ERDC/CHL TR-17-1

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Upper and Lower Hamburg Bend 2011 Flood Evaluation on the Missouri River near Hamburg, Iowa

Nathan Clifton, David Abraham, and Dan Pridal

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Final report

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

This report describes a numerical modeling study on the Missouri River in the vicinity of Hamburg, IA, specifically in the vicinity of River Miles 557 to 550. The study was conducted by the Engineering and Research Development Center, Coastal and Hydraulics Laboratory. The purpose of the study was to assist the U.S. Army Corps of Engineers, Omaha District, to define the impact of constructed chutes on floodplain flow velocity and direction within Hamburg Bend during the 2011 flood event. The evaluation required numerical hydrodynamic modeling of a pre-2011 flood condition of the entire floodplain and main channel with and without the constructed chutes to determine whether the implementation of the Upper and Lower Hamburg Bend chutes had any hydraulic effect in the study area during the flood.

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Preface

This study was conducted for the U.S. Army Corps of Engineers, Omaha District. The technical monitor was Dan Pridal, Omaha District Hydrologic Engineering Branch, River and Reservoir Engineering Section.

The work was performed by the River Engineering Branch of the Flood and Storm Protection Division, U.S. Army Engineer Research and Development Center, Coastal and Hydraulics Laboratory (ERDC-CHL). At the time of publication, Keith Flowers (CEERD-HFR) was Branch Chief. The Deputy Director of ERDC-CHL was Jeffrey R. Eckstein, and the Director was José E. Sánchez.

COL Bryan S. Green was the Commander of ERDC, and the Director of ERDC was Dr. Jeffery P. Holland.

Unit Conversion Factors

Multiply	By	To Obtain
cubic feet	0.02831685	cubic meters
feet	0.3048	meters
inches	0.0254	meters
miles (U.S. statute)	1,609.347	meters

Executive Summary

This report describes a numerical modeling study on the Missouri River in the vicinity of Hamburg, IA, specifically in the vicinity of River Miles 557 to 550. The study was conducted by the U.S. Army Engineer Research and Development Center, Coastal and Hydraulics Laboratory, (ERDC-CHL). The purpose of the study was to assist the U.S. Army Corps of Engineers, Omaha District, to define the impact of constructed chutes on floodplain flow velocity and direction within Hamburg Bend during the 2011 flood event. The evaluation required numerical hydrodynamic modeling of a pre-2011 flood condition of the entire floodplain and main channel with and without the constructed chutes to determine whether the implementation of the Upper and Lower Hamburg Bend chutes had any hydraulic effect in the study area during the flood.

The evaluation performed in this study used existing-condition model results compared to alternative conditions to examine changes in depth and velocity. Floodplain hydraulics is just one of many factors that contribute to levee performance. Geotechnical factors such as soil conditions, pre-event levee condition, and other similar factors are not addressed in this analysis. The extent to which changes in floodplain hydraulics may or may not have contributed to the levee performance through interactions with other factors is beyond the scope of this study. The comparison of the model results pertaining to velocity magnitude and direction were the focus of the alternative analysis.

The model produces reasonably high-quality determinations of flow depth, velocity magnitude, and velocity direction for a wide range of conditions. Comparisons between modeled base and plan conditions can provide a meaningful way to evaluate different parameters that may or may not have contributed to significant changes in flow conditions at selected locations. However, the model results should be viewed with caution, good engineering judgment, and a sound understanding of the model's limitations.

The base condition model consisted of channel and floodplain conditions in June 2011 prior to the levee breach. The topography and bathymetry were comprised of several different data sets since there was no single data source sufficient for the entire reach (channel, floodplains, and chutes) prior to the flood. A wide variety of material types was assigned within the

model for the main channel, chutes, and floodplain to reflect the variation in vegetation cover and channel roughness. Comparisons were made to water surface slope to obtain a limited validation since measured velocity data at the June 2011 flow of 160,000 cubic feet per second (cfs) were not available to validate the computed model velocity distribution, magnitude, and direction.

The objectives of the evaluation are the following:

- Model floodplain flow conditions using the pre-2011 geometry and assess how vegetative, geometric and/or structural channel, chute, and floodplain features affect flow patterns.
- Model floodplain flow conditions using the post-2011 geometry and assess how the post-flood levee alignment, chute structures, and floodplain repairs affect flow for that new condition.
- Compare the post-2011 model results to the pre-2011 model results. An additional objective was to evaluate whether or not adding additional structures in the post 2011 flood chutes could provide beneficial flow distribution changes.

Model results demonstrate how the Missouri River main channel, constructed chutes, and Federal levee alignment affect flow stage, velocity, and distribution through Hamburg Bend. Model conditions are static and do not include the simulation of sediment transport nor scour or deposition processes that typically occur in river flow corridors.

Model simulations were initially performed at three different model flows. Model results indicated that a 160,000 cfs flow created the largest differential in velocity magnitude between alternatives of the four flows that were examined. Comparisons at other flow rates would generally show a smaller difference. Therefore, result comparisons tend to over exaggerate how the alternative may have affected actual floodplain evolution over time.

General observations from the base condition model and alternative condition comparisons are as follows:

- The existing condition levee alignment concentrated floodplain flow velocities along the levee toe throughout Hamburg Bend. In particular, the abrupt bend near the levee breach area likely created an area of elevated velocity. Whether the chutes were constructed or not, the area

of elevated velocities at that location would have existed since the levees were constructed. Model computed velocities were greater than 6 feet per second (ft/sec) at this location and are much greater than the average floodplain velocities that generally ranged from 2 to 4 ft/sec.
- Higher flow depths, which are associated with greater flow conveyance, are visible along the levee toe the entire model length of approximately 10 miles. This indicates a flow corridor along the levee toe that results in higher flows in the vicinity of the levee, with lower flows in the adjacent floodplain. This is likely due to a combination of factors including floodplain elevations and roughness.
- Inspection of the computed flow vectors demonstrated that the model is capable of determining variation in floodplain flow direction. Neither velocity vectors toward the levee nor highly turbulent eddy zones were observed in the vicinity of the levee breach. The results illustrate that the Lower Hamburg chute did not redirect flow or provide a conduit for impinging flow to the levee.
- Alternatives to examine hydraulics with the post-2011 flood geometry indicated lower velocities along the levee than the pre-2011 flood geometry.
- Comparing model results from pre- and post-2011 flood geometry illustrates the dynamic conditions within the floodplain and how the floodplain hydraulics are subject to change as geometry varies between and even during flow events.

Changes to flow velocity in the proximity of the levee breach were determined for many alternatives. A summary of those alternatives that significantly affected flow velocity in the vicinity of the levee breach (greater difference than 10%) is as follows:

- Vegetation had a large effect on floodplain flow distribution including velocity magnitude and velocity direction. Converting dense vegetation areas east of the Lower Hamburg chute to farmland with lower roughness increased the velocity in the farmland area, which reduced velocity by approximately 1.8 ft/sec in the adjacent levee breach proximity.
- The post-flood levee alignment significantly changes floodplain flow direction and hydraulics near the levee breach vicinity. Velocity reduction in the range of 1.5 ft/sec was observed.
- Main channel and chute degradation, which was based on survey observations collected in an upstream area around Nebraska City, NE,

during the 2011 event, increased main channel and chute flow. This caused reduced flow in the floodplain and thus a reduced floodplain velocity in the levee breach vicinity of approximately 0.9 ft/sec.

- All other alternatives resulted in minor changes in floodplain hydraulics with velocity change near the levee breach vicinity less than 0.5 ft/sec.

1 Introduction

1.1 Purpose

This report describes a numerical modeling study on the Missouri River in the vicinity of Hamburg, IA, specifically in the vicinity of River Miles (RMs) 557 to 550. The study was conducted by the U.S. Army Engineer Research Development Center, Coastal and Hydraulics Laboratory (ERDC-CHL). The purpose of the study was to assist the U.S. Army Corps of Engineers, Omaha District, to define the impact of constructed chutes on floodplain flow velocity and direction within Hamburg Bend during the 2011 flood event. The evaluation requires numerical hydrodynamic modeling of a pre-2011 flood condition of the entire floodplain and main channel with a variety of alternatives, as described in Section 1.4, to evaluate how the chutes and floodplain features within Hamburg Bend affected floodplain flow hydraulics in the levee vicinity during the flood of 2011.

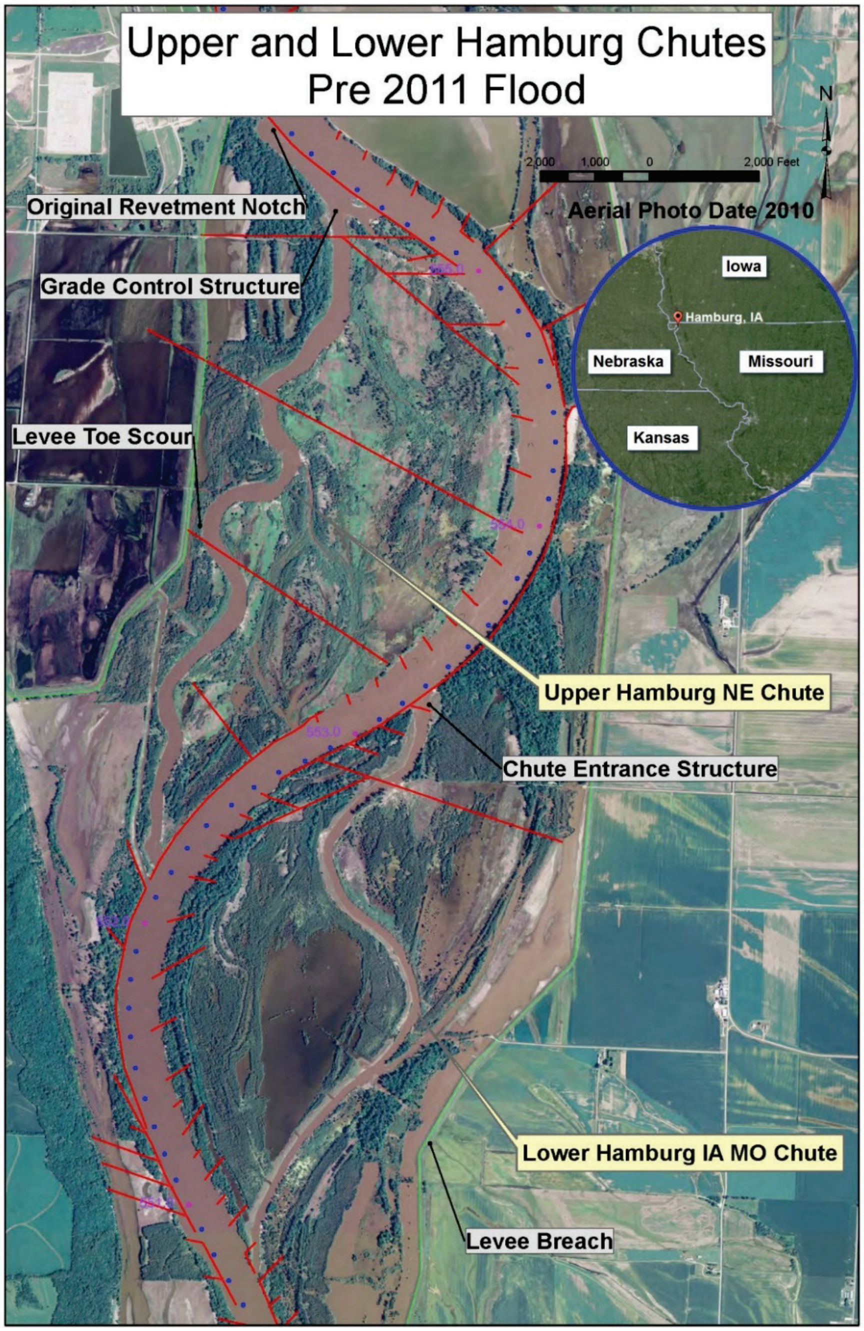
1.2 Background

During a 2011 flood on the Missouri River, there was a levee breach near Hamburg, IA, in a region called Hamburg Bend. Prior to the 2011 flood, chutes were cut in the Hamburg Bend floodplain. The effects of the Hamburg chutes on the hydraulics of Hamburg Bend and its levee are not well defined. Multiple floodplain, chute, and channel conditions will be modeled to reflect conditions that existed at the time of the 2011 flood, alternative conditions that could have existed at the time of the 2011 flood, and the post-2011 flood condition. The models will extend from levee top to levee top and include the main channel, both chutes, and the floodplain.

1.3 Site description

The site location for this study is on the Missouri River approximately 5 miles west of Hamburg, IA, which is approximately 6.5 RMs downstream of Nebraska City, NE. The stretch of river being modeled consists of two major river bends with reconstructed old channel chutes across each of the bends as shown in Figure 1. In 1995, a chute was constructed in an off-channel mitigation site on the Nebraska side of the northern bend to provide increased shallow water habitat in a continuously flowing chute, referred to as Upper Hamburg Chute. A second chute was constructed on the Iowa side of the southern bend with construction complete in 2006.

Figure 1. Hamburg Bend study area.



1.4 Study task overview

The objective of the study is to evaluate the effect of constructed chutes on floodplain flow velocity and direction within Hamburg Bend during the 2011 flood event. The primary focus is during the period prior to the levee breach that occurred within Lower Hamburg Bend in June 2011. To get a better understanding of system response, the following alternatives where modeled. Tasks 1 and 3 were not listed below as they were described in the Scope of Work as a kick-off meeting and intermediate report, respectively.

Task 2

ERDC shall construct a two-dimensional (2D) Adaptive Hydraulics (AdH) model using the best available survey data for the main channel (hydrographic surveys from 2008 and 2009), floodplain (pre-flood lidar 2008), and chutes (2010). Due to age and quality of the data, some discrepancies may be identified between the multiple sources of the provided surveys. ERDC shall apply reasonable engineering judgment to create a consistent pre-flood floodplain topography model. This model represents the conditions pre-2011 flood.

Task 4A

Starting with the Task 2 geometry, remove all Lower Hamburg Chute features and assign topography and vegetation as they existed prior to chute construction.

Task 4B

Starting with the Task 2 geometry, remove side-cast earth mounds in Lower Hamburg and keep remaining chute features intact.

Task 4C

Starting with the Task 2 geometry, remove near-levee features in only the Lower Hamburg Bend that affected flow (access ramps, riverside roads, and cuts through the vegetation between the levee and chute).

Task 4D

Starting with the Task 2 geometry, change all floodplain vegetation roughness east of the Lower Hamburg Chute to farmland.

Task 4E

Starting with the Task 2 geometry, remove both Upper and Lower Hamburg Chutes with topography and vegetation assigned as existed prior to chute construction.

Task 5

ERDC will create a post-2011 flood, current-condition model to include the floodplain topography, main channel and chute topography, and the 2012/2013 constructed rock structure repairs. This includes the expanded chutes, post-flood structures within each chute, scour hole fill in Upper Hamburg Chute, and the post-flood levee alignment (referred to as "levee setback") and scour hole repair in Lower Hamburg Chute.

Task 6.1

Using the base condition Task 2 model (pre-flood with both chutes and all features), add a Lower Hamburg levee setback as is currently constructed in order to illustrate the effect of levee alignment on flow velocities at the levee point.

Task 6.2

Using the base condition Task 2 model (pre-flood with both chutes and all features), employ the model to evaluate the effect of the Lower Hamburg tree-heavy vegetation zone on the area's hydraulics. Conduct three separate runs to evaluate the benefit of vegetation management in the floodplain:

1. Remove trees from the zone along the chute levee side bank (east).
2. Add a tree strip adjacent to the levee toe (maintain a 15-foot [ft] buffer from the toe) to fill the currently open area between the chute and levee with trees from near the access road to downstream of the levee point near where the existing tree line tapers.
3. Run 6.2a and 6.2b together. This involves swapping the trees and open area that currently exist in order to put the trees next to the levee and create a flow-through corridor away from the levee.

Task 6.3

Using the base condition Task 2 model (pre-flood with both chutes and all features), create a degraded channel model (both a high and low degraded condition) as an approximate representation of the 2011 flood peak. Data from June 2011 and post-flood 2012 surveys will be used to estimate a reasonable main channel degradation amount for the two levels (high and low). Chute degradation will be estimated from the post-flood surveys. This will provide a tool to evaluate the effect of channel and chute degradation on computed velocities, elevations, and turbulence in key areas. Results will be used to evaluate differences between alternatives.

Task 6.4

Using the Task 5 model (current post flood condition with setback levee, new structures, etc.), remove the Lower Hamburg chute sidecast spoil berms. Two flows will be modeled: 160,000 and 240,000 cfs (4,530.7 and 6,796.2 cms).

Task 6.5

Using the Task 5 model (current post flood condition with setback levee, new structures, etc.), add additional structures within each chute. Post-flood construction added two new chute control structures within each chute. Add two more structures within each chute with approximately the same geometry as the existing structures (mid-bank height rock with a lower center section) that are equally spaced from the current downstream structure to the chute exit. The intent is to test if these new structures can affect the flow split between the river and the chutes and to estimate the flow velocity in the chutes during flood events of 160,000 and 240,000 cfs (4,530.7 and 6,796.2 cms).

1.5 Study results with respect to levee performance in 2011 event

The floodplain hydraulics that were occurring at the time of the levee breach in June 2011 at Lower Hamburg Bend was a focus of this study. The evaluation performed in this study used existing-condition model results compared to alternative-condition model results to examine changes in depth and velocity. Floodplain hydraulics is just one of many factors that contribute to levee performance. Geotechnical factors such as soil conditions, pre-event levee condition, and other similar factors are not addressed in this analysis. The extent to which changes in floodplain hydraulics may or may not have contributed to the levee performance through interactions with other factors is beyond the scope of this study.

The model produces reasonably high quality determinations of flow depth, velocity magnitude, and velocity direction for a wide range of conditions. Comparisons between modeled base and plan conditions can provide a meaningful way to evaluate different parameters that may or may not have contributed to significant changes in flow conditions at selected locations.

However, the model results should be viewed with caution, good engineering judgment, and a sound understanding of the model's limitations.

2 Methodology

2.1 Numerical model preparation

A numerical simulation of the Missouri River in the vicinity of Hamburg, IA, was conducted. The numerical model applied was a 2D hydrodynamic version of the AdH code developed at ERDC-CHL. The initial task was to assemble a model that reproduced channel, floodplain, and chute topography and bathymetry as closely as possible to the conditions prior to the levee break that occurred during the 2011 flood. For this, a model grid was built with north/south boundaries extending from RM 557 to RM 550. The eastern boundary was set along the eastern levee (L-575). The western boundary was set along the western levee (R-573) and/or the base of the bluff along the Nebraska side of the river.

The topography and bathymetry used for this model were comprised of several different data sets since there was no single data source sufficient for the entire reach (channel, floodplains, and chutes) prior to the flood. The main channel bathymetry was constructed with cross sections supplied by the Omaha District accompanied with structure data from the previous in-bank AdH model. The floodplain topography was obtained from a 2008 lidar set. Since there were no recorded elevation data for either chute immediately prior to the flood, ERDC-CHL took the 2011 pre-flood plan form of each chute and combined the 2008 lidar with after-the-flood-chute bathymetry and made models of each chute separately. Each chute was run with the sediment transport turned on in the AdH code with a sand bed in order to acquire a realistic bed form in each. The two models were run to an equilibrium sediment transport condition and reviewed to assure that a reasonable, natural bed planform had been attained. The result was a chute bathymetry that represented that of the 2011 pre-flood chute. Then the two model bathymetries were merged with the previously mentioned floodplain and main channel bathymetry to form the overall model elevation data. The Universal Transverse Mercator (UTM) coordinate system in zone 15N with a vertical datum in NAVD88 and horizontal datum in NAD83 was used throughout this study. The boundaries of the model along with the entire topography and bathymetry are shown in Figure 2. Flow is from top to bottom.

Figure 3 shows the definition of the cells and elevation data in the grid in the area of the levee breach as well as the surrounding area upstream.

Figure 2. Task 2 AdH model elevation data.

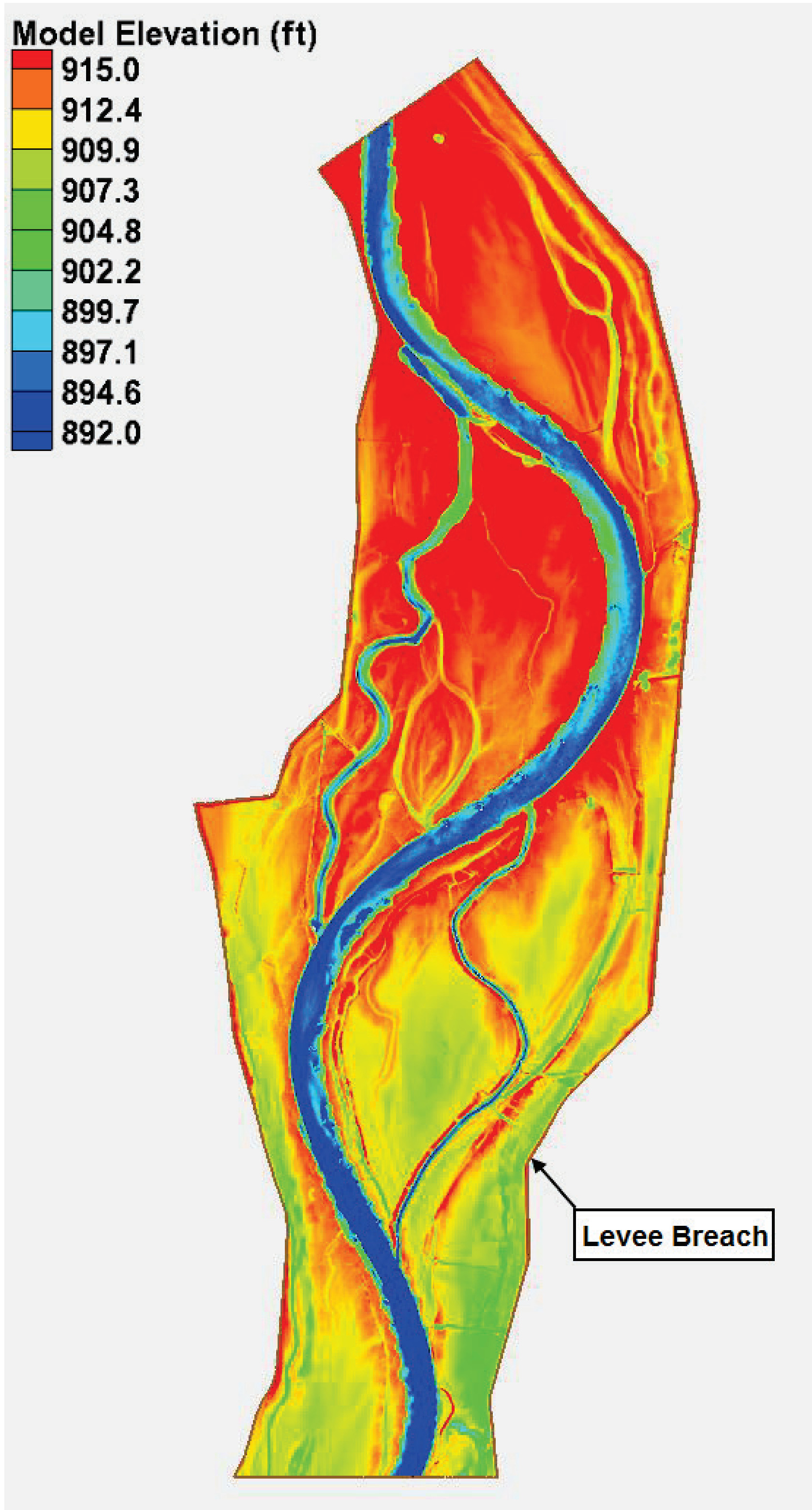
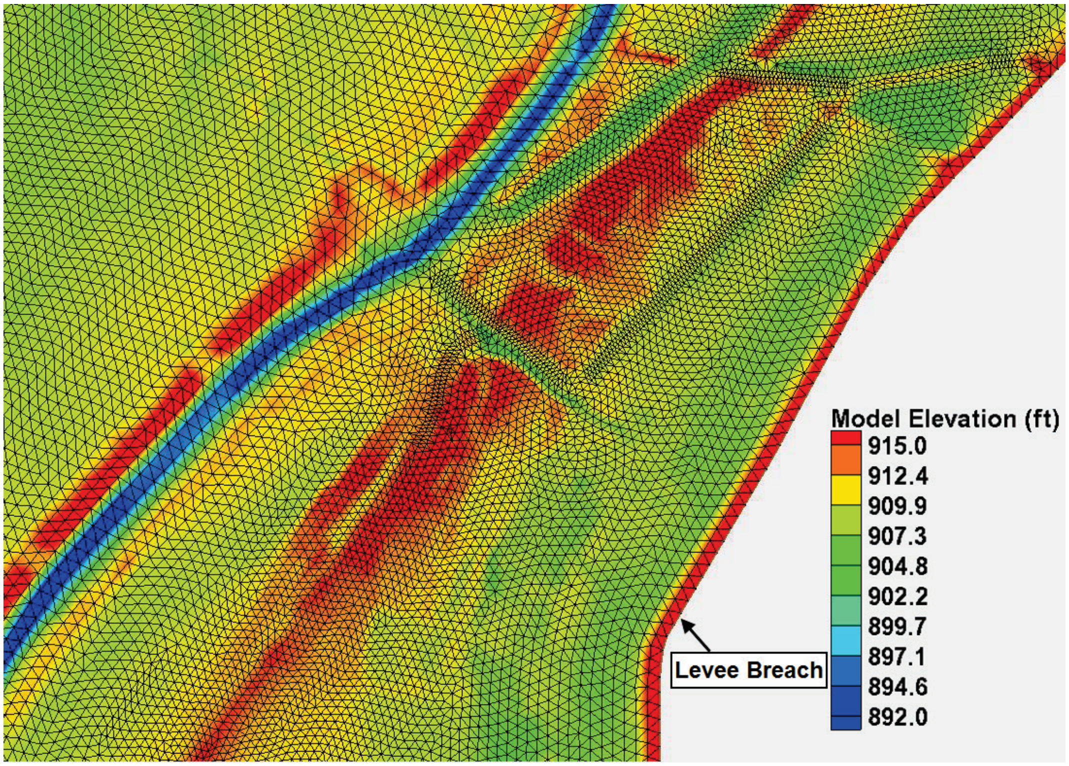


Figure 3. Task 2 mesh view of levee breach area.



2.2 Model validation

A flow of 160,000 cfs (4530.7 cms) was the flow prior to the levee breach the morning of 13 June 2011. The downstream boundary elevation of 914.70 ft (278.80 m) came from Omaha District data from a previous frequency study. The frequency study was previously performed by the Omaha District with a HEC-RAS model in which the resulting model water surface elevations were calibrated to previous field observations. The AdH model for this study is validated only to the computed water surface elevations from the frequency study. The 160,000 cfs (4,530.7 cms) inflow and 914.70 ft (278.8 m) tailwater were the boundary conditions used for a base-condition, steady non-uniform flow simulation that was used to validate the model.

The Manning's friction coefficients used for this model simulation for the various model material types are shown in Figure 4. The Manning's *n*-values were selected based on engineering experience and judgement using standard references such as Chow (1988) and Arcment and Schneider (1989) and are within the given range of values. The floodplains were broken up into different roughnesses to represent the different types of vegetative cover assigned to each of the areas. Descriptions for these materials are as follows:

- Material 1 represents the deeper area of the main channel (thalweg). (*n* = 0.028)
- Material 2 represents the mid-depth area of the main channel. (*n* = 0.028)
- Material 3 represents the shallow area of the main channel which holds the majority of the river training structures. (*n* = 0.030)
- Material 4 represents the river training structures. (*n* = 0.060)
- A URV (unsubmerged rigid vegetation) card was used for Material 5 as these areas consist mainly of trees that were not submerged during the flood. This card uses a bed roughness height, stem density, and stem diameter to compute a skin friction and form drag. This allows the model to adjust the roughness due to depth.
- Material 6 represents a mid-height, relatively thick shrub with grass or other low vegetation. (*n* = 0.060)
- Material 7 represents a lightly vegetated slough that runs between the Upper Hamburg Chute and the main channel. (*n* = 0.030)
- Material 8 represents the Upper Hamburg Chute. (*n* = 0.024)
- Material 9 represents the top of any levee or roadway out in the floodplain.(*n* = 0.020)
- Material 10 represents the Lower Hamburg Chute (*n* = 0.024)
- Material 11 represents open areas with no more than grass vegetation. (*n* = 0.030)

Comparisons were made to computed water surface slope from the Omaha District's frequency study to obtain a limited validation for the flow used in this model run of 160,000 cfs (4,530.7 cms). ERDC-CHL used an observation arc shown in Figure 5 (thick black line) to obtain the water surface elevation of the main channel for the model run.

Figure 6 shows the comparison of the two water surface elevations. The slight variations are believed to be due to slight differences in the models as well as different observation arcs for obtaining these values.

Figure 4.Task 2 AdH model materials.

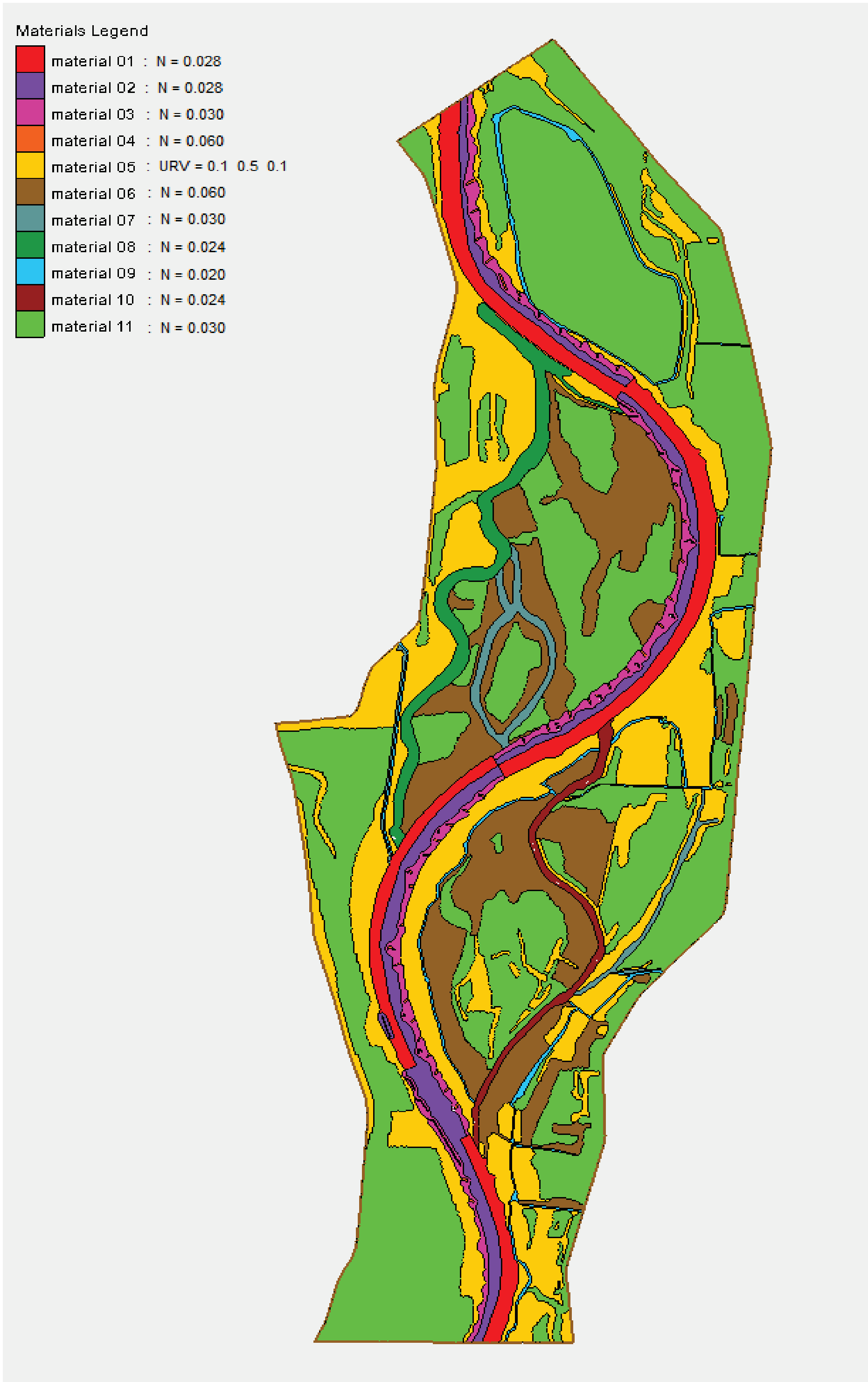


Figure 5. Observation arc overlaid on AdH model elevation data.

