VIA ELECTRONIC MAIL

March 10, 2020

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

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

Dear Mr. Zeli:

This letter presents a summary of WSP USA's (WSP) river bottom 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.

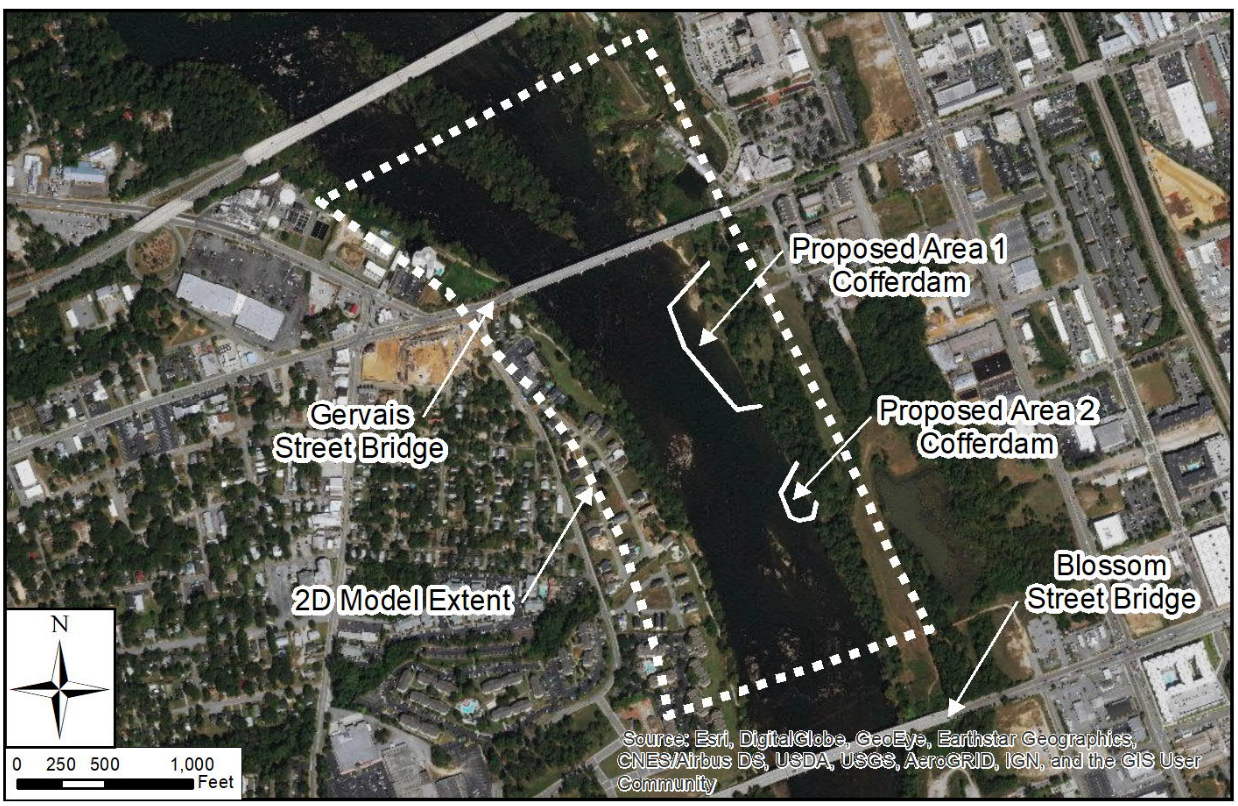


Figure 1: Model Extent

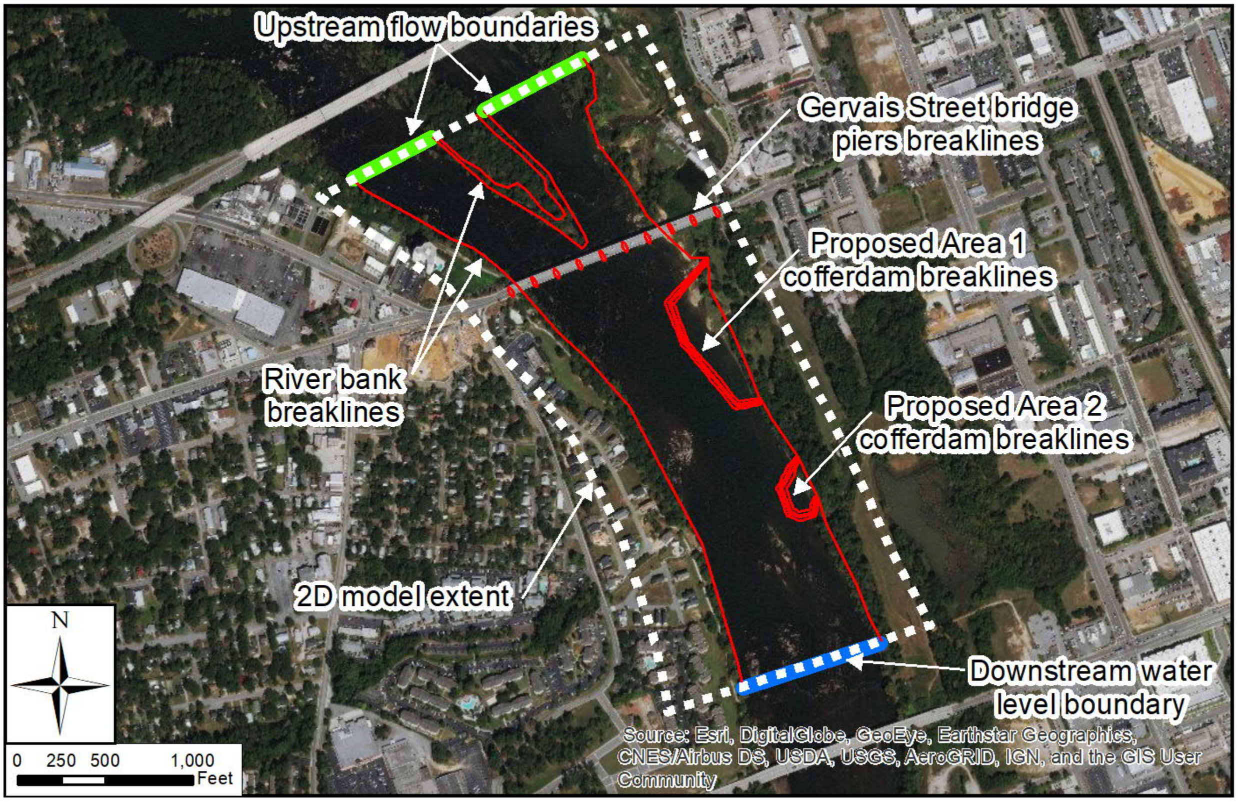


Figure 2: Model Details

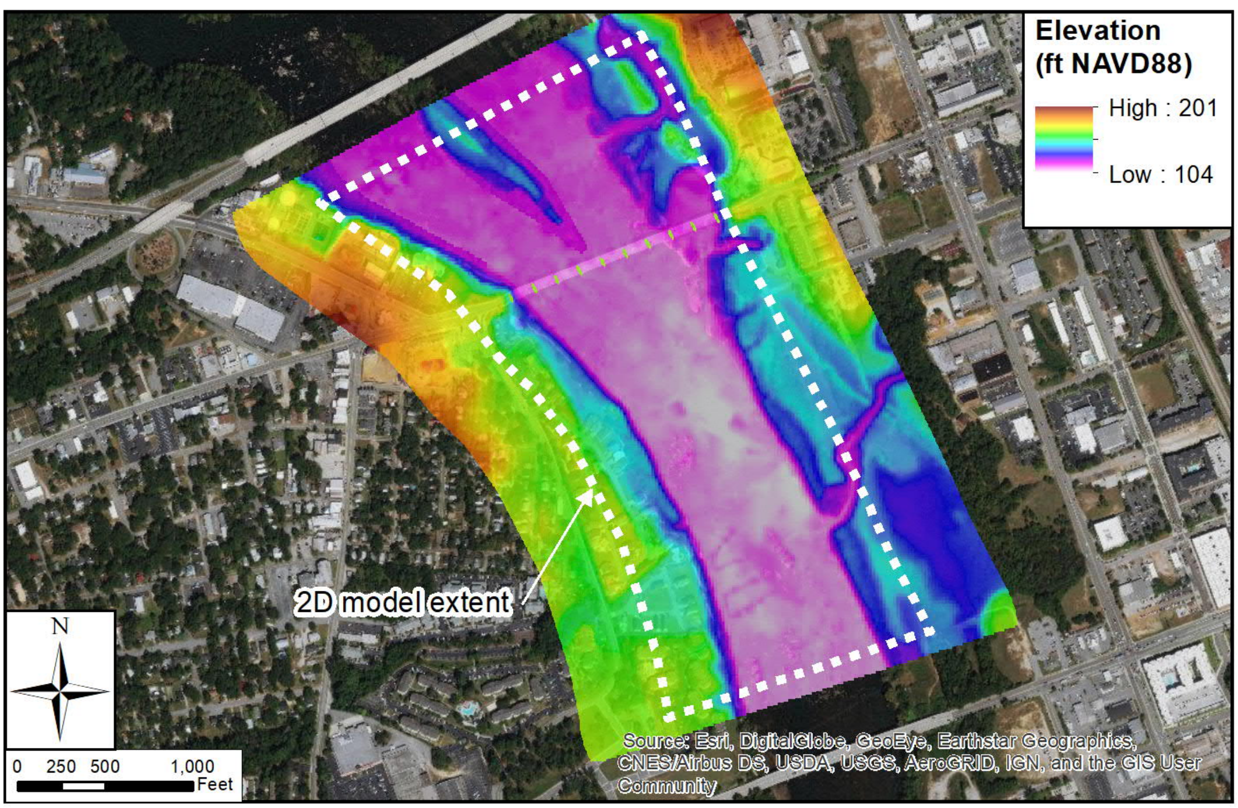


Figure 3: Existing Digital Elevation Model

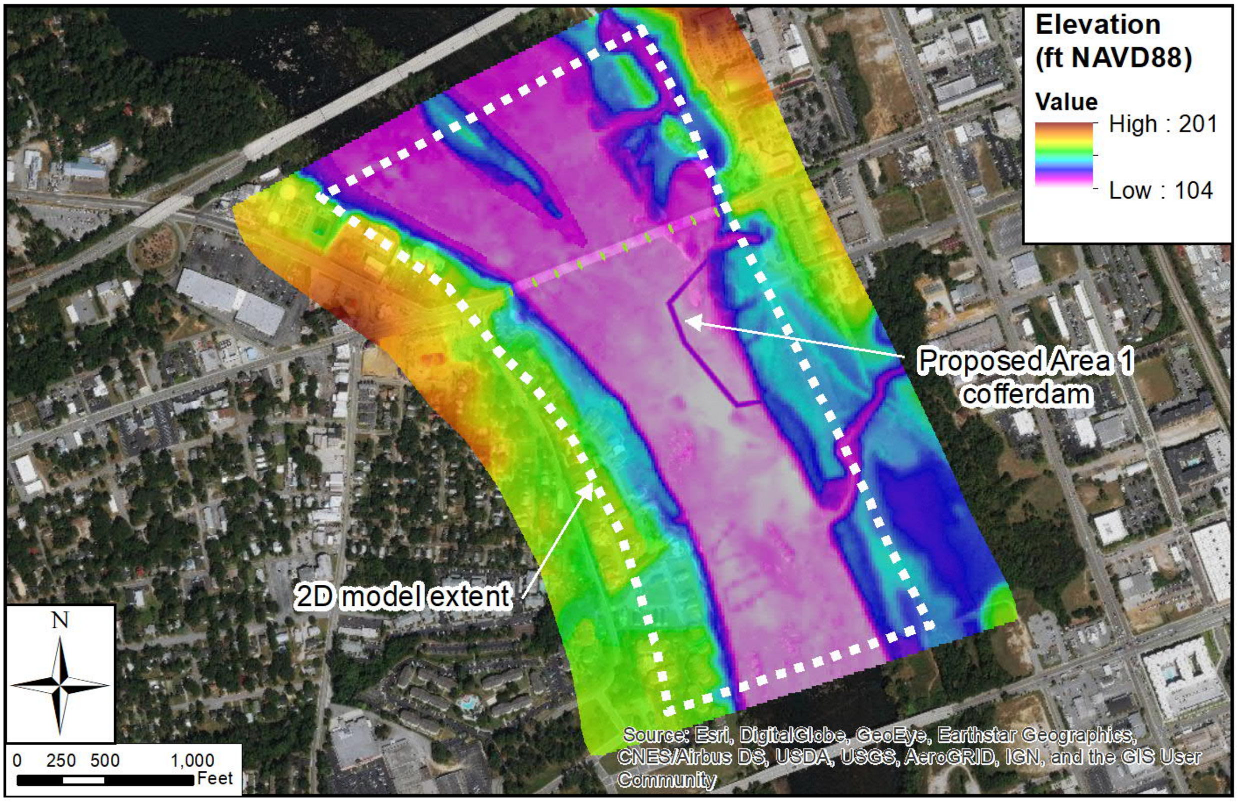


Figure 4: Proposed Area 1 Cofferdam Digital Elevation Model

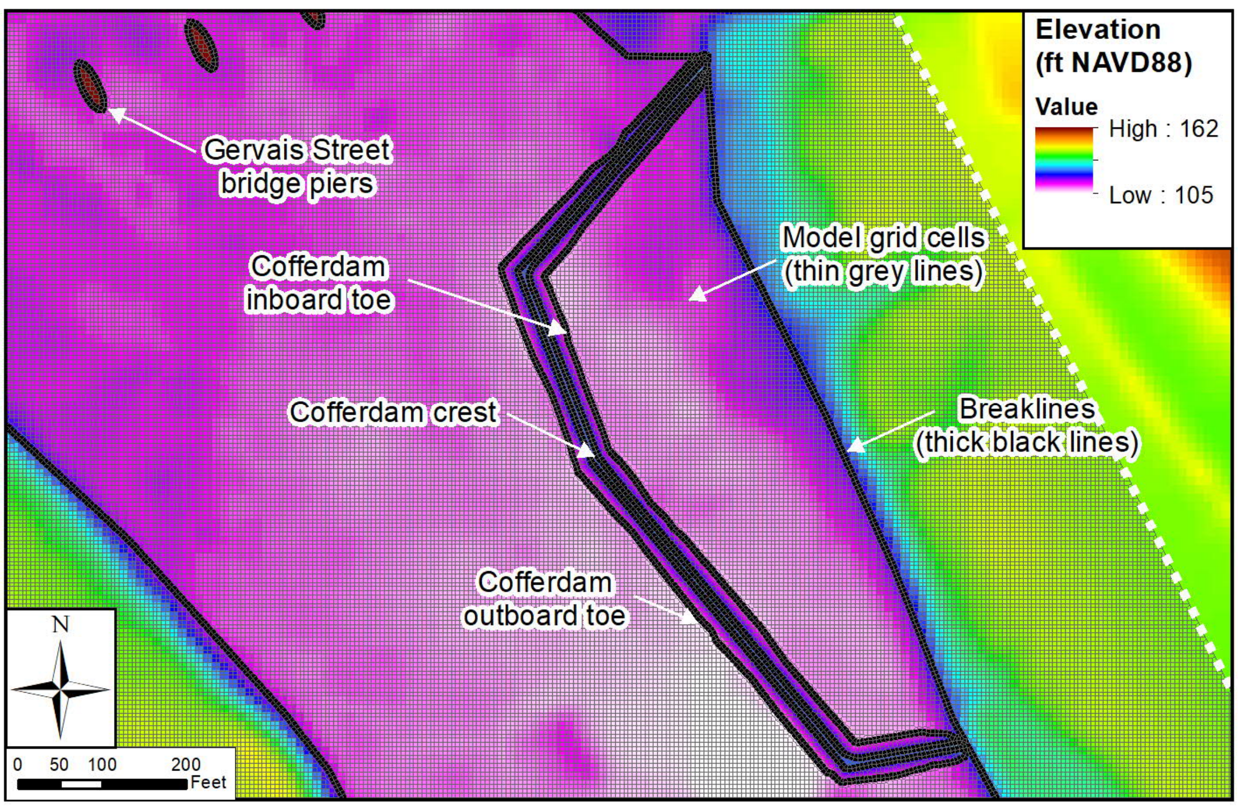


Figure 5: Proposed Area 1 Cofferdam Mesh Details

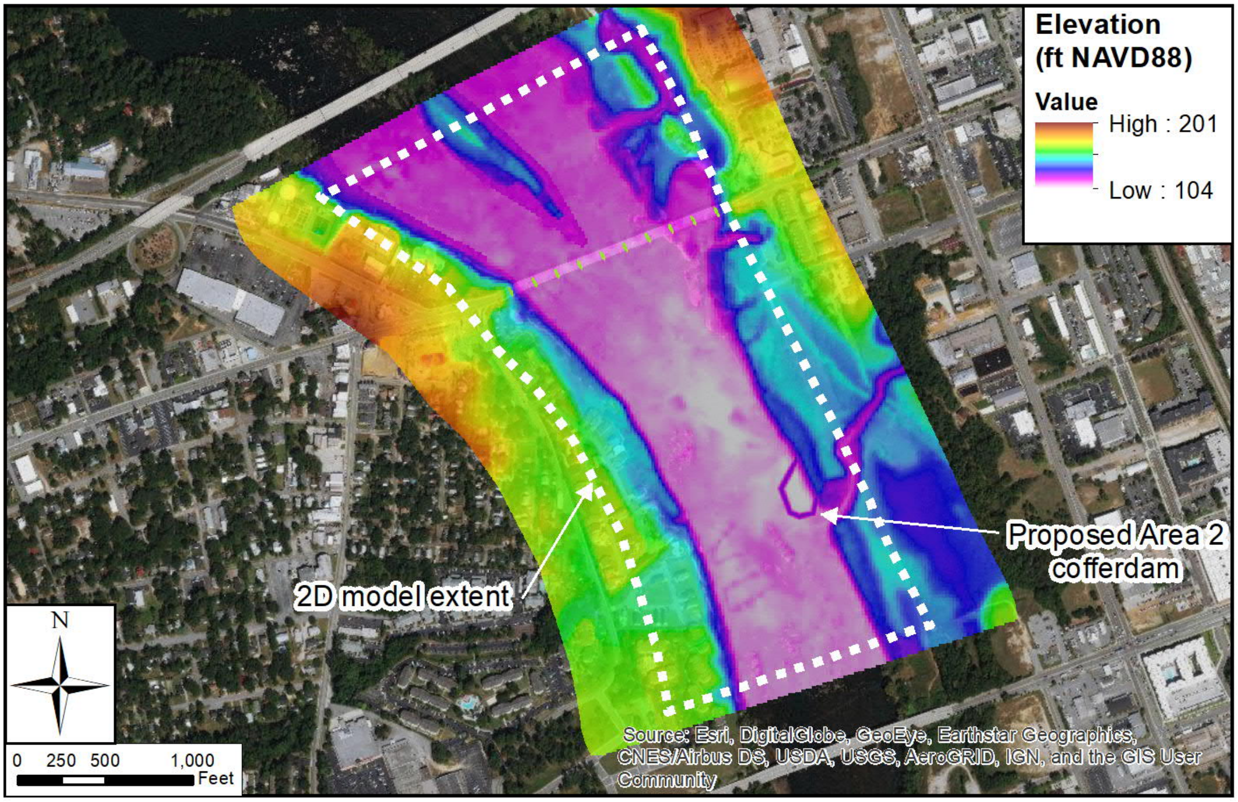


Figure 6: Proposed Area 2 Cofferdam Digital Elevation Model

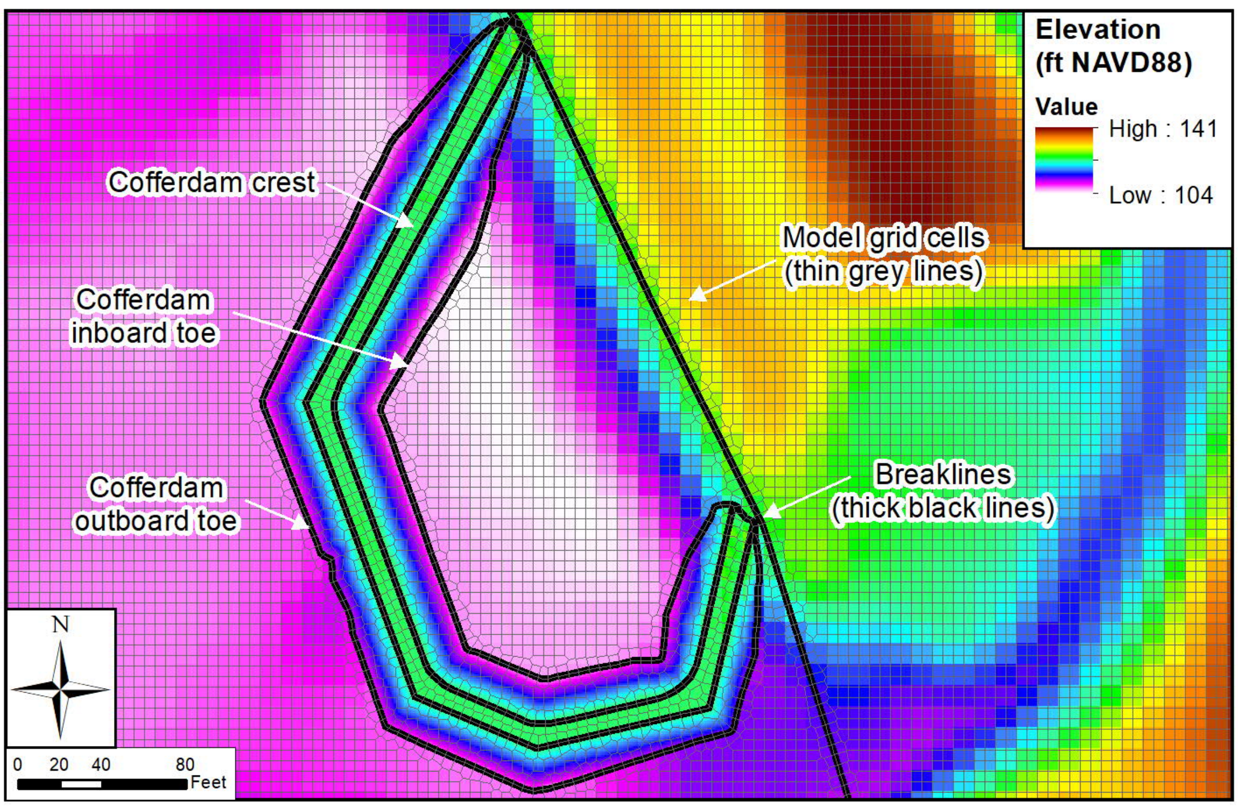


Figure 7: Proposed Area 2 Cofferdam Mesh Details

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.

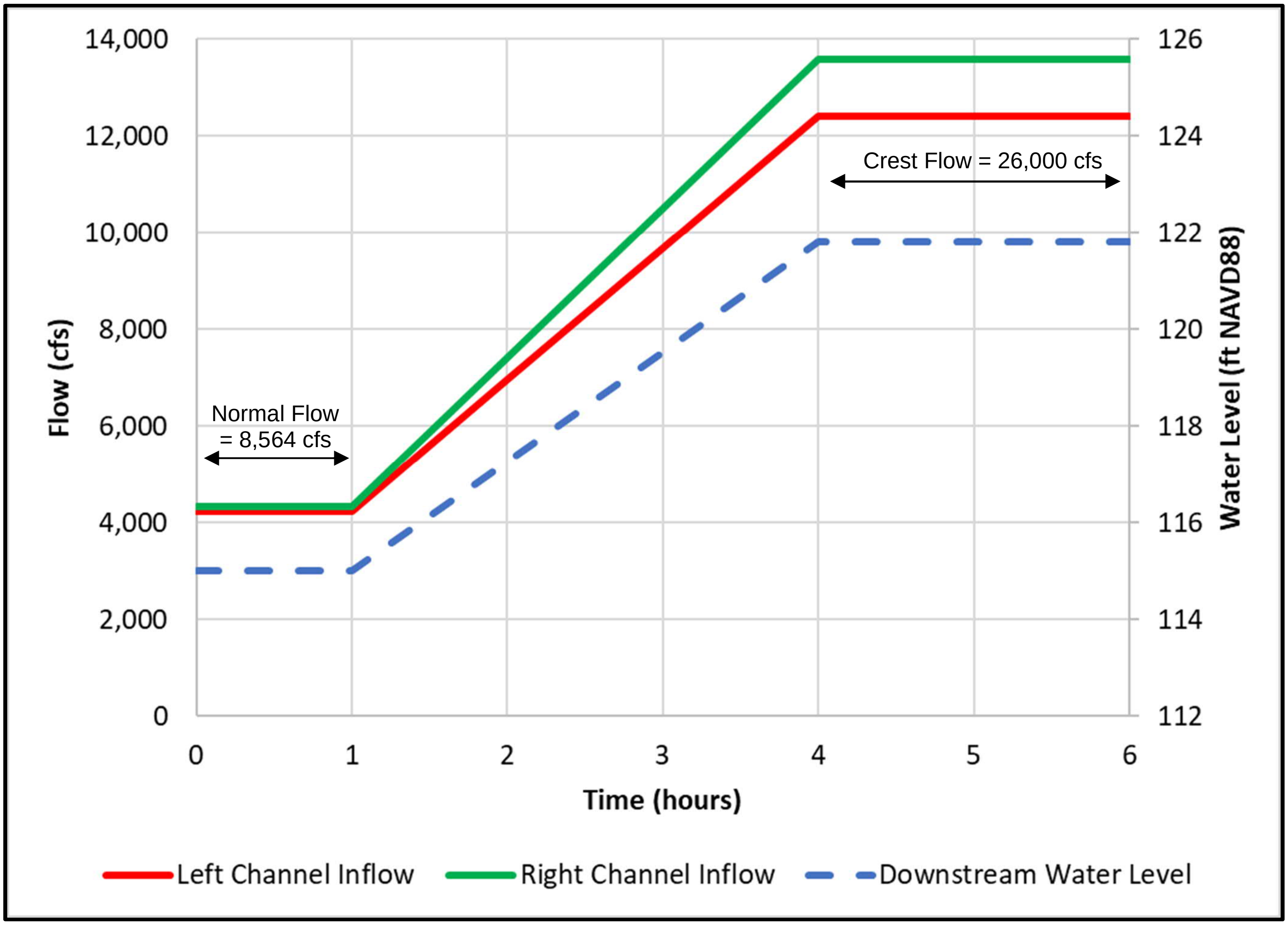


Figure 8: Upstream and Downstream Boundary Conditions

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: Normal Flow (8,564 cfs) Existing Scenario – Shear Stress
- Figure A12: Crest Flow (26,000 cfs) Existing Scenario – Shear Stress
- Figure A13: Normal Flow (8,564 cfs) Proposed Area-1 Scenario – Shear Stress
- Figure A14: Crest Flow (26,000 cfs) Proposed Area-1 Scenario – Shear Stress
- Figure A15: Normal Flow (8,564 cfs) Proposed Area-1 Scenario – Change in Shear Stress
- Figure A16: Crest Flow (26,000 cfs) Proposed Area-1 Scenario – Change in Shear Stress
- Figure A17: Normal Flow (8,564 cfs) Proposed Area-2 Scenario – Shear Stress
- Figure A18: Crest Flow (26,000 cfs) Proposed Area-2 Scenario – Shear Stress
- Figure A19: Normal Flow (8,564 cfs) Proposed Area-2 Scenario – Change in Shear Stress
- Figure A20: Crest Flow (26,000 cfs) Proposed Area-2 Scenario – Change in Shear Stress

The following sections discuss the **velocity and shear stress results for the Congaree River in the vicinity of the project area** for the Existing, Proposed Area-1, and Proposed Area-2 scenarios. A summary of the velocity and shear stress results is provided in Table 1 and 2, respectively.

