SIMULATION OF SEDIMENT TRANSPORT AND CHANNEL MORPHOLOGY CHANGE IN LARGE RIVER SYSTEMS

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ABSTRACT

Multi-dimensional sediment transport models are valuable tools for conducting river engineering investigations. Frequently, river engineers are called on to evaluate the impacts of naturally occurring or man-made changes to river systems. These changes may result from altered watershed hydrology or sediment supply, construction of riverine training structures, or channel alterations to support navigation or environmental needs.

Engineering studies are needed to evaluate both spatial and temporal sediment transport and morphology change concerns. An evaluation of short-term channel response in the affected river reach is required for planning and design purposes, while an understanding of long-term channel response is need to predict future project operations and maintenance needs. Traditionally, because of the computational time requirements of multi-dimensional simulations, models are run for relatively short periods of time on relatively short river reaches. Although this provides an indicator of initial channel response, it does not provide an indicator of long-term changes in river morphology. To reduce simulation time requirements, a quasi-steady approach can be undertaken for long-term simulations in large river systems with gradually varying hydrographs. Although riverine sediment transport and hydrodynamics are inherently unsteady in nature, the quasi-steady approach has proven to provide adequate problem resolution for supporting engineering decisions.

A number of river engineering studies are presented that were successfully conducted with CCHE2D (Jia and Wang, 1999; Jia et al. 2002), a two-dimensional hydrodynamic and sediment transport model (Wu, 2001) developed at the National Center for Computational Hydro Sciences and Engineering (NCCHE). These studies demonstrate the model capability for addressing sediment transport problems in the Mississippi and Arkansas Rivers.

1. NTRODUCTION

River Engineering studies typically require some level of river hydrodynamic and sediment transport analysis. For projects that are relatively simple, computer programs that provide an analysis of the hydraulics and sediment transport capacity of a typical river crossection will provide sufficient information for making engineering decisions. For more complex alluvial channels that exhibit

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widely varying channel plan form, morphology, and bed composition, a more rigorous approach is required to evaluate both short and long term channel response. Multi-dimensional hydrodynamic and sediment transport models can potentially provide this level of analysis.

The ideal riverine model should have the following capabilities: 1) provide fully unsteady and steady or quasi-steady simulation capability 2) provide analysis of varying flow regimes from sub-critical to supercritical flow 3) provide a layered bed with bed sorting capability 4) provide multiple grain size analysis capability for both non-cohesive and cohesive sediments 5) provide a selection of sediment transport relationships for both bed, suspended, and total load transport 6) provide a selection of turbulence modeling schemes for enhanced hydrodynamic simulation 7) provide a method for computing the effects of bend way hydrodynamics on sediment transport and 8) provide a suitable interface for mesh generation and visualization of results.

The Engineering Research and Development Center (ERDC) at Waterways Experiment Station (WES) commissioned a survey of existing two dimensional sediment transport models in the year 2002 (Langendoen 2002). The purpose of the survey was to evaluate the state of the art in riverine sediment transport and morphology modeling capability. A number of models were evaluated that were developed both in the United States and other countries. The survey results indicated that the models developed by the National Center for Computational Hydrosciences and Engineering (NCCHE) at the University of Mississippi and the Danish Hydraulics Institute (DHI) had the highest level of capability for addressing riverine sediment transport and morphology change problems. These models were subsequently tested in a side-by-side comparison on a reach of the Mississippi River. The goal of the test simulations was to evaluate capability in predicting general change in channel morphology over a period of time (years) and evaluate the ability of the model to simulate the short and long term impacts of hydraulic structures (dikes). The results of the study indicated that the NCCHE model, CCHE2D, provided the most representative results (Scott 2002). The model has since been applied to numerous complex river engineering studies and has proven to be a valuable tool for aiding the planning and design process for riverine projects.

The following section describes three projects that detail applications of CCHE2D. Project descriptions are provided as well as discussion of general results.

2. APPLICATIONS

The CCHE2D model has been applied to a number of River Engineering projects by the ERDC. The following applications demonstrate model capability for simulating sediment transport and channel morphology change over varying spatial and temporal scales. To simulate long-term simulations of up to and exceeding one year of flow records, the quasi-steady simulation option in CCHE2D has proven to be a useful tool. For large rivers with gradually varying hydrographs, the quasi-steady approach assumes a stepped hydrograph, which assumes steady state conditions exist between each time step in the simulations.

2.1 Catfish Point Reach – Mississippi River

This simulation was conducted to evaluate model capability for reproducing general bed change in a long river reach over a significant period of time. Catfish point is located about 555 miles upstream from the mouth of the Mississippi River. The length of the modeled reach was about 25 miles. The average width at mean flow is about 2500 ft, with a median bed sediment grain size of about 0.30 mm. The reach was chosen for the study because it includes typical channel morphology representative of large alluvial rivers, including a relatively short radius bend way with dikes on the inside point bar and a channel bifurcation at the lower end of the reach (Figure 1).