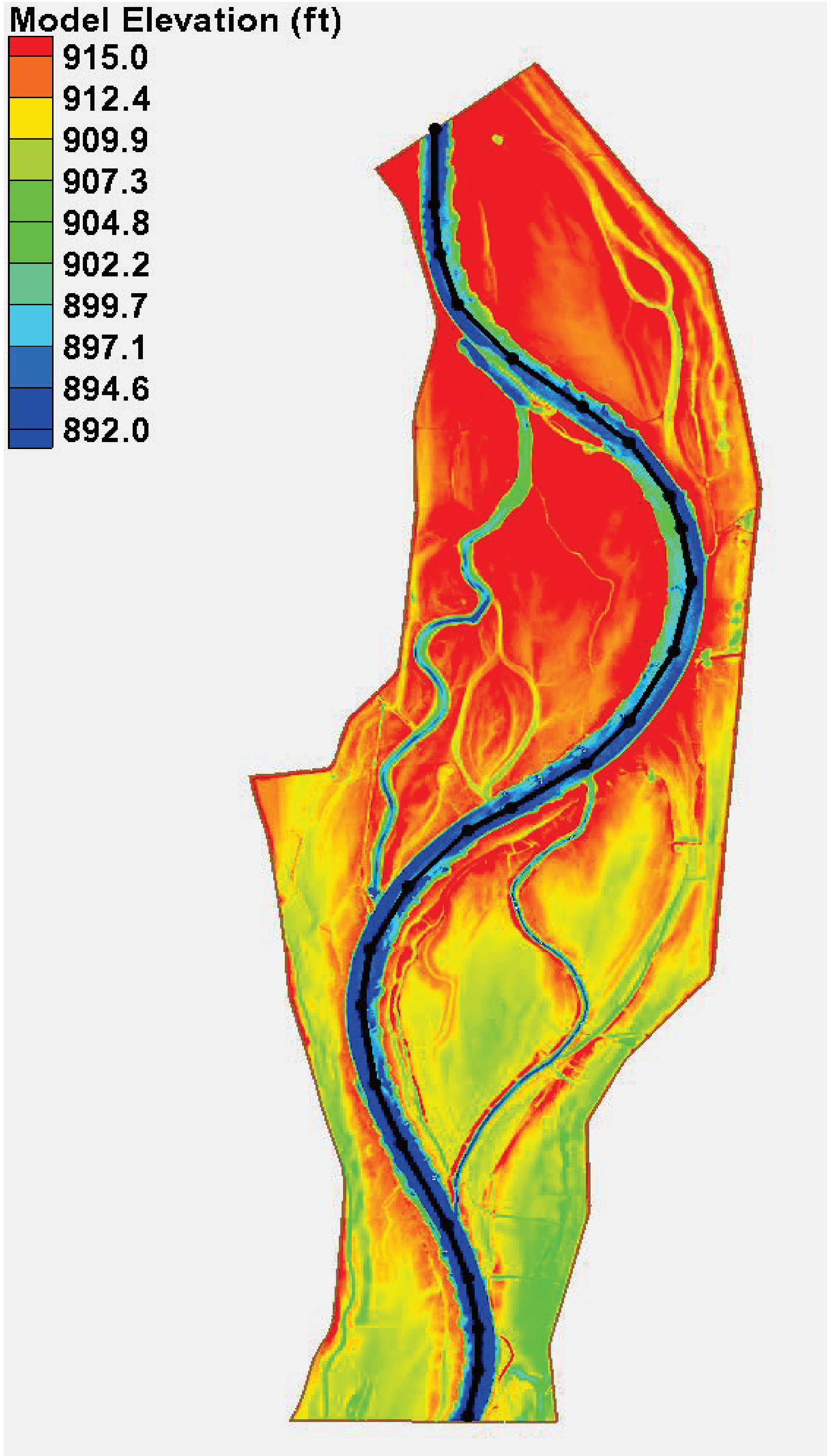
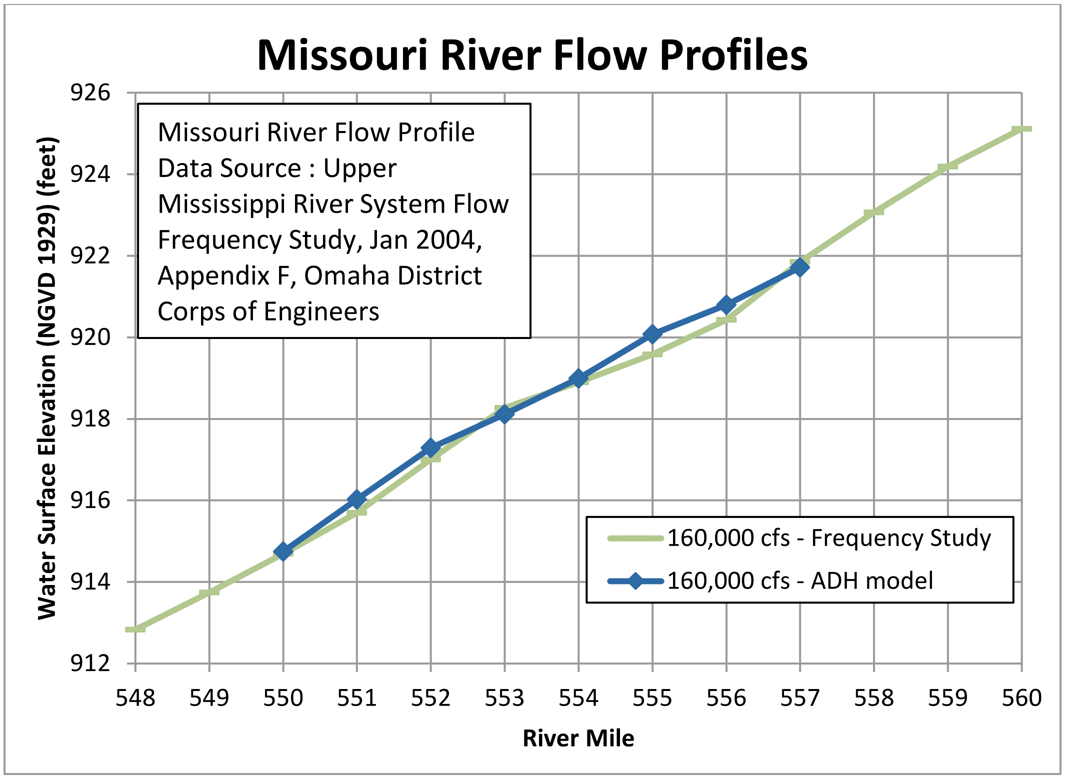


Figure 6. Water surface elevation profile comparison.



The Omaha District's HEC-RAS model from the frequency study produced a water surface elevation of 921.80 ft (280.96 m) at RM 557 and 914.7 ft (278.8 m) at RM 550 for a slope of 0.000194. The results of the AdH model produced a water surface elevation of 921.94 ft (281.01 m) at RM 557 and 914.7 ft (278.8 m) at RM 550 for a slope of 0.000196. This resulted in a water surface elevation difference of 0.14 ft (0.0426 m) (approximately 1.6 inches) at the upper boundary of the reach. Overall, the water surfaces of the two models and the resulting slopes are in very close agreement; thus, this model is considered to have a limited validation with respect to the water surface data. Measured velocity data, which is valuable to compare velocity distribution, magnitude, and direction determined by a 2D model, were not available within the model reach at the 160,000 cfs (4,530.7 cms) flow. Therefore, the water surface slope is the only measurable data available for validation purpose.

3 Model Simulations and Results

3.1 Pre-2011 flood existing condition (Task 2)

Task 2 required the building of a model of the pre-2011 flood conditions throughout the reach. This model provides insight into how the flows in the reach acted during the 2011 flood prior to the levee breach. Note that there were small areas of missing bathymetry data, so the elevations in those areas were determined by surrounding elevations and engineering judgement.

Model simulations were initially performed at three different total model flows. Model total flow values initially selected for simulation consisted of an intermediate floodplain flow of 120,000 cfs (3,398.02 cms), the June 2011 flow prior to the levee breach of 160,000 cfs (4,530.7 cms), and near the levee capacity of 240,000 cfs (6,796.2 cms). Alternative simulation results were compared to Task 2 simulation results for the three flows. This produced velocity differences between the alternative conditions and the Task 2 condition. The 120,000 cfs (3,398.02 cms) flow provided a floodplain with minimum inundation and was not believed to provide enough insight into the changes due to the alternatives. The flow rate of 160,000 cfs (4,530.7 cms) generated a higher flow velocity difference when compared to the 240,000 cfs (3,398.02 cms) flow rate. Therefore, the results shown in the alternative sections are mainly from the ERDC-CHL's AdH model simulation of 160,000 cfs (4,530.7 cms). The 120,000 cfs (3,398.02 cms) and 240,000 cfs (6,796.2 cms) results for Task 2 are included to provide examples of the pre-2011 flood depths and velocities.

The different materials used throughout the model grid were set up using aerial imagery as well as personal knowledge of the area. The different simulation consisted of a 30-day, steady-state run to ensure the model was at equilibrium before the results were analyzed. The results were reviewed and compared to the frequency study to validate the model. The following results are from the limited validation model simulation.

Figure 7, Figure 8, and Figure 9 show the water depths at the end of the model simulation for each flow over the entire grid. The upper limit of legend was set to 9.84 ft (2.99 m) for each image in order to show the variation of depths in the floodplains and for each flow. Figure 8 shows the majority of the floodplains were completely inundated at 160,000 cfs

(4,530.7 cms) while there were very few small areas still above the water surface. The image also provides insight into the water depths in the area of the levee breach and surrounding areas. Higher flow depths are visible along most of the levee toe the entire model length of approximately 10 miles. This indicates a flow corridor along the levee toe and unequal floodplain flow distribution. This is likely due to a combination of factors including floodplain elevations and roughness.

One of the key aspects of this study is the velocity magnitudes throughout this stretch of river. Figure 10, Figure 11, and Figure 12 display the velocity magnitudes at the end of the 30-day model simulation for each flow over the entire grid. The upper limit of legend was set to 6.56 ft/sec (1.99 m/sec) for each image in order to show the variation of velocity magnitude in the floodplains and for each flow. The velocity range for the image was originally set in metric units (0–2 m/sec) and was converted to English units. The range was chosen as it shows sufficient contour changes at the levee breach and surrounding area. The range does not include the maximum velocity, which was shown in red in the main channel.

Figure 13 shows a zoomed-in view of the model elevation data overlaid with velocity vectors for the 160,000 cfs (4,530.7 cms) flow in the area of the levee breach and surrounding areas. The vectors are pointed in the direction of the water flow at that model node as well as being scaled to the magnitude of the velocity with small arrows being low velocity and long arrows having higher velocities. This image allows presents the direction of the flow over the road crossing on the levee as well as through the opening where the old road bed goes to the chute. Although there are slight redirections in the direction of the flow, it is important to note that flow velocities are not impinging on the levee at a perpendicular angle in the area of the levee breach, nor are there any impinging velocities from the chute.

Figure 14 shows a zoomed-in view of the velocity magnitudes overlaid with velocity vectors in the area of the levee breach and surrounding areas. As in the previous image, the vectors are pointed in the direction of the water flow at that model node as well as being scaled to the magnitude of the velocity with small arrows being low velocity and long arrows having higher velocities.

Figure 7. Task 2 water depth (ft) for 120,000 cfs (3,398.02 cms) flow.

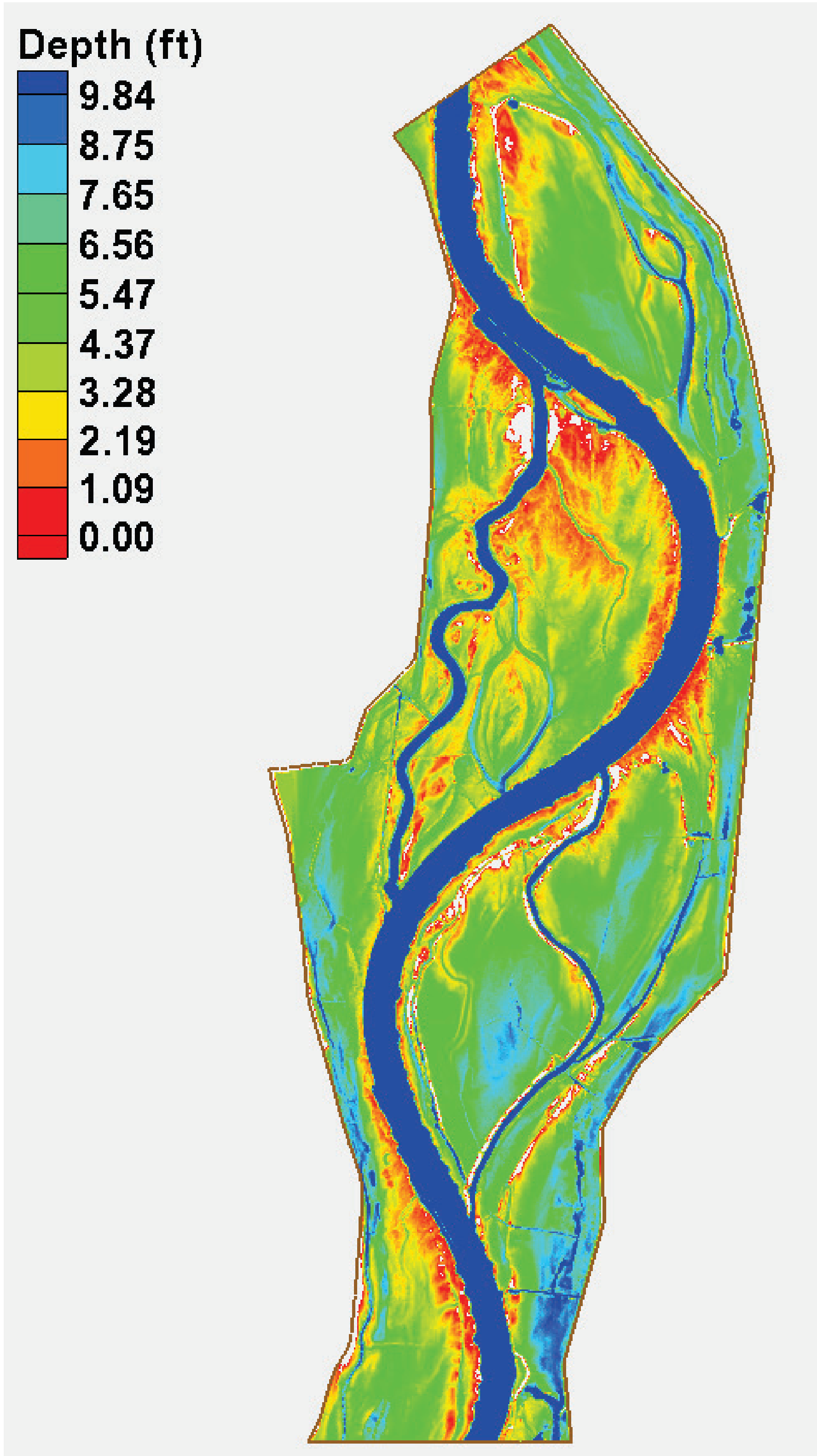


Figure 8. Task 2 water depth (ft) for 160,000 cfs (4,530.7 cms) flow.

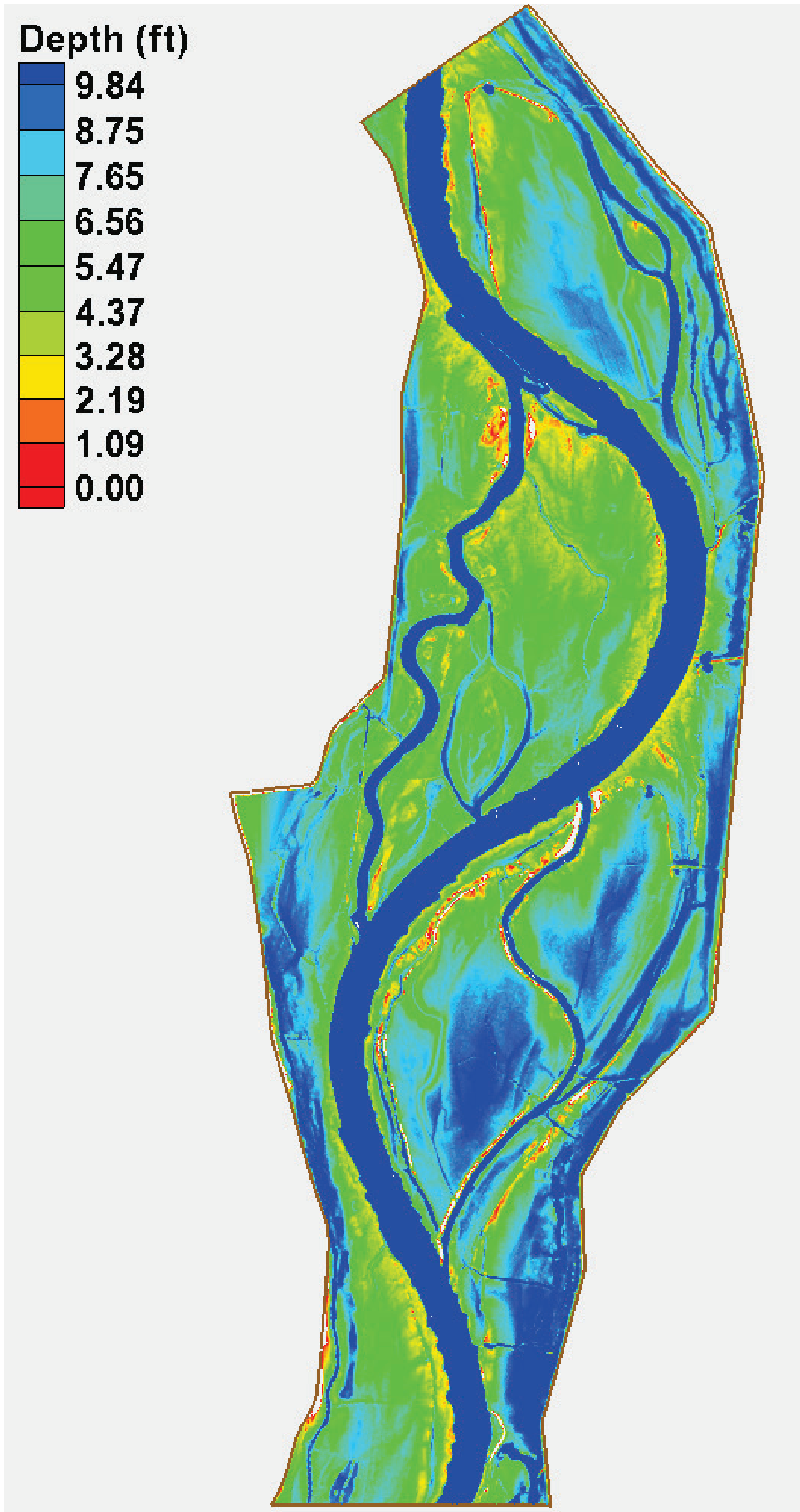


Figure 9. Task 2 water depth (ft) for 240,000 cfs (6,796.17 cms) flow.

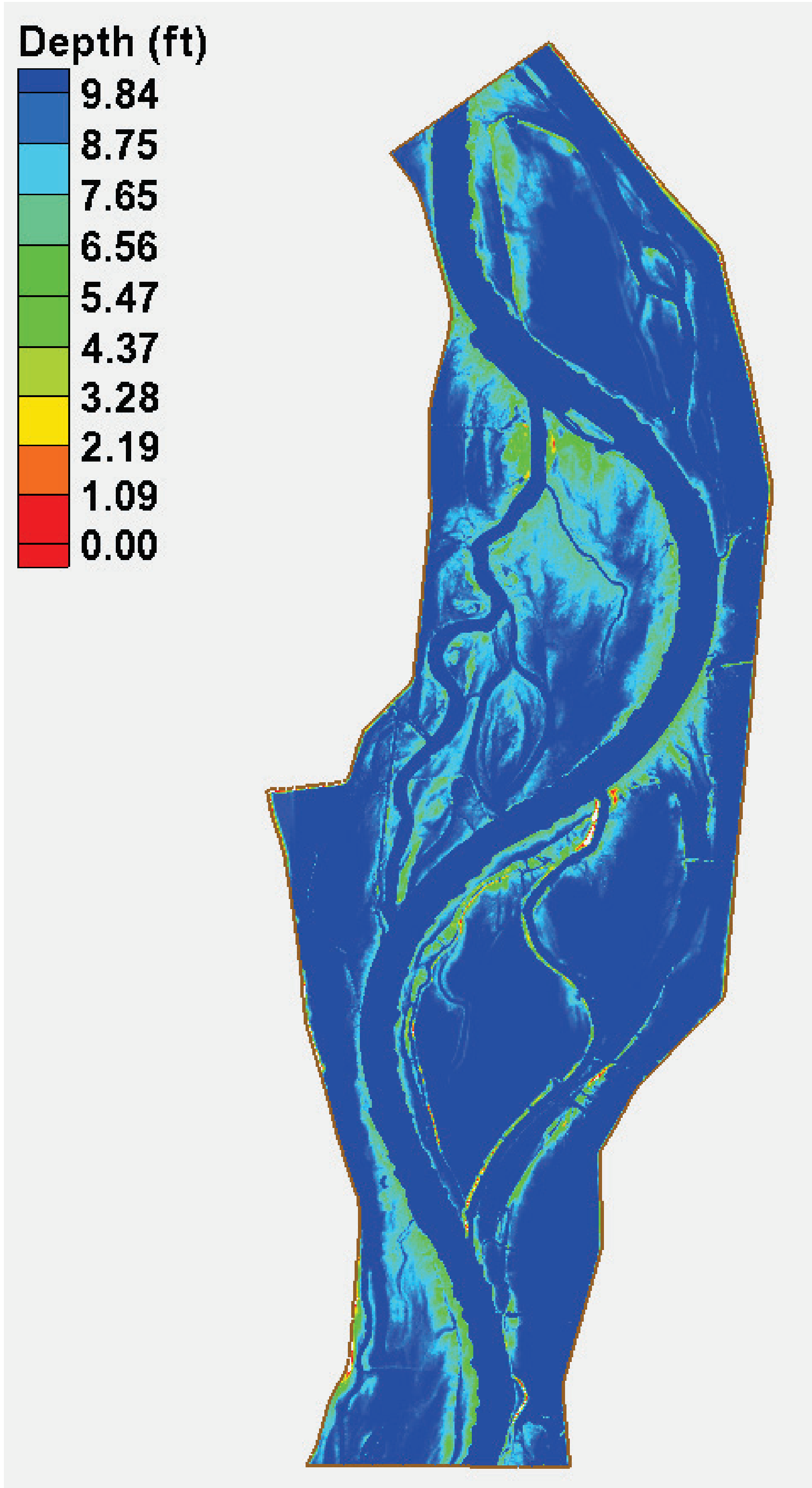


Figure 10. Task 2 velocity magnitudes (ft/sec) for 120,000 cfs (3,398.02 cms) flow.

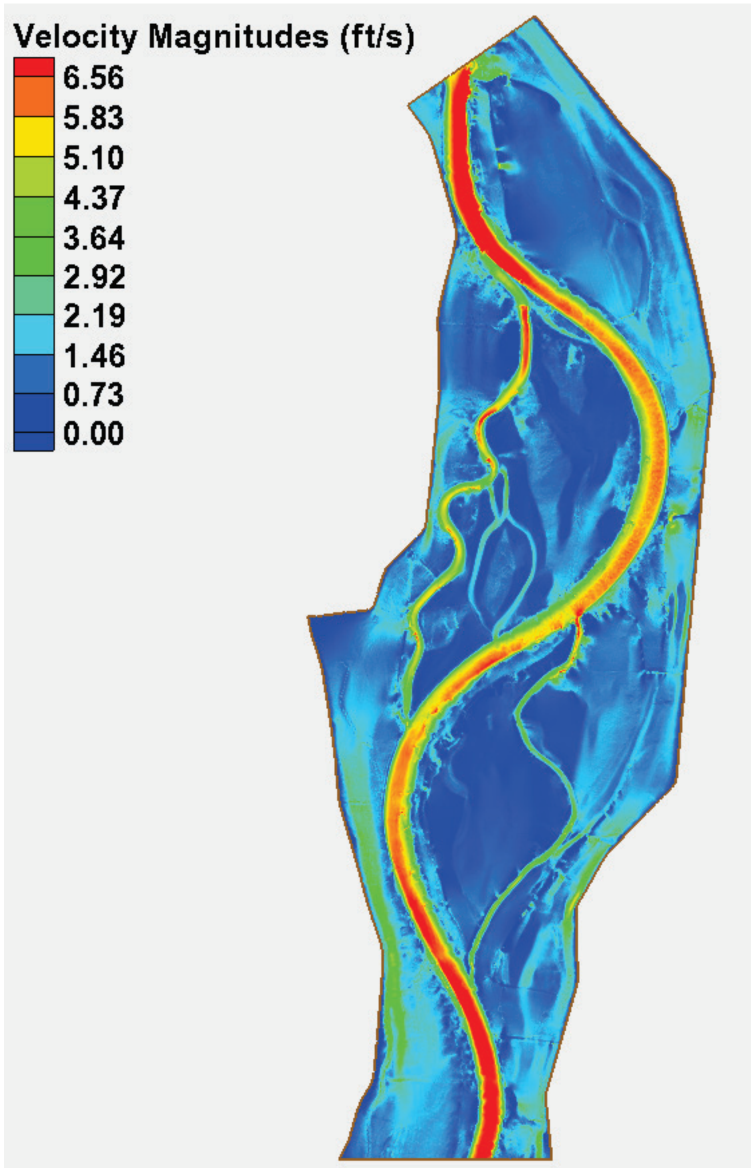


Figure 11. Task 2 velocity magnitudes (ft/sec) for 160,000 cfs (4,530.7 cms) flow.

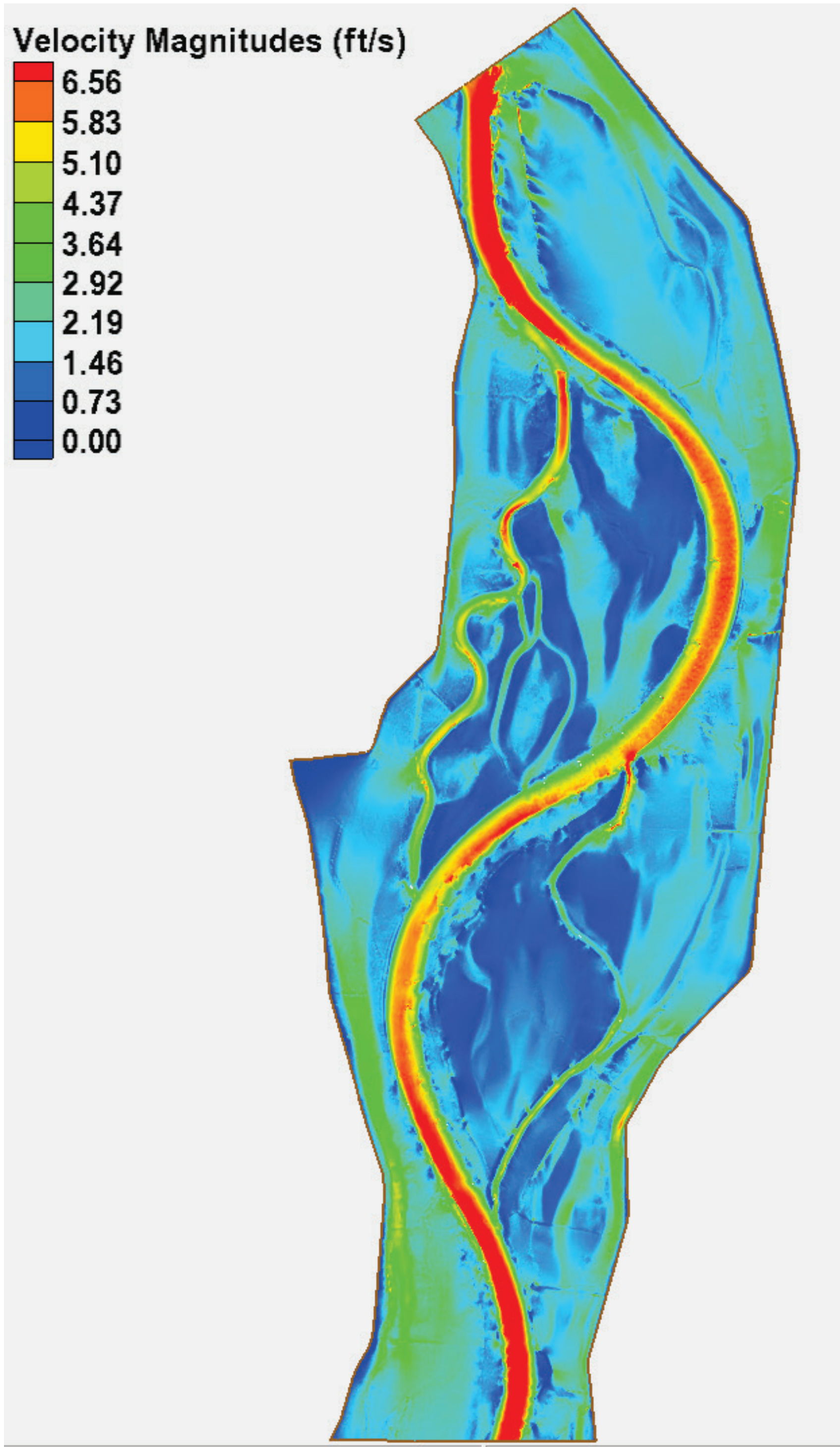


Figure 12. Task 2 velocity magnitudes (ft/sec) for 240,000 cfs (6,796.17 cms) flow.

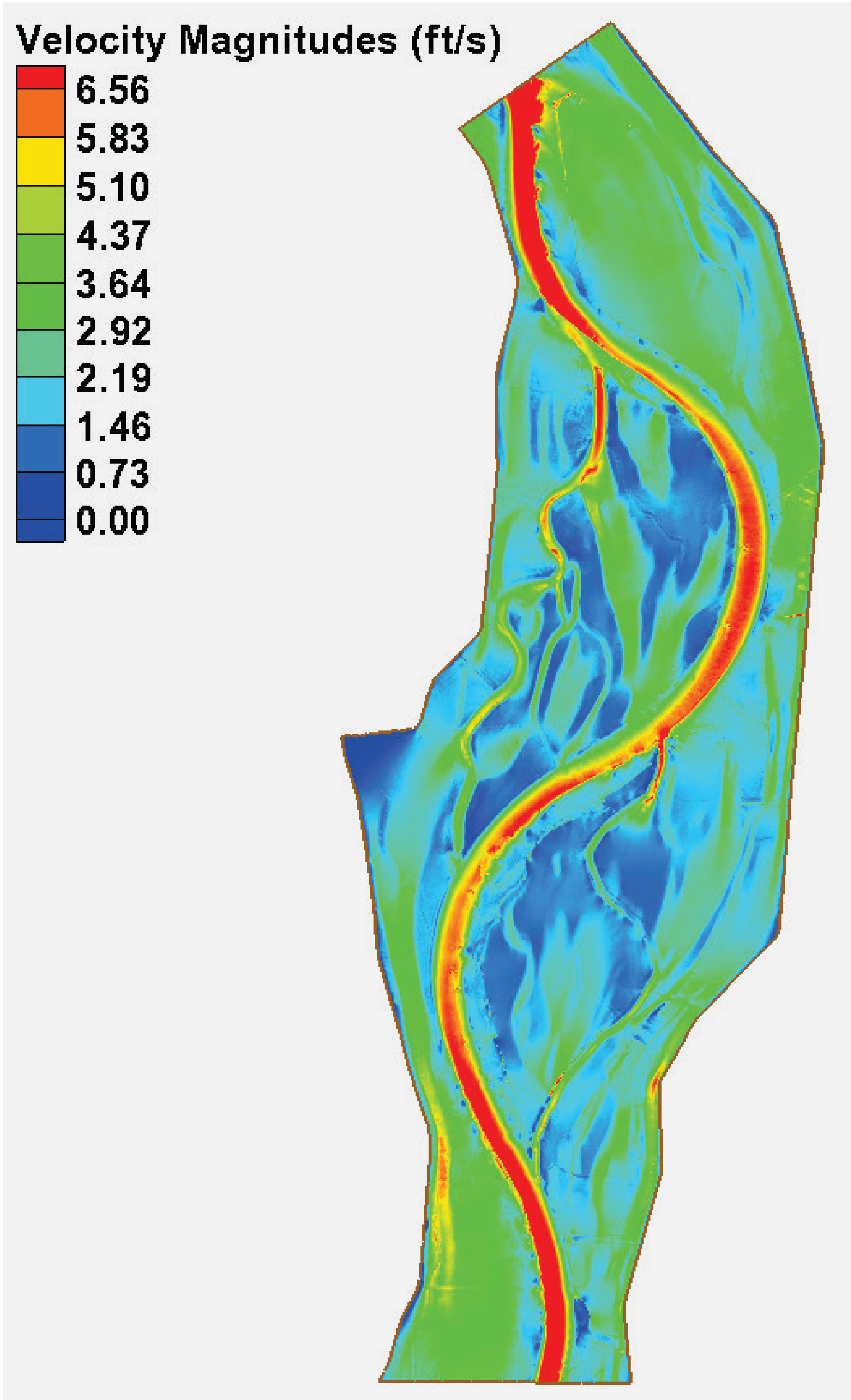


Figure 13. Task 2 model elevation data (ft) overlain with velocity vectors near the levee breach for the 160,000 cfs (4,530.7 cms) flow.

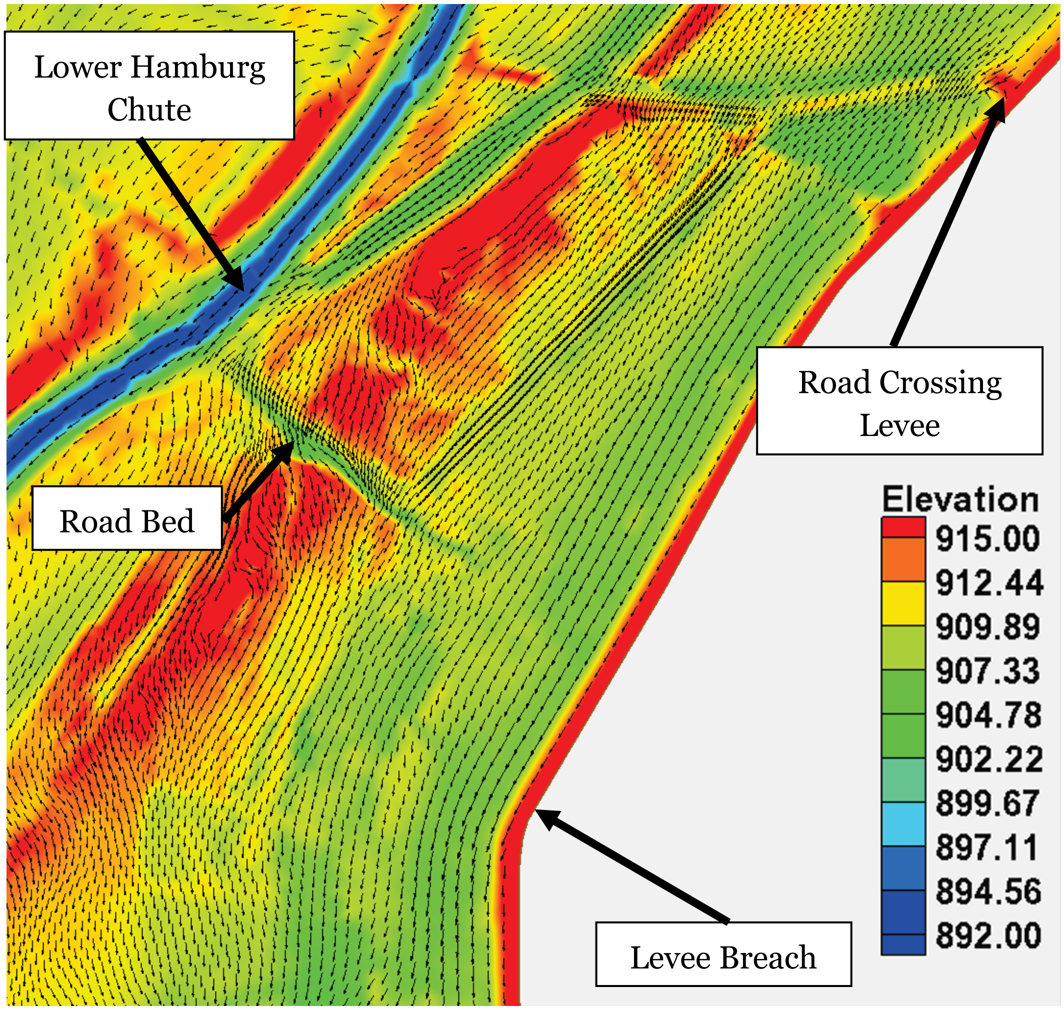


Figure 13 and Figure 14 images also present the direction of the flow over the road crossing at the levee as well as through the opening for the road bed. The figures show multiple areas of the floodplain in which the velocity vector directions are not oriented in the prevailing downstream direction. However, neither velocity vectors toward the levee nor highly turbulent eddy zones were observed in model results within any area where higher velocities were noted. The levee access road ramp (top right corner of Figure 13 and Figure 14) has some indications of an eddy, but it is located in an area with velocities of less than 1 ft/sec (0.3048 m/sec). Vector plots do show areas of flow redirection zones and convergence that indicate areas of non-normal flow patterns. The zones of greatest redirection and/or convergence are associated with the access routes from the levee to the chute as shown in Figure 9 and Figure 14. The access routes have both a varied elevation and roughness compared to the surrounding floodplain that are possibly the cause of this redirection and/or convergence. The results indicate that the road bed and Lower Hamburg chute, as labeled in Figure 9, do not redirect flow or provide a conduit for impinging flow to the levee.