Table 1: Velocity Results Summary

Velocity (ft/s)	Reference Values (USBR, 2015)	Existing Scenario		Proposed Area-1 Scenario		Proposed Area-2 Scenario	
		Normal Flow (8,564 cfs)	Crest Flow (26,000 cfs)	Normal Flow (8,564 cfs)	Crest Flow (26,000 cfs)	Normal Flow (8,564 cfs)	Crest Flow (26,000 cfs)
Upstream and immediately downstream of Gervais St Bridge	1.5 – 6	3 – 5	4 – 6	3 – 5	4 – 6	3 – 5	4 – 6
Next 1,200 feet		1 – 3	2 – 4, some localized 5	2 – 4, some localized 4.5	4 – 6, some localized 6.5	1 – 3	2 – 4, some localized 5
Final 800 feet		2 – 4, some localized 5	2 – 4, some localized 5	2 – 4, some localized 5	2 – 4, some localized 5	2 – 4, some localized 6	3.5 – 5.5, some localized 6

Table 2: Shear Stress Results Summary

Shear Stress (lb/ft^2)	Reference Values (USBR, 2015)	Existing Scenario		Proposed Area-1 Scenario		Proposed Area-2 Scenario	
		Normal Flow (8,564 cfs)	Crest Flow (26,000 cfs)	Normal Flow (8,564 cfs)	Crest Flow (26,000 cfs)	Normal Flow (8,564 cfs)	Crest Flow (26,000 cfs)
Upstream and immediately downstream of Gervais St Bridge	0.02 – 0.67	0.2 – 0.5, some localized 0.7	0.3 – 0.5, some localized >0.7	0.2 – 0.5, some localized 0.7	0.3 – 0.5, some localized >0.7	0.2 – 0.5, some localized 0.7	0.3 – 0.5, some localized >0.7
Next 1,200 feet		0.05 – 0.2	0.1 – 0.2	0.1 – 0.4, some localized 0.6	0.2 – 0.5, some localized 0.7	0.05 – 0.2	0.1 – 0.2
Final 800 feet		0.1 – 0.5, some localized 0.7	0.1 – 0.4, some localized 0.5	0.1 – 0.5, some localized 0.7	0.1 – 0.4, some localized 0.5	0.1 – 0.4, some localized >0.9	0.2 – 0.5, some localized 0.7

RIVER BOTTOM EROSION POTENTIAL EVALUATION

For existing conditions, the river velocities within the Congaree River during normal (8,564 cfs) and crest (26,000 cfs) flow conditions vary between 1 and 6 ft/s. Shear stresses range between 0.05 and 0.5 lb/ft^2, with some localized areas of increased shear of approximately 0.7 lb/ft^2. Note that the annual probability of exceedance for crest flow conditions is approximately 50%, i.e., a 1 in 2-year flood event.