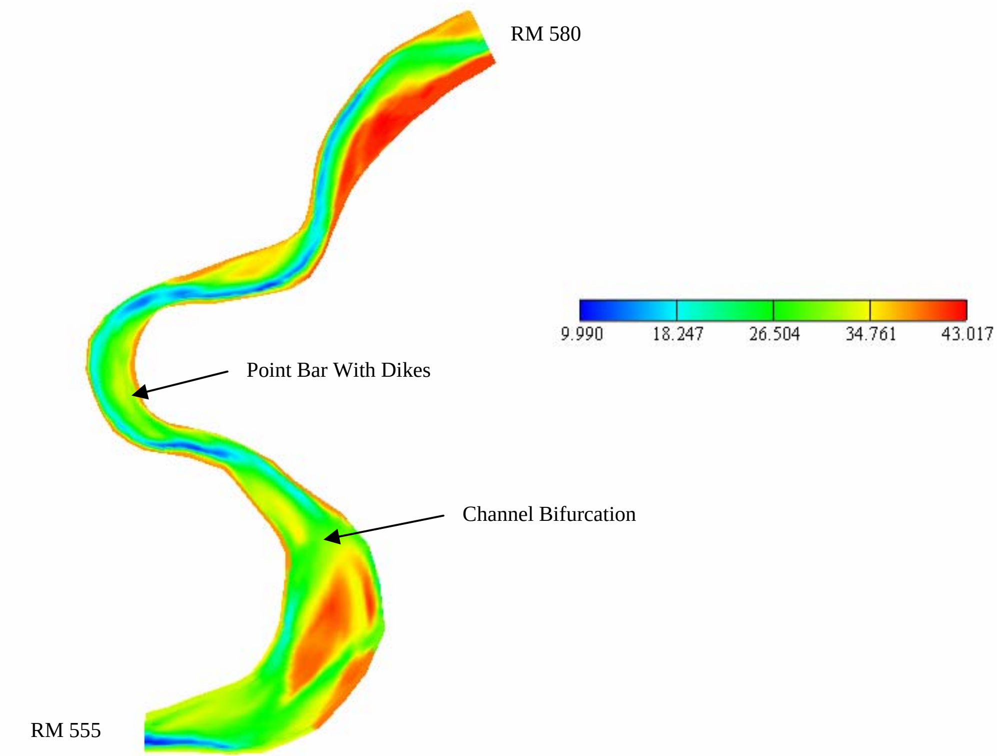

Figure 1. Catfish Point channel features

Two simulations were conducted. The initial model run was to evaluate the ability of the model to compute general morphology change over a three year time period using the quasi-steady simulation. Historical survey data was used to compare to the simulation. The results indicated that

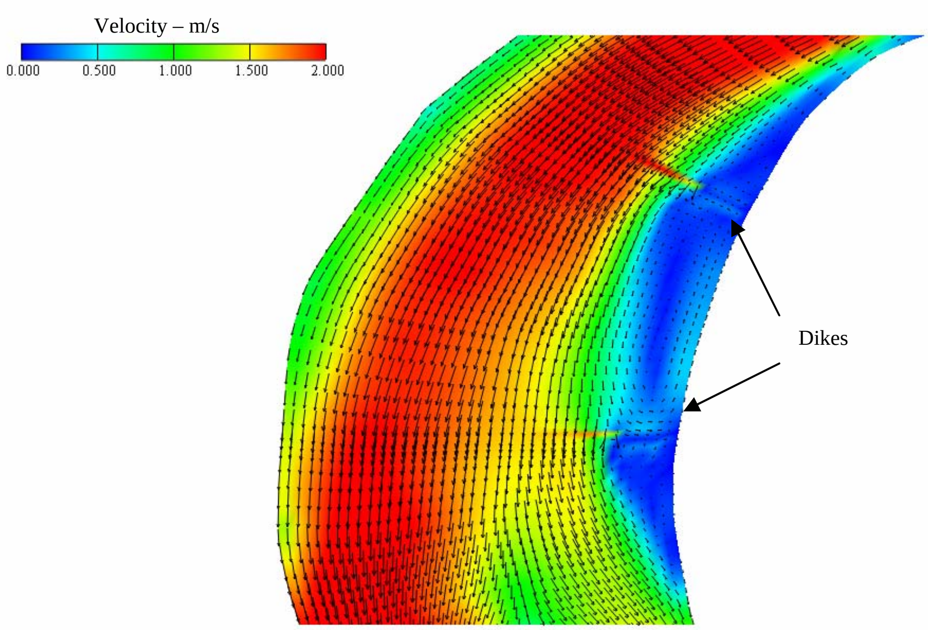

Figure 2. Flow field in vicinity of the Catfish Point dike field

the model provided good spatial delineation of scour and deposition characteristics. Because of bank protection and channel armoring in the bend ways, the scour in the prototype channel bend way was somewhat less than computed by the model.

The second simulation was conducted to evaluate sedimentation in the point bar dike field (Figures 2 and 3). A ten-year period of record flow was simulated. The model adequately predicted the spatial pattern of sedimentation just downstream of the tip of the dike, however, the near-field sedimentation adjacent to the dike was overestimated. The complex flow over and around the dike is three dimensional in nature and cannot be adequately represented by a two dimensional model. However, the model proved useful in defining the far field sedimentation effects of the dikes.

