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EXPANDED TWO DIMENSIONAL FLOW ANALYSIS AND

DETERMINATION OF NO FLOODWAY FOR THE CONGAREE RIVER

FLOODPLAIN IN RICHLAND COUNTY, SOUTH CAROLINA

Feb 12, 2001

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Finding:

Based on the definition and purpose of a floodway, and the results of an expanded two dimensional flow analysis, this study concludes that there is no floodway on the Richland County, South Carolina side of the Congaree River downstream of the City of Columbia. No change to the Lexington County floodway delineation as shown in the September 26, 2000 map by FEMA occurs as a result of this study. The floodplain on the Richland County side of the river is not an unobstructed waterway. The only way for water to enter the floodplain is via a flood-caused levee breach. Considering worst-case conditions, the flow patterns are divergent, and the floodplain areas with flow velocities greater than one foot per second are discontinuous. No coherent corridor to convey floodwaters exists on the Richland County side of the Congaree River.

Executive Summary:

On September 26, 2000, FEMA issued an Appeal Resolution Report for the Congaree River in Richland and Lexington Counties, South Carolina. The Appeal Resolution Report presents an analysis of two-dimensional flow patterns in the Congaree River assuming certain levee breach scenarios. The computer program RMA-2 is used for their analysis. The Appeal Resolution report uses a finite element mesh developed in 1981 by the USGS for the purpose of analyzing the effects of the Interstate Highway on flood flows. The report states that the RMA-2 approach was chosen because of the complexity of flooding patterns in the Congaree River floodplain. Furthermore, the computed results would be used to identify areas in the floodplain that have point velocities that exceed 1 foot per second. The floodplain areas that meet this criterion would be considered effective flow and preserved as floodway. Based on the RMA-2 analysis, the Appeal Resolution report designates as floodway most of the area in Richland County behind the uncertified Manning Levee.

The purpose of this study is to prepare an expanded two-dimensional flow model that is based on existing land use conditions, more accurate topography, extensive field investigation of floodplain physical features, and a more realistic treatment of model boundary conditions. This analysis considers the potential for a series of levee breaches that would enable water to flow through the floodplain on the

Richland County side of the river during a peak 100-year flood and evaluates the appropriateness of this floodplain to serve as a floodway under existing conditions.

By including all of the existing features in the floodplain as required by FEMA in the conduct of Flood Insurance Studies, by expanding the finite element mesh, and by using the levee breach scenarios adopted in the Appeal Resolution Report, this study concludes that there are no significant continuous areas with flow velocities greater than 1 foot per second on the Richland County floodplain and that this area should not be designated as a floodway. Even by assuming that a series of levee breaches occur in a manner to achieve the worst-case flow through, the flow direction generally diverges to the east rather than flowing parallel to the main stem of the Congaree River. Based on the high roughness characteristics of the floodplain, low water velocity magnitudes, and divergent flow directions caused by obstructions in the Congaree River floodplain on the Richland County side of the river, it is not realistic to require the community to reserve a floodway here even if the worst-case series of levee breaches occur during the base flood.

Page 5-1 FEMA Document No. 37, the Study Contractor Guidelines states:

> *It is extremely important that roughness coefficients in overbank areas be selected to carefully represent the effective flow in those areas. There is a general tendency to overestimate the amount of flow occurring in overbank areas, particularly in broad, flat floodplains.*

Considering the extent, size, and historical precedence of the levees, berms, forests, and other obstructions in the floodplain, it is not realistic to assume that a significant amount of flow would be conveyed through the Richland County floodplain either for purposes of calculating the Base Flood Elevations or for the designation of a floodway. On page 5-2 of the FEMA Study Contractor Guidelines document, floodway determination is discussed.

> *A floodway is defined as the channel of a river or other watercourse and the adjacent land areas that must be reserved in order to discharge the base flood without cumulatively increasing the water-surface elevation by more than a designated height. Floodways are developed by the* [Study Contractor] *SC as unobstructed waterways to convey floodwaters. The floodway, developed by the SC, is coordinated with the community, Regional* [Project Officer] *PO, and, if applicable, with the State Coordinating Agency. The community is responsible for maintaining the conveyance of flooding sources to mitigate flood hazards.*

In order for any floodwaters to pass through the Richland County floodplain, at least four major levee breaches must occur. The first breach is to let water into the floodplain. The second breach is through the ring levee south of the Interstate Highway, and the third and fourth are through the Gills Creek levees. The second, third, and fourth breaches are necessary in order to let water out of the floodplain creating a flow through condition. FEMA's analysis did not consider this, but it is included in this study to analyze the worst-case scenario. Without the three downstream breaches, there is no conveyance through the floodplain. Water will merely pond. Even if this worst-case flow through condition happens, this area should not be characterized as a floodway.

The Appeal Resolution Report claims that the RMA-2 computer program has no floodway determination tools and that revising the model may prove too challenging for the affected communities. Based on these factors, a HEC-2 one-dimensional analysis was developed and calibrated to the RMA-2 results. The HEC-2 analysis was used to delineate FEMA's recommended floodway. FEMA's HEC-2 results, however, show significantly more water flowing through the Richland County floodplain than do their RMA-2 results. This means that the suggested floodway is not based on an accurate depiction of the existing characteristics of the Richland County floodplain. Page 5-5 of the FEMA Study Contractor Guidelines address the use of two-dimensional models as follows:

> *Two-dimensional (2-D) computer models may be used to determine the water-surface elevations in two directions in the horizontal plane, where one-dimensional computer models may have difficulty analyzing these situations.*
>
> *2-D computer models may be used for shallow flooding areas, split flow situations, and at complex bridge sites. Although it is not recommended because of the complexities involved and the costs that would be incurred, 2-D models can be used in areas subject to alluvial fan flooding.*
>
> *These models will only be requested where 1-D models, current accepted techniques, and engineering judgment will not provide satisfactory information for floodplain management and flood insurance purposes. All 2-D models must meet the criteria as specified in 44 CFR 65.6 (a)(6).*
>
> *Floodways must be developed through an interactive trial-and-error procedure and must be based on equal conveyance reduction.*

The guidelines state that if a two-dimensional flow analysis is required, the reason is that a one-dimensional analysis does not provide satisfactory information. Furthermore, the two-dimensional model can be used to determine a floodway, it is just not an automatic procedure like it is for HEC-2. It is unlikely that during a 100-year flood, levee breaches would develop to such an extent that FEMA's suggested floodway would convey the amount of water assumed in their HEC-2 analysis because FEMA's analysis incorrectly assumes an unobstructed waterway (no levee).

Because a floodway is to be an unobstructed waterway, the proposed designation puts the community in a difficult situation. To expect or rely upon any significant amount of flow conveyance behind the levee systems in the Richland County floodplain during an actual flood is inconsistent with both the purpose of a floodway designation and with sound floodplain management.

Based on the definition and purpose of a floodway and the results of the expanded two dimensional flow analysis that includes existing floodplain features, this study concludes that there is no floodway on the Richland County side of the Congaree River within the area studied.

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Introduction

Two-dimensional finite element models for shallow water flow models are currently one of the most useful tools for the analysis of overbank flood flows. While one-dimensional models are still widely used to reproduce some of the features of real flood phenomena (the propagation and diffusion of the flood wave, for example), they cannot represent the spatially complex flow patterns that characterize a river overbank. One-dimensional models limit topographic information to the channel bed slope and channel cross-section information, lumping into the model friction parameterization, the effects of hydraulic processes in the meandering channel and limiting the effects of the floodplain to simple storage and routing schemes.

