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Development of Methodology for Predicting Fate of Dredged Material Placed on Riverbanks

PURPOSE: A method of dredged material disposal used by site managers on inland rivers is called mechanical redistribution. This involves initially placing the dredged material on the adjacent banks of the channel where the material is dredged. With the onset of high flows moving down the river, the material is then either pushed back into the stream or is expected to be eroded by the overbank flows. There is a need for a numerical predictive capability for the fate of dredged material disposed in this manner. This technical note (TN) describes such a capability.

BACKGROUND: Dredging and the subsequent disposal of the dredged material occur in most of the nation's inland waterways that are used for commercial navigation. An important aspect in determining the impact of these operations is predicting where and how the disposed material is dispersed and/or deposited after the disposal operation. The initial deposition may take place over a time frame ranging from minutes to hours. A second major consideration is the longer-term sediment movement patterns (over a time frame of perhaps days or months) in or near the disposal sites and waterways.

One method of dredged material disposal that is sometimes used on inland waterways involves the placement of the dredged material along the banks of the waterway. During high-water periods, these sediments are then either swept back into the stream by the water currents or mechanically pushed into the waterway. This type of dredged material disposal is often referred to as mechanical redistribution. The basic assumption in this operation is that the currents generated by the high-water flows will sweep the previously dredged sediments downstream and away from the location where they were dredged. Numerical prediction tools are required to adequately assess if the sediments moving from the riverbank back into the stream are indeed transported away from the dredging site or if in reality they are redeposited and remain at the dredging site. For those sediments that are transported away from the placement site, the path and fate of the sediments should be known.

To provide such a prediction tool, a three-dimensional model called CH3D-SED has been used for simulating the movement of dredged material disposed on riverbanks and the subsequent fate of that material. Due to the complex pattern of currents that often exist in natural riverine environments, i.e., the secondary currents in river bendways, a three-dimensional numerical approach is required. The methodology has been demonstrated by an application to a disposal operation involving dredged sediments from the Corley Slough reach in the Apalachicola River.

MODELING FRAMEWORK – CH3D-SED: As previously noted, the numerical model CH3D-SED was used for developing a capability to predict the fate of dredged material disposed by mechanical redistribution. A brief discussion of the theoretical aspects of CH3D-SED follows. Details concerning CH3-D can be found in Johnson et al. (1991).

As its name implies, CH3D-SED (Curvilinear Hydrodynamics in 3 Dimensions with SEDiment) makes computations on a curvilinear boundary-fitted planform grid. Physical processes that are modeled which impact circulation and vertical mixing in a wide range of water bodies include tides, wind, density effects (salinity, temperature, and suspended sediment), freshwater inflows, turbulence, and the effect of the earth's rotation. The boundary-fitted coordinate feature of the model in the horizontal dimensions provides grid resolution enhancement necessary to adequately represent navigation channels and irregular shoreline configurations of the water body.

The governing partial differential equations that are solved represent the conservation of momentum of the flow field, conservation of water volume, conservation of heat, conservation of salt, and conservation of suspended sediment, along with an equation of state relating the water density to the salinity, temperature, and suspended sediment. In applications where salinity and temperature are not important, computations are not made for those variables. Basic assumptions that are made in the conservation of momentum equations are that the water pressure is assumed to be hydrostatic and that the eddy viscosity approach adequately describes turbulent mixing in the flow.

Sedimentation computations are based on a two-dimensional solution of the conservation of mass equation for the channel bed, i.e., the Exner equation (Simons and Senturk 1992), and the three-dimensional conservation equation for suspended sediment transport. The sediment bed is assumed to be composed of several layers, including an active layer on the top (Figure 1).

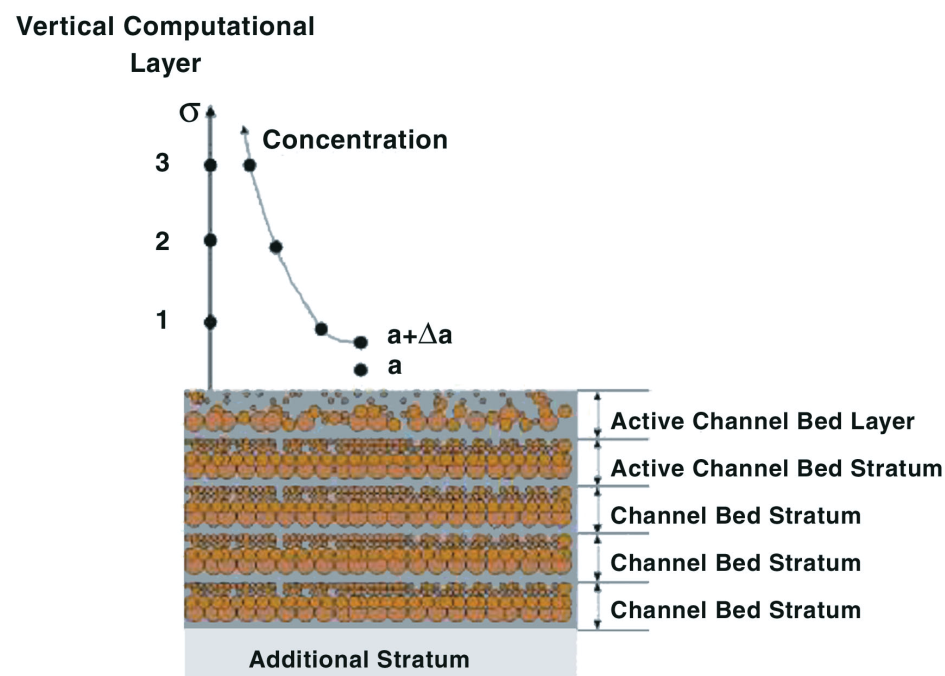

Figure 1. Sediment bed structure

The active layer description and hiding effects due to nonuniform bed material gradation, along with the manner in which sediment moves among the bed layers illustrated in Figure 1 are described in Spasojevic and Holly (1994). A unique feature of the mobile bed model, CH3D-SED, is the allocation of bed material transport as either bed load or suspended load. The sediment transport algorithms independently account for the movement of sediment as either bed load or suspended load, and also allow for the exchange of sediment between these two modes of transport. The bed-load flux predictor, as well as the relationship which relates the suspended load to the total load (bed load plus suspended load), was developed by Van Rijn (1984a, b).

In summary, CH3D-SED is a generalized model for applications with mixed grain-size sediments, with appropriate bed material sorting and armoring routines. Thus, it is well suited for computing the fate of the dredged material disposed by mechanical redistribution. However, a major consideration in the development of a capability for predicting the fate of bank disposed material concerns the simulation of the mechanical redistribution operation itself.

Numerical Representation of On-Bank Disposal. As previously stated, the dredged material is stacked at the disposal site near the river's edge. This material is often then pushed into the river using bulldozers when river stages are forecast to rise for extended periods. Depending on the amount of material, the entire operation can take on the order of days. To simulate this activity, CH3D-SED was applied in the following way. In the computational cells adjacent to a riverbank, the boundary condition is normally no flow across the boundary. Thus, the normal component of the flow velocity is zero. However, in those cells adjacent to a specified bank disposal site the model was modified to accept a hypothetical water inflow, resulting in the computation of a non-zero normal component of flow velocity. A sediment concentration was then attached to this lateral flow.

The sediment concentration specified for a particular mechanical redistribution operation is determined in the following manner. First, an inflowing water and sediment boundary is placed at the area of mechanical redistribution, with a low value selected for the flow (Q) at the boundary so that it has negligible influence on the stream flow. For the sediment boundary condition, a concentration in parts per million (ppm) must be calculated. This is done by using the following equation:

$$V \text{ (100 lb/ft}^3\text{) (27 ft}^3\text{/1 yd) (1 ton/2000 lbs) = tons}$$

where V is the volume to be moved in cubic yards, and 100 lb/ft^3 is the assumed unit weight of sand. Next, the value in tons is divided by the number of days mechanical redistribution will take place to yield tons/day. To convert tons/day to ppm, the following equation is used:

$$\text{ppm} = (\text{tons/day})/(0.0027(Q))$$

where Q is in cubic feet per second and 0.0027 is a conversion factor. The sediment concentration in ppm is then specified as the sediment inflowing boundary condition.

Because the ultimate fate of material disposed in the river depends on the capacity of the river to transport sediment, simulation of such an operation must also include the transport of sediment naturally occurring in the river. Thus, to be able to distinguish the disposed material from the naturally occurring material moving down the river, the disposal material is classified as a separate sediment class. Of course, in many cases the same sediment characteristics are prescribed for the disposal material as for the in-river material.