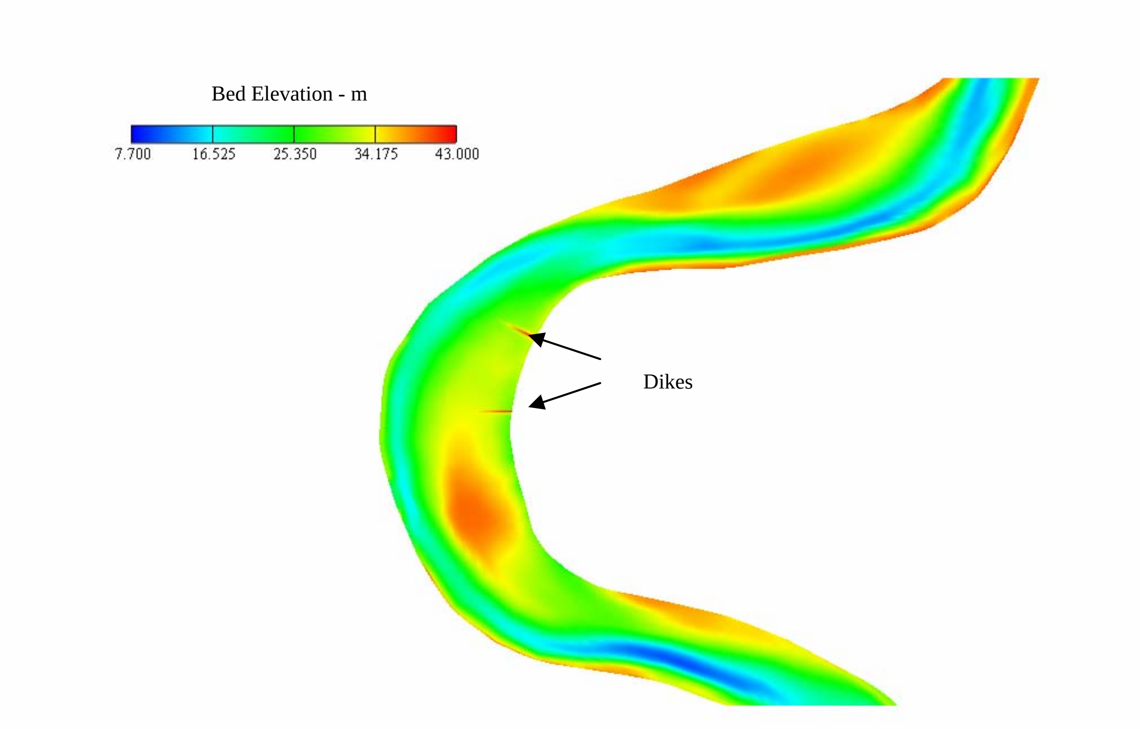

Figure 3. Bed elevation in the vicinity of the Catfish Point dike field

2.2 Redeye Crossing Reach – Mississippi River

The Redeye Crossing Reach is located approximately 220 miles above the mouth of the Mississippi River, about two miles downstream of Baton Rouge Louisiana (Figure 4). The length of the modeled reach is about 5.5 miles, with an average width of about 3000 ft. The sediment size distribution is relatively narrow, with a median grain size of about 0.30 mm. As with many crossings in the Mississippi River, routine dredging is required to maintain a navigable depth. To reduce the dredging quantities, a series of dikes were constructed on the left channel bank just above Missouri Bend. These dikes effectively reduced the dredging frequency, however, a large bar subsequently formed downstream of the dike field. This bar has effectively separated the channel into two distinct branches, a deep and relatively narrow channel on the right bank and a shallow secondary channel adjacent to the left bank. For higher river stages, shallow draft navigation use the secondary channel and deep draft navigation use the narrow deep channel. At river stages below +18.0 ft as referenced from the low water reference plane, both deep and shallow draft vessels must share the deep draft channel, thus increasing the likelihood of vessel collisions.

The New Orleans District of the US Army Corps of Engineers (USACE) commissioned the ERDC to study the use of riverine training structures to reduce the bar elevation to facilitate navigation over the bar area at lower river stages. Two designs were chosen by the District for testing. A longitudinal dike plan and a series of low elevation dikes in the secondary channel were simulated using CCHE2D (Figures 5 and 6). The simulations were conducted over a one-year hydrograph, with a peak flow represented by a bank full discharge (two year return flow).