Figure 14 also shows higher velocity magnitudes (contoured as orange and red) in the area of the levee breach. This likely occurred due to the influence of levee alignment as the water is being forced around the protruding levee corner. Velocities in this area exceed 6 ft/sec (1.828 m/sec) and are significantly greater than the 2–4 ft/sec (.606 – 1.219 m/sec) range determined for much of the floodplain.

Figure 15 shows the water depth (ft) of Task 2, validated model of Hamburg Bend pre-2011 flood conditions, at the end of a 30-day, steady-state simulation with a flow of 160,000 cfs (4,530.7 cms).

Figure 14. Task 2 velocity magnitudes (ft/sec) overlain with velocity vectors near levee breach for the 160,000 cfs (4,530.7 cms) flow.

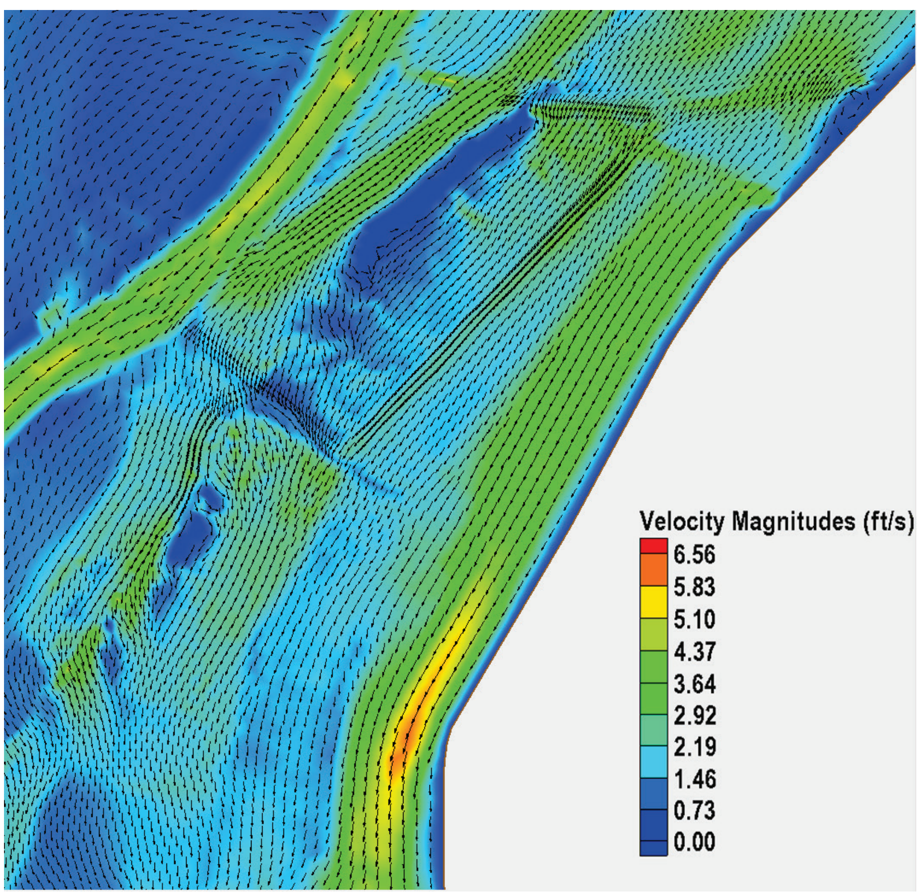
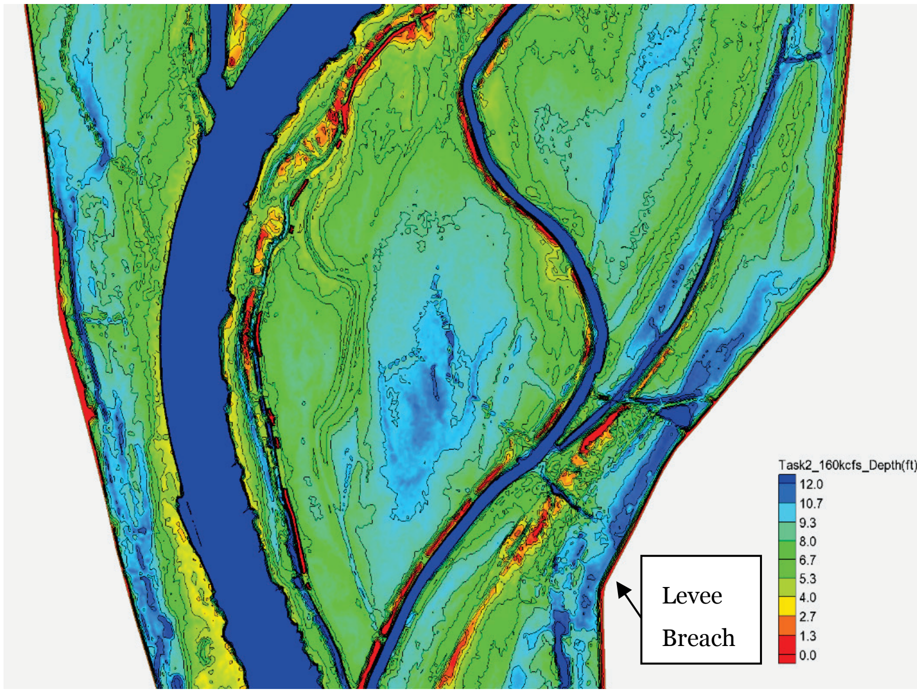


Figure 15. Task 2 model depths (ft) for 160,000 cfs (4,530.7 cms) flow



3.2 Task 4A alternative

Task 4A required all Lower Hamburg Chute features to be removed and for topography and vegetation to be assigned as existed prior to chute construction. This model provides insight into how the flows in the reach would have acted during the 2011 flood if the Lower Chute had never been built and how the flows would have differed from as-built modeled conditions. This was done by comparing Task 4A to Task 2. To do this, the Task 2 model's elevation data and material types were altered to recreate the pre-chute conditions by observing historic images and area knowledge from Omaha District. Note that there were no pre-chute elevation data available, so the elevations were recreated by surrounding elevations and engineering judgement. Pre-chute construction floodplain topography was estimated by comparing to surrounding elevations. Since the lower chute followed old drainage swales, it is possible that this method underestimated depth. Upper Hamburg Bend chute construction was initiated in 1996 and was considered to be in the 2011 pre-flood condition for the analysis. The Task 4A model was run for flows of 160,000 cfs (4530.7 cms) and 240,000 cfs (6,796.2 cms). Figure 16 shows the elevation data (feet) of Task 4A model. Throughout the lower chute, the difference in elevations between this task and Task 2 is clearly seen by comparing Figure 16 to Figure 2. Figure 17 shows the new material type configuration for the alternative.

Figure 16. Task 4A model elevation data (ft).

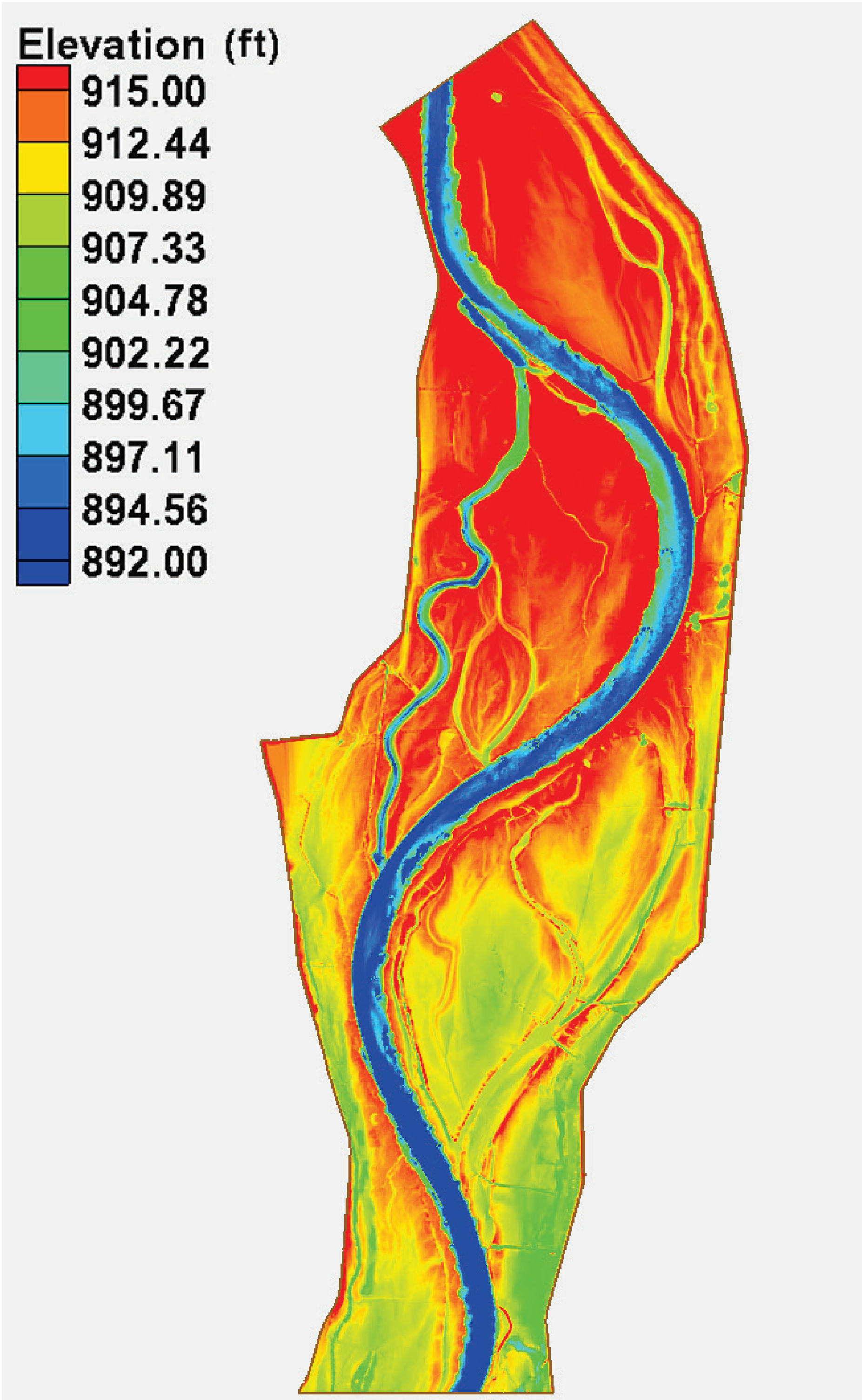


Figure 17. Task 4A model material types.

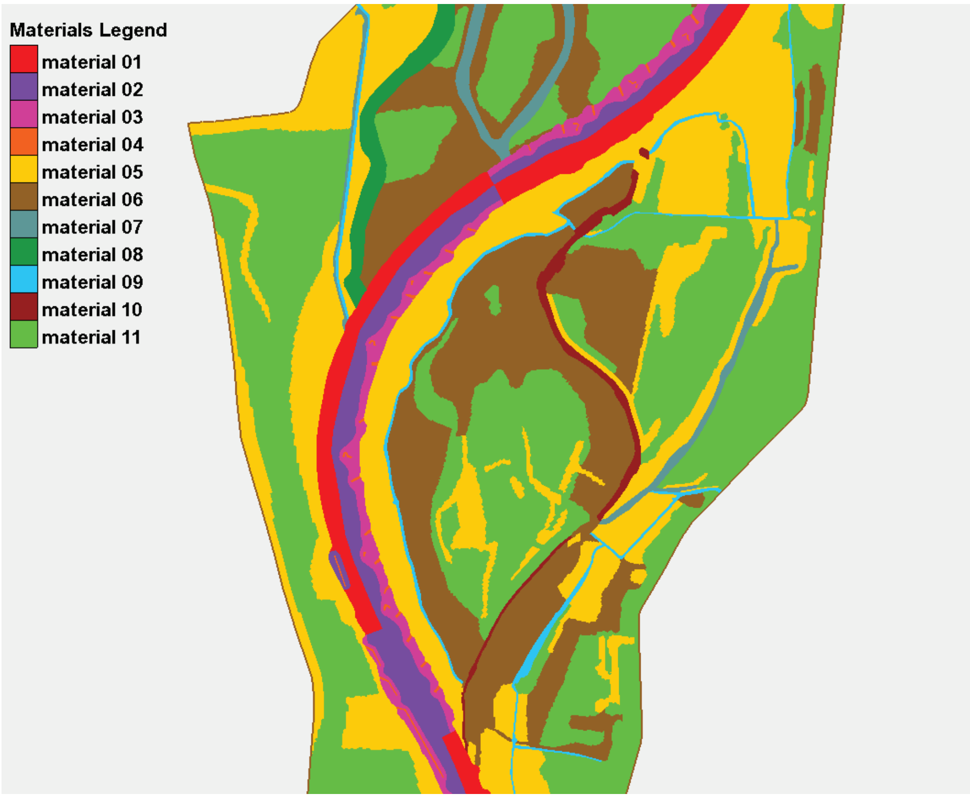


Figure 18 is the velocity in feet per second at the end the 160,000 cfs (4,530.7 cms) Task 4A simulation in the Lower Hamburg Chute area.

Figure 19 is the difference in velocity in feet per second between Task 4A and Task 2. Red and yellow colors show a larger increase in velocity, blue shows a larger reduction in velocity, and green shows from a slight increase to slight decrease in velocity.

These results show that the pre-chute conditions in the Lower Hamburg chute reach produced slightly slower velocities (maximum of 0.5 ft/sec) within the floodplain adjacent to the area of the levee breach than that of the pre-2011 flood conditions. As shown in the red shaded areas, higher velocities would have occurred farther out in the floodplain. The velocities in the entire chute area are lower since depths are much different.

Figure 18. Task 4A velocity magnitudes (ft/sec) for 160,000 cfs (4,530.7 cms) flow.

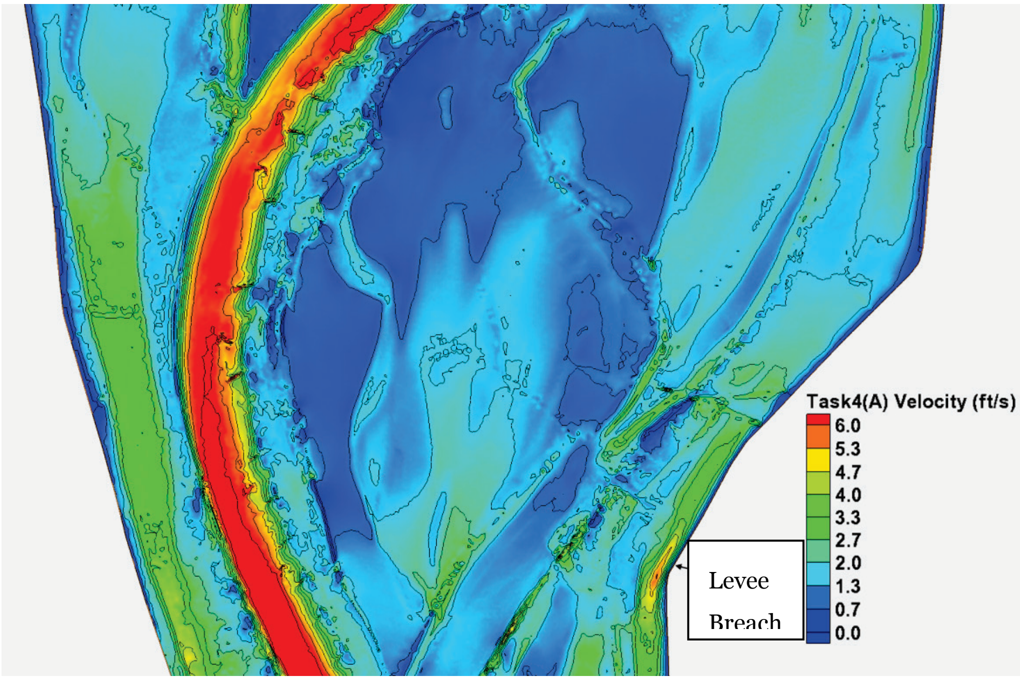
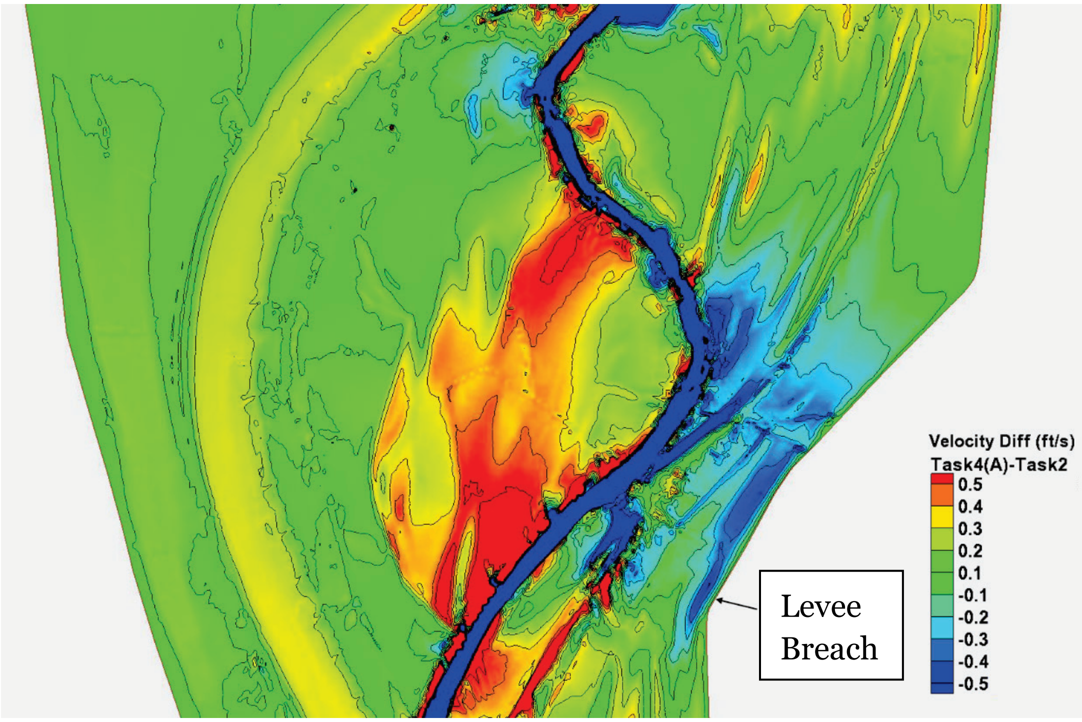


Figure 19. Task 4A – Task 2 velocity magnitude differences (ft/sec) for 160,000 cfs (4,530.7 cms) flow.



3.3 Task 4B alternative

Task 4B required all side-cast earth mounds that were created during the Lower Hamburg Chute construction to be removed while leaving the remaining chute features intact. This model provides insight into how the velocities in the floodplain in the reach would have acted during the 2011 flood if the berms were not there and how the velocities would differ from what actually occurred. This was done by comparing Task 4B to Task 2. To do this, the Task 2 model's elevation data were altered to create the scenario by observing the model elevation data and guidance from the Omaha District to locate the mounds and remove them. Note that there were no pre-chute elevation data available in the area of the mounds, so the elevations were recreated by surrounding elevations and engineering judgment. The Task 4(B) model was run for flows of 160,000 cfs (4530.7 cms) and 240,000 cfs (6,796.2 cms). Figure 20 shows the elevation data (ft) of Task 4B model.

Figure 21 is the velocity in feet per second at the end the Task 4B simulation.

Figure 22 is the difference in velocity in feet per second between Task 4B and Task 2. Red and yellow colors show a larger increase in velocity, blue shows a larger reduction in velocity, and green shows from a slight increase to slight decrease in velocity.

These results show that an alternative that removed the side-cast spoil piles around the Lower Chute would have had slightly slower velocities (maximum of 0.5 ft/sec) in the area of the levee breach than that of the pre-2011 flood conditions. Similar to Task 4A results, higher velocities occurred farther out in the floodplain. Velocity change from the Task 2 condition for Task 4B is similar to that previously illustrated in Task 4A but slightly higher in the floodplain between the Lower Chute and the main channel.

Figure 20. Task 4B model elevation data (ft).

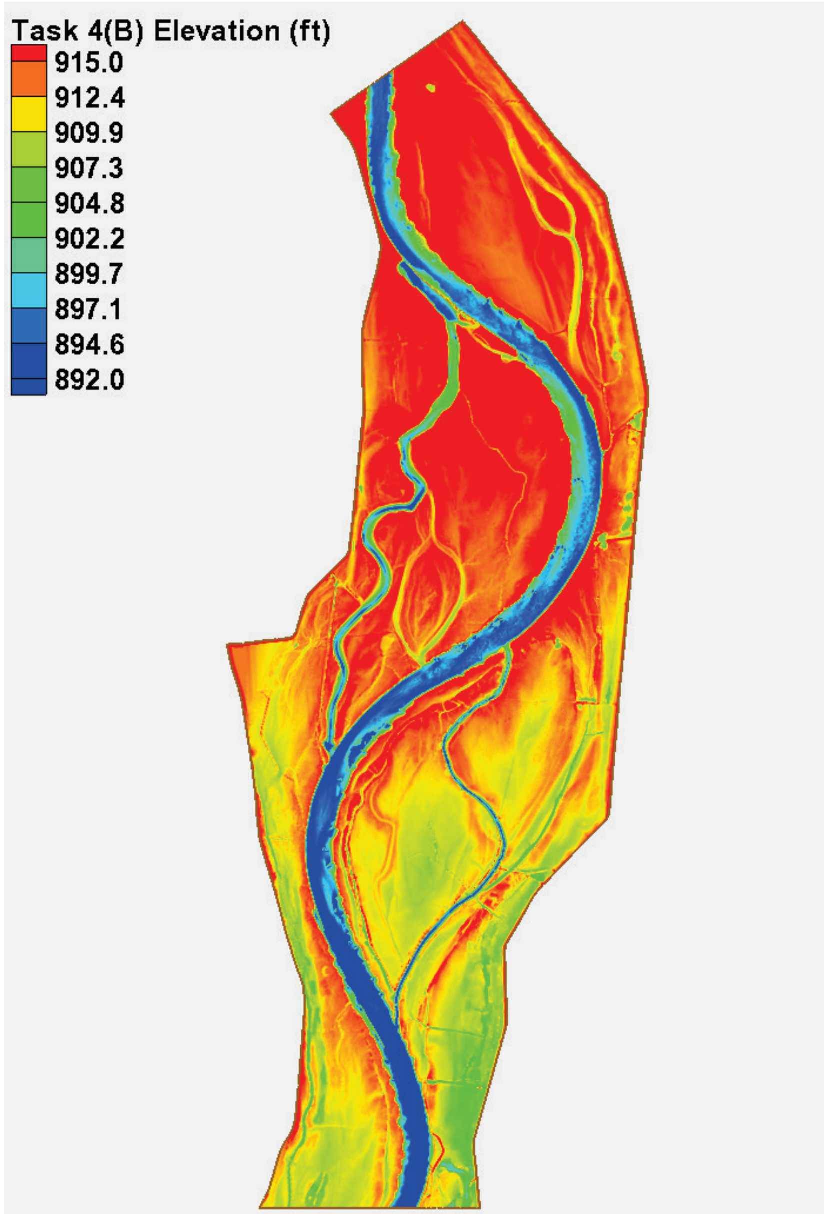


Figure 21. Task 4B velocity magnitudes (ft/sec) for 160,000 cfs (4,530.7 cms) flow.

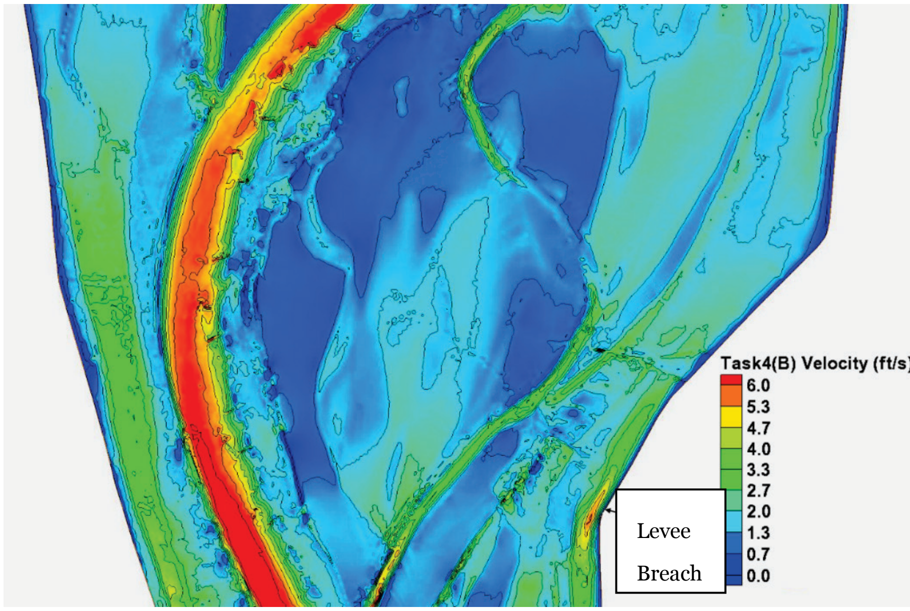
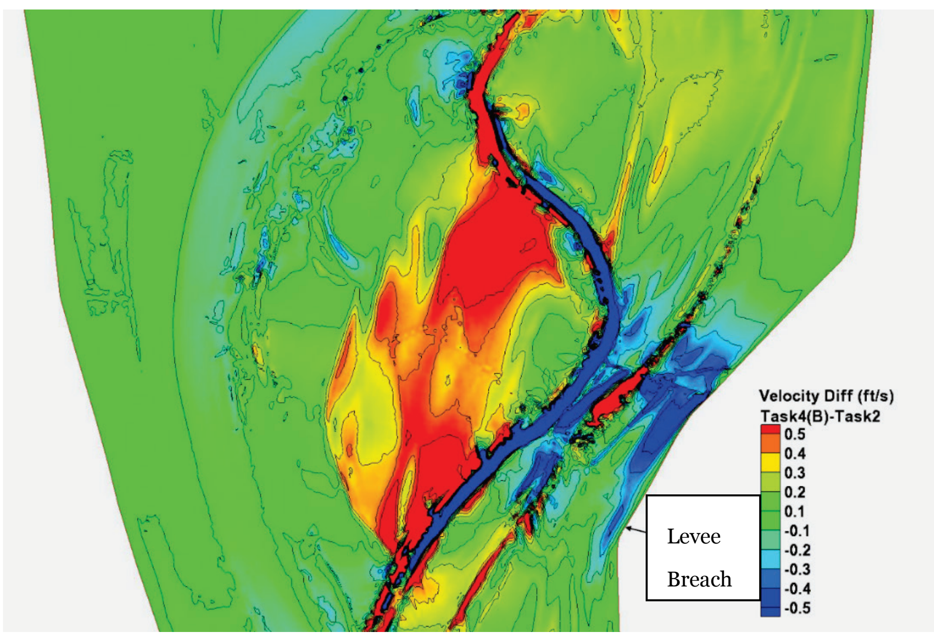


Figure 22. Task 4B – Task 2 velocity magnitude differences (ft/sec) for 160,000 cfs (4,530.7 cms) flow.



3.4 Task 4C alternative

Task 4C required removal of all near-levee features in only the Lower Hamburg Bend that affected flow (access ramps, riverside roads, and cuts through the vegetation between the levee and chute). This model provides insight into how the flows would have distributed in the areas near the levee east of the Lower Chute if they were cleared of access ramps, riverside roads and cuts through the vegetation and how the flows differ from what actually occurred. This was done by comparing Task 4C to Task 2. To do this the Task 2 model's elevations were altered to create the scenario by observing images, local data, and model elevation data to locate all objects impeding flow in the area and changing the elevations. The Task 4C model was run for flows of 160,000 cfs (4,530.7 cms) and 240,000 cfs (6,796.2 cms). Figure 23 shows the elevation data (ft) of Task 4C model.

Figure 23. Task 4C model elevation data (ft).

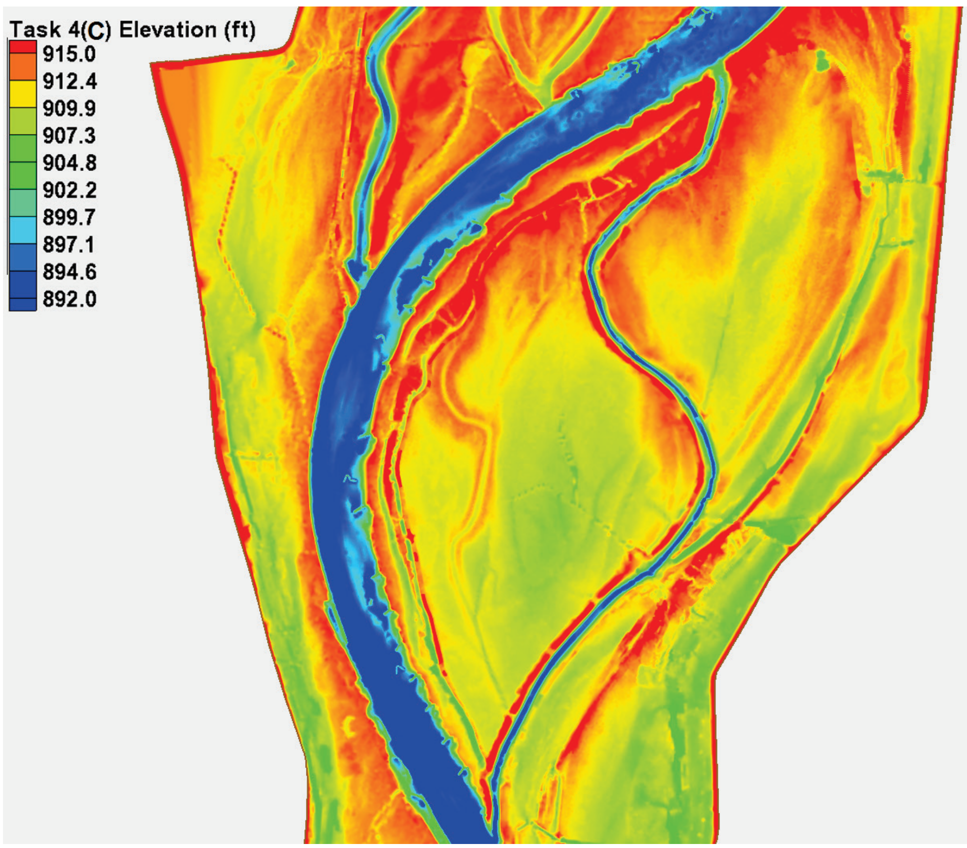


Figure 24 is the velocity in feet per second at the end the Task 4C simulation.

Figure 25 is the difference in velocity in feet per second between Task 4C and Task 2. Red and yellow colors show a larger increase in velocity, blue shows a larger reduction in velocity, and green shows from a slight increase to slight decrease in velocity.

Figure 24. Task 4C velocity magnitudes (ft/sec) for 160,000 cfs (4,530.7 cms) flow.