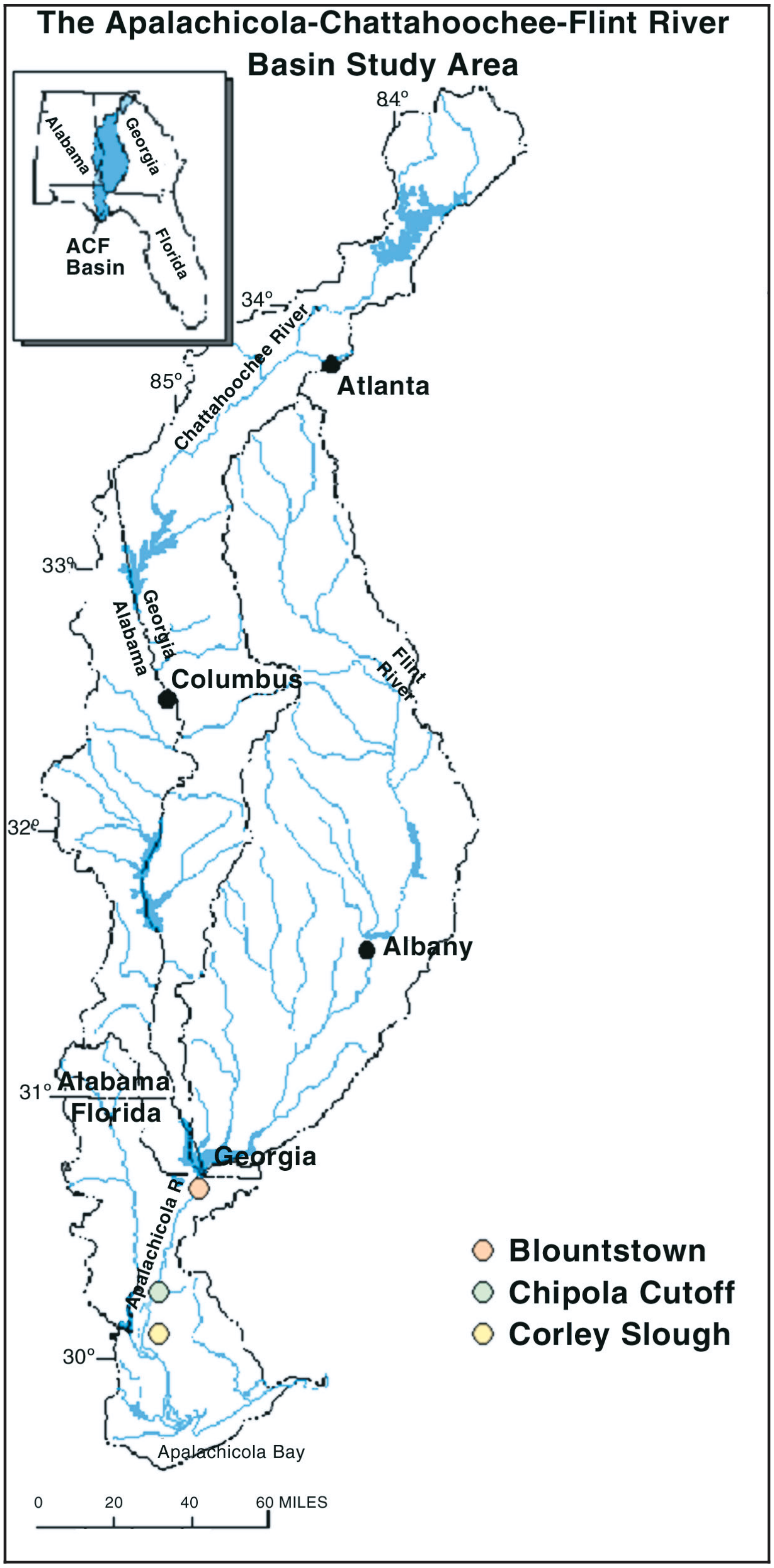

Figure 2. Apalachicola-Chattahoochee-Flint Waterway drainage basin

Description of the Demonstration Site. The Apalachicola River (Figure 2) is formed by the confluence of the Chattahoochee and Flint Rivers. The drainage basin encompasses 19,200 square miles in Georgia, Alabama, and Florida. The Apalachicola River is part of a navigation system known as the Apalachicola-Chattahoochee-Flint (ACF) Waterway. It was authorized in the River and Harbors Act of 1945 (amended in 1946) and called for construction of a 9-ft deep by 100-ft wide navigation channel. The navigation channel was initially dredged in 1958 to provide adequate depths. Since then annual dredging has been required to maintain the project. The majority of the dredging occurs within three problem reaches of the river, namely, Blountstown (navigation mile, NM 76-81), Chipola Cutoff (NM 39-42), and Corley Slough (NM 35-37) as shown in Figure 2.

In 1987, mechanical redistribution was first used to manage the limited capacity of Disposal Site 43 (NM 37) (see Figure 3). Mechanical redistribution is accomplished by regrading the dredged material placed on the bank at Site 43. This practice may include reshaping of the within bank disposal site in preparation for mechanical redistribution by stacking the material on the site adjacent to the river's edge. Bulldozers are then used to push the material into the river when river stages are forecast to rise for extended flow events. Mechanical redistribution is normally scheduled to occur in the late fall and winter months prior to the onset of sustained high flows over the winter and spring. The goal of mechanical redistribution is to utilize the natural sediment transport capabilities of the river to restore additional capacity to the within bank disposal site prior to the next dredging season.

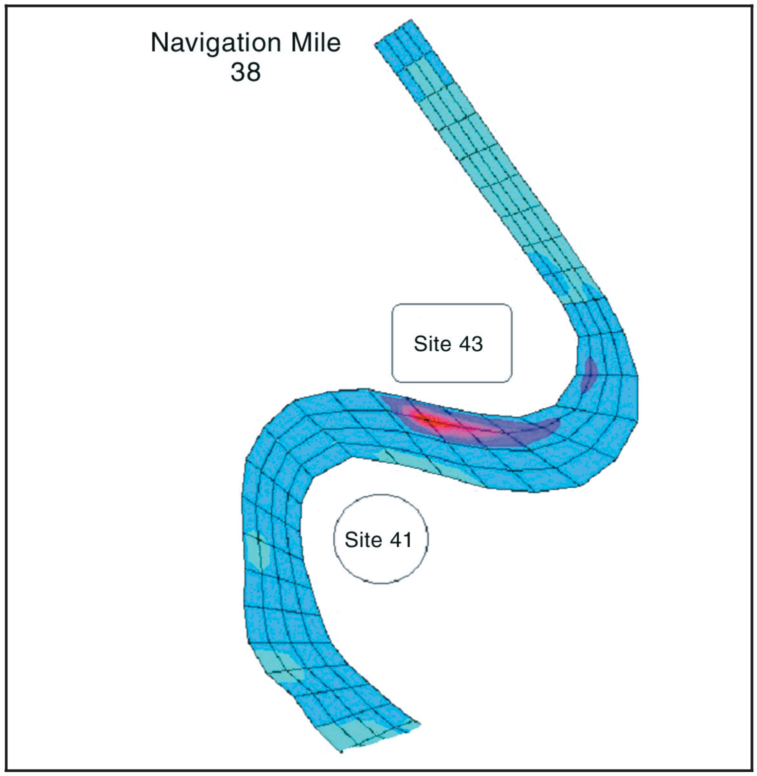

Figure 3. Site map of disposal Sites 43 and 41

Data Requirements. Basic data required in the model include water depths prescribed on the computational grid, the initial state of the system, and upstream and downstream boundary conditions. The channel geometry for the existing condition was obtained from the 1998 hydrographic survey performed by the U.S. Army Engineer District, Mobile. The alignment for the navigation channel was determined using the channel depths reported in the hydrographic survey and dredging records.

In addition to accurate geometric representation of the domain, appropriate hydraulic data and sediment concentrations must be prescribed at the inflow and outflow boundaries. At every location where water enters or exits the computational domain either the stage or discharge must be specified along with the suspended sediment concentration of the inflowing water and the grain-size distribution for the material entering those cells. Model boundary conditions were based primarily on historical data collected on the river.

For this application, a discharge was specified at the upstream boundary and a stage was specified at the downstream boundary. At the downstream end of the model the stage was determined using the U.S. Geological Survey (USGS) gauge records from October 1989 to September 1998.

The upstream discharge was based upon a historical annual average hydrograph (Figure 4). The U.S. Army Corps of Engineers also provided the flow going into the Chipola Cutoff (Figure 2) located above the upstream boundary of the model. The flows from the Bluntstown hydrograph were then reduced by the Chipola Cutoff flow to acquire the flow just above Corley Slough.

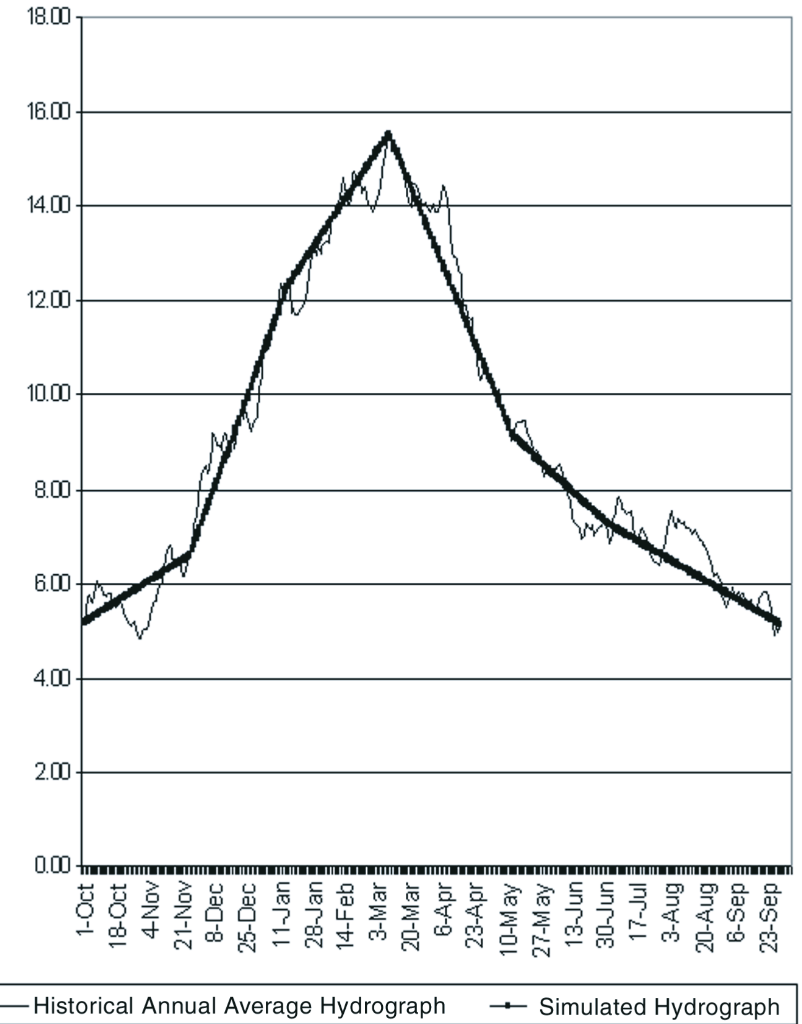

Figure 4. Historical annual average hydrograph at Blountstown

The suspended sediment concentration must also be specified at every location where water enters the computational domain. Sediment concentrations are specified for each size fraction for each cell in the water column at inflow locations, i.e., a vertical sediment concentration profile is described. The inflowing suspended sediment concentration and the grain-size distribution at the upstream boundary were based on data collected in May 1998 by the Mobile District. These data collected from 2 May 1998, which was the day before mechanical redistribution, through 5 May 1998 included discharge measurements, suspended sediment samples, and bed material samples. A summary of the suspended sediment data is shown in Table 1. The analysis from the samples showed that 85 percent of the sand consisted of fine sand and 10 percent consisted of medium sand, with the remaining 5 percent consisting primarily of silt and clay. Based on the data collected at NM 37.8, the inflow concentration was set at 30 ppm for fine sand and 10 ppm for medium sand. The grain-size distribution for the bed material in the river must also be specified. Three grain sizes were used to represent the bed material in the model. A fourth grain size was used to represent the dredged material disposed by mechanical redistribution at Site 43. Sediment data were collected in 1999 from Site 43 to determine the grain size of the material being mechanically redistributed, whereas, the grain-size distribution for the bed material was determined from bed samples taken from the May 1998 data collection previously mentioned. The composition of the suspended concentration and the composition of the bed material that were used in the model are listed in Table 1.