The maximum increase in flow velocity across the river after cofferdam construction is up to 1.5 ft/s during normal and crest flow conditions. However, the velocities in this area remain within the 4 to 6 ft/s range. The maximum flow velocity increase within the immediate vicinity of the cofferdams is up to 3 ft/s but the velocities remain within the 5.5 to 6.5 ft/s range.

The change in shear stress after cofferdam construction follows a similar pattern, with increases between 0.1 and 0.4 lb/ft^2 adjacent to the structures, and the highest increases in close proximity to the structure, with peak values typically up to 0.5 lb/ft^2. Further out into the main river channel, the increase in shear stress typically ranges between 0 and 0.2 lb/ft^2. Some localized areas of higher shear values are located where rock outcrops are visible in the aerial imagery. The velocities suddenly increase at these locations to account for a reduced flow depth.

The U.S Department of the Interior, Bureau of Reclamation's (USBR's) Bank Stabilization Guidelines, Report No. SRH-2015-25 provides shear and velocity resistance values for various liner materials in Table 4-2. The table indicates that 'Soils' can withstand a shear stresses ranging between 0.02 to 0.67 lb/ft^2 and velocities ranging between 1.5 and 6 ft/s before eroding, depending upon the specific soil type. The sands and clays encountered in the soil samples and borings advanced along the river bottom at the project location can withstand velocities and shear stresses towards the lower end of the published range. Therefore, during existing flow conditions, some erosion of the river bottom should be anticipated. This is consistent with visual observations of the river that show cloudy water from suspended sediment during higher than normal flow conditions.

Figure B1 provided in Attachment B shows the anticipated depth of sediment in the river at the location of the proposed cofferdams based on a 2018 bathymetric survey and top of bedrock estimates from soil borings advanced between 2010 to 2012. The figure shows that the sediment depth around the perimeter of the cofferdam structures varies between 0 and 3 feet before top of rock is encountered.

The results of our hydraulic analyses indicate that the construction of the proposed cofferdams during normal and crest flow conditions will result in some localized increases in flow velocity and shear stress in the channel. However, the maximum reported values are already experienced in close proximity to the project site under existing conditions; therefore, the proposed cofferdams are unlikely to result in any significant changes to the river morphology in the area which is currently constantly changing and evolving over time in response to current flows and storm events. Therefore, in our professional opinion, erosion protection measures are not necessary for the river bottom or toe of the cofferdam during the construction period.

The proposed cofferdam design includes erosion protection provided by Articulated Concrete Block (ACB) Mats or Rock Mattresses along the outboard slope and extend onto the river bottom. Rock mattresses and ACB's can withstand maximum flow velocities of 19 and 25 ft/s respectively, which is significantly greater than the maximum values between 5.5 to 6.5 ft/s located in the vicinity of the cofferdams. The ACBs or rock mattresses will provide an additional factor of safety against erosion at the toe of the cofferdam and will also account for any complex localized three-dimensional flow patterns that are not represented using a 2D depth-averaged model.

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 412-535-9818 or thomas.edwards@wsp.com.

