# NUMERICAL MODEL SEDIMENTATION ANALYSIS REPORT UPPER MISSISSIPPI RIVER, LOCK AND DAM NO. 22

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**Abstract** Sediment transport modeling was performed by the Rock Island District (MVR) Corps of Engineers using the numerical model ADH for the Upper Mississippi River at Lock and Dam 22. The purpose of the study is to locate probable scour and deposition areas following the proposed construction of a new 1200 ft lock chamber and associated features (guard walls, wing dams, vane dikes, etc). Study results address potential navigation and environmental questions.

ADH (ADaptive Hydraulics) is the newest multi-dimensional hydraulic modeling program by the Coastal and Hydraulics Laboratory (CHL) of the Corps' Engineering and Research Development Center (ERDC). The shallow water ADH model was publicly released in September 2007 but has been used by MVR since January 2006. The sediment module of ADH is capable of transporting suspended and bed loads, and can use multiple grain size sediments (both cohesionless and cohesive sediments), but is still under development and not yet available to the public. MVR has been successful using ADH for many 2D applications including sedimentation analysis at Lock and Dam 22.

Conclusions from the sediment analysis at Lock and Dam 22 indicate minor changes to bedform geometry due to the construction of the proposed NESP project features. The fate of this sediment depends largely upon grain size and river velocity. In the pool model, scour occurred predominately near newly constructed structures and the main area of deposition was located riverward of the proposed guardwall and will not pose a problem for navigation. In the tailwater model, scour occurred in an area riverward and downstream of the proposed guardwall and vane dike. This material was deposited further downstream in a navigable area that is currently prone to chronic dredging. This location in the tail is approximately 1400 ft downstream of the dam but appears to be safely upstream of known mussel beds.

## INTRODUCTION

This report contains the numerical model results for sedimentation analysis in the pool and tailwater of Lock and Dam 22 on the Upper Mississippi River. The addition of a 1200 ft lock is proposed for this project under the Navigation and Ecosystem Sustainability Program (NESP). The purpose of this study is to detail probable scour and deposition effects following the construction of the proposed NESP project and to address potential navigation and environmental questions such as whether or not the proposed NESP project would increase future dredging needs in the area, create hazardous navigation conditions by altering river currents, deposit sediment upon existing mussel beds, etc.

Numerical modeling was performed using the Adaptive Hydraulics (ADH) program developed by the Engineer Research and Development Center (ERDC). The 2-D finite element mesh was created using the Surface water Modeling System (SMS) developed by the Environmental Modeling Research Laboratory (EMRL) at Brigham Young University. SMS was also used to visualize and plot the hydraulic model results presented herein. Since this is one of the first sediment models at MVR to use ADH, ERDC was periodically consulted during the modeling process to arrive at the results contained in this report.

Existing condition and future condition (NESP project) sediment models were developed for both the pool and tailwater of Lock and Dam 22. Numerical models from prior construction sequencing modeling served as initial starting files which were modified to conduct sedimentation analysis. Each model extends approximately three miles (upstream or downstream) from the dam. Grain size information was obtained from dredge records from 1999. Four grain sizes were chosen to represent the main channel sediment properties of the area.

A single discharge was used for the sediment models, 209,000 cfs, which corresponds to the 50% annual exceedance event (or 2-year frequency event). This discharge was chosen to represent a "channel forming" discharge. The model duration of 10 days simulation time was chosen so that the model computations had enough time to reach a sediment equilibrium. Resulting sediment concentrations in the pool model were used as input to the tailwater model. Real areas of scour and deposition fluctuate with daily fluctuations of discharge and sediment inflow. Daily flow rates and forecasted stages can be found at www.rivergages.com using the Mississippi River gage at Saverton, MO (gage "MI22"). Due to these simplifying assumptions, model results should be viewed as qualitative in nature and not as yielding exact values of scour and deposition which could be expected to occur over predictable time intervals.