Two-dimensional models can more realistically represent the different hydraulic conditions of the main channel and of the overbank by being able to spatially vary topography and friction. Some combining of processes is still applied in the depth averaging process but to a lesser degree than for one-dimensional models. Important processes such as the lateral transfer of momentum between the main channel and the floodplain fluid, can also be represented in a two-dimensional formulation if correct parameterization is used.

Several one and two-dimensional computer programs were developed during the past 15 years to analyze the complex topography that is characteristic of the Congaree River situation. The USGS and FEMA have applied RMA-2 to the Congaree River floodplain. The USGS studied the area in 1981 for the purposes of analyzing the effects of the construction of Interstate 77 which crosses the Congaree River. FEMA obtained and used the USGS finite element mesh for their recent floodway analysis.

The analysis in this report uses the RMA-2 two-dimensional computer program. Because of recent detailed topographic surveys available in both Richland and Lexington Counties, and access to the USGS digital elevation data, we have been able to significantly expand and refine the mesh. The boundary conditions on the USGS/FEMA model were too close to the area of interest and affected the computed results. Recent aerial photography and field investigation was used to specify up-to-date land use conditions. The RMA-2 model with the expanded mesh is used to analyze a number of overbank flow scenarios considering different breach conditions.

Preparers' Qualifications

This study was prepared by [redacted] of Exponent, Inc. [redacted] is a registered civil engineer with extensive experience applying hydrodynamic computer programs for the analysis of flood hazards, and for the development of Flood Insurance Studies. He has analyzed leveed flood control systems, reservoirs, and channels in both alluvial and coastal environments. While in graduate school, [redacted] studied with [redacted] the developer of computer program RMA-2. While at the Hydrologic Engineering Center of the U.S. Army Corps of Engineers, he worked with the application of RMA-2 to the Fisherman's Wharf Breakwater in San Francisco, California. [redacted] has authored more than 40 journal articles, chapters in several published texts on water resources issues, and has served on the National Research Council's Committee on Alluvial Fan Flooding, which was sponsored by FEMA.

[redacted] of Exponent, Inc. was a key technical contributor. He has a Dr. of Engineering from the University of Padova, Italy. He has done extensive analysis applying two-dimensional flow models to riverine and coastal flooding including the Venice Lagoon, Italy; and Morongo Creek, California.

Model Description

RMA-2 is a two-dimensional depth averaged finite element hydrodynamic numerical model. It computes water surface elevations and horizontal velocity components for subcritical, free surface two-dimensional flow fields. The model computes a finite element solution of the Reynolds form of the Navier-Stokes equations for turbulent flows. Friction is calculated with the Manning's or Chezy equation, and eddy viscosity coefficients are used to define turbulence characteristics.

For this study, steady state analyses are done to analyze flow patterns for the peak 100-year flow. FEMA has adopted a 100-year peak flow value of 292,000 cfs. The study also considers the 100-year peak flow estimate of 259,000 cfs developed by [redacted] using the FEMA procedure and the SCANA letter dated December 15, 2000. The moving spatial boundary nature of the problem is handled by combining a simple wetting and drying algorithm. An element is considered "wet" or "dry" if any one of its nodes is higher than a specified water elevation. A more sophisticated marsh porosity approach is also available, where an element can still carry flow even if is partially dry. This additional approach is particularly efficient where shallow water is present in a mild sloped area.

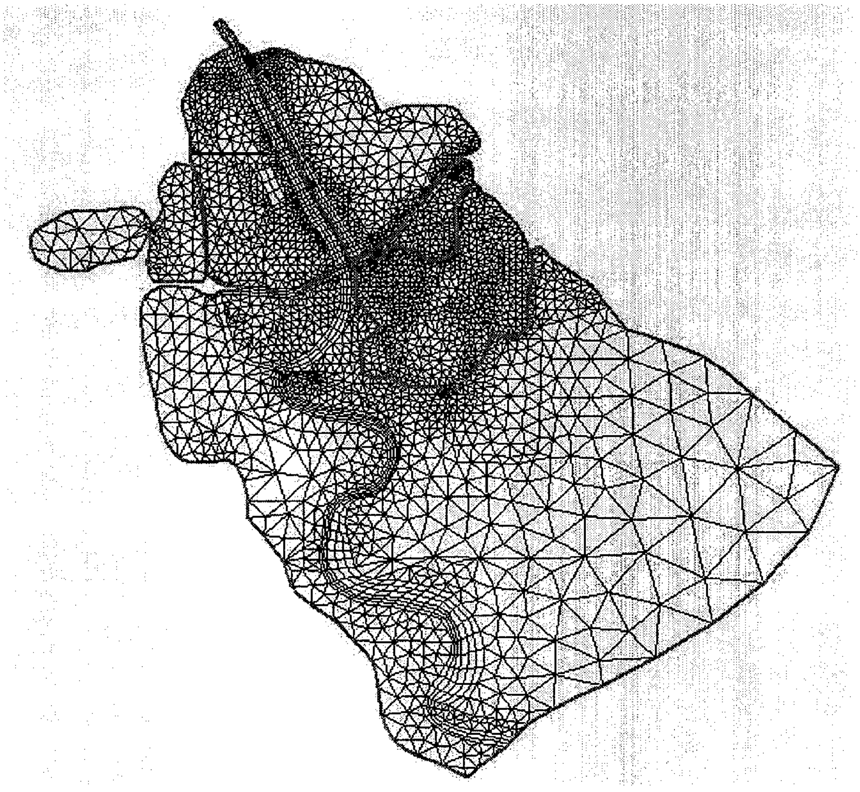


Figure 1: Mesh Representation of the Study Area.

A finite element mesh (see figure 1 and the broader scale plot included in the appendix) has been developed over an area approximately 8 miles long and 4 miles wide. The mesh starts near the railroad bridge just south of the city of Columbia and extends to a location approximately two miles downstream of Gills Creek.

The mesh was built using an "adaptive tessellation" technique for triangular elements and a "patch" technique for rectangular ones. In this case, the more computationally stable rectangular elements are used to define the channel, levees and road banks following a curvature/contour-dependent discretization strategy. This method uses long rectangular elements in the channel, which allows the model to represent cross-channel velocity and depth gradients with fewer elements than would be required using other element typology. Shorter elements are used in regions of high streamline curvature, which promotes the accurate representation of the velocity advection term with a minimum number of elements. Rectangular elements are also used to represent the levee and road bank with the intent of providing a more natural mesh representation. The model is computationally more stable during the wetting and drying process if rectangular elements are designed to follow the natural contour lines along those areas where sudden changes in elevation are expected. Rectangular elements are added at the upstream boundary to minimize any instability imposed by the boundary conditions before entering the main body of the mesh.

The main challenge in mesh discretization is a pragmatic one: the floodplain element size near the channel, potential levee breaches and bridge openings is determined by the channel, breaches and bridge width. This fixes the minimum total number of elements. This mesh contains almost 6,000 elements and uses variable resolution to incorporate the transition from the small elements at the channel, breach openings, etc., to the larger ones near the domain boundary.

Topographic information is developed from a combination of channel cross sections (from the original HEC-2 study), surveyed data provided by Lookwood Greene for Richland County, a recent topographic survey done by Lexington County, and a USGS stereophotogrammetric digital elevation model (DEM) with a resolution of 30 meters and a height precision of ±25 cm. These data are sampled onto the computational nodes of the mesh using a linear interpolation scheme to have a stable and physically realistic model solution. It is assumed that water will not overtop levees except at those locations where potential breaches are considered to happen. With this assumption, elements that lay on the top of the levees are excluded from the mesh and an internal boundary line is substituted. Slope adjustments were necessary at some locations along the Interstate Highway and the banks of the river. This modification helps model solution stability but does not affect the computed conveyance of the river channel. No detailed topography is available for the transverse levee that is located on the south side of Gills Creek so it has been omitted from the mesh.