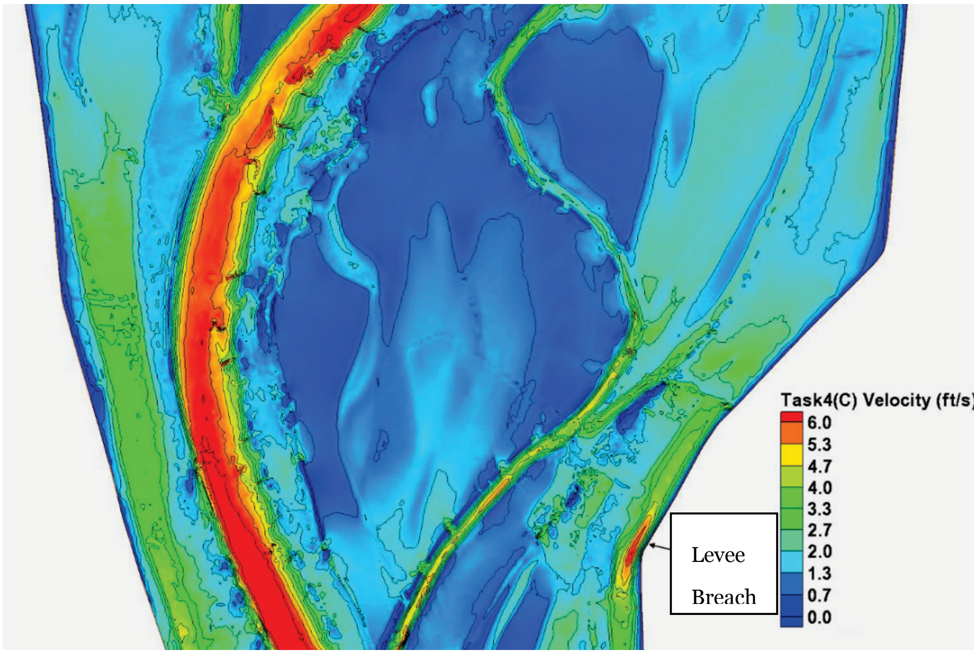
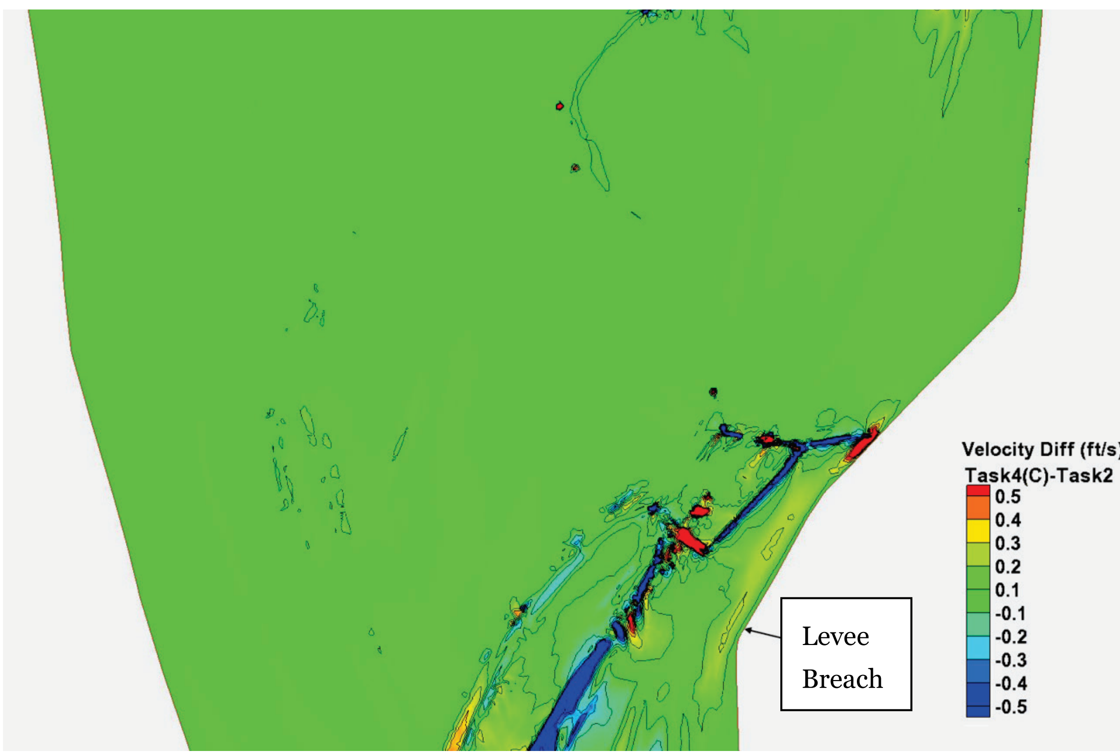


Figure 25. Task 4C – Task 2 velocity magnitude differences (ft/sec) for 160,000 cfs (4,530.7 cms) flow.



These results show that an alternative that removed all access ramps, riverside roads, and cuts through the vegetation between the levee and chute would have had higher velocities in the area of the levee breach than that of the pre-2011 flood conditions. The alternative resulted in small, concentrated changes in velocities in the immediate vicinity of where the model geometry changes were made and had little to no impact on the rest of the floodplain.

3.5 Task 4D alternative

Task 4D required all of the area east of the Lower Hamburg Chute to be changed to a vegetation roughness of farmland. This model provides insight into how the flows in the reach would have acted during the 2011 flood if the areas east of the Lower Chute had been cleared of all trees and other large vegetation and was replaced with open fields. This was done by comparing Task 4D to Task 2. To do this, the Task 2 model's material types east of the Lower Chute were changed to portray open fields. The Task 4(D) model was run for flows of 160,000 cfs (4,530.7 cms) and 240,000 cfs (6,796.2 cms). Figure 26 shows the model material types of Task 4D model.

Figure 26. Task 4D model material types (ft).

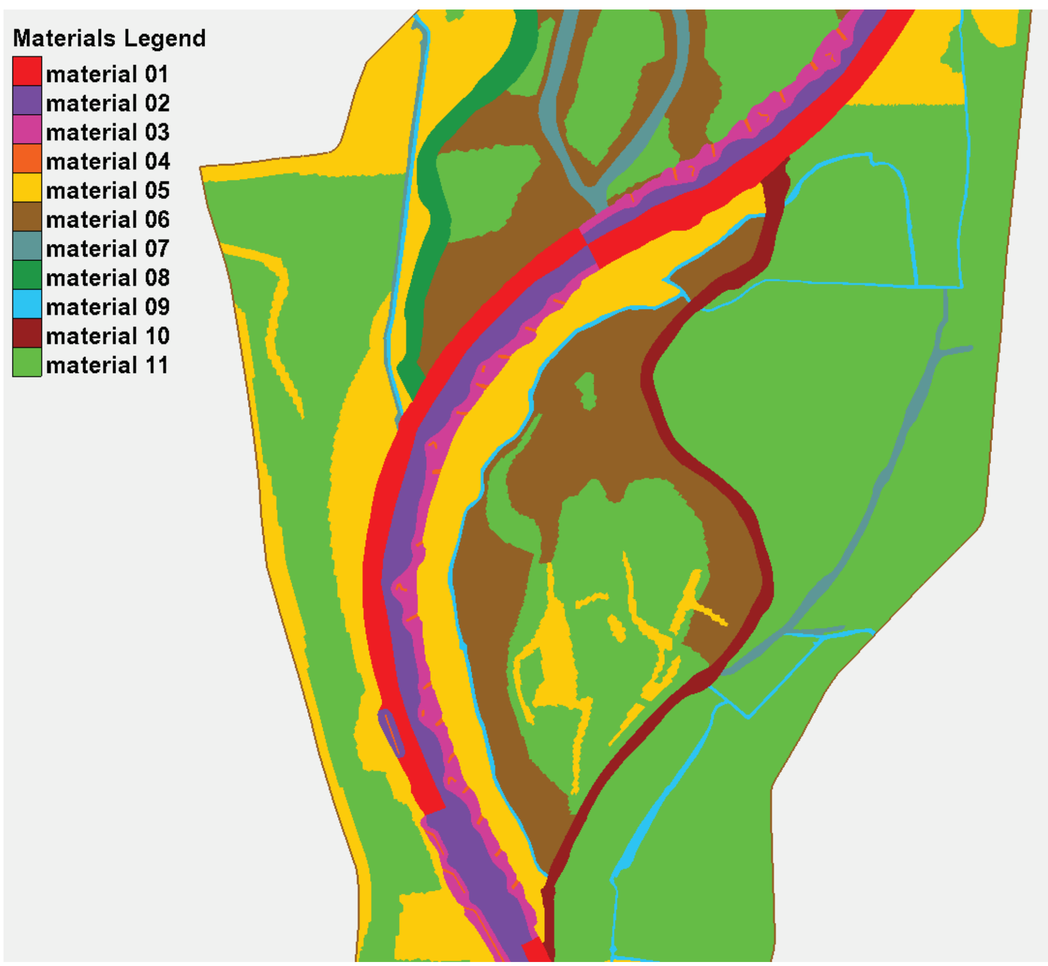


Figure 27 is the velocity in feet per second at the end the Task 4D simulation.

Figure 28 is the difference in velocity in feet per second between Task 4D and Task 2. Red and yellow colors show a larger increase in velocity, blue shows a larger reduction in velocity, and green shows from a slight increase to slight decrease in velocity. Note that the scale is much larger than in recent alternatives.

Figure 27. Task 4D velocity magnitudes (ft/sec) for 160,000 cfs (4,530.7 cms) flow.

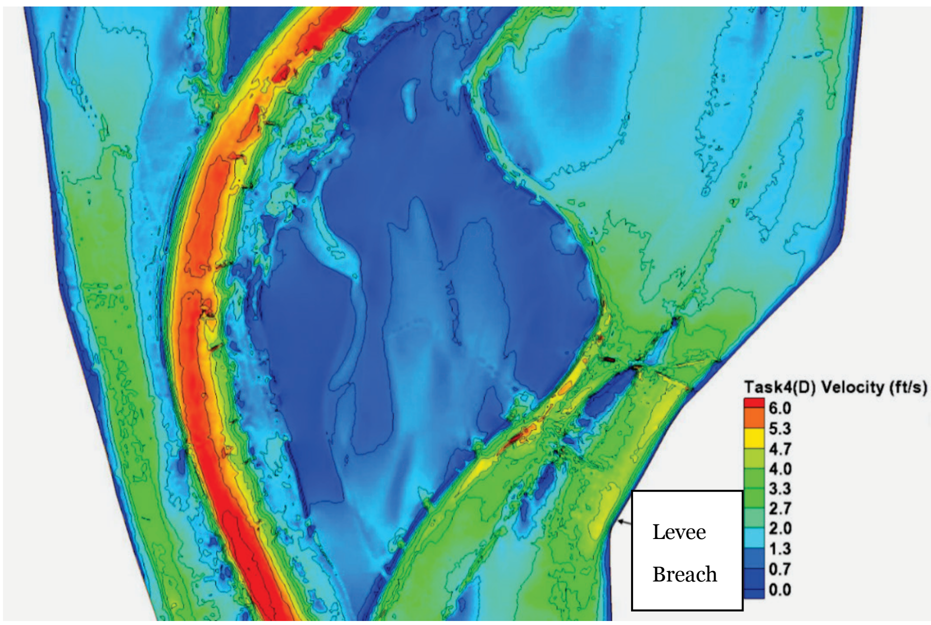
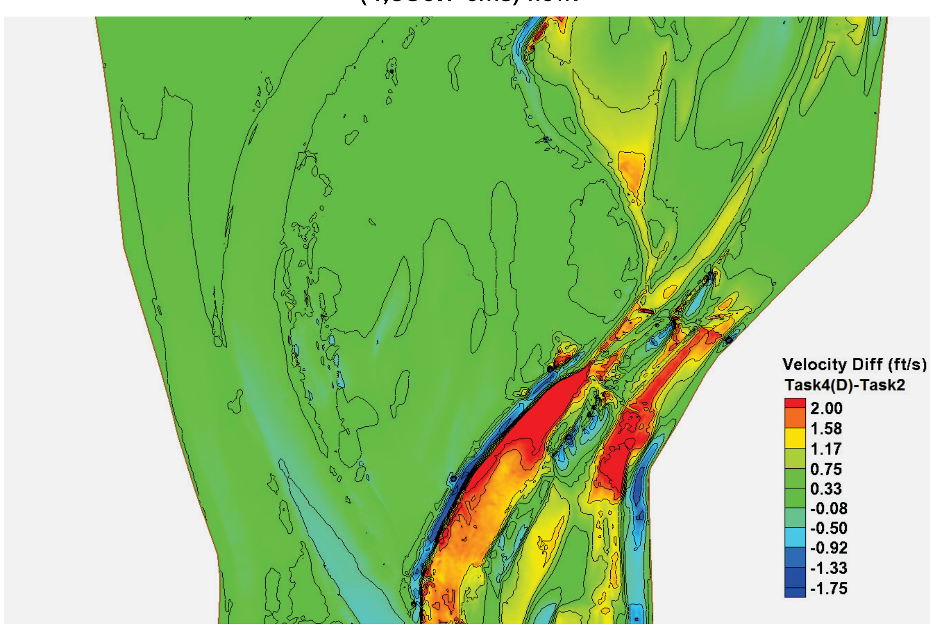


Figure 28. Task 4D – Task 2 velocity magnitude differences (ft/sec) for 160,000 cfs (4,530.7 cms) flow.



These results show that an alternative with all land east of the Lower Chute converted to farmland would have significantly increased nearby floodplain velocities in areas that were dense vegetation but decreased velocities in the near-levee-breach proximity, with a maximum reduction of approximately 1.8 ft/sec, compared to that of the pre-2011 flood conditions. The alternative resulted in much higher conveyance and velocity changes in the area east of the Lower Chute compared to the previous alternatives in both magnitude and area influenced.

3.6 Task 4E alternative

Task 4E required all Upper and Lower Hamburg Chute features to be removed and for topography and vegetation to be assigned as existed prior to chute construction. This model provides insight into how the flows in the reach would have acted during the 2011 flood if both the Upper and Lower Chutes had never been built and how the flows would have differed from as-built modeled conditions. This was done by comparing Task 4E to Task 2. This alternative differs from the previous Task 4A, which removed the Lower Hamburg chute features and left the Upper Hamburg chute in the pre-flood condition. To do this, the Task 2 model's bathymetry and material types were altered to create the scenario by observing historic images and recreating the pre-chute conditions. Note that there were no pre-chute elevation data available, so the elevations were recreated by surrounding elevations and engineering judgment. The Task 4E model was run for flows of 160,000 cfs (4530.7 cms) and 240,000 cfs (6,796.2 cms). Figure 29 shows the elevation data (feet) of Task 4E model. Figure 30 shows the new material type configuration for the alternative.

Figure 31 is the velocity in feet per second at the end the Task 4E simulation where Figure 32 shows the velocities in the areas near the levee breach.

Figure 33 is the difference in velocity in feet per second between Task 4E and Task 2. Red and yellow colors show a larger increase in velocity, blue shows a larger reduction in velocity, and green shows from a slight increase to slight decrease in velocity. Figure 34 also shows the difference in velocities but shows a zoomed-in view of the area near the levee breach.

Figure 29. Task 4E model elevation data (ft).

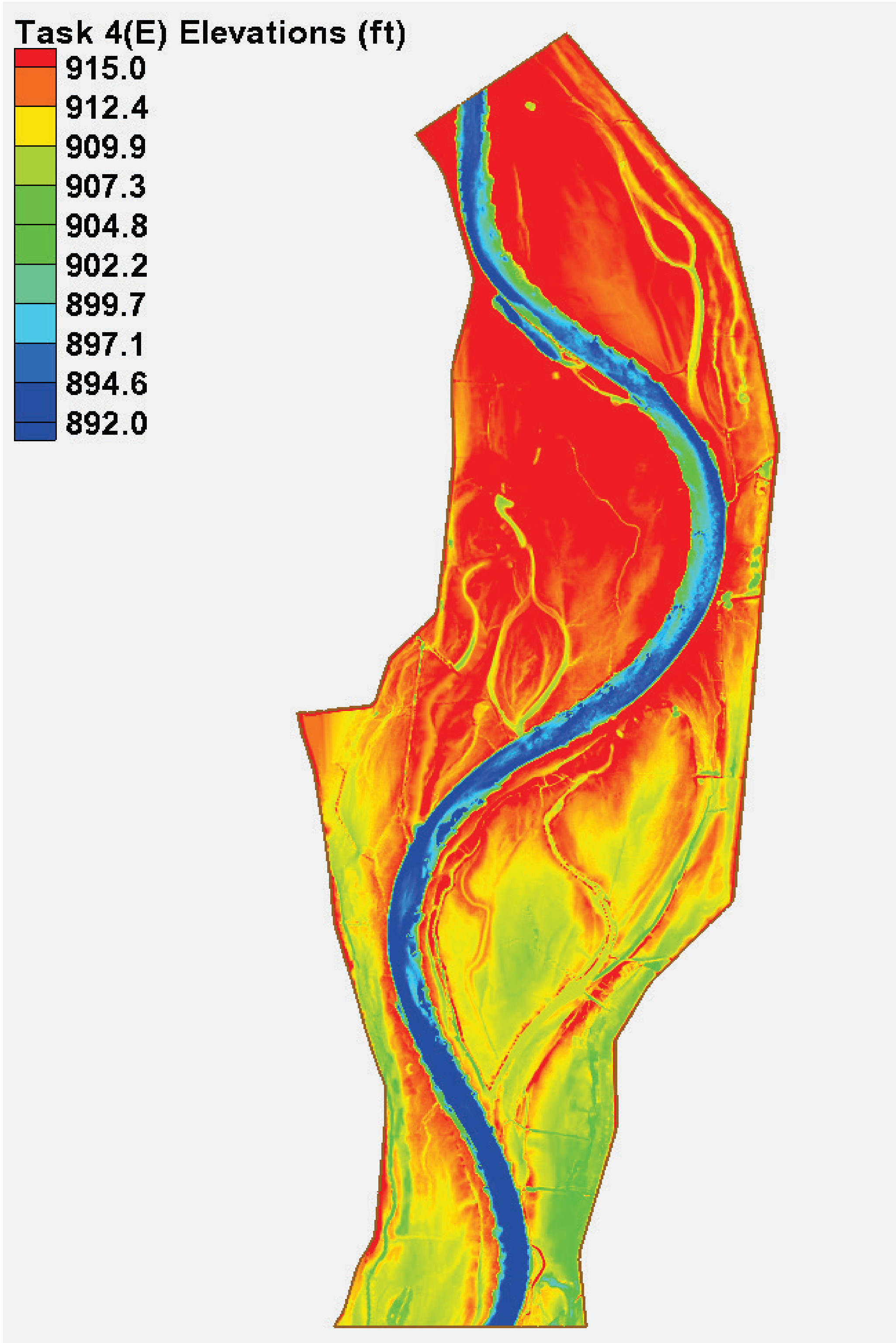


Figure 30. Task 4E model material types.

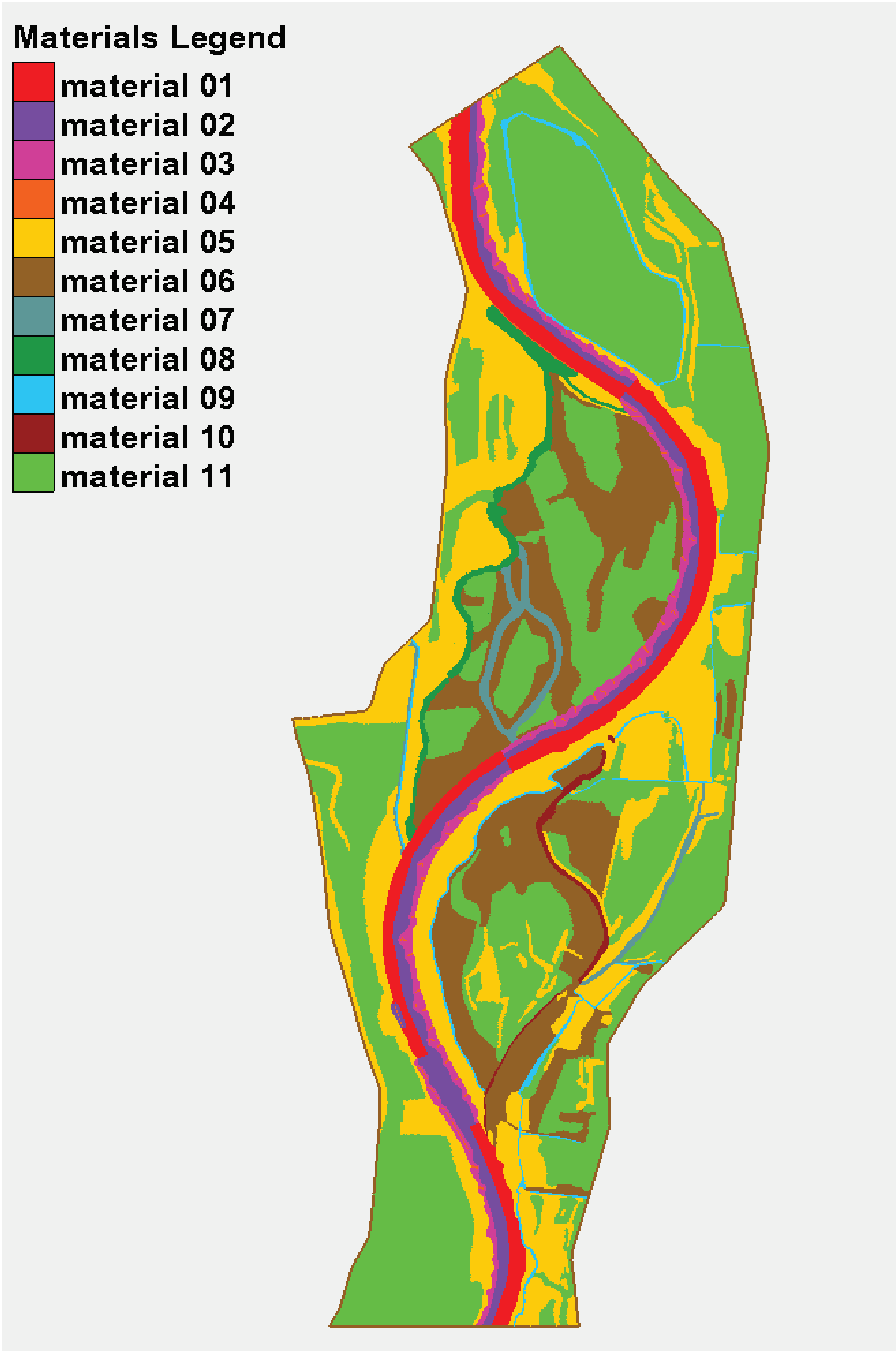


Figure 31. Task 4E velocity magnitudes (ft/sec) for 160,000 cfs (4,530.7 cms) flow.

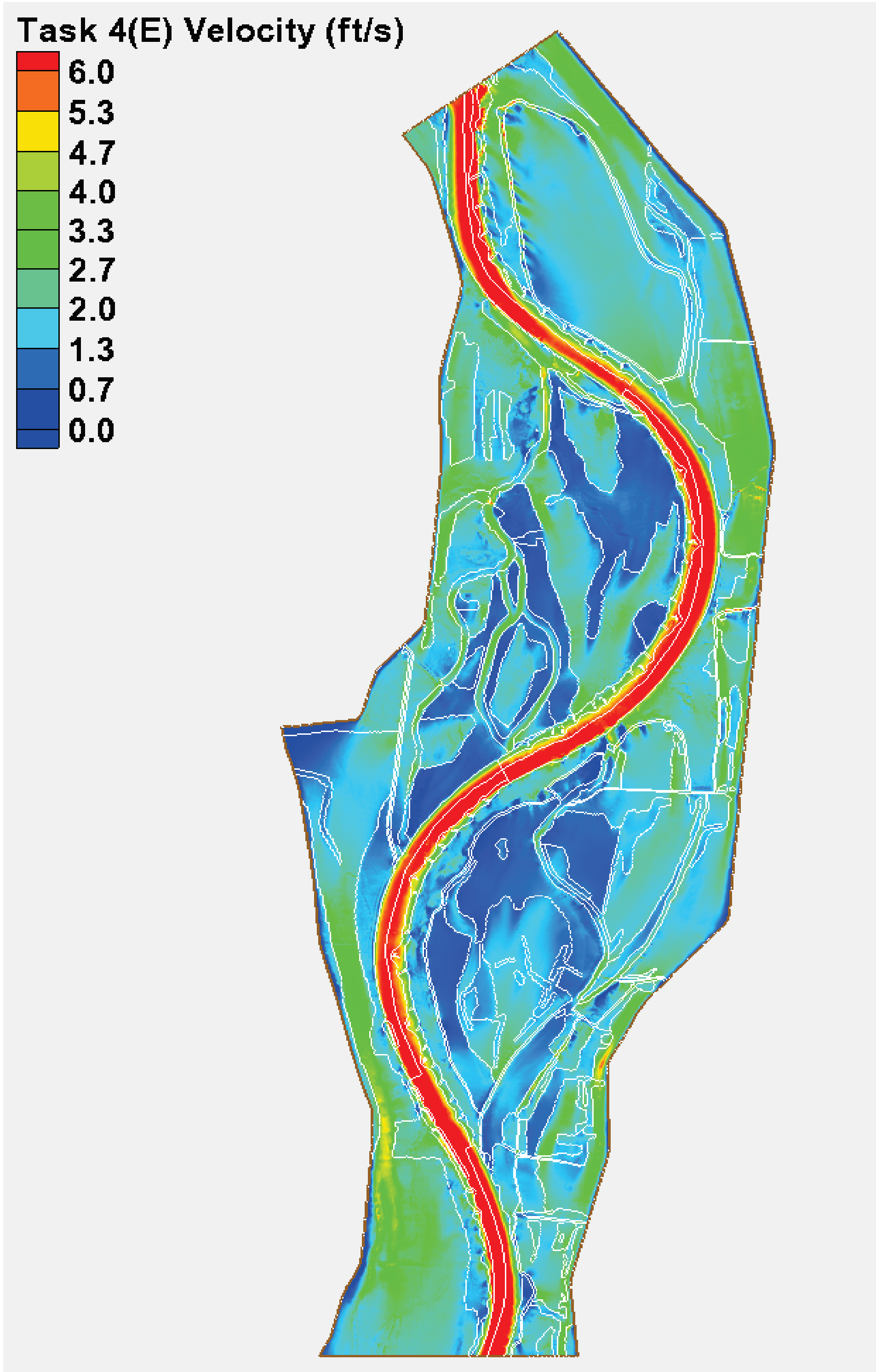
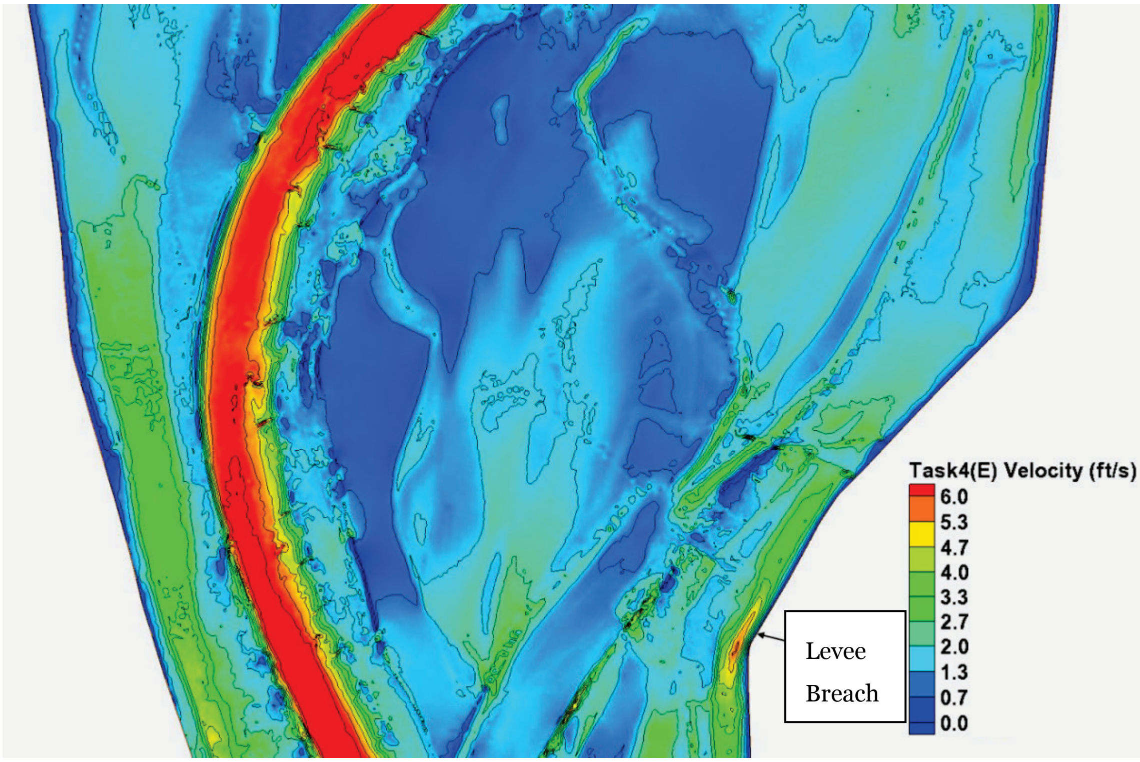


Figure 32. Task 4E velocity magnitudes (ft/sec) for 160,000 cfs (4,530.7 cms) flow near levee breach.



These results show that an alternative that returned both the Upper and Lower Chutes to pre-chute conditions would have had slightly lower velocities (maximum of 0.5 ft/sec) in the area of the Lower Hamburg levee breach than that of the pre-2011 flood conditions. Figure 33 also shows large areas along both the left and right levees of velocity increase (maximum of 0.5 ft/sec). In addition, the alternative resulted in a wide area of mostly small changes to velocity (plus or minus 0.3 ft/sec or less) and conveyance throughout most of the floodplain.

Figure 33. Task 4E – Task 2 velocity magnitude differences (ft/sec) for 160,000 cfs (4,530.7 cms) flow.

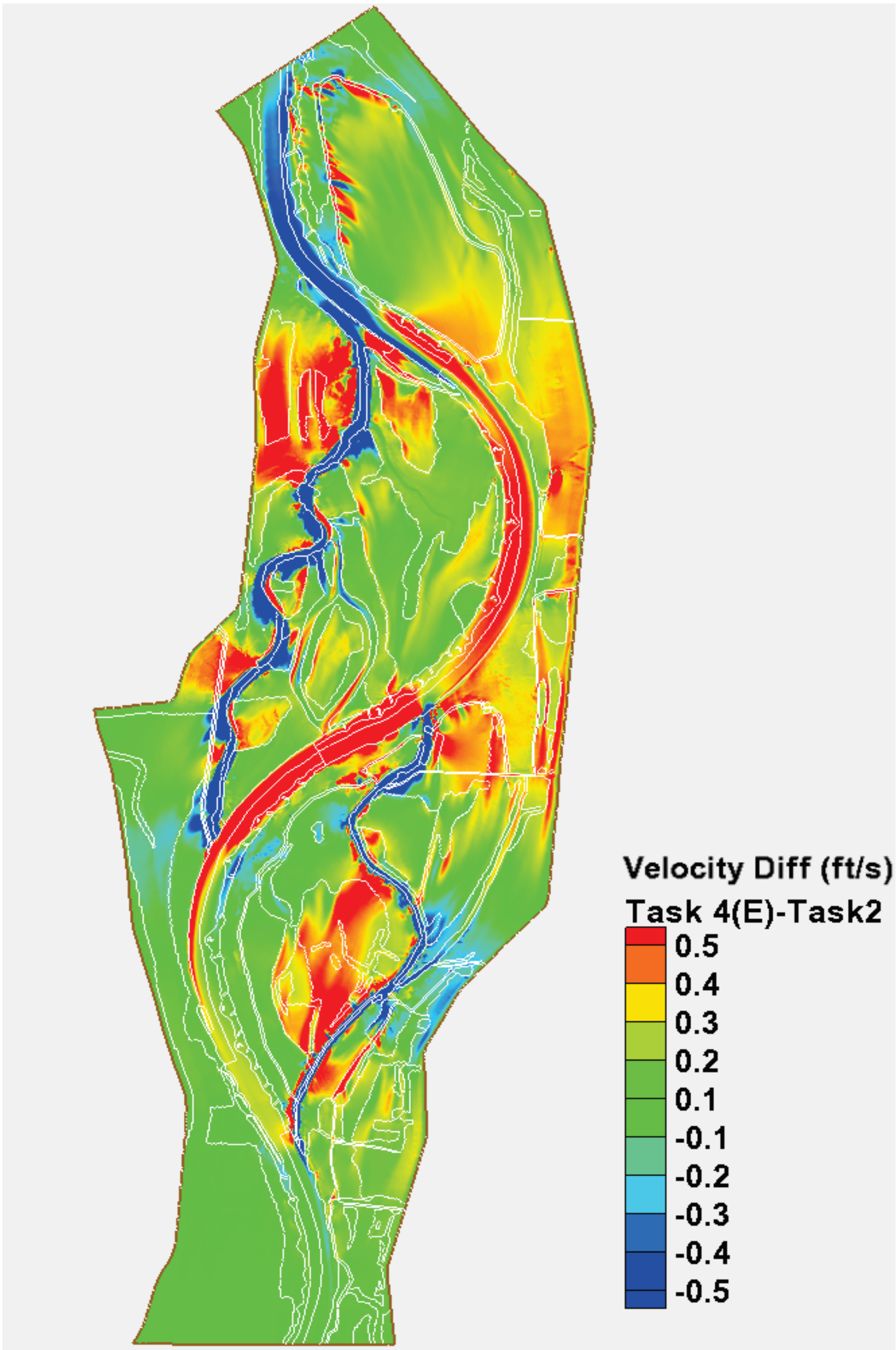
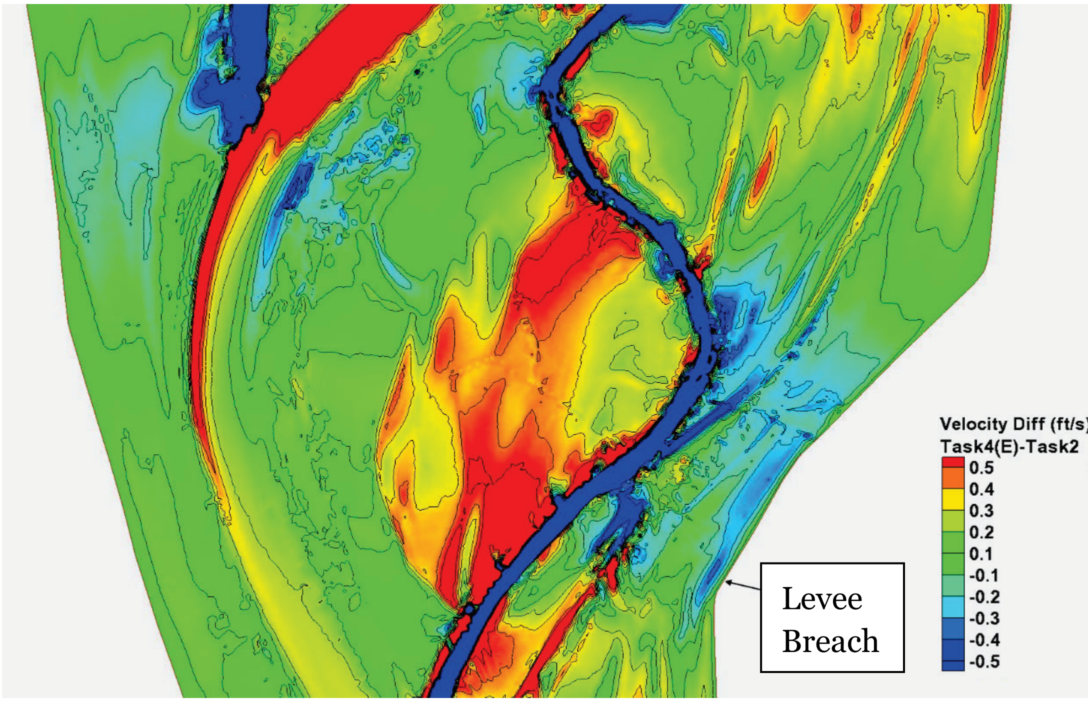


Figure 34. Task 4E – Task 2 velocity magnitude differences (ft/sec) for 160,000 cfs (4,530.7 cms) flow near levee breach.