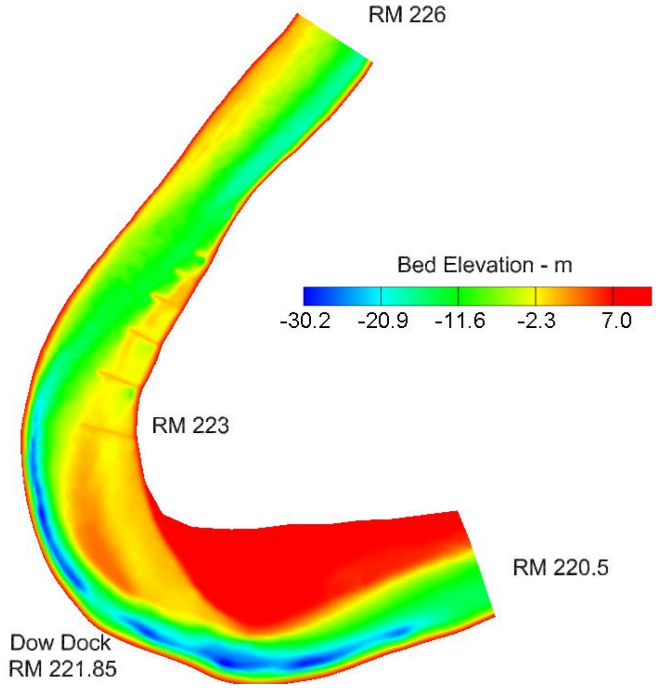

Figure 4. Redeye Crossing dike field

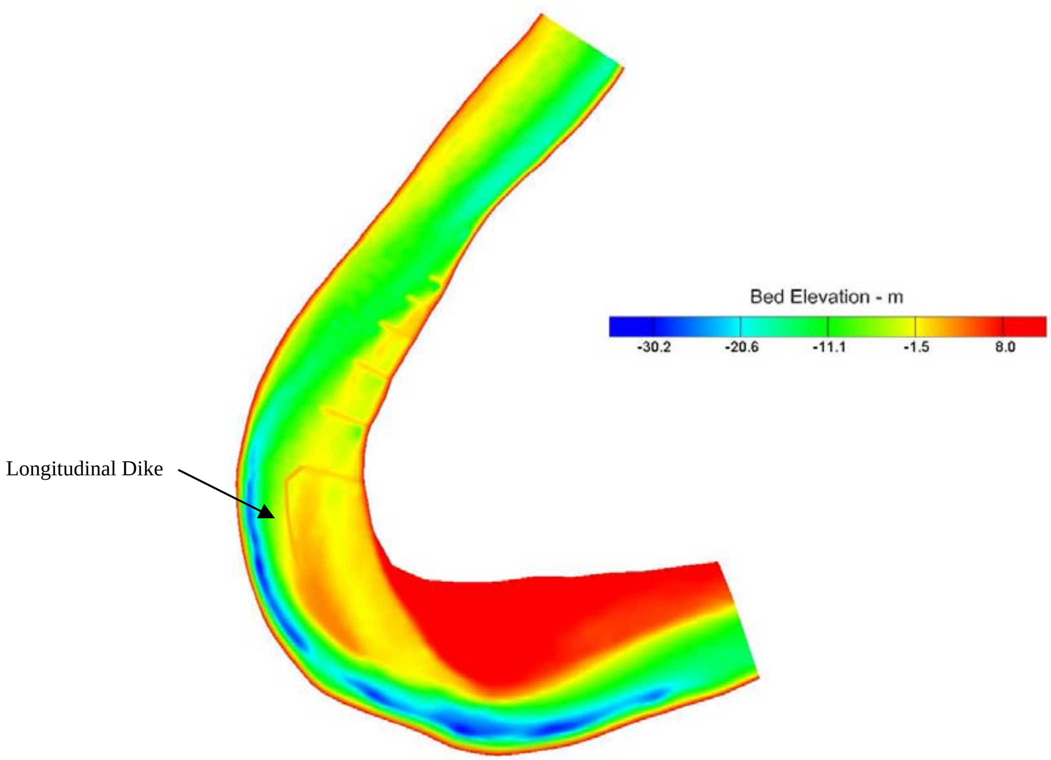

Figure 5. Longitudinal dike plan in Redeye Crossing

Study results indicated that the longitudinal dike plan encouraged further sedimentation of the bar (Figure 7). The secondary channel dike plan was effective in scouring and reducing bar area; however, the fate of the scoured material was the entrance to the secondary channel, thus negatively impacting shallow draft navigation (Figure 8).

