Appendix F:

ERDC Letter Report: “Pool 2 Numerical Modeling”

ERDC/CHL Letter Report

Enigineer Research and Development Center
Coastal and Hydraulics Laboratory

US Army Corps of Engineers®
Engineer Research and Development Center

Pool 2 Numerical Modeling

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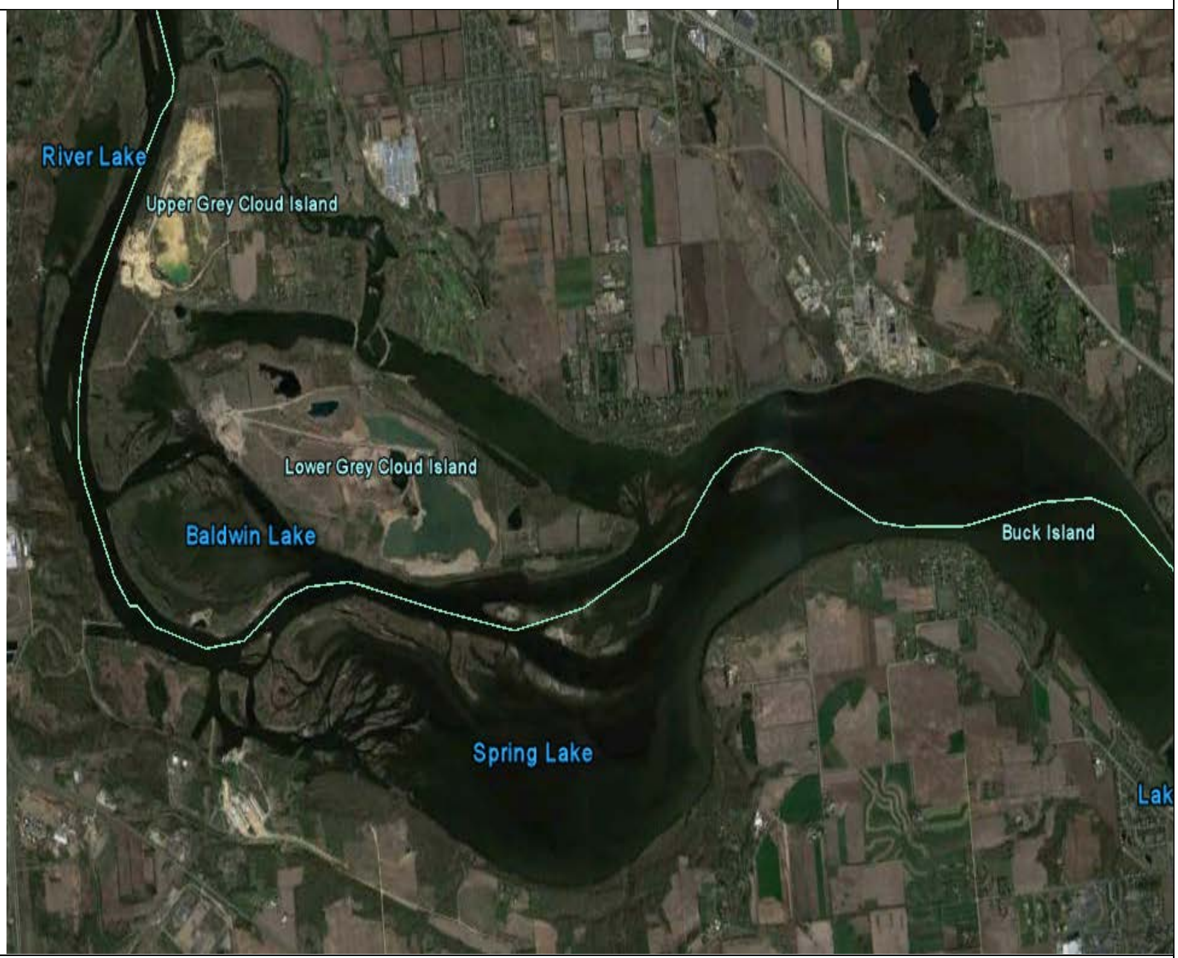
August 16 , 2012



Prepared for U.S. Army Corps of Engineers, Omaha District

LETTER REPORT

SUBJECT: Pool 2 Numerical Modeling

To: Scott Goodfellow

From: David Abraham, David May, CEERD-HF-RS

Date: 16-Aug-12

Purpose:

The purpose of this work was to assist the US Army Engineer District, St. Paul, with evaluation of four alternatives (1A, 1B, 2A, and 2B) to address sedimentation issues on the Mississippi River, Pool2, just downstream of Boulanger Bend. This document briefly describes the work and products from that study.

Alternatives:

Alternative 1A and 1B, Navigation Control Structures

This alternative addresses the control structures as shown in Figure 1a below. It consists of some revetment construction generally along old revetment. The revetments are linear rock mounds roughly parallel to the navigation channel. These revetments were constructed both prior to and after construction of the locks and dams. The alignments can be seen in Figure 1A. The thought behind the alternative was to keep more flow from breaking out of the channel. The previous model had these revetments elevated to 1.3 feet above low control pool elevation (686.7(LCP) MSL1912). The modeling results showed stage increases that were unacceptable. In order to meet this criterion, Alternative 1a in the ERDC modeling effort consisted of reducing the elevation of the revetment by 1 foot. The second alternative, 1b shown in Figure 1b, consisted of dropping the elevations along with eliminating the southwest half of the west revetment.

For an alternative to be viable, stage increases due to the alternative must be below 0.005 feet along nearby shorelines for the 100 year discharge, and significantly improved channel maintenance (sediment) conditions in Boulanger and Freeborn Bends must be achieved. Alternatives 1A and 1B were run for the following discharges without sediment. They were compared to a base condition which was modeled using the WEST Consultants existing condition geometry file.

Low – 75% Duration = 5970 cfs (Little sediment moving in system)

Medium 25% Duration = 20560cfs - (Project should pass sediment)

High 2-year = 43000 cfs – (Project should pass sediment)

100 Year – 150,000 cfs (latest FIS) for stage comparison between Existing and Alternative

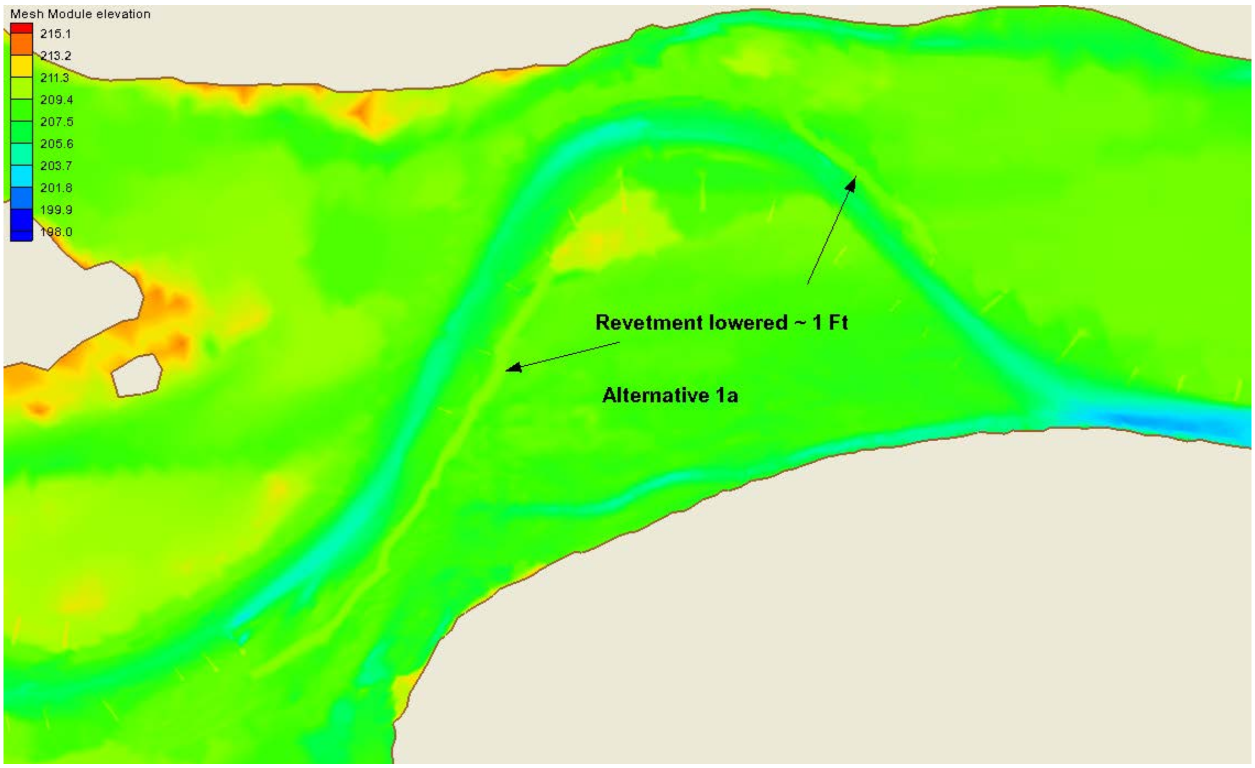


Figure 1A.

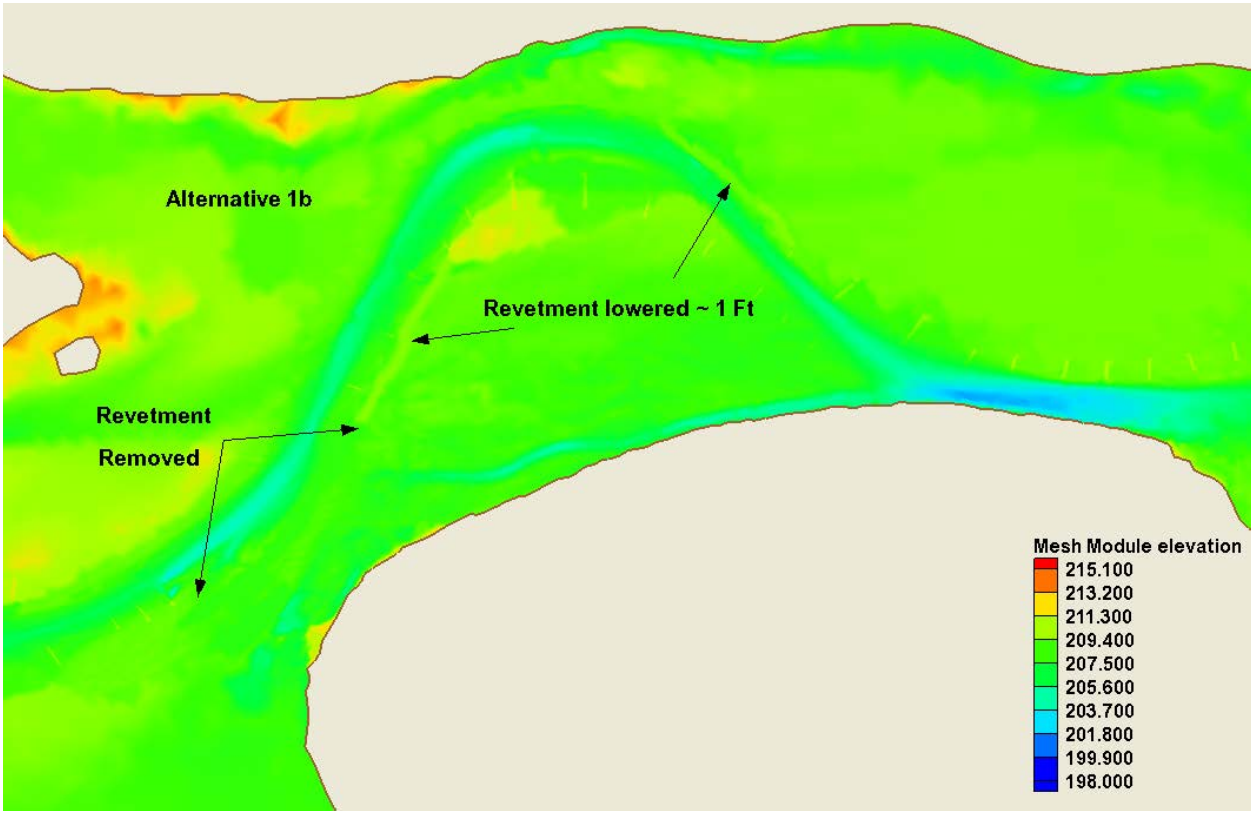


Figure 1B

Alternative 2, Boulanger Slough

The second alternative (Alternative 2A) modeled by ERDC was the addition of a cut in the vicinity of Boulanger Slough. It calls for an excavation of a 13 foot deep channel in the vicinity of a submerged meander in Lower Pool 2, as shown in Figure 2A, with the intent to bypass Freeborn Bend. This alternative was modeled using AdH with hydrodynamics only, no sediment runs were made. Nodal elevations and positions were changed in the WEST AdH model in order to simulate the channel cut. No new nodes were added nor were any deleted, so that comparisons of existing conditions and alternatives would remain consistent. The alternative 2a results were compared to a base condition which was modeled using the WEST Consultants existing condition geometry file. The cut was modeled for the following geometric specifications and flow conditions.

200 foot bottom width

Approximate 3H: 1V side slopes of cut

Bottom elevation = 686.7(LCP)- 13'=673.7 (1912datum)

Centerline of expected Dredge Cut -

Alternatives 2A and 2B will be for the following discharges without sediment.

Low – 75% Duration = 5970 cfs (Little sediment moving in system)

Medium 25% Duration = 20560cfs - (Project should pass sediment)

High 2-year = 43000 cfs – (Project should pass sediment)

100yr(1%) = 150,000 cfs

Concerns that Alternative 2A might not provide sufficient flow to keep sediment mobilized in the new cut led to an additional plan. That plan was to place a partial closure across the channel downstream of the cut entrance (Alternative 2B). The purpose of the partial closure was to insure that enough flow is sent through the proposed new channel. Alternative 2A did show a need for such a partial closure and thus Alternative 2B was run as well. The location and general shape of the closure structure is shown in Figure 2B. It was made with a flat crest one cell-width wide and set to elevation 682.7 feet (208.06m). A constraint for this partial closure structure is that no rock can be added above the LCP – 4 foot elevation (686.7 – 4 = 684.7 feet, or 208.7 meters).

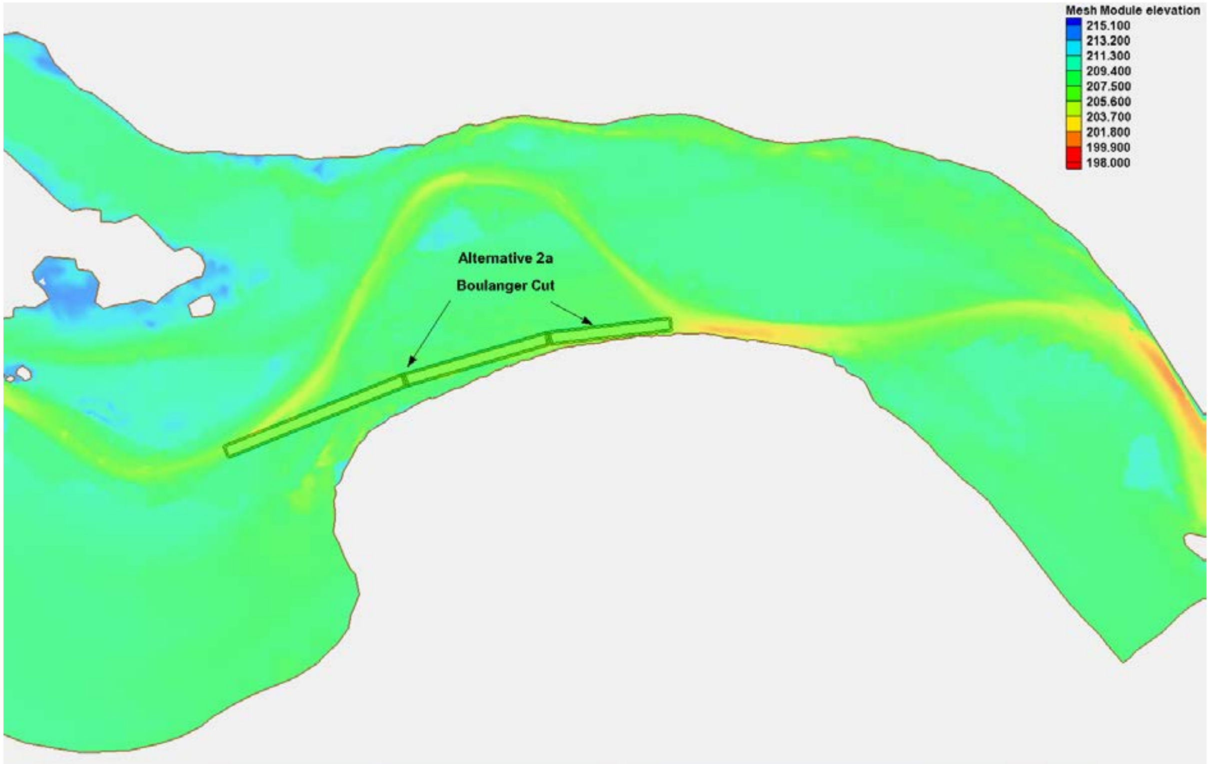

Mesh Module elevation
215.100
213.200
211.300
209.400
207.500
205.600
203.700
201.800
199.900
198.000
Alternative 2a
Boulanger Cut

Figure 2A.

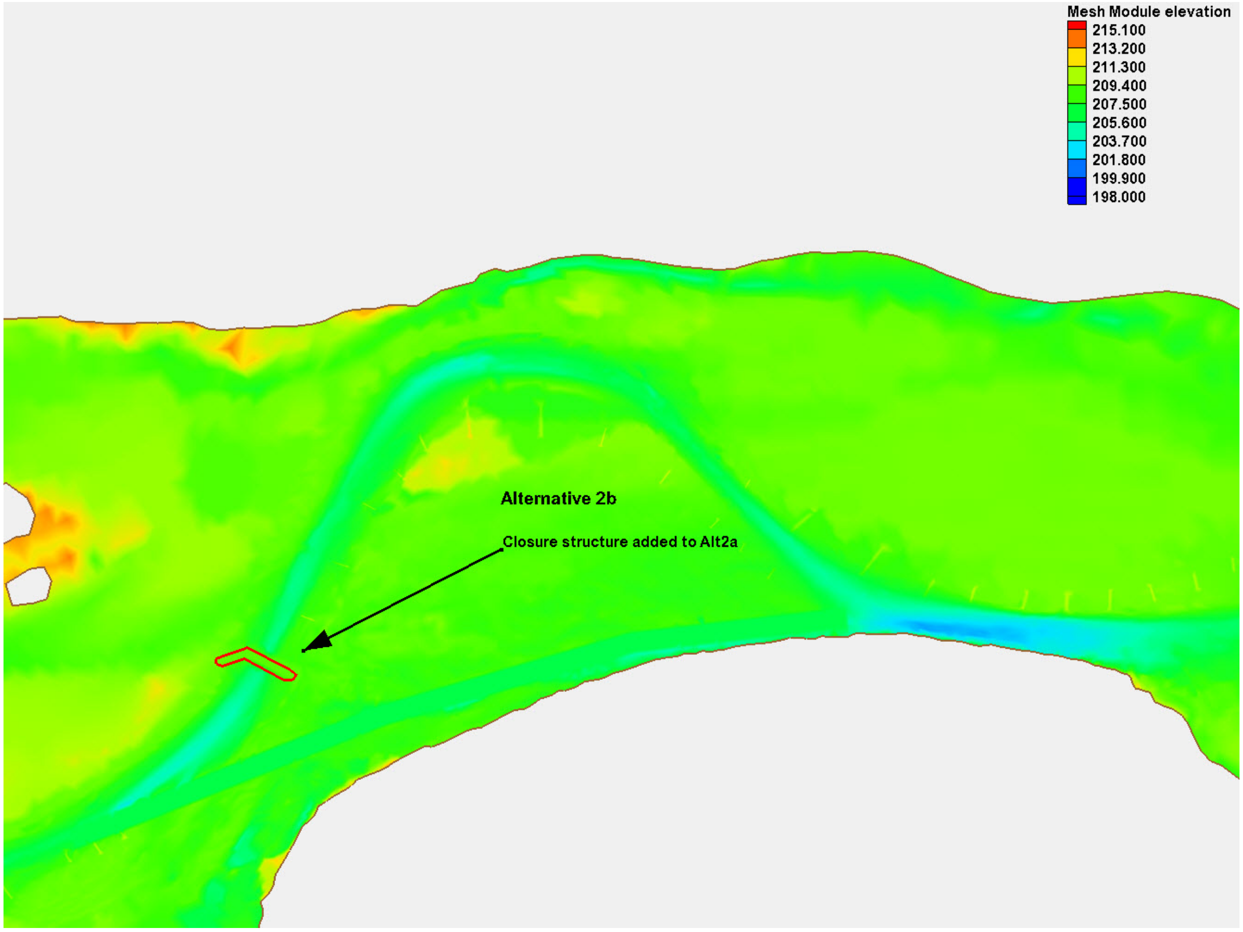


Figure 2B.

