United States Department of the Interior

U.S. GEOLOGICAL SURVEY
Reston, Virginia 20192

In Reply Refer To:
Mail Stop 415

Mr. Mike Buckley
Federal Emergency Management Agency
500 C Street, N.W.
Washington, D.C. 20472

Dear Mr. Buckley:

As requested by the Federal Emergency Management Agency (FEMA), attached is the review by the U.S. Geological Survey (USGS) of the model prepared for a reach of the Congaree River in South Carolina. The area covered by the model is for the reach of the Congaree River spanning the area north and south of highway I-77 embankment in Columbia, South Carolina.

Although the (RMA2) model reviewed has some improvements over the older RMA2 models for this river reach, the model has several deficiencies that FEMA should consider before using the model results for defining floodways in the modeled area. For example, the model can not be used to accurately determine the portion of the 100-year flood that would pass through Manning's dike breaks into the Richland side of the flood plain because of local computational errors which produce large errors in the flow computed through the bridge and dike openings. In addition, it appears as if the floodway determination methodologies used do not follow standard FEMA methodologies. It also appears that the conclusion that the Richland side of the flood plain is not a floodway is not supported by the model results. Results show there is more flow through the Richland relief bridges than the Lexington relief bridges and contour plots of unit width discharge show a significant portion of the flow passes through the Richland side of the flood plain.

The USGS is pleased to perform this review for FEMA. If there are any questions, please contact Janice Fulford (228/688-1501) or me (703/648-5304).

Sincerely,

J. Michael Norris
Acting Chief, Office of Surface Water

The following documents were reviewed by Janice M. Fulford of the U.S. Geological Survey for technical clarity and accuracy:

1. Report prepared by Exponent Inc., for Columbia Venture (Downloaded from: www.fema.gov/MIT/TSD/ST_Cong6.htm)
2. Model archive prepared by Exponent Inc. for Columbia Venture (Downloaded from: www.fema.gov/MIT/TSD/ST_Cong6.htm)
3. Report prepared by [redacted] Consulting for Columbia Venture (Downloaded from: www.fema.gov/MIT/TSD/ST_Cong6.htm)

Summary and detailed comments on the reviewed documents follow and are submitted to the Federal Emergency Management Agency for their consideration. The detailed comments contain information that supports the statements presented in the summary comments.

Summary Comments:

I. The RMA2 model prepared by Exponent Inc. for Columbia Venture has some improvements over the older RMA2 models for the Congaree River reach spanning the area north and south of the I-77 highway embankment. Model improvements included enlarging the modeled area and increasing model resolution in areas covered by the older models.

II. The RMA2 model prepared by Exponent Inc. for Columbia Venture has several deficiencies that prevent it from being useful in determining a floodway.

III. The Exponent model did not remove Manning's dike when modeling a floodway for the Richland side of the floodplain as required by FEMA guidelines.

IV. The Exponent model cannot be used to accurately determine the portion of the 100-year flood flow that is passing through the Manning's dike breaks onto the Richland side of the flood plain. The Exponent model has local computational errors that produce large errors in the flow computed through the I-77 highway bridges and Manning's dike openings. The computational errors prevent the accurate analysis of flow distributions in the Exponent model.

V. The Exponent model has increased the roughness coefficients for elements just south of the portion of the Manning's dike that runs east west in the northern end of the model. No information was given to support increasing the roughness values in this area of the model.

VI. The water-surface elevations computed by the Exponent model may be too low in some areas because of the outflow water-surface elevation used.

VII. The floodway determination methodologies used by Exponent Inc. and accepted by [redacted] Consulting did not follow standard, FEMA accepted methodologies for determining floodways.

VIII. The conclusion by Exponent Inc. and [redacted] Consulting that the Richland side of the floodplain is not a floodway is not supported by the Exponent model results. Results from the Exponent model indicate that the Richland side of the flood plain conveys a significant portion of the 100-year flood flow. Flow through the Richland relief bridges is larger than the flow through the Lexington relief bridges, and contour plots of unit-width discharge show that a significant portion of the flow passes through the Richland side of the flood plain.

IX. The definition of a floodway used in the Exponent Inc. and [redacted] Consulting reports is questionable because the definition ignores the effects of any flow due to a natural or man made feature that is not parallel to the main channel.