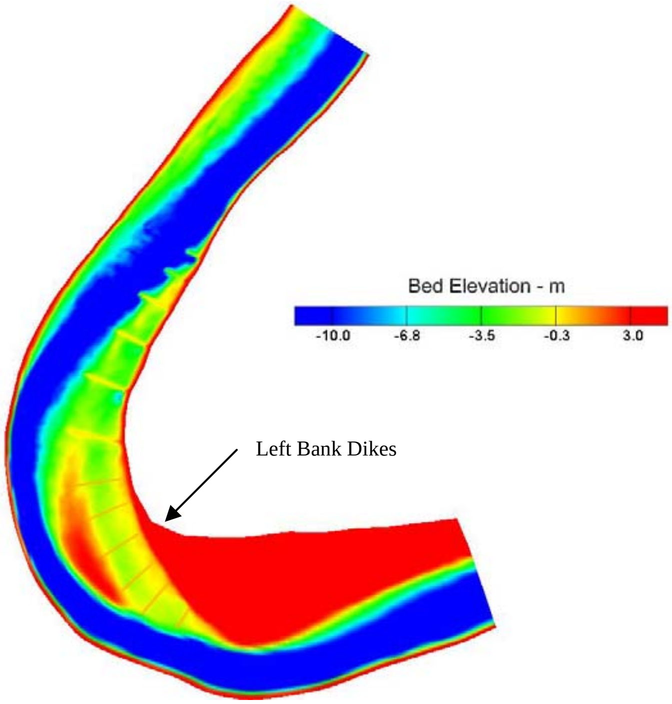

Figure 6. Left bank dike field plan in Redeye Crossing

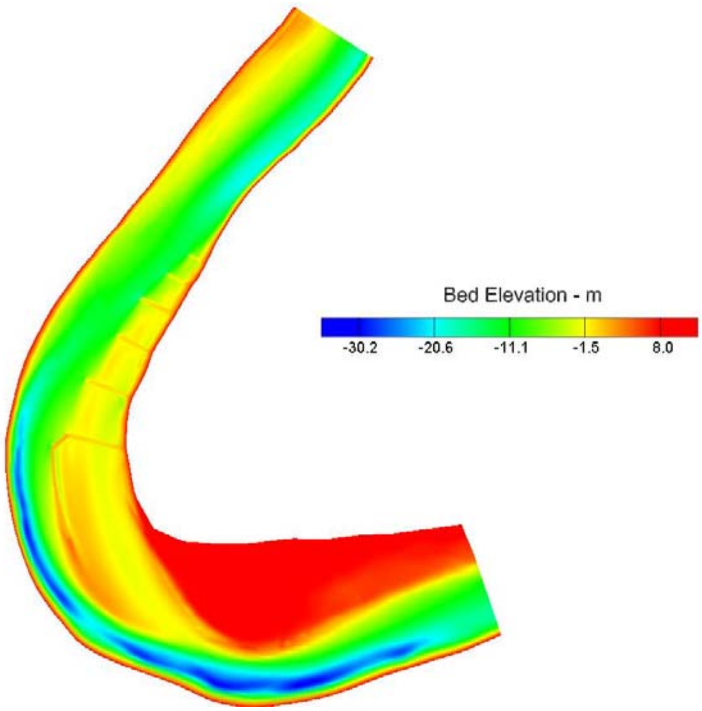

Figure 7. Final bed elevation from the longitudinal dike simulation

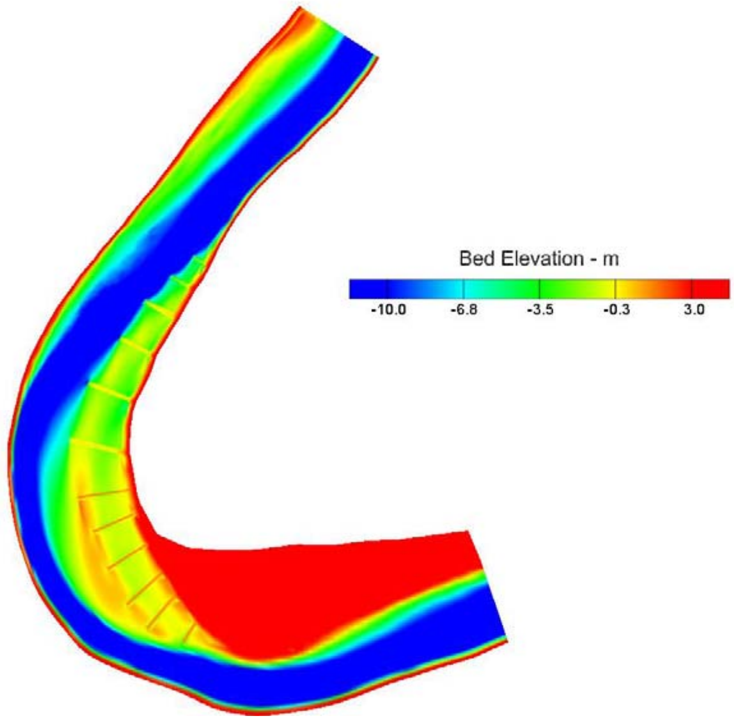

Figure 8. Final bed elevation from the left bank dike field simulation

2.3 Pool 2 – Arkansas River

Navigation on the Arkansas River is controlled by a series of eighteen lock and dam installations known as the McClelland-Kerr River Navigation System. This system spans a distance of 445 miles from the Mississippi River to the head of navigation at Catoosa Oklahoma. A series of navigation pools between the locks must be maintained for navigation. The navigable depth in these pools is maintained by numerous river training structures such as dikes and revetment. Currently, the navigation system requires a minimum of 9.0 feet of navigable depth as referenced to a specific water surface elevation in the pool. Future navigation plans for this system require a 12.0 ft navigable depth. The Little Rock District USACE is considering raising the elevation of existing river training structures to provide the additional three feet of depth.

A feasibility study was conducted by the ERDC to evaluate the impact of raising the elevation of dikes and revetment in Pool 2 in the McClelland-Kerr River Navigation System. The average navigation channel width in Pool 2 is approximately 1000 ft, with a median bed sediment gradation of about 0.35 mm. A CCHE2D model of 15 miles of Pool 2 (Navigation miles 48 – 33) was constructed (Figure 9). Numerous dikes and associated longitudinal revetment were included in the model (Figure 10). The simulations included both bank full discharge (two year return flood flow) and a one-year hydrograph based on flow duration statistics developed from 30-year period of record flows. The goal of the study was to evaluate channel response to raising revetment and dike elevations 5.0 ft in a one-mile reach of the river (navigation mile 44 – 43).

