VIA ELECTRONIC MAIL

November 26, 2019

William Zeli, P.E., Environment Program Manager
Apex Companies, LLC
1600 Commerce Circle
Trafford, PA 15085

Subject: **West Bank Erosion Potential Evaluation**
Congaree River Remediation Project
Columbia, South Carolina

Dear Mr. Zeli:

This letter presents a summary of WSP USA's (WSP) west bank erosion potential evaluation completed using a two-dimensional (2D) HEC-RAS model of the Congaree River near the proposed Area 1 and Area 2 cofferdams.

2D MODEL DEVELOPMENT

A 2D HEC-RAS model was developed for the purposes of completing the erosion potential evaluation. The model was constructed using the same bathymetry, topographic survey, and LiDAR data used to develop a one-dimensional (1D) HEC-RAS model for the Hydraulic Analysis (WSP; April 12, 2019) and Low Flow Sensitivity Analysis (WSP; July 26, 2019). Boundary conditions were determined from the Low Flow Sensitivity Analysis model outputs.

The key characteristics of the 2D model are listed below:

- Upstream extent located approximately 1,000 feet (ft) upstream of Gervais Street bridge
- Downstream extent located approximately 500 ft upstream of Blossom Street bridge, at 1D model Sta. 282071
- Typical cell size of 5 ft x 5 ft, giving a total of approximately 225,000 cells
- Constant Manning's roughness value of 0.038 specified for existing river channel (as per 1D model) and proposed cofferdam structures.
- Upstream inflow boundary conditions for normal flow (8,564 cubic feet per second [cfs]) and crest flow (26,000 cfs) from 1D model. Flow split between left and right channels calculated based on flow area of

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each side of channel at normal/crest flow conditions from 1D model outputs. Results in approximately 50-50 split between channels.

- Downstream water level boundary conditions for normal and crest flow conditions determined from 1D model outputs as 115.0 and 121.8 ft NAVD 88, respectively.
- Separate Digital Elevation Models (DEMs) developed for Existing, Proposed Area-1 Cofferdam, and Proposed Area-2 Cofferdam scenarios. Cofferdams and river banks specified as break lines for all scenarios, ensuring a consistent 2D flow area with identical computation point locations is used for all models. Therefore, any changes in results can be attributed to elevation changes, not model schematization.
- Gervais Street bridge piers are represented in the models assuming an ellipse shape approximately 60 ft long and 20ft wide, based on Google Earth imagery.
- Final model simulations run using the full momentum equations and an adaptive computation interval with a maximum value of 30-seconds.

Figures 1 through 7 provide a summary of the model setup and input data.