Table 1
Grain Sizes Used in Apalachicola Model

Lower Size Particle Diameter (mm)	Upper Size Particle Diameter (mm)	Geometric Mean Particle Diameter (mm)	Inflowing Suspended Sediment Concentration (ppm)	Percentage of Bed Material
0.5	1.0	0.707	0	35
0.25	0.5	0.354	10	51
0.125	0.25	0.177	30	14
Dredged material placed at Sites 41 and 43		0.355		100

Numerical Grid. To develop an adequate computational model it is important to select an appropriate level of grid discretization. Adequate resolution should yield sufficiently accurate results while producing a model that minimizes computational requirements. Preliminary calculations were made to determine an adequate discretization level for the Corley Slough model that resulted in computed results that compared well with observed data when proper values for model parameters were selected. The final grid selected is presented in Figure 5.

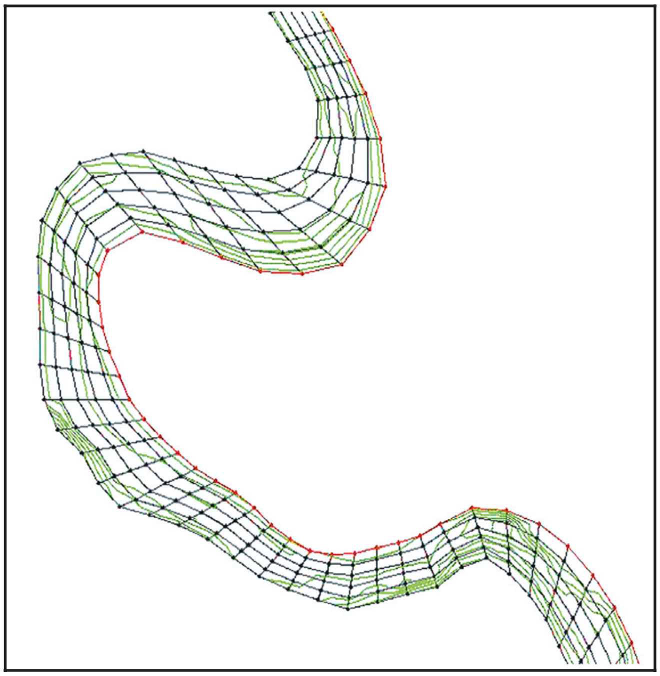

Figure 5. Grid 4 (233 cells long by 5 cells wide) from NM 34 to NM 37, colored lines represent channel bathymetry contours

Model Validation. The only data available for validation of the computed hydrodynamics were water surface elevations at the upstream end of the model (Table 2). Recall that the water discharge is specified at the upstream end with the water surface elevation then computed from the conservation of volume equation. It is realized the validation results (Table 2) do not constitute a full validation of the hydrodynamics. However, the good validation achieved in the sediment computations, shown in Figures 6-7, implies that the hydrodynamics are adequate.

Table 2
Water Surface Elevation Validation

Flow Rate (cfs)	Computed Stage RM 38.5	Observed Stage RM 38.5
10,039	10.66	10.76
17,558	14.72	14.70
23,518	16.79	16.76
15,000*	13.58	13.57

* 15,000-cfs flow represents the flow used to model the May 1998 event.

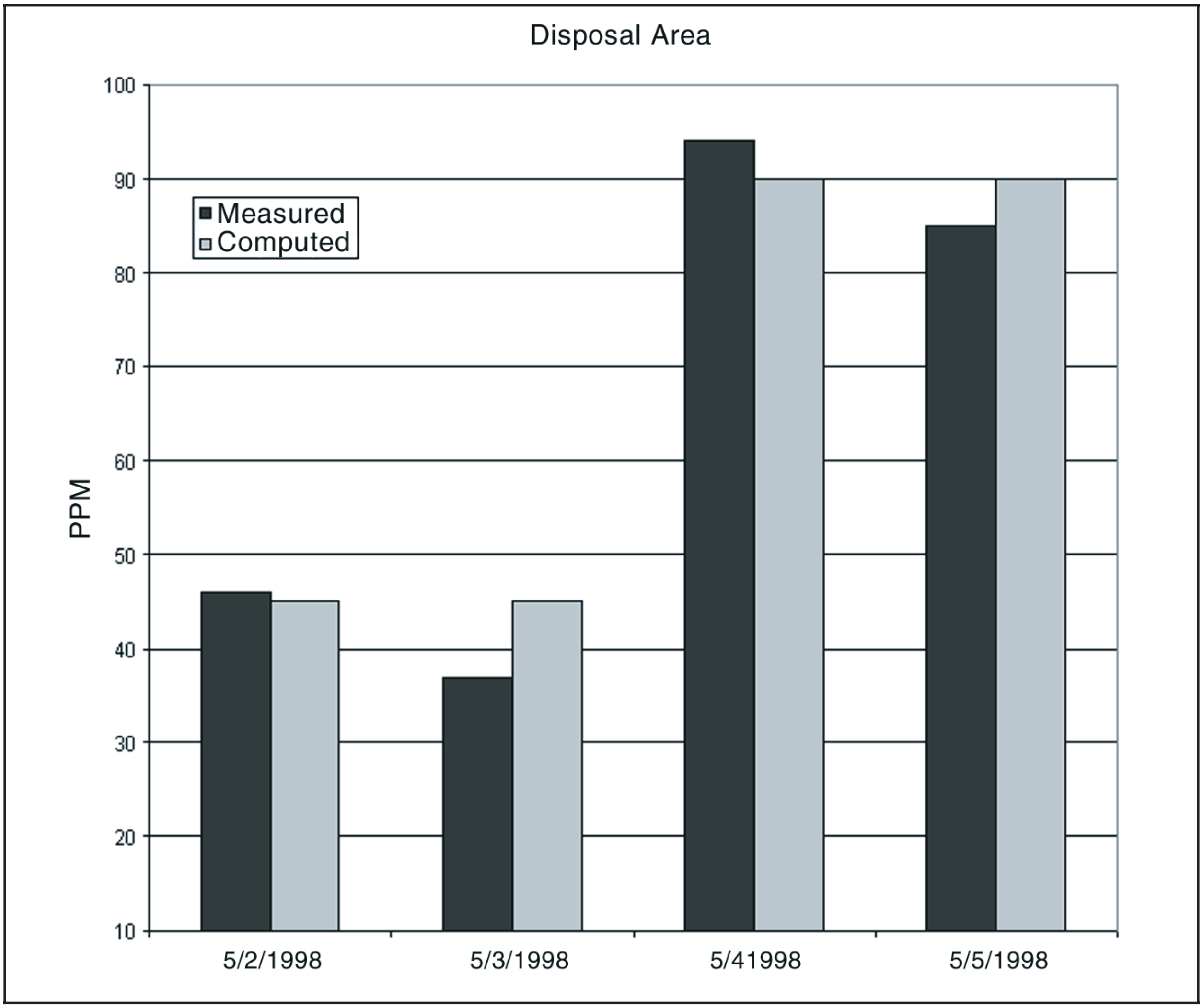

Figure 6. Comparisons of suspended sediment concentration at disposal area

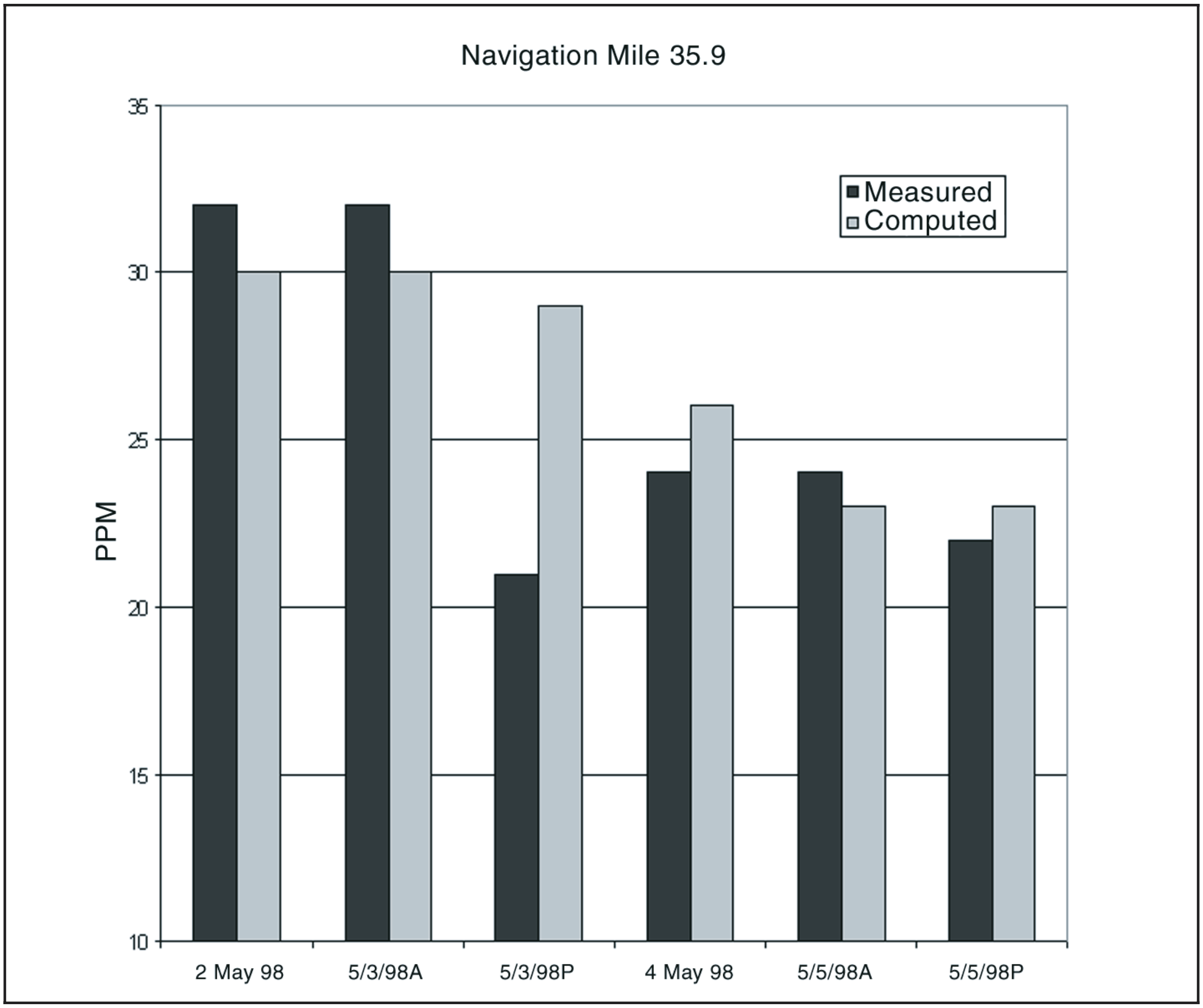

Figure 7. Comparisons of suspended sediment concentration at NM 35.9

With the numerical model considered to be an adequate representation of the hydrodynamics and sediment transport in Corley Slough, it was then applied to demonstrate the methodology for predicting the fate of dredged material disposed by mechanical redistribution.