Simulations were conducted for a base model with existing structures and a plan model with structure modifications. The relative results between the base and plan simulations indicated the effectiveness of modifying the structures. Hydrodynamic results for the reach in question show the increase in velocity after the structures were modified (Figures 11 and 12). This results in a subsequent increase in transport capacity through the reach (Figure 13). The increase in channel depth was computed for both the bank full simulations and the one-year quasi-steady simulation (Figure 14). Model results indicated that the scour depth for both the bank full and one-year simulation were similar (approximately 3.0 – 5.0 ft depth). The width of scour was greater for the one-year simulation.

After the dike and revetment modifications were constructed in pool 2, surveys were conducted by the Little Rock District for a series of high flow events. The surveys validated the CCHE2D results within the one-mile test section of pool 2.

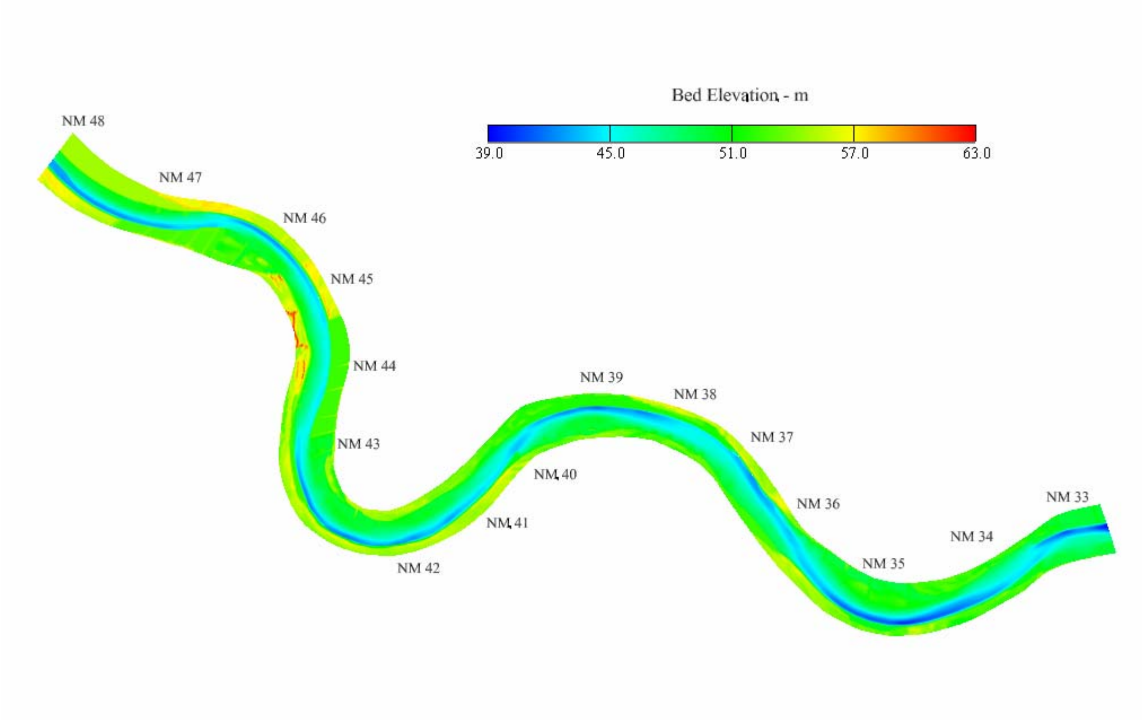

Figure 9. Arkansas River study reach in Pool 2 with designated navigation miles (NM)