The complete definition of the model geometry requires friction factors to be assigned at each mesh element. High resolution April, 2000 and May, 2000 orthorectified aerial photos are available and cover most of the expanded mesh. From this source and based on field investigation, areas with different vegetative conditions were located in the model (see following figures and plots enclosed in the appendix) and a specific friction factor was assigned. Adopted friction factors are listed in Table 2. A value for eddy viscosity is required to allow the model to solve the equations. As typical for all finite elements models, the eddy viscosity affects stability and turbulent fluid characteristics. We checked the solution for a range of eddy viscosities to see if there is an impact in the results.

In the section devoted to the description of the model calibration process a more detailed list of the adopted parameters are presented. At this point it is important to point out that two different techniques were adopted in the definition of the eddy viscosity number. The first is to specify directly an eddy viscosity value and the second is to let the model automatically compute an appropriate value via the "automatic Peclet number". The Peclet number is defined by the following equation:

$$P = \frac{\rho \cdot u \cdot dx}{E}$$

Where ρ is the fluid density, ***u*** is the average element velocity, ***dx*** is the length of the element in the stream wise direction and ***E*** is the eddy viscosity. Within the model we used both definitions of the eddy viscosity and let the model to decide where it was more appropriate to use one or the other method. Finally, wetting and drying parameters had to be specified as part of the geometry.

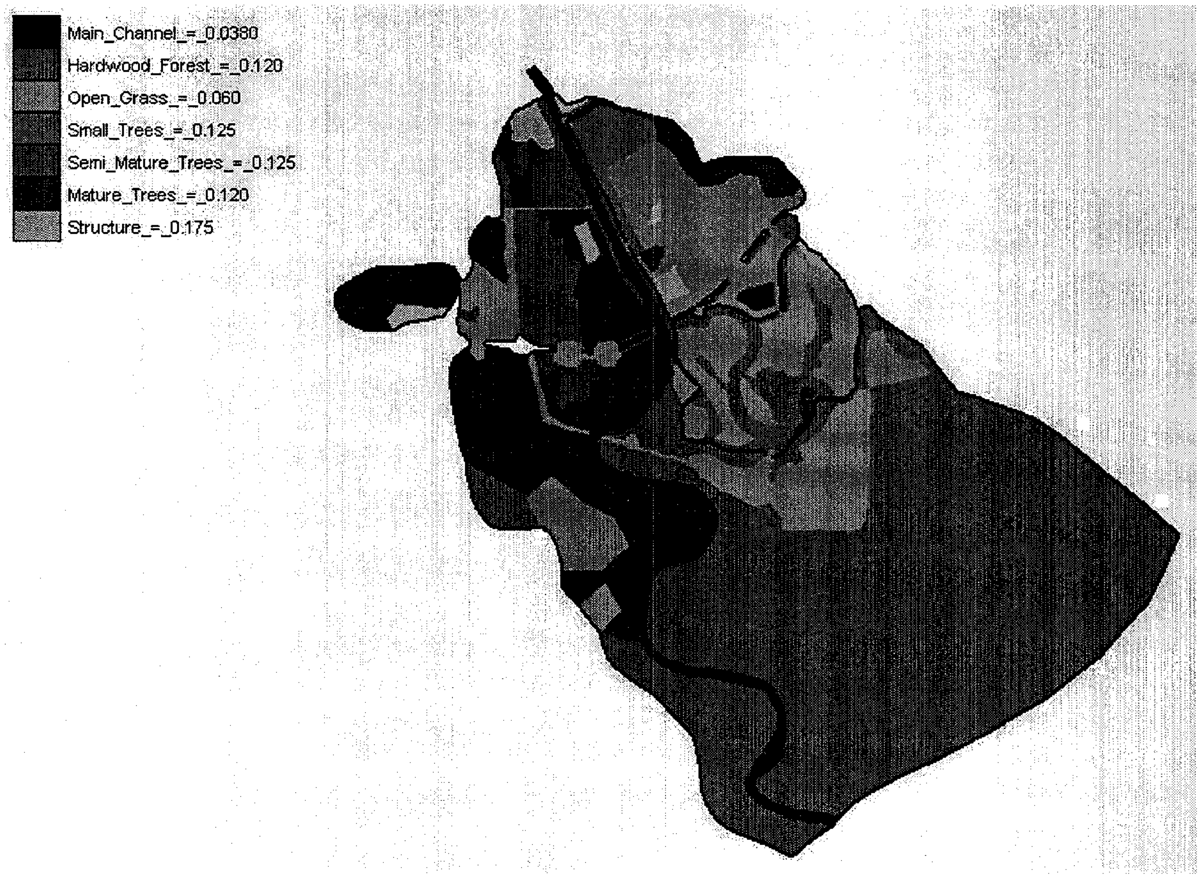
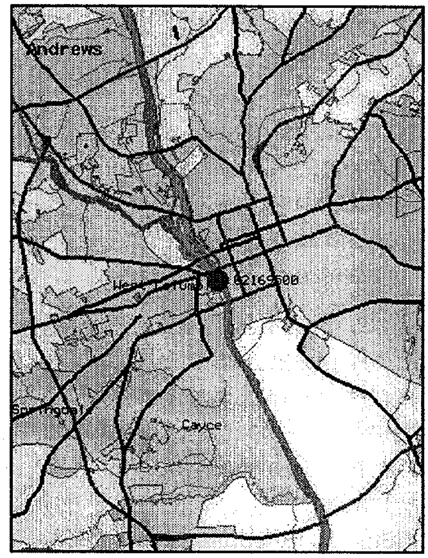


Figure 2: Material Property Distribution

Model Boundary Conditions



The main flooding source in the study area is the Congaree River. Additional inflow sources are Congaree Creek on west and Gills Creek on the east, south of the Interstate Highway. Stream gaging stations collect data for all of these sources. Data for the lower Congaree River have been collected since 1891 by the National Weather Service and the USGS at gaging station number 02169500. The figure on the right shows an approximate position of this station that is located just upstream of the railroad bridge.

Several studies have been conducted to estimate the 100-year peak flow. FEMA has chosen 292,000 cfs to use for the 100-year peak flow. An alternative value for the 100-year peak flow of 259,000 cfs was developed in a letter by Leo R. Beard. The analyses in this study consider both of these 100-year peak flow values. For the scope of this study, an inflow hydrograph is developed using a simple correlation between hourly recorded data for the 1976 flood and the estimated 100-year peak flow. Hourly-flow recorded data were retrieved from the USGS data store for the flood event that happened during the August, 1976 which had a peak of 155,000 cfs. Those records were then linearly correlated to the 100-year peak flow to provide a 100-year flood hydrograph. The result of this analysis is displayed in figure 3. Recorded and estimated data are reported in an appendix.

The other two additional inflow sources were analyzed as well. Data for the 1976 event are available from gage stations 02169550 and 02169570. Daily flow data were collected and analyzed during the 7 day flood and are displayed in

Figure 4. Statistical analysis was not conducted for these two sources. Figure 3 and

Figure 4 show events that tributary flows are of three orders of magnitude different from the main stem flow. For this reason, and considering that any additional inflow boundary condition could be a source of numerical instability for the model, we are not incorporating the tributary inflows in this analysis.

Table 1 summarizes the information related with the USGS gage station used in this study.