Kind regards,

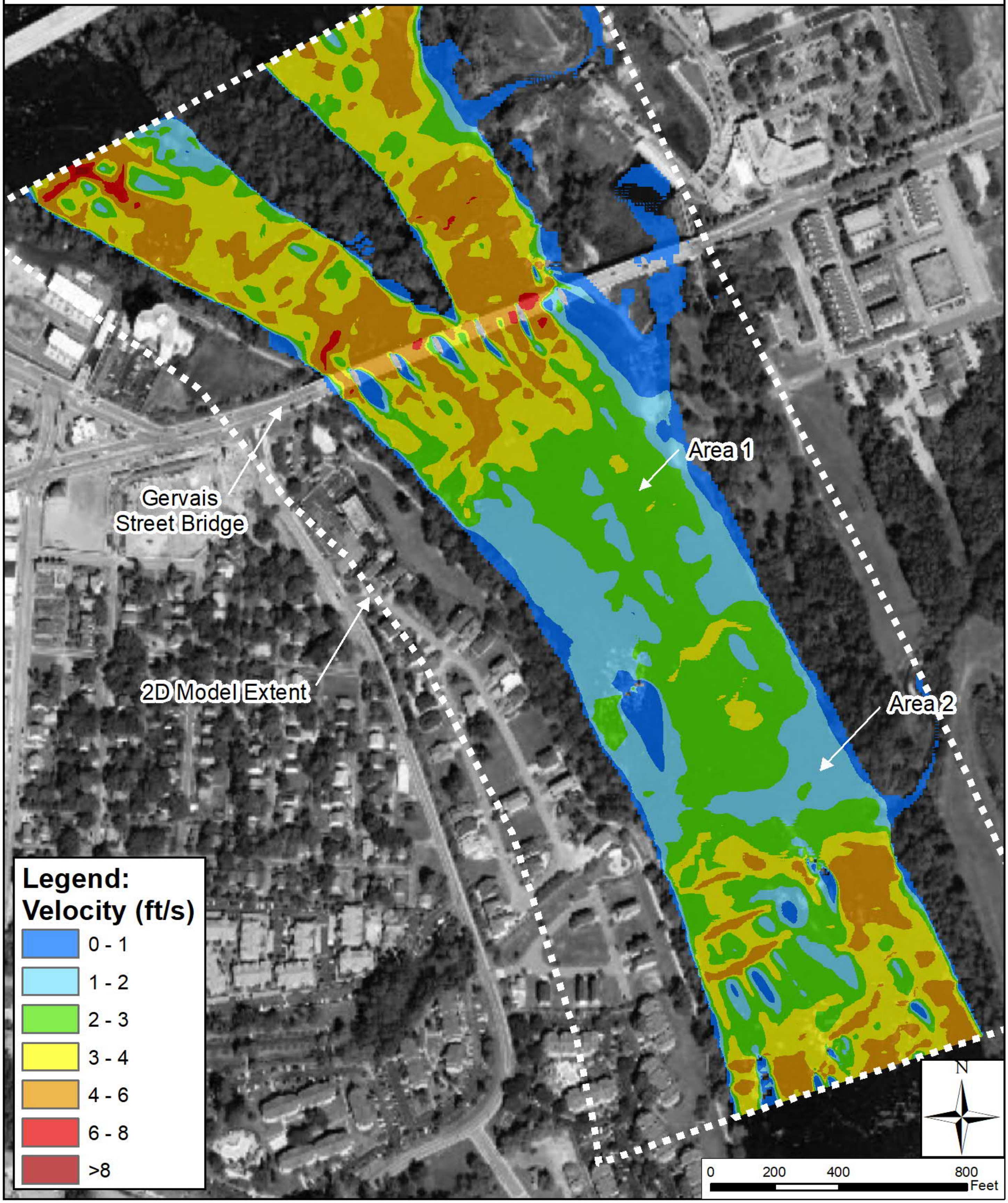
John P. Osterle, P.E.
Project Manager

Tom Edwards
Water Resources Engineer

TE: JPO

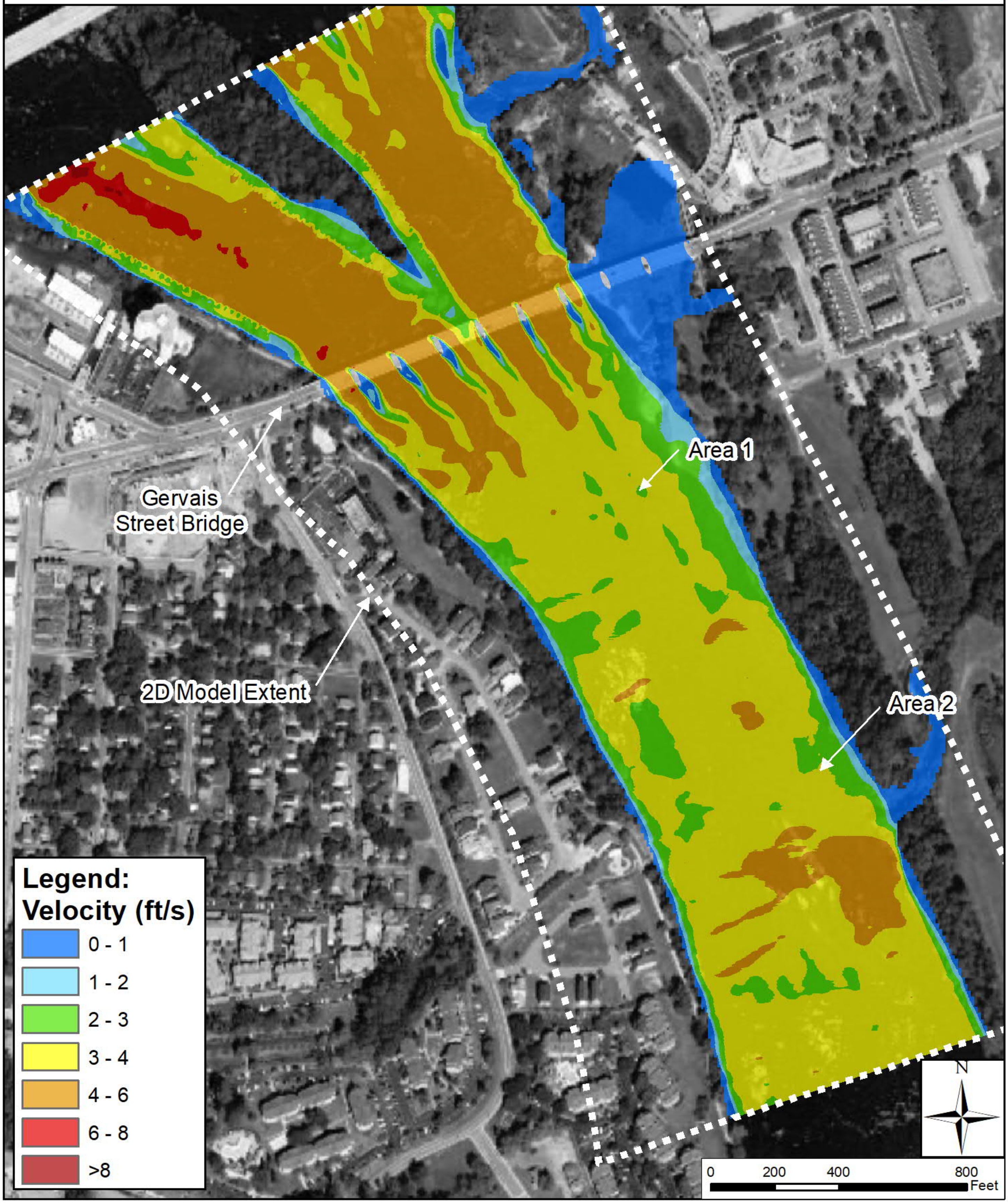
ATTACHMENT A: FIGURES

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

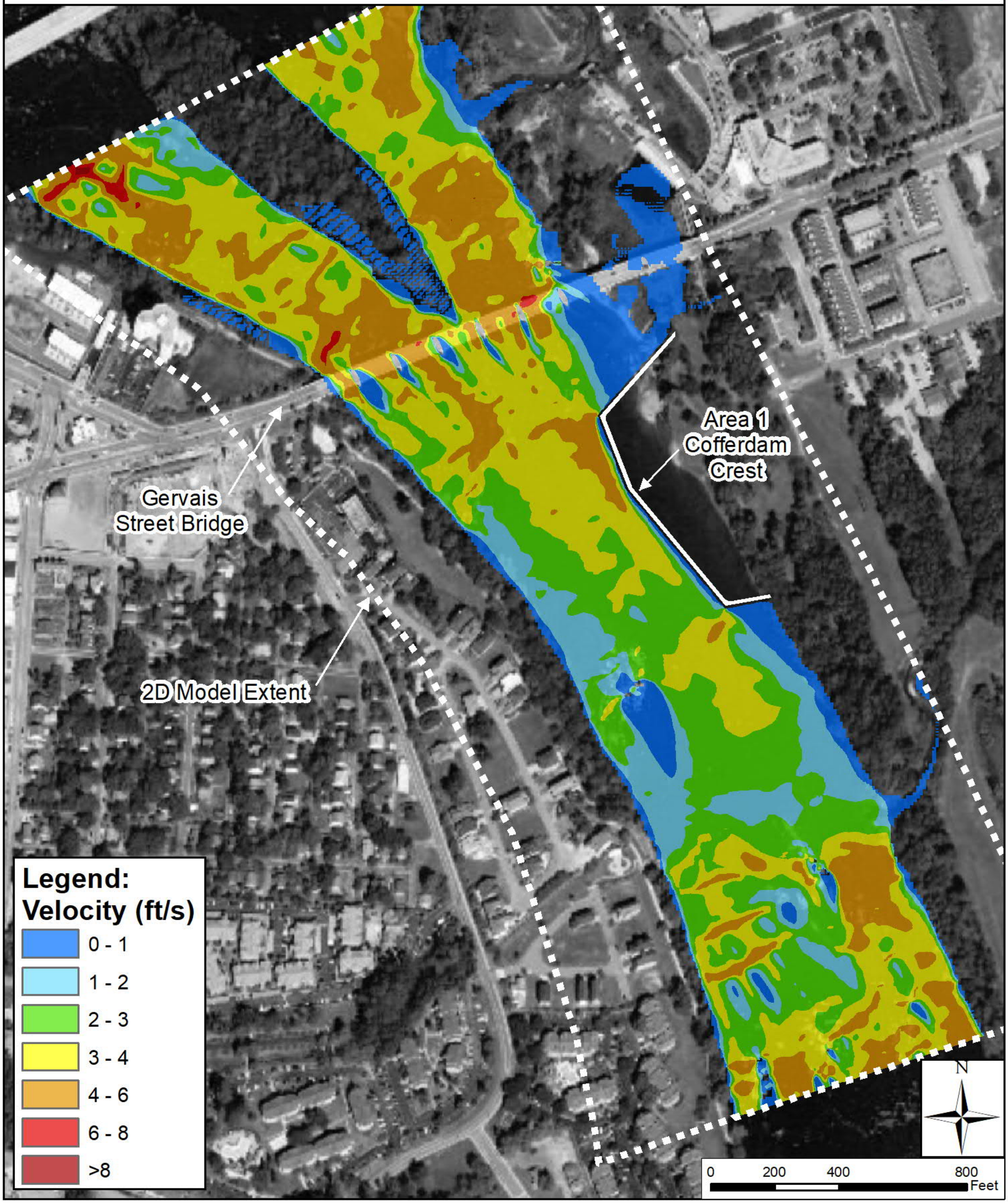


Congaree River Remediation Project
River Bottom Erosion Potential Evaluation

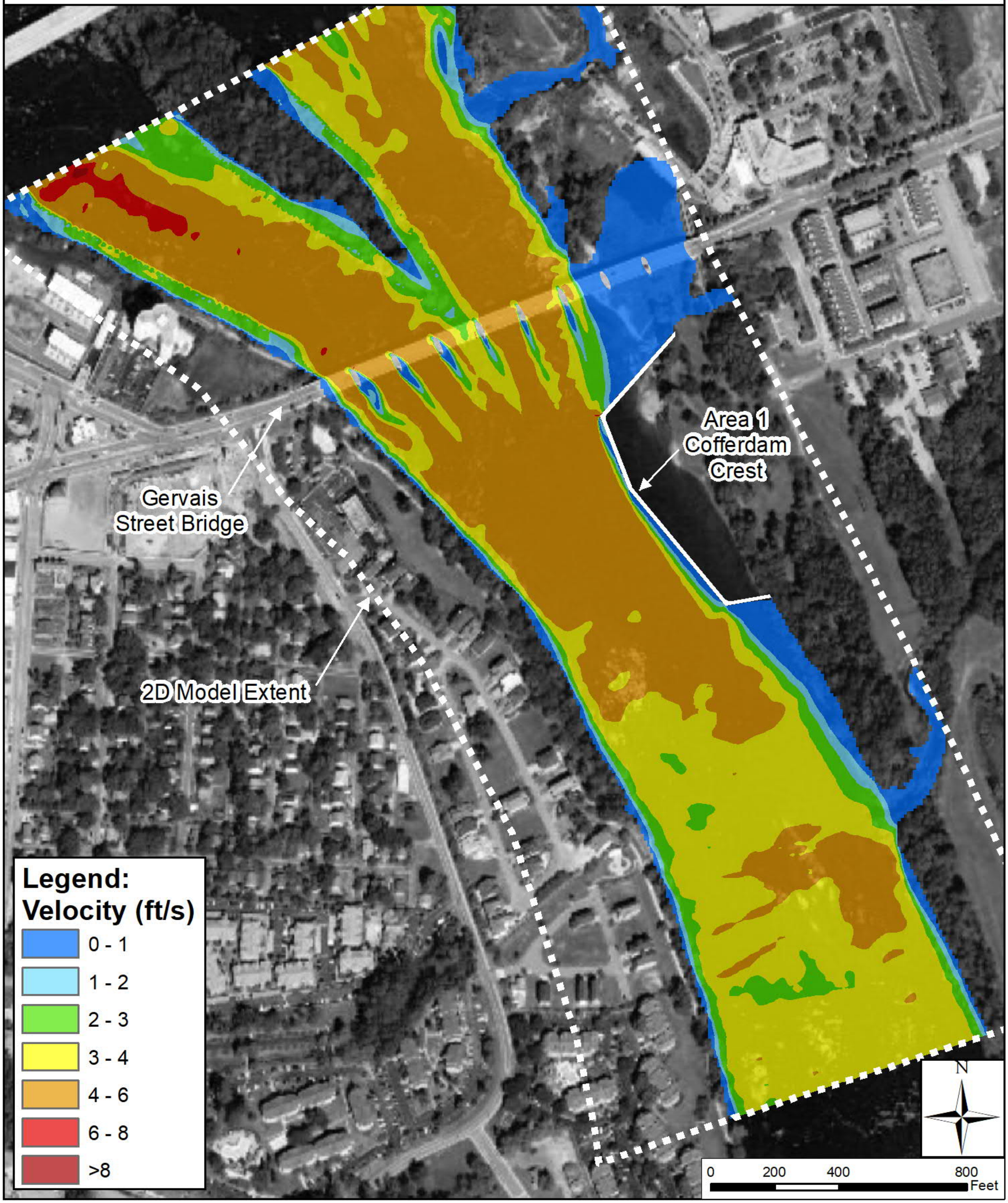
Figure A2: Crest Flow (26,000 cfs)
Existing Scenario: Flow Velocity



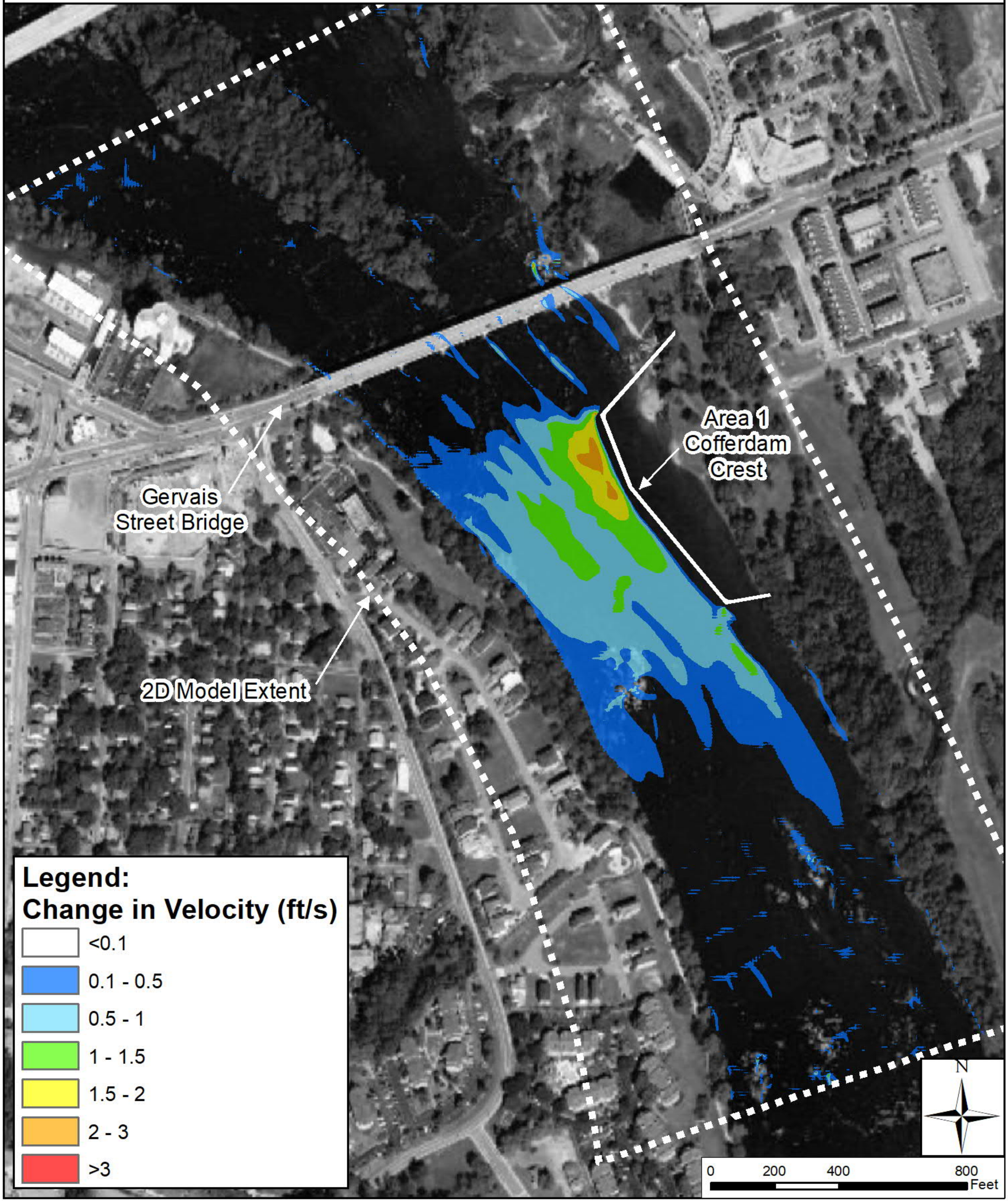
Congaree River Remediation Project
River Bottom Erosion Potential Evaluation
Figure A3: Normal Flow (8,564 cfs)
Proposed Area-1 Scenario: Flow Velocity



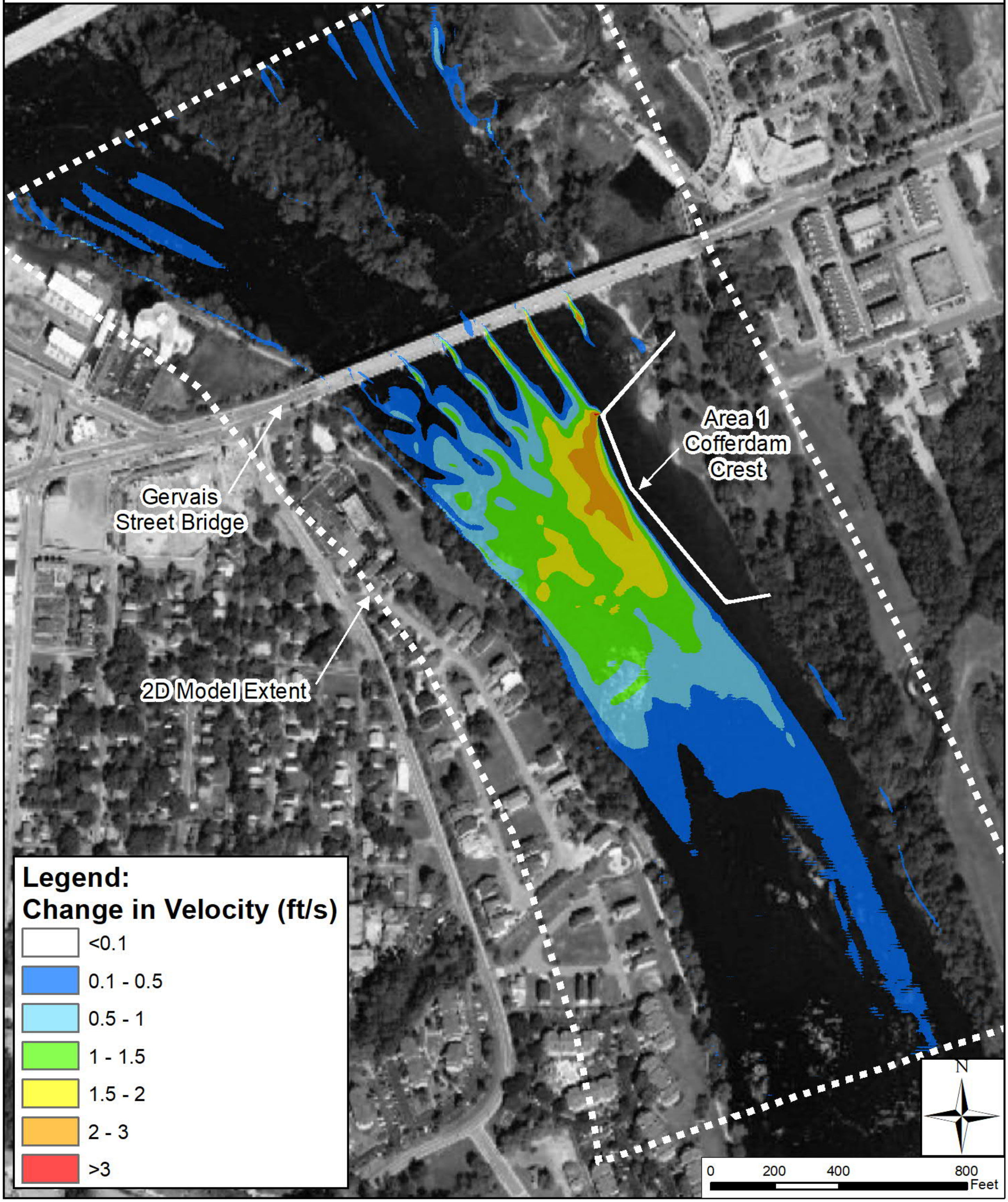
Congaree River Remediation Project
River Bottom Erosion Potential Evaluation
Figure A4: Crest Flow (26,000 cfs)
Proposed Area-1 Scenario: Flow Velocity