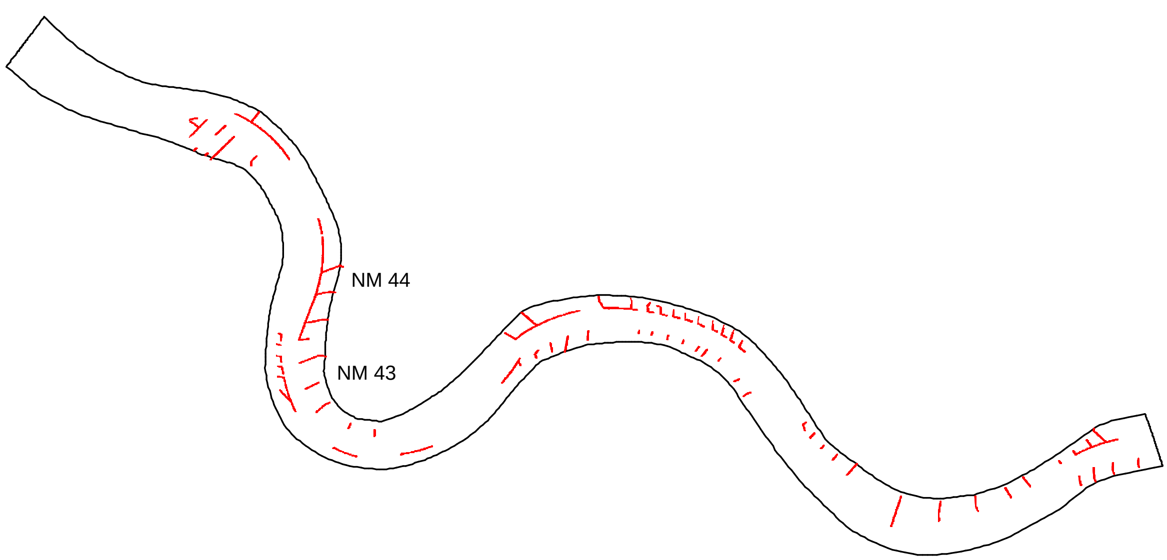

Figure 10. Dike and revetment locations within the study reach

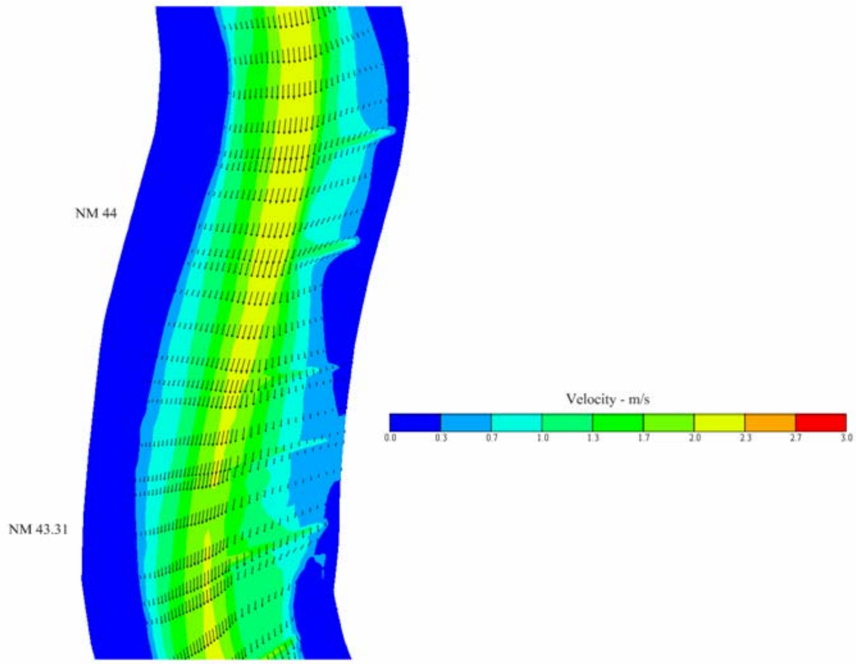

Figure 11. Velocity in the channel thalweg for the existing condition bank full discharge simulation

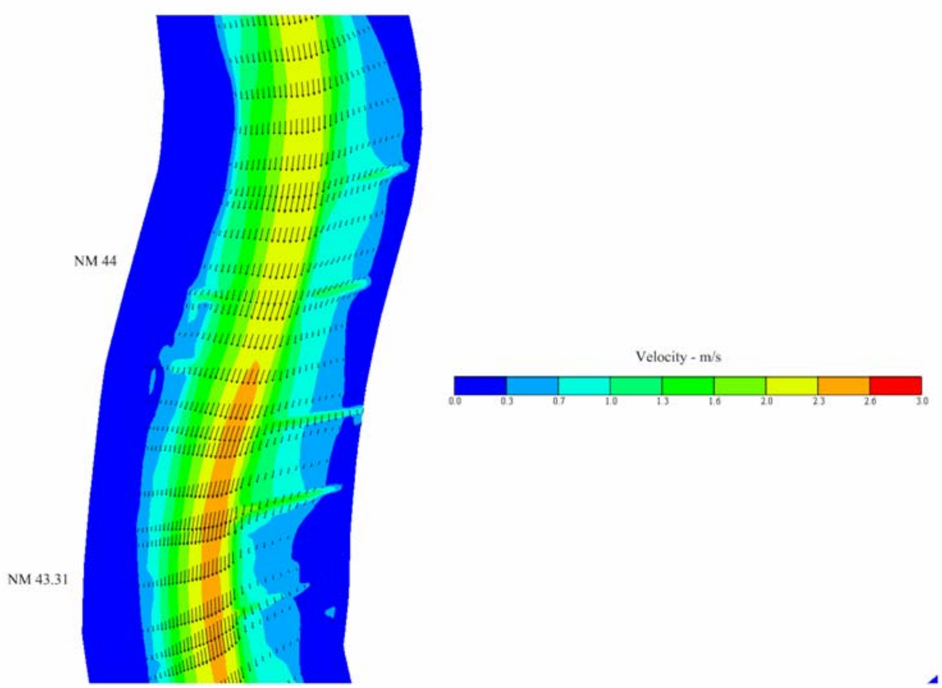

Figure 12. Velocity in the channel thalweg for the modified dike and revetment bank full discharge simulation