Station Number	Station Name	Latitude	Longitude	County	Drainage Area	Datum	Record Period	Peak Flow
		(ddmmss)	(ddmmss)		(square miles)	(ft above NGVD)	(years)	(CFS)
02169500	Congaree River at Columbia, SC	335935	810300	Lexington	7850	113.02	1852 - 1998	155,000
02169550	Congaree Creek at Cayce, SC	335615	810440	Lexington	122	128.98	1959 -1980	1,840
02169570	Gills Creek at Columbia, SC	335922	805828	Richland	59.6	137.38	1967 - 1998	2,880

Table 1: USGS Gage station at the Congaree River confluence

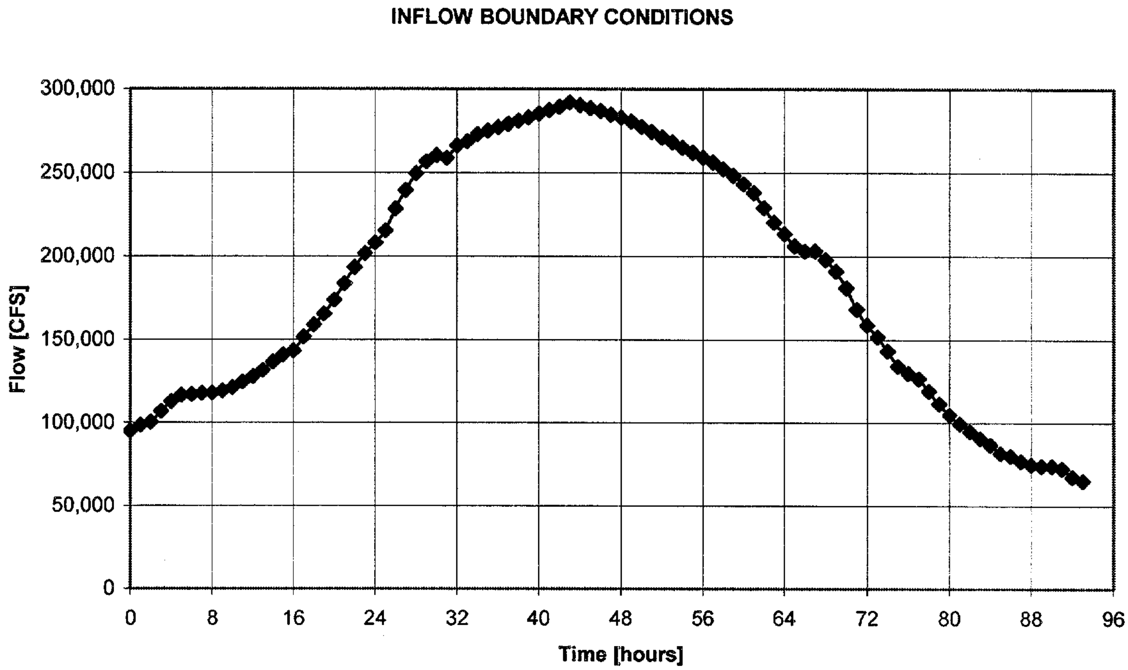


Figure 3: Inflow Hydrograph.

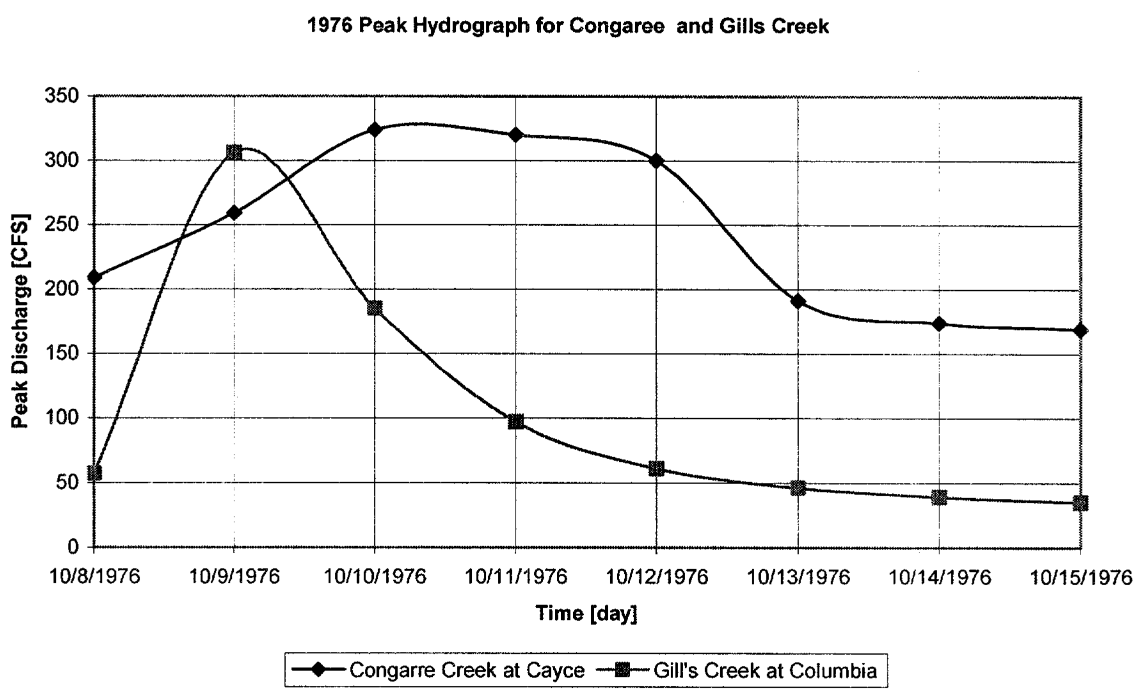


Figure 4: Lateral Inflow Hydrographs.

In order to develop a downstream boundary condition for both the steady-state and dynamic analysis, stage-elevation data is necessary. No measured information is available at the downstream model location. A common practice is to set up such a boundary near a gaging site where recorded data are available. Unfortunately, such information is available only too far downstream to make it feasible for the development of the mesh to be extended to those locations. The FEMA and USGS studies introduce errors at the downstream boundary of the steady state model because the mesh terminates too close to an important part of the study (i.e. the Interstate 77 bridge and the existing levees). For this reason we have developed an additional one-dimensional unsteady model using the computer program UNET. This model requires geometry cross-section information, stream slope values and roughness cross-section data. This information was developed from a stereophotogrammetric digital elevation model (DEM) retrieved from USGS along an area stretching from the intake canal to Lake Marion located several miles downstream. At this location, records for the lake stage elevation are available.

The DEM data provide a 30 x 30 meter point grid that was later used to develop a Digital Terrain Model (DTM) which provided enough data resolution to generate cross sections for the UNET model. The upstream cross section is located just downstream of the railroad bridge. At the downstream side, the railway line that crosses Lake Marion at the border between Sumter and Clarendon County was used to establish the model boundary line. The same inflow hydrograph later used in the 2-D unsteady model was adopted for the UNET model. At the downstream side, a fixed water surface elevation was estimated.

Results for the UNET model provided information for the RMA-2 model at the downstream side. Such data are reported in the following graph. The UNET cross section locations are displayed in PLATE 3 enclosed in appendix.