SIMULATIONS OF BANK PLACEMENT: Mechanical redistribution was first used in 1987 to manage the limited capacity of disposal Site 43 on the Apalachicola River. The mechanical redistribution usually occurs in the late fall and winter months prior to the onset of sustained high flows during the winter and spring months. Three different bank disposal scenarios at Corley Slough (NM 35-37) have been modeled. Each is discussed in the following paragraphs before presenting model results. Figure 8 shows the location of Corley Slough, key river miles, and the area of mechanical redistribution.

Scenario 1 - Mechanical redistribution of 30,000 cu yd of dredged material occurred at Site 43, with disposal Site 41 receiving approximately 18,000 cu yd. Under this scenario, no mechanical redistribution occurs at Site 41. However, the edges of this site naturally erode. The height of material placed on Site 43 is limited to approximately +8.6 ft on the dredging reference gauge (dredging reference elevation is 9.22 ft msl) prior to mechanical redistribution. This represents the height limit imposed by the current State Water Quality Certification.

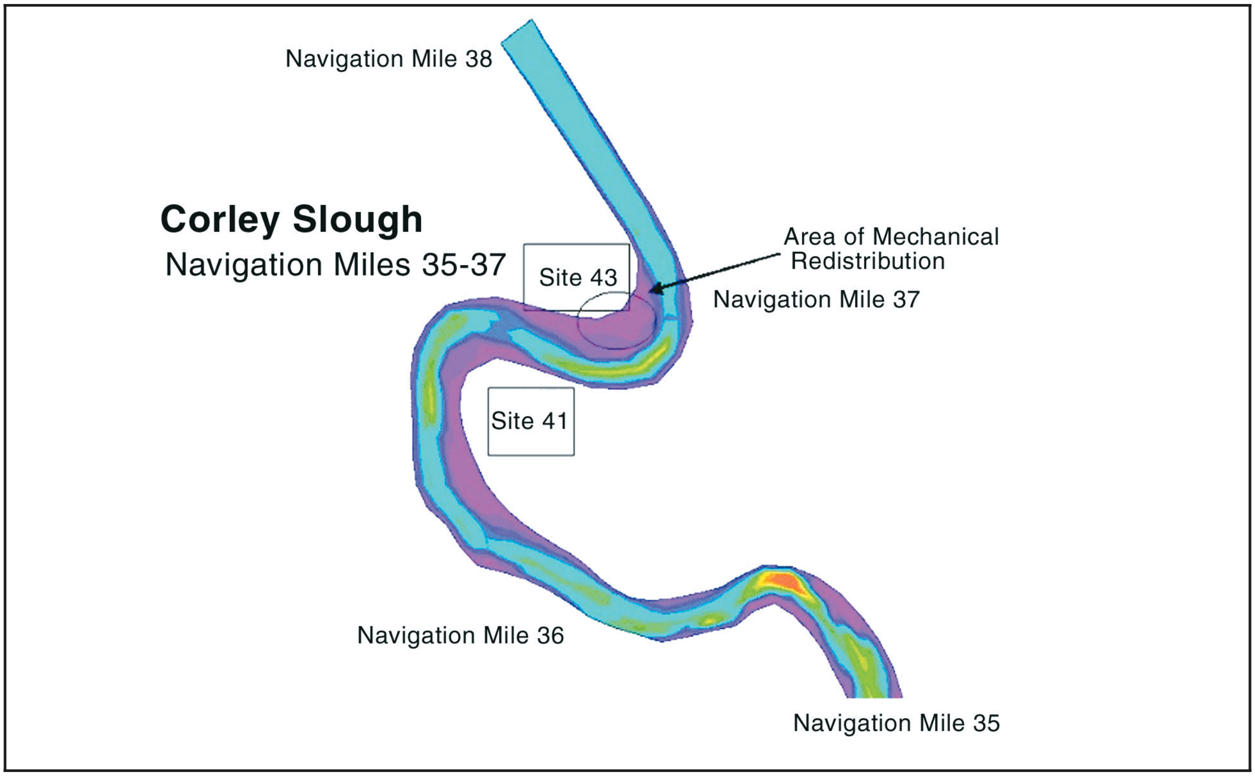

Figure 8. Site map of Corley Slough

Scenario 2 - In this scenario, disposal Sites 41 and 43 received the current estimated dredging quantities normally removed from the Corley Slough reach. Records from the last few years show that approximately 50,000 cu yd are normally placed on Site 41 and approximately 100,000 cu yd are normally placed on Site 43. This result in material placed on Site 43 accumulating to an elevation of approximately +14 ft on the dredging reference gauge. As in Scenario 1, the 100,000 cu yd of dredged material placed on Site 43 were mechanically redistributed, but no mechanical redistribution occurred at Site 41.

Scenario 3 - Scenario 3 assumed that dredging of the Federal Project Channel takes place, but no material was placed on Sites 41 or 43. Thus, dredged material was assumed being placed at a location away from the river, e.g., upland.

Simulation Results - To account for the material placed on Sites 41 and 43, the bottom elevation was increased at those areas in the computational grid. As previously described, mechanical redistribution was accomplished by the specification of a sediment boundary condition attached to an inflow of 600 cfs at Site 43. This flow is about 4 percent of the riverflow during the period of mechanical redistribution. A comparison of the magnitude of the flow velocity at a point near the location of mechanical redistribution showed a value of 2.24 fps without mechanical redistribution and a value of 2.26 fps with mechanical redistribution. Modeling also included the contribution of highly erosive banks in the reach. The contribution of the sediment from these locations was accounted for by allowing the banks in these areas of the model to erode. This was accomplished by assuming that the sediment in the bed at these bank areas had different sediment characteristics than the sediment in the main channel.

Each scenario was run for 1 year, with mechanical redistribution initiated on Day 88 for Scenarios 1 and 2. Disposal of the bank material at Site 43 continued for 7 days in Scenario 1 and for 14 days in Scenario 2. During mechanical redistribution at Site 43, the concentration of disposal material was 3,125 ppm in Scenario 1 and 5,952 ppm in Scenario 2.

During Days 88-96, mechanical redistribution occurred in both Scenarios 1 and 2, although, as previously noted, at different rates. As the material is injected into the model cells covering Site 43, some of the material immediately settles and is redeposited at the site with the remaining material transported away from the site. Very little difference can be seen in the bed elevation changes plotted in Figures 9-11 for the three scenarios. Figures 12 and 13 show the higher suspended sediment concentration resulting from mechanical redistribution at Site 43. Note that before the onset of redistribution background concentrations are about 10 ppm, whereas, during redistribution, maximum concentrations of about 40-50 ppm are computed. Though difficult to see at the scale of the figures in the report, these plots also show that the suspended concentrations are higher for Scenario 2 due to the larger amount of material being injected into the river.

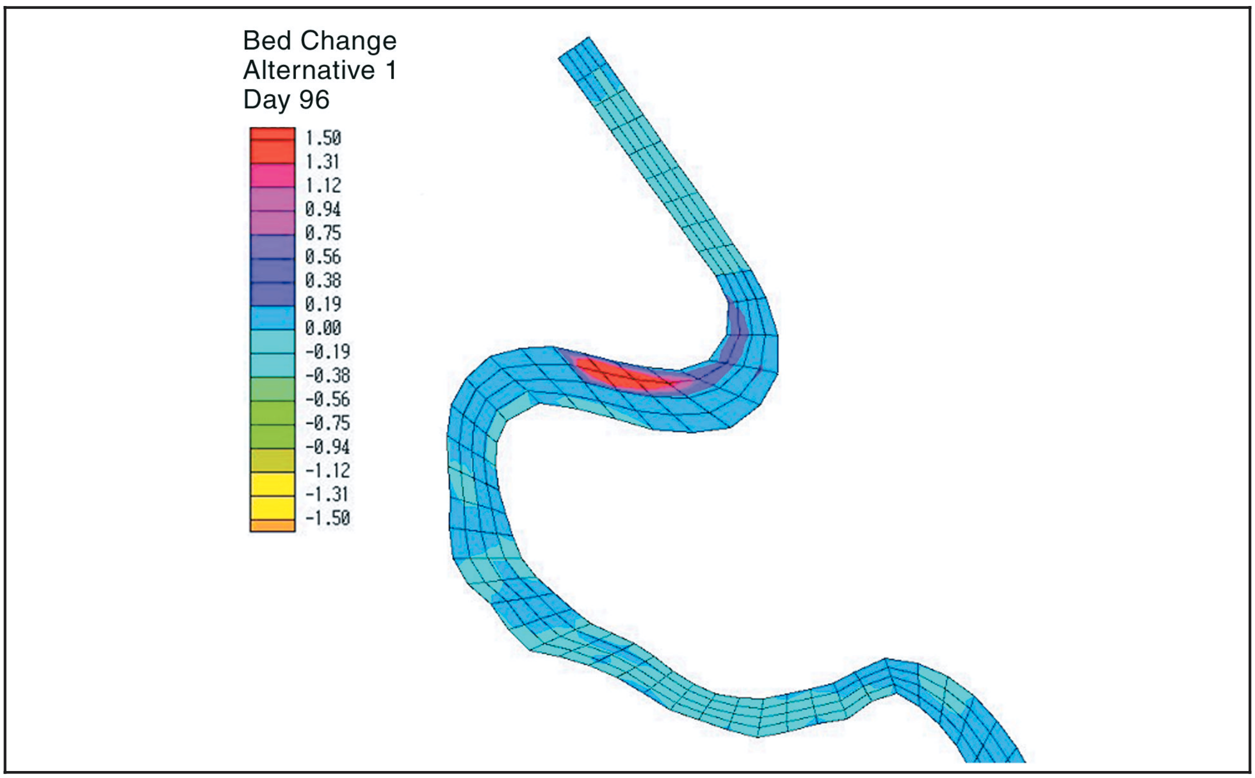

Figure 9. Scenario 1 bed elevation (ft) change on Day 96 (Q = 15,600 cfs)