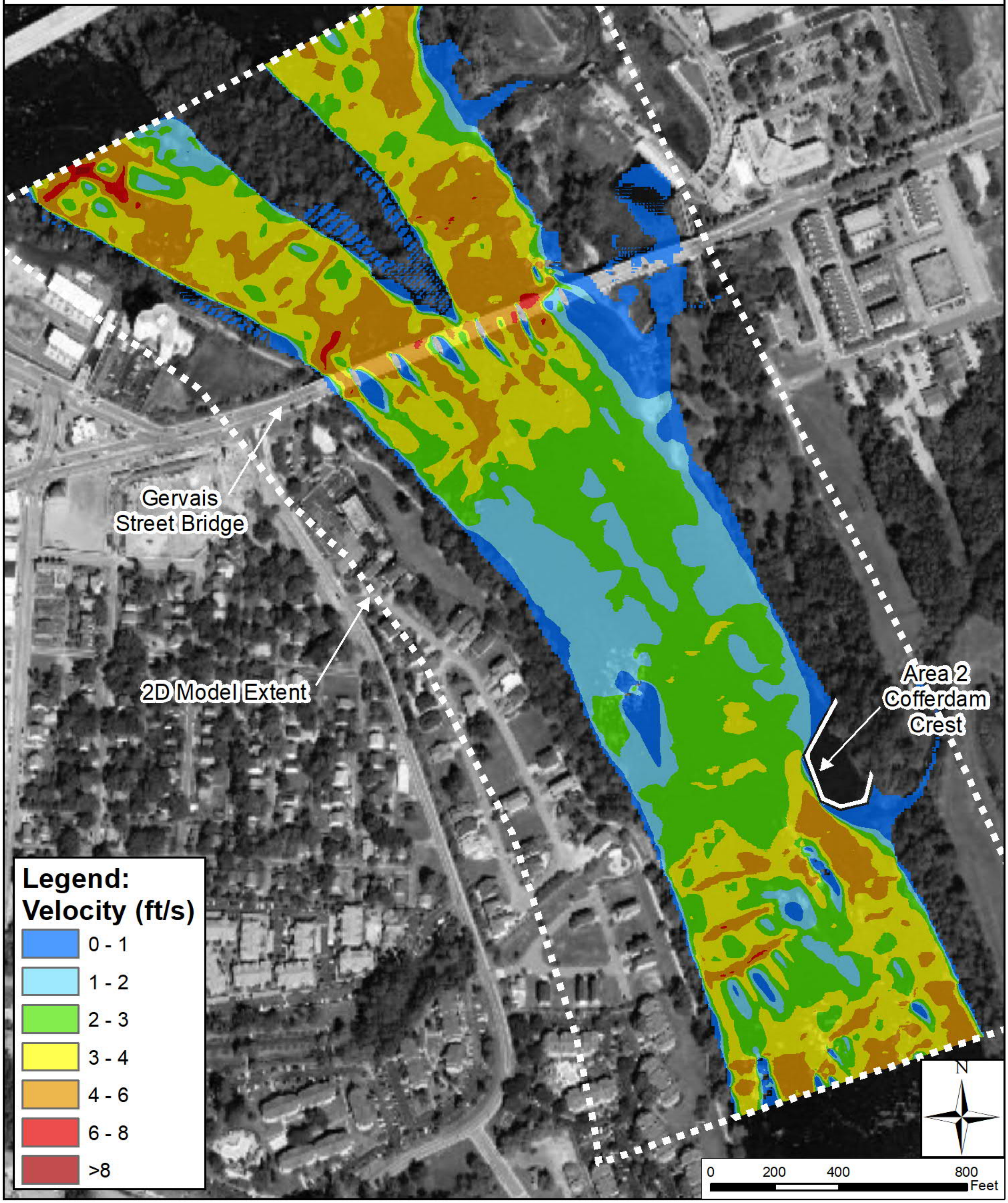
Congaree River Remediation Project
River Bottom Erosion Potential Evaluation
Figure A5: Normal Flow (8,564 cfs)
Proposed Area-1 Scenario: Change in Flow Velocity



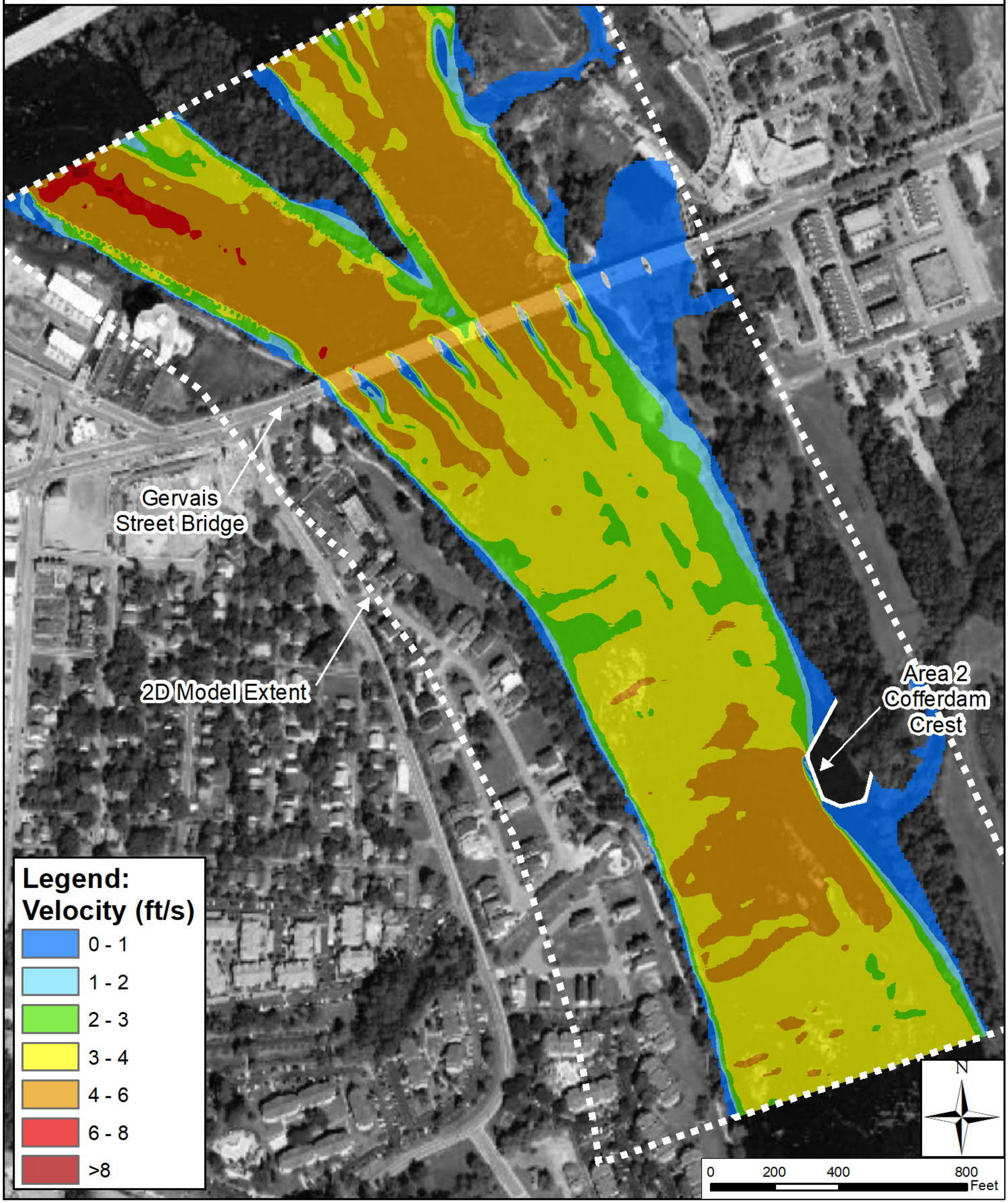
Congaree River Remediation Project
River Bottom Erosion Potential Evaluation
Figure A6: Crest Flow (26,000 cfs)
Proposed Area-1 Scenario: Change in Flow Velocity



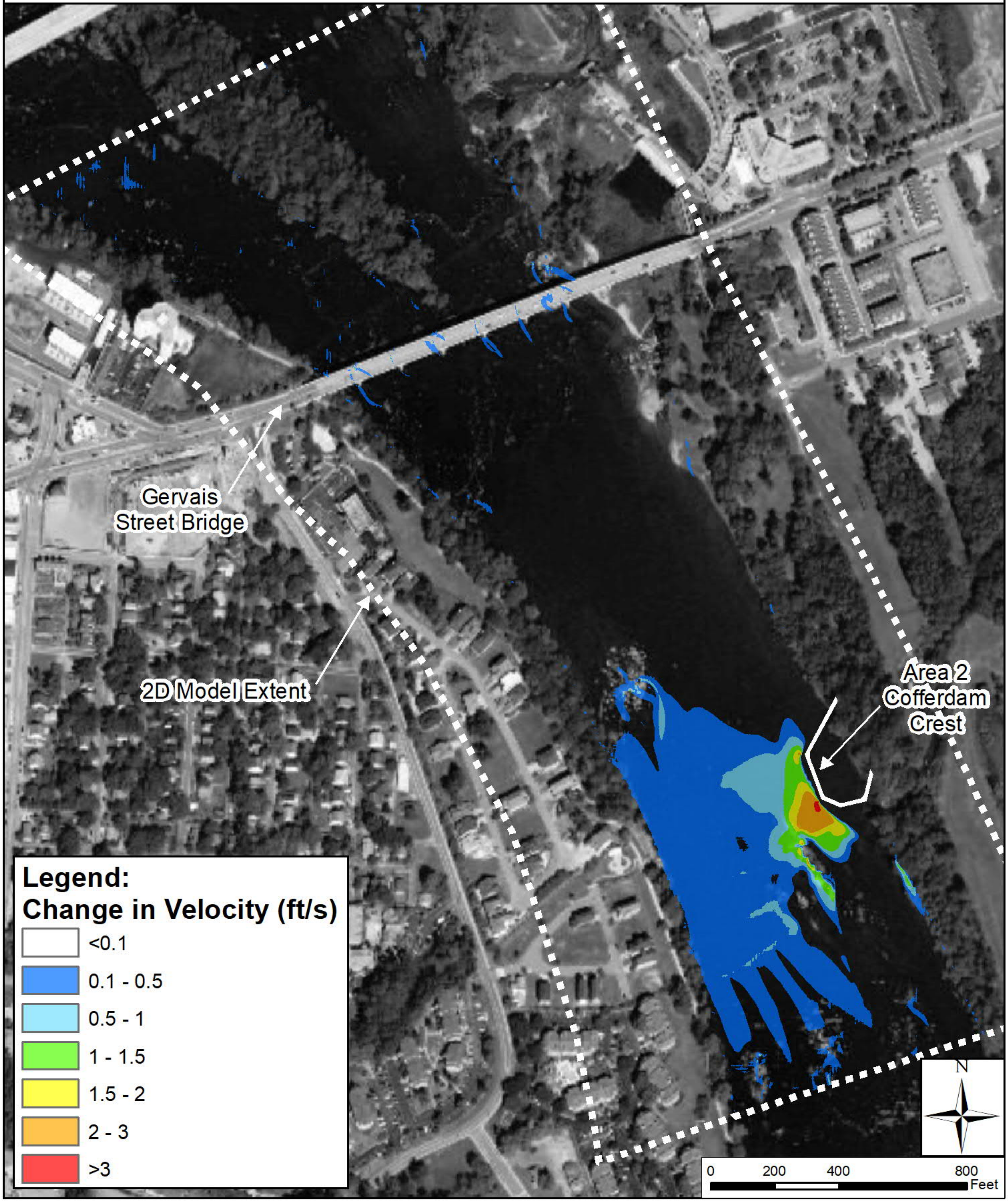
Congaree River Remediation Project
River Bottom Erosion Potential Evaluation
Figure A7: Normal Flow (8,564 cfs)
Proposed Area-2 Scenario: Flow Velocity



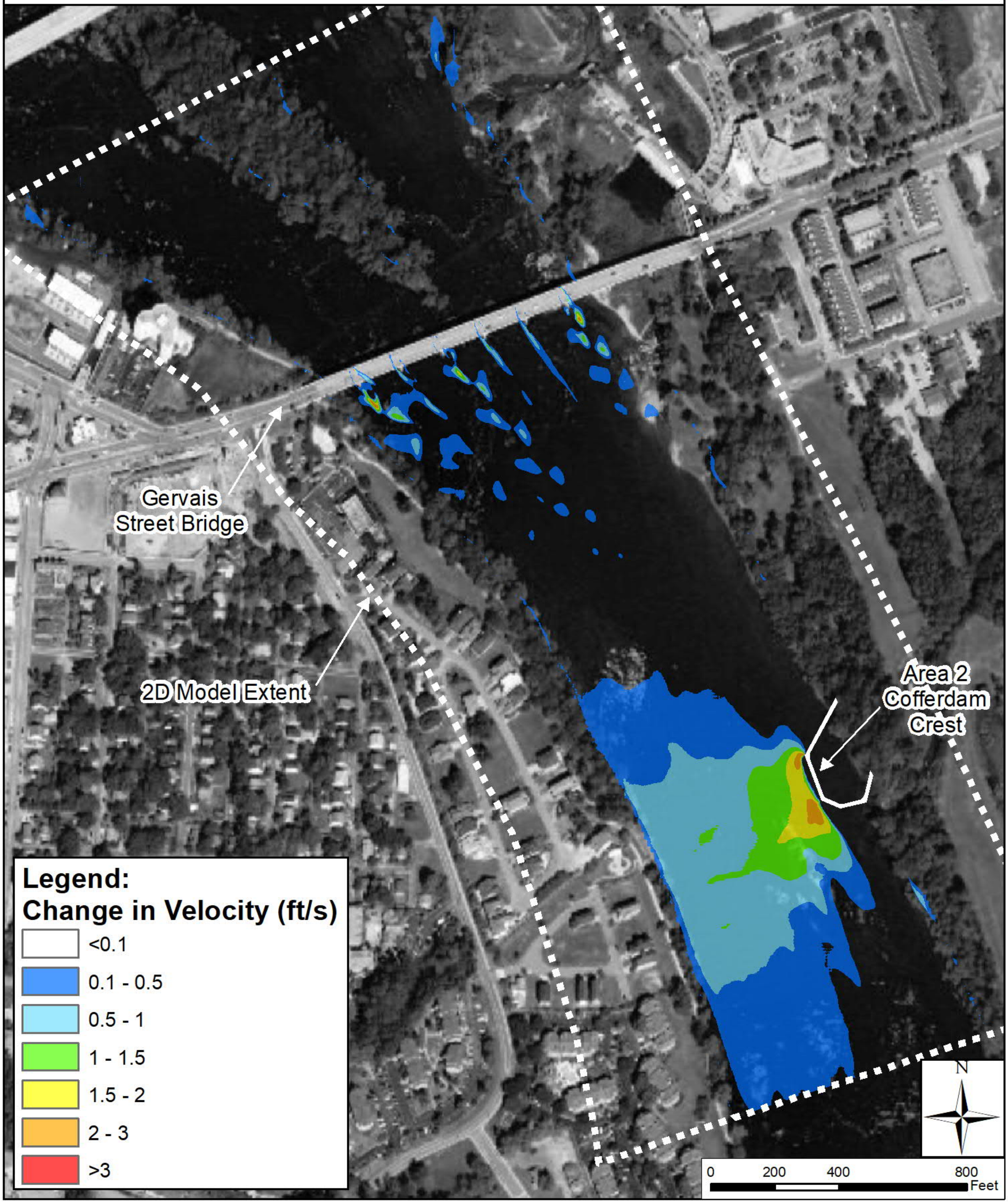
Congaree River Remediation Project
River Bottom Erosion Potential Evaluation
Figure A8: Crest Flow (26,000 cfs)
Proposed Area-2 Scenario: Flow Velocity