Detailed Comments:

I. The RMA2 model prepared by Exponent Inc. for Columbia Venture has some improvements over the older RMA2 models of the reach of the Congaree River reach spanning the area north and south of the I-77 highway embankment.

a) The Exponent model extended the model domain and located the downstream outflow boundary below the Eastman Kodak Company plant. The modelers correctly located the boundary below the plant because the distribution of water-surface elevation along the outflow boundary is unknown.

b) The Exponent model increased the resolution of the model in some areas.

II. The RMA2 model prepared by Exponent Inc. for Columbia Venture has several deficiencies that prevent it from being used to determine a floodway.

a) The Exponent model does not seem to have been calibrated or verified. No runs or materials were posted to indicate that the Exponent model roughness parameters had been calibrated or verified. The Exponent model greatly enlarged the modeled area. Roughness values in the added area will have a significant effect on the computed upstream water-surface elevations. Typically, a model is calibrated by adjusting roughness values until the computed water-surface matches a measured water-surface. Calibration ensures that friction losses computed by the model are appropriate. Calibration is only possible if measured data exist. Uncalibrated models may have considerable error in the results. If no measured data exist for roughness calibration, the sensitivity of the model results to the roughness values used should be evaluated and water depths should be expressed to have a possible range of that computed from the range of roughness values used.
b) The roughness value used by the Exponent and FEMA models for grassland or cropland in the Richland area of each model may be too high. A value of 0.06 was used and seems high in comparison to the values of 0.035 to 0.050 recommended in V.T. Chow's book, "Open-Channel Hydraulics". None of the previous models by the U.S. Geological Survey calibrated the roughness values on the Richland side of the floodplain. The study documented in USGS WRI 90-4056 used a value of 0.024 for grassland or cropland.
c) The Exponent model does not include a gap in the Manning's dike south of the highway embankment that previous models included. This gap is visible on the 7.5 minute topographic map of the Southwest Columbia Quadrangle (photorevised in 1982). A road that is visible on the recent aerial photo (dated 3.22.1999, file name Congaree-SmallerFile.tif) passes through the dike south of I-77. It appears from the photo that the road is at the level of the flood plain and acts as a local breach in the dike.
d) The Exponent model has only fair convergence on the final iteration. Large changes are still occurring between the last 2 iterations for at least a few nodes. For the water-surface elevation the largest change on the final iteration is –1.7ft. The large change may indicate either poor grid construction or the need to run more iterations. Either additional iterations

or improved grid construction may change the water-surface elevations computed in the model.

e) Several elements have gone dry or have negative depths along the model boundaries. This results in a ragged no flow boundary that doesn't seem to relate to ground topography. One element has gone dry below a small relief bridge on the Richland side of the flood plain. These dry elements may be indicative of poor grid construction.

f) Few elements (or nodes) are placed in many of the bridge openings. The Exponent model did not significantly increase the resolution of the model in the bridge openings over the FEMA model. Typically, more elements are placed in and around openings because of the local acceleration of velocity and locally steep water-surface curvatures. The addition of more nodes in bridge openings usually improves the local conservation of mass in the openings.

III. The Exponent model did not remove Manning's dike when modeling the floodway for the Richland side of the floodplain as required by FEMA guidelines for study contractors. FEMA "Study Contractor Guidelines and Specifications" (from FRM_SCg.zip at www.fema.gov/mit/tsd/DL_SCg.htm) states that computation of a floodway should recognize the likely failure of substandard levees on the dike side of the floodplain. Manning's dike does not meet the requirements of 44 CFR 65.10 and should not be included when a floodway is calculated for the Richland side of the floodplain ("In all FIRMS which FEMA has put forth for Richland County, FEMA has always maintained that Manning's dike and Gill's Creek ring dike are not certified to meet the standards of Section 65.10 of the NFIP regulations", from Appeal Resolution for Congaree River in Richland and Lexington Counties, South Carolina; FEMA, September 26, 2000).

IV. The Exponent model does not accurately determine the portion of the 100-year flood flow passing through the Manning's dike breaks onto the Richland side of the flood plain. The Exponent model has local computational errors that produce significant errors in the flow computed through the bridge and dike openings. The sum of the flows passing through the dike breaks and the Lexington I-77 bridge openings (figure 1) should equal the total discharge of 292,000 cubic feet per second (cfs). Also, the flow through the dike breaks should equal the flow through the Richland I-77 bridge openings, and the sum of the flows passing through the I-77 bridge openings should equal the total model flow of 292,000cfs. The mass conservation error computed by summing the Manning's dike breaks and Lexington county bridge openings discharges and comparing it to the 100-year flood flow is about 17%. The finite-element method used by RMA2 does not guarantee local mass conservation. It is standard finite-element modeling practice to include flow (continuity) check lines to determine if mass is being adequately conserved locally. Poor local mass conservation can be due to poorly constructed model grids. Table A lists the discharges through the various bridge openings and dike breaks computed by using the Exponent model flow check lines and one hand calculation. Note that the flow through the dike breaks differ by 16% from the flow through the Richland Bridges, indicating that mass is not being properly conserved at the embankment openings.