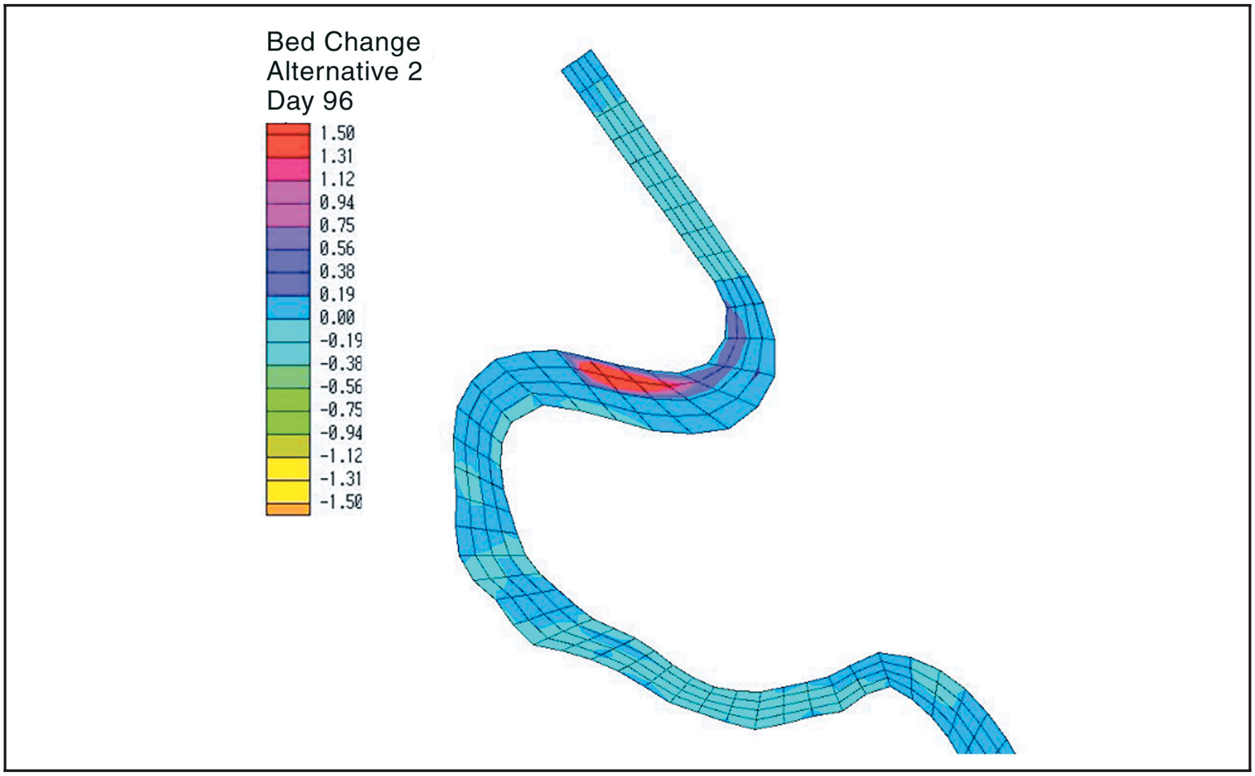

Figure 10. Scenario 2 bed elevation (ft) change on Day 96 (*Q* = 15,600 cfs)

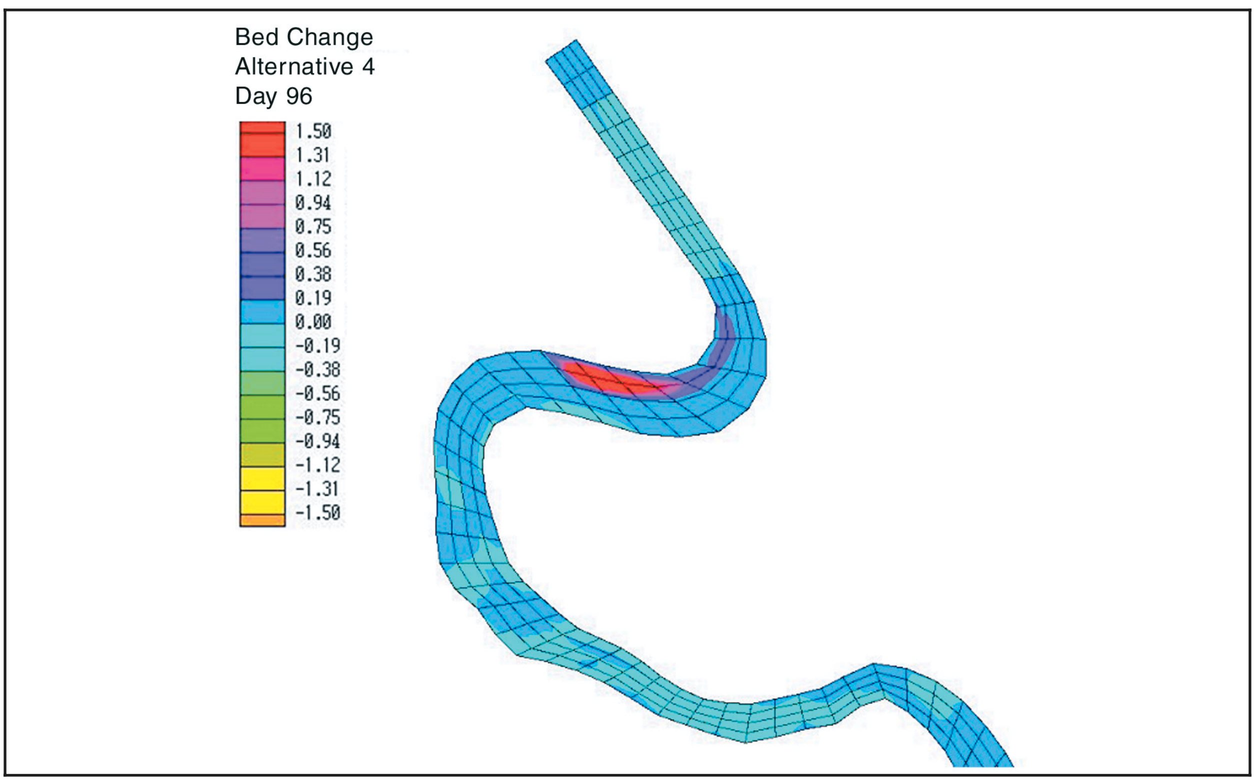

Figure 11. Scenario 3 bed change on Day 96 (*Q* = 15,600 cfs)