3.7 Task 5 alternative

Task 5 required the creation of a post-2011 flood, current-condition model that was used to evaluate future flood conditions throughout Hamburg Bend. Comparison to pre-2011 event conditions was done by comparing Task 2 to Task 5 results. This included assessing results in the near-levee region, chute channels, new chute structures, and main channel. To do this, the Task 2 model had to be modified to include the expanded chutes geometry, post-flood structures within each chute, the scour hole and fill in Upper Hamburg Chute, the eastern main levee setback, and the scour hole repair between the Lower Chute and the levee setback. Figure 35 shows the Task 5 mesh elevation data and floodplain elevations with all the previously mentioned changes made.

The Task 5 model was run for flows of 80,000 cfs, 160,000 cfs, and 240,000 cfs (2265.36 cms, 4,350.7 cms, and 6,796.2 cms). Figure 36 shows the computed velocity contours for the Task 5 model. These computed velocities can be compared to the Task 2 computed velocities, which are shown in Figure 37. These two plots can be considered as a sort of base condition, or datum, against which to compare the difference plots. Both figures are for the flow condition of 240,000 cfs (6,796.2 cms), which for this task was considered the worst-case conditions that the new structures and other repairs would be subjected to.

Figure 35. Task 5 model elevations (ft).

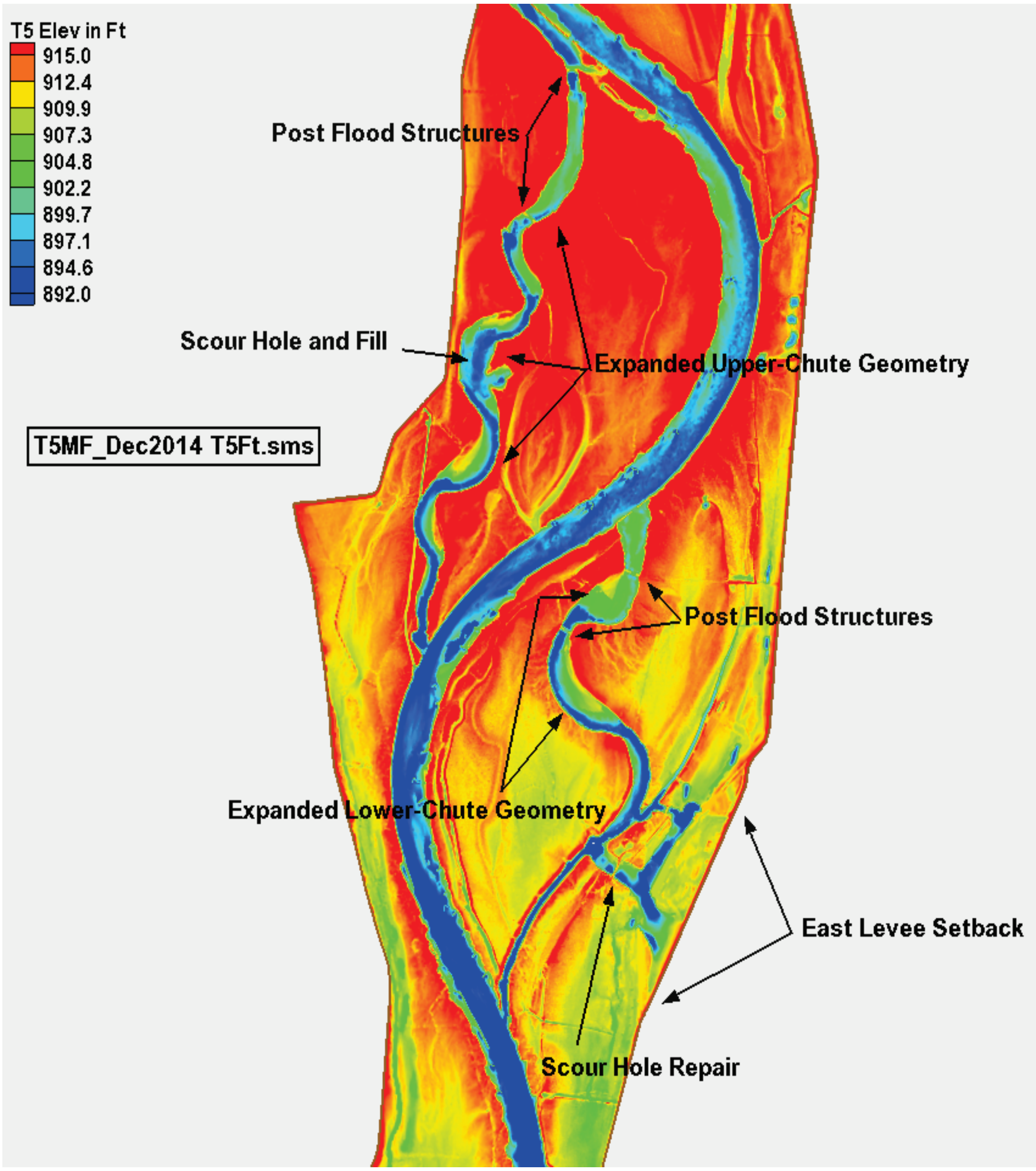


Figure 36. Task 5 velocity magnitudes (ft/sec) for 240,000 cfs (6,796.17 cms) flow.

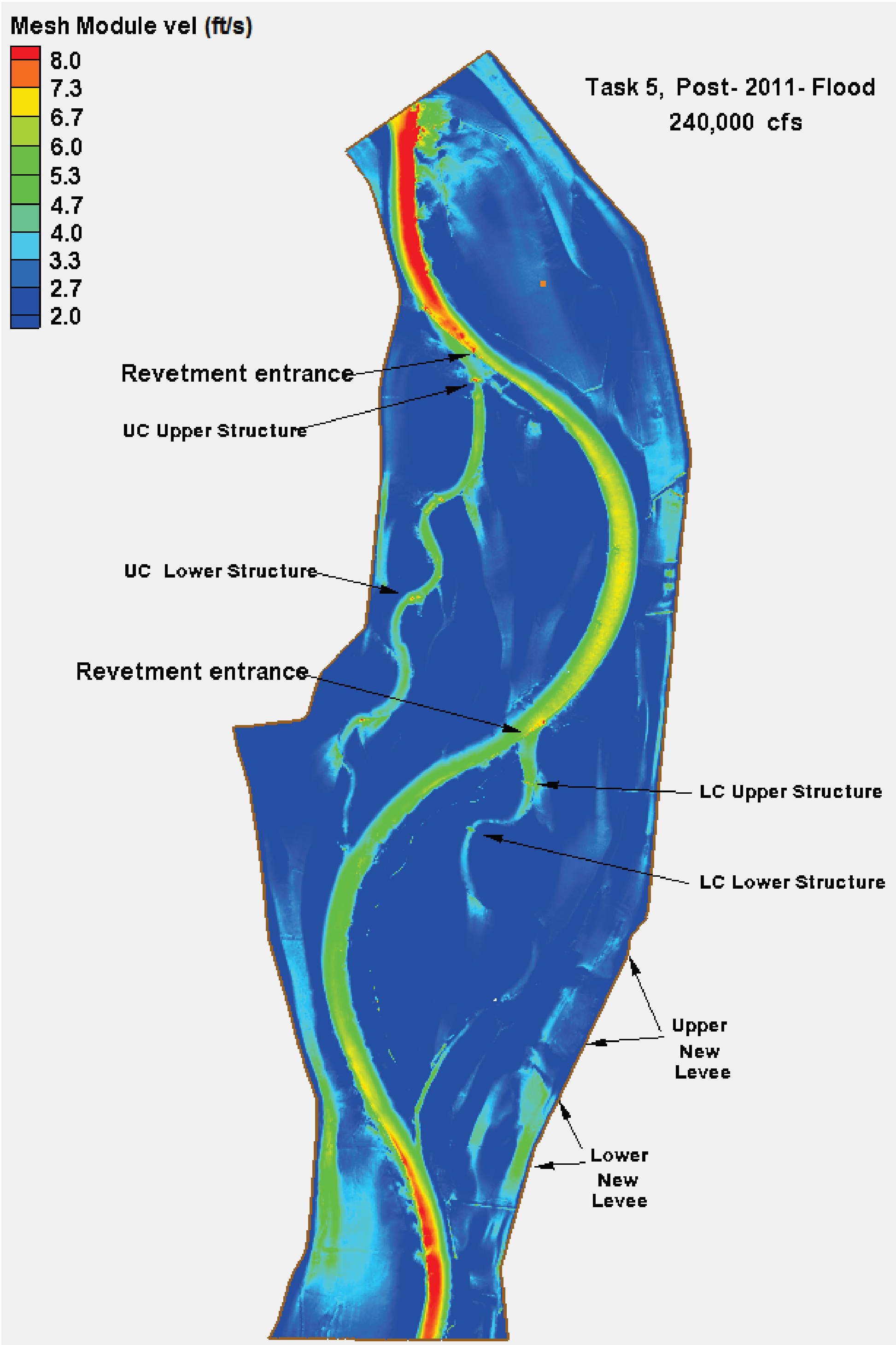
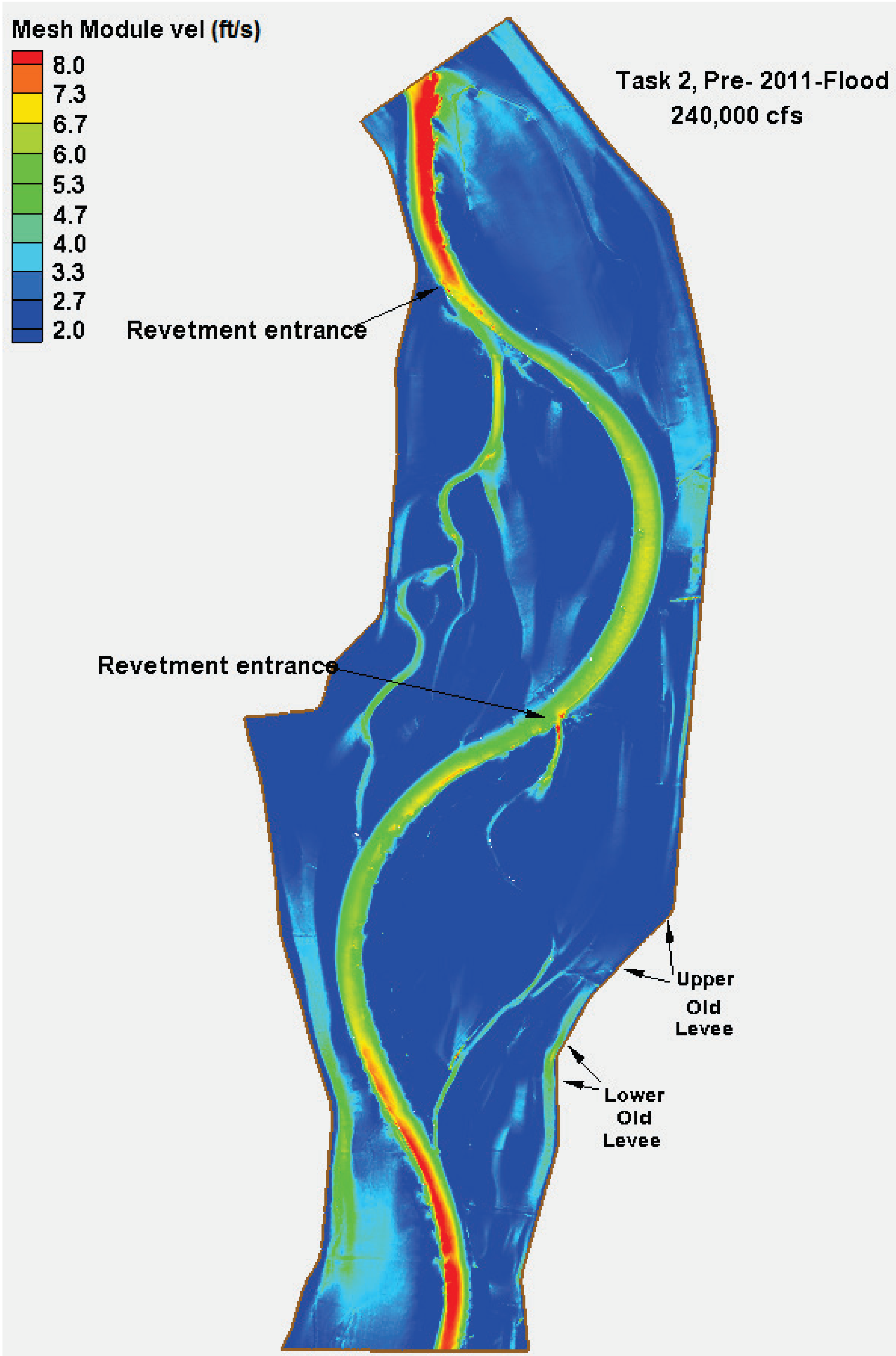


Figure 37. Task 2 velocity magnitudes (ft/sec) for 240,000 cfs (6,796.17 cms) flow.



Computed velocities for the two tasks are shown in Table 1.

Table 1. Task 2 and Task 5 computed velocities (ft/sec).

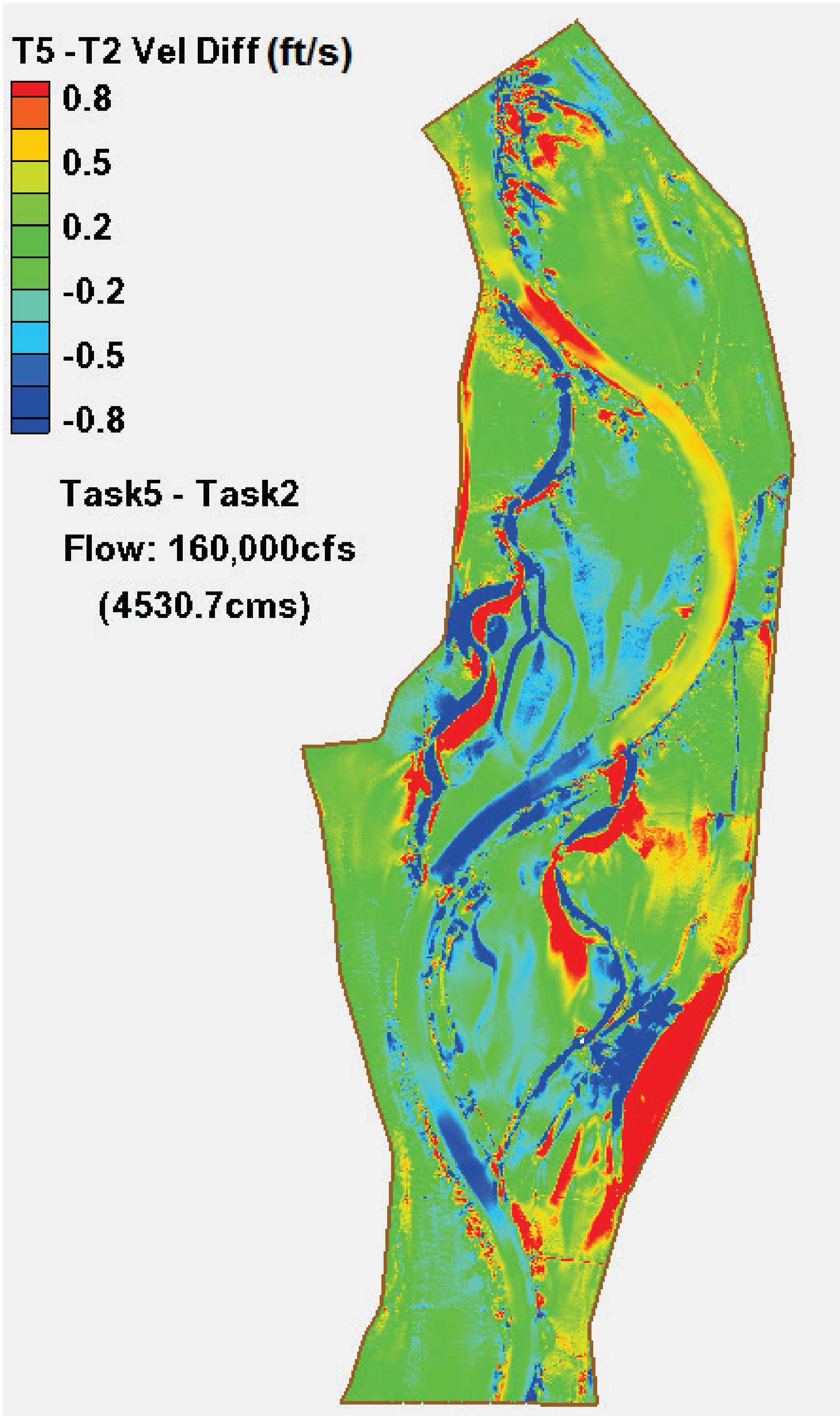
1	Location	Flow		%	Flow		%	Flow		%
2		80 kcfs		Diff.	160 kcfs		Diff.	240 kcfs		Diff.
3										
4	***Upper Chute***	Task 2	Task 5		Task 2	Task 5		Task 2	Task 5	
5		ft/s	ft/s		ft/s	ft/s		ft/s	ft/s	
6										
7	Revetment entrance	6.4	1.7	-73	7.2	2	-72	6.7	2.8	-58
8										
9	Upper Chute upper structure	X	6.4		X	7.2		X	6.8	
10	Upper Chute lower structure	X	6.1		X	6.6		X	6.4	
11										
12	upstream end of new stone	X	0.32		X	0.5		X	1.3	
13	revetment for scour hole near									
14	the levee									
18										
19										
20	***Lower Chute***									
21										
22	Revetment entrance	4.3	2.5	-42	6.7	3.6	-46	6.6	4.6	-30
23										
24	Lower Chute upper structure	X	5.1		X	5.4		X	5.6	
25	Lower Chute lower structure	X	6.2		X	5.1		X	4.8	
26										
27	upper part of old/new levee	0.58	0.04	-93	1.7	1.3	-24	2.1	2.3	10
28	lower part of old/new levee	1.58	1.1	-30	3.6	2.8	-22	4.4	3.8	-14
29	X = Structure did not exist									

As mentioned previously, the purpose of Task 5 is to model the newly repaired “system” (including changes to chutes, levees, and floodplain where applicable) for varying flows. The results from these models can then be compared to before-flood (Task 2) model results to see if any significant changes in flows and velocities occur at selected locations. The locations in Table 1 were of particular interest because rock structure failure at these locations could impact other areas of the system. The comparison intent is to show whether or not the sum of the changes shows significant velocity increases at the selected locations. For the revetment entrances and chute structures, the values in the table represent the highest values in the middle of the openings. As shown on line 7 and line 22, the velocities in the Task 5 revetment entrances are significantly reduced. The negative sign in the “% Diff” column indicates a reduction from Task 2 to Task 5. There were no pre-flood structures in either chute to provide comparisons to (lines 9 and 10; lines 24 and 25). For the Task 5 model, the velocity magnitudes at these locations are valuable to show in that they provide necessary information for tractive force computations at critical locations. The same applies to line 12, where repairs were made for a degraded levee toe. For lines 27 and 28, the pre-flood and post-flood levee alignments, a comparison is made for the locations shown in Figure 36 and Figure 37. These locations were selected because they show the greatest angular change in levee alignment for both Task 2 and Task 5 in the vicinity of the breach. Values at the toe of each levee were used in computing an average velocity value. Line 28 shows a 14% reduction from Task 2 to Task 5, that is, from the pre-flood alignment to the post-flood. Line 27, the upper location, shows a slight increase of 10%.

To show how the various changes made in Task 5 affect flow and velocities throughout the floodplain, in the main channel, and near the levees throughout the model, a difference plot of velocities was made. The values from Task 2 were subtracted from Task 5. The resulting values were plotted and are shown in Figure 38.

Red values indicate higher velocities in the Task 5 model, and blue values indicate lower velocities in the Task 5 model. In portions of the study area where the elevation data of the two task models were significantly different, the utility of this plot is marginal. For instance, the large red crescent just west of the levee setback shows large changes because in the Task 2 model there was no computational mesh in that area, and therefore a value of zero was subtracted from the Task 5 results. No matter what the Task 5 velocities were, the change appears big but is meaningless. The same goes for what appears as big changes in the chutes and anywhere else where large amounts of scour and deposition occurred that changed elevation between the pre- and post-2011 flood geometry. Therefore, the main value in this plot is to note the difference in portions of the floodplain and/or the main channel. In the main channel, it can be seen that velocities are a bit higher upstream of the Lower Chute entrance and slower downstream of the Lower Chute entrance. In the floodplain, increased velocity differences are noticeable just east of the Lower Chute. Also, some higher velocity differences are apparent near the west levee by the Upper Chute and near the east levee north of the levee setback. These two areas are lower velocity magnitude areas and also consistent with elevation differences between the two geometries.

Figure 38. Task 5 – Task 2 velocity magnitude differences (ft/sec) for 160,000 cfs (4,530.7 cms) flow.



3.8 Task 6.1 alternative

Task 6.1 required using the base condition Task 2 model (pre-2011 flood with both chutes and all features) and only added the Lower Hamburg levee setback as is currently constructed. There were no expanded chutes, no chute structures, and no scour-hole fills or repairs as in the Task 5 Alternative. Only the east levee setback was added. This was done to illustrate the effect of a changed levee alignment on flow velocities in the vicinity of the levee. All of the following images were created using the results of the 160,000 cfs (4530.7 cms) runs. Figure 39 shows a difference plot where the computed velocities of the Task 2 simulation were subtracted from the Task 6.1 simulation.

Red and yellow colors show an increase in velocity, blue shows a reduction in velocity, and green shows no change in velocity. Figure 40 is a zoomed-in view of Figure 39 with wider limits to show the upper limits of the difference in velocity magnitude.

The dotted line shows the levee alignment in Task 2, and therefore all values between the pre-flood and post-flood levee alignments are Task 6.1 geometry velocities, not velocity differences. Figure 40 shows that the realignment of the levee decreases the velocities in the levee failure area. The added conveyance provided by moving the levee back significantly changes the velocity profiles throughout most of the lower floodplain. The magnitude area of velocity change is very large compared to other alternatives in the vicinity of the levee breach area with a velocity reduction of over 1.5 ft/sec (0.457 m/sec).

3.9 Task 6.2(a) alternative

Task 6.2 was comprised of three different alternatives. All alternatives started with the original base condition model (Task 2) and then changed different floodplain attributes to compare their effect on flow through that vicinity of the floodplain and along the area of the levee that breached. Figure 41 shows the materials and material boundaries from the Task 2 Base Condition model. Material 5 (yellow in Figure 41) is a tree-heavy vegetation zone, and Material 11 is an open, grassy vegetation zone. These two material types were alternated in specific locations to determine their impact on the overbank velocities.

Figure 39. Task 6.1 – Task 2 velocity differences for a flow of 160,000 cfs (4,530.7 cms).

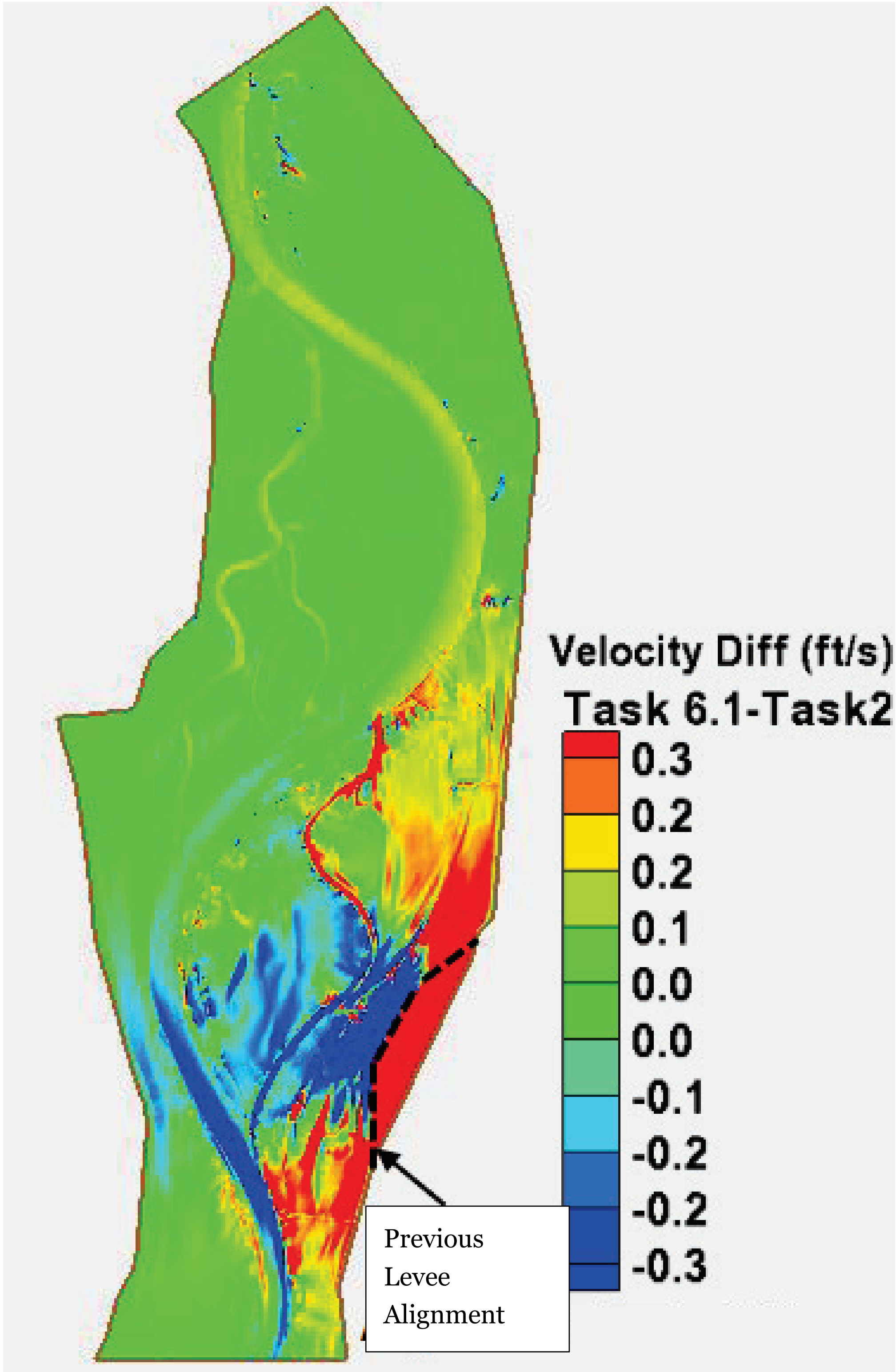


Figure 40. Zoomed view of Task 6.1 – Task 2 velocity differences for a flow of 160,000 cfs (4,530.7 cms).

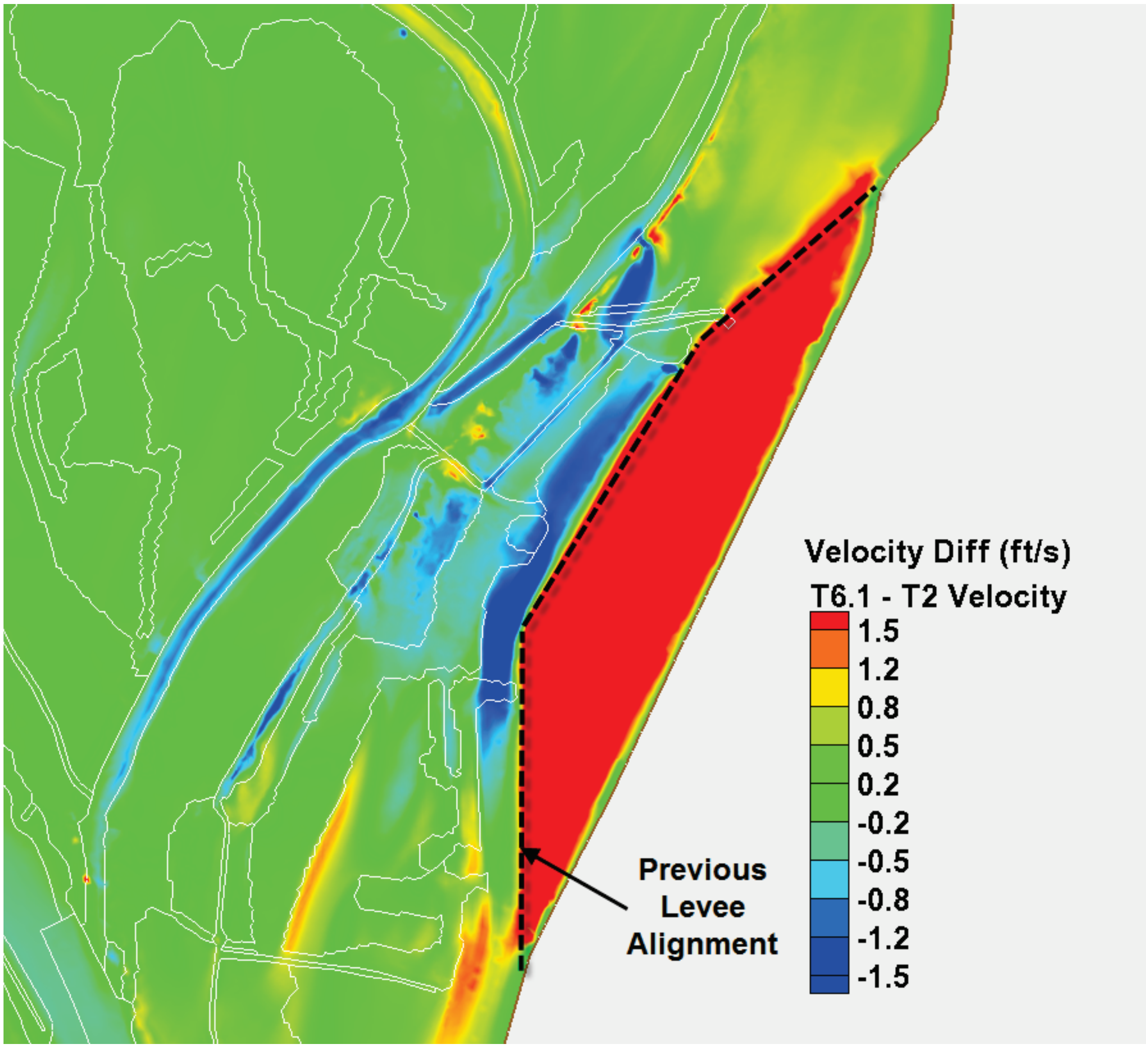
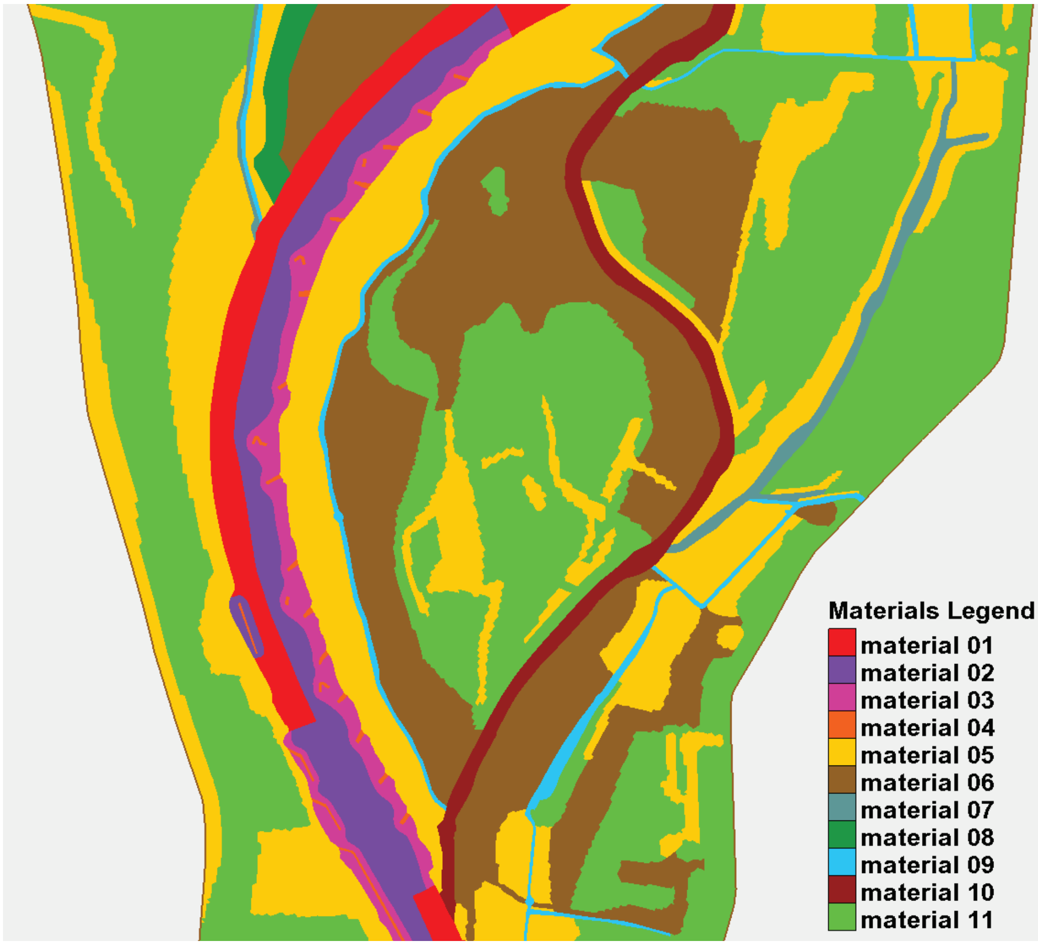


Figure 41. Task 2 (base condition) materials in area of interest.