Figure 1. Model boundaries, bridge opening locations and dike break locations from the Exponent RMA2 model of the Congaree River.

Table A. Discharges in cubic feet per second through various I-77 bridge openings and levee breaks as computed by the Exponent model for the 100-year flood flow of 292,000 cubic feet per second. (*hand computation from RMA2 results)

Levee Breaks	Discharge, cubic feet per second	Percent of flood flow
Manning's Dike Breaks (8489. 44,800.)	53,289.	18.3
I-77 Bridge Openings	Discharge, cubic feet per second	Percent of flood flow
Lexington County Bridges (3276.* 2356. 39,410. 143,200.)	188,243.	64.5
Richland County Bridges (53,830. 6888. 2356.)	63,074.	21.6

V. The Exponent model has increased the roughness coefficients (from 0.06 to 0.125) for elements just south of the portion of the Manning's dike that runs east west near the northern (upstream) limits of the model. Elements just north of Manning's dike in this area were also assigned larger roughness values (from 0.06 to 0.175). No information is given to support increasing the roughness values in this area of the model. Aerial photos (dated 01.21.1994 found on the web at terraserver.homeadvisor.msn.com, jpeg file attached NElevee.jpg) appear to show open cropland south of the levee. The area in the photo is similar in appearance to model areas that have roughness values of 0.06. The recent photo (dated 3.22.1999, file name Congaree-SmallerFile.tif) used by the FEMA report does not seem to show a change in land use for that area. A small portion of the area in question can be seen in the recent photo just above the white text, 1"=3000'. The roughness values used in this area should be confirmed. Roughness values can significantly change flow directions and flow depths. A comparison of the roughness values used for the Exponent model with those used for the FEMA model is in figure 2.