Methodology:

The 2-dimensional shallow water version of the hydrodynamic numerical model AdH was used to simulate flow conditions for the alternatives described above. The sediment transport module of the code was not run. These runs were hydrodynamic only. The rationale for this was to use the results as a screening tool to determine the possibility of sediment movement through the various river reaches for the different alternatives. The short time frame was also a consideration for not running the sediment transport version of the code.

For each alternative the appropriate geometry changes were made to the original 'base condition' model as described above and shown in Figures 1A-2B. Each alternative was then run for the four steady-state flow rates of 5970, 20560, 43000, and 150000 cfs respectively (169.053, 582.199, 1217.634, and 4247.559 cms). Model outputs include water depth and velocity along with several other parameters. However, bottom shear stress is not an automatic output parameter of the code.

Since the initiation of sediment movement is important in this study, the bottom shear stress is a parameter that must be computed. For this project, using the gradation information in the WEST Report in Figure 3, and other derivations, bottom shear can be computed using:

$\tau = 2.006\ v^2/\max(d,0.1)^{1/3}$ Eq. 1

Where τ = bed shear in Pascals, v = computed velocity in meters per second, and d = water depth in meters. This shear stress must be compared to something. In the case of this study, that something is the critical shear stress for initiation of motion as determined by the Shields Diagram. Using Brownlie's relationship for critical dimensionless shear (eq. 2-59a) *and* eq. 2-57 for critical dimensionless shear in ASCE Manual No. 110 'Sedimentation Engineering', the value of critical bed shear stress (τ_{bc}) for any grain size of sand can be computed. Using a D50 of 0.4mm sand as a good indicator of sediment movement in Pool2, the critical shear stress for that grain size is found to be 0.22 Pa. When the bed shear stress from the model results is computed using Eq. 1, it can be compared with the critical shear stress of 0.22 Pa for 0.4 mm sand. If the model value is greater than 0.22, then that grain size will be mobilized. This is the rational for interpreting the bed shear plots that are shown in the Results section of this report.

Knowing that sediment will be mobilized is good, but can any more information be teased out of the basic hydraulic parameters output by the model? Answer is yes. One can use the Rouse Number to help identify whether a given size of sediment will be moved in suspension or as bedload. For purposes of this study, the Rouse Number can be computed with the following equation.

Rouse No. = $0.05 / [(\text{computed bed shear} / 1000)^{1/2} * 0.4]$ Eq. 2

This equation is valid only for 0.4 mm sand. Please note, the 0.4 in Eq. 2 does NOT represent 0.4 mm sand, but rather the Von Karman constant. It is only a coincidence that the size class of sand we are interested in has the same value. The sand size is reflected in the numerator of the equation, which is the fall velocity of the specific sediment size. Thus the numerator of the equation will change with varying sediment size classes, and can be determined for instance, from figure 2.9 ASCE Manual 54. For this study we used a shape factor of 0.7 and water temperature of 10 degrees C. From K. Whipple, MITOPENCOURSEWARE, course#12.163/12.463, 'Surface Processes and Landscape Evolution, Fall 2004, the Rouse Number can be interpreted as follows regarding mode of transport (See Table 1).

Table 1

Rouse Number Mode of Transport	
Mode of Transport	Range of Rouse # Values
	R# = Rouse Number
Bed-load	R# > 2.5
50 % Suspended	1.2 < R# < 2.5
100 % Suspended	0.8 < R# < 1.2
Wash Load	R# < 0.8

The methodology discussed above should allow a reasonable assessment to be made regarding the initiation of sediment motion and mode of transport for any location in the models for which water depths and velocities are computed.

Results

Numerical model (AdH) simulations were made for all four alternatives for the four differing flow rates. A total of 20 different runs were made, which includes the four runs for the base condition. Water surface elevation difference plots were made for the 150000 cfs runs only. For all runs two plots were made for each run. The first were the bed shear plots. These plots show contours of computed bed shear stress in Pascals. Values greater than 0.22 indicate the initiation of motion for sand sizes of 0.4mm and smaller. This sand size was chosen based on Figure 3-1 of the West Report. The tan-brown color that appears in the main channel for flows of 20,000 cfs and higher, indicates values above 0.22 Pa.

The second graphic for each model run is the Rouse Number plot. Contours are scaled from a high of 2.5 to low of 0.8. This number is the ratio of the particle settling velocity to the shear velocity. It indicates the mode of sediment transport. Values can be interpreted as in Table 1. The Rouse numbers in these plots were computed for 0.4mm sand. The tan-brown color indicates a value greater than 2.5 and means there should be no 0.4mm sand in suspension. Red to dark blue colors can be interpreted according to the contour scale and the table above. Any purple-grey color indicates a value less than 0.8, and thus all bed material less than 0.4mm will be in suspension.

Good engineering judgment should be applied in using the plots to make management decisions, taking into account the following considerations.

Values in both sets of plots are based on a D-50 of 0.4mm sand.

The bed shear and Rouse numbers were computed using only hydraulic parameters.

No sediment transport functions were used in developing the plots.

The plots only indicate the possibility of initiation of motion and/or the mode of transport (bed-load vs suspended bed-material-load).

They cannot be used for quantification of scour or deposition depths or areal extant.

They cannot be used to predict long term sedimentation trends.

Notwithstanding these considerations, details derived from these plots are good indicators of sediment mobility and transport mode for initial planning stages of a study.

The results of all 20 runs are shown in sets of plots, which have no titles or sub headings above or below the plots. The information for each plot is listed in combination with the color legend on the plot, and identifies the flow rate, alternative, and type of plot. The three types of plots provided are, 'wsel' for water surface elevations, bed shear, and Rouse Number. All 'wsel' plots are for the 150,000 cfs runs. The bed shear and Rouse No. plots are for all flow rates with the flow rate identified in the first one to three digits. For example, 5 is for 5970 cfs, 20 for 20560 cfs, 43 for 43000 cfs and 150 for 150000 cfs. The next number identifies the alternative, as in 1a, 1b, 2a, and 2b. In viewing the plots, the main concern is in the navigation channel or the proposed new channel dredge-cut. The exception to this is the 'wsel' plots, where the focus in on the difference in water surface elevations between the base and plan condition throughout the pool. These plots have been transmitted to the District as separate files.

For alternatives 1a and 1b, water surface differences between the base and plan condition do exceed 0.005 ft in various locations throughout the grid, shown by the yellow to brown colors in the plots. For alternative 2a, there are some wsel differences in the downstream end of the dredge-cut that exceed 0.005 ft. Alternative 2b shows the same results in the downstream end of the dredge-cut as well as in some local areas near the closure structure in Freeborn Bend.

Regarding bed shear and Rouse No. plots; in general, all the alternatives show insufficient flow in the 5970 cfs runs to mobilize sediment in the lower pool.

For the 20560 cfs flow, the movement of sediment throughout the pool is much improved, but in all alternatives there are still areas in Freeborn Bend and upstream of the dam where bed-material entrainment and/or suspension will not occur.   In alternatives 2a and 2b the same problem occurs in the upstream end of the new dredge-cut.

For the 43000 cfs flow, both alternatives 1a and 1b show both mobilization and suspension of the 0.4 mm sand in the main channel throughout the entire reach. However, in alternative 2a and 2b mobilization and suspension of the same sand size is still a problem in the upstream end of the dredge-cut.

For the 150000 cfs flow, all alternatives show mobilization and suspension of 0.4 mm sand in the main channel and dredge-cut throughout the entire study area.