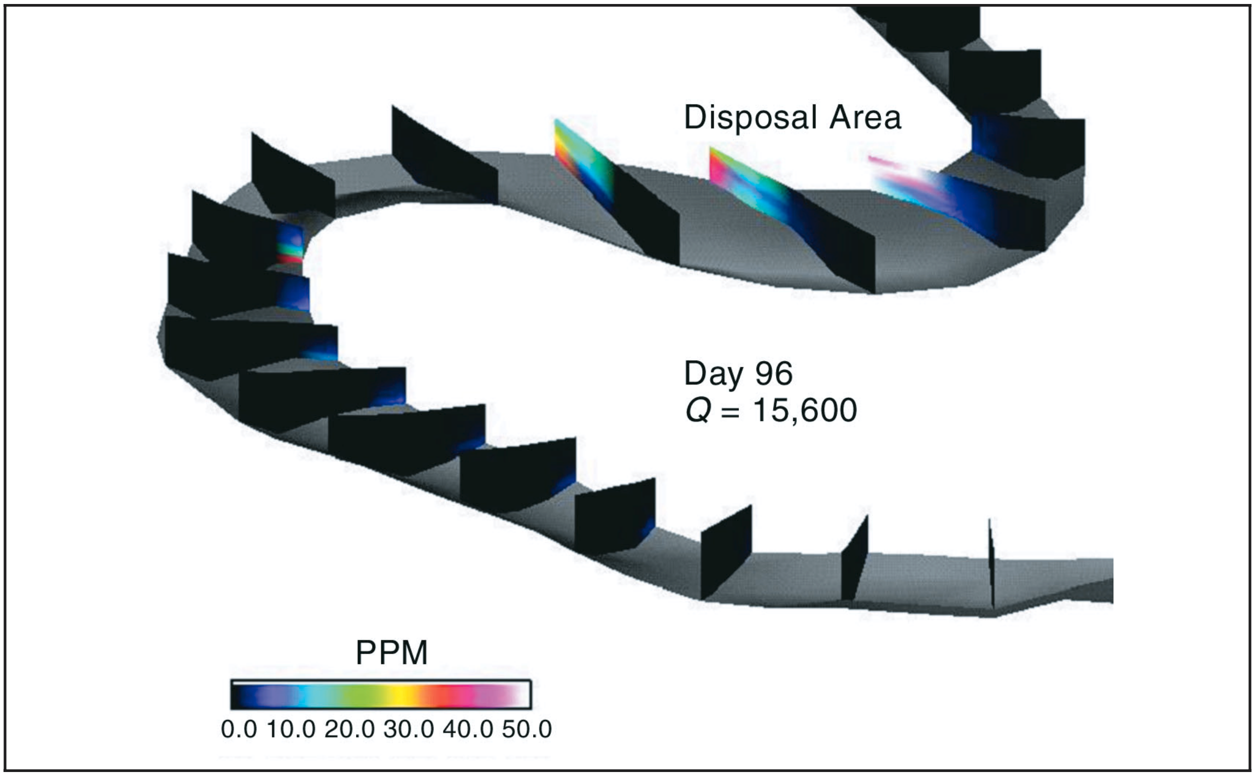

Figure 12. Scenario 1, Day 96, suspended sediment concentration in ppm

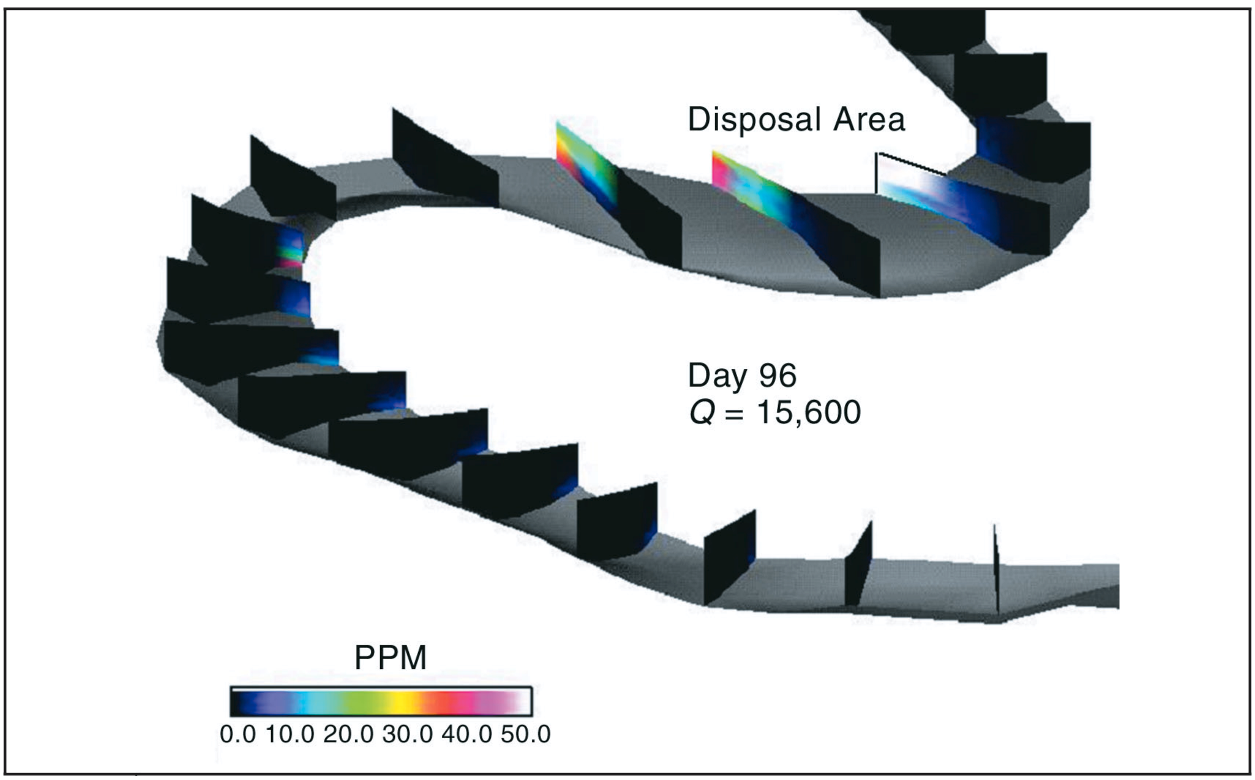

Figure 13. Scenario 2, Day 96, suspended sediment concentration in ppm

By Day 138, Figures 14-16 show that, as the river flow increases, material on Site 43 has begun eroding, but material continues to be deposited in the adjacent channel. The channel deposition is likely due to sediment entering the upstream boundary as well as from eroded material that deposits there. More erosion over the site occurs for Scenario 3 than Scenarios 1 and 2, with more deposition occurring in the channel for Scenarios 1 and 2 than for Scenario 3. Again it appears that more of the material eroded from the site settles in the adjacent channel in Scenarios 1 and 2. Figures 17-18 illustrate the high-suspended sediment concentration levels that occur over the site as a result of the erosion material from the site during the high flows experienced on Day 138. These values are equivalent to those computed during the mechanical redistribution process.

As noted earlier, erosion of material over Site 43 occurs during high riverflow. However, as the flow decreases during the latter part of the simulation period, deposition of material occurs at the site. At the end of the yearlong simulation, a maximum of about 1.5 ft of sediment has deposited at Site 43 in all three scenarios (see Figures 19-21). However, the simulation with no mechanical redistribution (Scenario 3) shows less deposition at the site but more deposition in the adjacent channel.

In summary, the results presented imply that the impact of mechanical redistribution will be small. It appears that the river has enough transport potential to handle the mechanical redistribution currently being practiced in the Corley Slough Reach. An inspection of the bed change results presented reveals little difference between Scenarios 1 and 2, implying that an even greater amount of mechanical redistribution could be accommodated than the 100,000 cu yd assumed in Scenario 2.

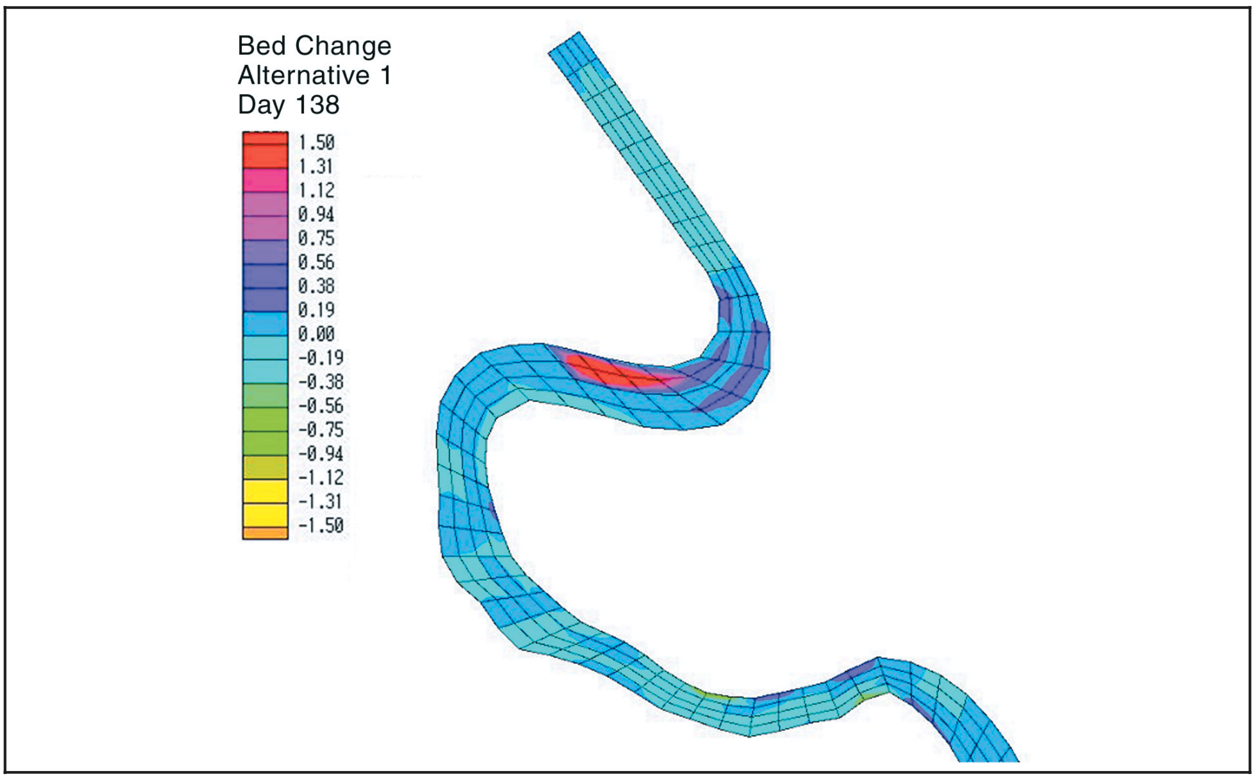

Figure 14. Scenario 1 bed elevation (ft) change on Day 138 (Q = 23,195 cfs)

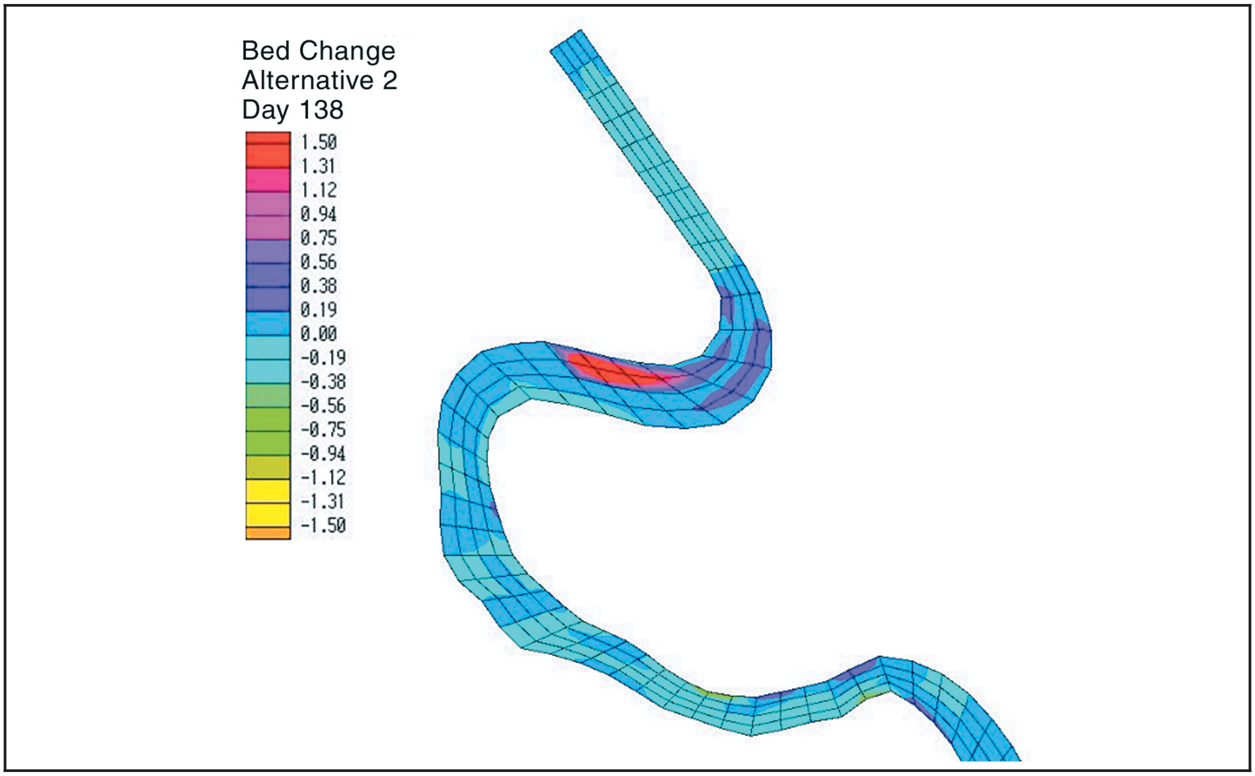

Figure 15. Scenario 2 bed elevation (ft) change on Day 138 (Q = 23,195 cfs)