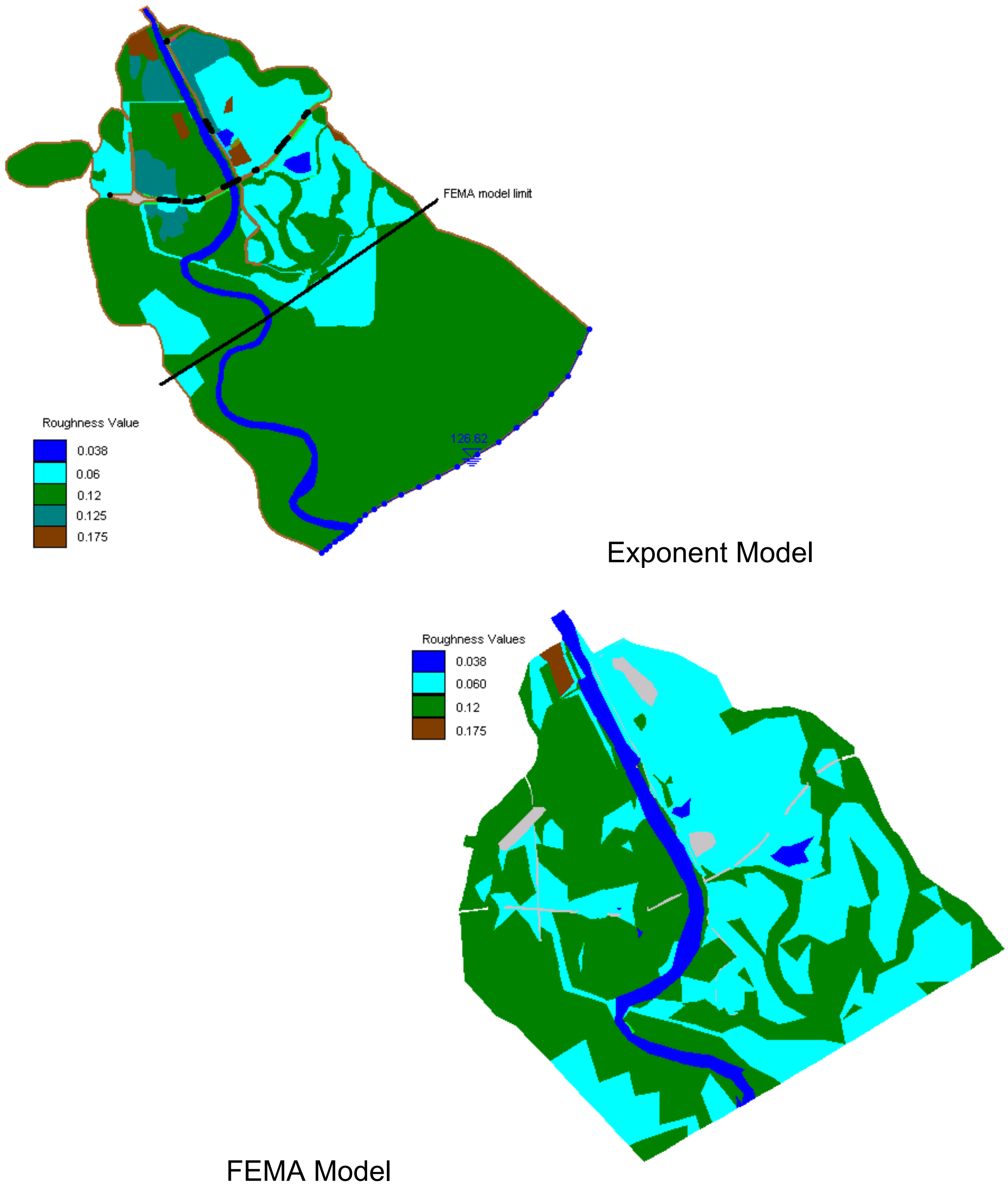

Figure 2. Comparison of roughness values and locations used for the Exponent and FEMA RMA2 models of the Congaree River.

VI. The water-surface elevations computed by the Exponent model may be too low because of the outflow water-surface elevation used. Exponent Inc. used a constant water-surface elevation of

126.2 feet at the outflow boundary that may be from 0.5ft to 5.3ft too low when compared to water-surface elevations estimated from stage-discharge measurement analysis. The reason for selecting 126.2 ft was not documented in the materials accompanying the Exponent model. It is likely that this value is based on 1-dimensional (HEC2) model runs that used an energy slope for the boundary condition. A stage-discharge (rating curve) analysis was made on the measurement data collected by the USGS between March 1986 and April 1987 at the Carolina Eastman gage and included the 1976 flood elevation at the gage. Because the gage datum is referenced to a topographic map, gage heights associated with USGS discharge measurements at the gage have a possible error of ± 5 ft. The elevation at the gage for the 1976 flood was assumed to be accurate for the analysis. Figure 3 shows the rating curves developed from discharge measurements and the 1976 flood information. One curve, of gage height, has no corrections for datum and offset adjustments. The other three curves shown are computed with offsets of 20ft and referenced to a vertical datum of 100ft. Extrapolation of the three curves plotted with an offset gives a range of estimated water-surface elevations at the Carolina Eastman gage for 292,000cfs of 129.62ft to134.53ft with 131.85ft for no datum correction. Because the Exponent model outflow boundary is located downstream of the gage, contours of the water-surface elevations estimated for the Carolina Eastman plant gage for the 100-year flood flow were plotted to check the boundary conditions used in the Exponent model. Figure 4 shows that the estimated elevations from the rating curve analysis are 0.5 to 5.3 ft higher than those computed by the Exponent model at the gage. Boundary conditions used by any flow model should be carefully selected and documented. Sensitivity of the model results to the likely range of water-surface elevations at the downstream outflow boundary should be investigated when the outflow water-surface elevation is not well known.