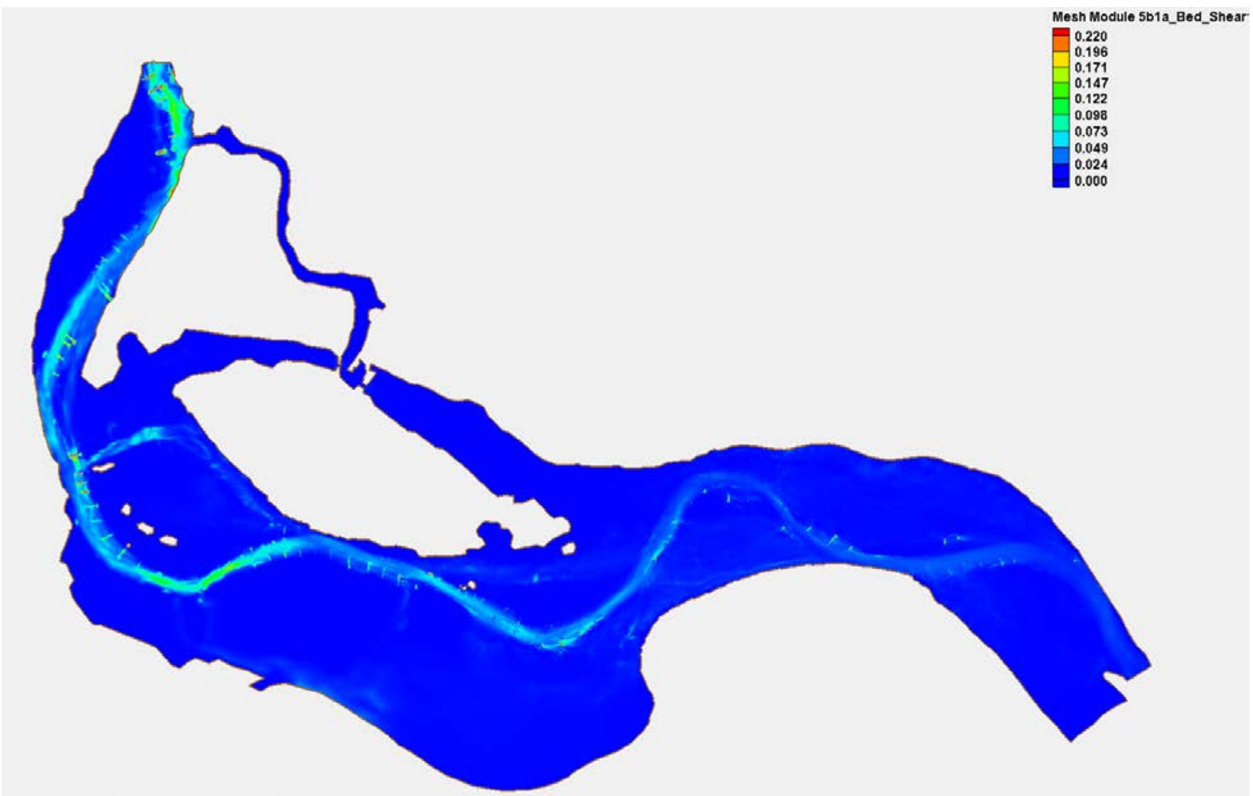


Figure C-1 Bed Shear (Low – 75% Duration) - 5970cfs – Base

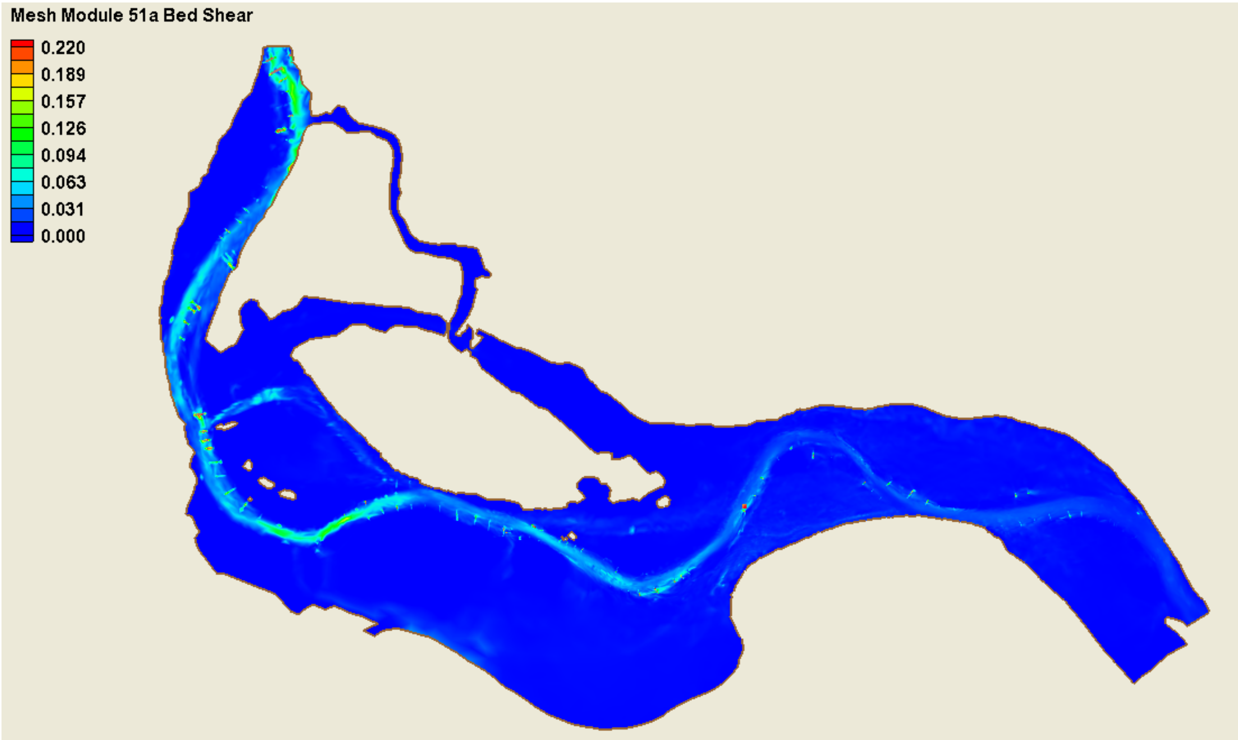


Figure C-2 Bed Shear (Low – 75% Duration) - 5970cfs - Alternative 1a

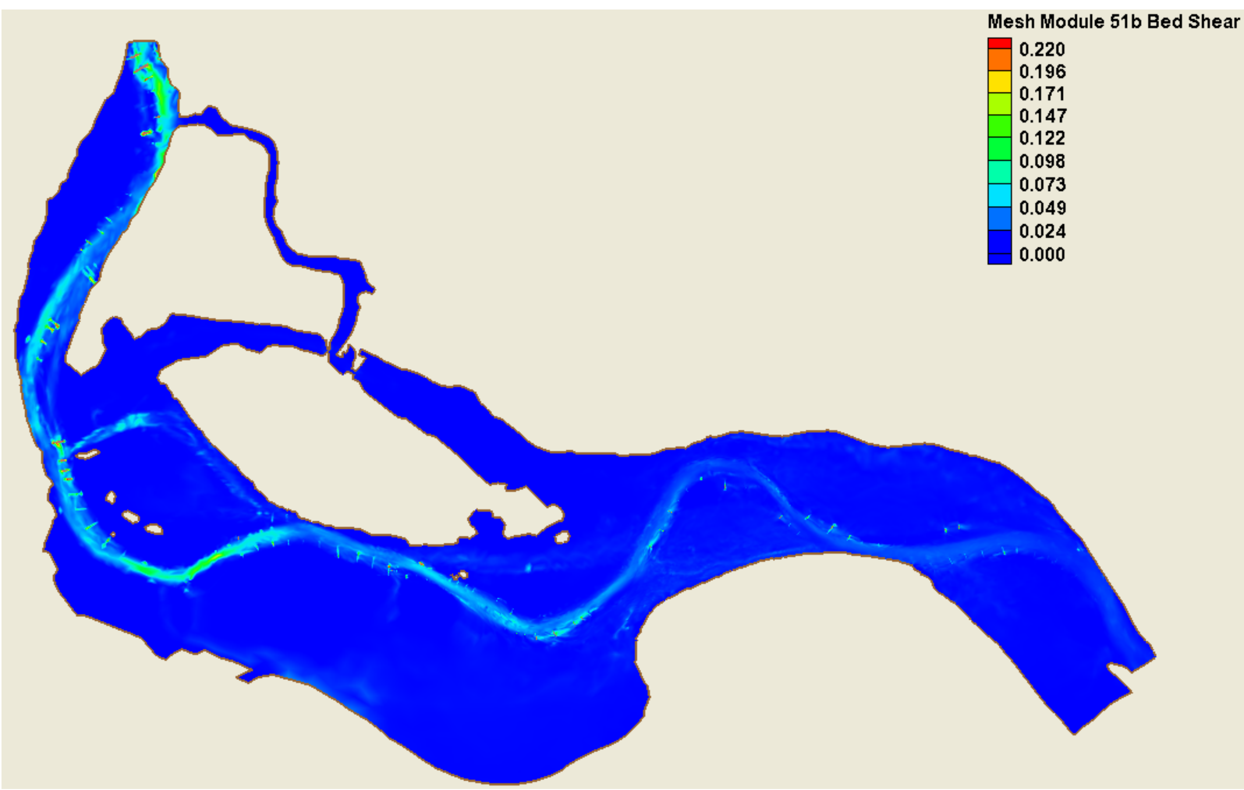


Figure C-3 Bed Shear (Low – 75% Duration) - 5970cfs - Alternative 1b

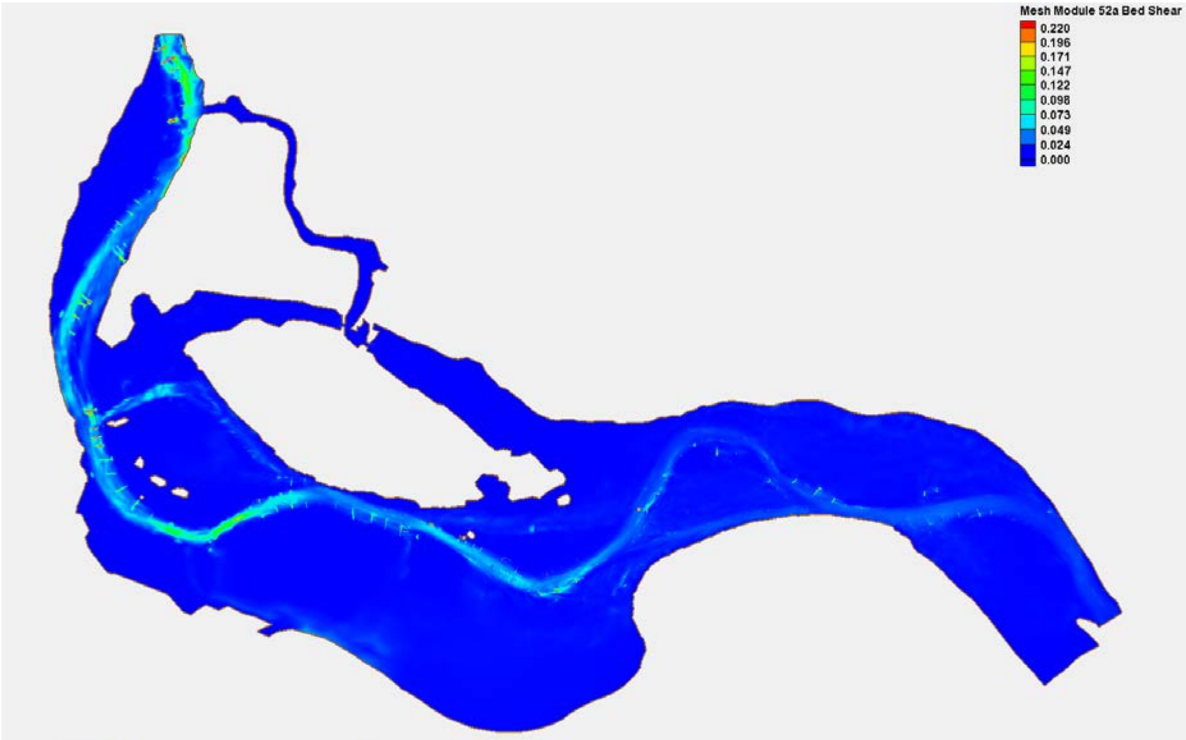


Figure C-4 Bed Shear (Low – 75% Duration) - 5970cfs - Alternative 2a

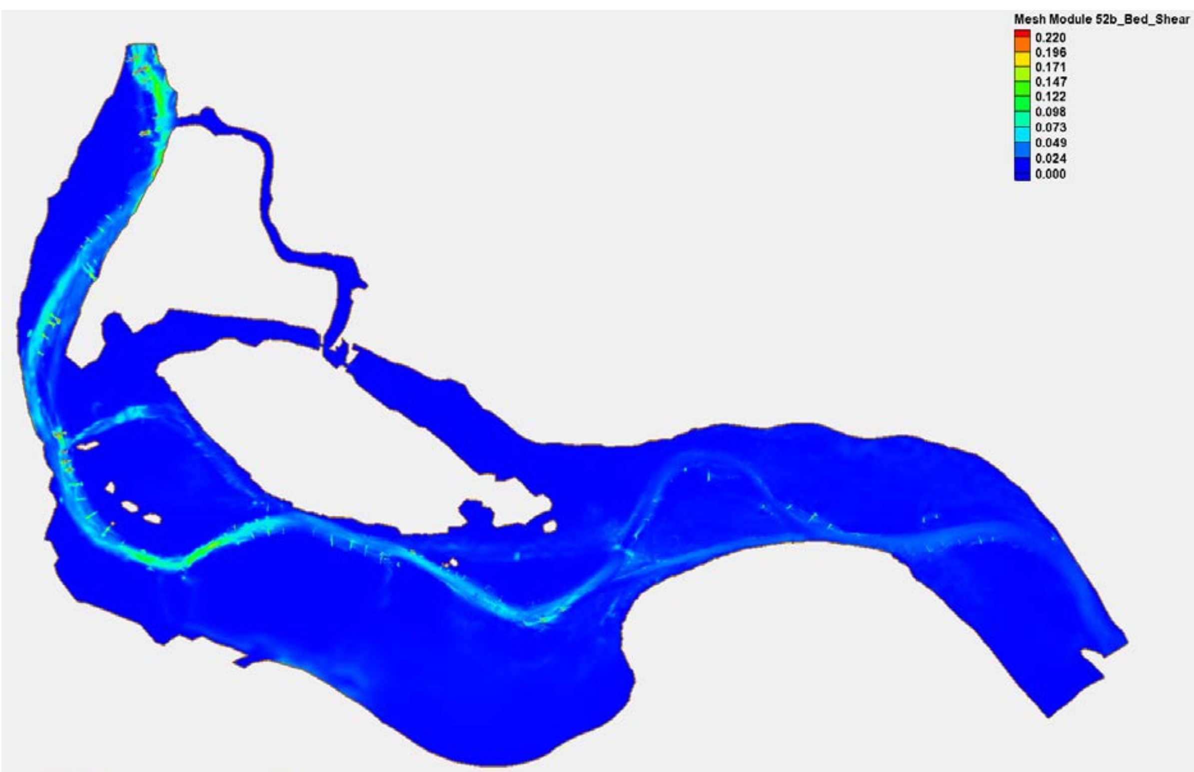


Figure C-5 Bed Shear (Low – 75% Duration) - 5970cfs - Alternative 2b

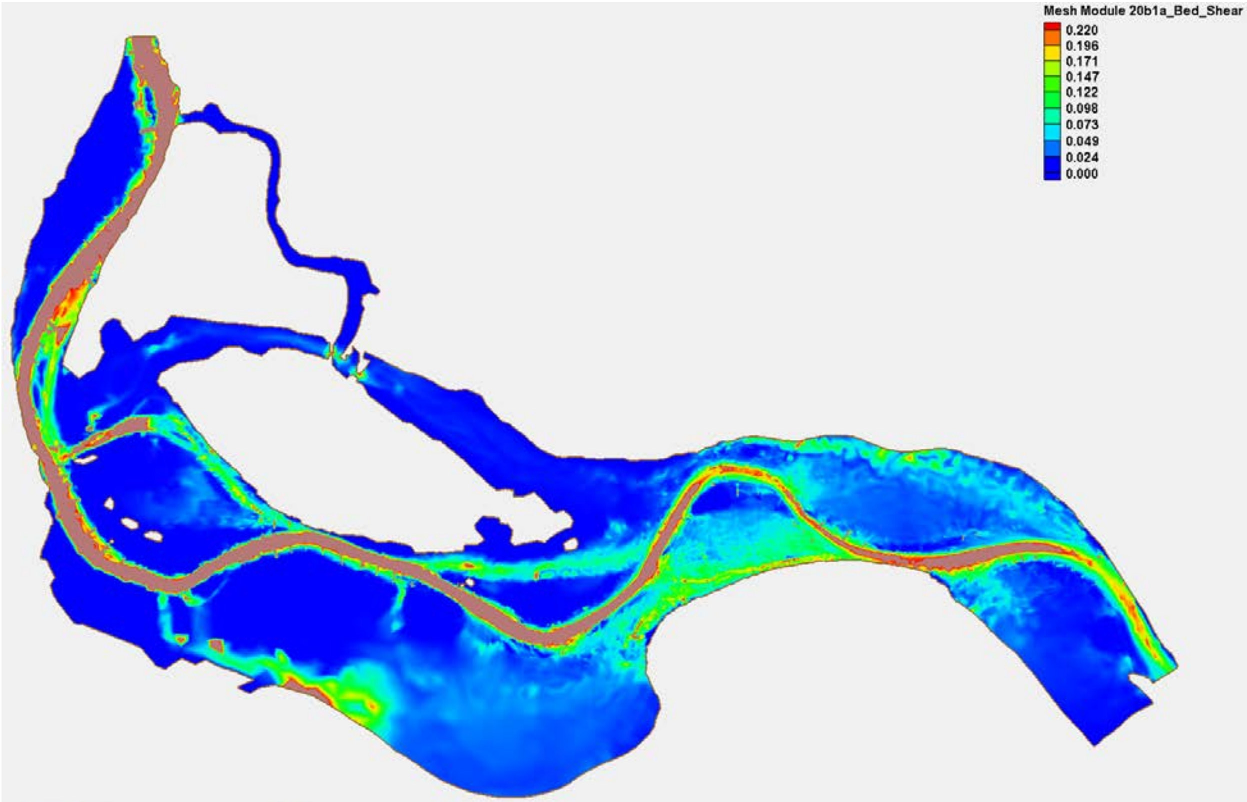


Figure C-6 Bed Shear (Medium - 25% Duration)- 20560 cfs- Base

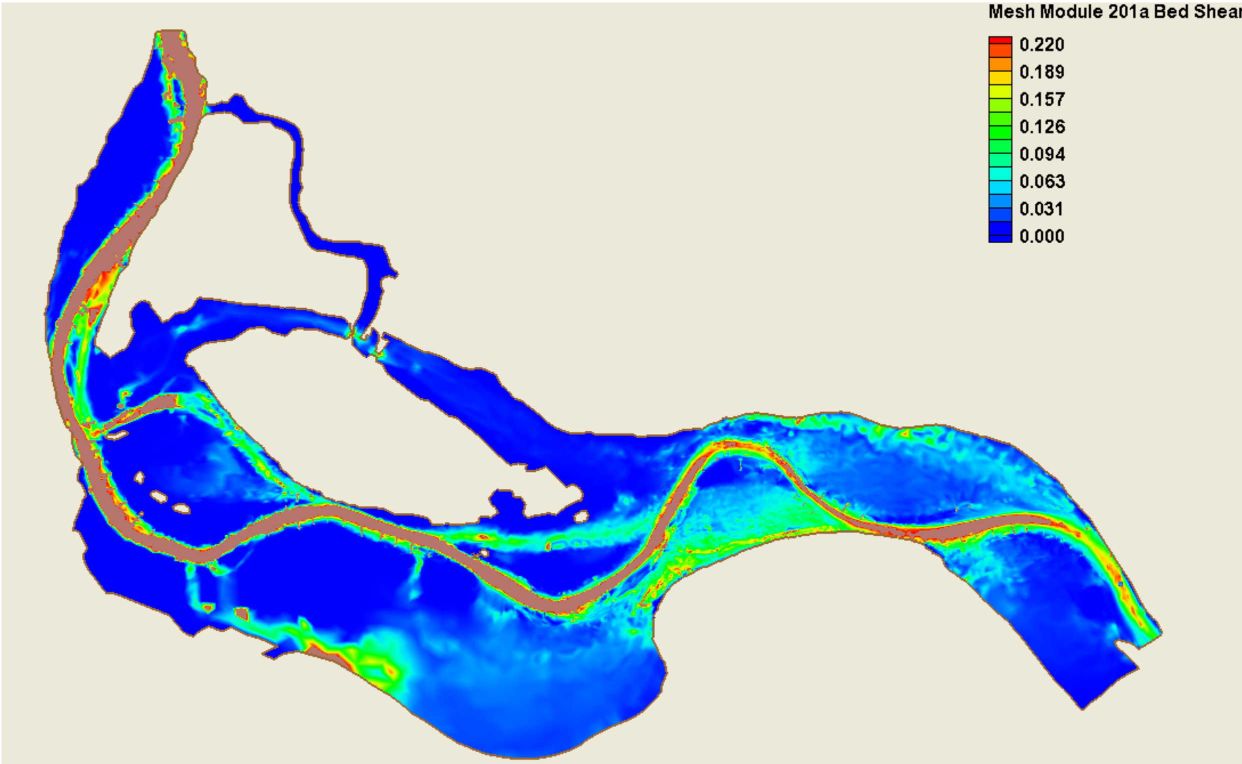


Figure C-7 Bed Shear (Medium - 25% Duration)- 20560 cfs- Alternative 1a

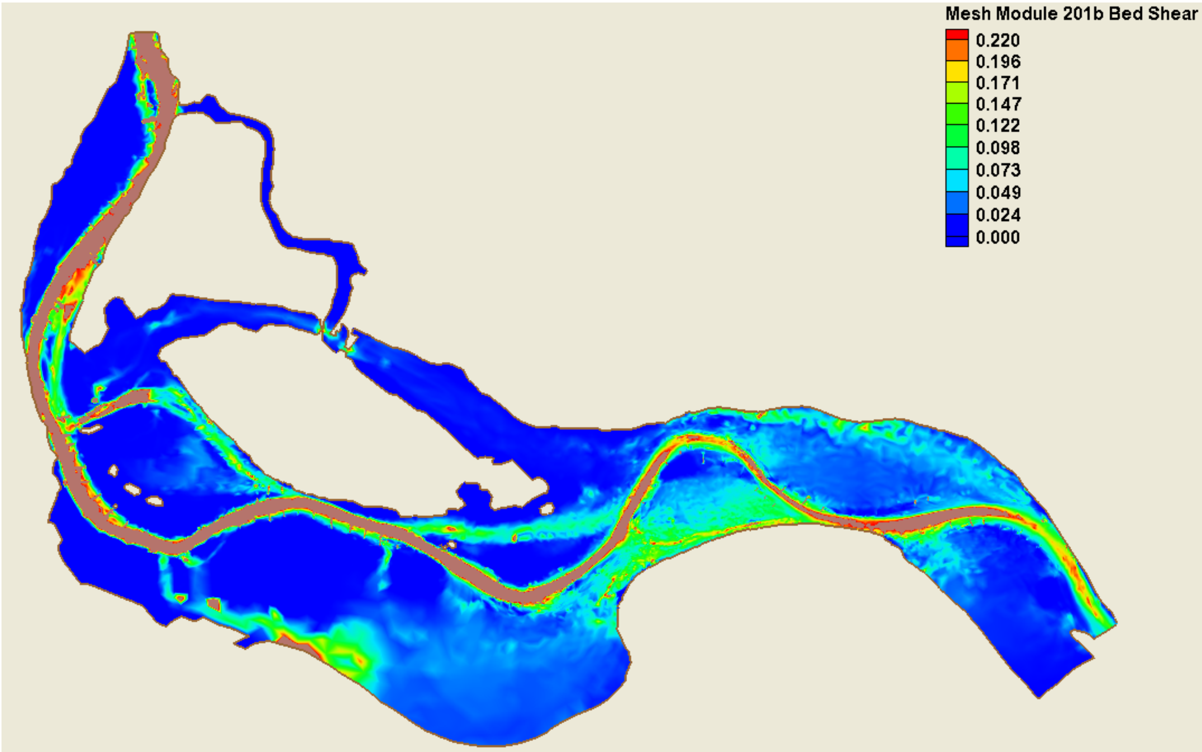