Conclusions from the sediment analysis indicate minor changes to bedform geometry due to the construction of the proposed NESP project features at Lock and Dam 22. The fate of this sediment depends largely upon grain size and river velocity. In the pool, scour occurred predominately near newly constructed structures. Widespread scour (such as occurred in 1996-8 in response to 1995 wingdam repairs) is not expected due to the construction of this project. The shortening of wingdam lengths on the left bank descending wingdams results in lower velocity in the main channel, countering the tendency for erosion due to the addition of a new emergent wingdam on the opposite side (right bank descending) of the river. The main area of increased deposition in Pool 22 was located riverward of the new guardwall which would not pose a problem for navigation. In the tailwater, scour occurred in an area riverward and downstream of the new guardwall and vane dike. This material was deposited further downstream in an area that is currently prone to chronic dredging and that barge traffic navigates through. This location in the tail is approximately 1400 ft downstream of the dam but appears to be upstream of known mussel beds called the "mussel sanctuary". The exact location of the mussel sanctuary was not available at the time of this report.

## TWO-DIMENSIONAL FINITE ELEMENT MODELING

**Adaptive Hydraulics (ADH) Modeling System** The ADH Model is a software package that can describe both saturated and unsaturated groundwater, overland flow, 3D Navier-Stokes, and 2D

or 3D Shallow Water problems. The model is designed to work in conjunction with the DoD Groundwater Modeling System (GMS) and the Surface Water Modeling System (SMS). The user's manual for ADH can be found at the following website: http://adh.usace.army.mil/manual_sw/adh_doc.html. Numerical modeling of sedimentation for Lock and Dam 22 was completed using SMS version 9.0 and the 2D shallow water module for ADH, version 3893.

Three files are needed to compute a solution in ADH, a mesh, a boundary condition, and a hot start file. The mesh file (*.3dm) is constructed first and can be generated directly with GMS (2D or 3D) or SMS (2D). Once a mesh file has been constructed, the boundary conditions for the situation and operating parameters are specified in the boundary condition file (*.bc). The hotstart file (*.hot) is prepared to establish the initial conditions of each 2D model.

ADH has the capability to simulate the effects of moving vessels within a waterway. This is accomplished by calculating a pressure field, which applies a draft equal to that of the modeled vessel. All vessel characteristics are defined in a boat file (*.bt). A ported guardwall can be treated as a stationary vessel located upon a line of guardwall cells. Thus, four files (the mesh file, the boundary condition file, the hot start file, and the boat file) are used to simulate navigation conditions in the pool of Lock and Dam 22 because it has a proposed ported guardwall upstream of the new lock chamber.

ADH allows the user to calculate the transport of cohesionless sediment (sand), cohesive sediment (clay and silt), and mixed sediments (i.e. sand, clay, and silt). Sediment parameters are added to the boundary condition file (*.bc). The sediment model is capable of running multiple grain sizes. The sediment is transported as suspended load and bed load. As suspended load, each grain class is transported as a moving constituent.

**Development of ADH Sediment Models for Lock and Dam 22** Below is a summary of the sediment modeling progression and tests made that lead to the final ADH sediment models for Lock and Dam 22.

A sediment modeling workshop was held on 13-14 March 2007 hosted by the Rock Island District hydrologic engineering section (MVR EC-HH). The "ADH Sedimentation Workshop" was instructed by Jennifer Tate and Gary Brown from the ERDC Coastal & Hydraulics Lab in Vicksburg, MS. The sixteen participants were from five districts including Omaha, St.Paul, St.Louis, New Orleans and Rock Island. The workshop instructed how to convert existing ADH models into sediment models. The main changes are the conversion from English to metric units and additional parameters to be entered into the boundary condition input files to ADH. At this workshop, the newest version of ADH (version 2395) was distributed and existing ADH models were worked on by the students to convert them into sediment models. The Pool 22 ADH model was modified with the help of the instructors to run sediment for an assumed four grain size distribution and four bed layers. Main areas of concern for this model were coding the wingdams and gate sills so that they would not erode. Only a simplified version of this model was conducted during the workshop. The model was not developed further until June of 2007.