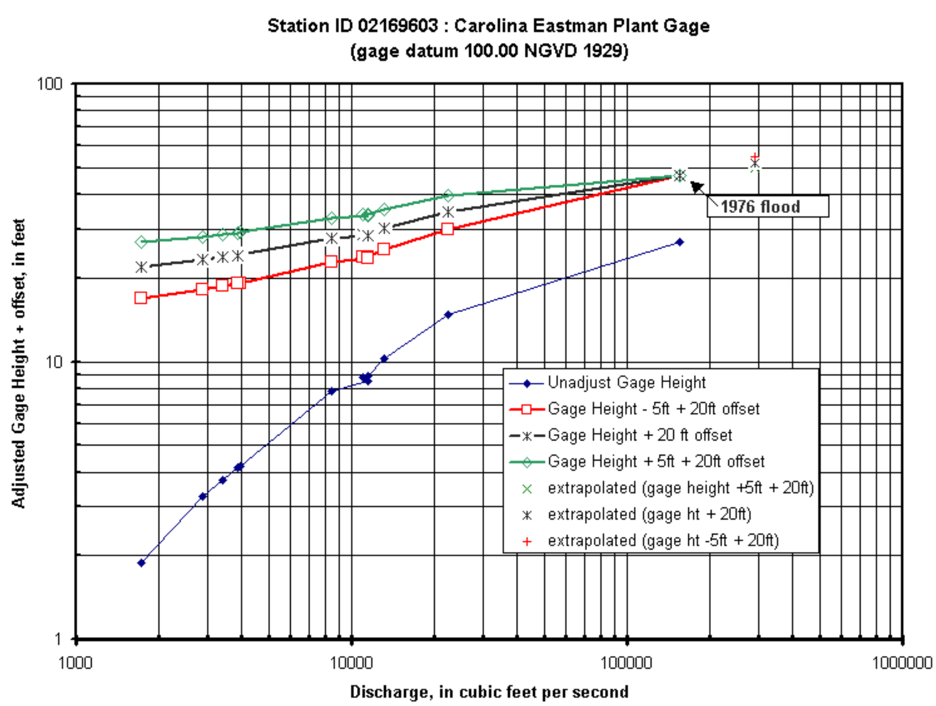

Figure 3. Rating curves estimated for Carolina Eastman gage.

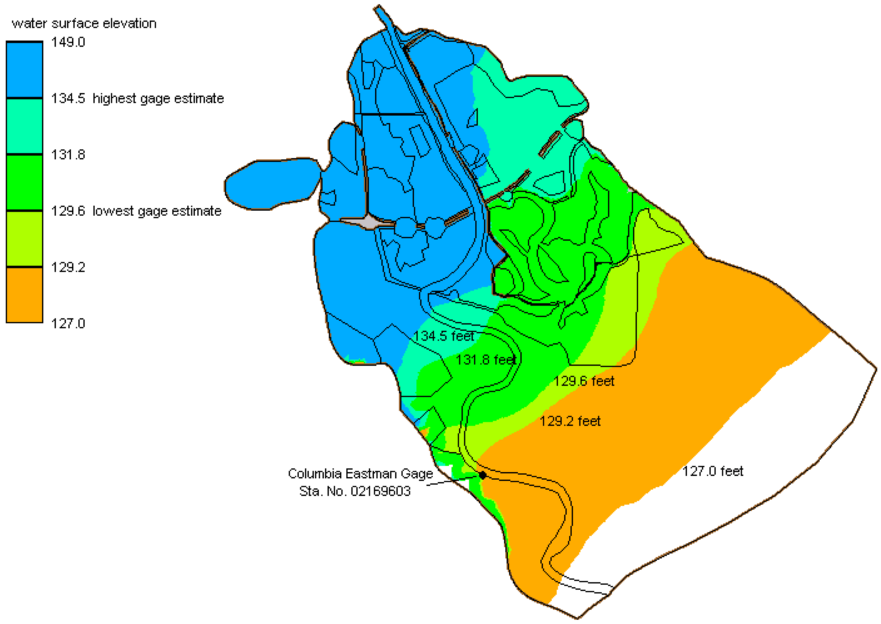

Figure 4. Contour plot of water-surface elevations computed by the Exponent RMA2 model. Contour intervals are for the water-surface elevations expected at the Carolina Eastman gage for a discharge of 292,000 cubic feet per second.

VII. The floodway determination methodologies used by Exponent Inc. and accepted by [redacted] Consulting did not follow standard FEMA accepted methodologies for determining floodways. FEMA "Study Contractor Guidelines and Specifications" states in the section titled "Two-Dimensional Water-Surface Computer Models" that "Floodways must be developed through an interactive trial-and-error procedure and must be based on equal conveyance reduction." Additionally, the guidelines state, "Where the stream forms the border between contiguous communities, and the floodway designation affects both of them, equal reduction of conveyance must be used." The floodway determination by Exponent Inc. did not use equal conveyance reduction and did not include any of the floodplain in Richland County. No justification for using velocities parallel to main channel velocities instead of equal conveyance reduction was given in any of the documents from Exponent Inc. or [redacted] Consulting.