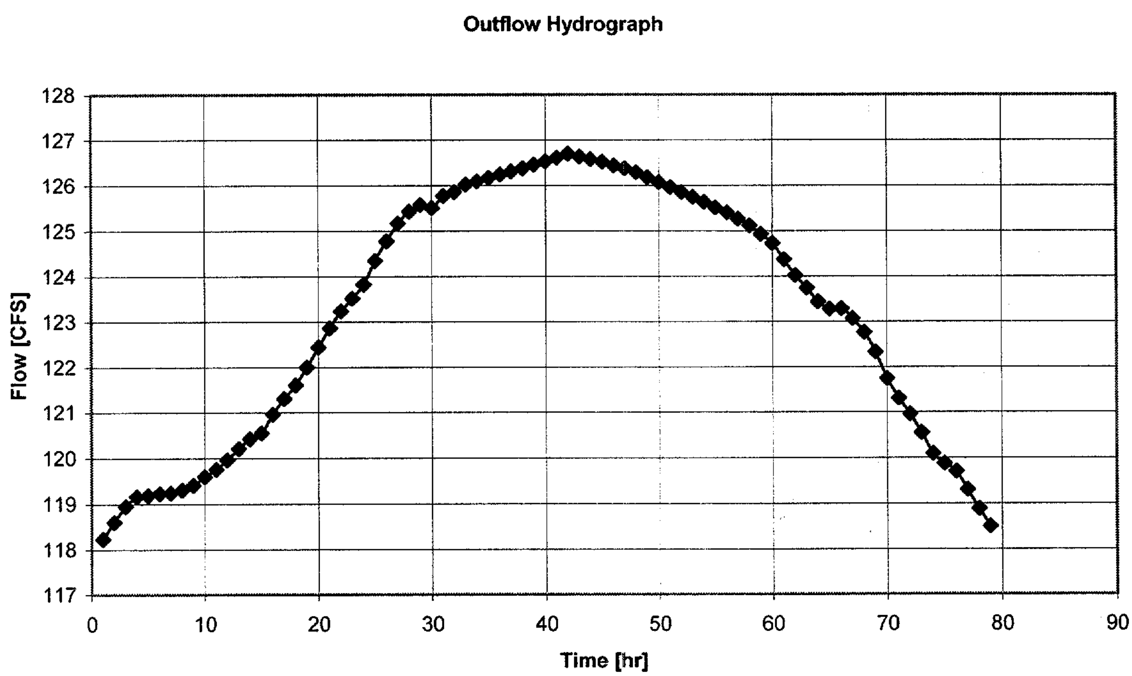


Figure 5: Outflow Stage Elevation Conditions.

Model Validation

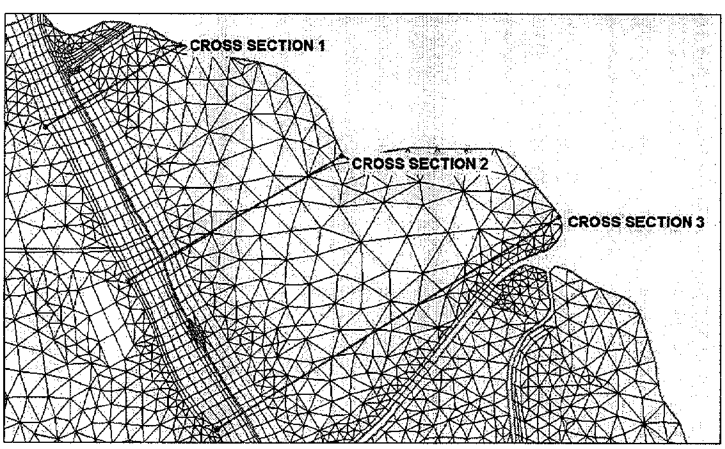
One challenge in the application of a two-dimensional model is the lack of appropriate distributed validation and calibration data. Previous studies have used a number of points hydrometric data recorded during past floods in order to calibrate the model. In particular, data recorded for the 1976 flood were used in the calibration process of the USGS model specifically developed to represent the existing topography of that time (Interstate-77 was not completed yet). The validation was limited to stage measurement within the reach. Using point (essentially zero-dimensional in space) data to validate a two-dimensional model is difficult. Further more there are no data to assess whether spatial flow patterns are being reproduced by the model. In this situation, the model's parameters are changed and the sensitivity of the results assessed.

The main unconstrained parameters in the modeling problem are the friction coefficients. These are used as calibration parameters. Simulations were performed using a steady state analysis. The adopted geometrical scheme for the sensitivity testing is the one with breaches developed in the north levee side, along the Congaree River and through exit points along both southern levees. In order to exhaustively perform the test, one strategy would be to perform simulations at a number of points spanning the complete parameter space, but given the computationally intensive nature of the modeling problem on this size of mesh, a more practical approach is adopted. Manning's number were globally varied within a range of +5% to -10% around the base line value shown in the following table.

MATERIAL DESCRIPTION	*N*
Main Channel	0.0380
Hardwood Dense Forest	0.1200
Cleared Area (open grass)	0.0600
Small Trees	0.1250
Semi Mature Trees	0.1250
Mature Trees	0.1200
Area with structures	0.1750

Table 2: Proposed Friction Factors

These values span a greater range of that suggested by manuals, common hydraulic experience and the USGS calibration process for the previous RMA-2 model, but at the same time they do represent a transition between overprediction and underprediction of inundation extent and velocity magnitude. The assumption of uniform variation of friction makes for a manageable analysis. The velocity magnitude is plotted along three cross sections. Their locations are shown on the left figure and results are presented in Figure 7. The plot shows that mis-estimating the friction factor will affect velocity magnitude along the Congaree River, but not on the overbank area.



Velocity magnitude is defined as $\overline{V} = \sqrt{V_X^2 + V_Y^2}$ where V_X and V_Y represent respectively the X and Y velocity component in a Cartesian system and does not represent a velocity along the floodway direction.

A similar test was also performed to investigate the sensitivity of the model to the eddy viscosity term. Values of 50, 100 and 250 lb-sec/ft^2 were used. Results are presented along the three different cross sections (Figure 8) and indicate that the overbank flow velocities are insensitive to this parameter's variation.

The overall result of the calibration test shows that the model, along the Richland overbank, is not sensitive to adjustments in the eddy viscosity. The Manning's roughness coefficient as presented in the previous table where adopted for the analysis. The eddy viscosity number test shows that even in the case of a high estimate, the automatic Peclet assignment technique will not affect the result.

A measure of mass conservation is another check on the validity of model results for two reasons. First, it is easy to verify (compared with conservation of momentum), and second, it is more likely to be measured during real flood events. Most of the accuracy loss in model process representation occurs in the momentum equation, whereas the continuity equation is more likely to balance.