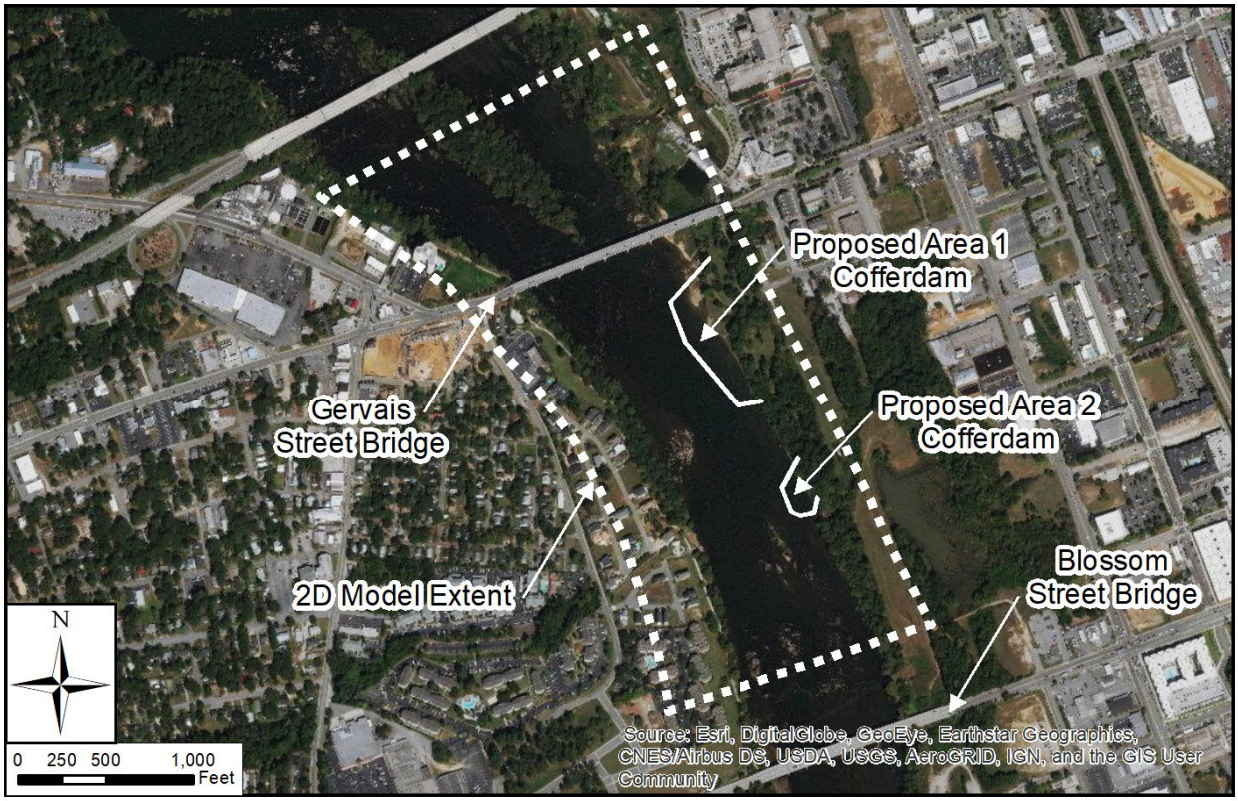


Figure 1: Model Extent

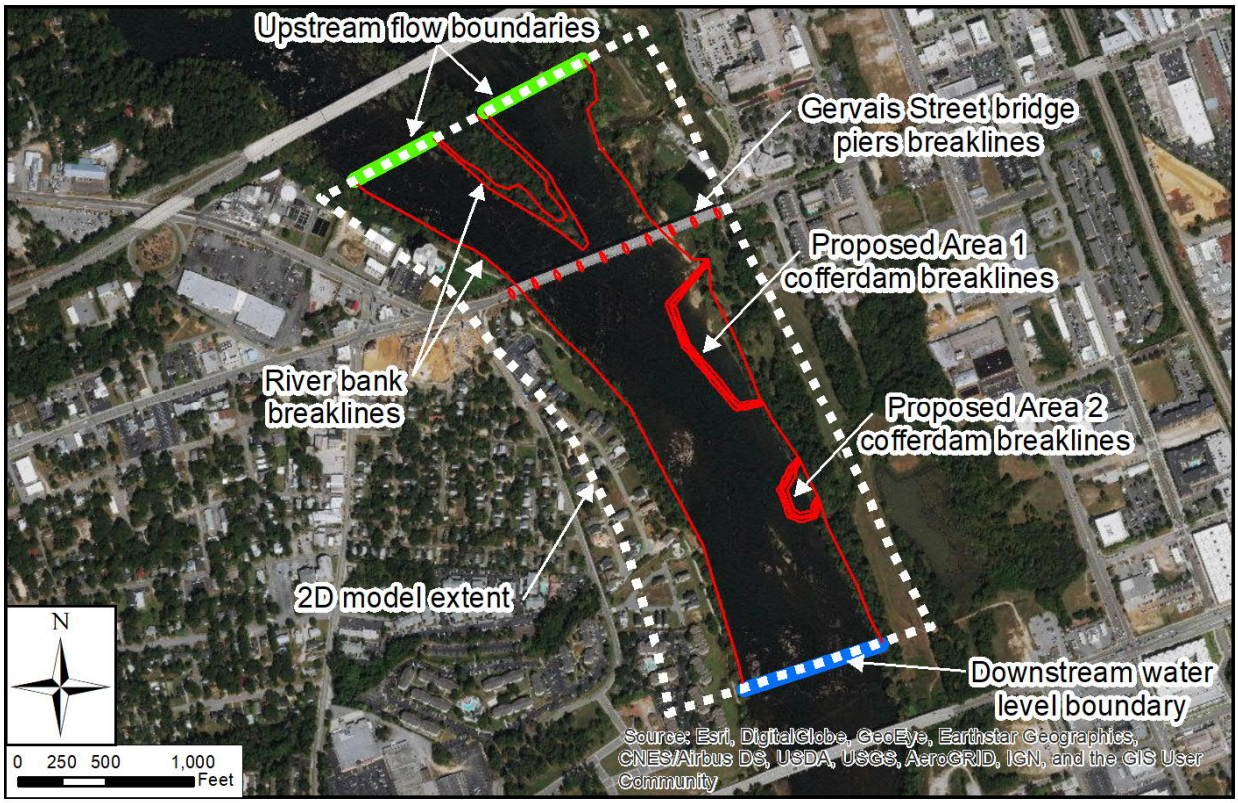


Figure 2: Model Details

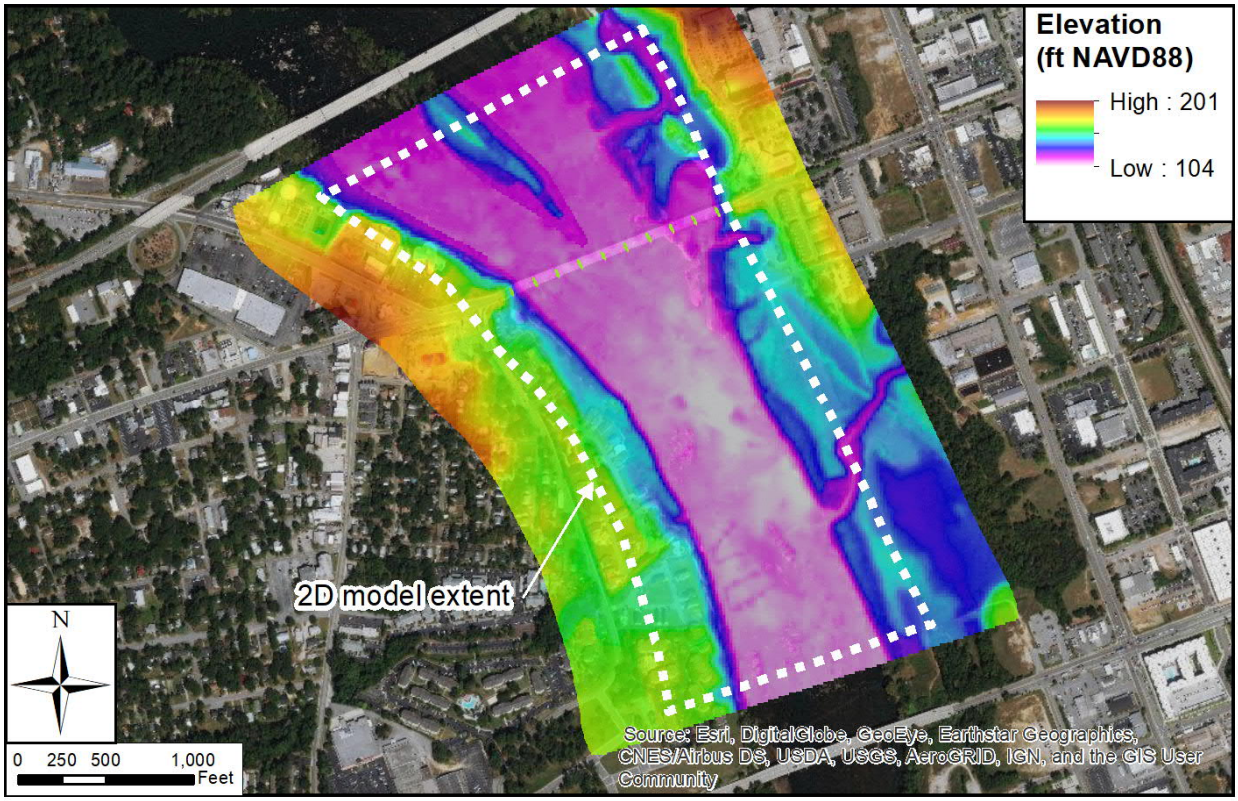


Figure 3: Existing Digital Elevation Model

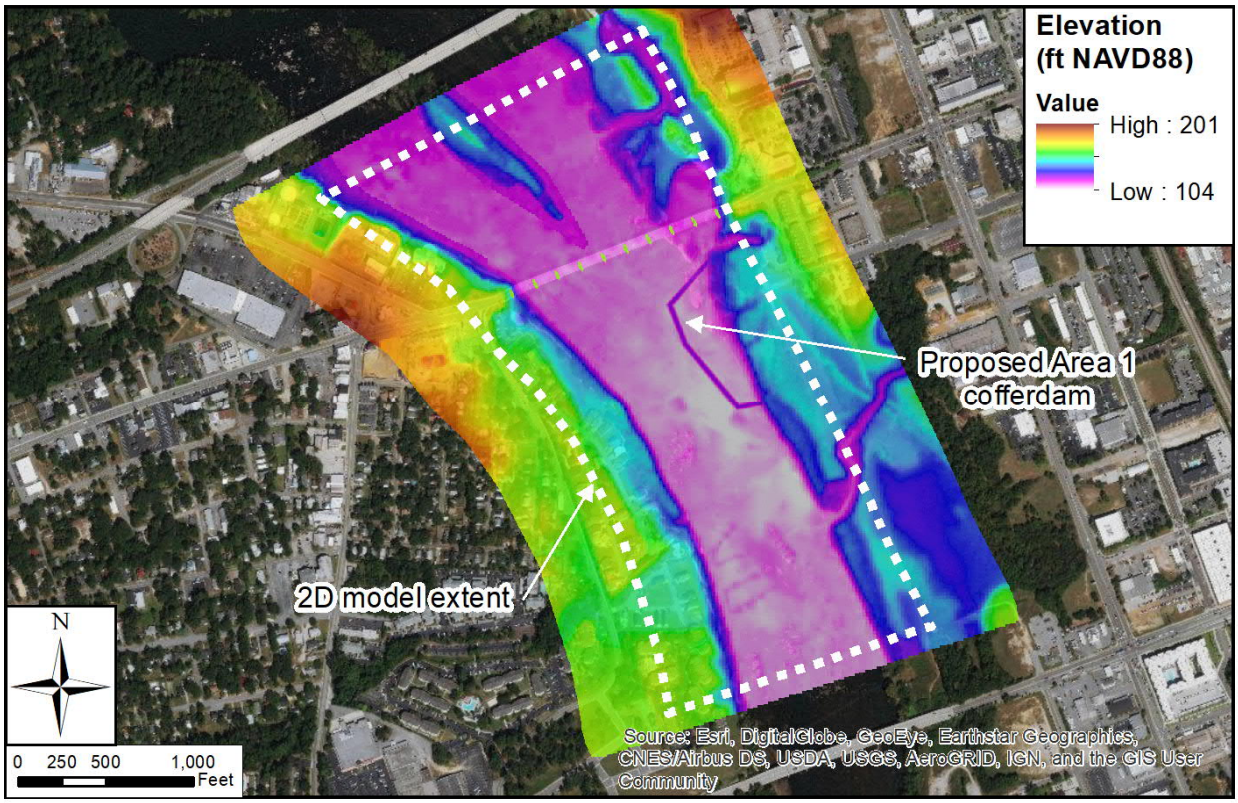


Figure 4: Proposed Area 1 Cofferdam Digital Elevation Model

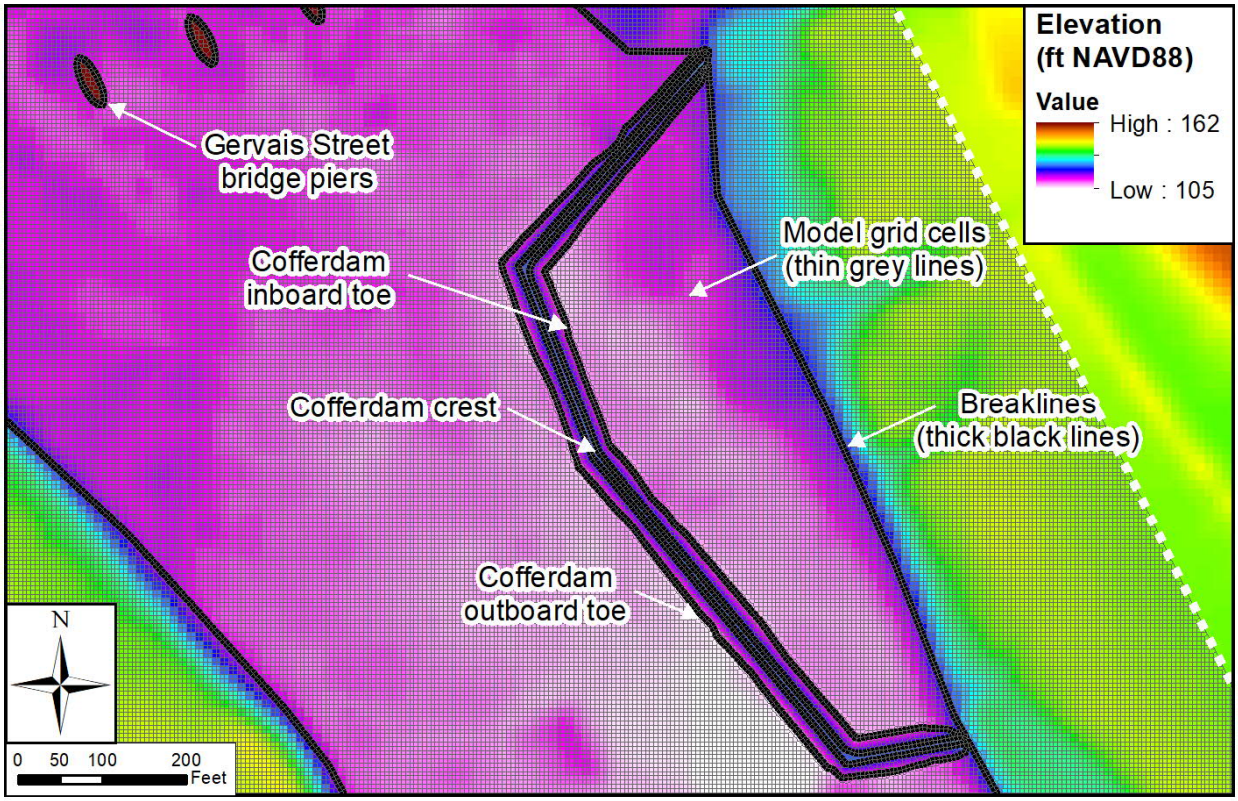


Figure 5: Proposed Area 1 Cofferdam Mesh Details

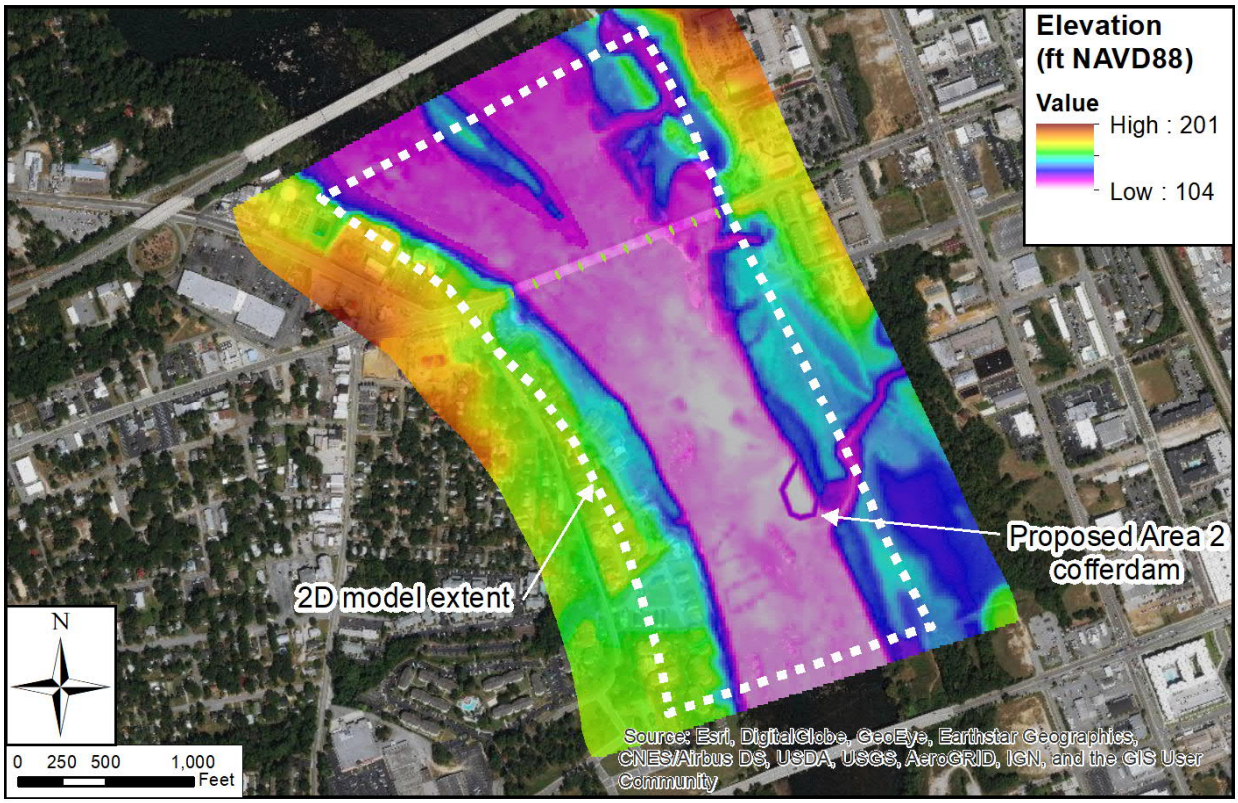


Figure 6: Proposed Area 2 Cofferdam Digital Elevation Model

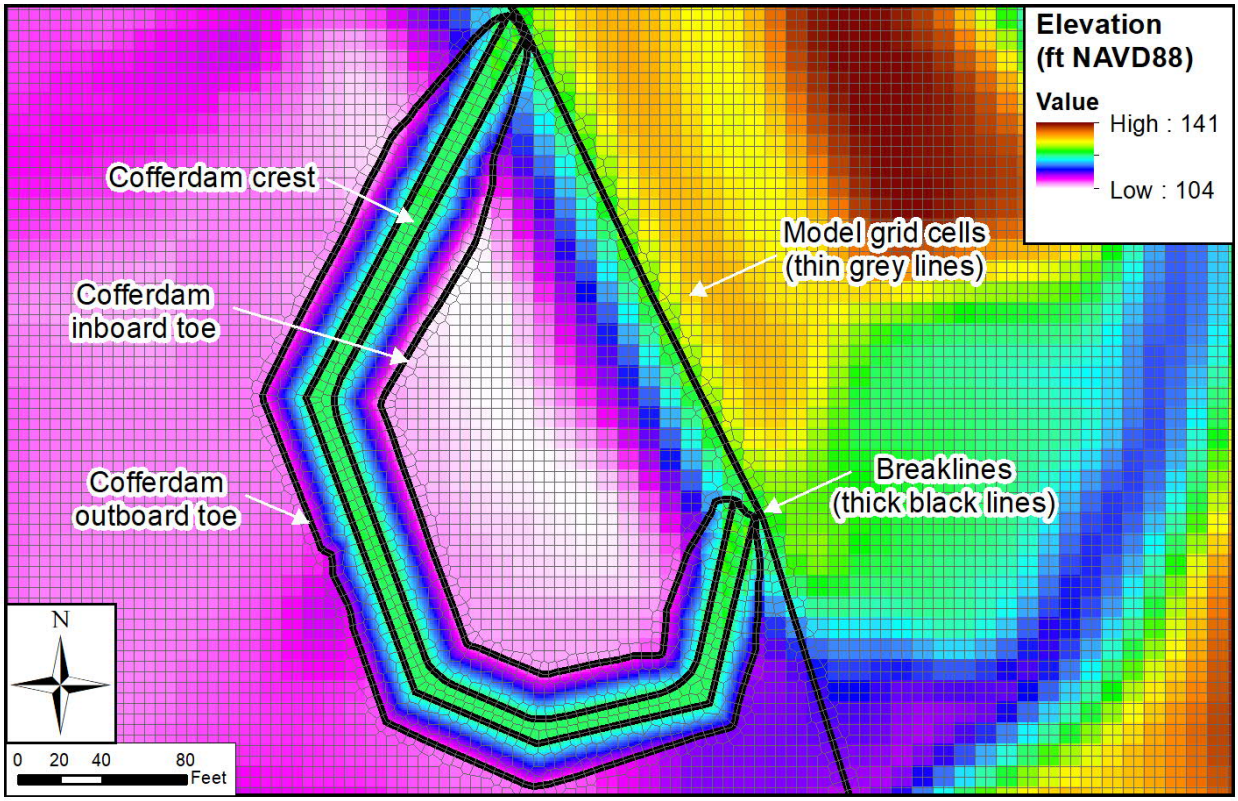


Figure 7: Proposed Area 2 Cofferdam Mesh Details

Figure 8 shows the upstream and downstream boundary conditions used for the model runs. The upstream inflow and downstream water level during the first hour of the run represents the "normal flow condition" of 8,564 cfs. Over the next four hours of the run, the boundary conditions ramp-up to the "crest flow condition" of 26,000 cfs, which is then maintained for the final two hours of the run. During development of the model, initial runs were completed to develop initial condition files at the start of the run for the Existing, Proposed Area 1 and Proposed Area 2 models.

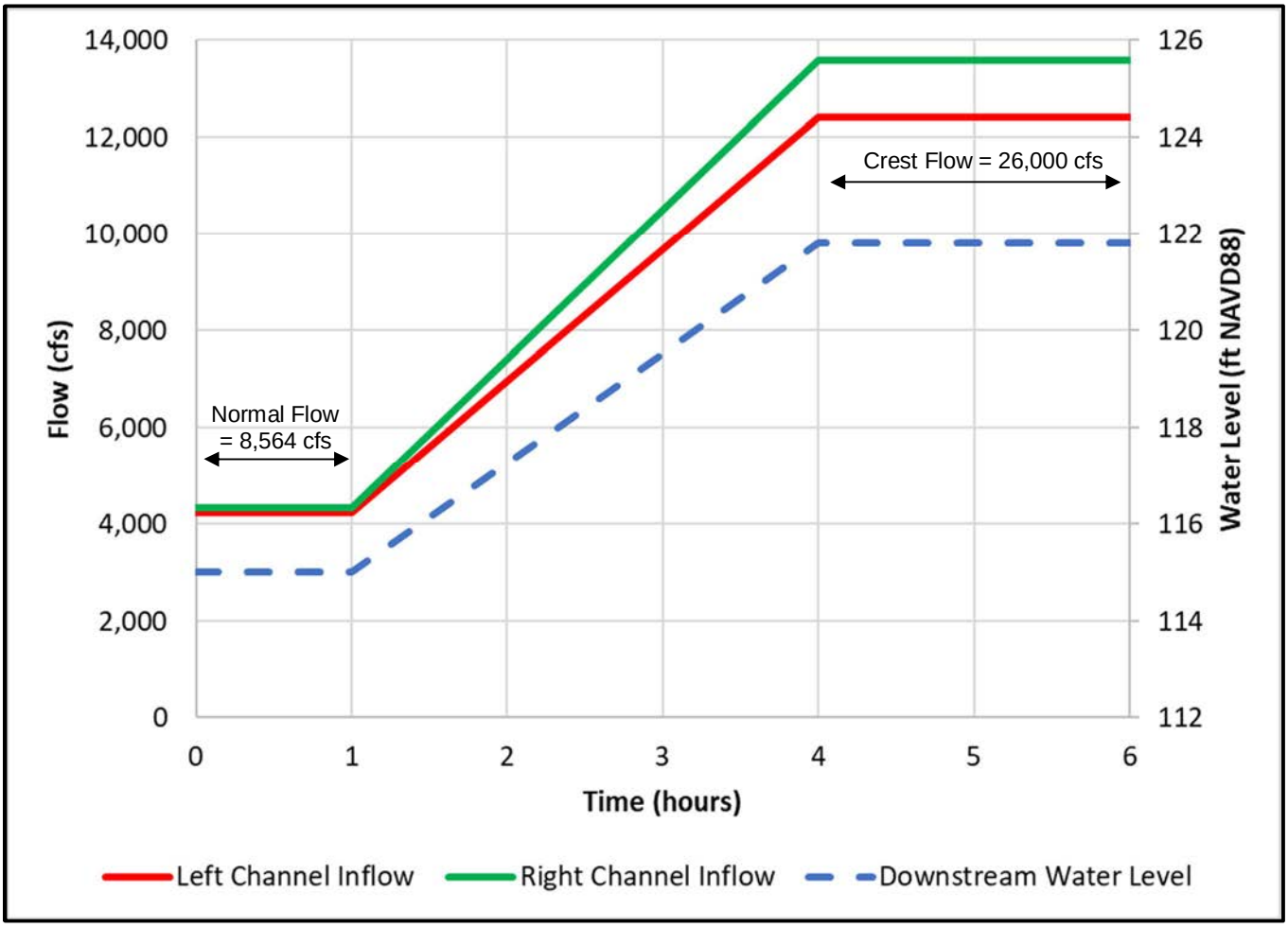


Figure 8: Upstream and Downstream Boundary Conditions

2D MODEL RESULTS

Separate two-dimensional unsteady flow analyses were performed for the Existing, Proposed Area 1, and Proposed Area 2 models. Additional trial analyses were also performed to test the model's sensitivity to the computational timestep interval and the application of the full momentum equations. After our initial quality assurance review, we determined that the adaptive computational interval and the full momentum equations should be utilized for the final model runs, in accordance with the HEC-RAS 2D Modeling User's Manual.

