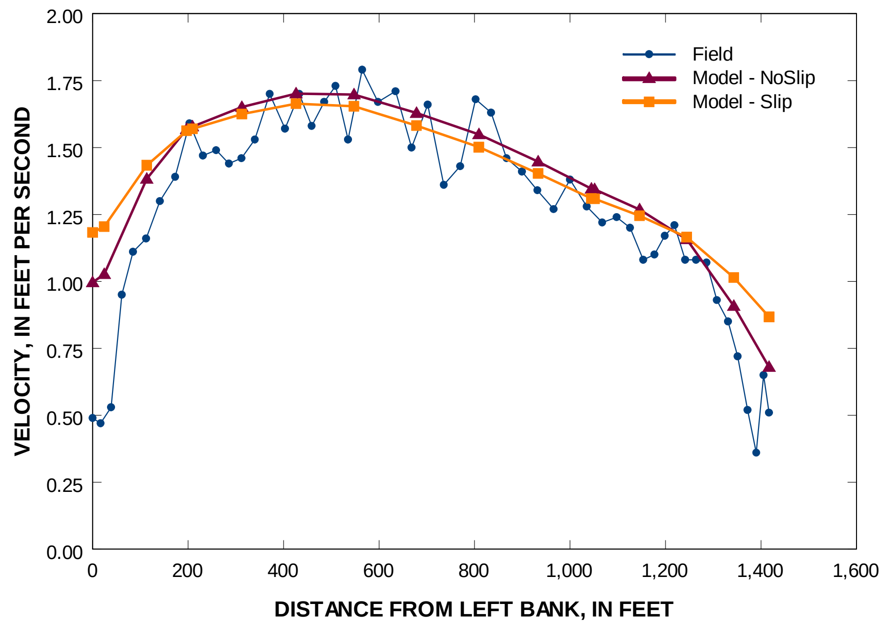


Figure 3. Field measured and model simulated velocity profiles at cross section 5, 13 miles upstream from McAlpine Locks and Dam near Louisville, Kentucky.

A. Low flow velocity profile for cross-section 19



B. Low flow velocity profile for cross-section 25

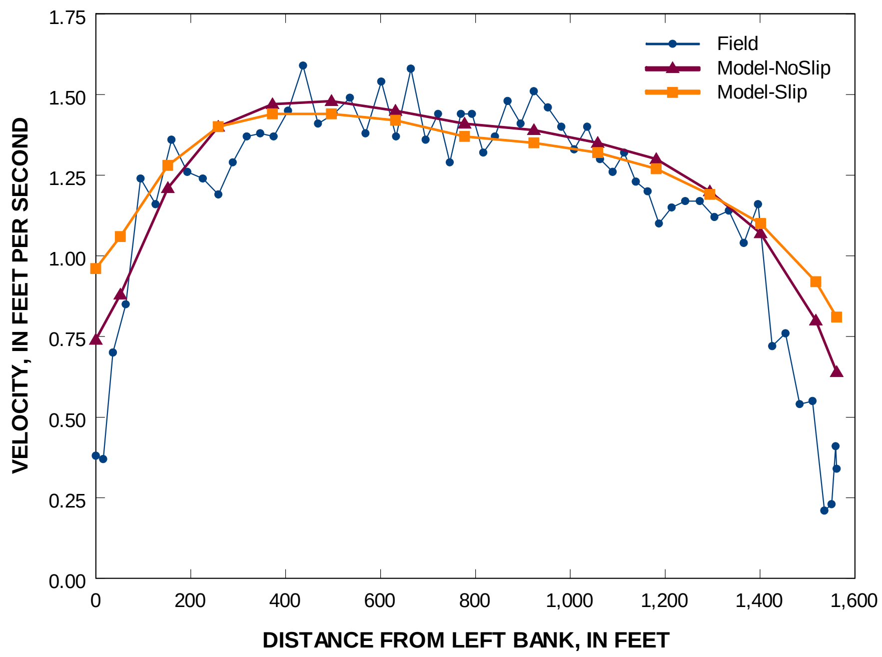


Figure 4. - Field measured and model simulated low-flow velocity profiles at cross-sections 19 and 25 in the downstream Ohio River study reach near Louisville, Kentucky.