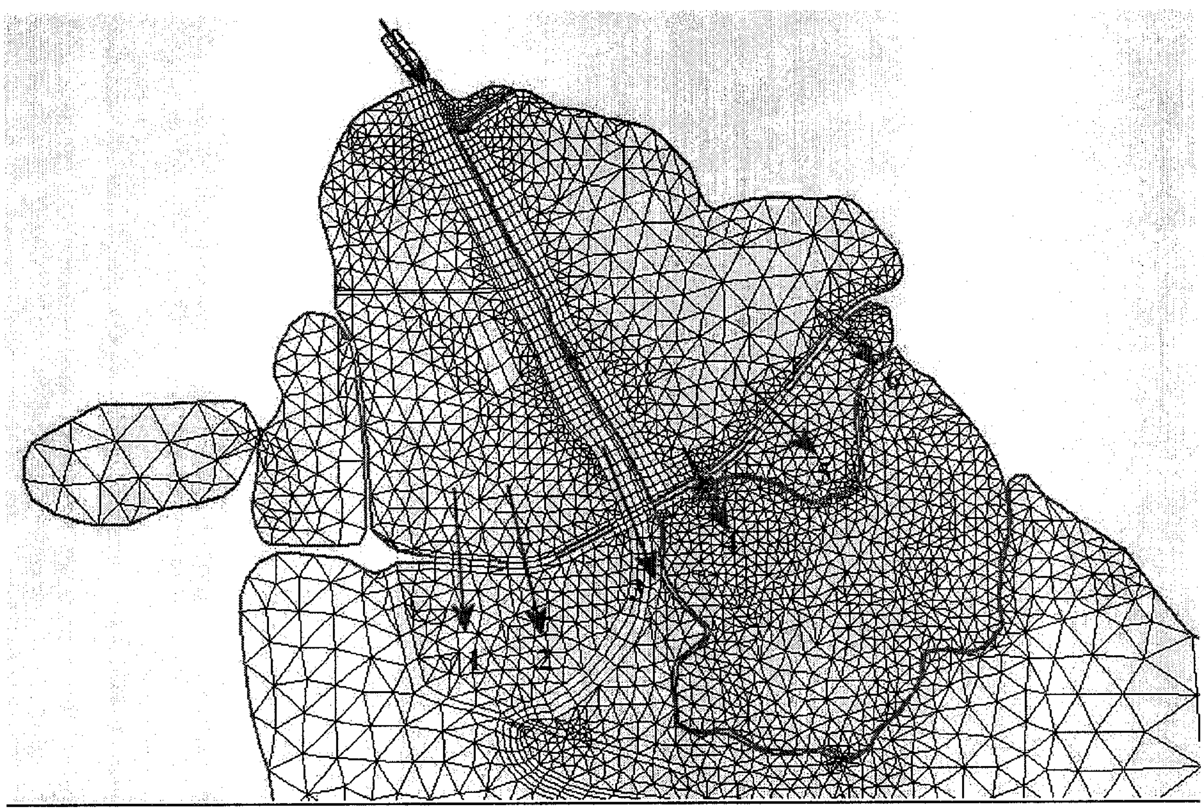


Figure 6: Continuity Check Lines.

A series of continuity check line were defined in the model to monitor the conservation of mass at different locations. In particular the geometry was refined and modified until the difference between the inflowing mass of water entering the model during a steady state run and the mass of water that exit the model at the downstream side was less than 1%. Continuity check line along the Interstate (as shown in Figure 6) were also placed to monitor the model quality at different location and evaluate the flow rate along different openings.

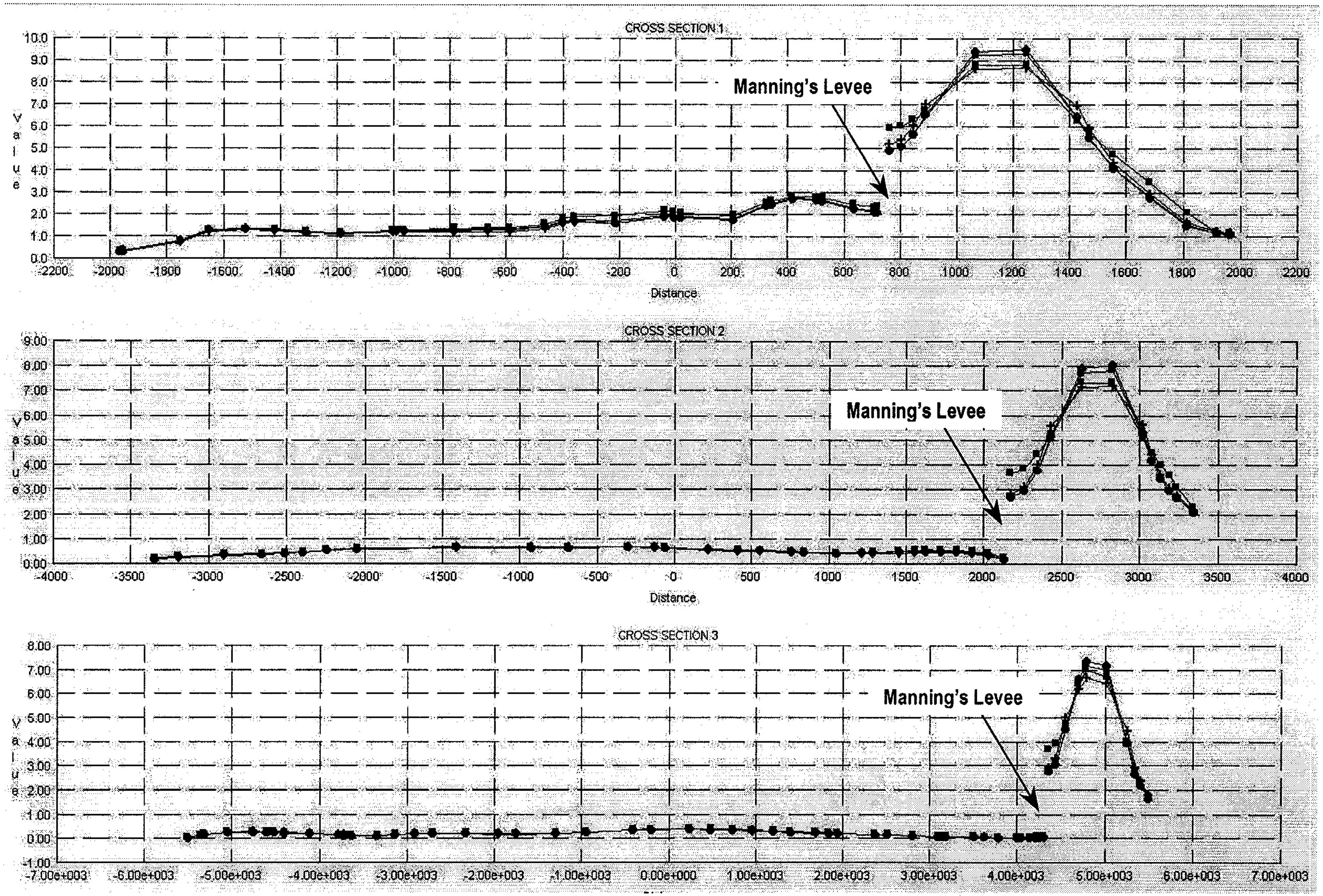


Figure 7: Sensitivity test on Manning's number along the three consecutive cross sections.