Figure C-8 Bed Shear (Medium - 25% Duration)- 20560 cfs- Alternative 1b

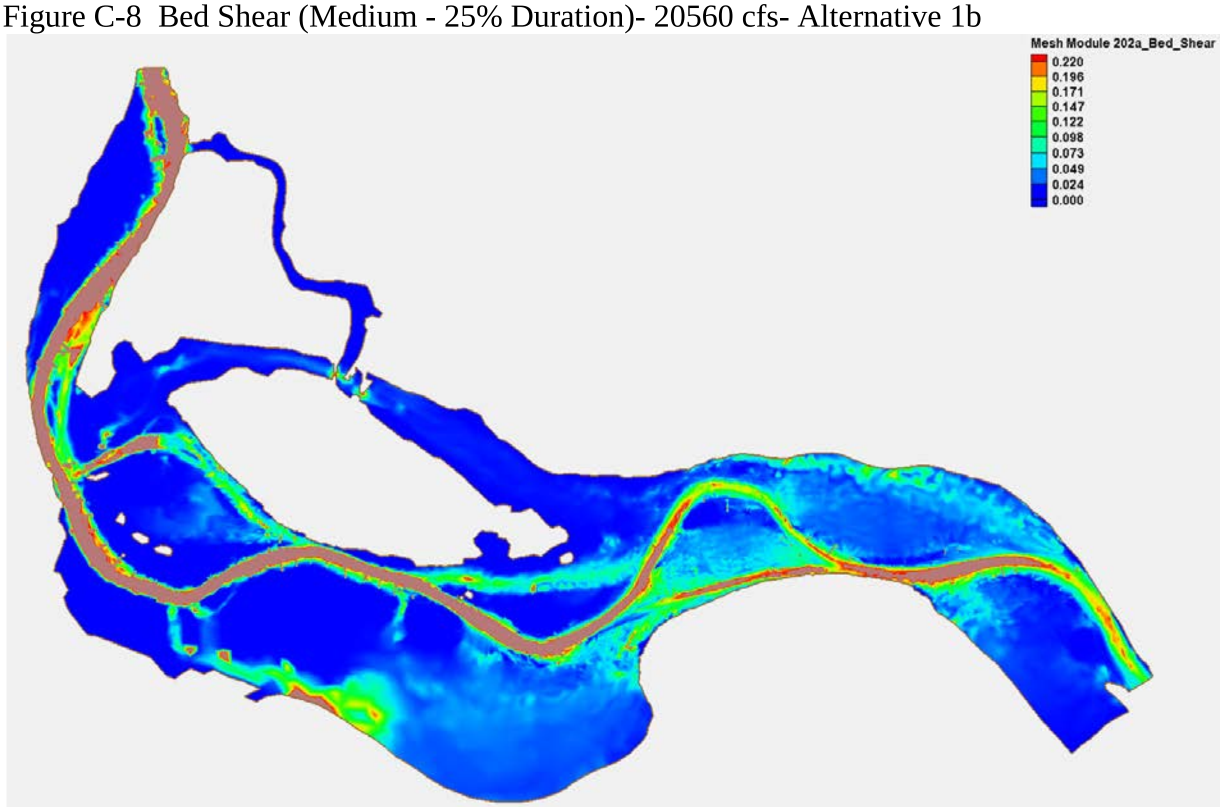


Figure C-9 Bed Shear (Medium - 25% Duration)- 20560 cfs- Alternative 2a

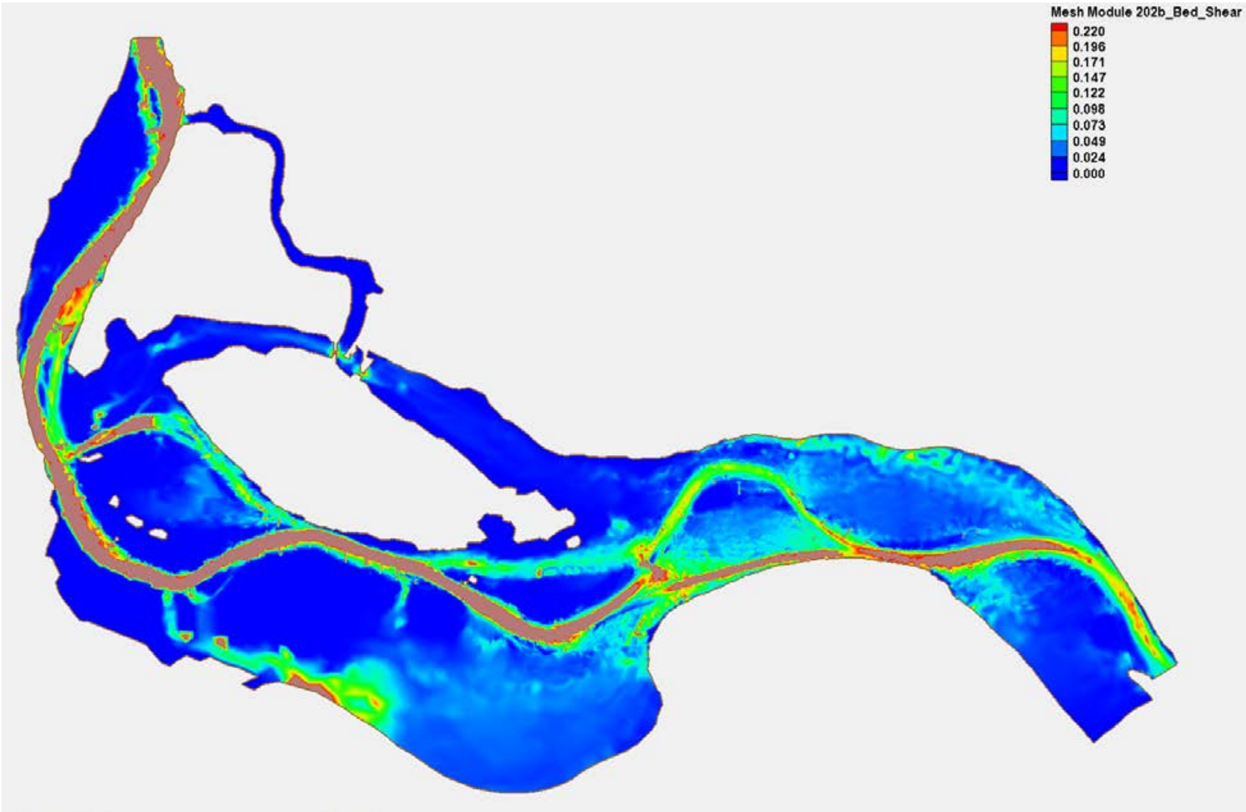


Figure C-10 Bed Shear (Medium - 25% Duration)- 20560 cfs- Alternative 2b

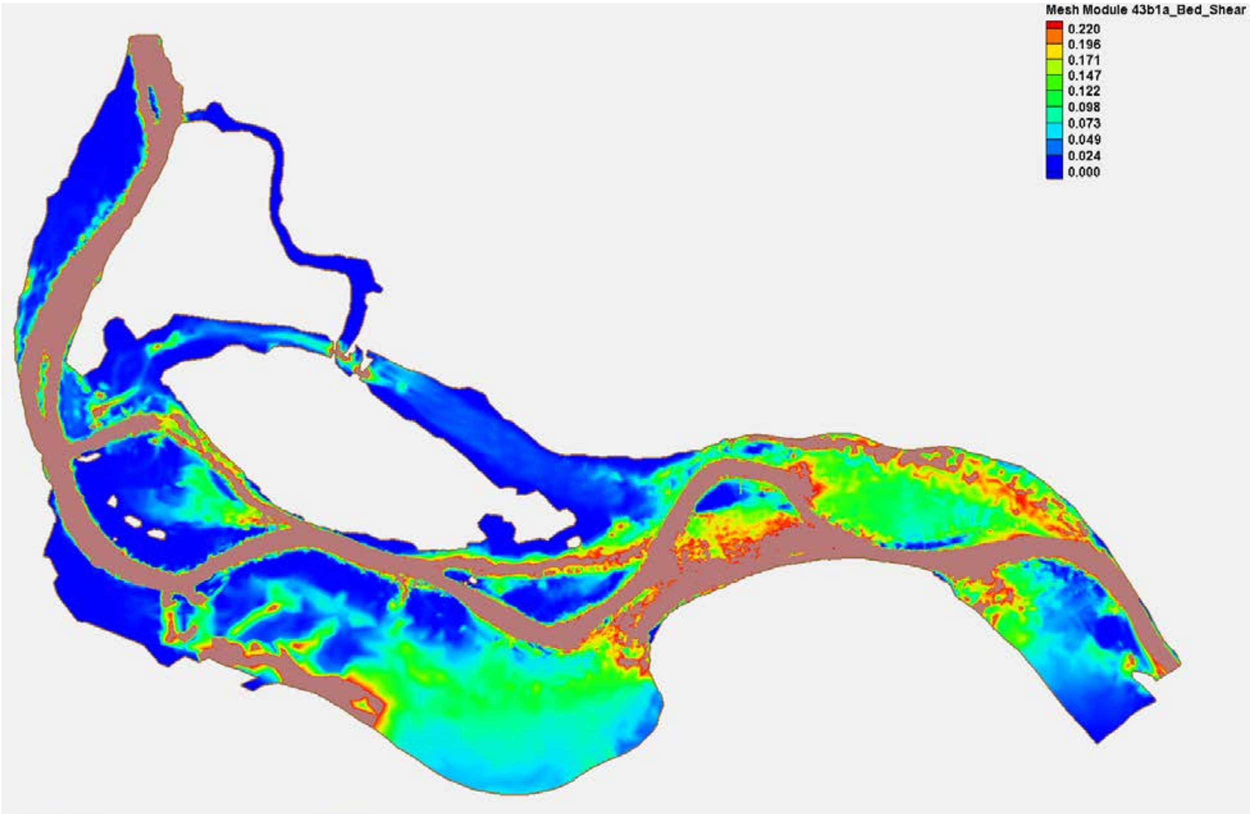


Figure C-11 Bed Shear (High - 2 Year) - 43000 cfs- Base

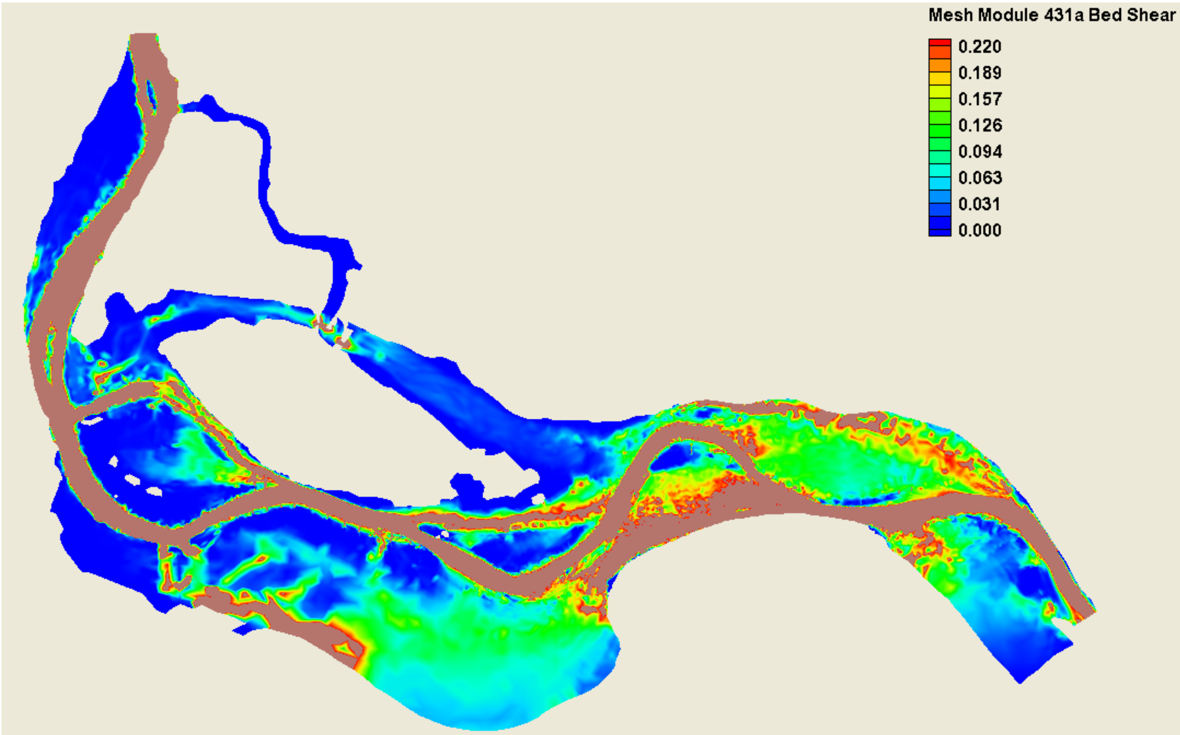


Figure C-12 Bed Shear (High - 2 Year) – 43000 cfs- Alternative 1a

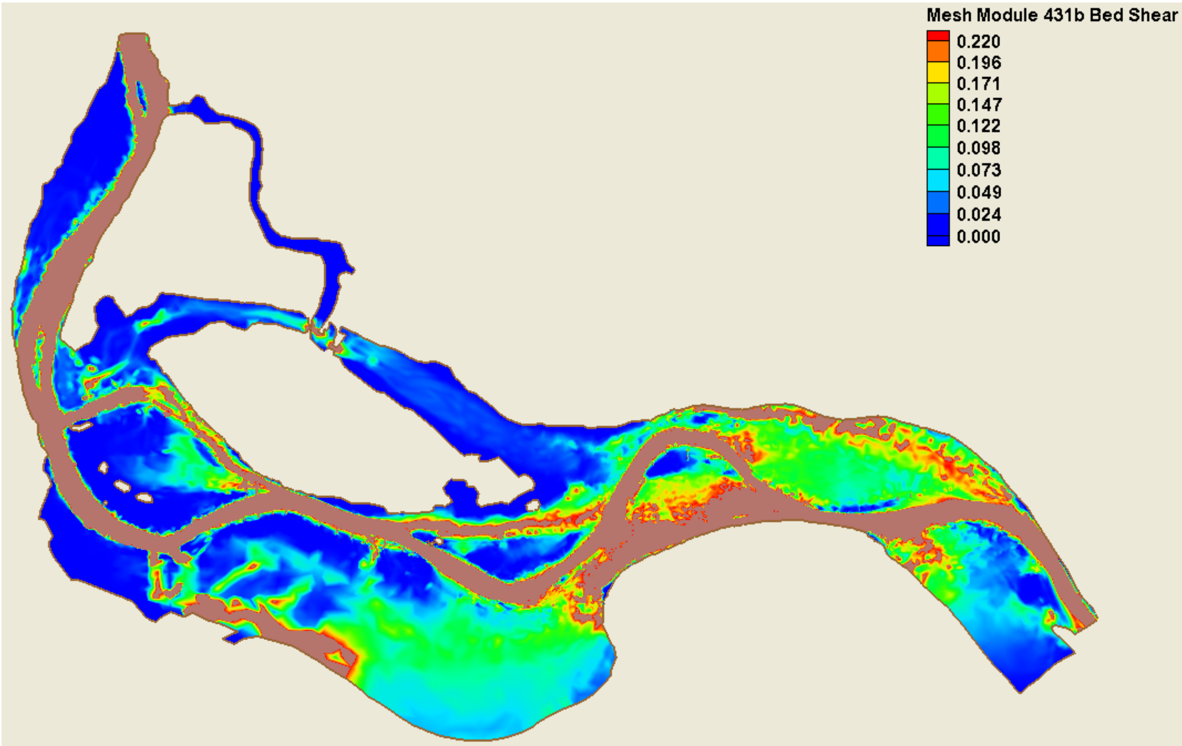


Figure C-13 Bed Shear (High - 2 Year) – 43000 cfs- Alternative 1b

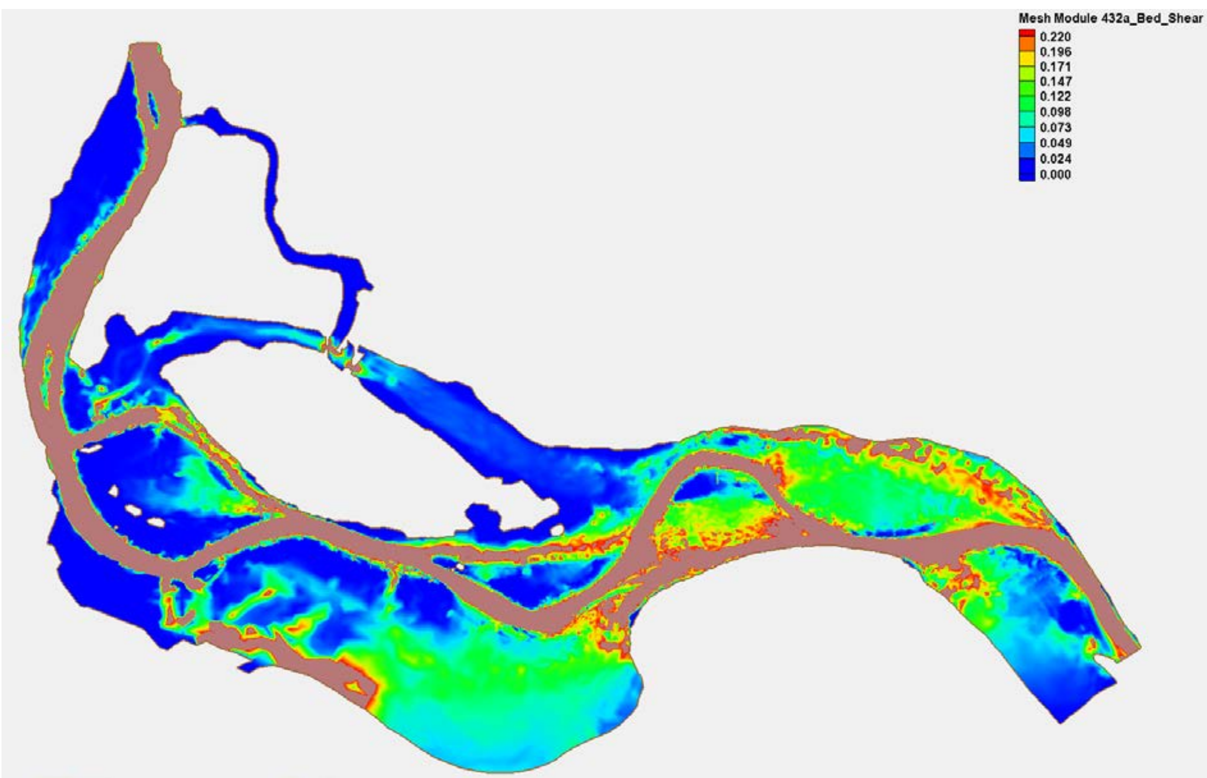


Figure C-14 Bed Shear (High - 2 Year) – 43000 cfs- Alternative 2a

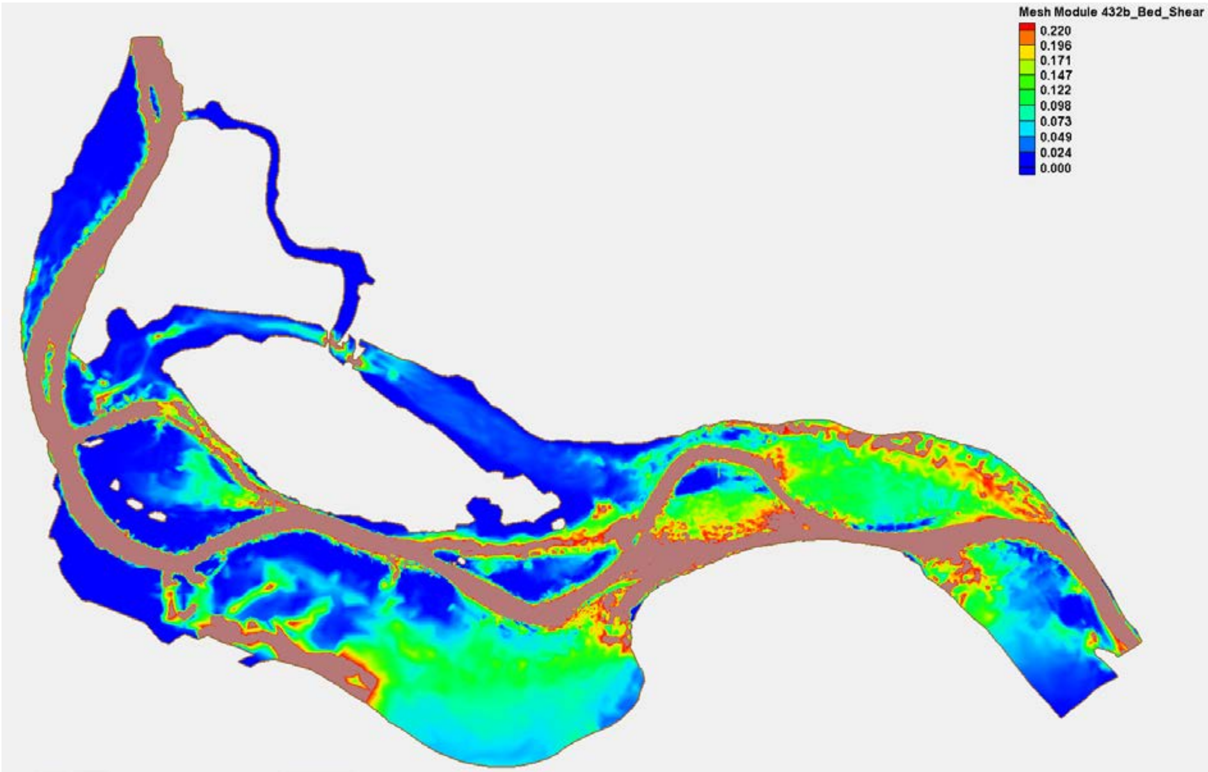