In June of 2007, the Pool 22 ADH sediment model resumed to add more detail. ADH version 2395 was used for this modeling. The initial modeling yielded high errors that required the refinement of elements in the 2D mesh. Two significant areas that were refined were the entrance to a back channel chute that gave high errors and at the tip of an island at River Mile 303.5. After revision of the 2D mesh was complete, a working model of Pool 22 was produced on June 16, 2007. This model lacked realistic grain sizes so no conclusions could be drawn from the model results. The sediment model was not developed further until August of 2007.

In August of 2007, ERDC/CHL sent an updated version of ADH (version 3556) to MVR. The new program was used on the working model from June and it was found that the new version of ADH ran much faster than the old version. Version 2395 took 6 hours 14 minutes to converge on a solution while version 3556 only took 1 hour 50 minutes. The grain sizes in the model were then updated to represent realistic grain sizes taken from Corps dredge records. Maximum sediment computation errors were examined and further grid refinement was made. The realistic grain size model completed computations in approximately 1.5 hours.

In October of 2007, working 2D sediment models of Pool 22 were completed for the existing and with-project conditions. The main issue to solve in October was running the sediment computations to a steady state condition. The model in August ran to a timestep of 9000 seconds, but conversations with Gary Brown at ERDC indicated the need to run the model to perhaps 432000 timesteps (5 days). Since the 9000 timestep models took 1.5 hours to run, it was very important to revise the new 432000 timestep model to cut down on computation time. ERDC assisted with revisions to the input (*.bc) file to troubleshoot the Pool 22 model. The new Pool 22 base conditions model successfully ran after approximately 3 hours of computation time. The with-project condition model, called the "navigation condition" model, was then set up and tested. This model needed a non-erodible surface (Material Type 4) underneath the ported guardwall. After troubleshooting this model, the working version of the model completed 2 days of simulation after 7 hours computation time. It was recognized that more refinement would be needed for the navigation condition Pool 22 model, but the focus of the ADH modeling effort shifted to construction sequencing aspects of the NESP project and did not return to sedimentation analysis until February 2008.

In February of 2008, a new version of ADH became available (version 3893) and the base condition sedimentation model was updated for Pool 22. The base condition tailwater model was then completed using the results from the pool model. The October navigation condition model for Pool 22 needed extensive revision due to changes to the with-project condition for the recommended NESP plan. The most notable change was the proposed bank shaving of the existing approach dike which required changing the 2D mesh and renumbering the node numbers throughout the input (*.bc) file. The with-project Pool 22 and Tailwater 22 models were also completed in February 2008. Future revision to the ADH sedimentation models are unlikely to occur due to time and cost considerations. The parameters and assumptions used in the final ADH sediment models are given in the following section of the report.

## SEDIMENT MODEL PARAMETERS AND ASSUMPTIONS

**Location of Lock and Dam 22** Lock and Dam 22 is located at River Mile 301.1 on the Upper Mississippi River downstream of Saverton, MO. Dam 22 consists of 10 tainter gates that are 60

ft wide, 3 roller gates that are 100 ft wide, and an uncontrolled overtop spillway that is 1600 ft wide. The 3 roller gates and Tainter Gate #13 are submersible but only the roller gates are submerged during winter operations.

**2D Model Mesh Overview** The 2D mesh extends 3.2 miles upstream of the dam and 2.9 miles downstream of the dam. In the base condition pool model there are 27925 elements and 14613 nodes. In the base condition tailwater model there are 10536 elements and 5522 nodes. In the future condition pool model there are 29415 elements and 15424 nodes. In the future condition tailwater model there are 10596 elements and 5636 nodes.

**Bathymetry in Pool 22** Bathymetry is based on soundings taken between years 2002 to 2005 in units of feet 1912 datum.

**Base Condition: Existing Pool Conditions** Because wingdams are constructed with riprap stones, degradation of wingdams is common due to debris, scour at high flows, and ice forces. The existing condition of the wingdams contains various low spots based upon soundings taken. Wingdams are proposed to be repaired to their design condition (crest 456.5 ft 1912 datum) as part of the NESP proposal and this elevation is represented in the future conditions model.