The velocity and shear stress results were extracted from all of the models after one hour to represent the normal flow condition of 8,564 cfs, and after six hours to represent the crest flow condition of 26,000 cfs. The results were used to develop figures that show the spatial variation of flow velocity/shear stress throughout the Congaree River channel and to show changes in velocity due to the construction of the Area 1 and Area 2 cofferdams.

The following figures are provided in Attachment A:

- Figure A1: Normal Flow (8,564 cfs) Existing Scenario – Flow Velocity
- Figure A2: Crest Flow (26,000 cfs) Existing Scenario – Flow Velocity
- Figure A3: Normal Flow (8,564 cfs) Proposed Area-1 Scenario – Flow Velocity
- Figure A4: Crest Flow (26,000 cfs) Proposed Area-1 Scenario – Flow Velocity
- Figure A5: Normal Flow (8,564 cfs) Proposed Area-1 Scenario – Change in Flow Velocity
- Figure A6: Crest Flow (26,000 cfs) Proposed Area-1 Scenario – Change in Flow Velocity
- Figure A7: Normal Flow (8,564 cfs) Proposed Area-2 Scenario – Flow Velocity
- Figure A8: Crest Flow (26,000 cfs) Proposed Area-2 Scenario – Flow Velocity
- Figure A9: Normal Flow (8,564 cfs) Proposed Area-2 Scenario – Change in Flow Velocity
- Figure A10: Crest Flow (26,000 cfs) Proposed Area-2 Scenario – Change in Flow Velocity
- Figure A11: Crest Flow (26,000 cfs) Existing Scenario – Shear Stress
- Figure A12: Crest Flow (26,000 cfs) Proposed Area-1 Scenario – Shear Stress
- Figure A13: Crest Flow (26,000 cfs) Proposed Area-2 Scenario – Shear Stress

The following sections discuss the velocity and shear stress results for the west bank of the Congaree River in the vicinity of the project area for the Existing, Proposed Area-1, and Proposed Area-2 scenarios.