Task 6.2(a) required using the base condition Task 2 model (pre-2011 flood with both chutes and all features) to evaluate the benefit of vegetation management in the floodplain by removing trees from the zone along a portion of the east bank of the Lower Hamburg Chute. The area outlined in Figure 42 with a dashed black line shows the previously tree-heavy vegetation area along the Lower Hamburg Chute that was converted to an open, grassy vegetation zone.

The velocities produced from the Task 2 model where subtracted from the Task 6.2(a) model, and the differences are shown in Figure 43. Red and yellow colors show an increase in velocity, blue shows a reduction in velocity, and green shows no change in velocity.

Figure 42. Task 6.2(a) Dotted enclosure indicates trees converted to grass.

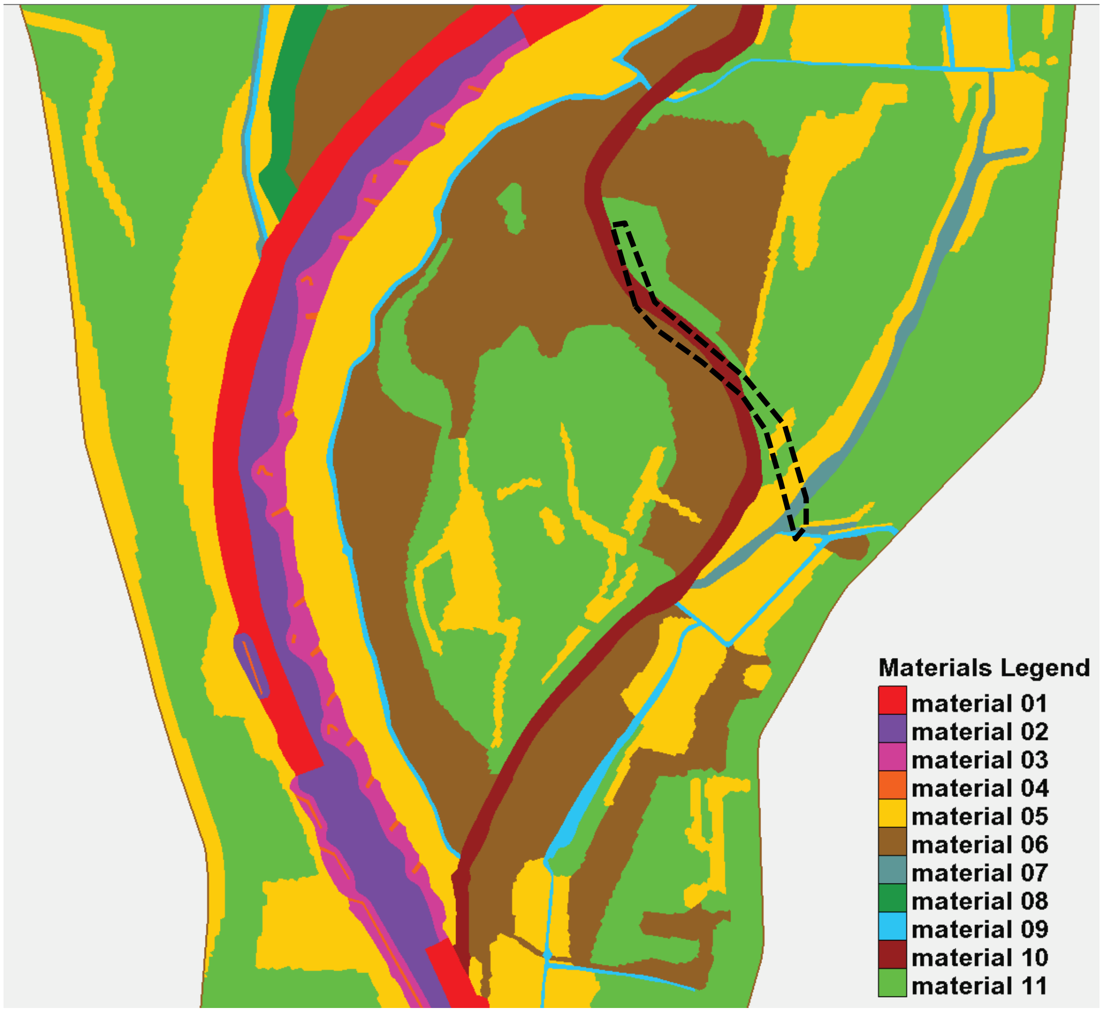
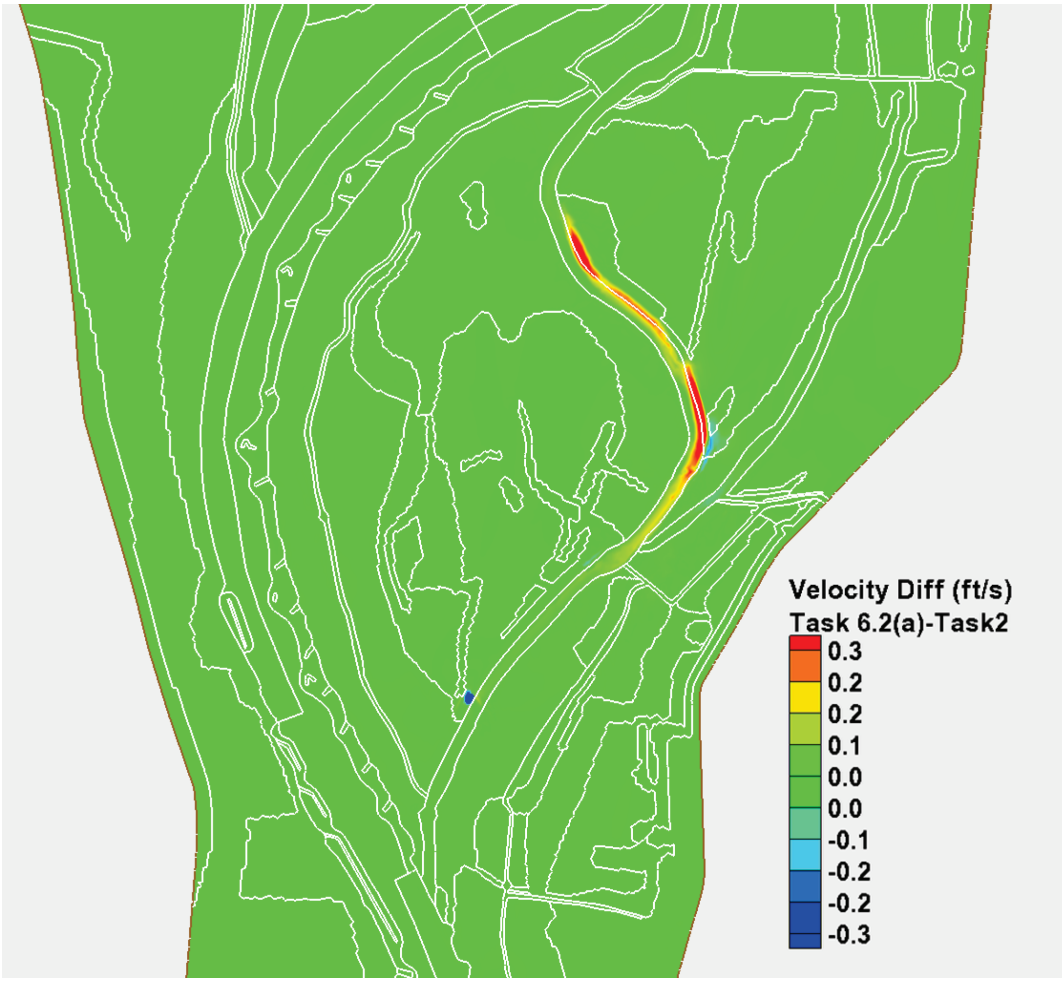


Figure 43. Task 6.2(a) – Task 2 velocity differences for a flow of 160,000 cfs (4,530.7 cms).

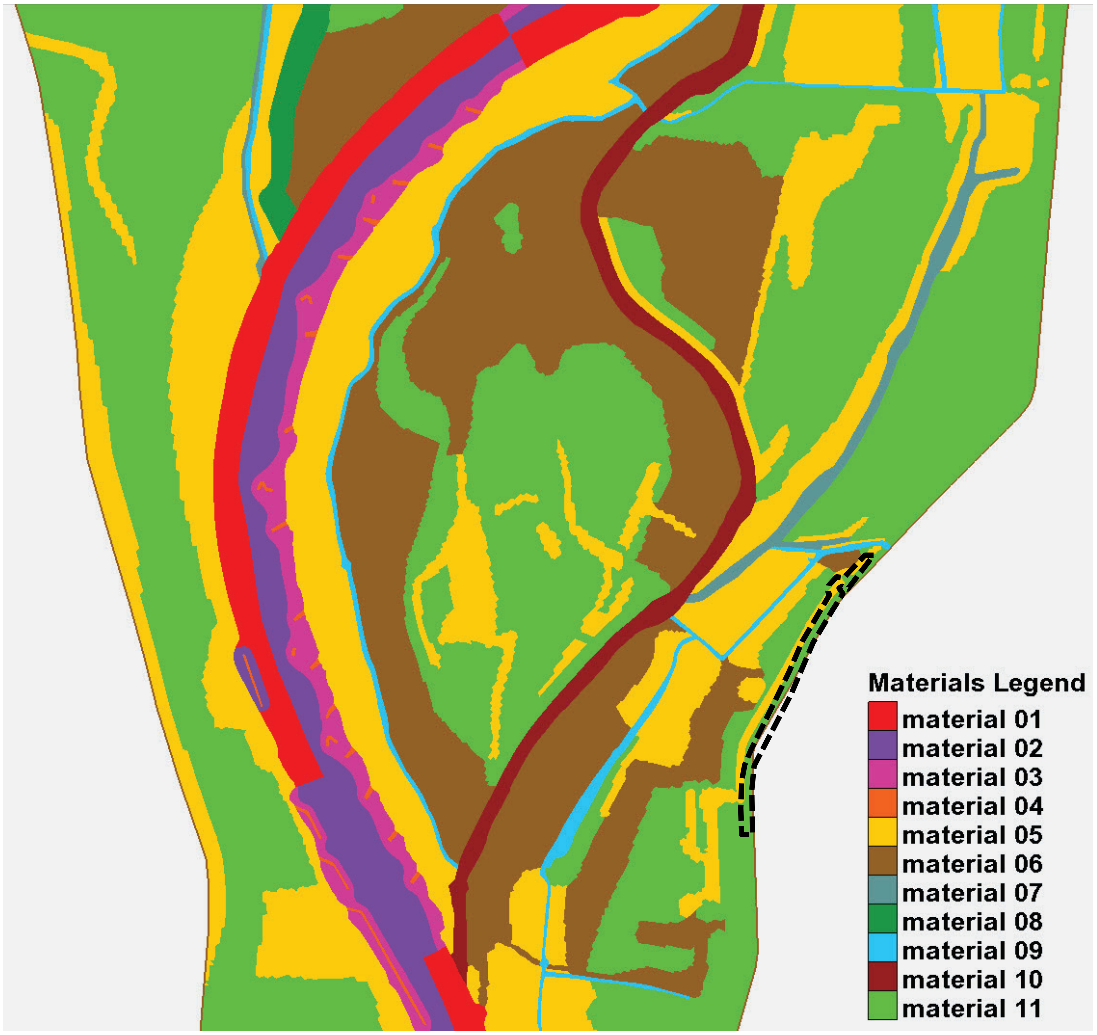


The image shows an increase in velocities in the area of the vegetation change and in the chute adjacent to the vegetation change. However, these changes are localized and have little effect throughout the rest of the floodplain.

3.10 Task 6.2(b) alternative

Task 6.2(b) required using the base condition Task 2 model (pre-2011 flood with both chutes and all features) to evaluate the benefit of vegetation management in the floodplain by adding a tree strip adjacent to the levee toe (maintaining a 15 ft buffer from the toe) to fill the area adjacent to the levee with a row of trees approximately 80 ft wide from near the access road to downstream of the levee point near where the existing tree line tapers. The area outlined with a dashed black line in Figure 44 shows the previously open, grassy vegetation area along the levee that was converted to a tree heavy vegetation strip.

Figure 44. Task 6.2(b) dotted enclosure indicates grass converted to trees.



The velocities produced from the Task 2 model where subtracted from the Task 6.2(b) model, and the differences are shown in Figure 45. Red and yellow colors show a larger increase in velocity, blue shows a larger reduction in velocity, and green shows from a slight increase to slight decrease in velocity.

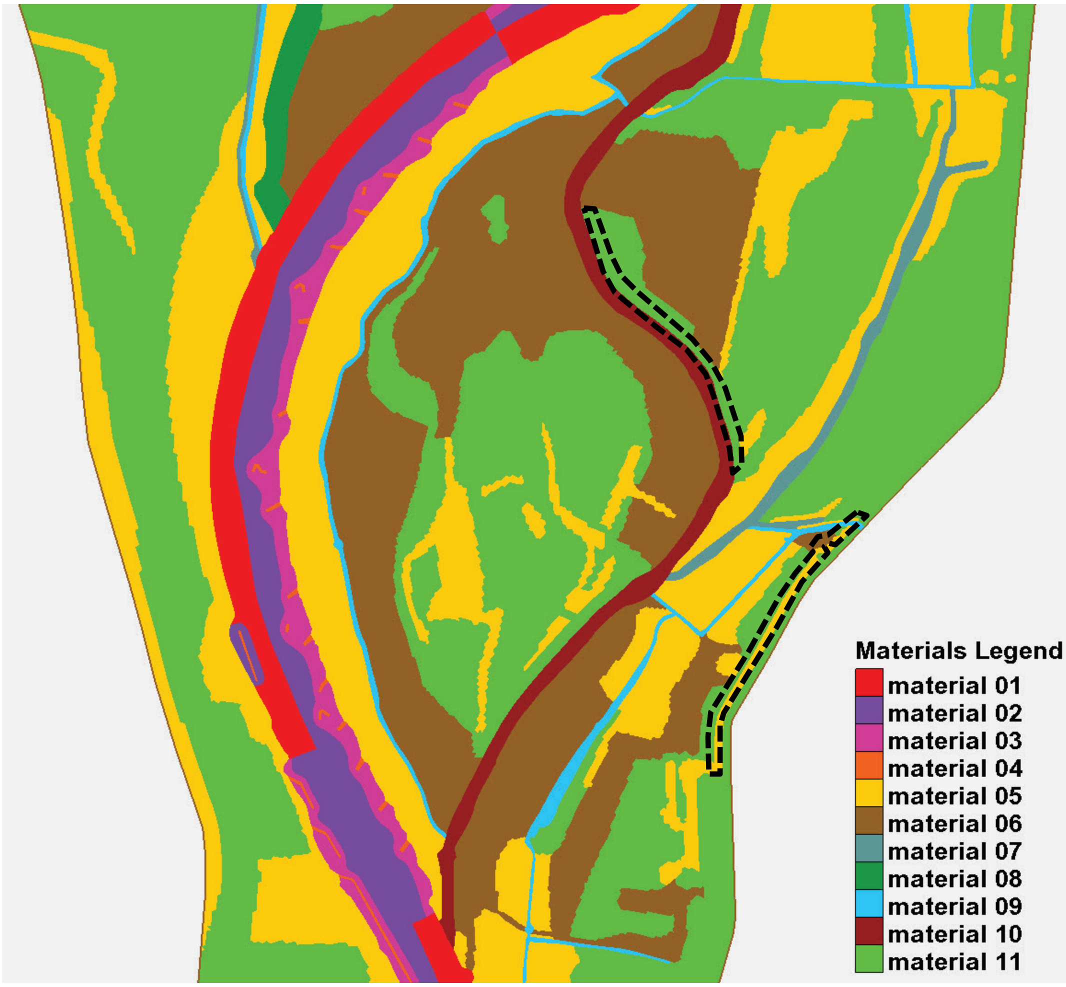
The image shows a clear reduction in velocities in the area of the trees and adjacent to the levee. This did increase velocities in the floodplain west of the vegetation change but still provides little to no change throughout the rest of the floodplain and model reach.

Figure 45. Task 6.2(b) – Task 2 velocity differences for a flow of 160,000 cfs (4530.7 cms).

3.11 Task 6.2(c) alternative

Task 6.2(c) required using the base condition Task 2 model (pre-2011 flood with both chutes and all features) to evaluate the benefit of vegetation management in the floodplain by running both 6.2(a) and 6.2(b) alternatives together. This involves swapping the trees and open area that currently exist to put the trees next to the levee and create a flow-through corridor away from the levee. The areas outlined with dashed black line in Figure 46 shows the previously tree-heavy vegetation area along the Lower Chute was converted to an open, grassy vegetation zone, and the previously open, grassy vegetation area along the levee east of the Lower Chute was converted to a tree-heavy vegetation strip.

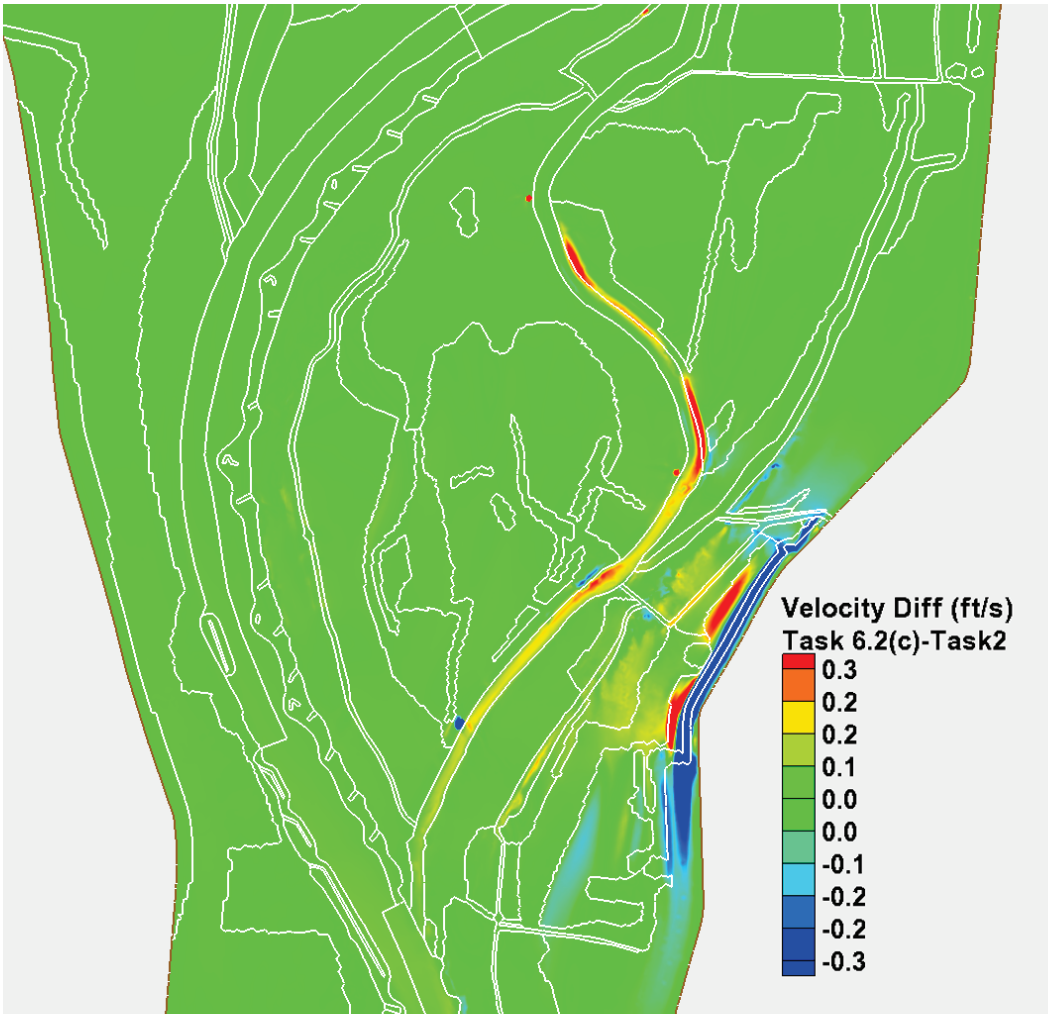
Figure 46. Task 6.2(c) Dotted enclosures indicate the two locations of vegetative changes



The velocities produced from the Task 2 model where subtracted from the Task 6.2(c) model and the differences are shown in Figure 47. Red and yellow colors show a larger increase in velocity, blue shows a larger reduction in velocity, and green shows from a slight increase to slight decrease in velocity.

The image shows an increase in velocities in the area where the trees were removed and in the chute adjacent to that location and a reduction in velocities in the strip of trees and the area between the strip of trees and the levee. The difference in velocity magnitudes for this alternative is approximately equal to that of Task 6.2(a) and (b) combined. Other than these two local changes in velocities, the vegetative changes have no effect throughout the majority of the floodplain except for the slight increase in velocities between the chute and the strip of trees adjacent to the levee.

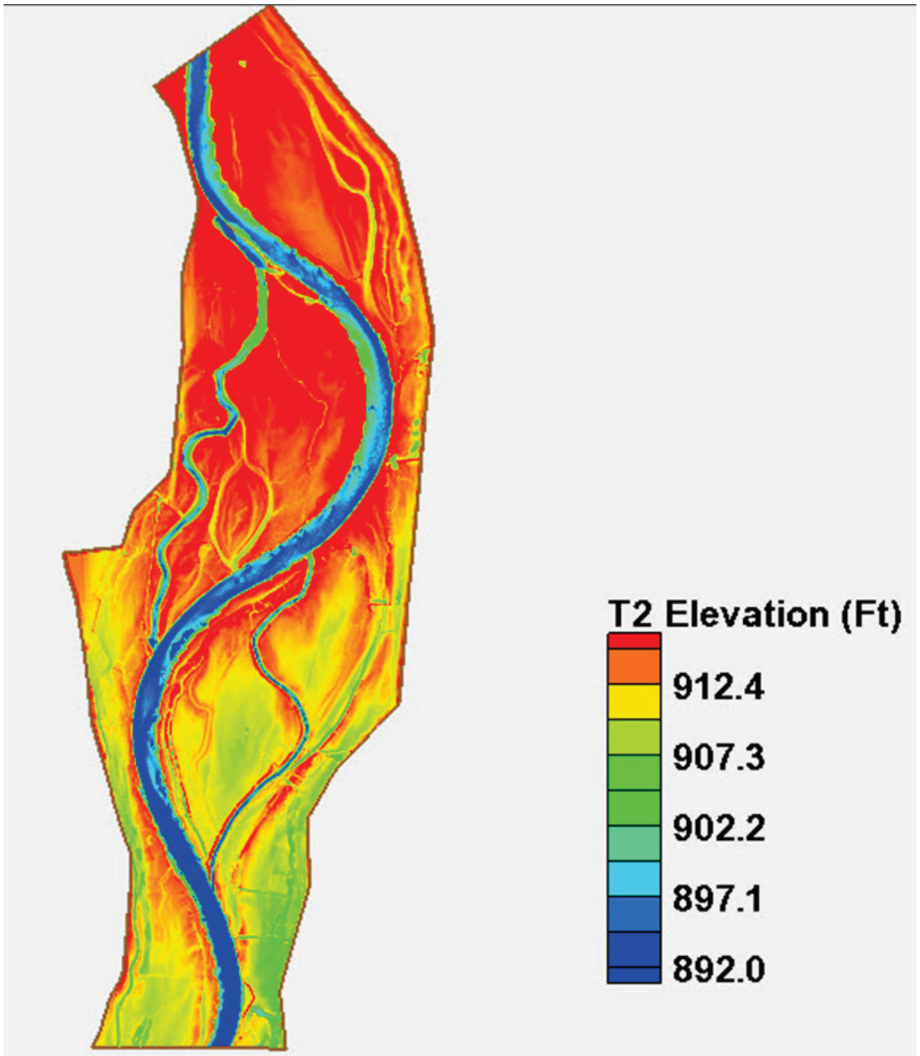
Figure 47. Task 6.2(c) – Task 2 velocity differences for a flow of 160,000 cfs (4,530.7 cms).



3.12 Task 6.3 alternative

Task 6.3 required using the base condition Task 2 model (pre-2011 flood with both chutes and all features) and a degraded channel and chute model to evaluate the effect of channel and chute degradation on computed velocities, elevations, and turbulence in key areas. Data from June 2011 and post flood 2012 surveys were used to estimate a reasonable main channel degradation amount for the two modeled flows (160,000 cfs and 240,000 cfs [4,530.7 cms and 6,796.2 cms]). Chute degradation was estimated from the post-2011 flood surveys. Results were used to evaluate differences between Task 2 and the Task 6.3 alternative. Figure 48 shows the elevation of the Task 2 (base condition) elevation data. Note the expected channel geomorphology with alternating point bars and thalweg, the deepest portion of a river channel, in both the main channel and chutes.

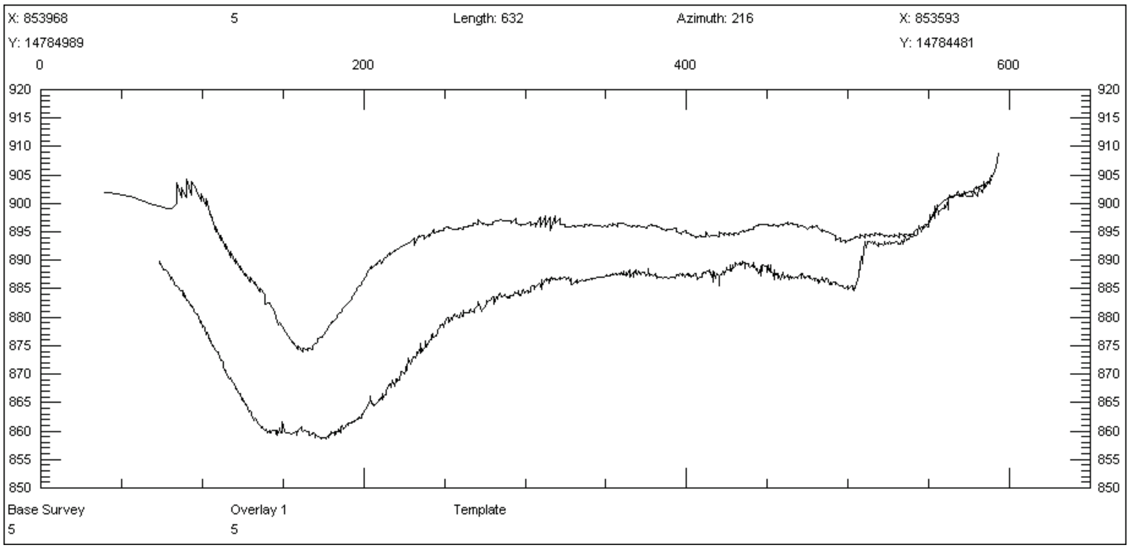
Figure 48. Task 2 (base condition) elevation contours from pre-2011 flood geometry.



An estimate of the amount of channel degradation was made based on information contained in a letter report of 22 February 2012 to Dan Pridal of Omaha District from David Abraham, Terry Waller, and Thad Pratt of ERDC (*Missouri River Flood Measurements of 2011, at Nebraska City, NE*). The data measurement site is approximately 6 RMs upstream of the Hamburg Bend area.

The letter report contains a discussion of main channel degradation and cross-section plots. The plots clearly show the elevation differences between pre- and post-flood measurements, both in the active sand transport portion of the channel and in the areas surrounding structures. Figure 49 shows the pre-2011 flood cross section as the top curve and the post-flood cross section as the bottom curve at a representative location identified in the report as cross section Line 5, which is approximately 0.4 miles north of the Highway 2/75 bridge at Nebraska City, NE. The other lines mentioned below can be seen in Figure 3 of the same referenced letter report and are all situated between RMs 561.4 and 561.8.

Figure 49. Typical cross sections for Line 5. Pre-2011 flood is top curve, and post-flood is bottom curve.



Lines (cross sections) 2 to 9 were used in determining some kind of average degradation during the flood event. A depth difference can be determined at any point along the cross section by subtracting the post-flood elevation (lower curve) from the pre-flood elevation (upper curve). This was done at two to four locations along each cross section that were different in depth and shape. An average of these values provided an estimate of the overall main Missouri River channel degradation. This was done for cross section lines 2 through 9. The average degradation value of all lines was 13.4 ft (4.08 m).

Similar cross-section degradation information for Hamburg Bend was not available, but the two sites are only 6 miles from one another, and thus the Nebraska City cross-section degradation is assumed to be a suitable representation of what might have happened at Hamburg Bend. A degradation elevation change of 11 ft (3.35 m) was settled upon for the main channel and 4 ft (1.21 m) in the chutes.

Figure 50 displays the changes in elevation from the Task 2 model to the Task 6.3 model. The red shows no change in elevation, the green shows a difference of 4 ft (1.21 m) in the chutes, and the blue shows a difference of 11 ft (3.35 m) in deeper sections of the main channel. No attempt was made to simulate natural morphologic features in the main channel and chutes because the intent of this comparison was to show the changes in floodplain flow due only to the increased conveyance in a severely degraded main channel and chutes.

Figure 50. Task 6.3 elevation differences for the degraded main channel and chutes.

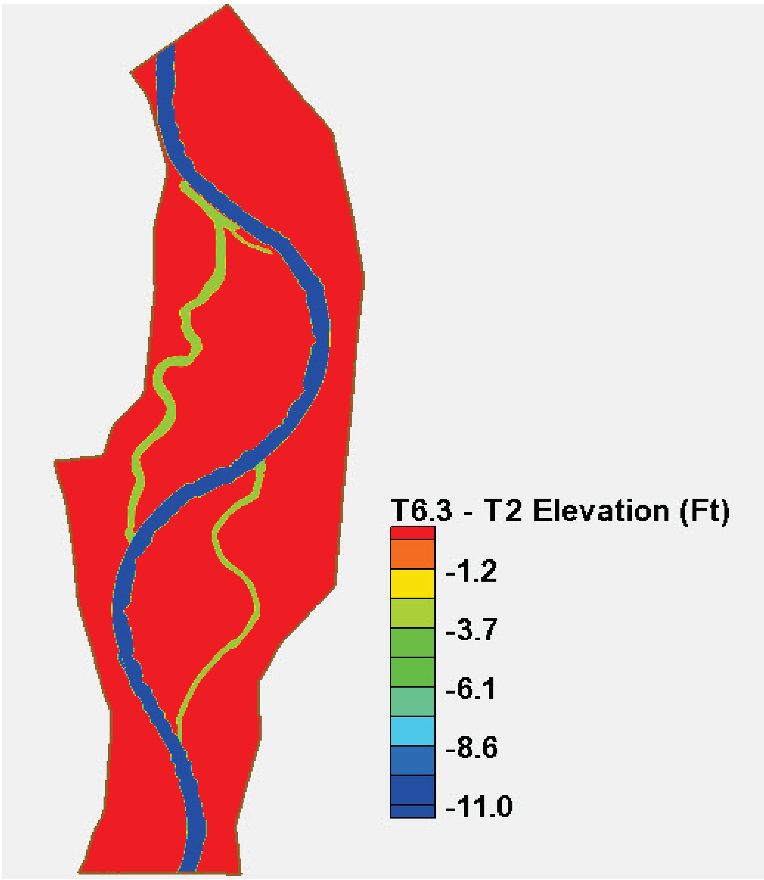


Figure 51 displays velocity differences in Task 6.3 from that of Task 2. Red and yellow colors show a larger increase in velocity, blue shows a larger reduction in velocity, and green shows from a slight increase to slight decrease in velocity.

The changes in the channel and chute elevations changed velocities up to 1 ft/sec throughout the model reach. The added conveyance in the main channel reduced the flow and velocities throughout the majority of the floodplain. Figure 52 and Figure 53 are zoomed-in views of the Upper and Lower Chute velocity magnitudes differences.

Figure 51. Task 6.3 – Task 2 velocity differences for a flow of 160,000 cfs (4,530.7 cms).