**Future Condition: Final NESP Configuration for LD 22 Pool** The NESP proposal adds a 1200 ft lock chamber in the auxiliary bay, located between the 600 ft lock chamber and Tainter Gate #1. The land wall approach dike has been cut back to improve entrance to the new chamber. The stub dike (or spur dike) upstream of the approach dike has also been removed.

**Bathymetry in Tailwater 22** Tailwater bathymetry is based on soundings taken between years 2002 to 2005 in units of feet 1929 datum. The datum was converted to 1912 datum by adding a correction of 0.3 ft to all nodes. Tailwater 22 is the same as Pool 24 which is located in St. Louis District. St. Louis District uses the 1929 datum for their projects. All sediment models were first converted to 1912 datum and then to metric units.

**Base Condition: Existing Tailwater Conditions** The tailwater 22 model contains the landside lock wall, the downstream gate of the existing lock, the existing riverside lock wall (600 ft), the space for the auxiliary lock, Tainter Gates 1, 2 and 3, Roller Gates 4, 5 and 6, Tainter Gates 7 through 13, the 1600 ft uncontrolled overflow spillway and the slough behind Cottel Island. Discharges are assigned to all the gates of the dam and for high discharges the overflow spillway.

**Navigation Condition: Final NESP Configuration for LD22 Tail** The NESP proposal adds an I-wall extension and miter gates on the new 1200 foot lock chamber. The total extended length of the I-wall is 700 feet, allowing for a 100 foot I-wall downstream of the miter gate pintle to assist navigation in and out of the new 1200 foot lock chamber. This condition represents the final NESP condition. Since this is a final condition model, the inflow to the model during open river (all 13 gates of the dam lifted above the river) are based on the final condition model results for the pool.

**Discharge Used for Sedimentation Analysis** A single discharge was used for the sediment models, 209,000 cfs, which corresponds to the 50% annual exceedance event (or 2-year frequency event). This discharge was chosen to represent a “channel forming” discharge. Total

discharges above 162,000 cfs represent open river conditions where all gates are completely out of the water. Gate discharges for 209,000 cfs were computed in each of the pool ADH sediment models using the ADH model flux output strings (TFLX) at each nodestring at the downstream boundary of the pool models. In addition to spillway discharges at the gates, spillway discharges were computed across the uncontrolled overflow spillway. Discharges used as upstream boundary conditions for the tailwater models are given in the full version of this report (MVR). The "adaption" feature was turned off near the gates for both pool and tail models by using a material type 4 in the models. This prevented circulation problems at the gates and scour from being computed at the gate sills.

For the pool model, computations were made with the OTW card along the gates and spillway. Use of this card means that the tailwater elevation is being assigned as a boundary condition and the discharge across the spillway was computed by ADH. It was observed that the spillway discharge for the future condition is much greater than the spillway discharge computed for the base condition (66 kcfs vs 22 kcfs). Hand calculations were performed that showed these values as too high. A sharp crested weir with no tailwater located along the spillway would produce a discharge 17,000 cfs. The estimated discharge for a broad crested weir was 15,000 cfs. While it is possible that the addition of project features could push river discharge across the river, it is unrealistic that the flow rate would triple in magnitude due to such changes. To better address discharge over the spillway, the DIS card was placed along the spillway with a value of 15,000 cfs while the gates remained with the OTW card; however this method produced computational errors that were never rectified. A possible method to achieve the proper spillway discharge is to alter the crest elevation or roughness of the spillway until the computed discharge approaches the expected value from a broad-crested weir equation. This process could iteratively solve the discharge distribution across the gates and spillway for both the base condition and the future condition models. This new method was never accomplished due to time and cost considerations on the project, but it may be thought of as a calibration technique to use at uncontrolled spillways. The effect upon the results due to the overestimation of spillway discharge in the future NESP condition is that velocities through the gates are lessened. This can lead to the incorrect conclusion about the output files that the future condition causes less scour above and below the gates of the dam. This is likely not the case and confirms that the model results should be viewed as qualitative in nature and not as yielding exact values of scour and deposition which could be expected to occur over predictable time intervals.