EXISTING SCENARIO

The velocity results along the west bank show that during normal flow conditions (8,564 cfs), the river velocity ranges between 2 to 4 feet per second (ft/s) approximately 550 feet downstream of the Gervais Street Bridge. The river velocity for the next 1,200 feet downstream ranges between 0.5 to 2 ft/s. The river velocity throughout the remaining 800 feet of the model ranges from 2 to 4 ft/s, with some localized areas of 5 ft/s. Upstream of the Gervais Street bridge, the river velocity ranges between 3 to 5 ft/s.

The velocity results along the west bank during crest flow conditions (26,000 cfs) range between 2 to 4 ft/s downstream of the Gervais Street bridge. Upstream of the bridge, the river velocity ranges between 4 to 5 ft/s.

PROPOSED AREA-1 SCENARIO

During normal flow conditions, the construction of the Area-1 cofferdam increases the river velocity between 0.1 to 1 ft/s for approximately 1,400 feet of the west bank area opposite the structure. During crest flow conditions, the river velocity increases up to 0.5 ft/s on the west bank upstream of the Gervais Street Bridge. The river velocity increases between 0.1 to 1 ft/s for approximately 1,600 feet of the west bank area opposite the structure. There are some localized areas along the bank which show a river velocity increase up to 1.5 ft/s.

PROPOSED AREA-2 SCENARIO

During normal flow conditions, the construction of the Area-2 cofferdam increases the river velocity between 0.1 to 0.5 ft/s for approximately 1,000 feet of the west bank area opposite the structure. During crest flow conditions, the river velocity increases between 0.5 to 1 ft/s for approximately 700 feet of the west bank opposite the structure. Upstream and downstream of Area 2, the river velocity increases between 0.1 to 0.5 ft/s, for bank lengths ranging from 300 to 400 feet.

WEST BANK EROSION POTENTIAL EVALUATION

The river velocities along the west bank of the Congaree River during normal (8,564 cfs) and crest (26,000 cfs) flow conditions range between 3 to 5 ft/s upstream of the Gervais Street Bridge and range between 0.5 to 4 ft/s downstream of the bridge.

The river velocity along the west bank after the construction of the Area 1 cofferdam increases up to 1 ft/s during normal flow conditions. The area affected is opposite the cofferdam structure and the velocities in this area remain within the 2 to 4 ft/s range. During crest flow conditions, there are some localized increases of up to 1.5 ft/s due to the construction of the Area-1 cofferdam. Similar to normal flow conditions, this increase also occurs opposite the proposed structure and the velocities remain within the 2 to 4 ft/s range during crest flow conditions.

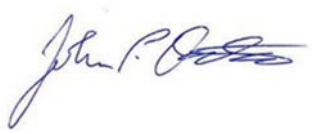
The river velocity along the west bank after the construction of the Area 2 cofferdam increases up to 0.5 ft/s during normal conditions and up to 1 ft/s during crest flow conditions. The area affected is opposite the cofferdam structure and the velocities in this area remain within the 2 to 4 ft/s range for normal and crest flow conditions. However, there is a localized area that has a river velocity up to 4.5 ft/s.

The change in velocity due to construction of the cofferdams is relatively small (i.e., less than 1.5 ft/s) and the velocities along the west bank of the Congaree River remain relatively low (i.e., 2 to 4 ft/s). Based on the flow velocities, erosion protection measures such as riprap or bank stabilization revetments are not necessary to provide river bank protection during the construction period.

Additional evaluation of the shear stress values near the west bank also confirms that erosion protection is not required. Table 6.2 of the Pennsylvania Department of Environmental Protection's "Erosion and Sediment Pollution Control Program Manual" provides maximum permissible shear stresses for various channel liners. The maximum permissible shear stress for non-reinforced vegetation is 1.0 lb/ft^2 and the average value for unlined soils is approximately 0.1 lb/ft^2. The model results show the shear stress along the west bank is typically less than 0.1 lb/ft^2 for the Existing, Proposed Area 1, and Proposed Area 2 scenarios.

If you have any questions or need any additional information, please contact John Osterle at 412-535-9823 or john.osterle@wsp.com, or Tom Edwards at 412-535-9889 or thomas.edwards@wsp.com.