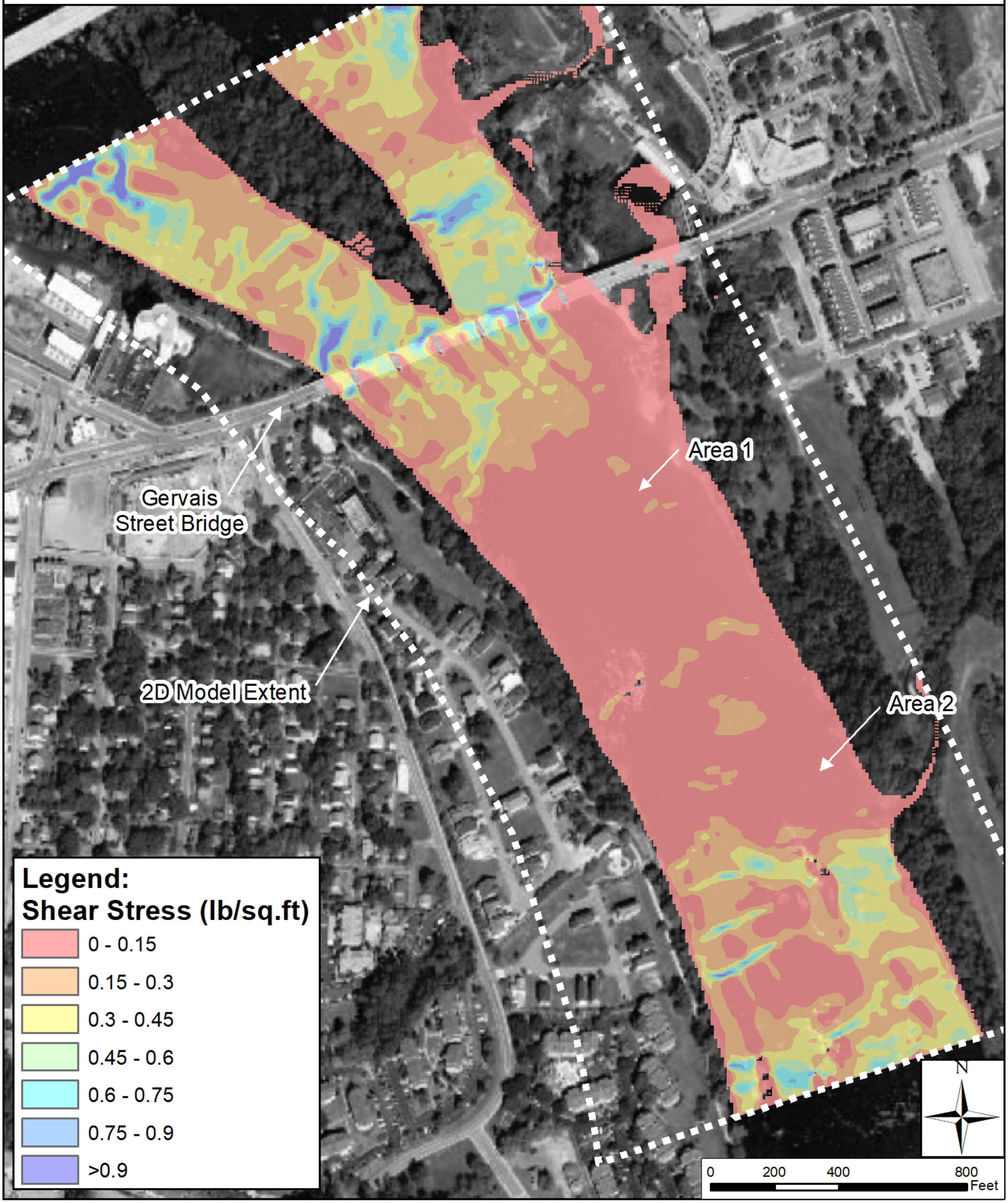
Congaree River Remediation Project
River Bottom Erosion Potential Evaluation
Figure A9: Normal Flow (8,564 cfs)
Proposed Area-2 Scenario: Change in Flow Velocity



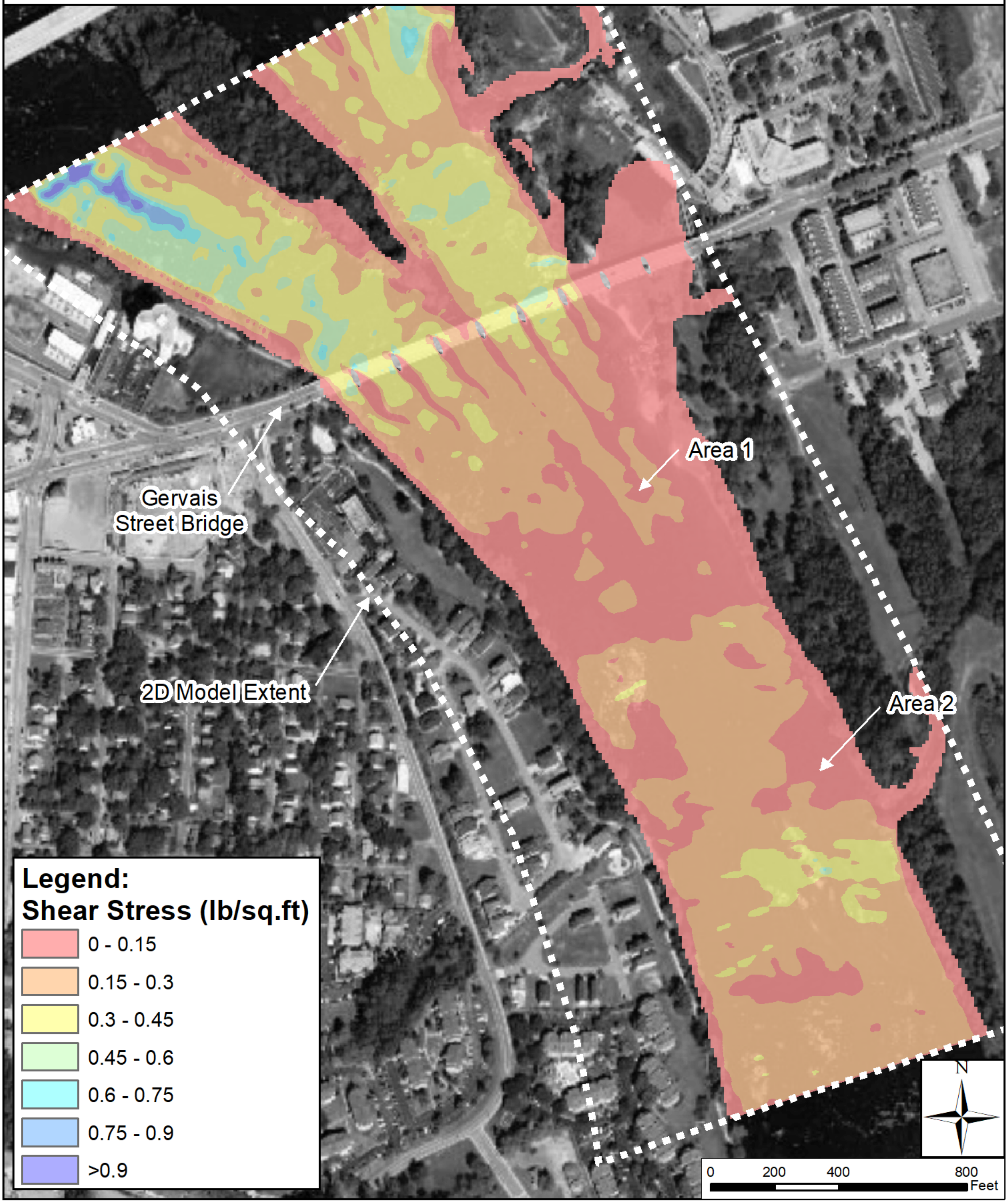
Congaree River Remediation Project
River Bottom Erosion Potential Evaluation
Figure A10: Crest Flow (26,000 cfs)
Proposed Area-2 Scenario: Change in Flow Velocity



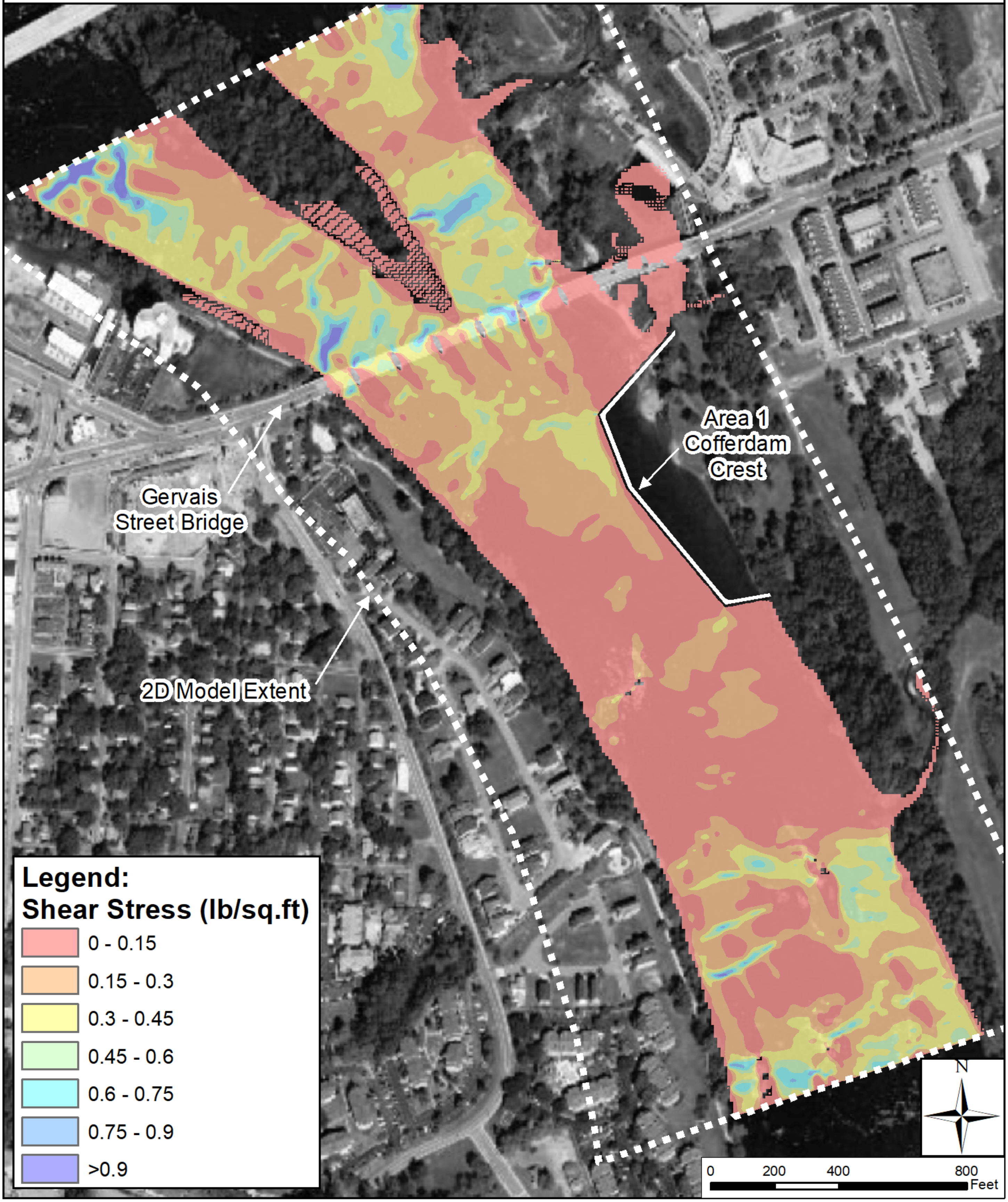
Congaree River Remediation Project
River Bottom Erosion Potential Evaluation
Figure A11: Normal Flow (8,564 cfs)
Existing Scenario: Shear Stress



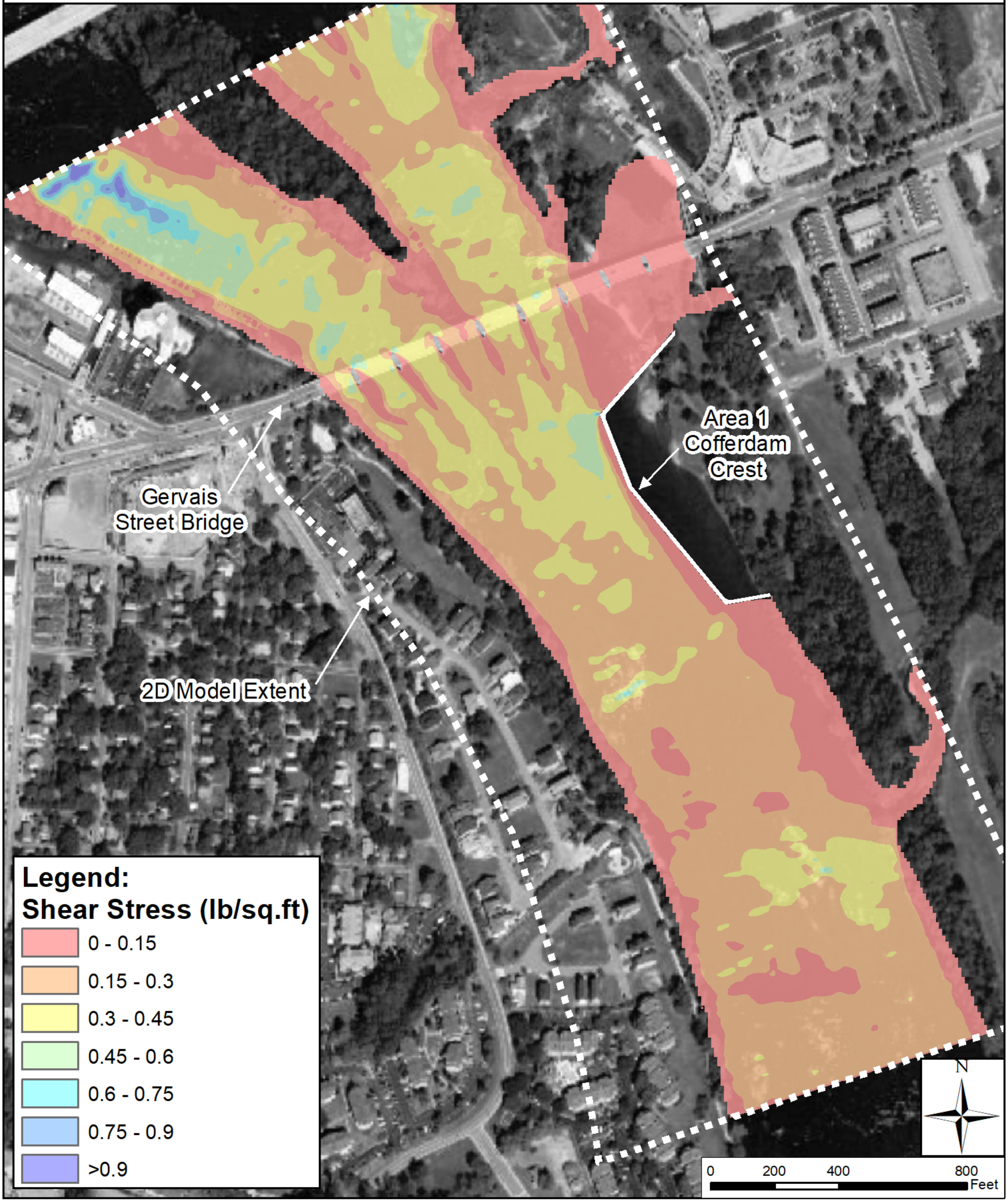
Congaree River Remediation Project
River Bottom Erosion Potential Evaluation
Figure A12: Crest Flow (26,000 cfs)
Existing Scenario: Shear Stress