VIII. The conclusion by Exponent Inc. and [redacted] Consulting that the Richland side of the floodplain is not a floodway is not supported by the Exponent model results. Results from the Exponent model indicate that the Richland side of the flood plain conveys a significant portion of the 100-year flood flow. Table B lists the percent of total bridge flow passing through the main bridge opening and through the Lexington and Richland county relief bridges as computed by the Exponent model. Flow through the Richland relief bridges (63,074 cfs) is larger than the flow through the Lexington relief bridges (45,042. cfs). Additionally, contour plots of unit-width discharge show that a significant portion of the flow passes through the Richland side of the flood plain (figure 5). Most of the entire floodplain, including the Richland side, is inundated with flow depths of 8 ft or more (figure 6). Only 65% of the total modeled flow (292,000cfs) passes through the openings in the I-77 embankment on the

Lexington County side of Manning's dike. This leaves a significant portion (35%) of the flow passing through the Manning's dike breaks or computationally unaccounted for by the Exponent model (due to mass conservation problems).

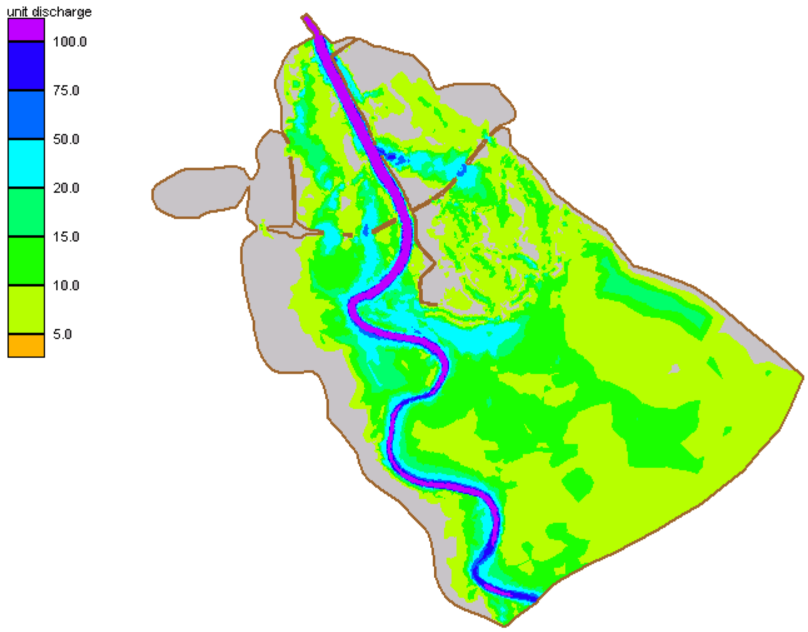

Figure 5. Contours of unit width discharge in cubic feet per second per one foot of width plotted for the Exponent RMA2 model.

Table B. Flow through I-77 highway crossing bridges. (Flow is less than modeled flow of 292,000cfs because of local mass conservation errors)

Bridge openings	Discharge, cubic feet per second	Percent of Total Flow
Main Channel	143,200	57.0
Lexington Relief Bridges	45,042	17.9
Richland Relief Bridges	63,074	25.1
Total Bridge Flow	251,316	100.0

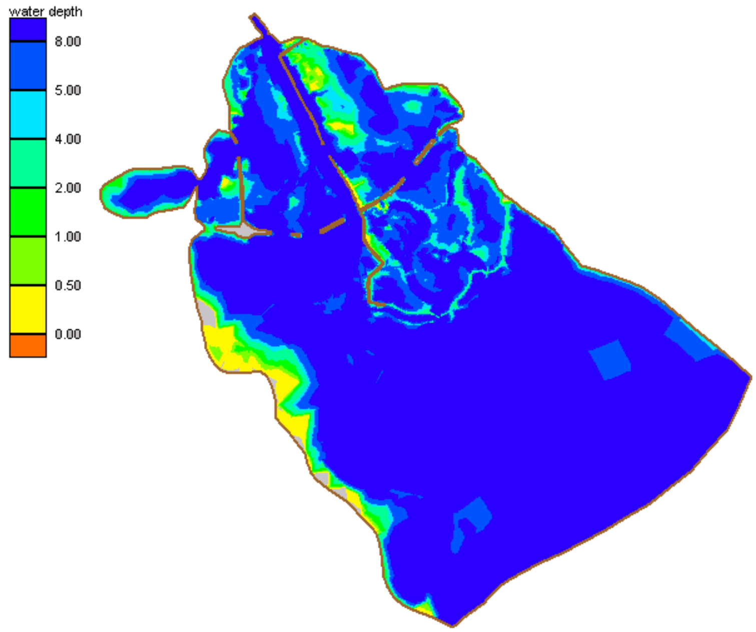

Figure 6. Contour plot of the Exponent model flow depths in feet for the 100-year flood flow.