**Initial Water Surface Elevations Used for ADH Hotstart Files** A sloping water surface corresponding to that of the 50% exceedance probability event (2-year frequency event) was used to generate the initial hotstart files for the Pool and Tailwater 22 models. Sloping water surface was created using the "interpolate to mesh" feature of the SMS scatter module. Initial depths used in the ADH hotstart file were created using the "data calculator" program of the SMS mesh module.

**Grain Sizes Used for Sedimentation Analysis** Grain size distributions from dredge records in 1999 were examined at various locations on the Upper Mississippi River and grouped into five grain size categories shown in Table 1 below:

Table 1 Grain Size Categories for ADH Sediment Models based on 1999 Dredge Records.

| | | | |
|---|---|---|---|
| 1) | Clays & Silts (cohesive) | - smaller than #200 sieve - | 0.000074 mm |
| 2) | Fine Sands | - from #40 to #200 sieve - | 0.00042 mm |
| 3) | Medium Sands | - from #10 to #40 sieve - | 0.00201 mm |
| 4) | Coarse Sands | - from #4 to #10 sieve - | 0.00475 mm |
| 5) | Gravels & Cobbles | - larger than #4 sieve - | 0.0381 mm |

At the time of the sediment modeling, the ADH sediment program was still in development and did not include support for cohesive particles; thus, four grain sizes were used to represent the sediment distribution for Pool 22 and Tailwater 22. It is important to note that of the 13.9% material of Fine Sand or smaller grain size, only 0.1% was classified as cohesive material. Because of the minimal amount of cohesive grains in the dredge records, future models were never upgraded to include the Clays & Silts grain size particles.

A literature search was conducted to validate the dredging records because it was believed that dredging records might contain larger grain sizes than samples taken outside of the navigation channel, and would thus produce less conservative results (i.e. less sediment motion). However, reports were found that indicated the opposite. USGS open file reports 95-708 and 96-580 contain sediment samples for a broad coverage of Pool 22. These reports show sediment grain sizes that were larger than the grain sizes in the Corps Dredging Records. Since the chosen grain sizes for the ADH models (Table 1) are smaller than the grain size distributions in the USGS reports, it was concluded that using the Corps dredging records would be a conservative approach.

**Bed Layer Assumptions Made for Sedimentation Analysis** Based on the ADH sediment workshop, the sediment model was set up with four bed layers that were assumed to be 1 meter thick per layer, with the exception of the wingdams (material type 2) and gate sill bottoms (material type 4) which were set to 0.001 m so that they would be resistant to scour during model runs. In addition to the four layers, ADH uses a fifth layer to represent a "hard bottom" for computational stability. Particles are allowed to be raised to a higher layer or fall to a lower layer during the computations. Particles in Layer 1 that are raised enter suspension and are carried with the current downstream where it might later be deposited. Particles that do not enter suspension may be carried downstream as bed load if river currents are strong enough. The inflow boundary to the model assumes an equilibrium transport of sediment across the furthest upstream section. Sediment concentrations are adjusted within ADH so that the bottom surface of the starting cross section remains unchanged. Sediment concentrations then travel downstream and are deposited and eroded as computed. Particles that exit the downstream boundary of the model are removed from further computations. The initial starting distribution of the four grain sizes was assumed to be equal for all four bed layers because no other information was available. In the model input (*.bc) file, the grain size distribution was coded for each layer and for each model material type as "MP SBM 1 1 1.0 0.139 0.735 0.096 0.030". What this means is that at the start of the model a bed layer will contain 13.9% of 0.00042 mm grains, 73.5% of 0.00201 mm grains, 9.6% of 0.00475 mm grains, and 3.0% of 0.0381 mm grains. The starting assumption that each bed layer contains an equal percentage distribution of grain sizes likely leads to longer computational times; however, no detailed information was

available to further define the starting assumptions. The reason why the ADH models were run for a long period of time was to allow sediment equilibrium (no bed changes) to be reached.