To identify the cause of the disagreement between the simulated and measured velocities for the high-flow condition, the cross-sectional areas of the model bathymetry were compared to the cross-sectional areas measured during the high-water survey. The differences between the magnitudes of the average cross-sectional velocities for the model and the field were correlated closely with differences in cross-sectional area. Comparison of the bathymetry collected during the high-flow hydraulic survey and the bathymetry used to develop the model showed that scour of the channel bottom occurred during high flow. The inability of the model to simulate the scouring of the channel bed is the primary reason for the differences between the model and field cross-sectional areas and average velocities during the high-flow condition.

The model was calibrated and validated using water-surface elevations and average cross-section velocities to achieve the minimum error for both high- and low-flow conditions. The simulated low-flow water-surface elevations typically were biased between 0.0 and 0.48 ft low, whereas the simulated high-flow, water-surface elevations were within 0.2 ft of the field conditions. Simulated, average cross-section velocities typically were within 0.1 ft/s for low flow and 0.3 ft/s for high flow when compared with field data. On the basis of the calibration and validation results, the model is a representative simulation of the Ohio River steady-flow patterns below discharges of approximately 400,000 ft^3/s (cubic feet per second).

<u>Olmsted Locks and Dam Study</u>: The model was calibrated to an intermediate-flow hydraulic survey (approximately 350,000 ft^3/s) and verified with data collected during a high and low-flow period (approximately 750,000 ft^3/s and 72,200 ft^3/s, respectively). The calibration and validation process consisted of comparing the simulated water-surface elevations at 3 water-surface elevation stations and 15 cross-sectional velocity profiles with those surveyed in the field. A Manning's n value was assigned to each element and iteratively adjusted until the model adequately simulated the surveyed water-surface elevations. Initially, a Manning's n value of 0.021 at all elements provided the best fit with the water-surface elevations for low-, mid- and high-flow conditions.

Inspection of the velocity profiles collected in the field showed that no-slip conditions along the riverbanks were required to obtain an accurate velocity distribution in the cross-section. To simulate this no-slip condition with RMA-2, the Manning's n value was increased to 0.036 for one row of elements along the outer boundary of the mesh. The calibrated Manning's n in the remainder of the channel was lowered to 0.020. This combination of Manning's n produced the best simulation of water-surface elevation (table 3), velocity magnitudes, and lateral velocity distribution for all of the measured flow conditions.

The simulated velocity magnitudes and distributions in the upstream reach compared well with the field measurements. A comparison of the model and field-velocity profiles for cross-section number 4 is shown in Figure 5; cross-section 4 is located 1000 ft downstream from the Olmsted Locks and Dam construction site. The shapes of the field- and model-velocity distributions throughout the reach were similar. The average simulated cross-sectional velocity magnitudes were within 0.3 ft/s of those measured in the field.

Table 3. Summary of water-surface elevation calibration and validation at the Olmsted Locks and Dam construction site.

[WS, water surface; ft, feet; Elev, elevation; cfs, cubic feet per second]

Discharge (cfs)	Field WS Elev (ft)	Model WS Elev (ft)	Difference (ft)
72,200	286.84	287.06	0.22
350,000	305.94	306.00	0.06
750,000	322.34	322.10	-0.24

Because the hydrodynamics are going to be used in a two-dimensional sediment transport model, the velocity directions also were a very important part of the calibration and validation process. A comparison of the simulated velocity vectors and those collected in the field shown in figure 6 indicates that the model accurately represents the field data throughout the reach, even in the hydraulically complex areas of reverse flow.

SUMMARY

The model calibration and validation process for both models included matching water-surface elevations and ADCP velocity direction and magnitude profiles at cross sections throughout the study reach. The USGS Kentucky District’s ability to compare the model to measured velocity data improved the overall calibration of the models from what would have been possible with only water-surface elevation data. In addition, the visual comparison of the modeled velocity vectors with the measured velocity vectors provided a validation of the model that was easy to understand by non-modelers.