IX. The definition of a floodway used in the Exponent Inc. and [redacted] Consulting reports is questionable because the definition ignores the effects of any flow due to a natural or man made feature that is not parallel to the main channel. Flow distribution in broad floodplains is determined by the location of bridge openings in highway crossings and other topographic or roughness features in the flood plain. The Exponent Inc. and [redacted] Consulting definition restricts the floodway to be adjacent and parallel to the main channel and ignores significant flow features that aren't parallel and adjacent to the main channel. For example, if a flood plain had a distributary branch that carried one half of the flow but at a 90-degree angle to the main channel, that distributary would never be part of a floodway using the Exponent Inc. and [redacted] Consulting definition because flow in the distributary would not be parallel to the main flow. FEMA does recognize that significant flow patterns can occur in a floodplain that do not flow parallel to the main channel. The FEMA "Study Contractor Guidelines and Specifications" recommend, "Split-flow analyses should be considered when flows overflow the banks of the main stream and take a different flow path." Also the FEMA document states, "2-D computer models may be used for shallow flooding areas, split flow situations, and complex bridge sites." The I-77 highway crossing of the Congaree floodplain is a significant feature affecting flow distribution on the floodplain. Placement of the main bridge and the relief bridges largely dictate how the flow north and south of the highway crossing is distributed. The effect of the Richland relief bridges on flow patterns should not be ignored because FEMA "Study Contractor Guidelines and Specifications" dictate for uncertified levees that "the 100-year flood elevations will be recomputed as if the levee did not exist" and because Manning's dike is expected to "likely fail in a 100-year flood"(Appeal Resolution for Congaree River in Richland and Lexington Counties, South Carolina, FEMA, September 26,2000) based on geotechnical studies of the levees. The force exerted by water during a flood could be one of many factors considered when determining a floodway. Figure 7 is a contour plot of force per unit width computed from the Exponent model results using the equation $F=\frac{1}{2}\rho y v^2$ where F is force, ρ is the density of water (1.94 slugs/ft^3), y is the flow depth at a model node and v is the velocity magnitude at a model node. This plot shows that significant forces are produced by the flow present in the Richland County side of the Exponent model.

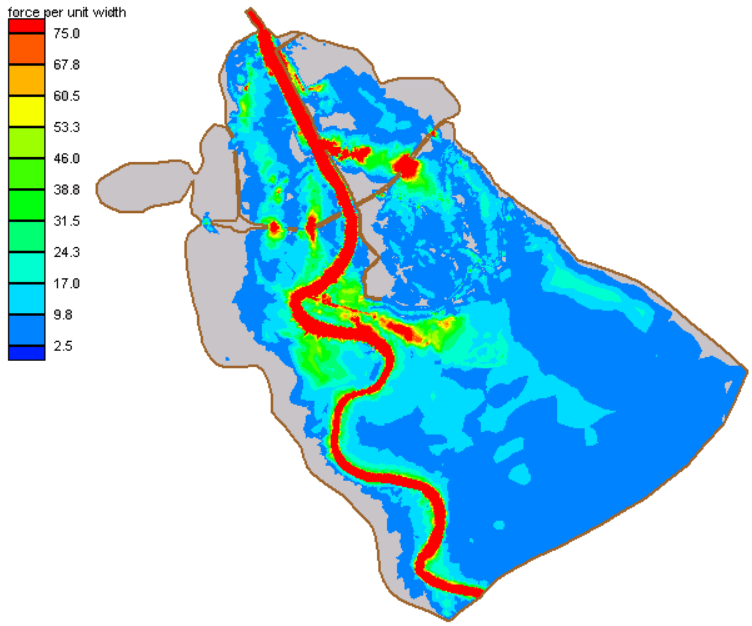

Figure 7. Force per unit width in units of slugs per second squared computed from the Exponent RMA2 model for a flow of 292,000 cubic feet per second.