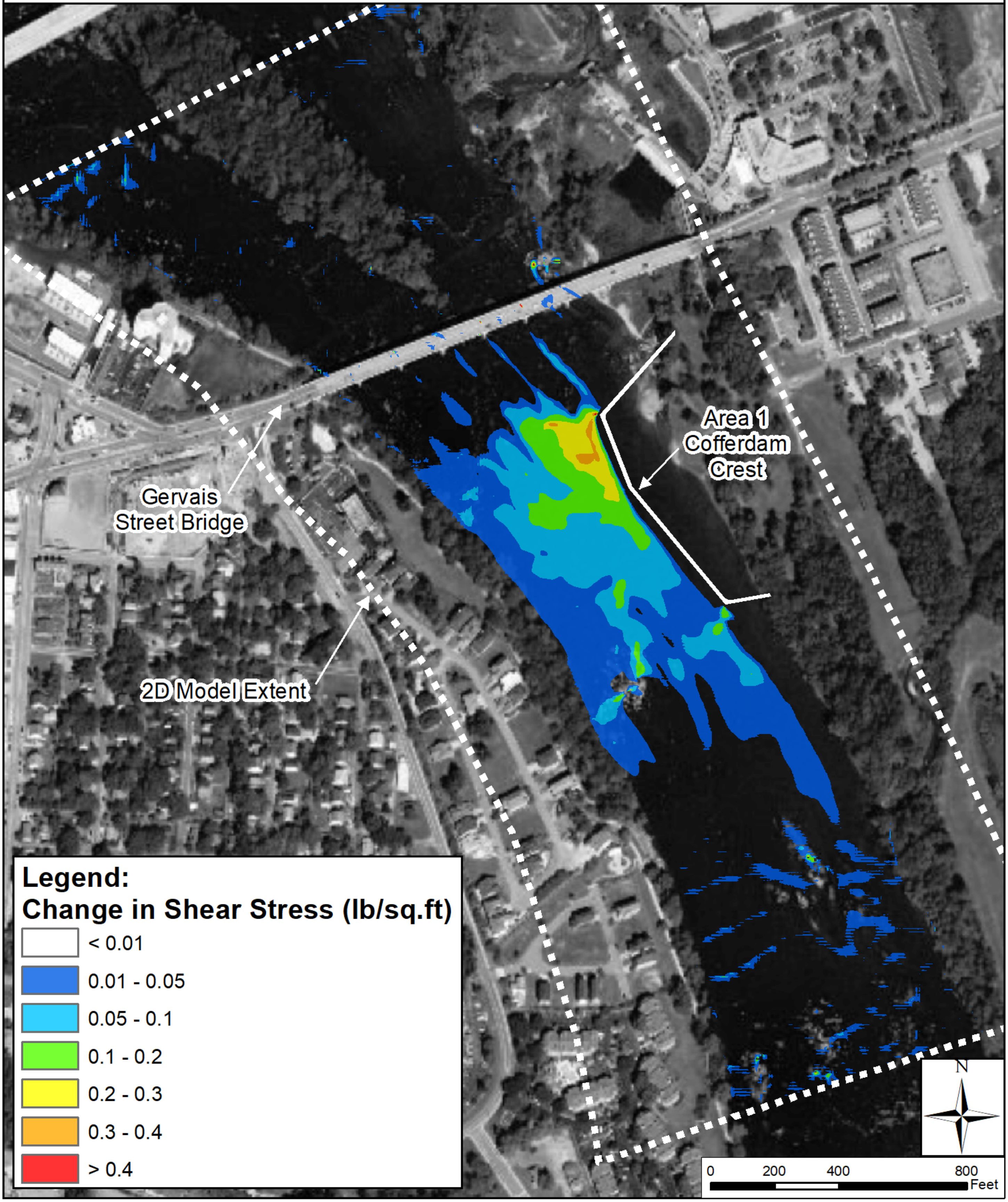
Congaree River Remediation Project
River Bottom Erosion Potential Evaluation
Figure A13: Normal Flow (8,564 cfs)
Proposed Area-1 Scenario: Shear Stress



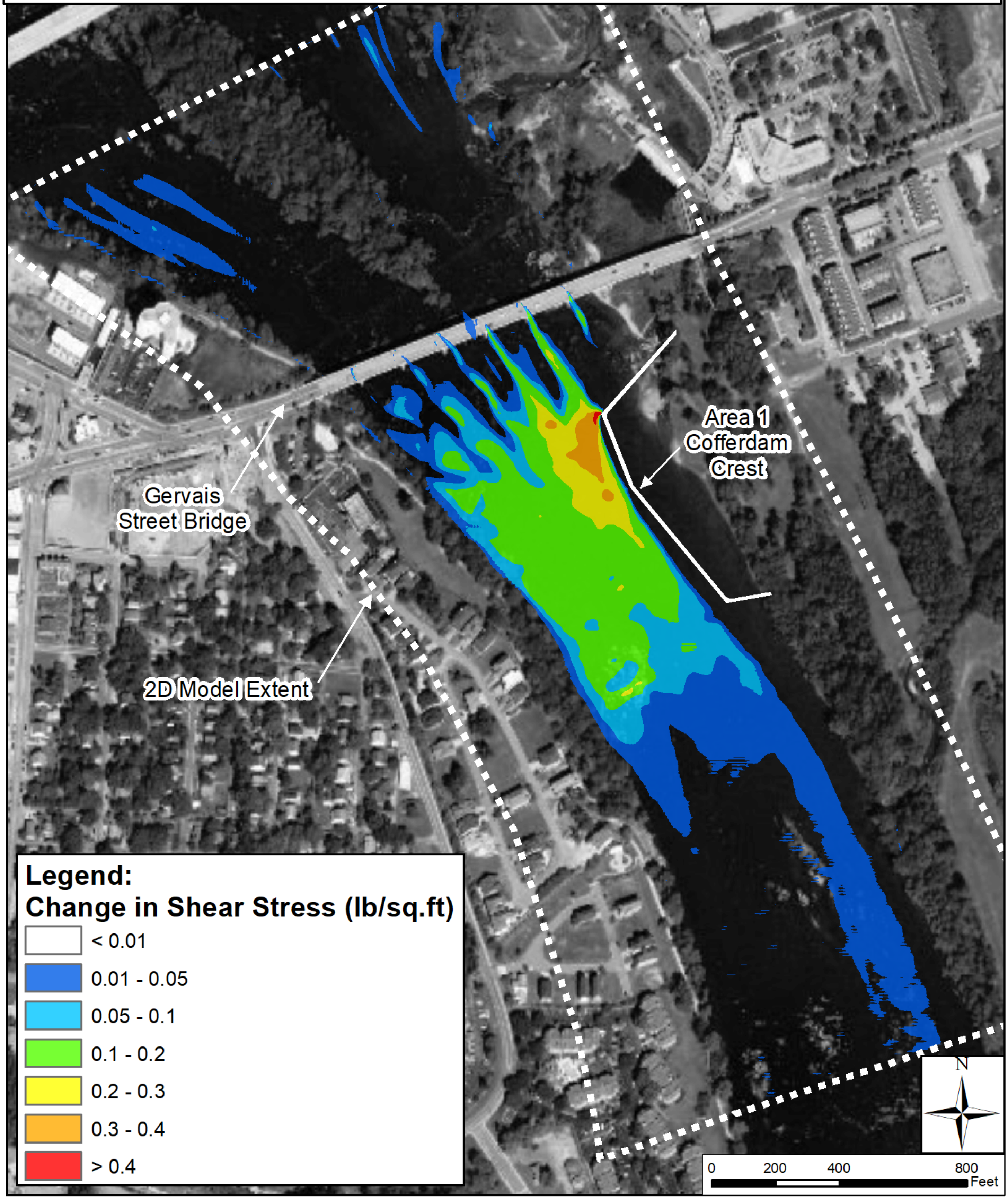
Congaree River Remediation Project
River Bottom Erosion Potential Evaluation
Figure A14: Crest Flow (26,000 cfs)
Proposed Area-1 Scenario: Shear Stress



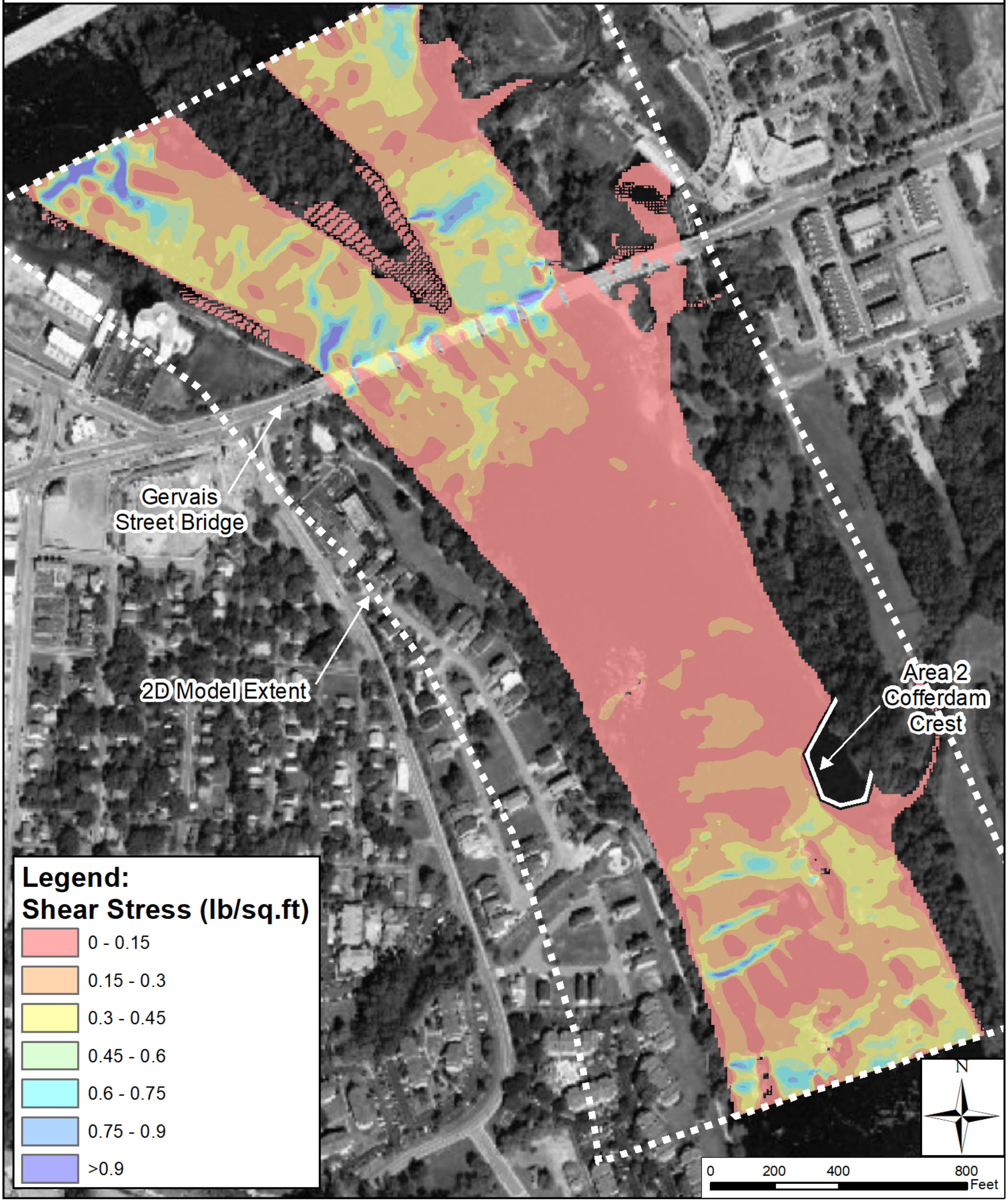
Congaree River Remediation Project
River Bottom Erosion Potential Evaluation
Figure A15: Normal Flow (8,564 cfs)
Proposed Area-1 Scenario: Change in Shear Stress



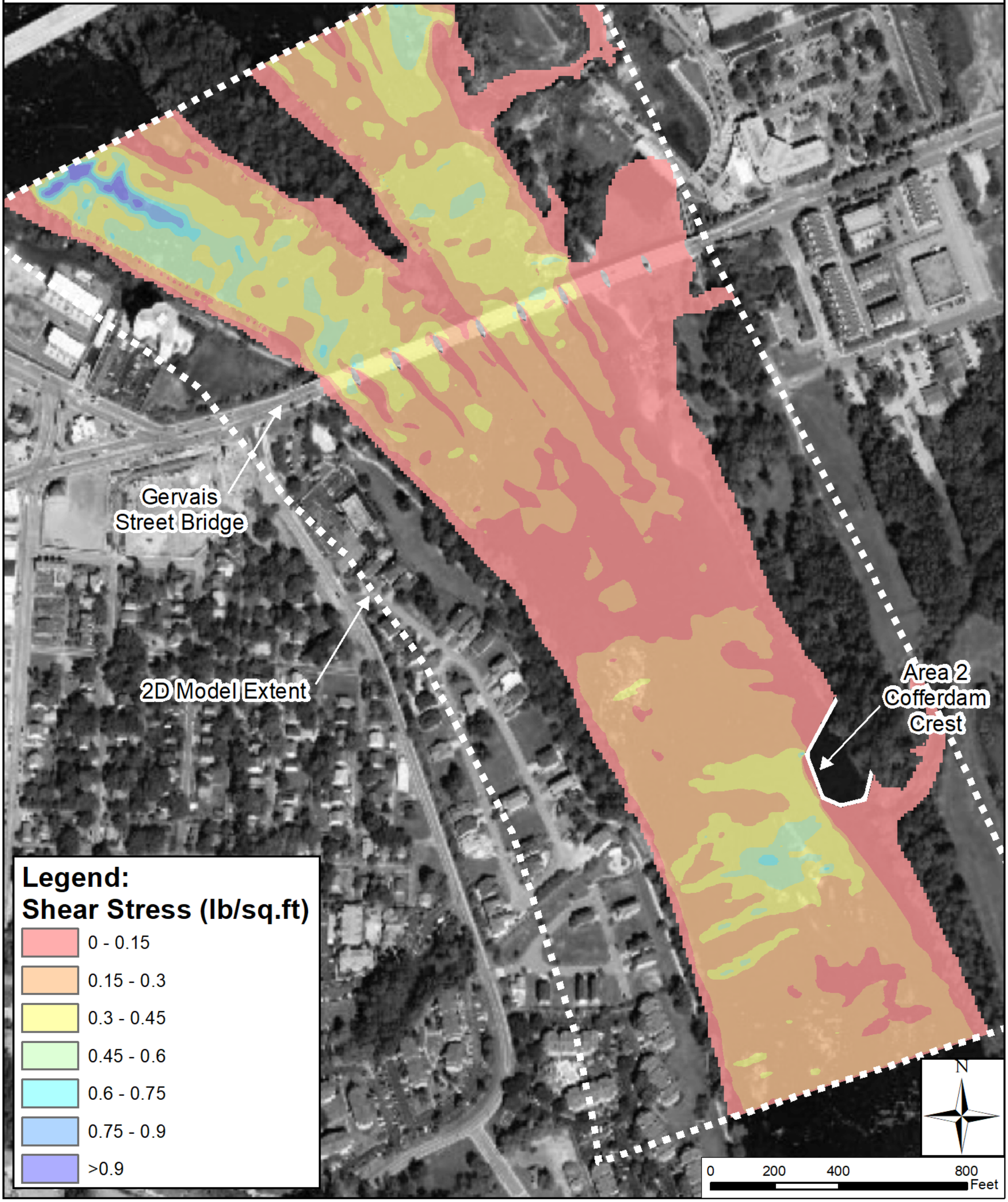
Congaree River Remediation Project
River Bottom Erosion Potential Evaluation
Figure A16: Crest Flow (26,000 cfs)
Proposed Area-1 Scenario: Change in Shear Stress