Figure C-15 Bed Shear (High - 2 Year) - 43000cfs- Alternative 2b

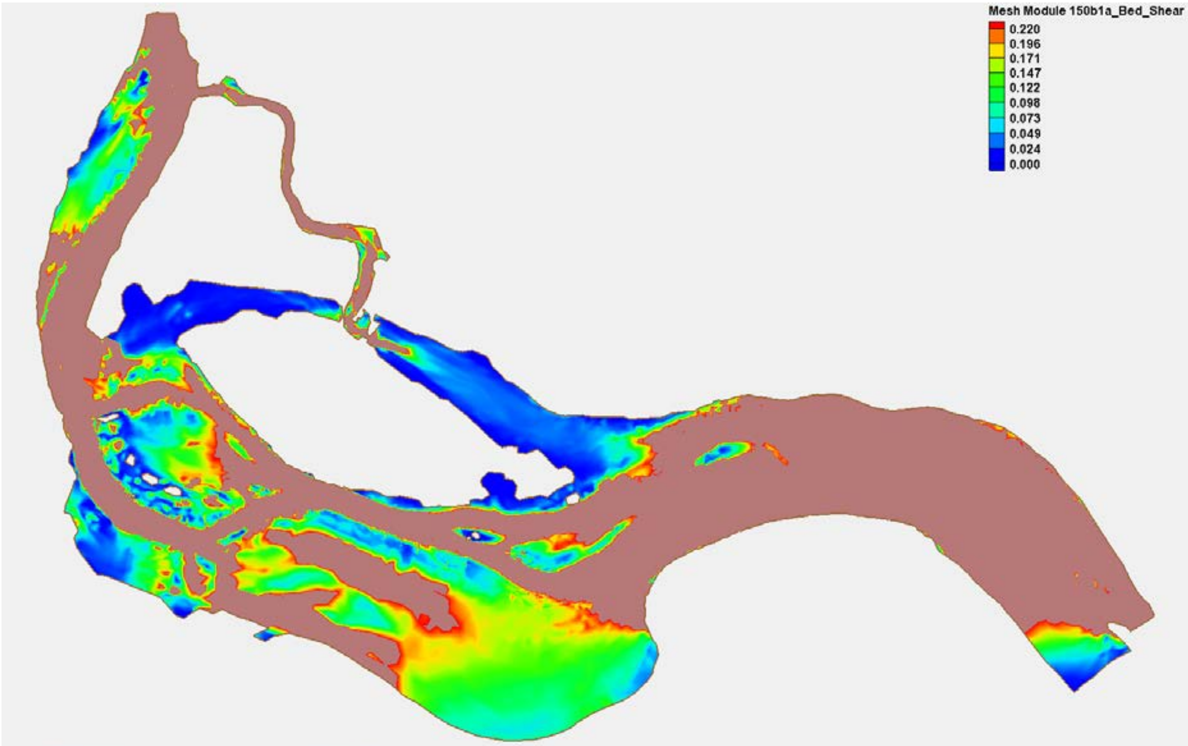


Figure C-16 Bed Shear (100 Year) - 150000 cfs cfs- Base

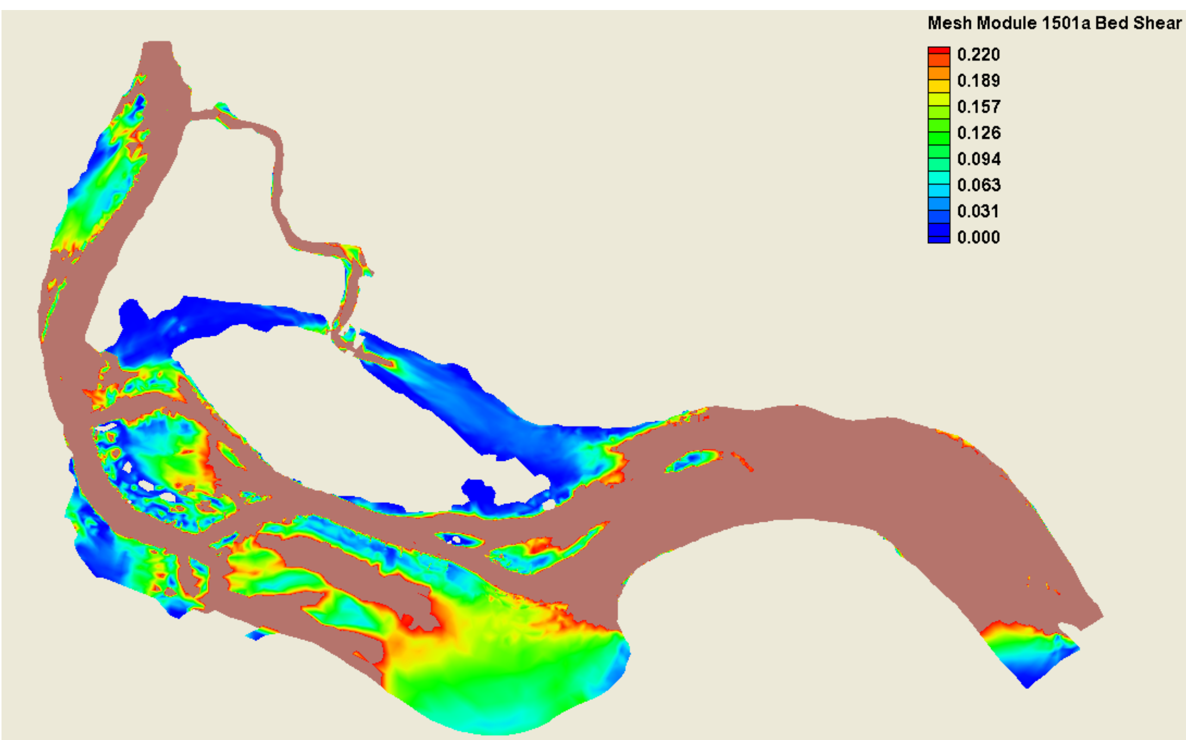


Figure C-17 Bed Shear (100 Year) - 150000 cfscfs- Alternative 1a

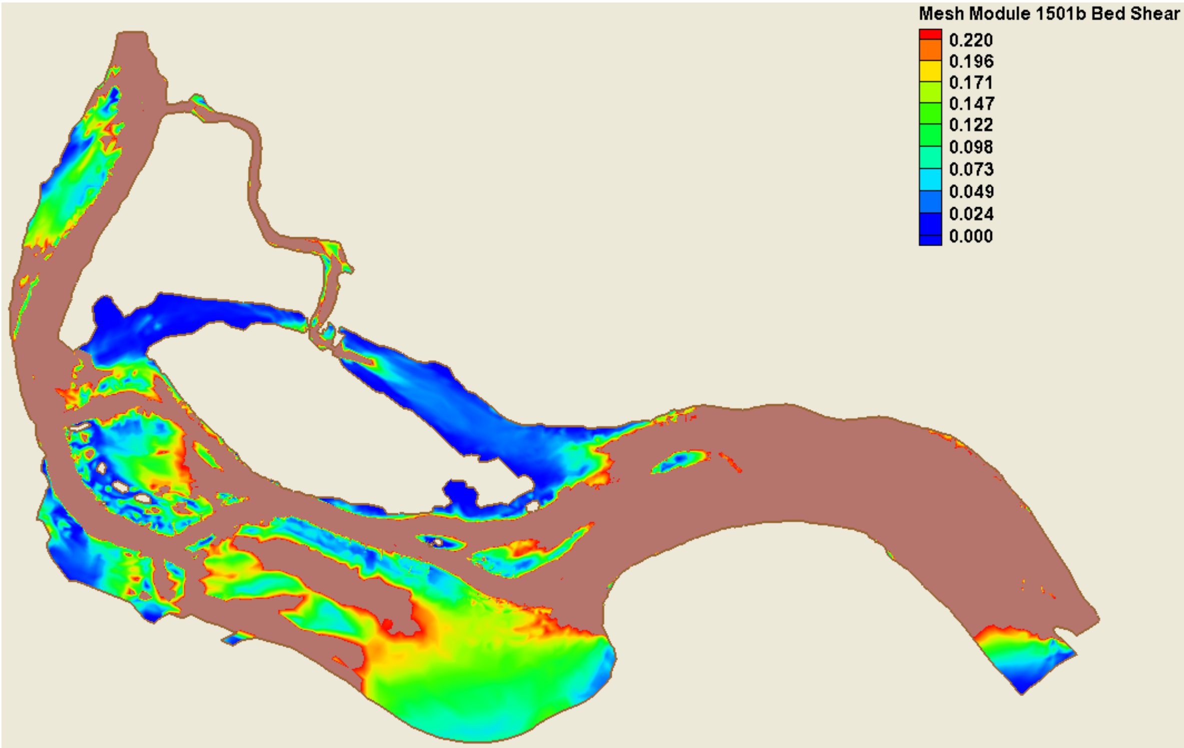


Figure C-18 Bed Shear (100 Year) - 150000 cfscfs- Alternative 1b

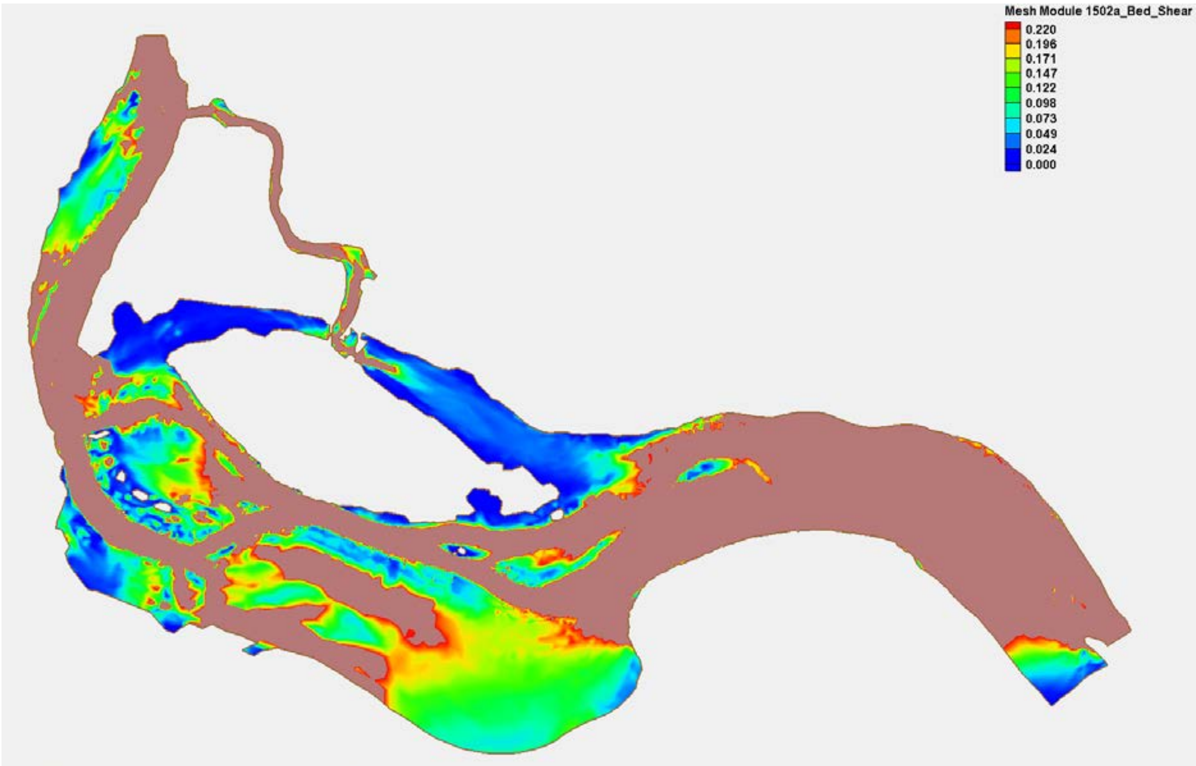


Figure C-19 Bed Shear (100 Year) - 150000 cfscfs- Alternative 2a

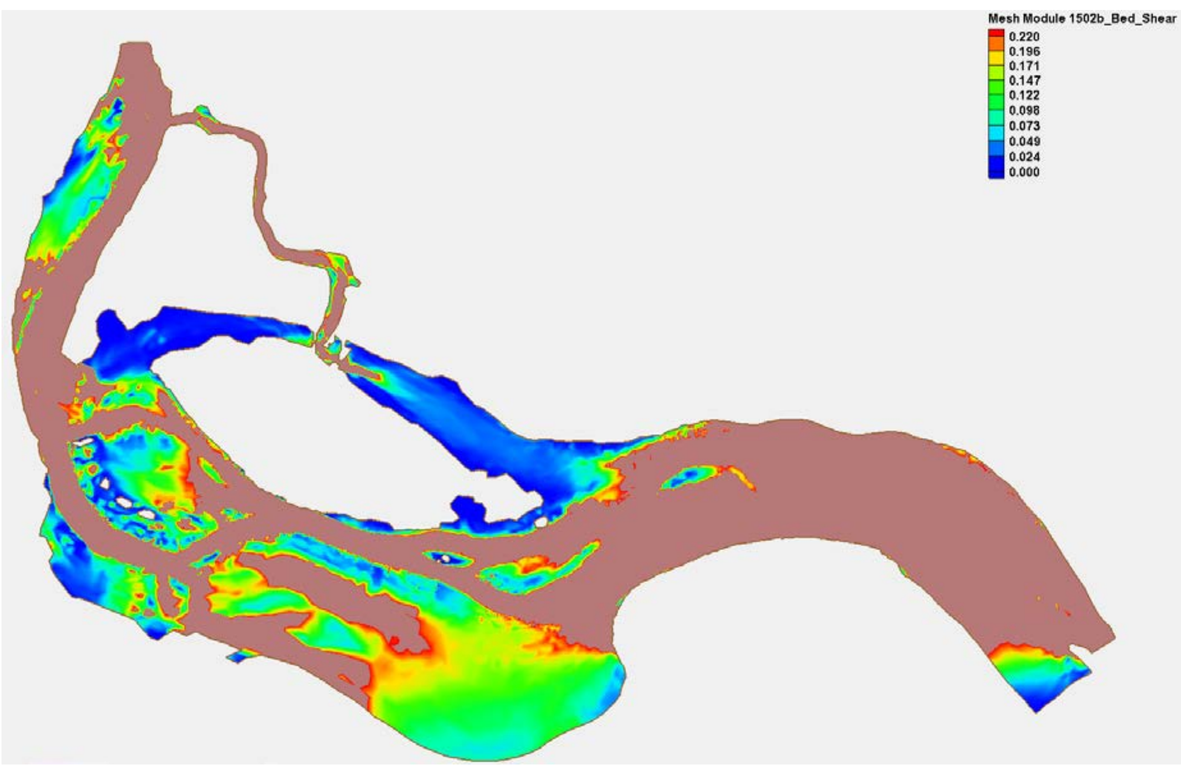


Figure C-20 Bed Shear (100 Year) - 150000 cfscfs- Alternative 2b

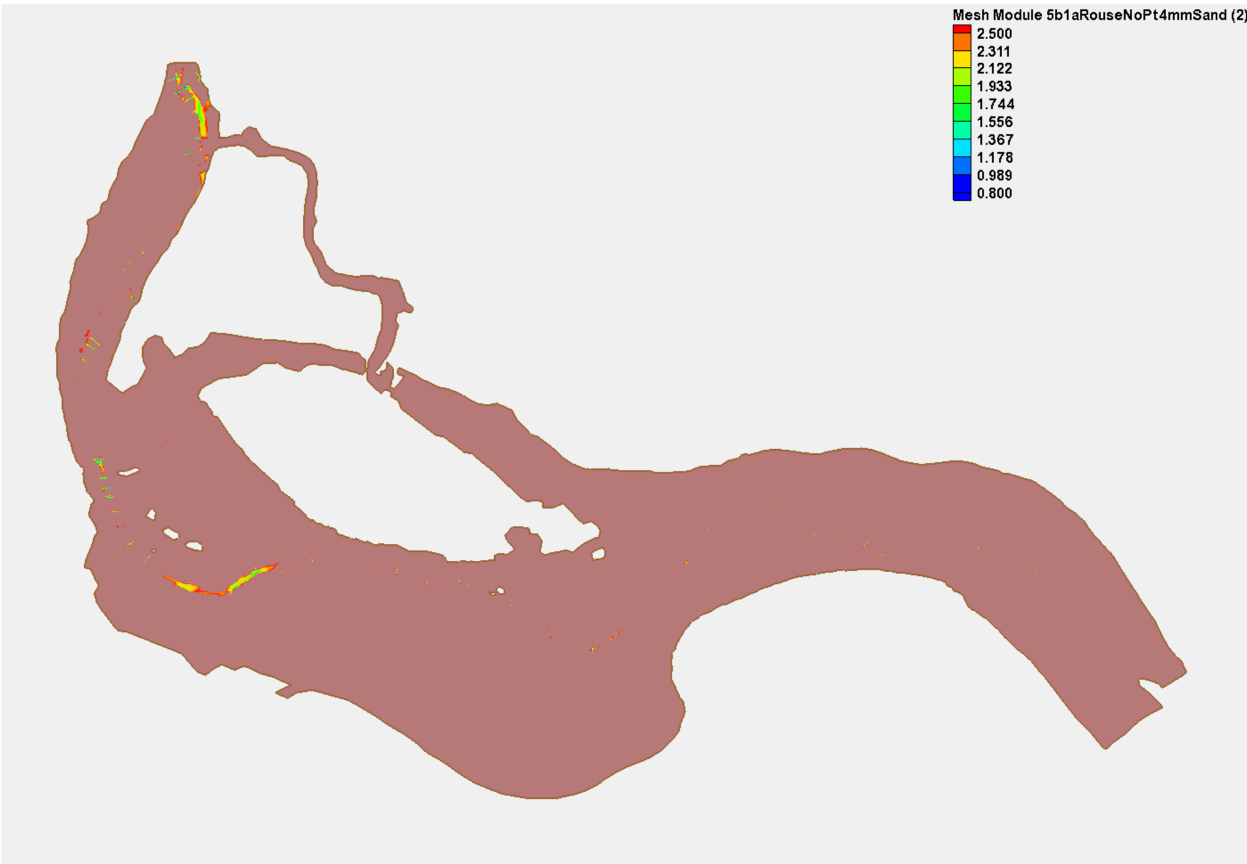


Figure C-21 Rouse (Low – 75% Duration) - 5970cfs – Base

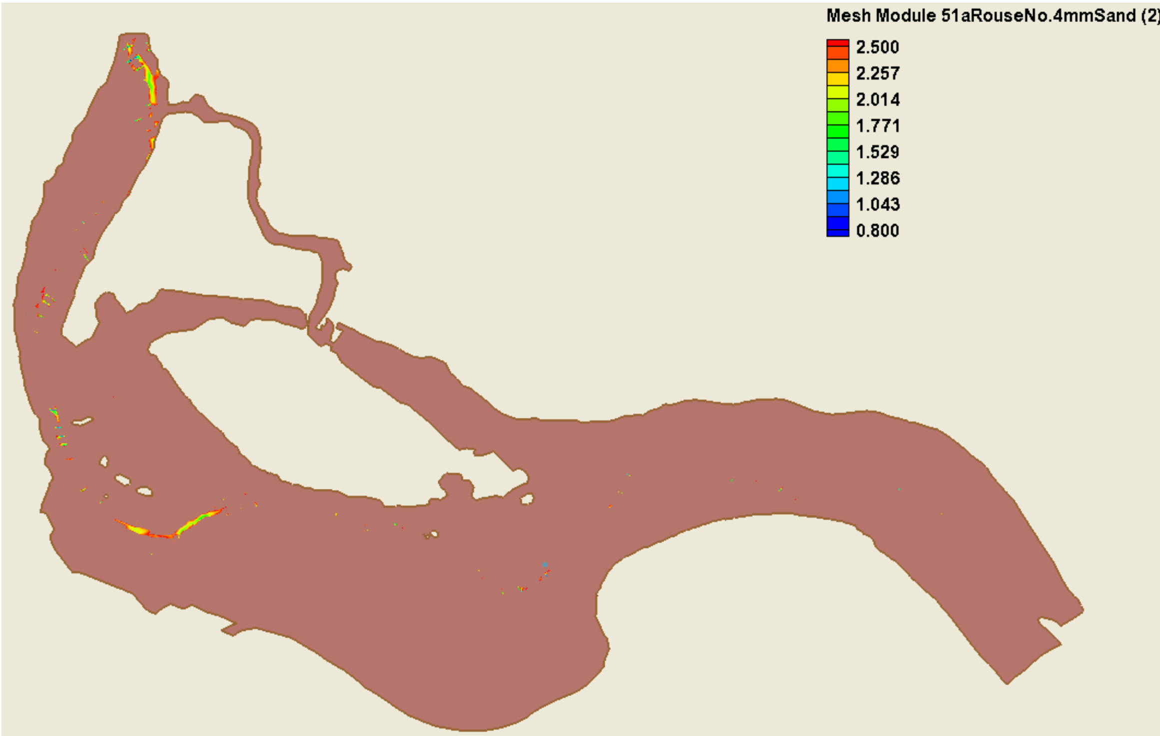


Figure C-22 Rouse (Low – 75% Duration) - 5970cfs - Alternative 1a

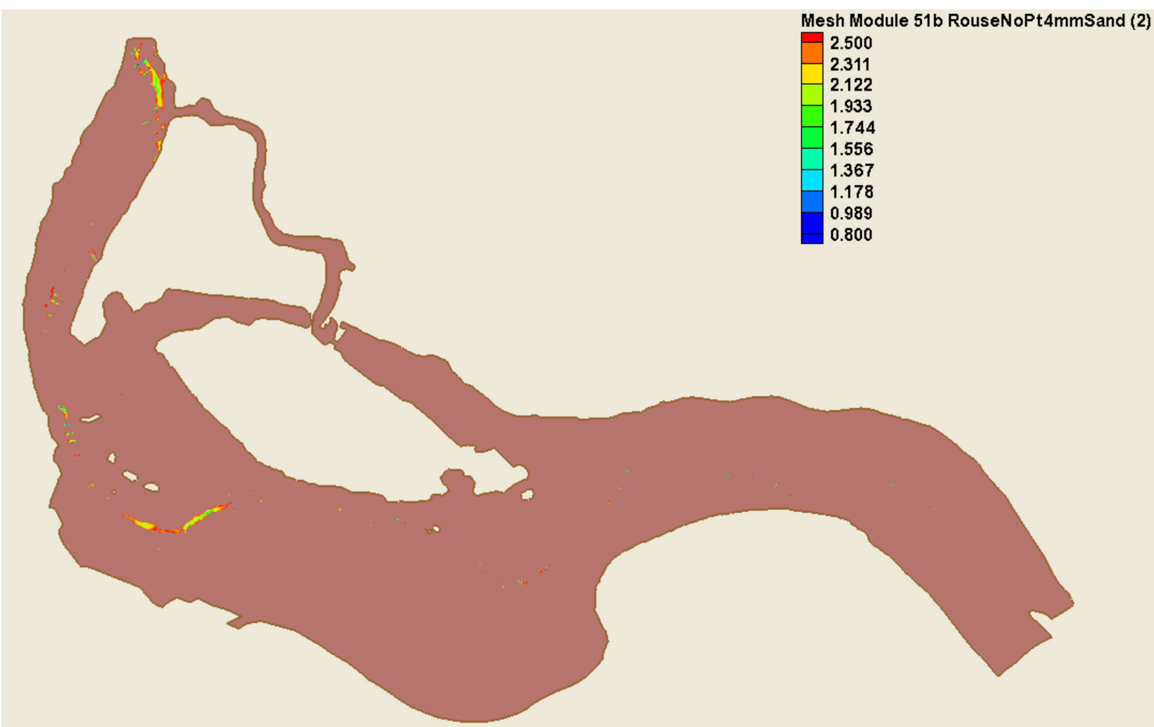