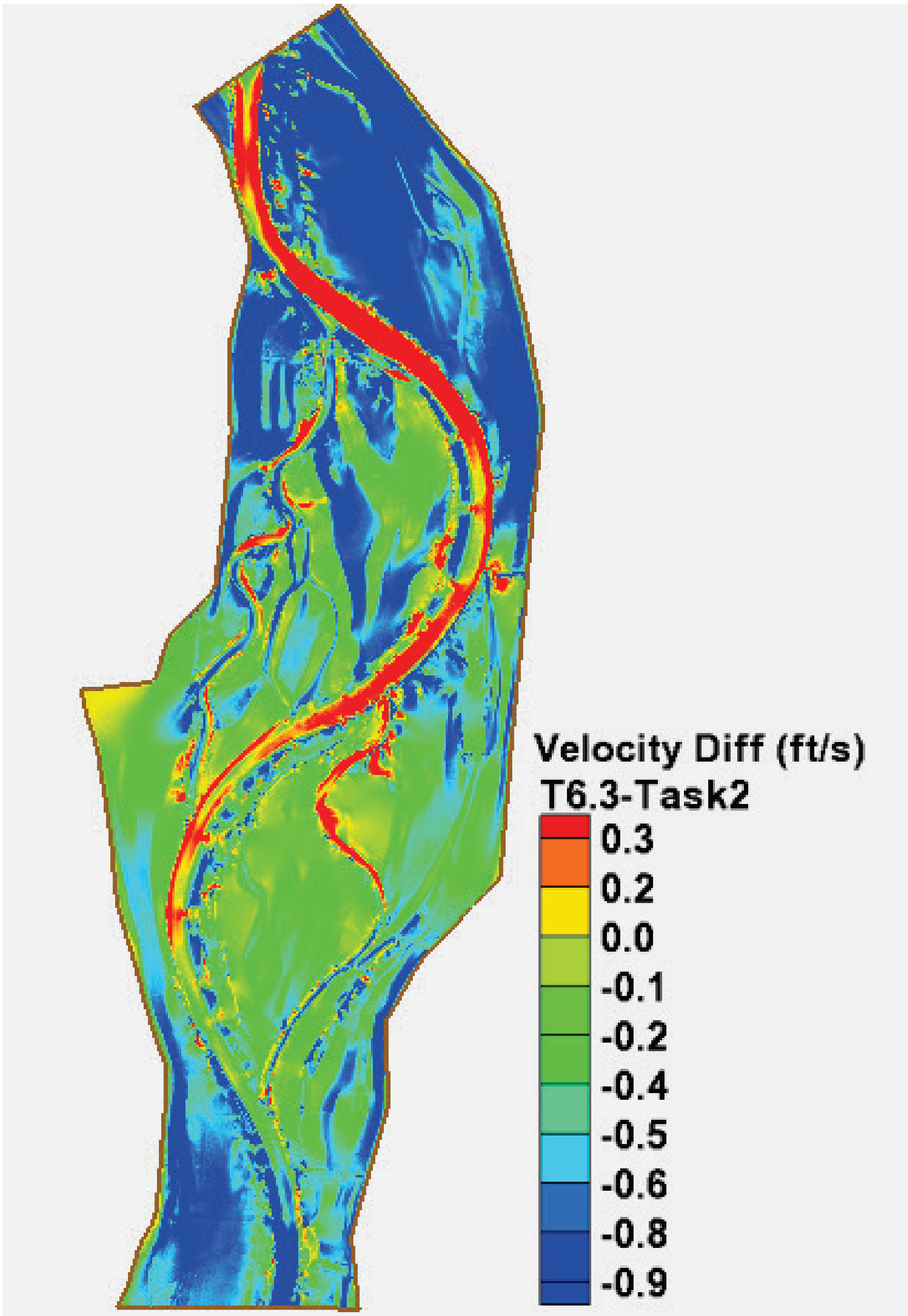
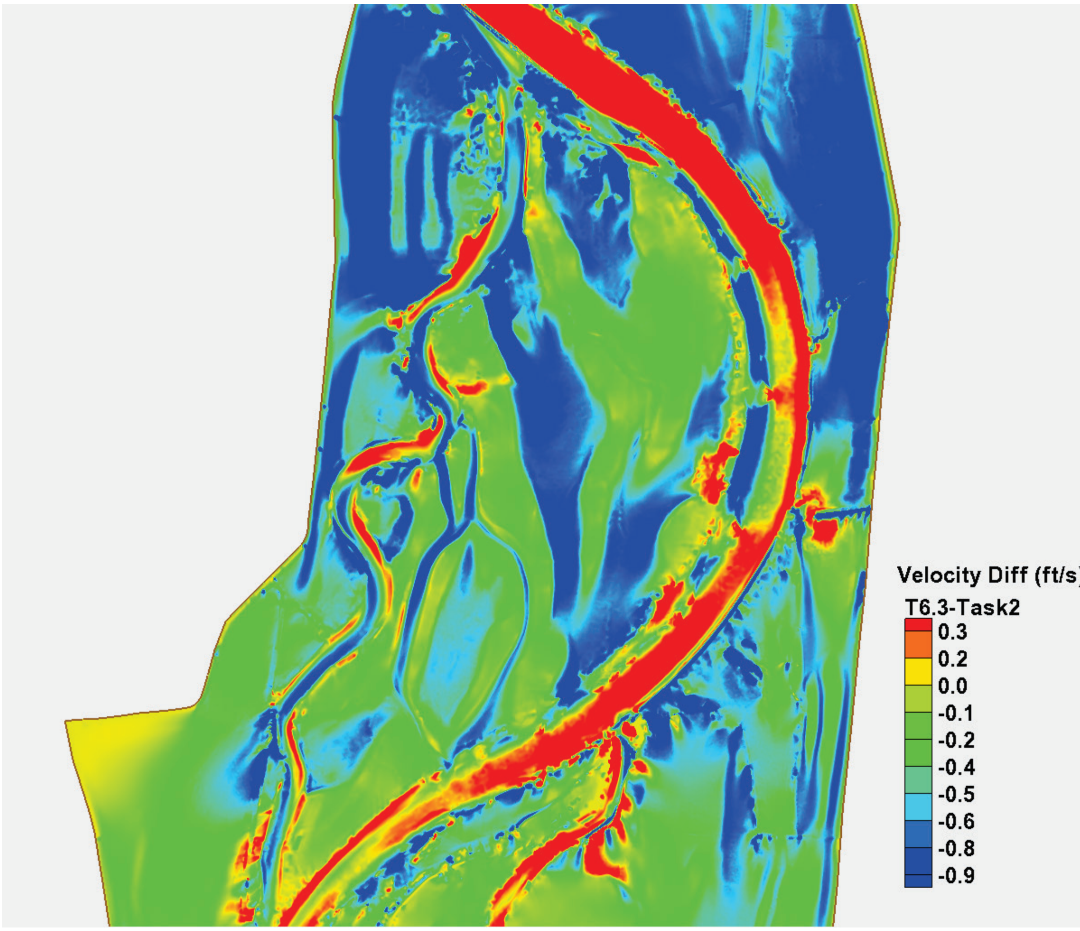
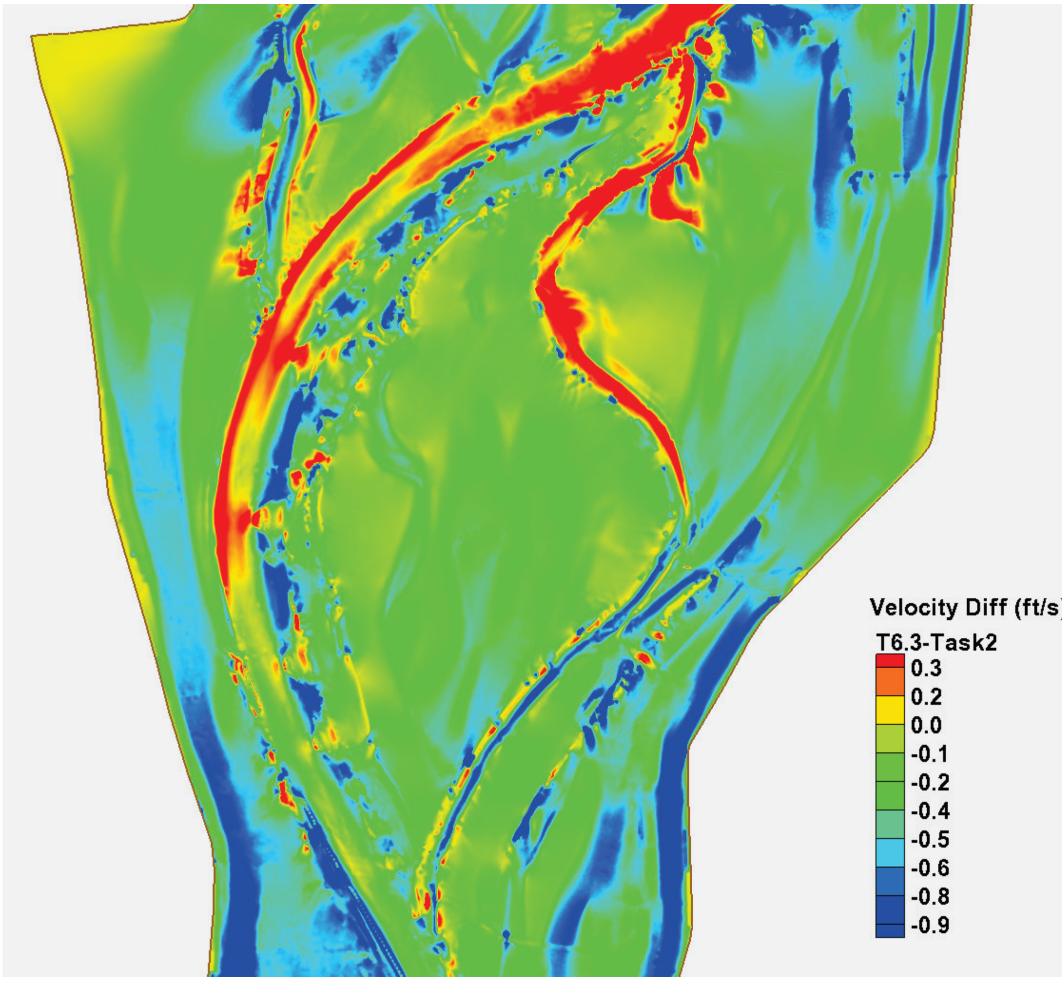


Figure 52. Zoomed view of Task 6.3 – Task 2 velocity differences for a flow of 160,000 cfs (4,530.7 cms) in the Upper Chute.



The velocities in the area surrounding the levee breach were decreased by over 0.9 ft/sec (0.274 m/sec) as the conveyance in the main channel and chutes was greatly increased, therefore lowering the floodplain conveyance and flow velocity. This large velocity decrease provides an indication of dynamic conditions that would have been experienced during the 2011 event.

Figure 53. Zoomed view of Task 6.3 – Task 2 velocity differences for a flow of 160,000 cfs (4,530.7 cms) in the Lower Chute.



3.13 Task 6.4 alternative

Task 6.4 required using the Task 5 model (current post-2011 flood condition with setback levee, new structures, etc.) and removing the Lower Hamburg chute side-cast spoil berms. Two flows were modeled, 160,000 and 240,000 cfs (4,530.7 and 6,796.2 cms). The intent was to determine if removing the spoil piles could affect water velocities along the levee setback. To do this, it was necessary to first identify the side-cast spoil berms in both the pre- and post-flood geometries. This was necessary because some of them were washed out during the flood and were therefore no longer clearly defined. What appeared as a spoil berm could also be a built-up channel bank. The following figures and discussion relate how the decisions were made regarding which riverside embankments should be considered as side-cast spoil berms to be removed for the purposes of this task.

Figure 54 shows the post flood geometry with six groups of possible side-cast spoil berms that could be removed for Task 6.4.

The floodplain data in Figure 54 are from post-flood 2011 lidar. For Task 6.4, it was necessary to determine which ones were actually placed as part of the chute construction that should be removed for purposes of this alternative and which ones were floodplain deposits and not construction-placed material. To address that question, Figure 55, which illustrates the pre-2011 flood side-cast berm geometry, was considered.

Figure 54. Elevation contours from post-2011 Flood, Task 5 geometry.

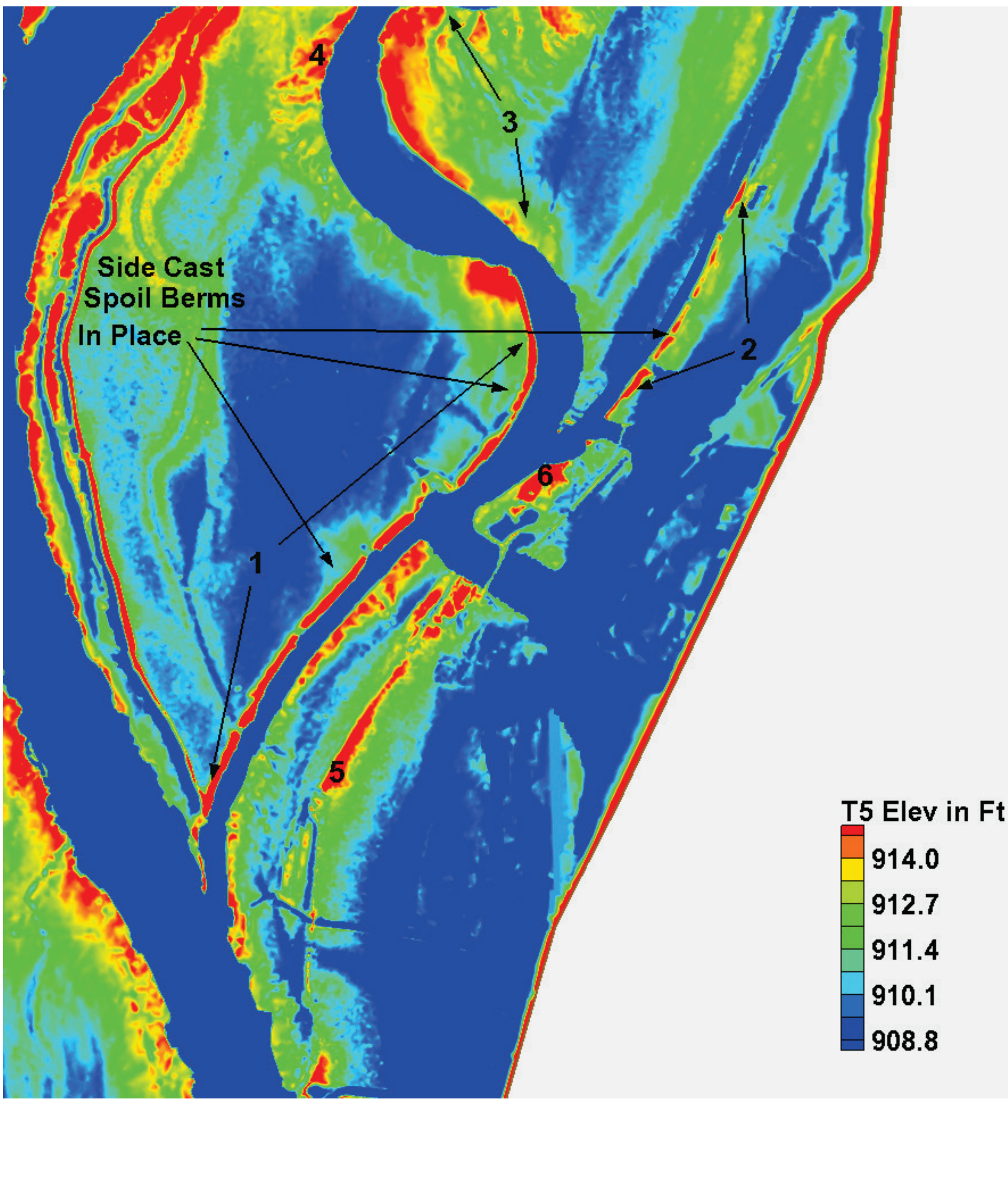


Figure 55. Pre-2011 flood geometry showing original side-cast spoil berms.

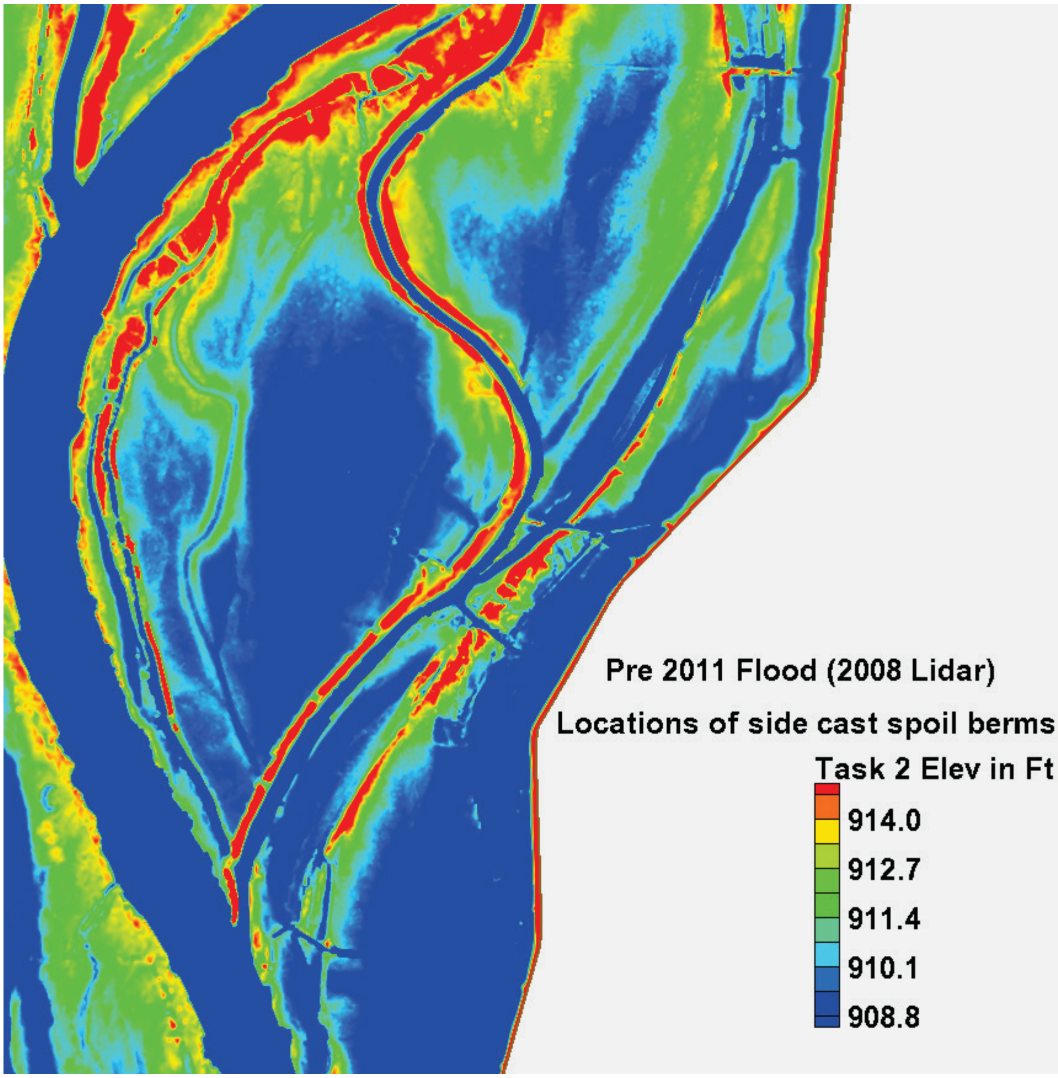


Figure 55 shows the pre-2011 flood (2008 lidar) floodplain geometry with the contours set to show the higher elevations. The pre-2011 flood chute is much narrower and the red bands along its banks show clearly the locations of the side-cast spoil berms. By comparing Figure 54 and Figure 55, it is evident that the spoil berms between berm groups 1 and 4 in Figure 54 (which are clearly shown in Figure 55) were completely washed out during the flood. Also, berm group 3 was originally a small group of two to three short berms before the flood (Figure 55), but during the flood (Figure 54), a large bank material was deposited around the entire inside bend. Therefore, most of berm group 3 in Figure 54 did not originate from the original project construction side-cast spoil berms. For purposes of Task 6.4, the post-flood deposited material within this whole bend was left intact within the model.

In Figure 54 and Figure 55, the solid red areas are at least elevation 915.4 (279 m). In the center of most of the side-cast spoil berms, the elevation is approximately 920.3 (280.5 m). The general flat area around the berms is approximately elevation 912.1 (278 m) or less. Thus, the berm elevations are anywhere from 3 to 8 ft (1 to 2.5 m) above the surrounding area. That is consistent with what was observed in field reconnaissance. Removing them would therefore mean reducing their elevations to approximately elevation 912.1 (278 m). Based on consultation with the Omaha District, it was decided to remove only berm groups 1 and 2 as being the most representative of a no-berm future sustainable condition. This process of comparing pre- and post-2011 flood geometry illustrates the dynamic conditions within the floodplain and how the floodplain hydraulics are subject to change as geometry varies between and even during flow events. The Task 5 mesh was used to create the mesh for Task 6.4. They are the same except that Task 6.4 has the side-cast spoil berm groups 1 and 2 removed as shown in Figure 56 by the dashed white line areas. In general, their elevations were reduced to approximately 912.1 (278 m). The "natural" bank that is likely the result of deposition by the 2011 flood at the north end of berm group 1 and at berm group 3, as well as berm groups 4, 5, and 6, were all left intact.

The created Task 6.4 model geometry was run to see if removing the side-cast spoil berms could have any effect on velocities in the vicinity of the levee setback. Two different flowrates were simulated. A flow of 160,000 cfs (4530.7 cms) was used to represent the flow that occurred prior to the levee breach the morning of June 13. The run was a steady-state flow, and the simulation run time was 15 days. Output files showed the run to be well converged.

To determine whether removing the side-cast spoil berms could have any effect on the levee setback, the run from Task 6.4 was compared to the run from Task 5. The computational comparison made was the Task 6.4 results minus the Task 5 results. At any location for which the difference was positive, it showed that the Task 6.4 alternative increased velocities. If the difference was negative, it showed that the Task 6.4 alternative decreased velocities. Figure 57 shows a difference plot where the computed velocities of the Task 5 simulation were subtracted from the Task 6.4 simulation.

Figure 56. Post-2011 flood geometry showing locations where side-cast spoil berms were removed for Task 6.4.

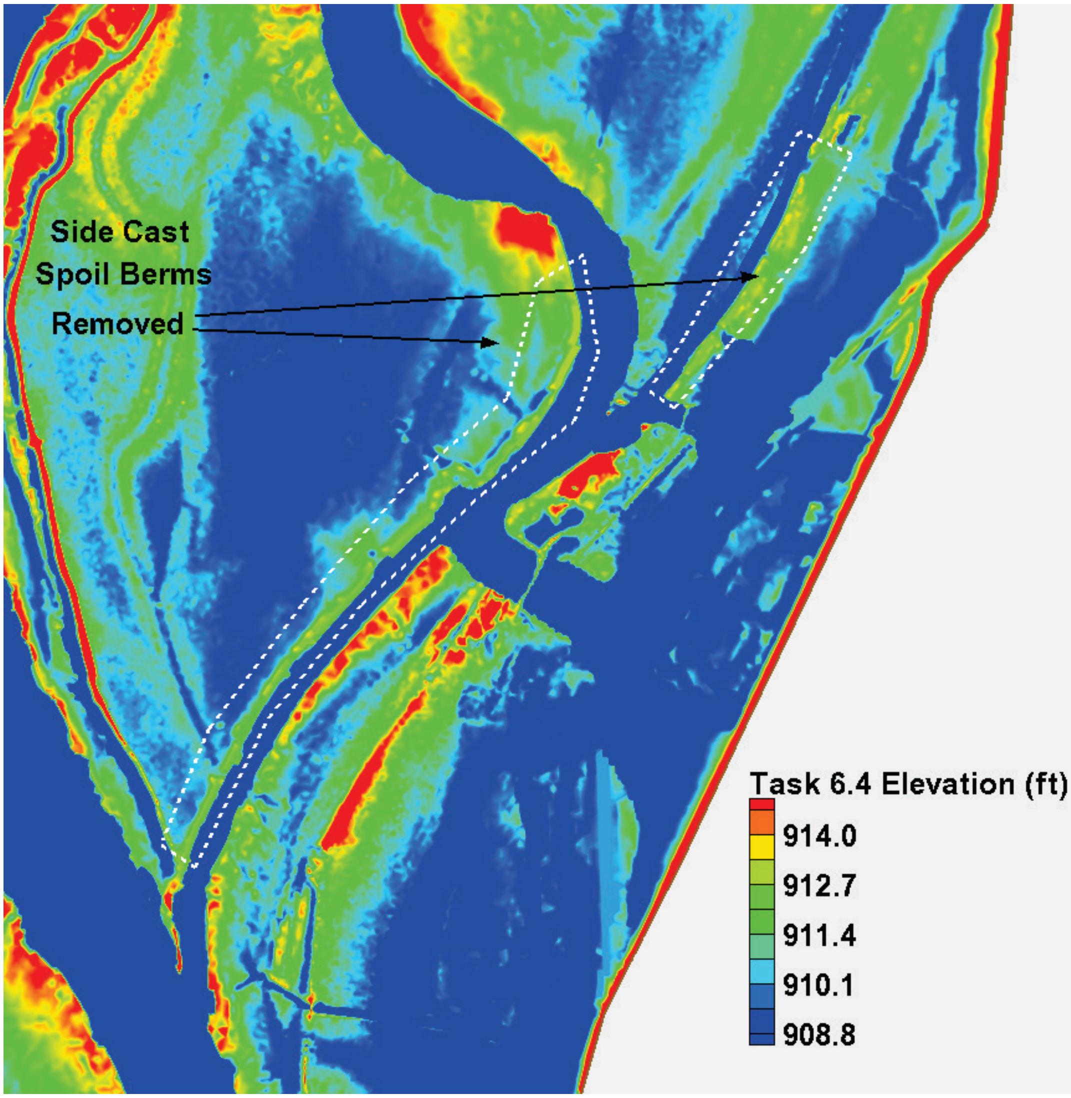
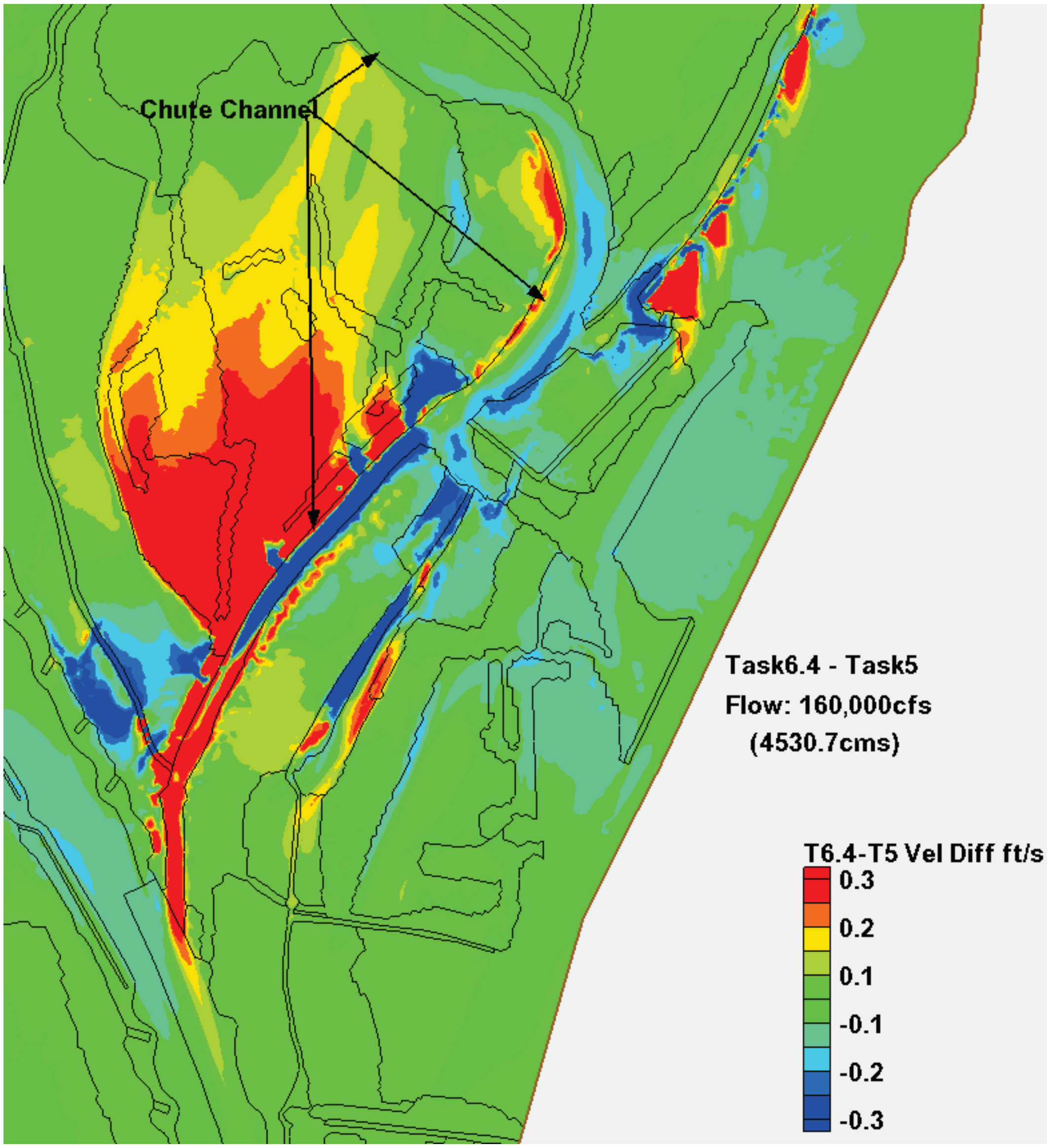


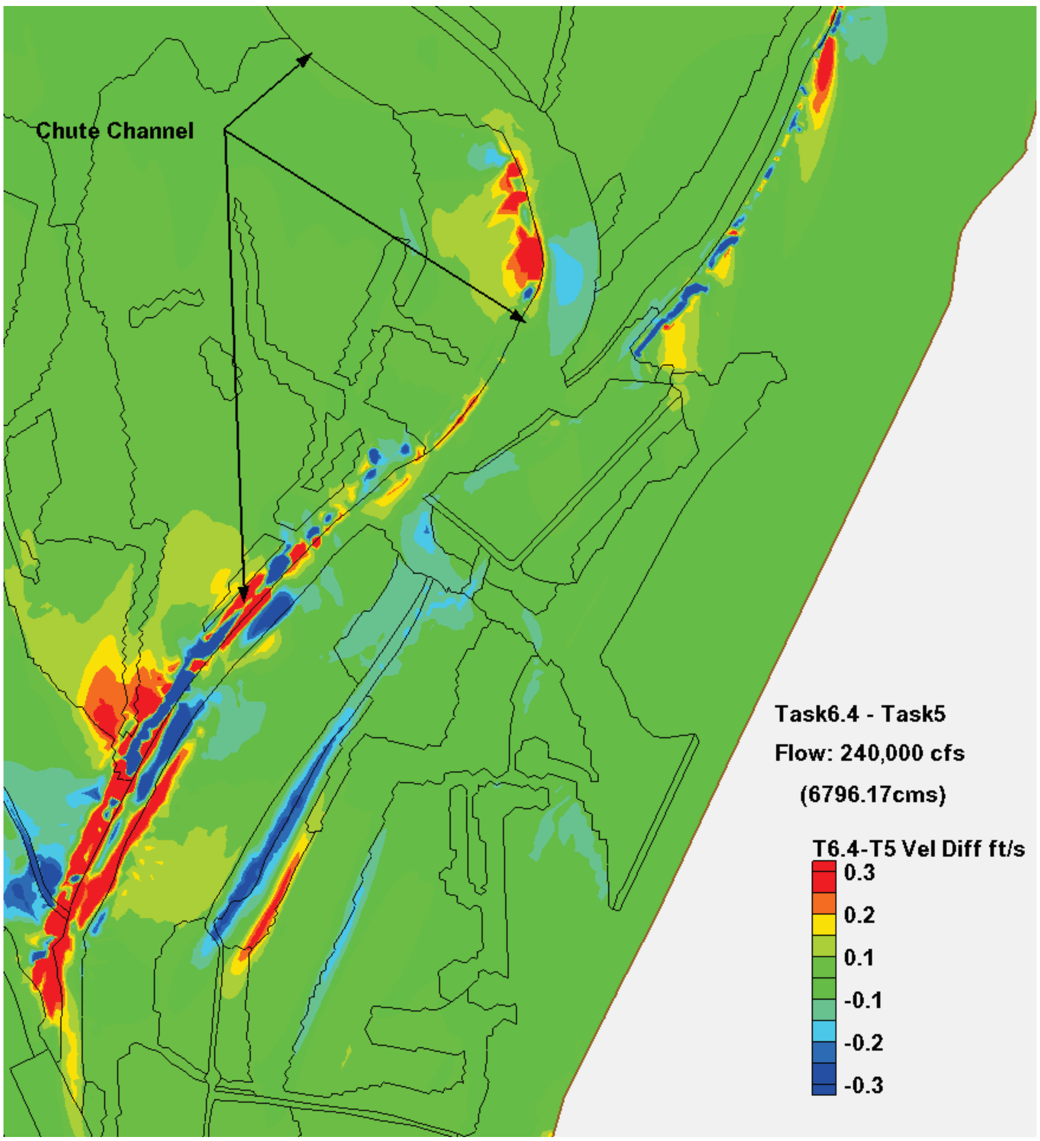
Figure 57. Task 6.4 - Task 5 velocity differences for a flow of 160,000 cfs (4,530.7 cms).



Red and yellow colors show an increase in velocity by removing the side-cast spoil berms, and blue shows a reduction in velocity. Green shows no change in velocity. In the vicinity of the levee setback, there was no noticeable change in velocity, showing that removing the berms has a neutral effect on flow adjacent to the levee.

The Task 6.4 high-flow simulation used the same grid as the medium flow. A flow of 240,000 cfs (6,796.17 cms) was used for this simulation and represents the levee top capacity flow. The same scale and colors are used in Figure 58 as in Figure 57, representing increases and decreases of velocity in the same manner. The figure shows that with an increased flow and higher inundation level, the removal of the berms has a lesser effect. As with the lower flow, there is a neutral effect on flow adjacent to the levee setback. A small, yellowish patch just south of the bend near the bottom of the figure is due to the model wetting and drying effect at that location because the simulated flow partially inundates the ground elevation there. Its value is negligible since the water depth associated with this location is basically zero.

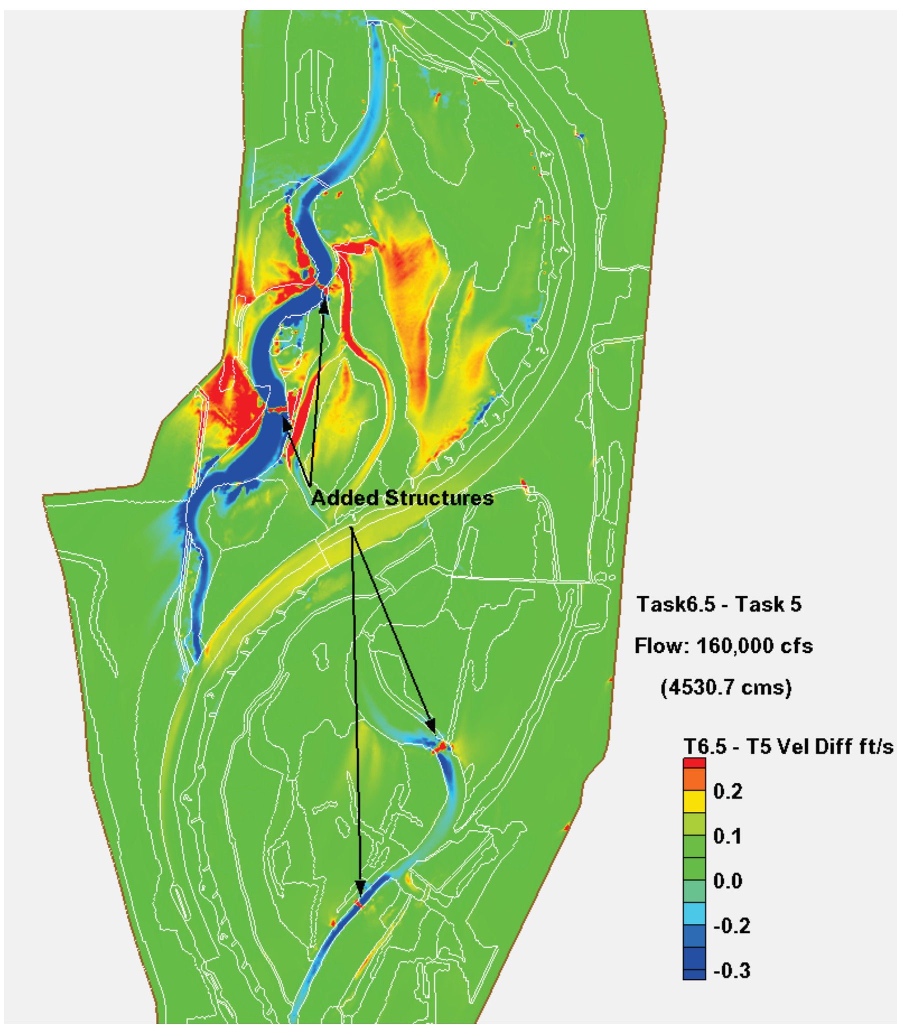
Figure 58. Task 6.4 - Task 5 velocity differences for a flow of 240,000 cfs (6,796.17 cms).