**Sediment Equilibrium Assumption for Sedimentation** Analysis ADH sediment models must be run until there are essential no bed displacement changes in order for sediment equilibrium to be reached. The final timestep chosen for the Lock and Dam 22 ADH models was 864000 seconds, or 10 days, of simulation time. This value was arrived at after many timestep trials, including a 30 day simulation. Models that run from more than 2 days take a very large amount of processor time on the PC computer and efforts were made to reduce computation time. One major revision involved changing the SDI card from 10 to 1, which speeds up the sedimentation computations and permits the model to adapt appropriately for the suspended sediment concentrations. Also, the TRT values were changed from 1000 to 100 so that the mesh would adapt to capture sediment erosion. The hotstarting technique was useful in saving processor time because it allowed a completed model to be used as the start of the next time increment.

The assumption of sediment reaching a steady state after 10 days of simulated time was examined by running a base condition pool model from 10 days to 30 days of simulated time. This model took over 34 hours of computation time to run on a 3.4 GHz Pentium D CPU, but the model ran to completion. The results of the 30 day model for most of the gate nodes confirm that steady state was a valid assumption at 10 days. It is uncertain that long durations are a valid approach because this implies that the river discharge holds steady at 209,000 cfs for the entire duration, which is extremely unlikely. Since the 10 day steady state assumption is also unlikely in the natural system, model results must be viewed as qualitative in nature and not as exact values of scour and deposition in the real world.

**Sediment Inflow Assumption for Tailwater Models** The upstream boundary of the tailwater models starts at the gates of the dam where the equilibrium transport function (EQ TRN card) does not apply. Instead, the Dirichlet Transport function (DB TRN card) was used at the gates of the dam and at the spillway. This was done by taking the concentration values from the pool model at timestep 864000 (10 days), assuming those concentrations were steady state, and inputting the concentrations into the tailwater model input (*.bc) file. Concentrations for each grain size were gathered from the pool model at each node of each gate across the dam and along the spillway.

## RESULTS

Abbreviated ADH sediment results are shown below to highlight the comparison of bed displacement changes between existing and future conditions. A full report is available at MVR that shows the following parameters: Bed Displacement, Depth, and Velocity. Bed displacements are shown in Figures 1-4 below:

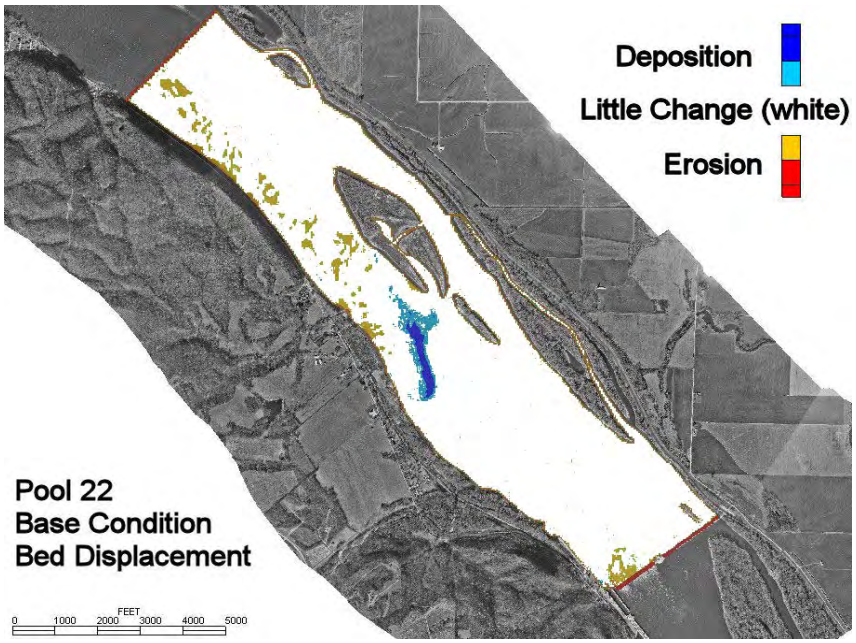


Figure 1 Sediment Displacement in Pool 22 (Base Condition).