Figure C-23 Rouse (Low – 75% Duration) - 5970cfs - Alternative 1b

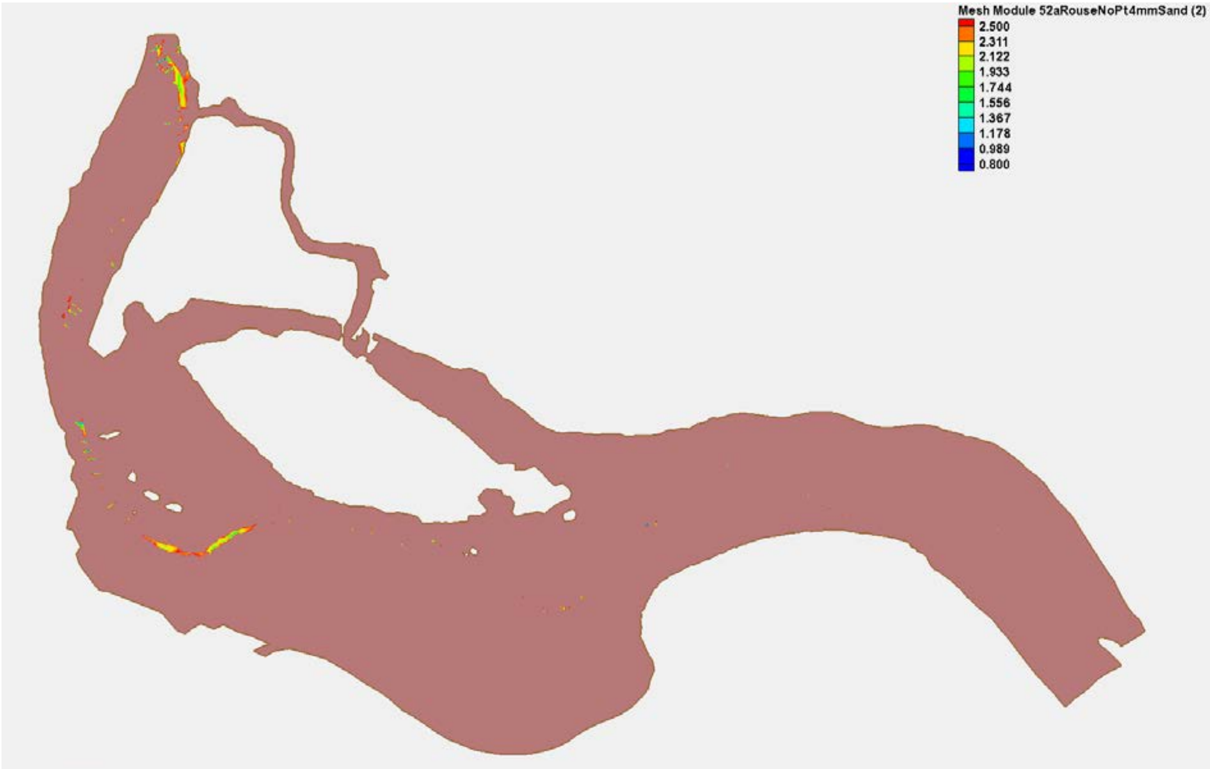


Figure C-24 Rouse (Low – 75% Duration) - 5970cfs - Alternative 2a

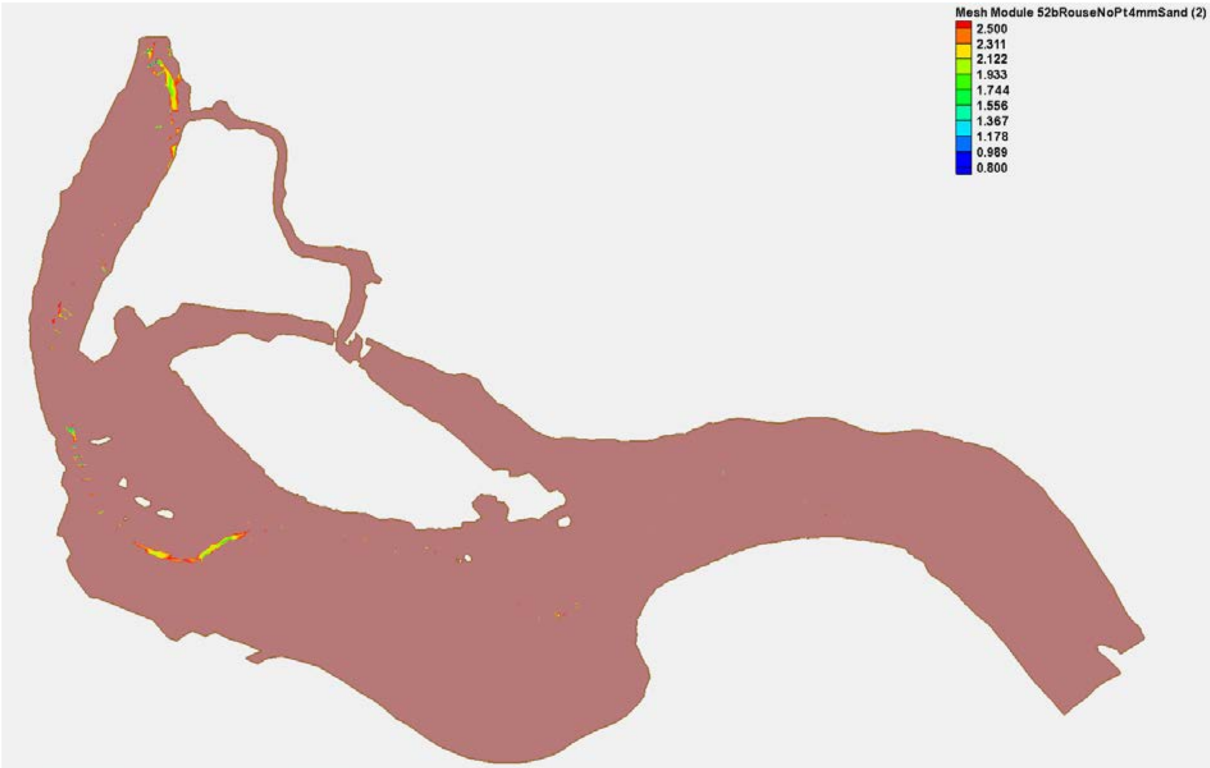


Figure C-25 Rouse (Low – 75% Duration) - 5970cfs - Alternative 2b

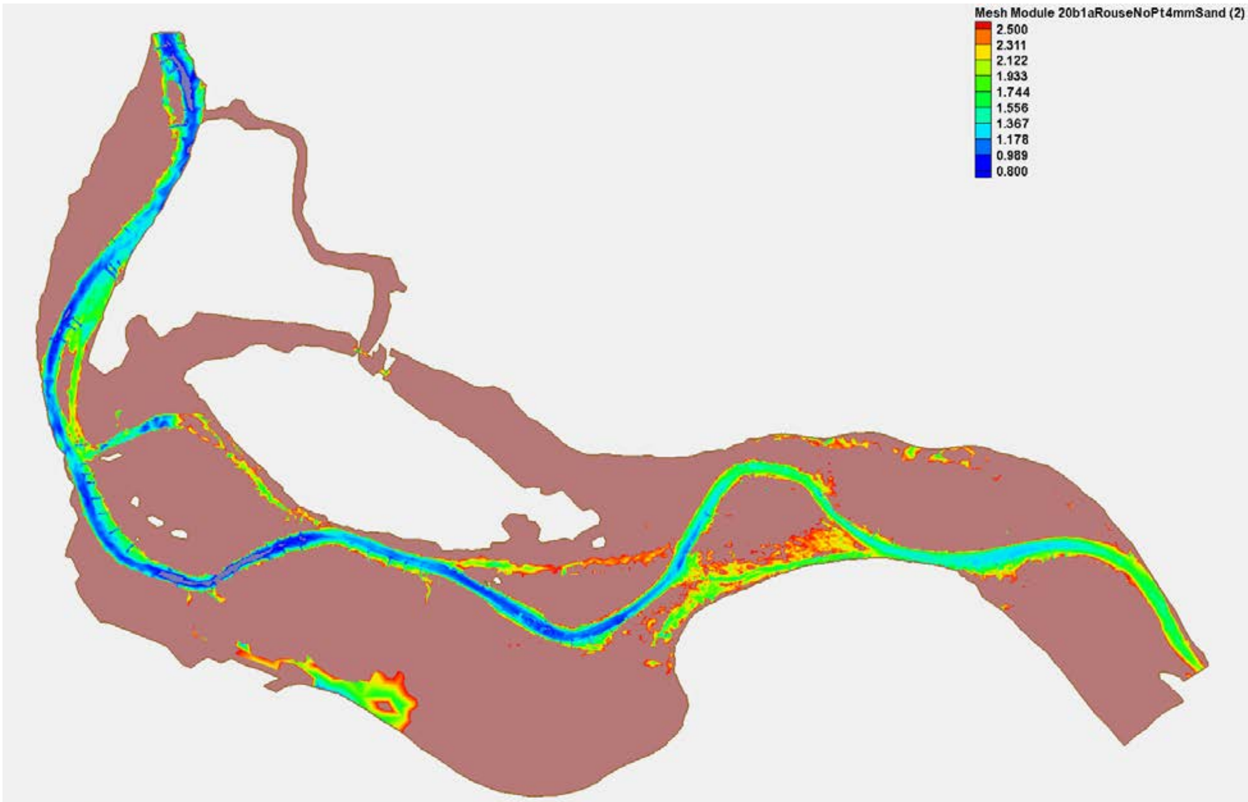


Figure C-1 Rouse (Medium - 25% Duration)- 20560 cfs- Base

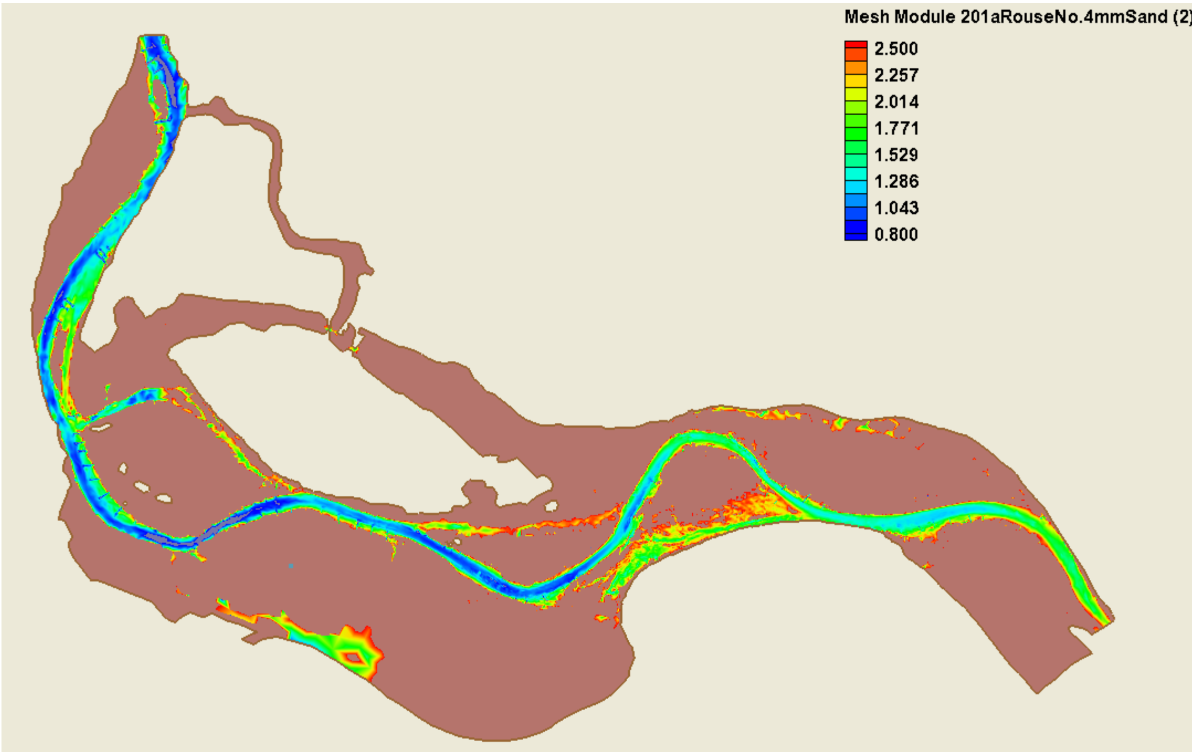


Figure C-2 Rouse (Medium - 25% Duration)- 20560 cfs- Alternative 1a

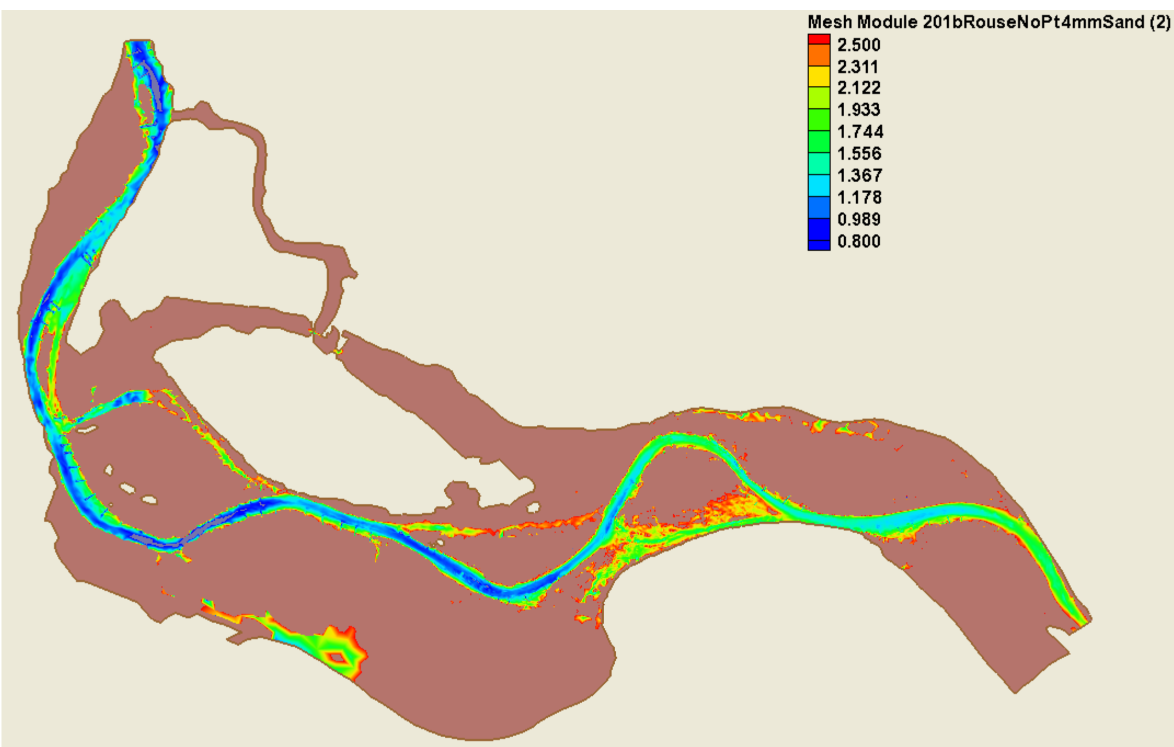


Figure C-3 Rouse (Medium - 25% Duration)- 20560 cfs- Alternative 1b

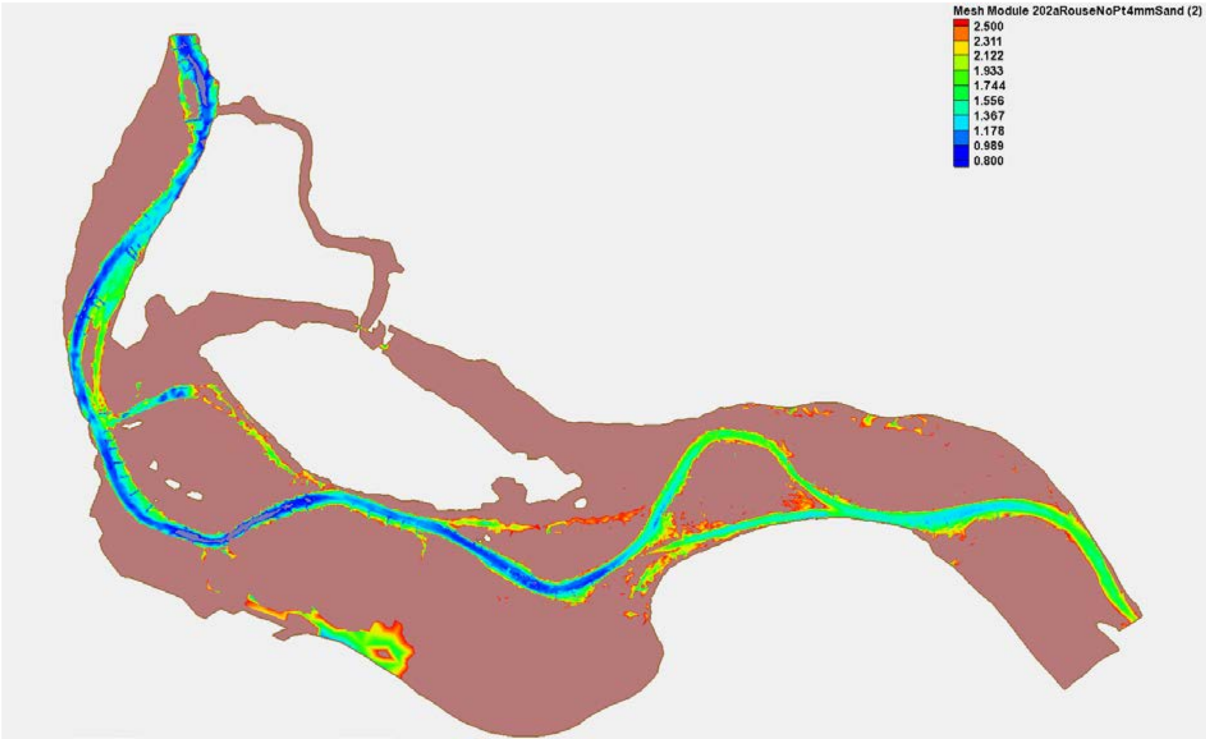


Figure C-4 Rouse (Medium - 25% Duration)- 20560 cfs- Alternative 2a

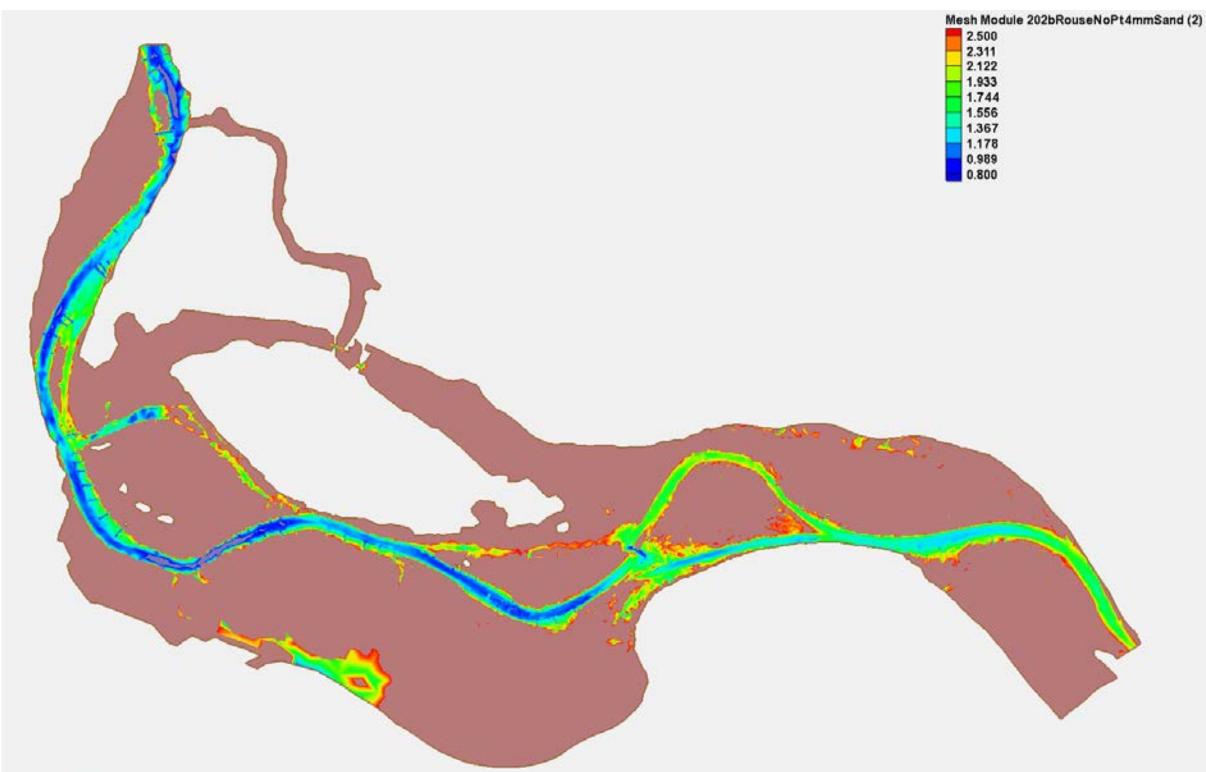
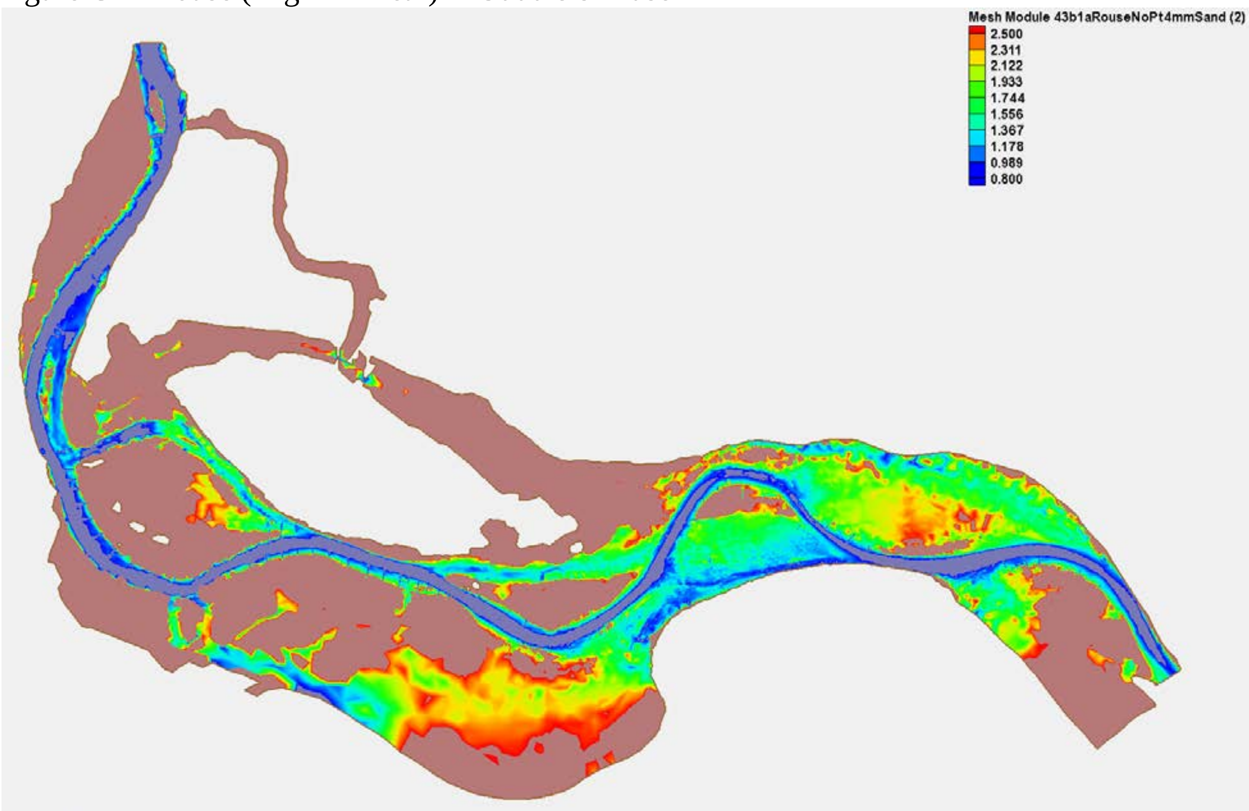