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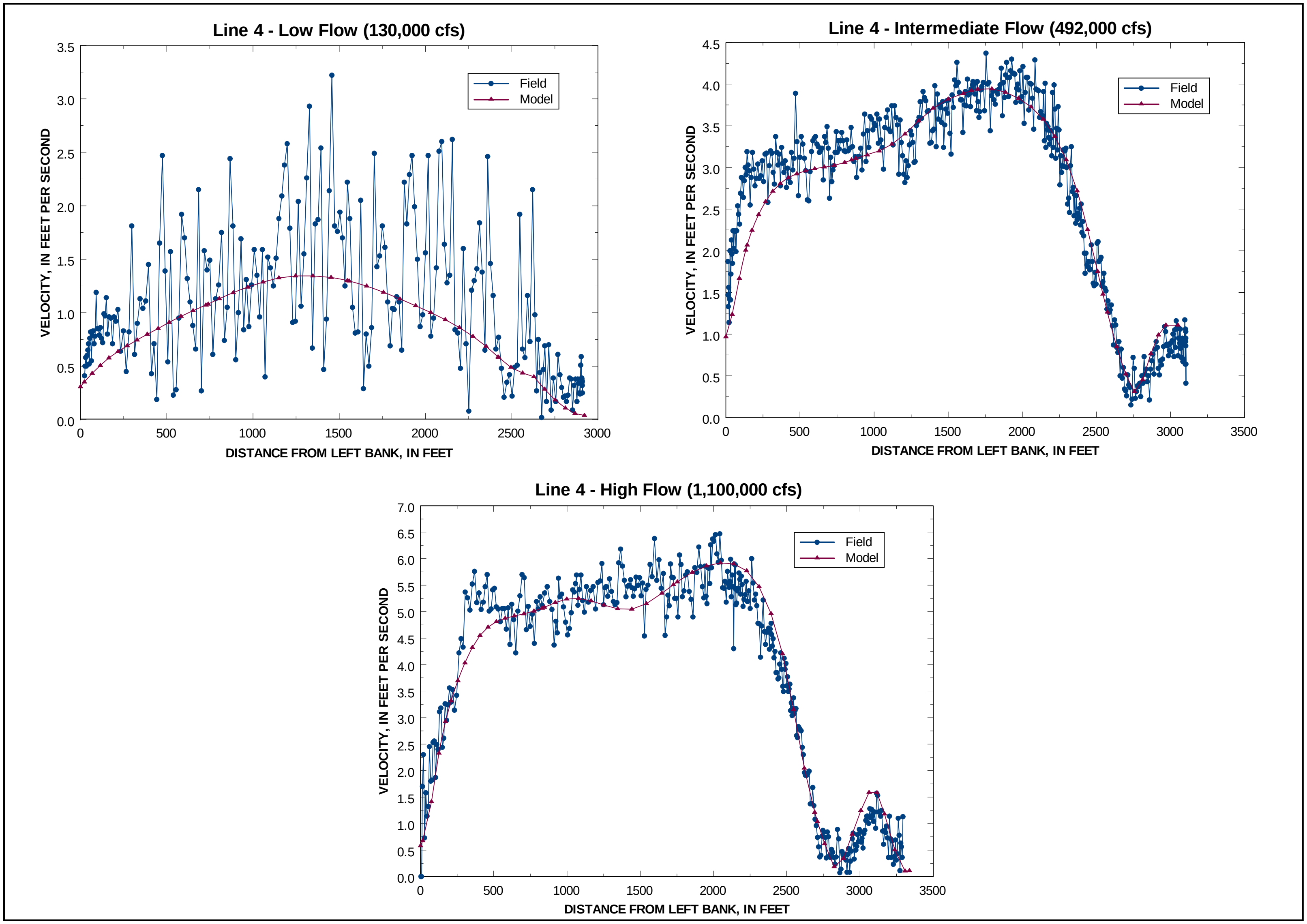

Figure 5. - Field measured and model simulated velocity profiles at cross section 4, 1000 ft downstream of Olmsted Locks and Dam.