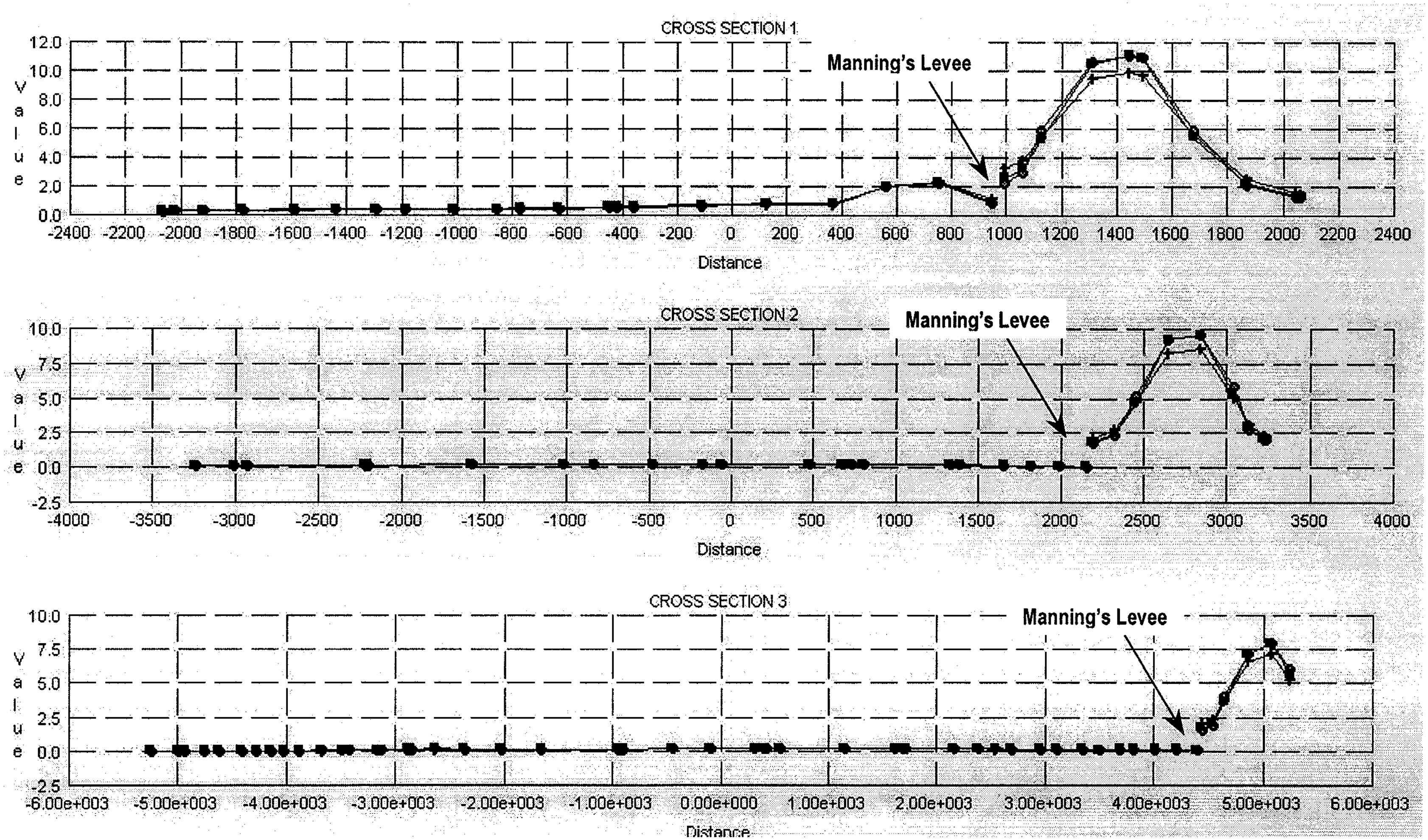


Figure 8: Sensitivity Test for Eddy Viscosity.

Modeling Different Breach Conditions with a Steady State Analysis

As discussed before, this study investigates the flow field on the Richland County overbank area east of the Congaree River. New topographic information allowed us to develop an expanded, more detailed RMA-2 model, that includes the effect of the Manning levee, the ring levee south of the Interstate 77, and the Gills Creek levee. With all these existing features introduced into the model we can determine floodplain velocities for several different levee breach scenarios.

The levee network and other physical features create a substantial impedance to the movement of floodwaters on the eastern side of the Congaree River. Geotechnical investigations have shown that a breach along the Manning levee is most likely to occur behind the Heathwood Hall School. FEMA considered the flooding condition if a breach is located at the upstream end of the Manning levee. This analysis considers these two breach locations as well as two others that allow water to exit the floodplain area and flow back into the main river. The potential breach locations are identified in Figure 9. The FEMA breach location is identified as "A". The most likely breach is identified as "B" in the figure and is located behind Heathwood Hall. In order to create a flow through situation, two additional breaches, labeled "C" and "D" are located on the ring levee and on the northern Gills Creek levee. There is a third levee on the south side of Gill's Creek that will influence flow behavior in the Richland County floodplain. This levee will further reduce floodplain conveyance but it was omitted from the mesh. These locations are displayed in the following sketch and in Plate 1 in the appendix.

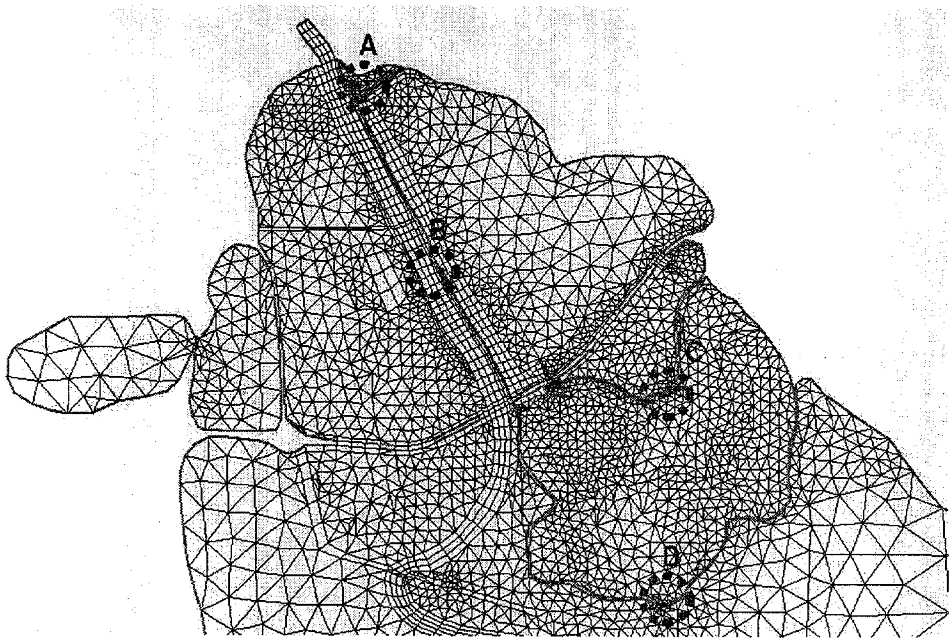


Figure 9: Potential Breach Locations.

Breach location "C" and "D" were not expressly identified in the geotechnical analysis. Their locations are chosen to achieve the worst-case flow through condition. These breach widths were assumed to be larger than the inflowing breach widths in order to prevent them from being a bottle neck. This assumption results in the maximum floodplain velocities behind the levees. We consider it unlikely that the outflow breaches will occur in the manner assumed and it is much more likely that will occur in a staggered alignment that would be difficult to anticipate and would result in less conveyance than computed in this study.

The first step in modeling the flood event is to establish the possible breach scenarios. The more realistic case would be for breach "A" and/or "B" to occur first, possibly at the peak of the 100-year event. Breach "C" and "D" may or may not occur but it is expected that, at the time of the breach, all the area upstream of these two levees will be filled with water.

Because the breach location is difficult to predict, several scenarios are evaluated. The following five scenarios were analyzed (refer to Figure 9 for the breach locations):

- CASE 1: breaches are located in positions "A", "C" and "D".
- CASE 2: breaches are located in positions "B", "C" and "D".
- CASE 3: breaches are located in positions "A", "B", "C" and "D".
- CASE 4: breaches are located as in CASE 3 but 12th Street was removed from the mesh.
- CASE 5: a breach is located in position "B" and a flow of 259,000 cfs is used.

CASES 1 to 4 use as inflow boundary condition the 100-year peak flow of 292,000 cfs and at the downstream boundary an elevation of 126.62 ft (derived as result from an HEC-RAS model that uses the same geometry adopted for the UNET model). CASE 5 uses an inflow value of 259,000 cfs and a water surface elevation of 125.51 ft at the downstream side.

CASE 1

CASE 1 models a breach 130 ft wide at Location A on the northern side of the Manning levee. Two other breaches are present in the area (respectively breach "C" and "D").

The following Figure 10 and Figure 11 show velocity magnitude and computed water surface elevation over the mesh (see print out in appendix C for further details). The velocity magnitude plot shows that velocities higher than 1 ft/sec are present along the river, at several opening locations and for few hundred feet in the floodplain direction that follows the breach in the northern side of the Manning's levee. The plot enclosed in appendix presents a velocity vector distribution in the study area and shows that the general direction for those vectors is not aligned with the main River direction therefore even where the velocity magnitudes are higher than one foot per second, it does not indicate effective conveyance through the floodplain. Note that the larger exhibits in the appendix are more detailed, and have greater resolution in the color scales. Therefore the colors shown in the Figures in the text of the report do not necessarily match the corresponding exhibits shown in the appendix.