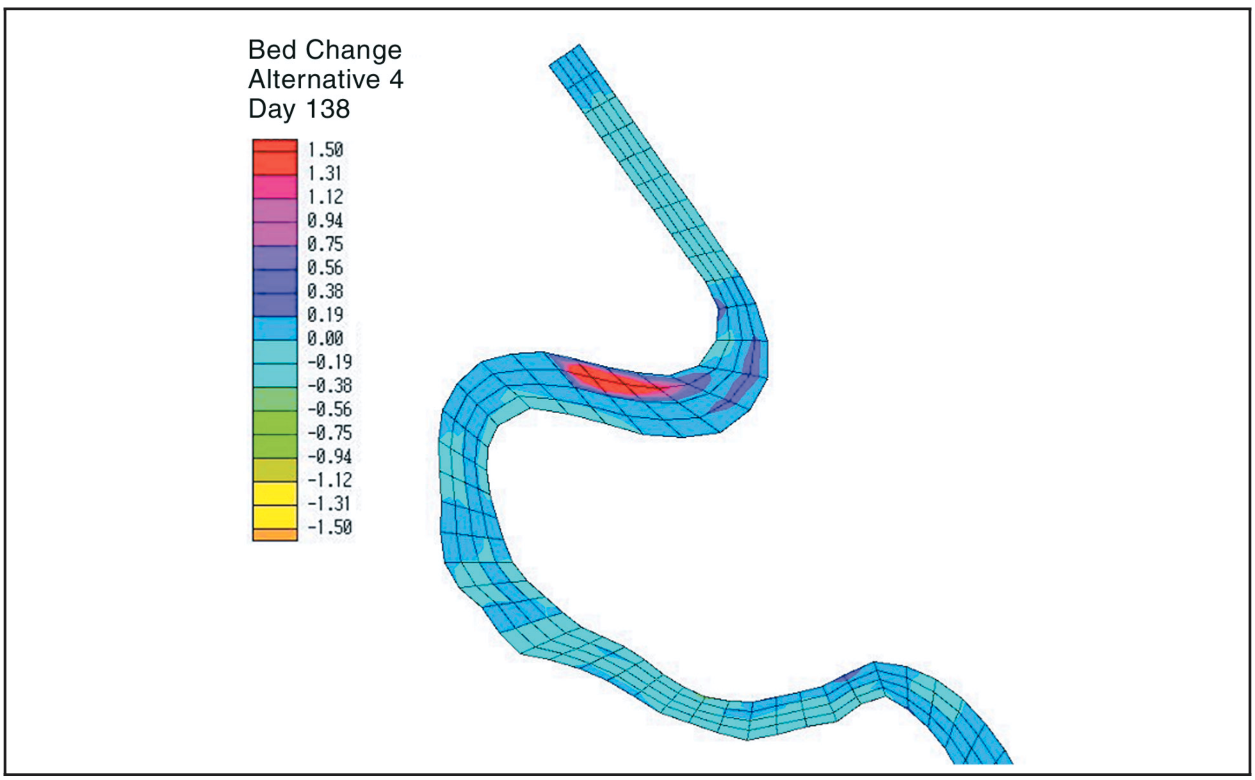

Figure 16. Scenario 3 bed elevation (ft) change on Day 138 (Q = 23,195 cfs)