Figure C-5 Rouse (Medium - 25% Duration)- 20560 cfs- Alternative 2b

Figure C-1 Rouse (High - 2 Year) - 43000 cfs- Base



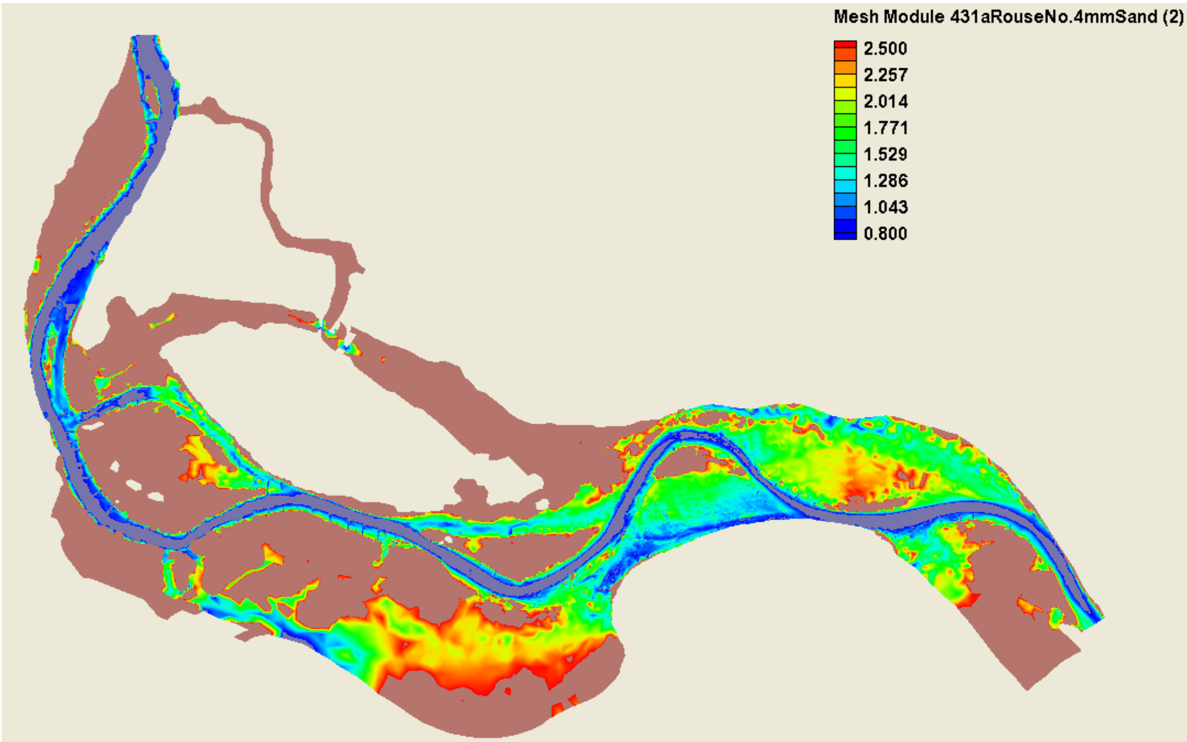


Figure C-2 Rouse (High - 2 Year) – 43000 cfs- Alternative 1a

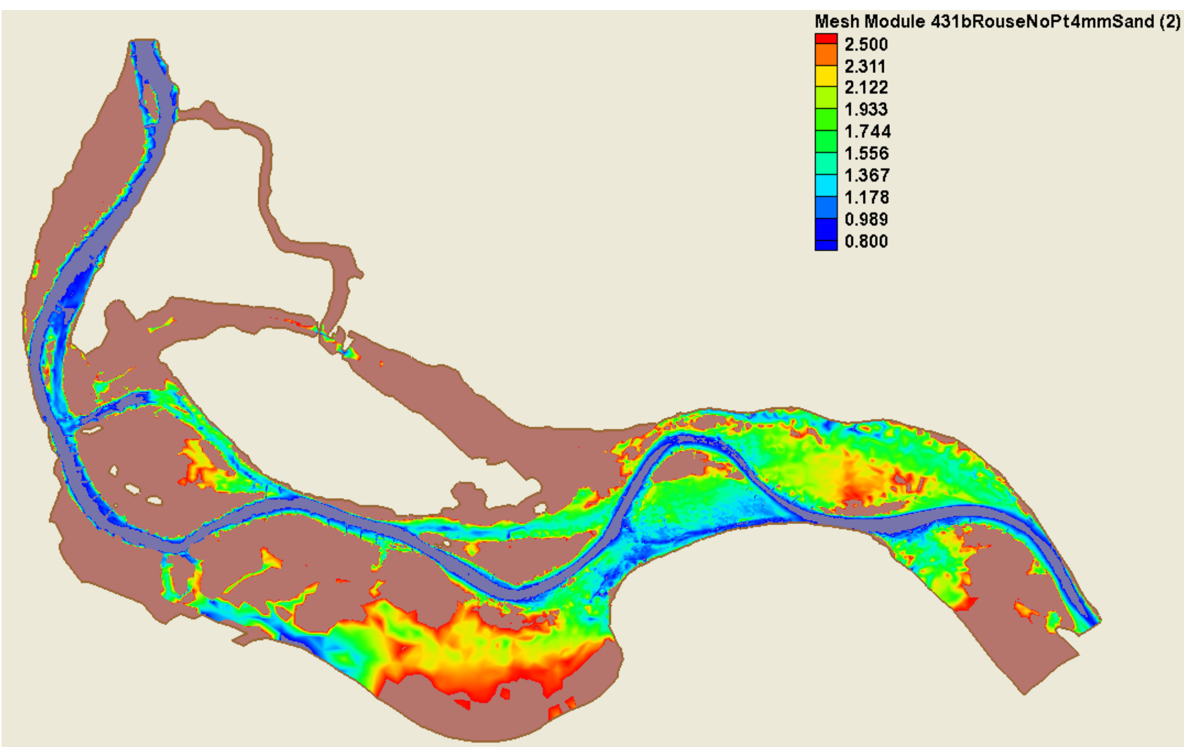


Figure C-3 Rouse (High - 2 Year) – 43000 cfs- Alternative 1b

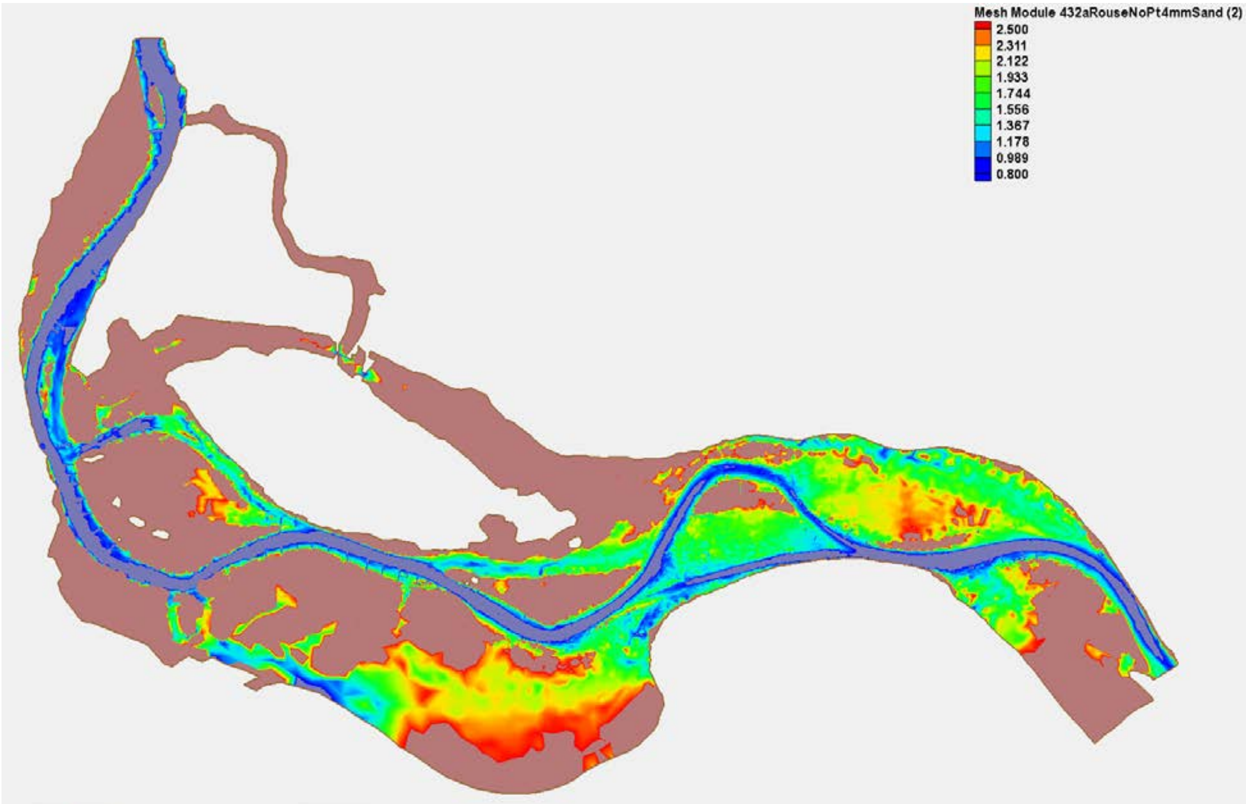


Figure C-4 Rouse (High - 2 Year) – 43000 cfs- Alternative 2a

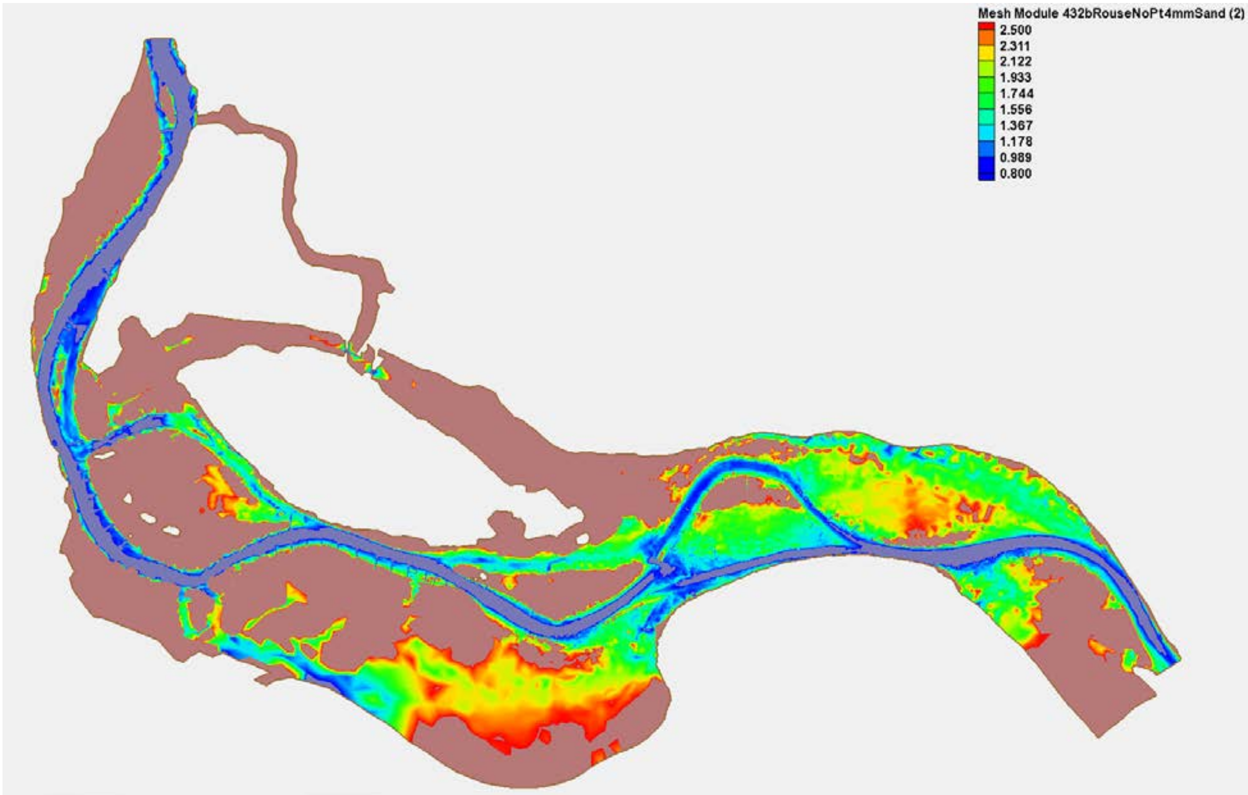


Figure C-5 Rouse (High - 2 Year) - 43000cfs- Alternative 2b

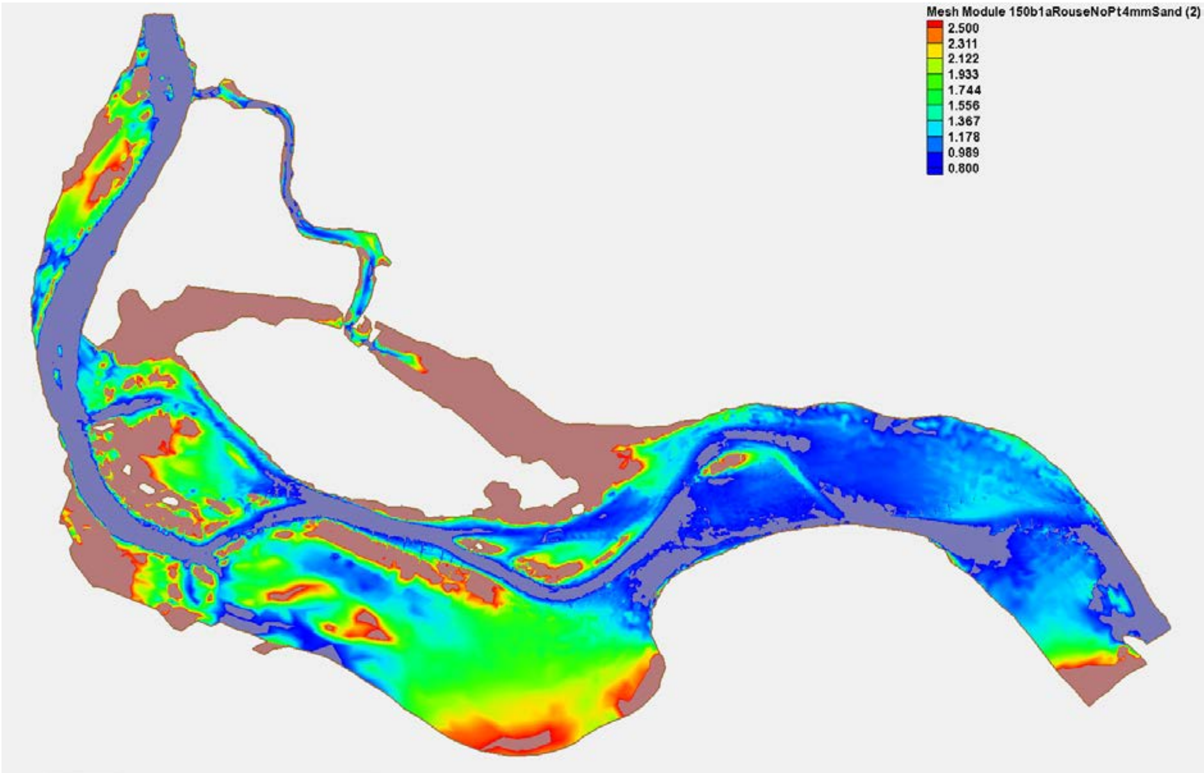


Figure C-1 Rouse (100 Year) - 150000 cfs cfs- Base

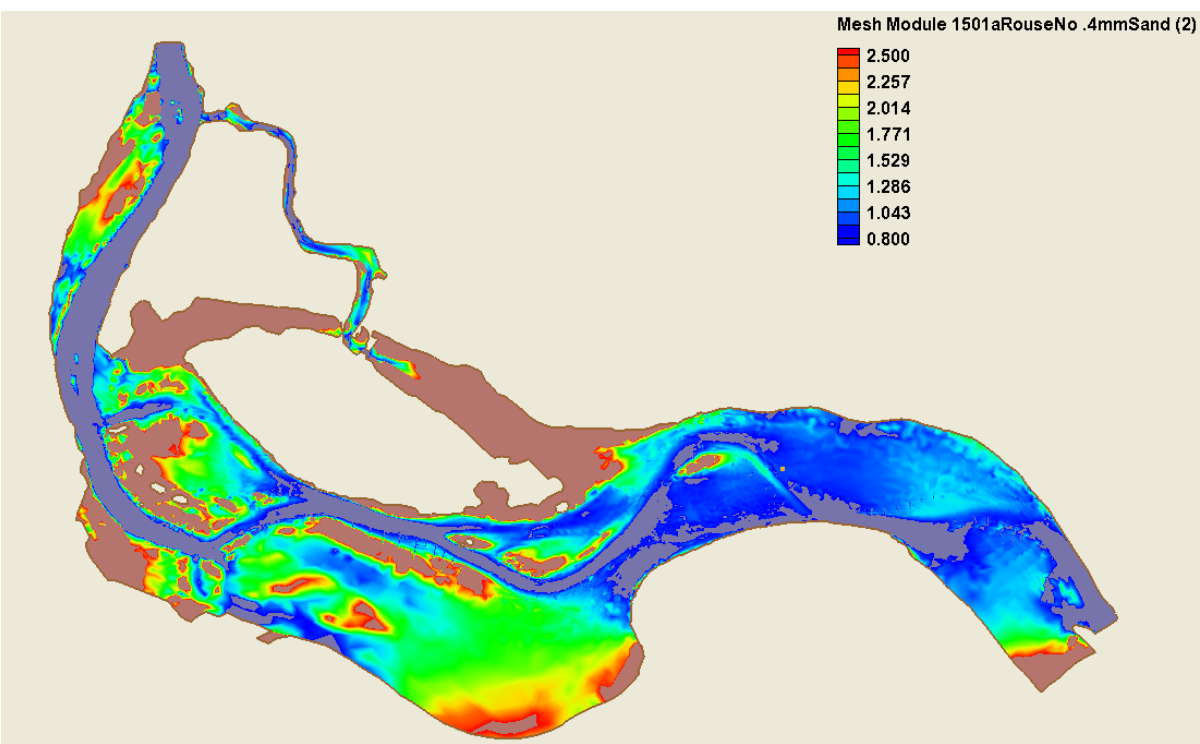


Figure C-2 Rouse (100 Year) - 150000 cfscfs- Alternative 1a

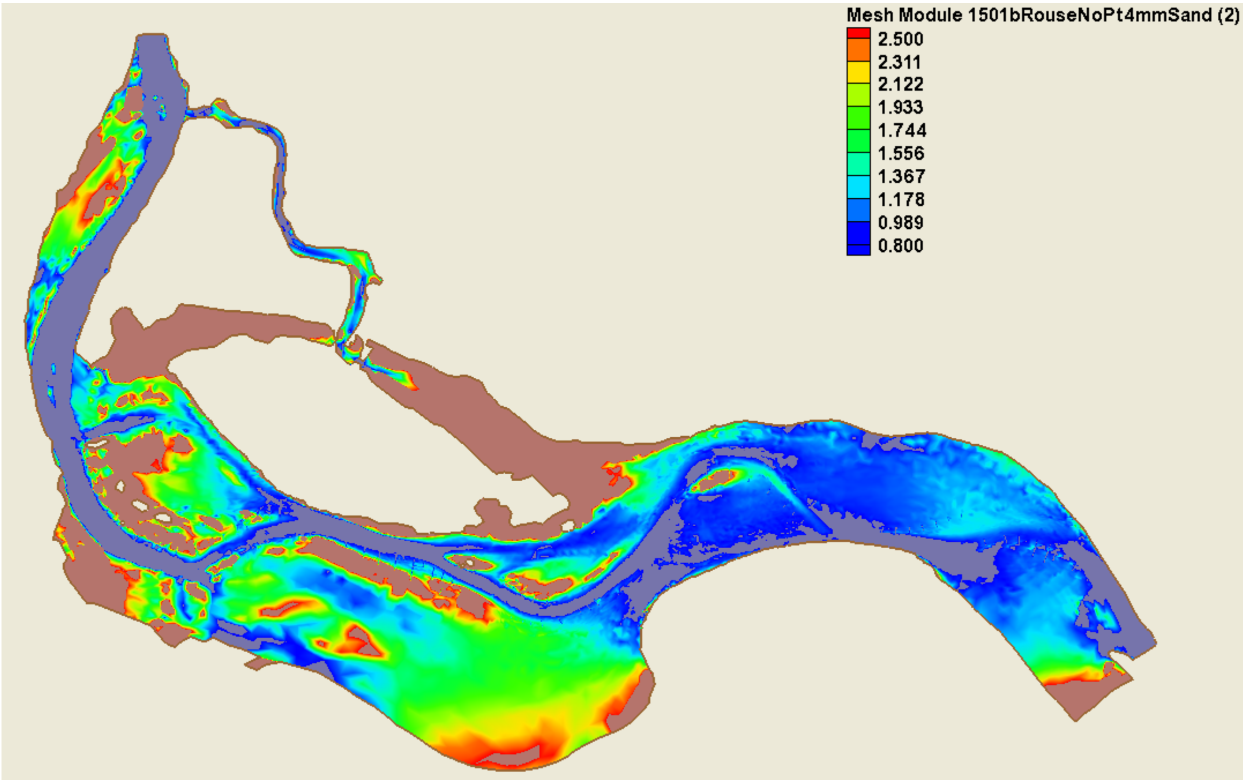


Figure C-3 Rouse (100 Year) - 150000 cfscfs- Alternative 1b