Kind regards,



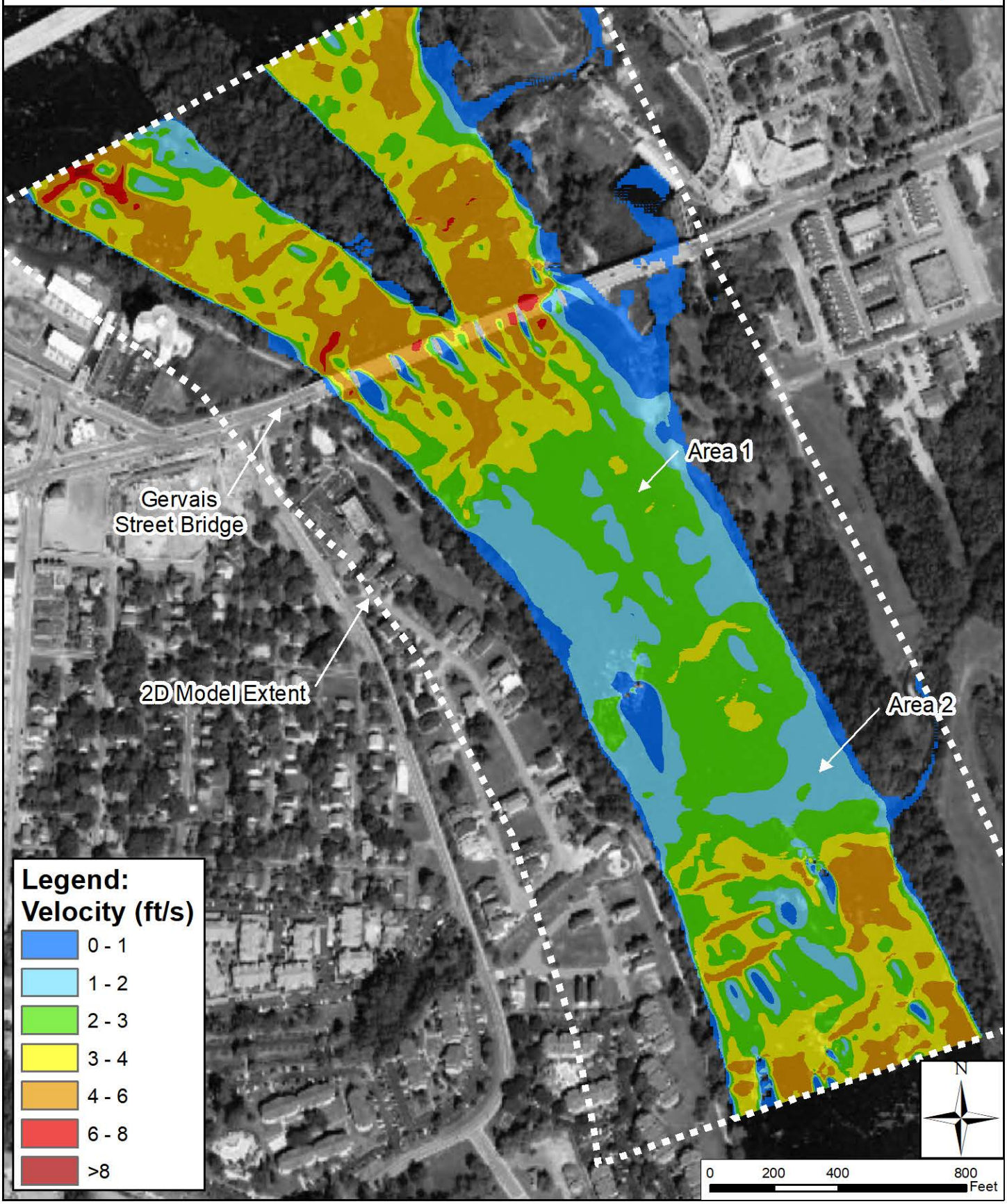
John P. Osterle, P.E.
Project Manager

Tom Edwards, P.E.
Water Resources Engineer

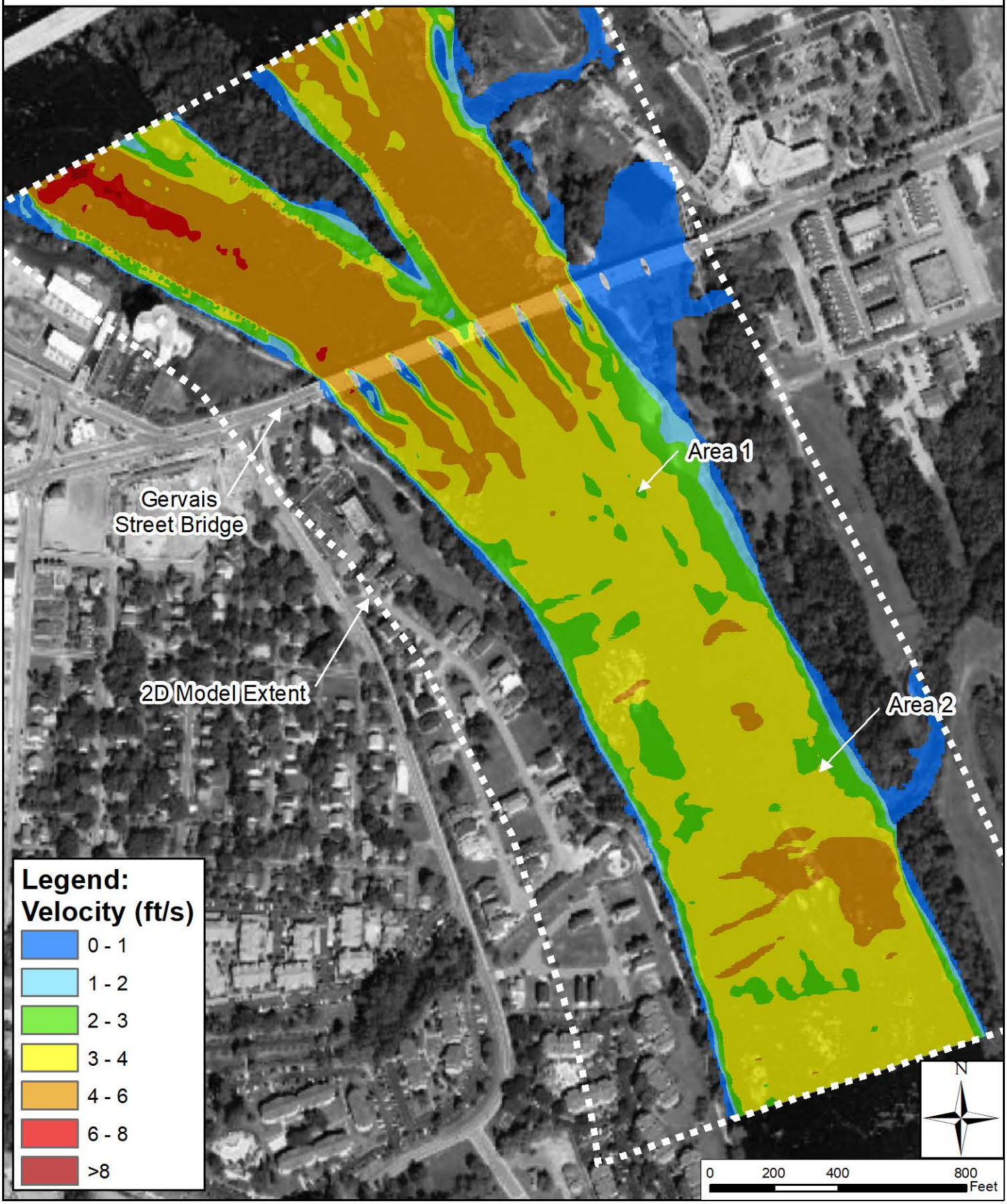
TE: JPO

ATTACHMENT A: FIGURES

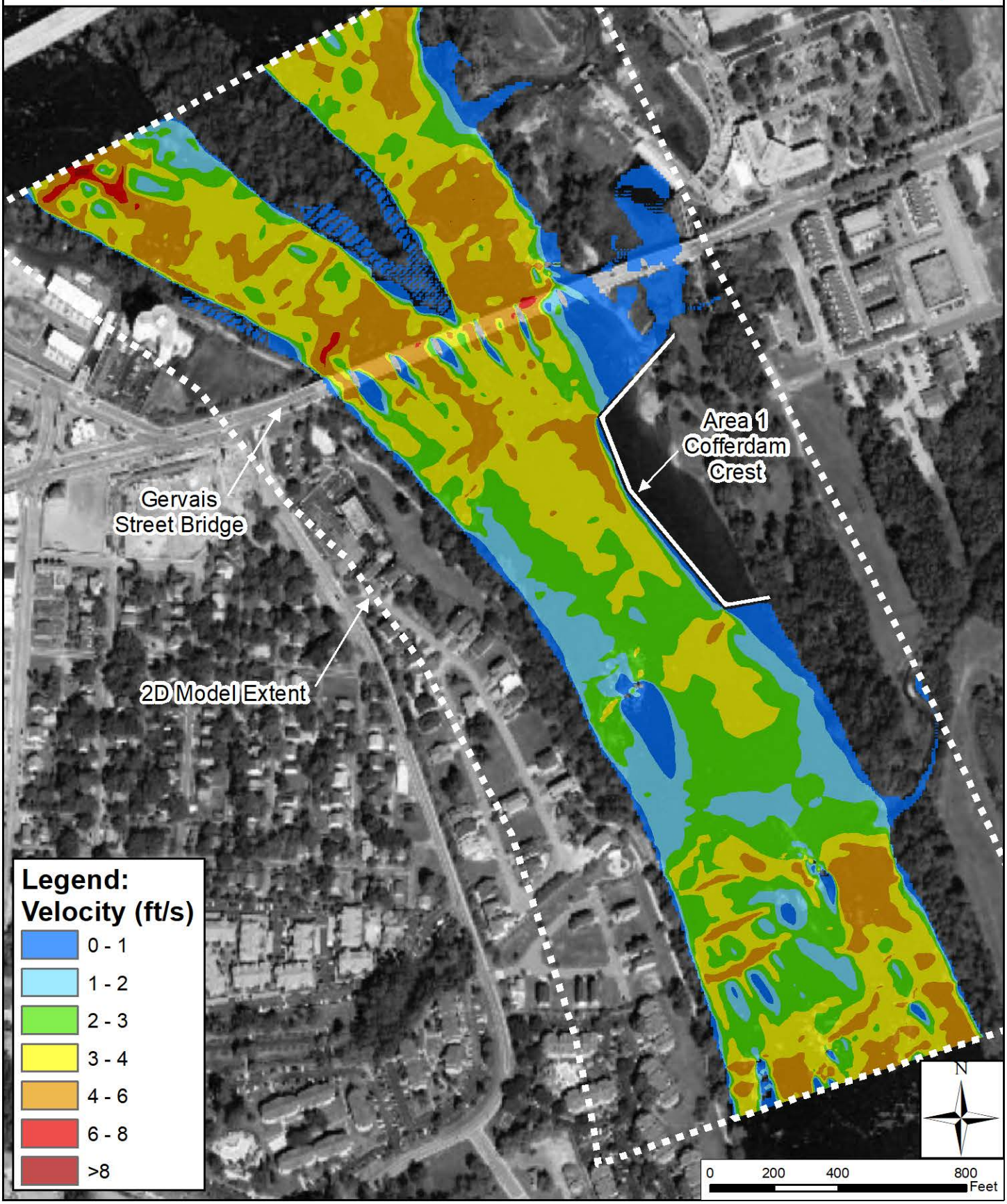
Congaree River Remediation Project
West Bank Erosion Potential Evaluation
Figure A1: Normal Flow (8,564 cfs)
Existing Scenario: Flow Velocity



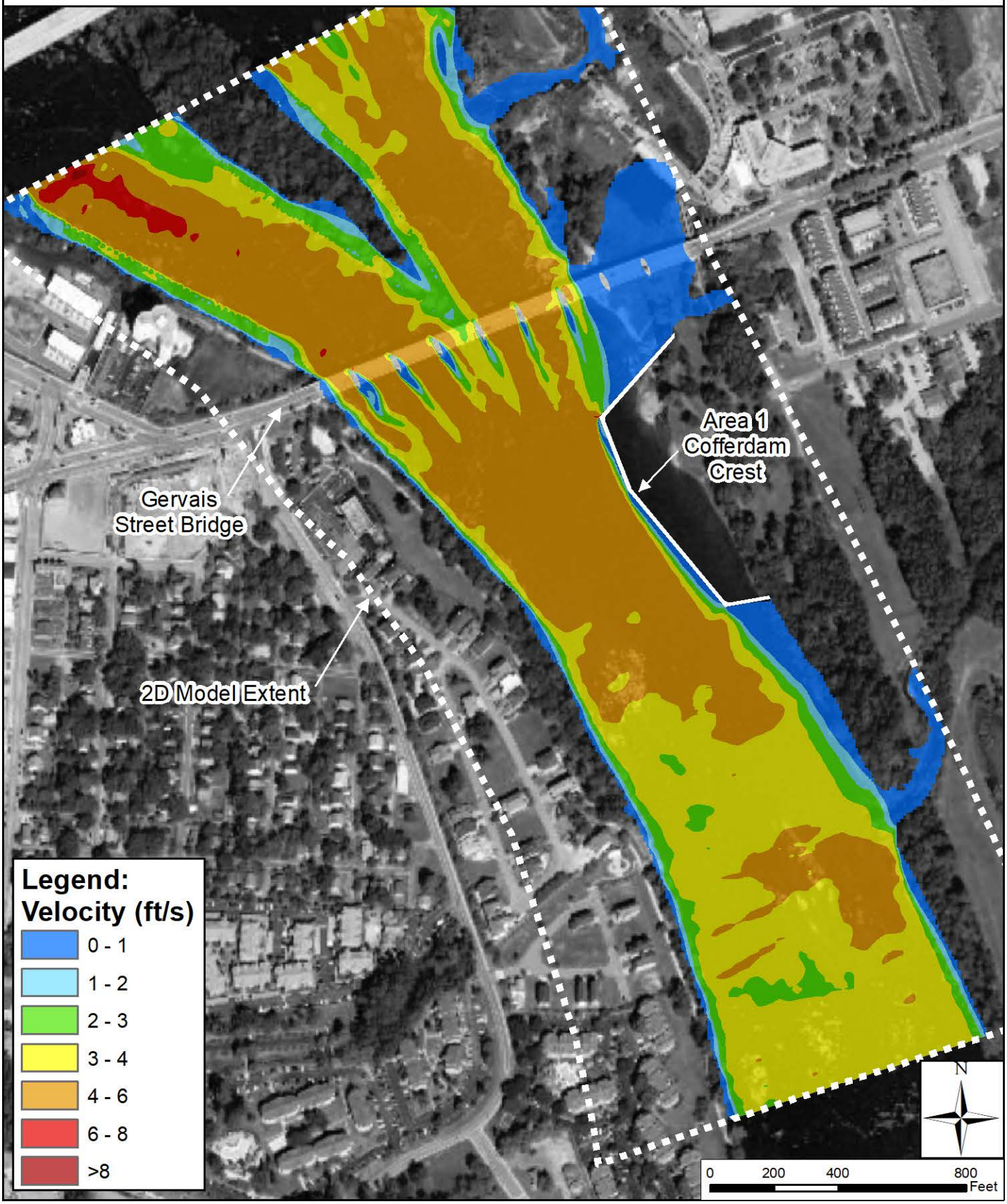
Congaree River Remediation Project
West Bank Erosion Potential Evaluation
Figure A2: Crest Flow (26,000 cfs)
Existing Scenario: Flow Velocity