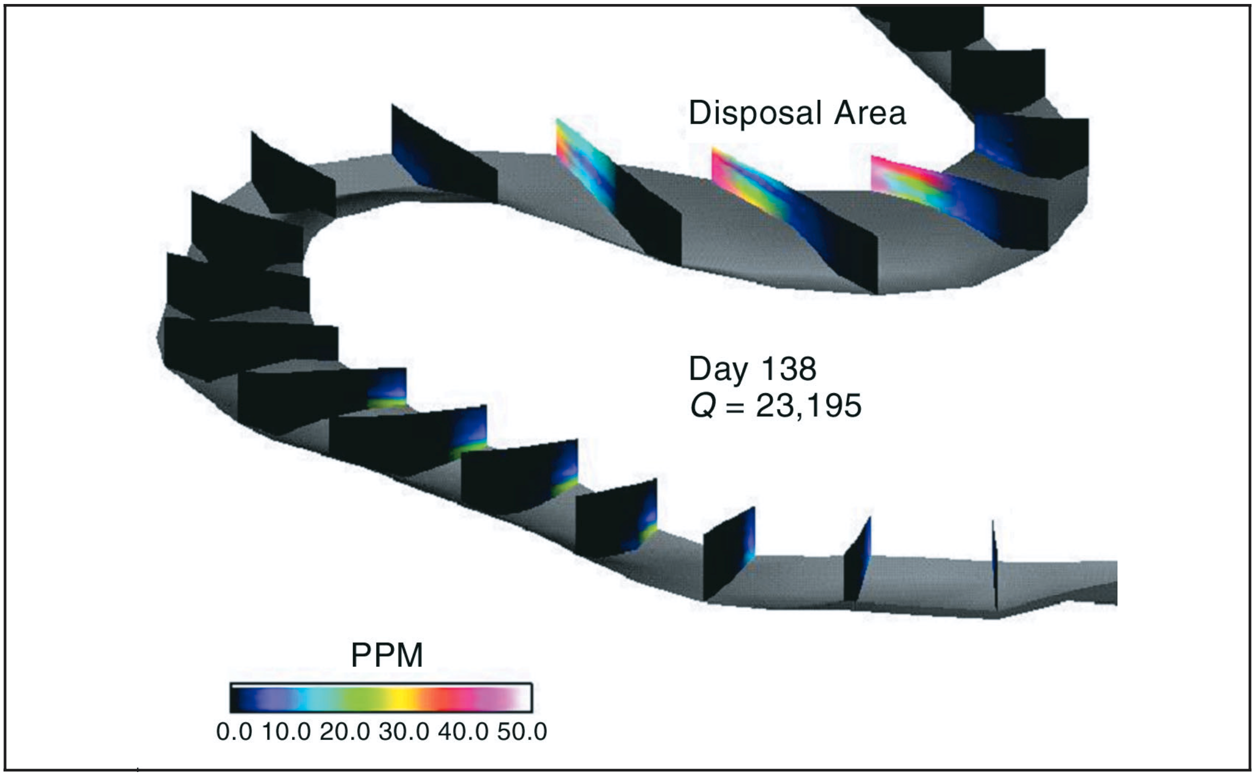

Figure 17. Scenario 1, Day 138, concentration in ppm

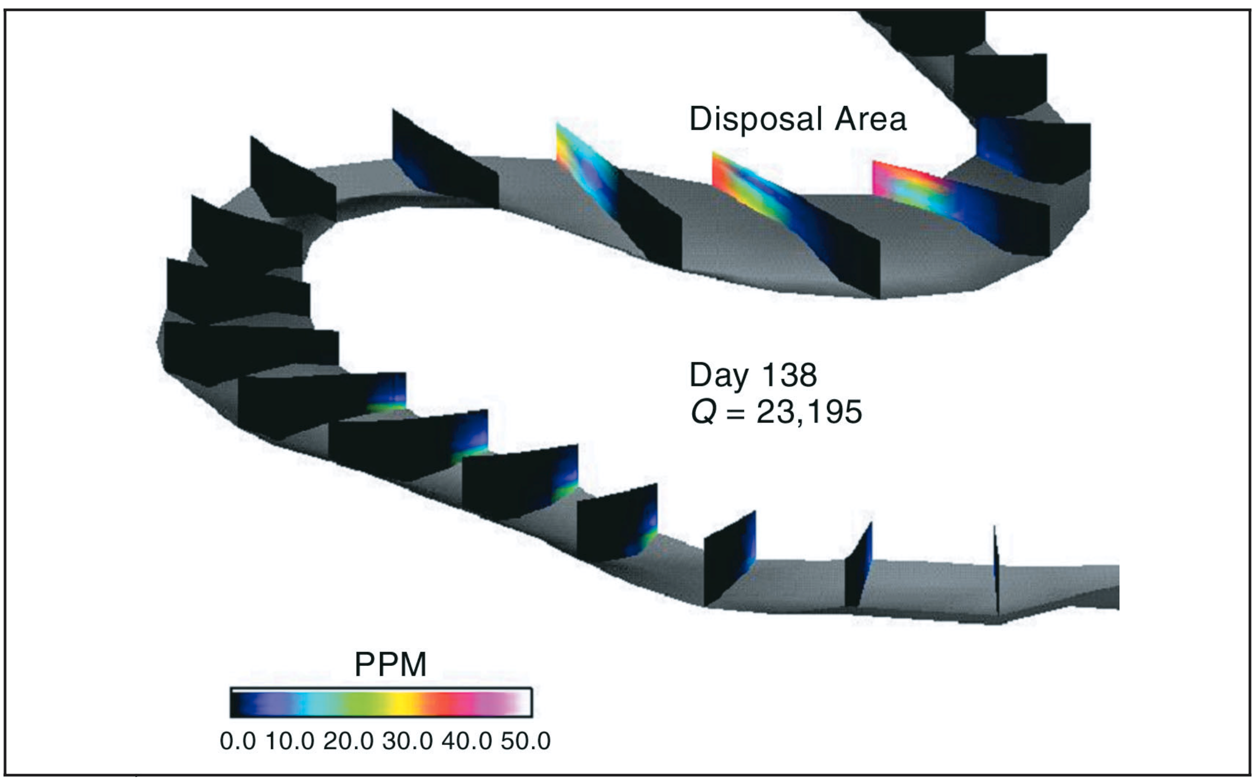

Figure18. Scenario 2, Day 138, concentration in ppm

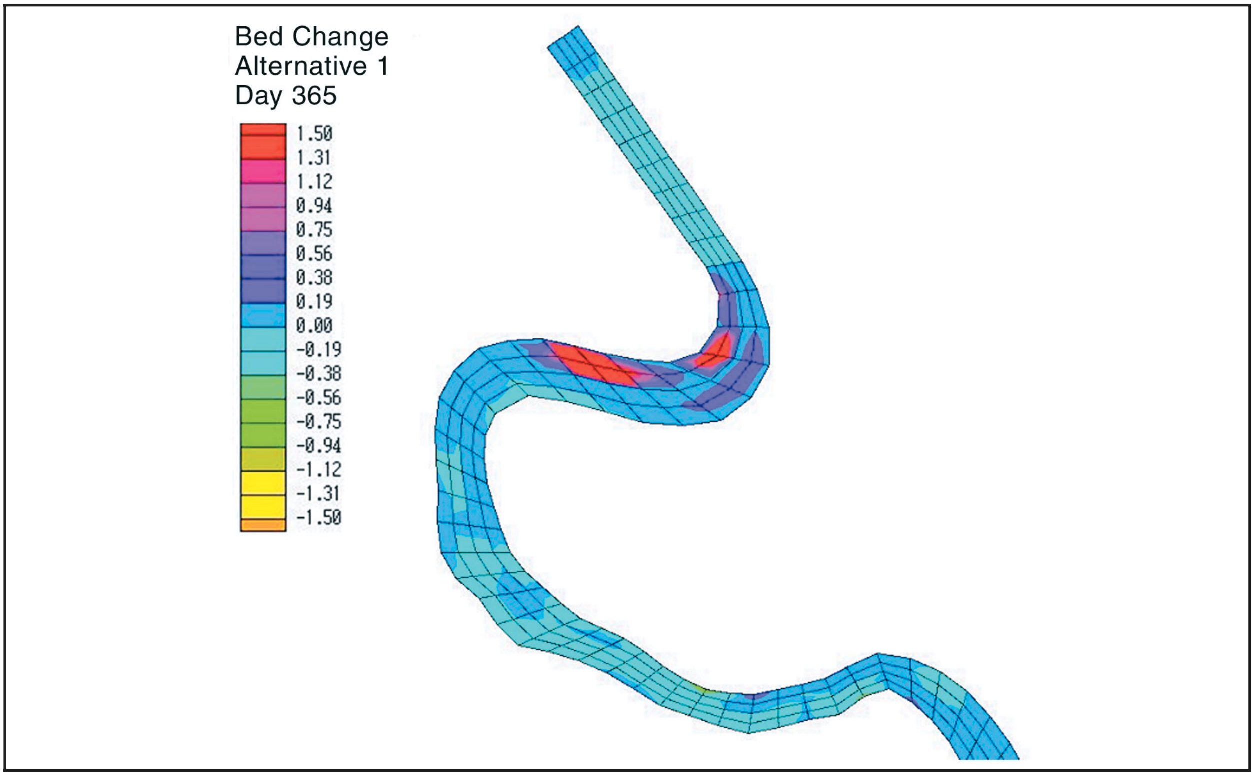

Figure 19. Scenario 1 bed elevation (ft) change on Day 365 (Q = 8,645 cfs)

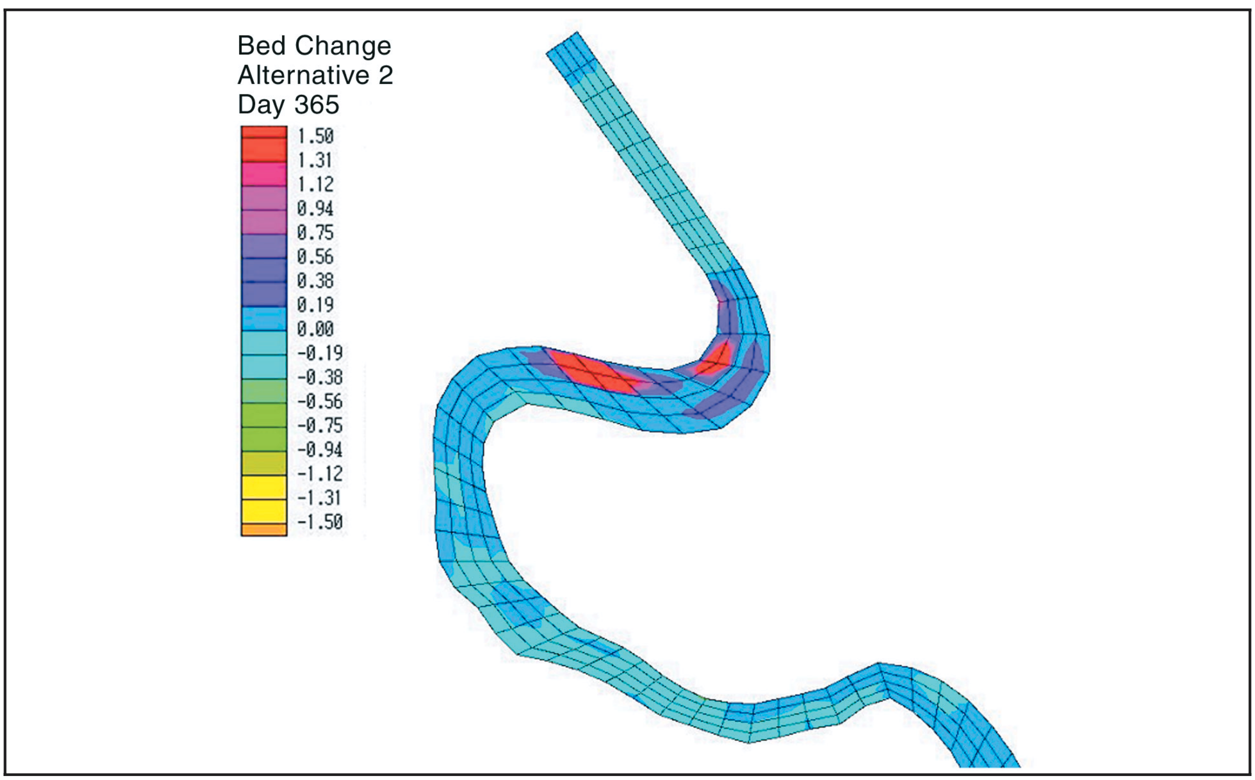

Figure 20. Scenario 2 bed elevation (ft) change on Day 365 (Q = 8,645 cfs)

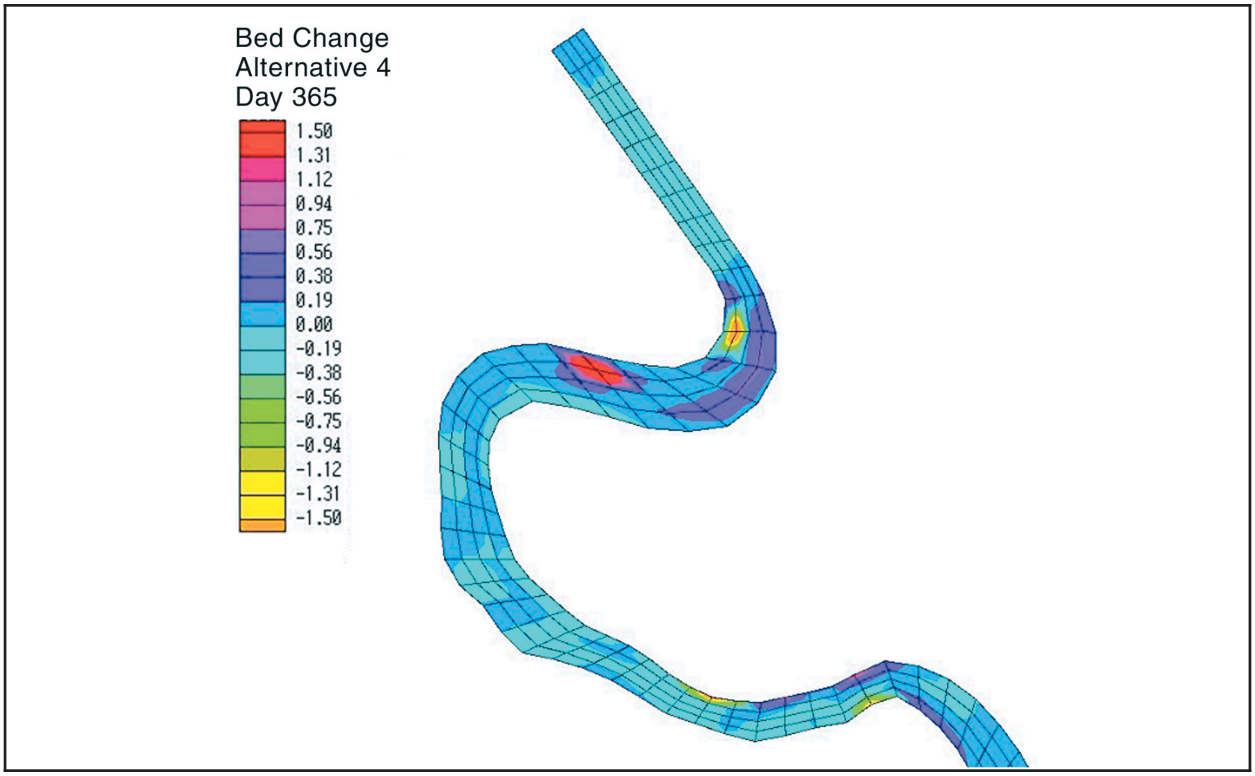

Figure 21. Scenario 3 bed elevation (ft) change on Day 365 (Q = 8,645 cfs)

SUMMARY AND CONCLUSIONS: Using a three-dimensional numerical sediment transport model, CH3D-SED, as the framework, a methodology for the simulation of the fate of dredged material placed on riverbanks and subsequently pushed back into the river before the onset of rising river stage, i.e., mechanical redistribution, has been developed. This methodology involved a modification of the CH3D-SED model and the development of analysis methods to aid in interpreting model results. With this modeling tool, the ability of the Corps to more effectively manage dredging projects over a wide range of environments is enhanced.

After validating CH3D-SED using field data collected on the Apalachicola River, the mechanical redistribution methodology was demonstrated through an application on the Corley Slough Reach of the Apalachicola River where mechanical redistribution is routinely used to manage the limited capacity of on bank disposal at Site 43. Three different disposal scenarios were modeled; namely, (1) 30,000 cu yd of dredged material were placed on Site 43 and subsequently mechanically redistributed with 18,000 cu yd placed on Site 41 without mechanical redistribution, (2) 100,000 cu yd of dredged material were placed on Site 43 and subsequently mechanically redistributed, with 50,000 cu yd placed at Site 41 without mechanical redistribution, and (3) dredging of the navigation channel but no placement of material on Sites 41 and 43.

Model results imply that the river can transport more than the amount of sediment that is currently being mechanically redistributed by the Mobile District in the Corley Slough Reach since mechanical redistribution does not appear to significantly affect sediment transport in the river.

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> Raphelt, K. N., Tingle, S., Heath, R. E., and Chu, Y. (2001). "Development of methodology for predicting fate of dredged material placed on riverbanks," *DOER Technical Notes Collection* (ERDC TN-DOER-N14), U.S. Army Engineer Research and Development Center, Vicksburg, MS. *www.wes.army.mil/el/dots/doer*

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