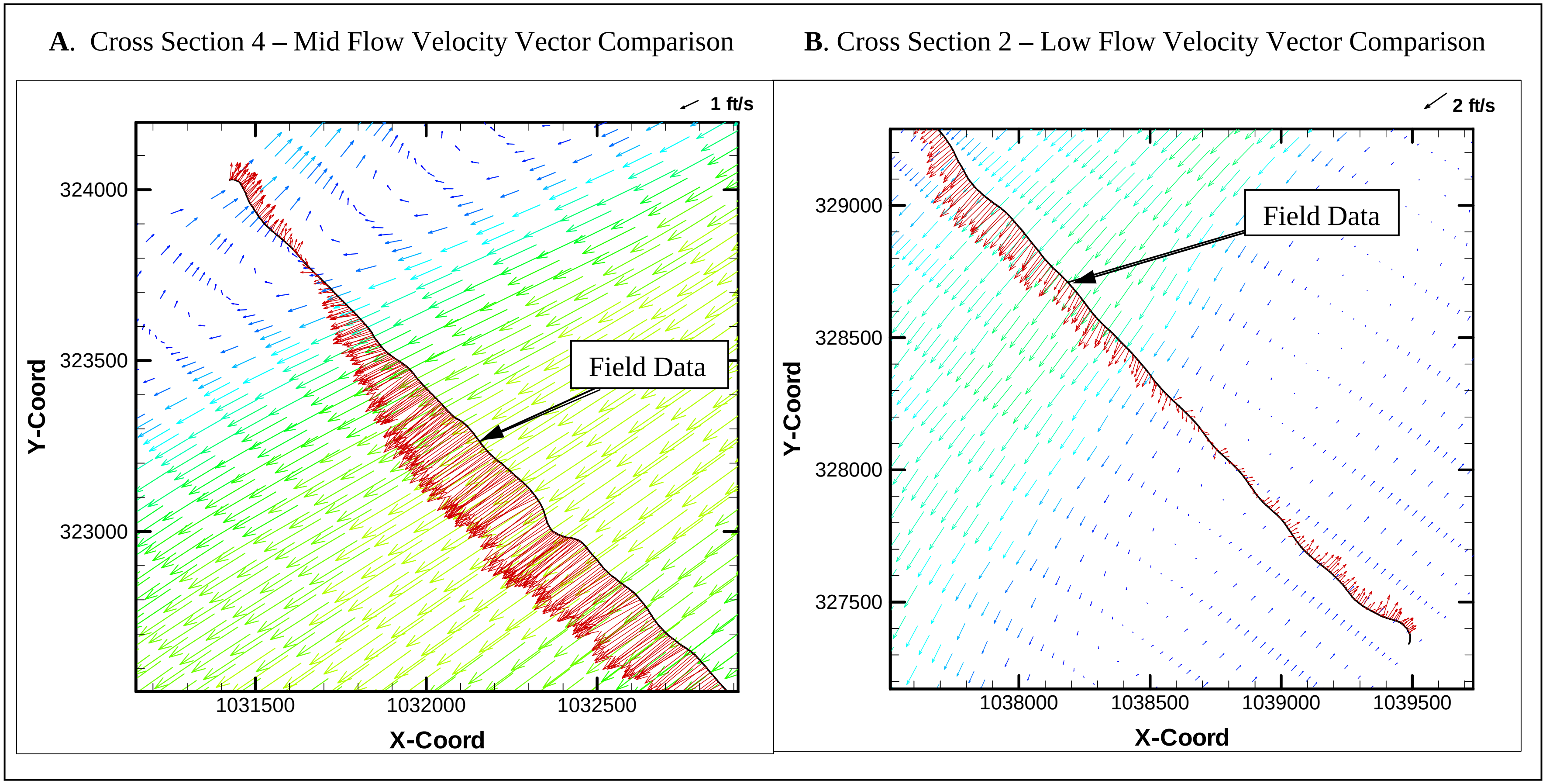

Figure 6. - Field measured and model simulated velocity vectors at cross section 4 during the mid flow and cross section 2 during the low flow, near the Olmsted Locks and Dam construction site.