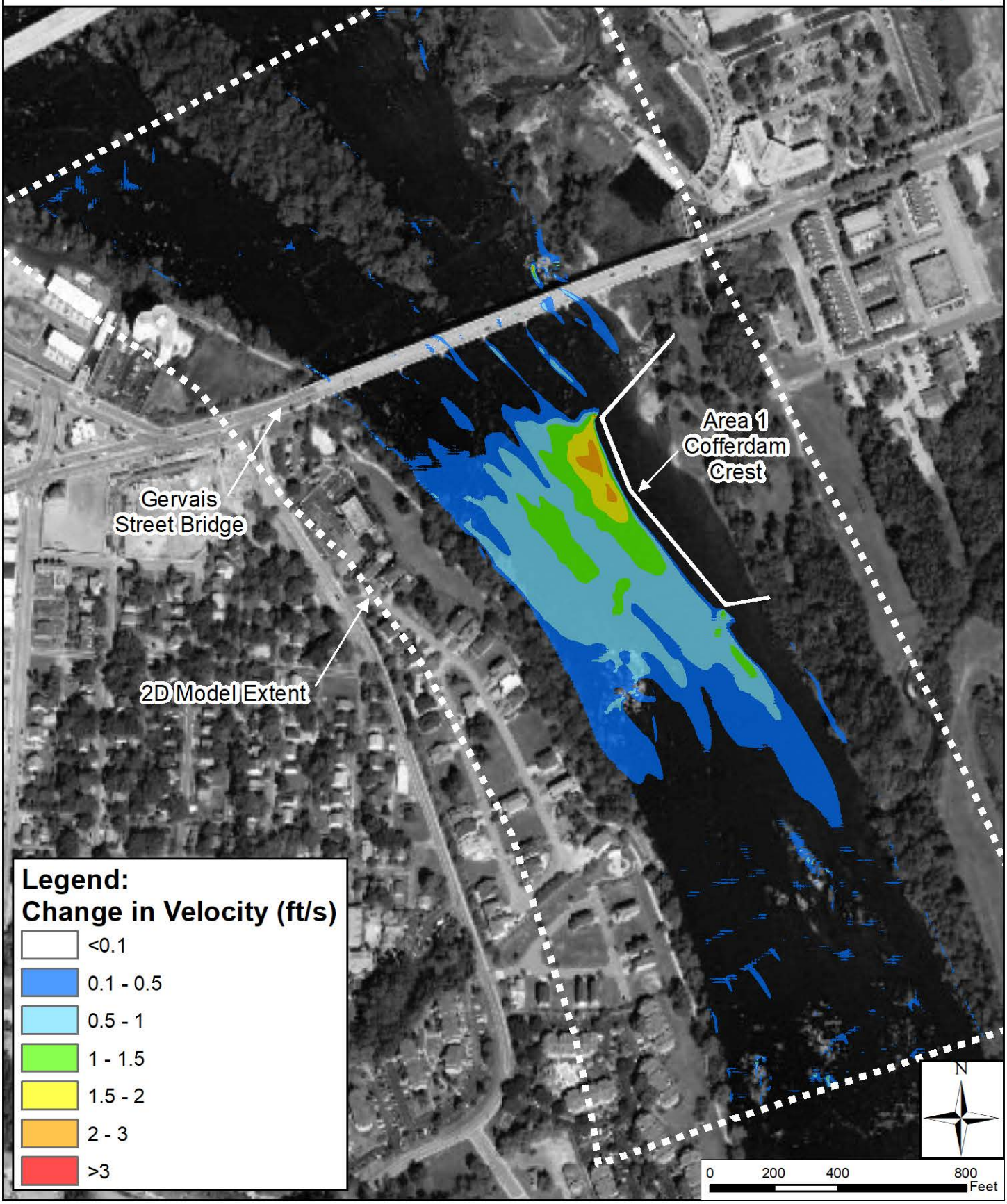
Congaree River Remediation Project
West Bank Erosion Potential Evaluation
Figure A3: Normal Flow (8,564 cfs)
Proposed Area-1 Scenario: Flow Velocity



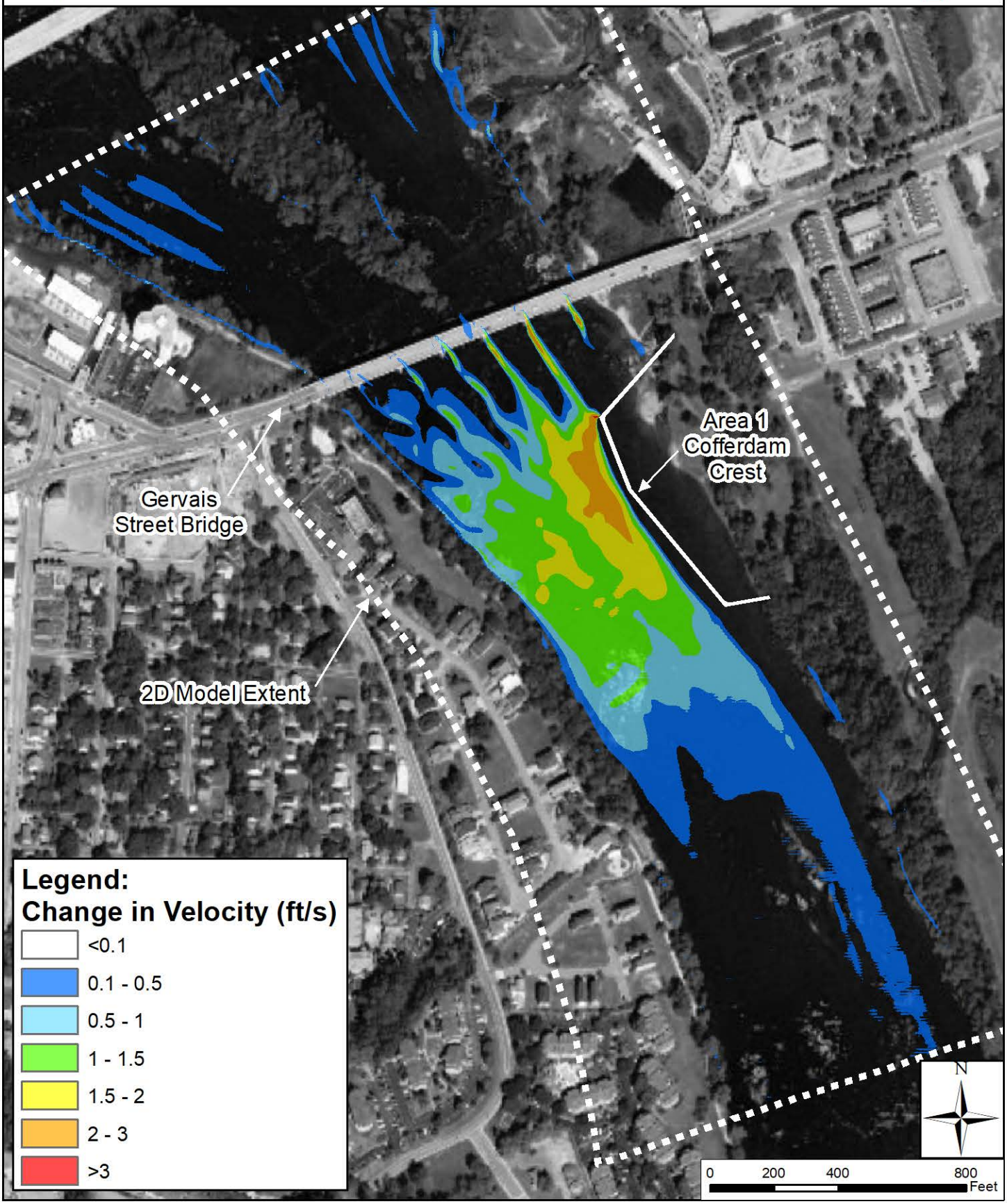
Congaree River Remediation Project
West Bank Erosion Potential Evaluation
Figure A4: Crest Flow (26,000 cfs)
Proposed Area-1 Scenario: Flow Velocity



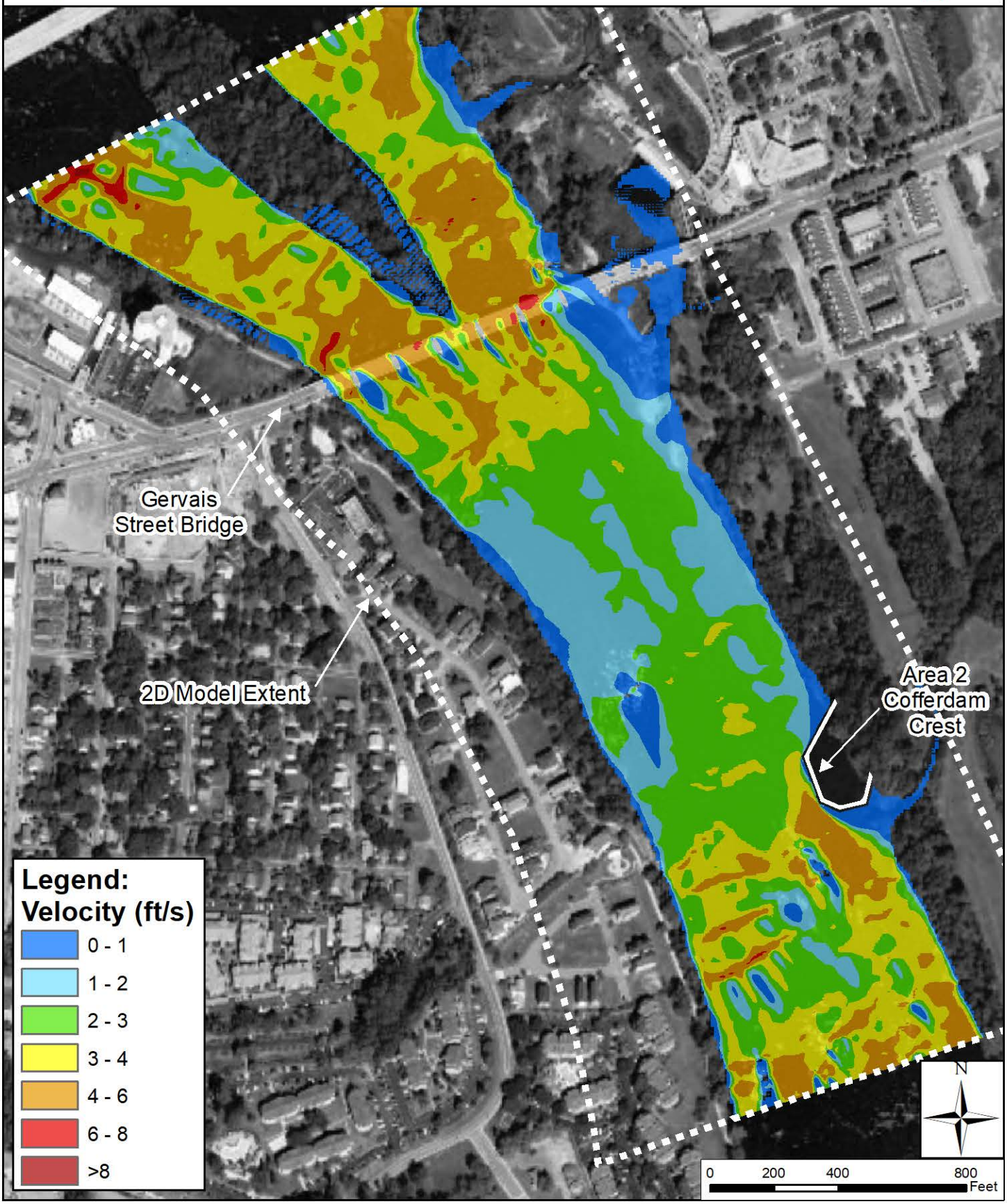
Congaree River Remediation Project
West Bank Erosion Potential Evaluation
Figure A5: Normal Flow (8,564 cfs)
Proposed Area-1 Scenario: Change in Flow Velocity