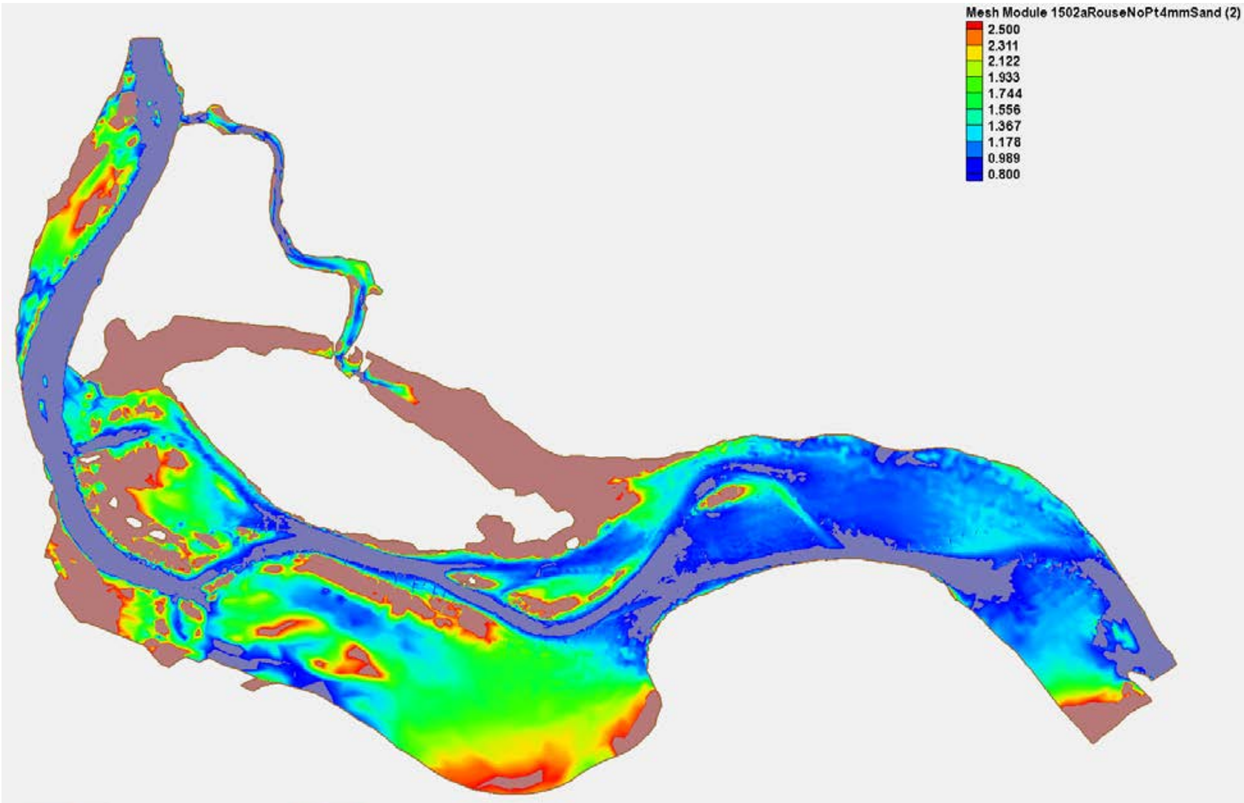


Figure C-4 Rouse (100 Year) - 150000 cfscfs- Alternative 2a

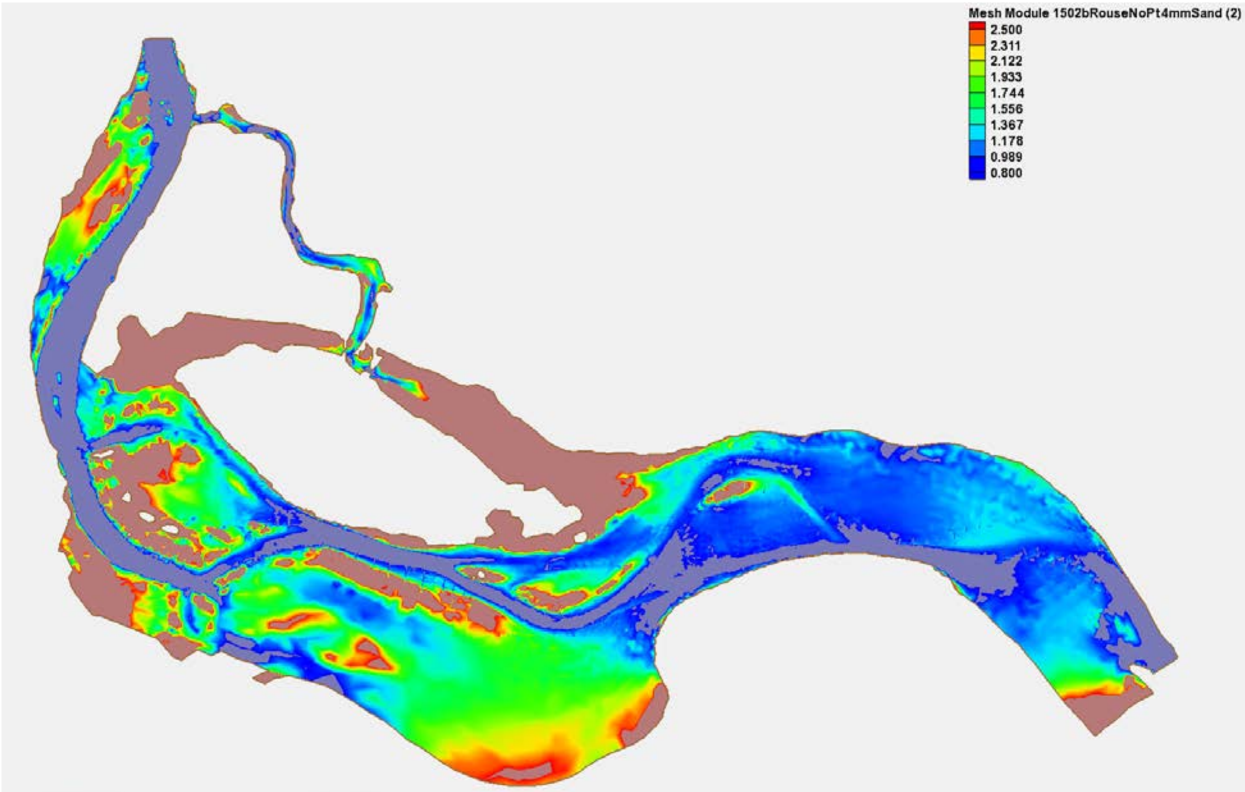


Figure C-5 Rouse (100 Year) - 150000 cfscfs- Alternative 2b

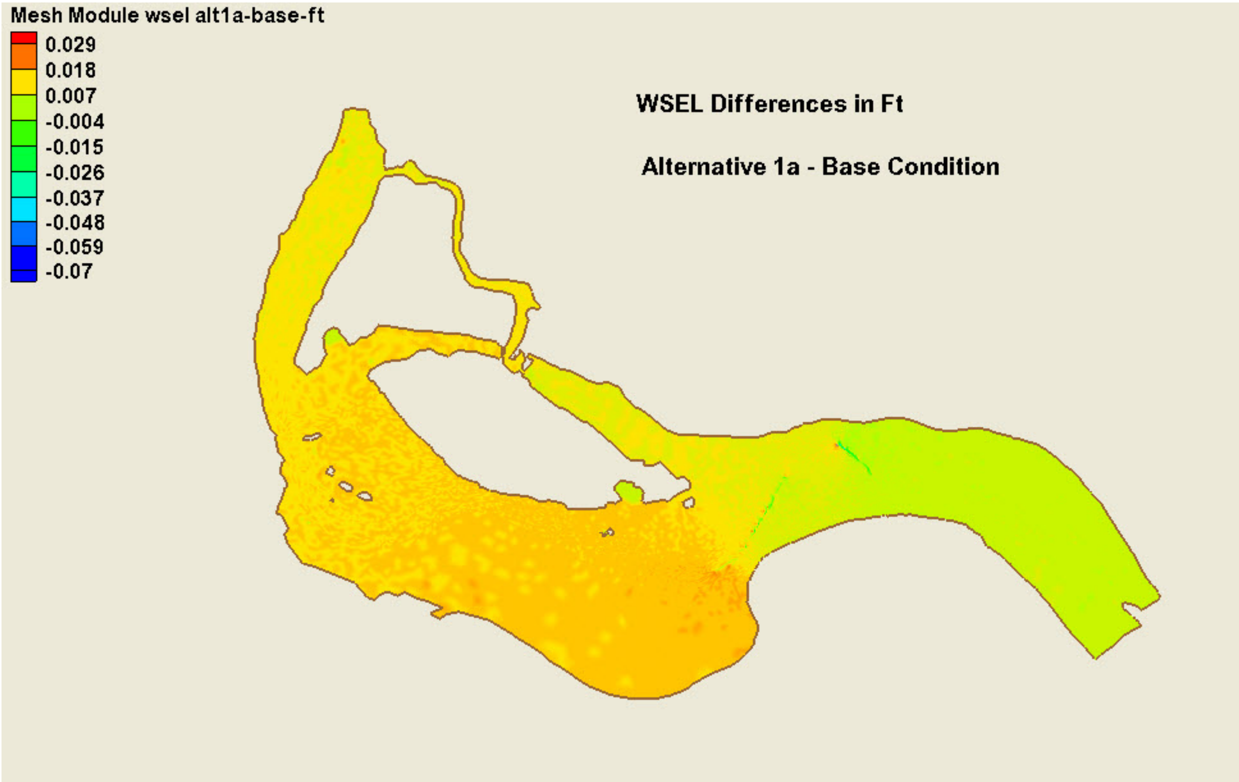


Figure C-2 Water Surface Elevation Change Above Base Conditions (100 Year) - 150000 cfscfs- Alternative 1a

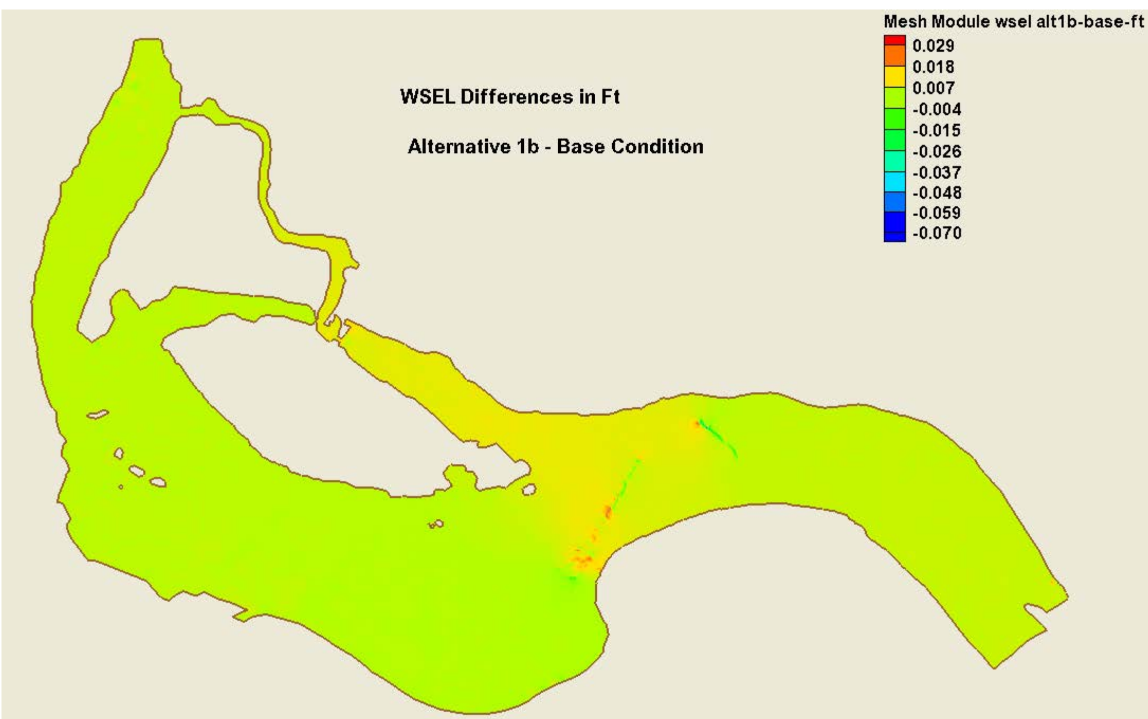


Figure C-3 Water Surface Elevation Change Above Base Conditions (100 Year) - 150000 cfscfs- Alternative 1b

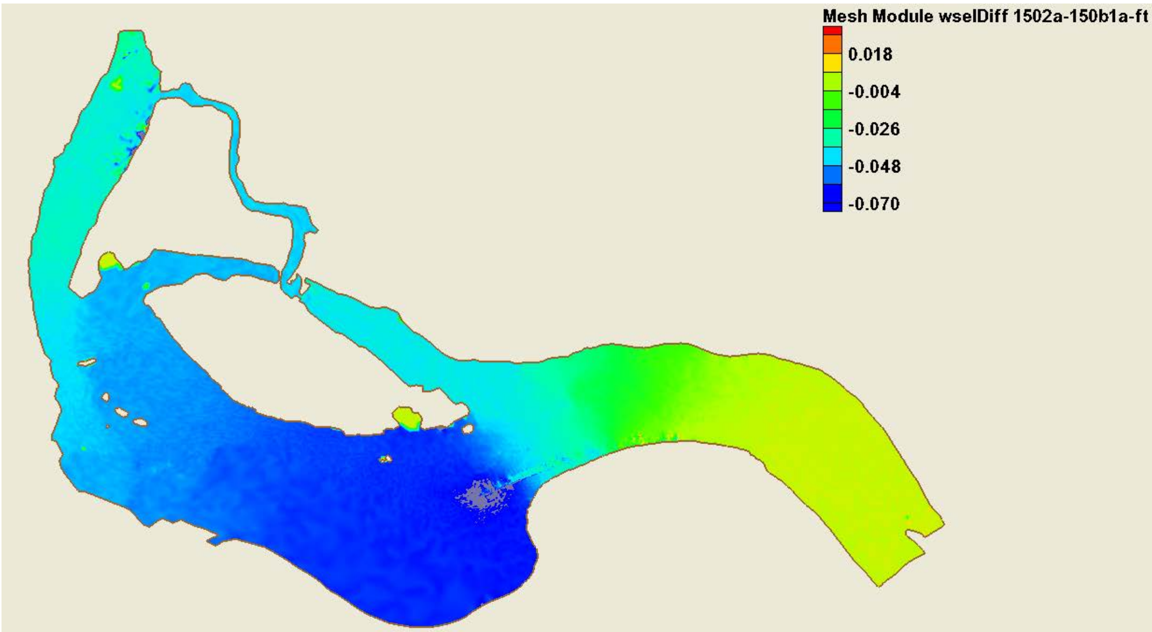


Figure C-4 Water Surface Elevation Change Above Base Conditions (100 Year) - 150000 cfscfs- Alternative 2a

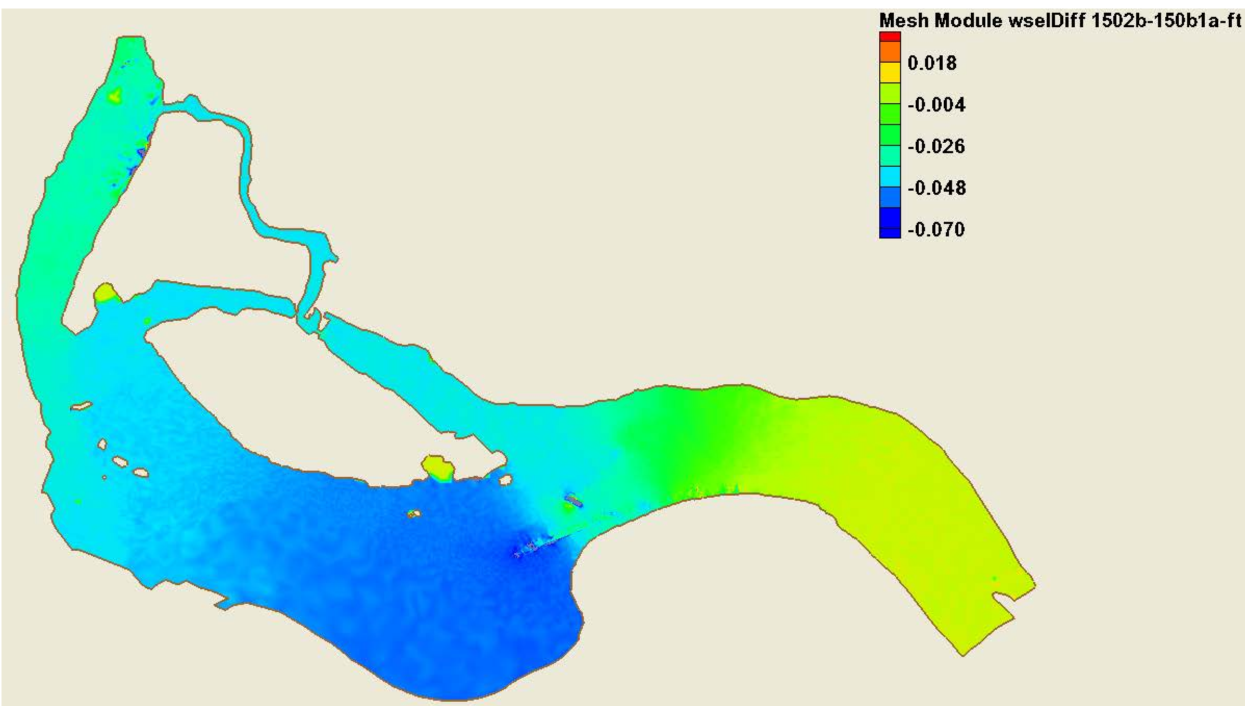


Figure C-5 Water Surface Elevation Change Above Base Conditions (100 Year) - 150000 cfscfs- Alternative 2b