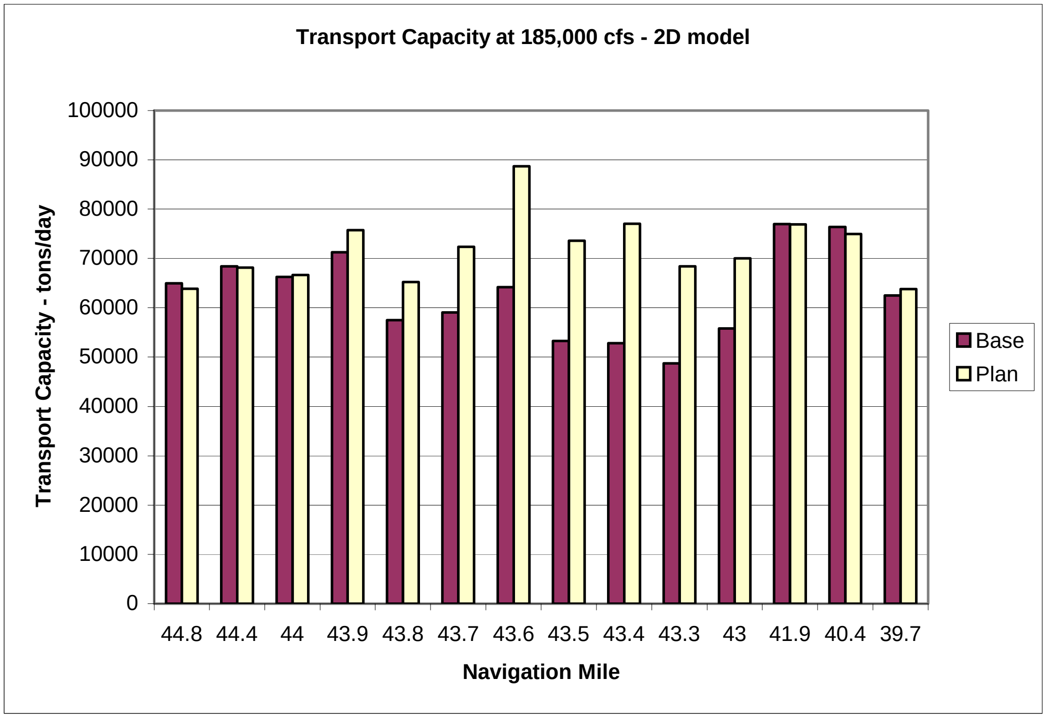

Figure 13. Change in transport capacity through the test section due to modified dike and revetment elevations.

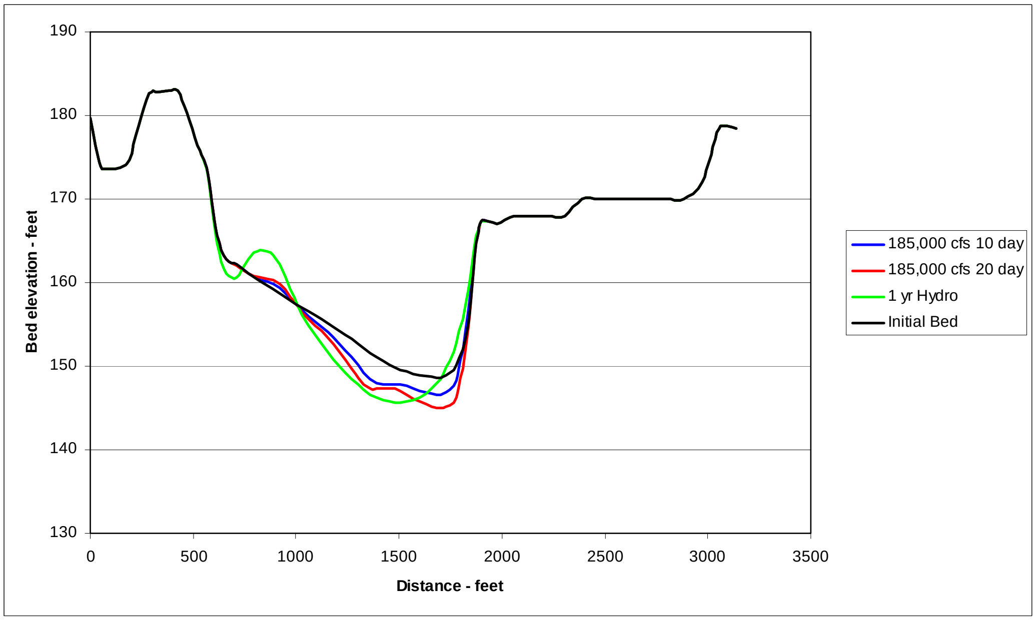

Figure 14. Change in thalweg elevation for the bank full discharge and one year hydrograph simulations – Section 43.6

3. CONCLUSIONS

The CCHE2D model has proven to be a valuable tool for supporting the engineering decision making process on river engineering projects. Both the hydrodynamic and sediment transport model are capable of adequately representing flow and sedimentation characteristics in river reaches containing hydraulic structures and complex channel geometry. Successful applications of this model to simulating large scale river channel flows and sediment transport problems associated with river training structures have indicated the strong applicability of the model to engineering practices. Collaborative efforts between NCCHE and ERDC have resulted in refinement and improvement of the CCHE2D model and will further enhance its capabilities.

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