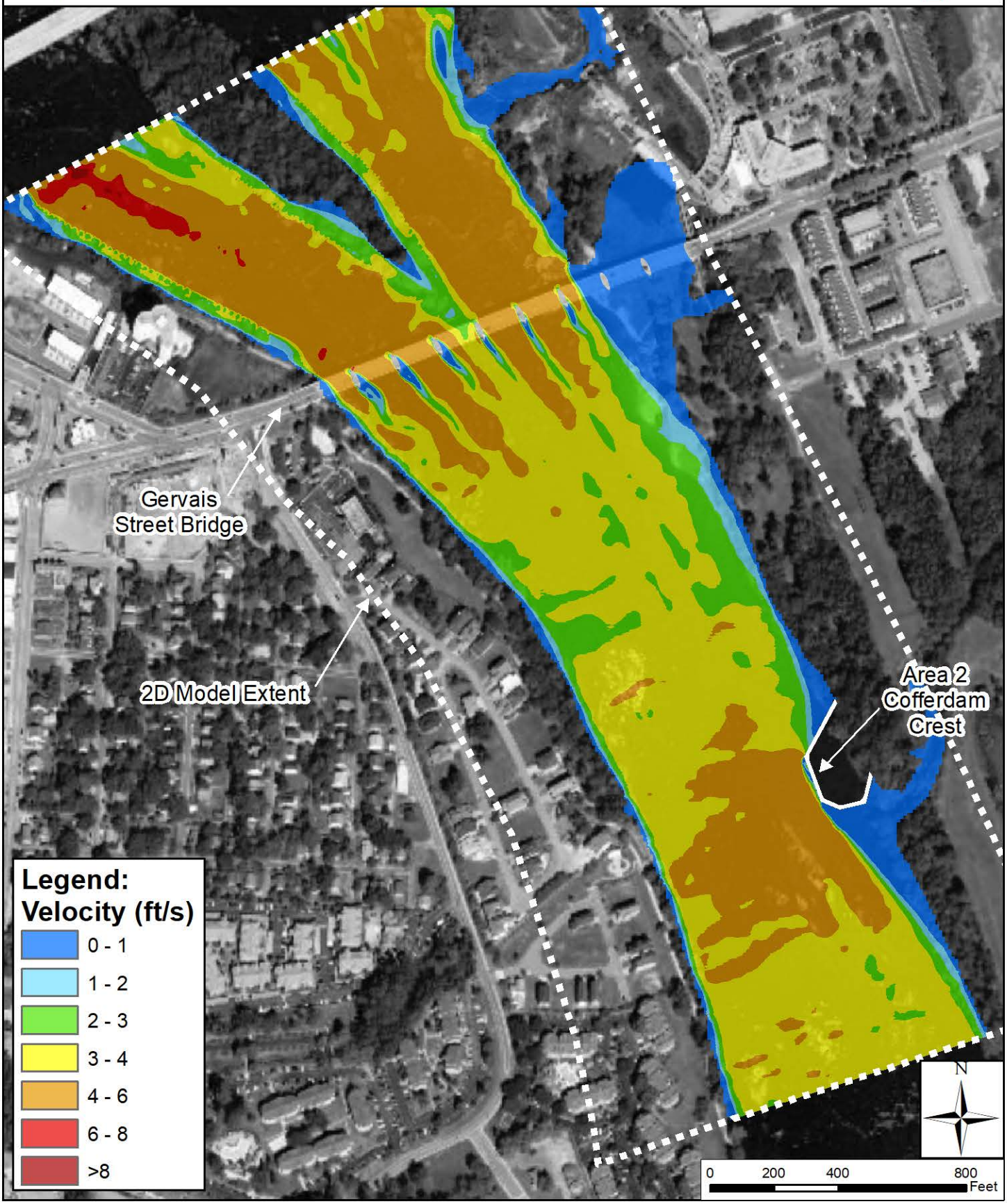
Congaree River Remediation Project
West Bank Erosion Potential Evaluation
Figure A6: Crest Flow (26,000 cfs)
Proposed Area-1 Scenario: Change in Flow Velocity



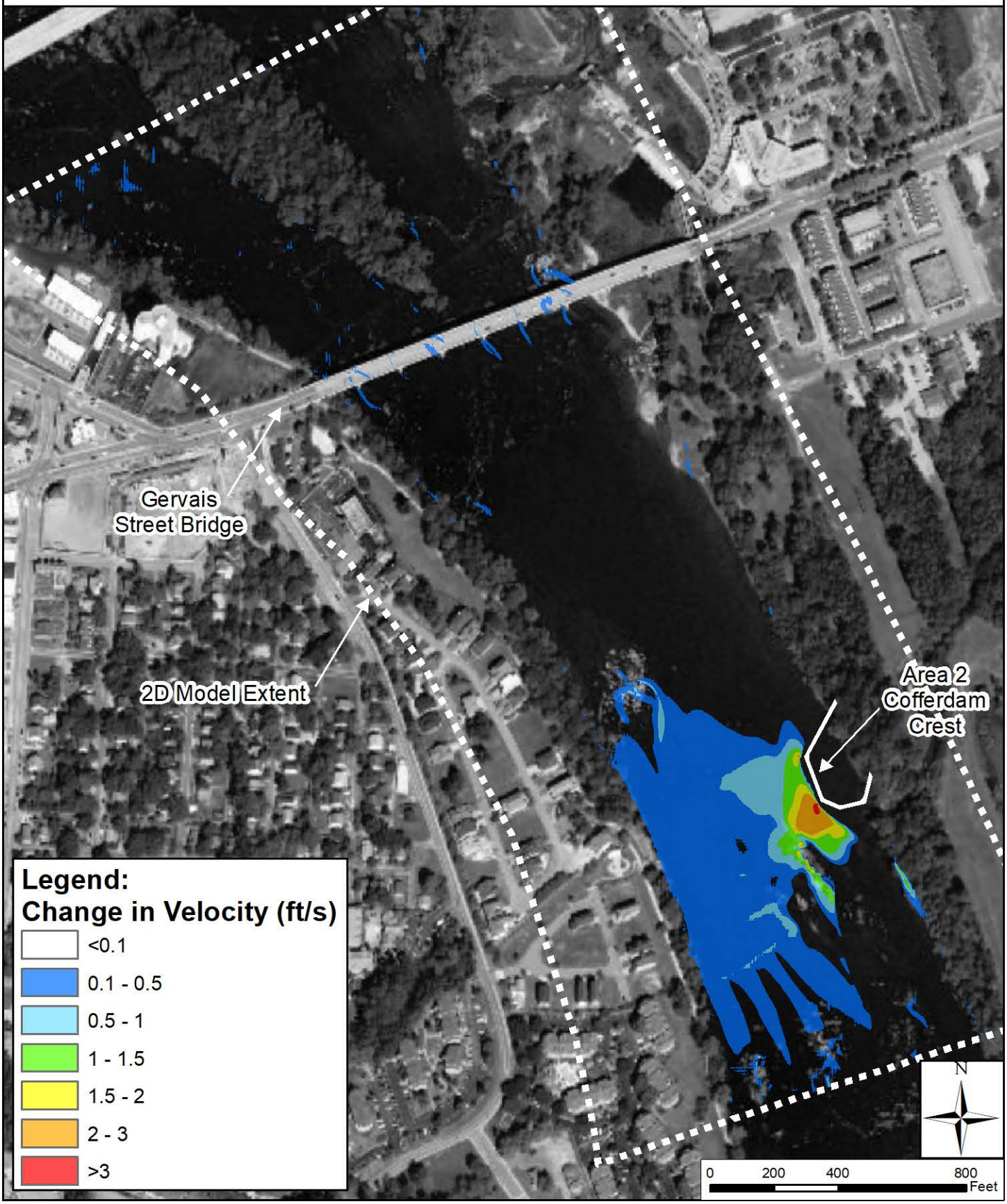
Congaree River Remediation Project
West Bank Erosion Potential Evaluation
Figure A7: Normal Flow (8,564 cfs)
Proposed Area-2 Scenario: Flow Velocity