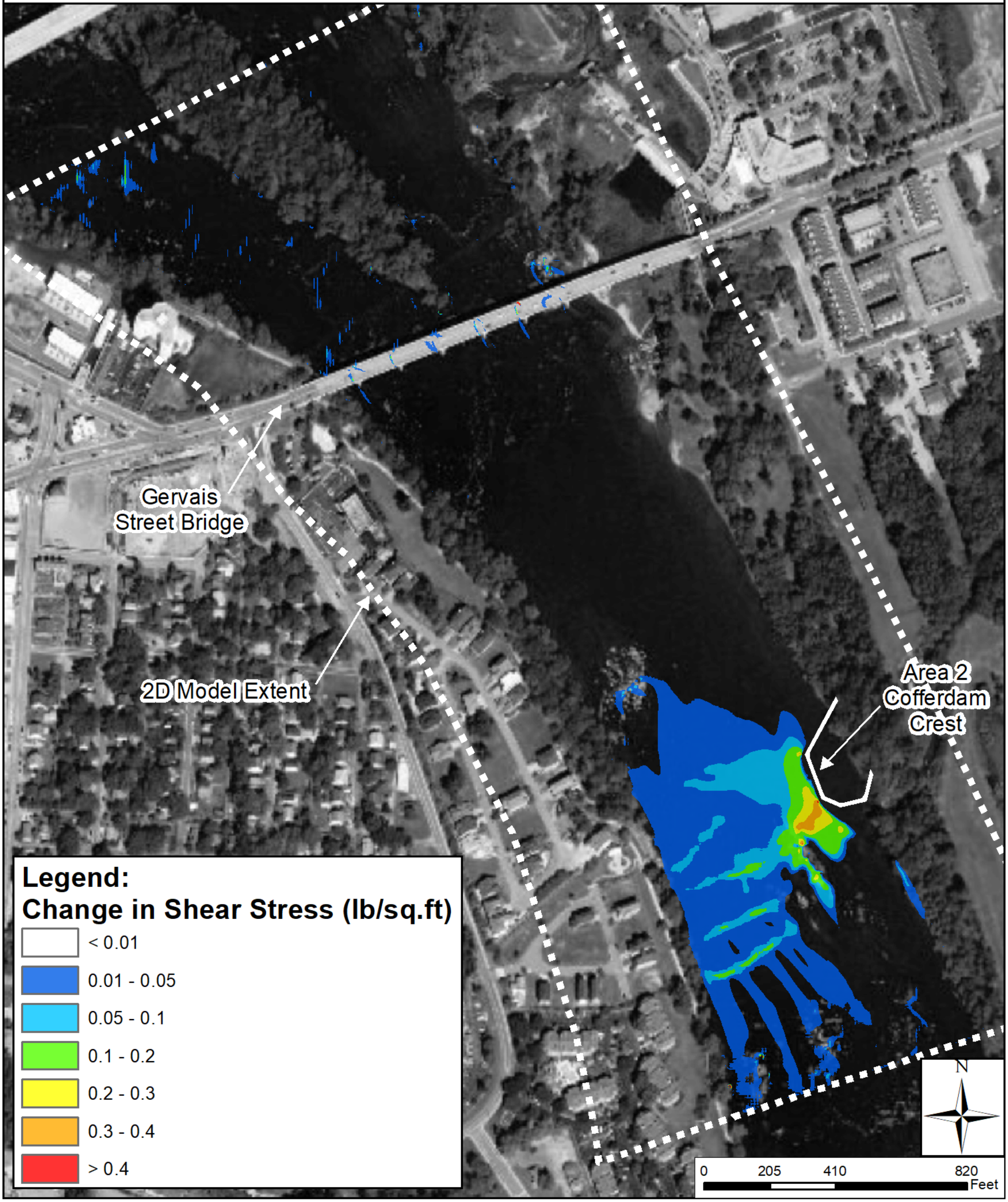
Congaree River Remediation Project
River Bottom Erosion Potential Evaluation
Figure A17: Normal Flow (8,564 cfs)
Proposed Area-2 Scenario: Shear Stress



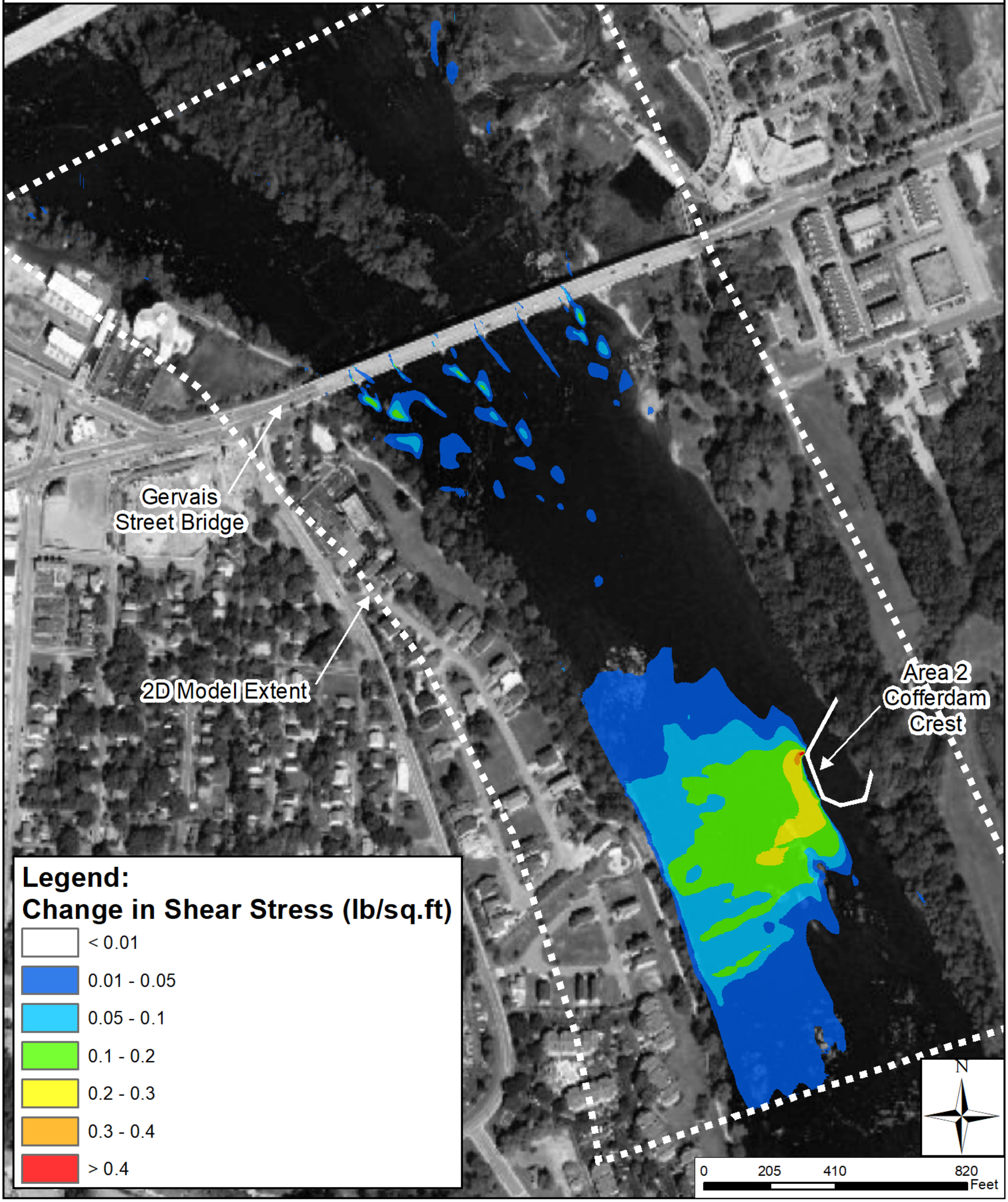
Congaree River Remediation Project
River Bottom Erosion Potential Evaluation
Figure A18: Crest Flow (26,000 cfs)
Proposed Area-2 Scenario: Shear Stress



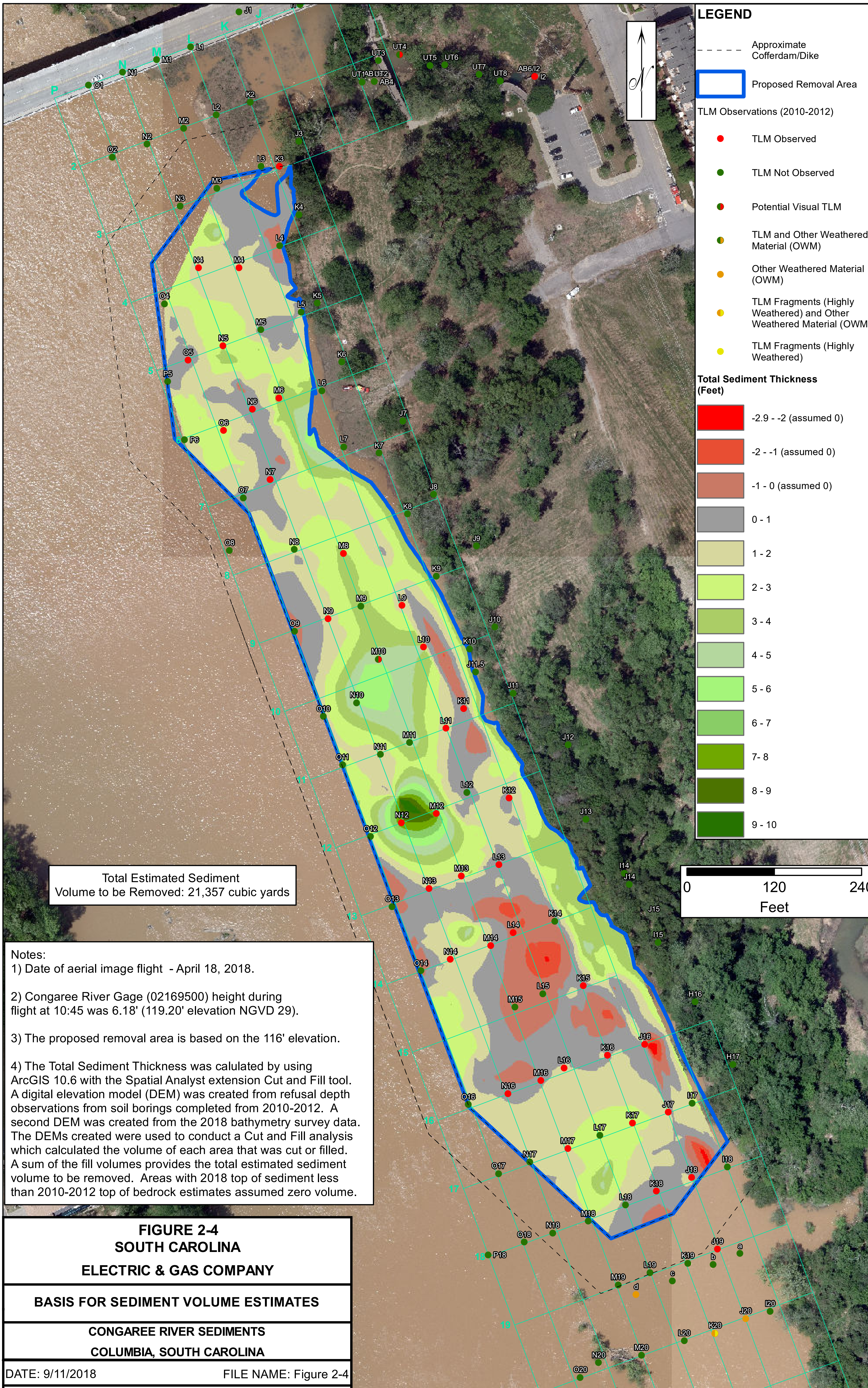
Congaree River Remediation Project
River Bottom Erosion Potential Evaluation
Figure A19: Normal Flow (8,564 cfs)
Proposed Area-2 Scenario: Change in Shear Stress



Congaree River Remediation Project
River Bottom Erosion Potential Evaluation
Figure A20: Crest Flow (26,000 cfs)
Proposed Area-2 Scenario: Change in Shear Stress



ATTACHMENT B: RIVER BOTTOM SEDIMENT DEPTHS



Notes:

1) Date of aerial image flight - April 18, 2018.

2) Congaree River Gage (02169500) height during flight at 10:45 was 6.18' (119.20' elevation NGVD 29).

3) The proposed removal area is based on the 116' elevation.

4) The Total Sediment Thickness was calulated by using ArcGIS 10.6 with the Spatial Analyst extension Cut and Fill tool. A digital elevation model (DEM) was created from refusal depth observations from soil borings completed from 2010-2012. A second DEM was created from the 2018 bathymetry survey data. The DEMs created were used to conduct a Cut and Fill analysis which calculated the volume of each area that was cut or filled. A sum of the fill volumes provides the total estimated sediment volume to be removed. Areas with 2018 top of sediment less than 2010-2012 top of bedrock estimates assumed zero volume.

FIGURE 2-4
SOUTH CAROLINA
ELECTRIC & GAS COMPANY

BASIS FOR SEDIMENT VOLUME ESTIMATES

CONGAREE RIVER SEDIMENTS
COLUMBIA, SOUTH CAROLINA

DATE: 9/11/2018 FILE NAME: Figure 2-4

APEX COMPANIES, LLC