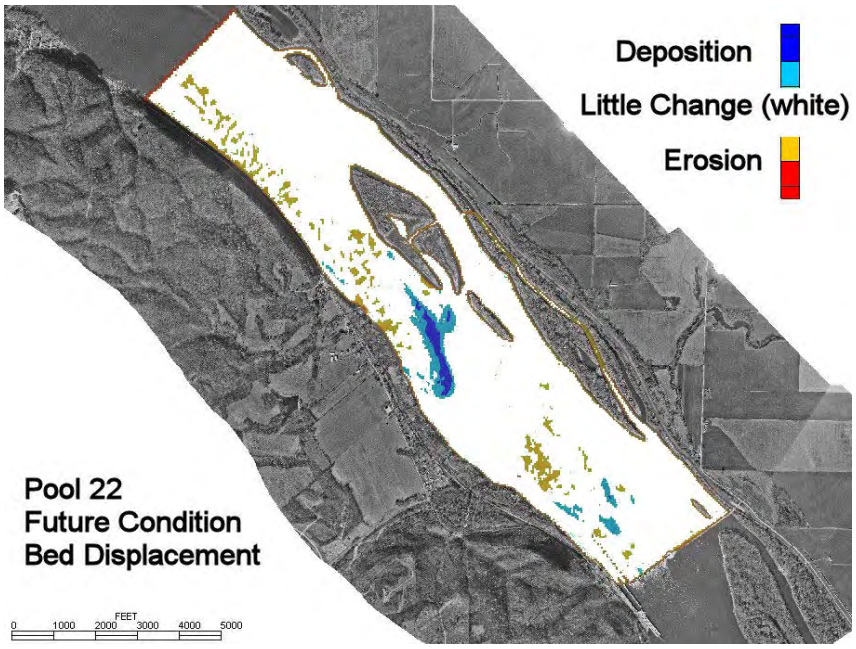


Figure 2 Sediment Displacement in Pool 22 (Future NESP Condition).

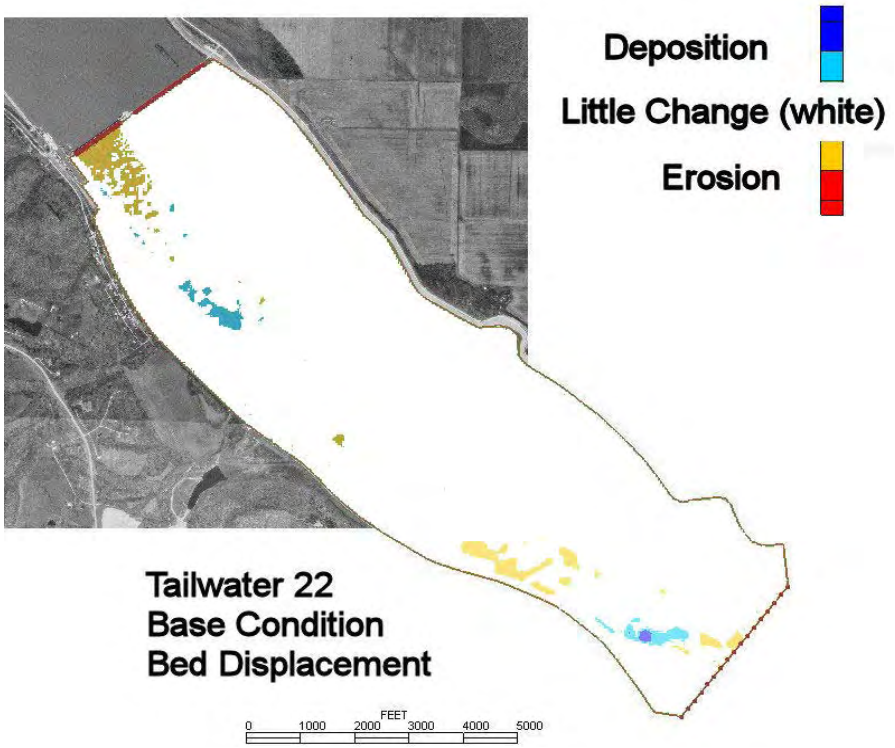


Figure 3 Sediment Displacement in Tailwater 22 (Base Condition).