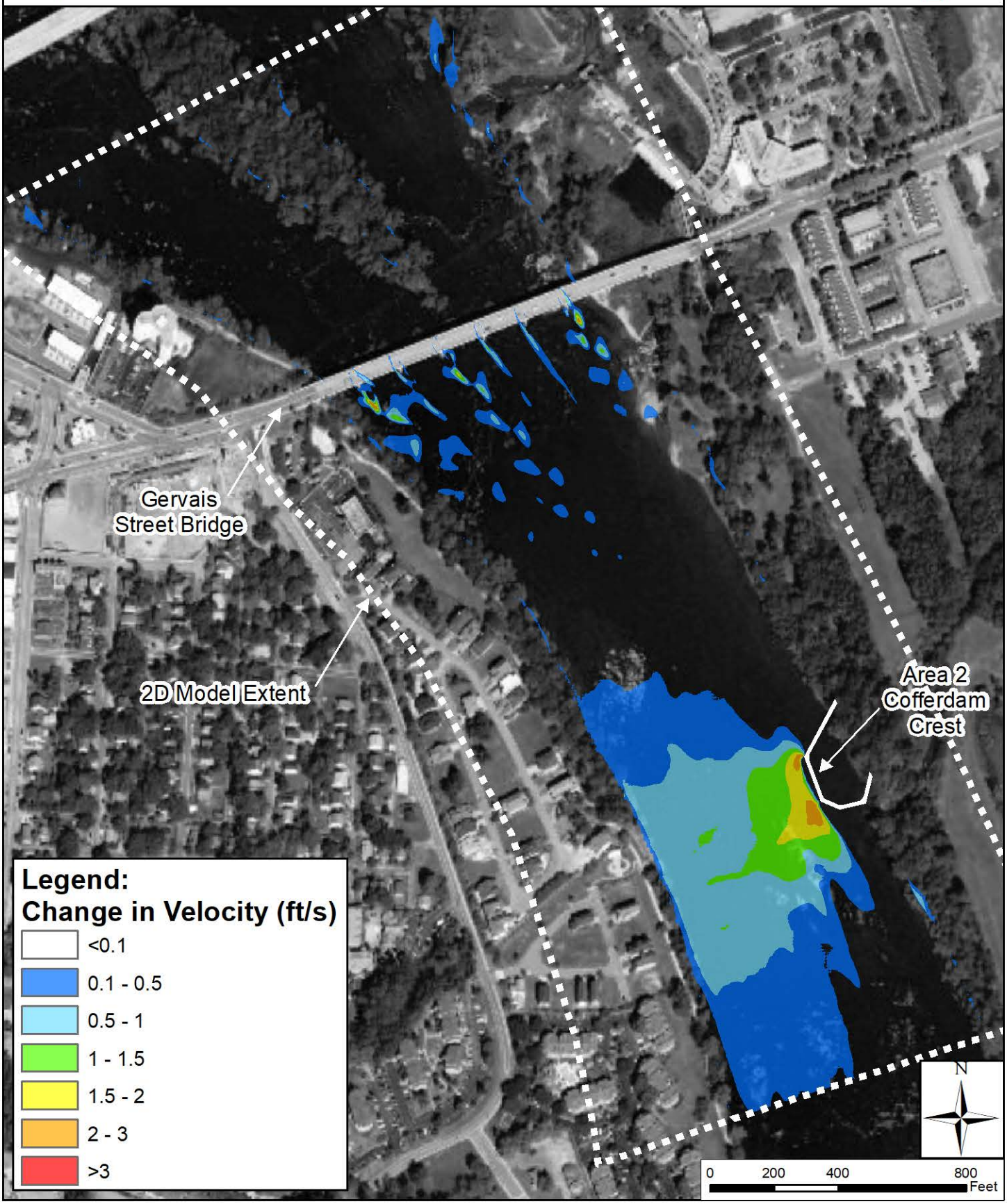
Congaree River Remediation Project
West Bank Erosion Potential Evaluation
Figure A8: Crest Flow (26,000 cfs)
Proposed Area-2 Scenario: Flow Velocity



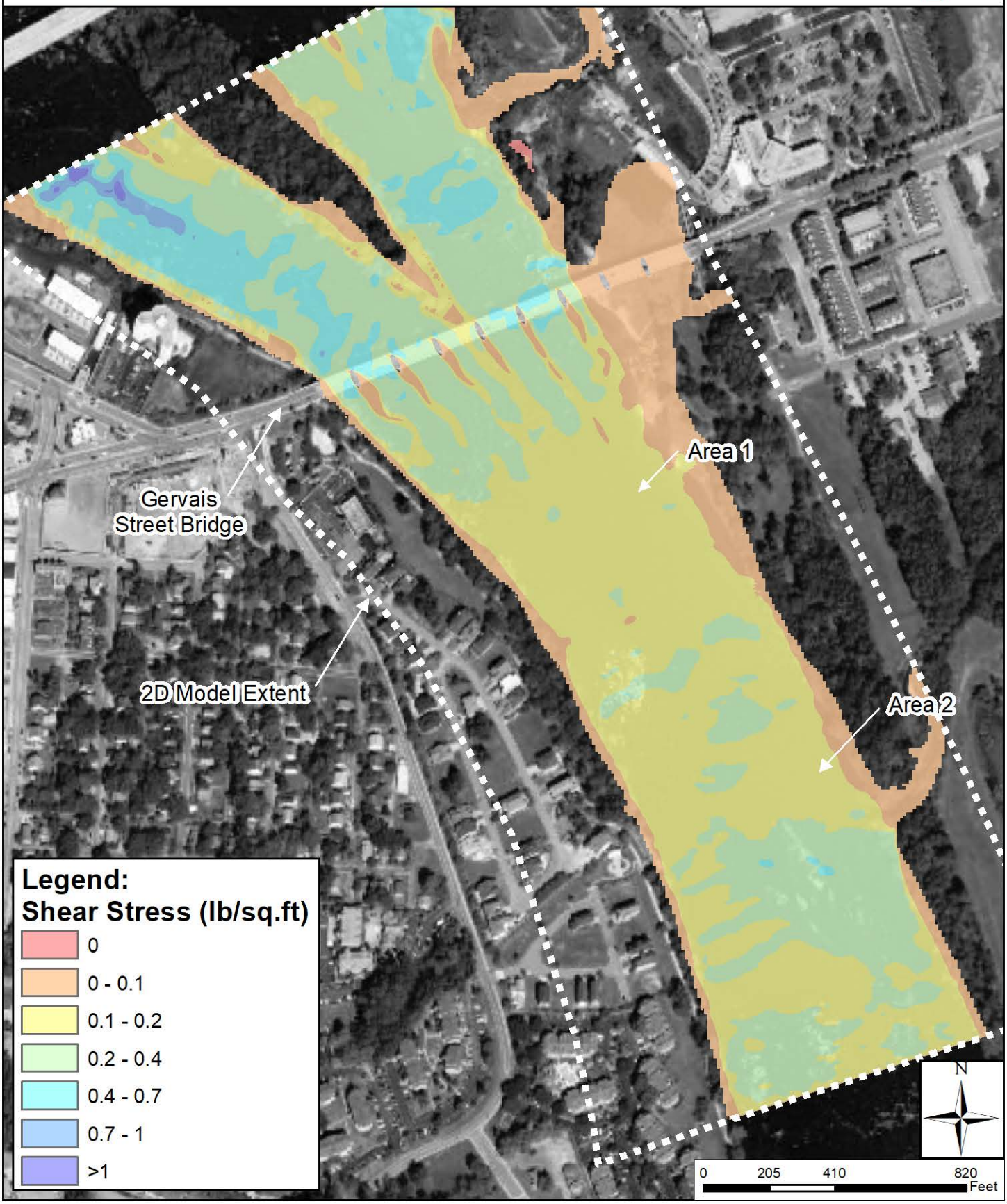
Congaree River Remediation Project
West Bank Erosion Potential Evaluation
Figure A9: Normal Flow (8,564 cfs)
Proposed Area-2 Scenario: Change in Flow Velocity



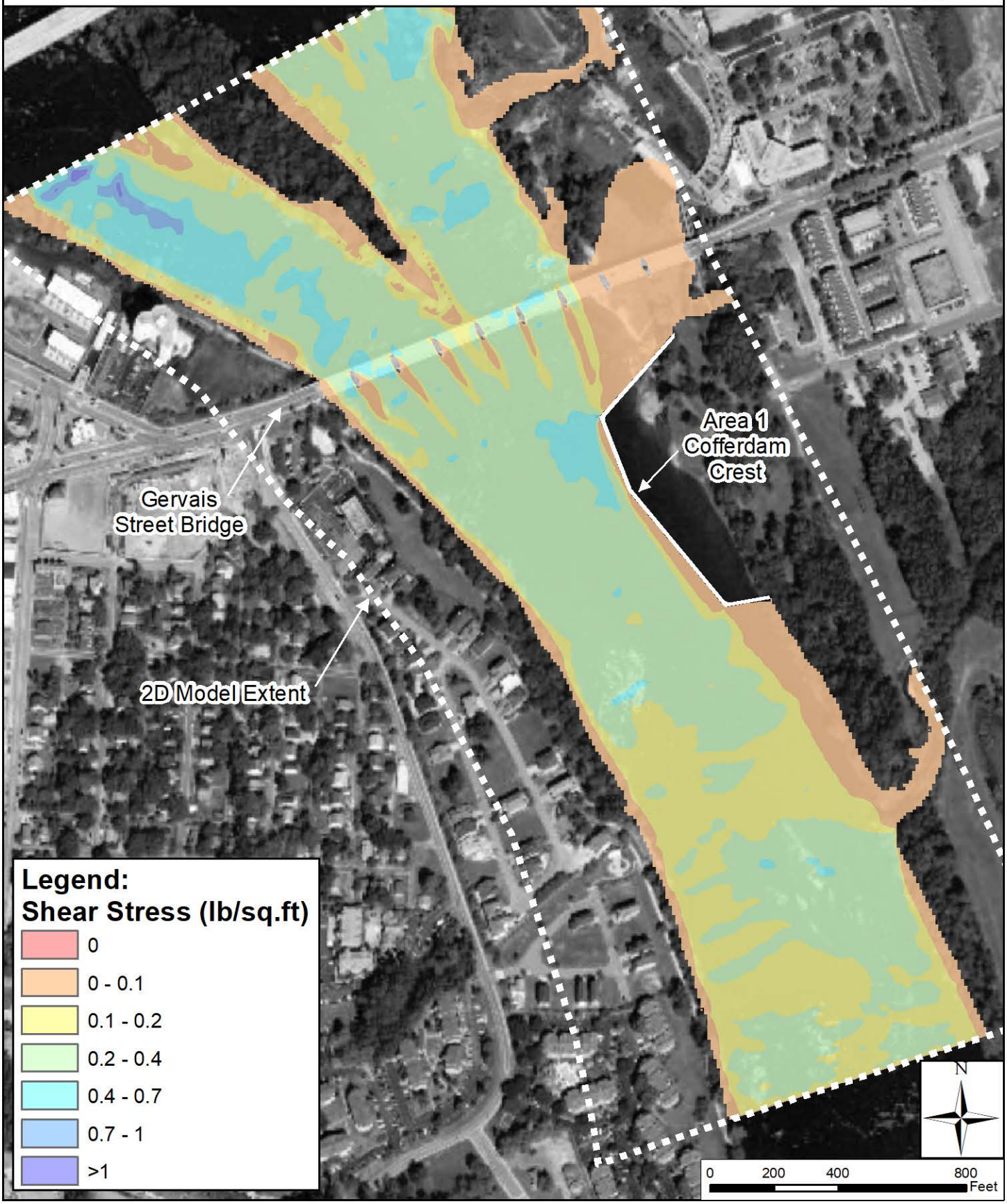
Congaree River Remediation Project
West Bank Erosion Potential Evaluation
Figure A10: Crest Flow (26,000 cfs)
Proposed Area-2 Scenario: Change in Flow Velocity



Congaree River Remediation Project
West Bank Erosion Potential Evaluation
Figure A11: Crest Flow (26,000 cfs)
Existing Scenario: Shear Stress



Congaree River Remediation Project
West Bank Erosion Potential Evaluation
Figure A12: Crest Flow (26,000 cfs)
Proposed Area-1 Scenario: Shear Stress



Congaree River Remediation Project
West Bank Erosion Potential Evaluation
Figure A13: Crest Flow (26,000 cfs)
Proposed Area-2 Scenario: Shear Stress