3.14 Task 6.5 alternative

Task 6.5 was run to see if adding additional structures in the chutes could affect the flow distribution between the floodplain, two chutes, and the main channel. Two additional structures were added to each chute in the Task 5 model as shown in Figure 59. Post-2011 flood construction added two chute control structures within the upper portion of each chute. Those two along with the two added in each chute for Task 6.5 makes a total of four structures in each chute. The added structures were made with approximately the same geometry as the existing structures (mid-bank height rock with a lower center section) and equally spaced from the current downstream structure to the chute exit. The intent was to test if added structures can affect flow distribution and flow velocities during flood events (160,000 and 240,000 cfs [4,530.7 and 6,796.2 cms]).

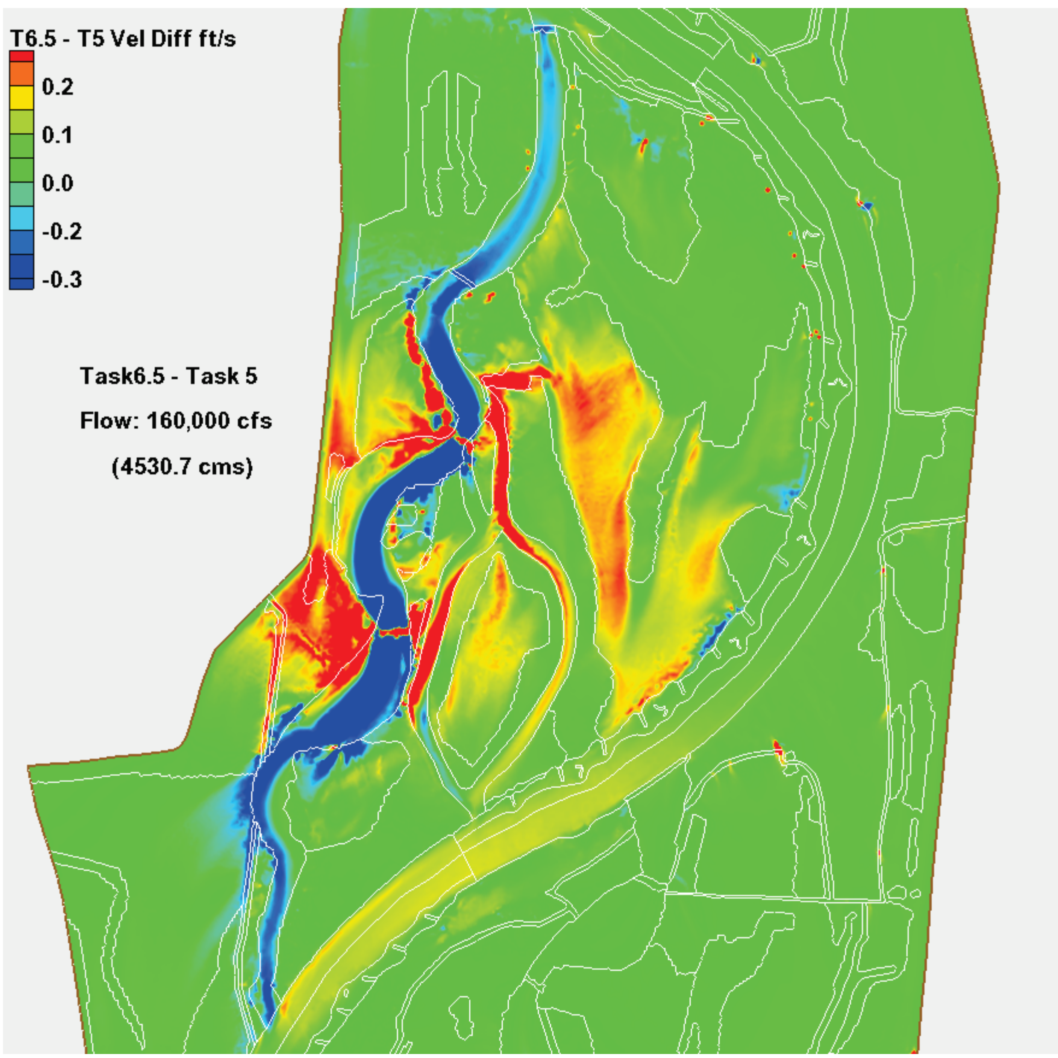
Figure 59. Task 6.5 – Task 5 velocity differences for a flow of 160,000 cfs (4,530.7 cms).



Evident in Figure 59, for a flow of 160,000 cfs (4,530.7 cms), the additional structures do cause noticeable velocity reductions of 0.3 to 0.5 ft/sec (0.091 to 0.15 m/sec) in the Upper Chute downstream of the new structures and even slight reductions of velocity upstream of the same structures. This flow is forced out into the floodplain where it is conveyed through old meander channels back into the main channel. The result is slightly increased flow in the main channel and floodplain as shown by the yellowish and reddish colors in the plot.

Figure 60 shows the same results zoomed in to display more details of the velocity differences within the Upper Hamburg Bend chute and floodplain.

Figure 60. Zoomed-in view of Figure 55.



A second model run simulating a flow of 240,000 cfs (6,796.17 cms) was also made. The results of this run are shown in Figure 61. The additional structures have less effect on the flow splits than at the lower flow. The reduction of flow in the chutes is less pronounced, and the increase of flow in the main channel is also smaller. Figure 62 shows the same results zoomed in to display more details of the velocity differences.

Figure 61. Task 6.5 – Task 5 velocity differences for a flow of 240,000 cfs (6,796.17 cms).

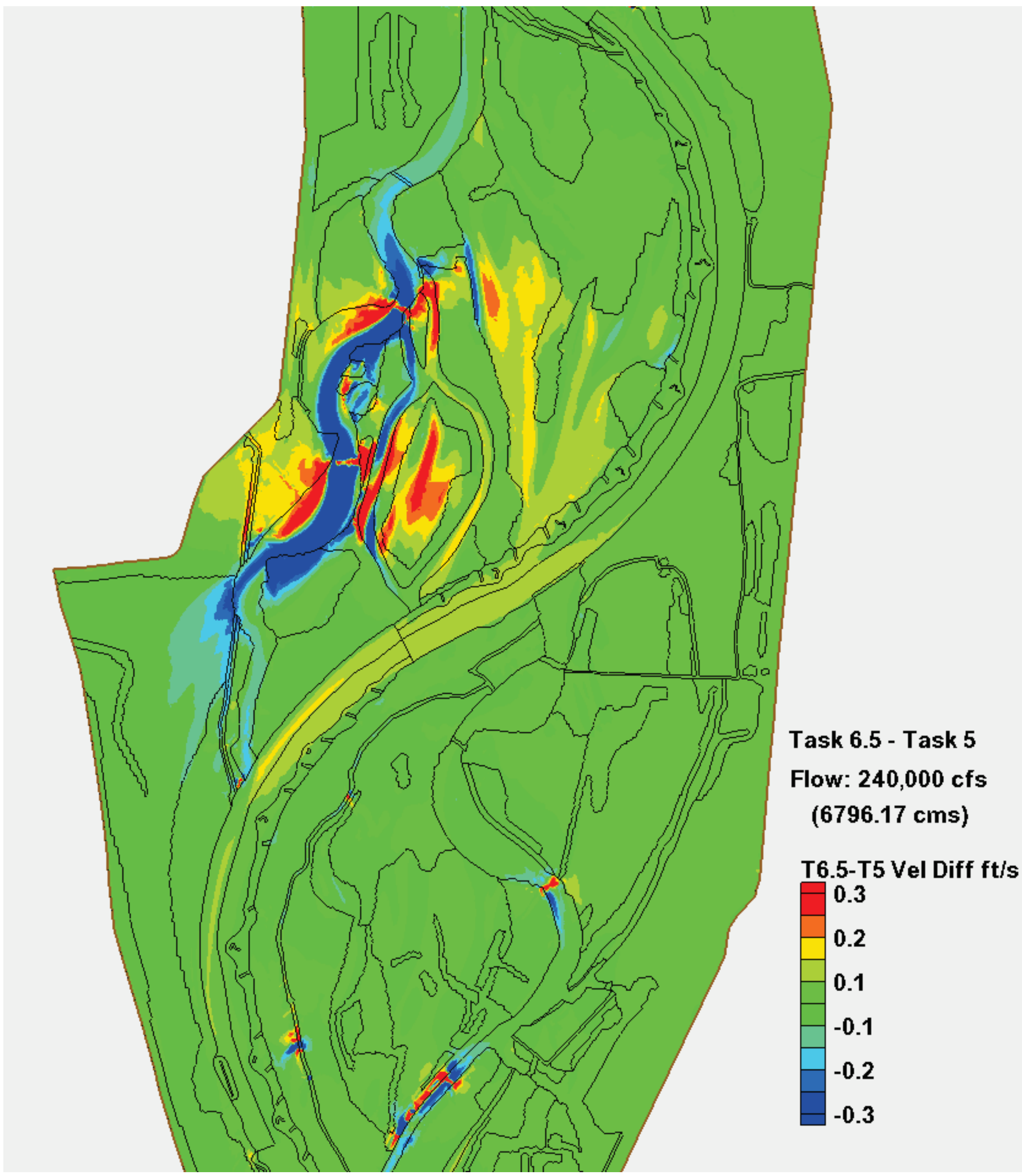


Figure 62. Zoomed-in view of Figure 61..

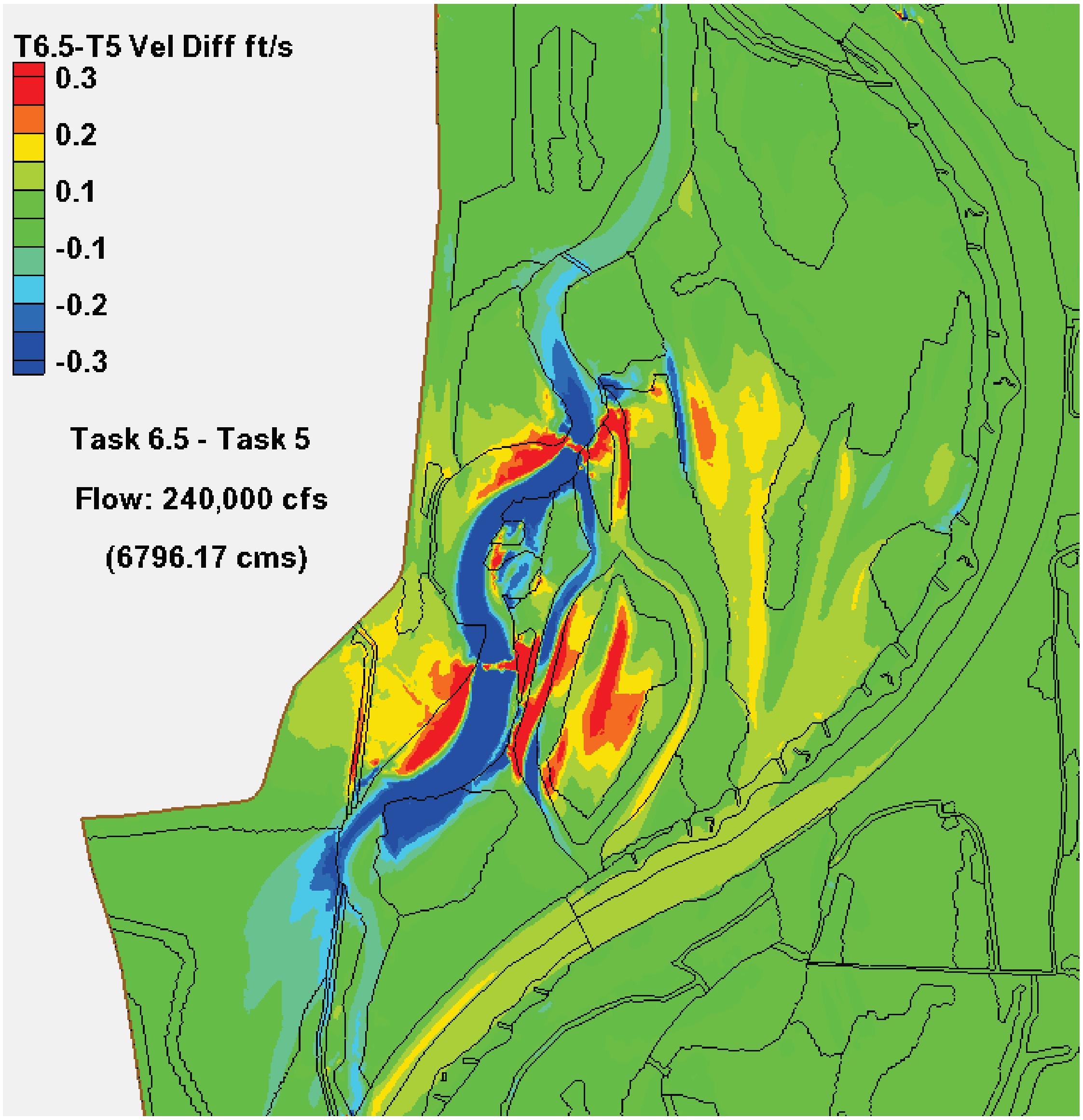
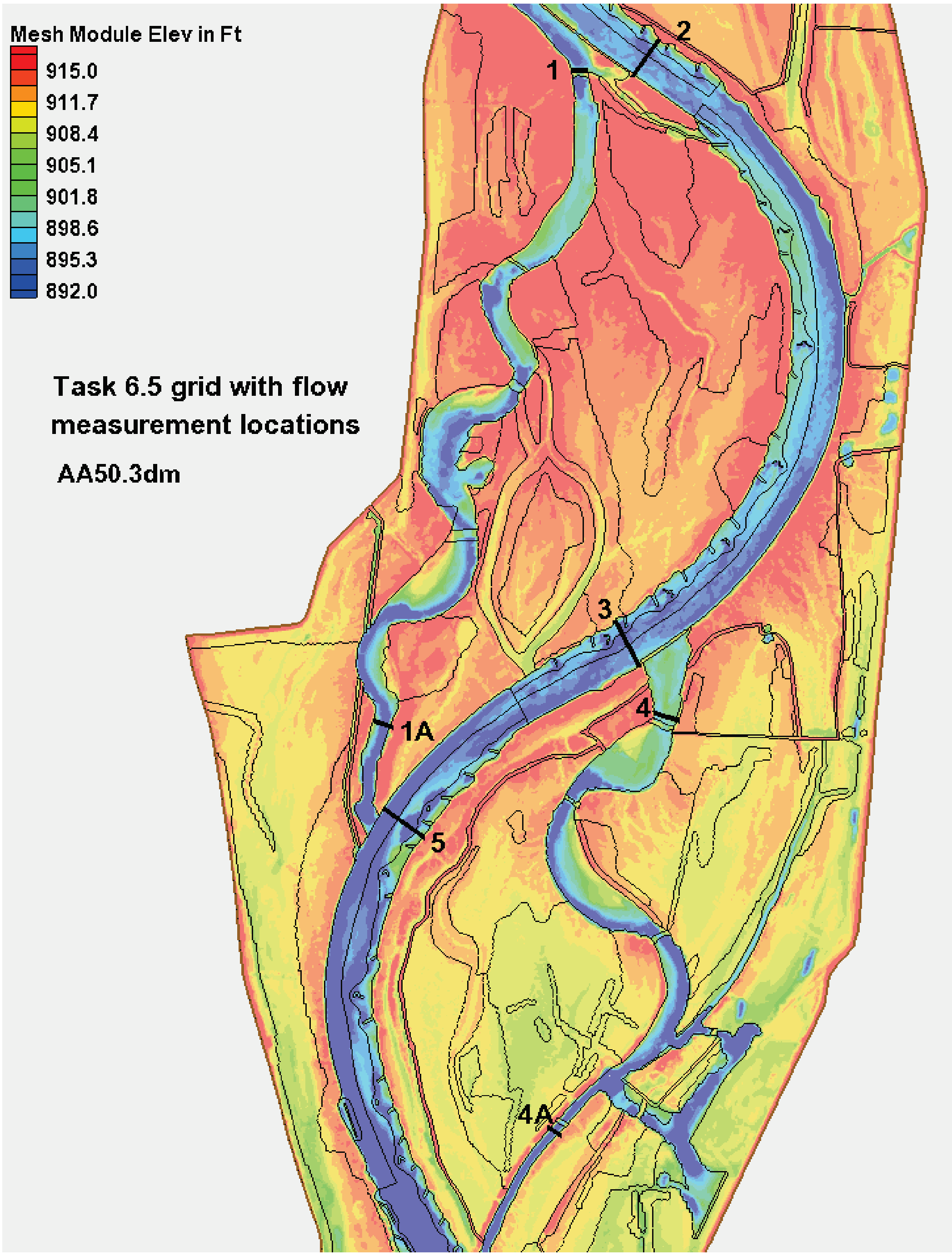


Figure 59, Figure 60, Figure 61, and Figure 62 show velocity differences. These are indicators of flow changes, but they are not computed flow changes; they are velocity differences. In order to compare actual flow changes induced by adding two structures to each chute, flow values were extracted from model output at the flux computation lines shown in Figure 63. The five lines reach bank to bank and capture the in-channel flow. The flow values are shown in Table 2 for the five lines for the case of four structures in each chute (Task 6.5) and two structures in each chute (Task 5) for both the medium- and high-flow conditions. The placement of the flux computation lines shown in Figure 63 was made based on locations where flow appeared to be controlled by banks that were still not completely inundated at the higher flows. The chute entrance locations allowed for the value of flow entering each chute to be compared to the main channel flow nearby. Thus, the sum of flow in the main channel and chute is reasonably well defined, and the two values can be added. This sum is called “total flow” for the purposes of this modeling task (Task 6.5). This total flow does not include flow through the floodplains and does not necessarily equal the model simulation flow (160,000 cfs or 240,000 cfs [4,530.7 cms and 6,796.2 cms]). The intent is to simply compare flow in the main channel at flux computation lines 2 and 3 with the diverted flow at lines 1 and 4, respectively.

Referring to Table 2, flow values in the Upper Chute changed from 21.4% with two structures, to 21% with four structures (a decrease in flow of .04%) for the medium flow of 160,000 cfs (4,530.7 cms). The medium flow is identified in the table under the heading ‘Task 6.5 MF,’” and the high flow as ‘Task 6.5 HF.” In the Lower Chute, flow values changed from 25.3% with two structures to 24.7% with four structures (a decrease in flow of .06%) for the same flow. The high flow of 240,000 cfs (6,796.17 cms) model results were similar. The change in flow values in the Upper Chute were so minimal that the percent change was basically zero when going from two structures to four structures. In the Lower Chute, flow values changed from 30.2% with two structures, to 29.8% with four structures (a decrease in flow of .04%) for the same flow. These results show that adding two additional structures in each chute does not affect the flow split between the chutes and main channel for either of the two flows modeled. Restated in another way, adding more structures has no effect on the amount of flow entering either chute at locations 1 or 4 in figure 63. However, once the flow has entered the chute and by the time it gets to positions 1A and 4A, it appears that the structures do affect the percentage of flow remaining in the chute. This can be seen by comparing line 1 to line 1A for the upper chute, and line 4 to line 4A for the lower chute for either two or four structures and for either medium or high flow. In all cases, by the time flow gets to the 1A or 4A positions, the percentage of flow is lower. This would seem to indicate that after the flow enters the chute, the structures cause some of the flow to be diverted into the floodplain. The in-channel flow at the lower ends of either chute varies considerably depending on the number of structures in the chute and flowrate. This can be seen by comparing all cross-section locations with the “A” suffix in the table and shown as lines 1A and 4A in Figure 63. A possible reason for this variability is that these locations receive considerable return flow from the floodplains.

Figure 63. Flux computation lines.



In summary, the major facts derived from this task are that adding additional structures in the chutes does not reduce the percent of flow carried by it and that the percentage of flow carried by each chute increases for the higher flow values and also shows no difference between using two or four structures. In addition, adding additional structures within the upper chute could possibly introduce more flow back into the main channel as shown by the slight increase in velocity contours (yellow/orange color) in the main channel of the difference plot in Figure 59.

Table 2. Model computed flow splits between the chutes and the main channel.

				4 Structures in each Chute					
		Task 6.5 MF		% of Total		Task 6.5 HF		% of Total	
	Location	Flow cfs	Flow cms	Flow in		Flow cfs	Flow cms	Flow in	
				Chute *				Chute *	
Upper Chute Line1		20723	586.8	21.0		28533	807.97	27.9	
Upper Chute Line 1A		9111	258	10.5		16986	481	18.7	
Main Channel Line2		77989	2208.4			73859	2091.45		
Main Channel Line3		64933	1838.7			72508	2053.2		
Lower Chute Line4		21259	602	24.7		30741	870.49	29.8	
Lower Chute Line4A		15694	444.4	19.5		10700	303	12.9	
Main Channel Line5		68213	1931.6			73100	2069.98		
				2 Structures in each Chute					
		Task 5 MF		% of Total		Task 5 HF		% of Total	
	Location	Flow cfs	Flow cms	Flow in		Flow cfs	Flow cms	Flow in	
				Chute *				Chute *	
Upper Chute Line1		21240	601.45	21.4		28649	811.26	27.9	
Upper Chute Line1A		15538	440	16.6		17233	488	18.9	
Main Channel Line2		77981	2208.2			73857	2091.4		
Main Channel Line3		63130	1787.64			70772	2004.05		
Lower Chute Line4		21340	604.29	25.3		30664	868.31	30.2	
Lower Chute Line 4A		10241	290	14.0		11018	312	13.5	
Main Channel Line5		66432	1881.15			71621	2028.1		
Q increase Line 5		1782				1479			
Q% increase Line 5		2.7				2.1			

* The total flow is the flow in the main channel plus the flow in the chute, excluding floodplain flow.

4 Summary

A numerical 2D modeling study was conducted on the Missouri River in the vicinity of Hamburg, IA, specifically in the vicinity of RMs 557 to 550. The purpose of the study was to assist the U.S. Army Corps of Engineer s, Omaha District, to define the impact of constructed chutes on levee and floodplain flow velocity and direction within Hamburg Bend during the 2011 flood event. The evaluation required numerical hydrodynamic modeling of a pre-2011 flood condition of the entire floodplain and main channel. Modeling was conducted for a variety of alternatives that affect floodplain conditions to quantify change in floodplain hydraulics within Hamburg Bend and specifically the 2011 levee breach vicinity.

Floodplain hydraulics is just one of many factors that contribute to levee performance. Geotechnical factors such as soil conditions, pre-event levee condition, and other similar factors are not addressed in this analysis. The extent to which changes in floodplain hydraulics may or may not have contributed to the levee performance and interacted with other factors is beyond the scope of this study. The comparison of the model results pertaining to velocity magnitude and direction were the focus of the alternative analysis.

Model results demonstrate how the Missouri River main channel, constructed chutes, and Federal levee alignment affect flow stage, velocity, and distribution through Hamburg Bend. Model conditions are static and do not include the simulation of sediment transport nor scour or deposition processes that typically occur in river flow corridors.

The initial modeling effort included the development and validation of a numerical model to represent pre-2011 flood conditions. This is described in section 2 and 3.1 of this report. The next effort included numerical modeling of multiple alternatives to address the following matters of inquiry:

1. A need to provide insight as to how the chutes could have affected flow patterns in the region.
2. A need to address how changes to vegetation, geometry, and structures in the channel and floodplain could have affected flow patterns in the study area.

3. A need to address possible future flow conditions using the as-constructed levee setback and floodplain repairs.
4. A need to address whether or not adding additional structures in the post-2011 flood chutes can be beneficial in helping to control flow distributions between the chutes and main channel.

A detailed analysis of all the alternatives developed to address these needs, by task number, is described in the Results section (section 3.2 to 3.14) of this report. The results show how water depths, flow circulation patterns, and velocity magnitudes were, or were not, altered by making the noted bathymetric, vegetative, or structural changes. In general, it appears that the changes in flow circulation patterns and velocity magnitude induced by the re-vitalization of the chutes in the vicinity of the levees were minimal. Additionally, the results from these modeling alternatives show methods for improving flow patterns by using natural landscaping, re-design of levees, relocation or removal of spoil piles, and/or adding additional structures in the chutes.

Model simulations were initially performed at three different model flows. Study objectives of evaluating floodplain flow hydraulics in the levee breach vicinity were considered. Model results indicated that a 160,000 cfs (4,530.7 cms) flow created the largest difference in velocity magnitude between alternatives of the three flows that were examined. Comparisons at 240,000 cfs (6,796.2 cms) generally showed a smaller difference. Therefore, results comparisons at the 160,000 cfs (4.530.7 cms) flow tend to show the worst-case scenario for velocity and flow redirection for the floodplain.

General observations from the base condition model and alternative condition comparisons are the following.

- The existing-condition levee alignment concentrated floodplain flow velocities along the levee toe throughout Hamburg Bend. In particular, the abrupt bend near the levee breach area likely created an area of elevated velocity. Whether the chutes were constructed or not, the area of elevated velocities at that location would have existed since the levees were constructed. Model-computed velocities were greater than 6 ft/sec (1.82 m/sec) at this location and are much greater than the average floodplain velocities that generally ranged from 2–4 ft/sec (0.609 – 1.21 m/sec).

- Higher flow depths, which are associated with greater flow conveyance, are visible along the levee toe the entire model length of approximately 10 miles. This indicates a flow corridor along the levee toe, which results in higher flows in the vicinity of the levee, with lower flows in the adjacent floodplain. This is likely due to a combination of factors including floodplain elevations and roughness.
- Neither velocity vectors toward the levee nor highly turbulent eddy zones were observed in the vicinity of the levee breach. The results illustrate that the Lower Hamburg chute did not redirect flow or provide a conduit for impinging flow to the levee.
- Alternatives to examine hydraulics with the post-2011 flood geometry indicated lower velocities along the levee than the pre-2011 flood geometry.
- Comparing model results from pre- and post-2011 flood geometry illustrates the dynamic conditions within the floodplain and how the floodplain hydraulics are subject to change as geometry varies between and even during flow events.

Changes to flow velocity in the near- to levee-breach proximity were determined for many alternatives. A summary of those alternatives, which significantly affected flow velocity in the vicinity of the levee breach (greater difference than 10%), is as follows:

- Vegetation had a large effect on floodplain flow distribution including velocity magnitude and velocity direction. Converting dense vegetation areas east of the Lower Hamburg chute to farmland with lower roughness reduced velocity by approximately 1.8 ft/sec (0.54 m/sec)at the levee in the breach proximity.
- The levee setback significantly changes floodplain flow direction and hydraulics near the levee breach vicinity. Velocity reduction in the range of 1.5 ft/sec (0.45 m/sec)was observed.
- Main channel and chute degradation, which was based on survey observations collected during the 2011 event, increased main channel and chute flow. This caused reduced flow in the floodplain and thus a reduced floodplain velocity in the levee breach vicinity of approximately 0.9 ft/sec (0.27 m/sec).
- All other alternatives resulted in minor changes in floodplain hydraulics with velocity change near the levee breach vicinity less than 0.5 ft/sec.

Specific results for individual alternatives are summarized as follows:

Task 4A

The results of removing the Lower Hamburg Chute and changing the area back to pre-construction characteristics from the Task 2 model provided slightly slower velocities (maximum 0.5 ft/sec [0.15 m/sec]) within the floodplain adjacent to the area of the levee breach than that of the pre-2011 flood conditions. As shown in the red-shaded areas of Figure 19, higher velocities would have occurred farther out in the floodplain. The velocities in the entire chute area are lower since depths are much different.

Task 4B

The results of removing the side-cast earth mounds on the sides of the Lower Hamburg Chute from the Task 2 model provided similar results to task 4A in which there were slightly slower velocities (maximum of 0.5 ft/sec [0.15 m/sec]) in the area of the levee breach than that of the pre-2011 flood conditions. Similar to Task 4A results, higher velocities occurred farther out in the floodplain. Velocity change from the Task 2 condition for Task 4B is similar to that previously illustrated in Task 4A but slightly higher in the floodplain between the Lower Chute and the main channel.

Task 4C

The results showed that an alternative that removed all access ramps, riverside roads, and cuts through the vegetation between the levee and Lower Hamburg Chute in the Task 2 model would have had higher velocities in the area of the levee breach than that of the pre-2011 flood conditions. The alternative resulted in small concentrated changes in velocities in the immediate vicinity of where the model geometry changes were made and had little to no impact on the rest of the floodplain.

Task 4D

The results show that an alternative with all land east of the Lower Chute in the Task 2 model converted to farmland would have significantly increased velocities in the nearby floodplain but significantly decreased velocities by up to 1.8 ft/sec (0.54 m/sec)in the near-levee breach proximity compared to that of the pre-2011 flood conditions. The alternative resulted in much higher conveyance and velocity changes in the area east of the Lower Chute compared to the previous alternatives in both magnitude and area influenced.

Task 4E

The results show that an alternative that returned both the Upper and Lower Chutes to pre-chute conditions in the Task 2 model would have had slightly lower velocities (maximum of 0.5 ft/sec (0.15 m/sec)) in the area of the Lower Hamburg levee breach than that of the pre-2011 flood conditions. Figure 33 also shows large areas along both the left and right levees of velocity increase (maximum of 0.5 ft/sec (0.15 m/sec)). In addition, the alternative resulted in a wide area of mostly small changes to velocity (plus or minus 0.3 ft/sec [0.09 m/sec] or less) and conveyance throughout most of the floodplain.

Task 5

Results from the Task 5 simulations (Table 1) showed that velocity magnitudes in the revetment entrances to the chutes and at the lower end of the levee setback are all lower in the post-2011 flood model than in the pre-2011 flood model. The exception to this is the upper location of the levee setback, where the velocity magnitude increased at the highest flow (240,000 cfs [6,796.2 cms]) by a value of 0.2 ft/sec (0.06 m/sec). The model difference plot shown in Figure 38 shows many changes in velocity magnitude; however, most of them are due to bathymetric or floodplain geometry changes that cannot necessarily be attributed to the levee setback but do show that higher velocities can be expected in future floods at those locations. Of particular interest could be the velocity magnitude increases (shown in red in Figure 38) in close proximity to the levees.

Task 6.1

The results of adding the Lower Hamburg Levee setback that is currently constructed to the Task 2 model shows that the realignment of the levee decreases the velocities in the levee failure area. The added conveyance provided by moving the levee back significantly changes the velocity profiles throughout most of the lower floodplain. The magnitude area of velocity change is very large compared to other alternatives in the vicinity of the levee breach area with a velocity reduction of over 1.5 ft/sec (0.45 m/sec).

Task 6.2(a)

The results of changing the roughness from the zone along the east side of the chute in the Task 2 model to represent grassy, open area instead of trees shows a clear reduction in velocities in the area of the trees and adjacent to the levee. This did increase velocities in the floodplain west of the vegetation change but still provides little to no change throughout the rest of the floodplain and model reach.

Task 6.2(b)

The results of adding a tree strip adjacent to the levee toe (maintaining a 15 ft (4.57 m) buffer from the toe) to fill the area adjacent to the levee with a row of trees approximately 80 ft (24.38 m) wide from near the access road to downstream of the levee point near where the existing tree line tapers to the Task 2 model shows a reduction in velocities in the area of the trees and adjacent to the levee. This did increase velocities in the floodplain west of the vegetation change but still provides little to no change throughout the rest of the floodplain and model reach.

Task 6.2(c)

The results of adding both Task 6.2(a) and Task 6.2(b) changes to the Task 2 model shows an increase in velocities in the area where the trees were removed and in the chute adjacent to that location and a reduction in velocities in the strip of trees and the area between the strip of trees and the levee. Other than these two local changes in velocities, the vegetative changes have no effect throughout the majority of the floodplain except for the slight increase in velocities between the chute and the strip of trees adjacent to the levee.

Task 6.3

The results of degrading the Main Channel 11 ft (3.35 m) and each of the chutes 4ft (1.21 m) in the Task 2 model show the velocities in the area surrounding the levee breach were decreased by over 0.9 ft/sec (0.27

m/sec) as the conveyance in the main channel and chutes were greatly increased, therefore lowering the floodplain conveyance and flow velocity. This large velocity decrease provides an indication of dynamic conditions that would have been experienced during the 2011 event.

Task 6.4

Removing the side-cast spoil berms along and in the vicinity of the lower Hamburg Chute as shown in Figure 56 produced no noticeable changes in velocity magnitudes along the levee setback. This is clearly shown in Figure 57.

Task 6.5

Results from the Task 6.5 simulations showed that adding additional structures (combinations of 2 or 4 structures) in the chutes does not reduce the percent of flow carried by it (see table 2 and the discussion in Section 3.14). The percentage of flow carried by each chute increases for the higher flow values and also shows no difference between using 2 or 4 structures.

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14. ABSTRACT
This report describes a numerical modeling study on the Missouri River in the vicinity of Hamburg, IA, specifically in the vicinity of River Miles 557 to 550. The study was conducted by the Engineering and Research Development Center, Coastal and Hydraulics Laboratory. The purpose of the study was to assist the U.S. Army Corps of Engineers, Omaha District, to define the impact of constructed chutes on floodplain flow velocity and direction within Hamburg Bend during the 2011 flood event. The evaluation required numerical hydrodynamic modeling of a pre-2011 flood condition of the entire floodplain and main channel with and without the constructed chutes to determine whether the implementation of the Upper and Lower Hamburg Bend chutes had any hydraulic effect in the study area during the flood.

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