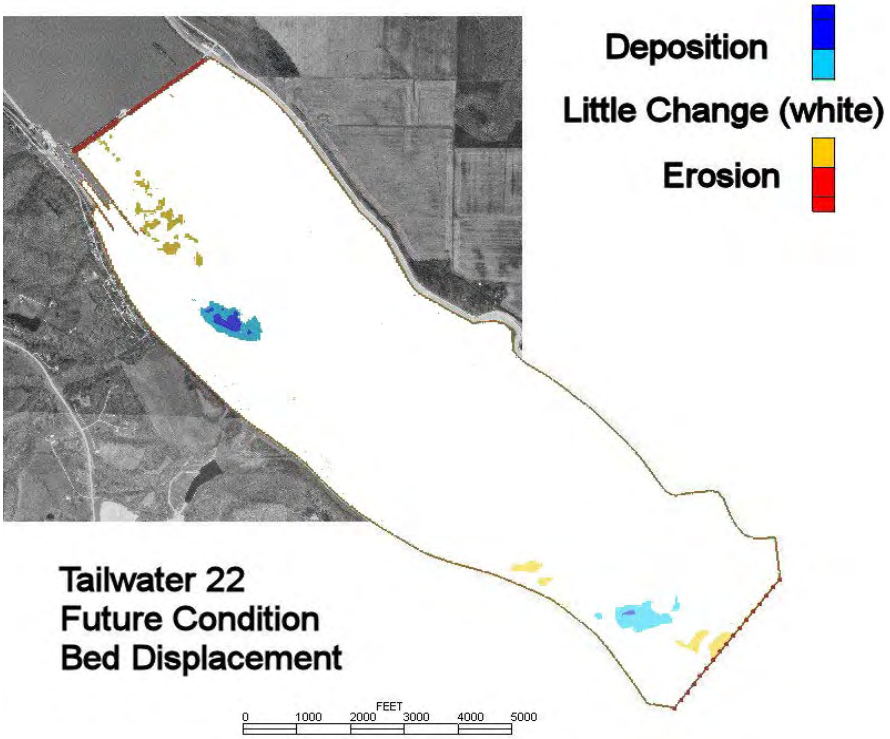


Figure 4 Sediment Displacement in Tailwater 22 (Future NESP Condition).

## CONCLUSION

Conclusions from the sediment analysis can be made by comparing the bed displacement figures of the future and existing conditions for both the pool and tail (Figure 2 vs. 1 and Figure 4 vs. 3). Visual comparison indicates minor changes to bedform geometry due to the construction of the proposed NESP project features at Lock and Dam 22. The fate of this sediment depends largely upon grain size and river velocity. In the pool, scour occurred predominately near newly constructed structures. Widespread scour (such as occurred in 1996-8 in response to 1995 wingdam repairs) is not expected due to the construction of this project. The shortening of wingdam lengths on the left bank descending wingdams results in lower velocity in the main channel, countering the tendency for erosion due to the addition of a new emergent wingdam on the opposite side (right bank descending) of the river. The main area of increased deposition in Pool 22 is expected to be riverward of the new guardwall which would not pose a problem for navigation. In the tailwater, scour is expected riverward and downstream of the new guardwall and vane dike. This material is expected to be deposited further downstream in an area that is currently prone to chronic dredging. Once this material has been removed from the system, it is expected to remain a scour hole and not cause additional maintenance needs. The location of deposition in the tailwater is approximately 1400 ft downstream of the dam along the Missouri shoreline and appears to be upstream of known mussel beds called the “mussel sanctuary” by the Fish and Wildlife Service. The exact location of the mussel sanctuary was not available at the time of this report.

This report is an abbreviated version of the full report available at the Rock Island District. Modeling was performed in 2007 and 2008. The full report contains the numerical model results for velocity, depth and bed displacement, expanded tables and figures of the model mesh and inputs, and an appendix containing computational code for all four ADH models.

The views expressed in this article are those of the author and do not reflect the official policy or position of the Department of the Army, Department of Defense, or the U.S. Government.