Water surface elevations are displayed in the following figure. The downstream boundary condition uses a 126.62 ft elevation from the one-dimensional flow analysis.

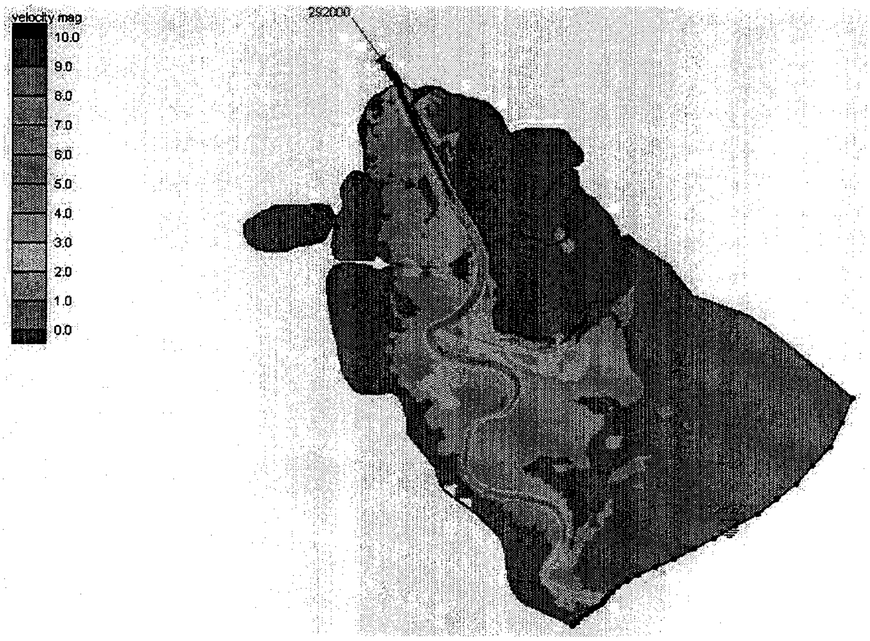


Figure 10: Velocity Magnitude "CASE 1".

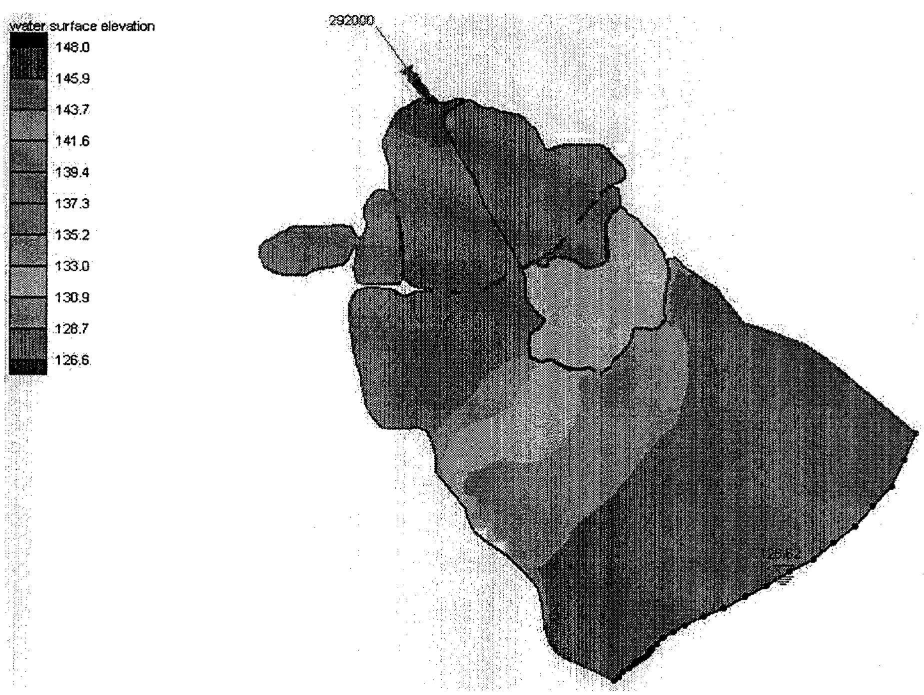


Figure 11: Waters Surface Elevation "CASE 1".

Table 3 at the end of this chapter displays computed flux values through the various openings. Computed flux through breach "A" is approximately 8,300 ft³/sec.

CASE 2

This scenario assumes that the most likely breach occurs at location "B". In conjunction, breaches also occur at locations "C" and "D". Breach "B" is located behind Heathwood Hall School and has a width of approximately 200 ft. The breach width considered here is wider than the expected width to illustrate the lack of conveyance in the floodplain area. Velocity magnitude inside Richland County overbank area is almost zero except at the two downstream breach locations "C" and "D". Water surface elevation behaves similar to the previous case.

Results are graphically displayed in Figures 12 and 13 and in larger scale print out included in appendix C. Computed flux thought different openings is summarized in Table 3 at the end of this chapter. The flux through breach "B" at the peak is 20,184 ft³/sec to illustrate floodplain conveyance. The actual maximum flow into the floodplain would be similar to Case 1.

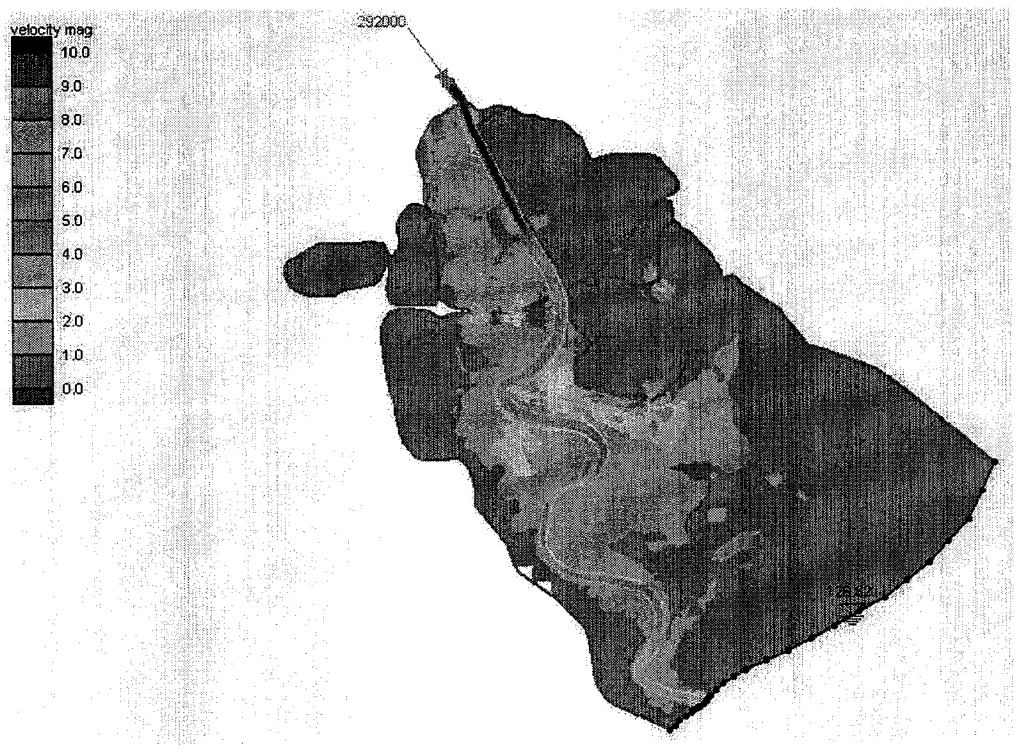


Figure 12: Velocity Magnitude "CASE 2".

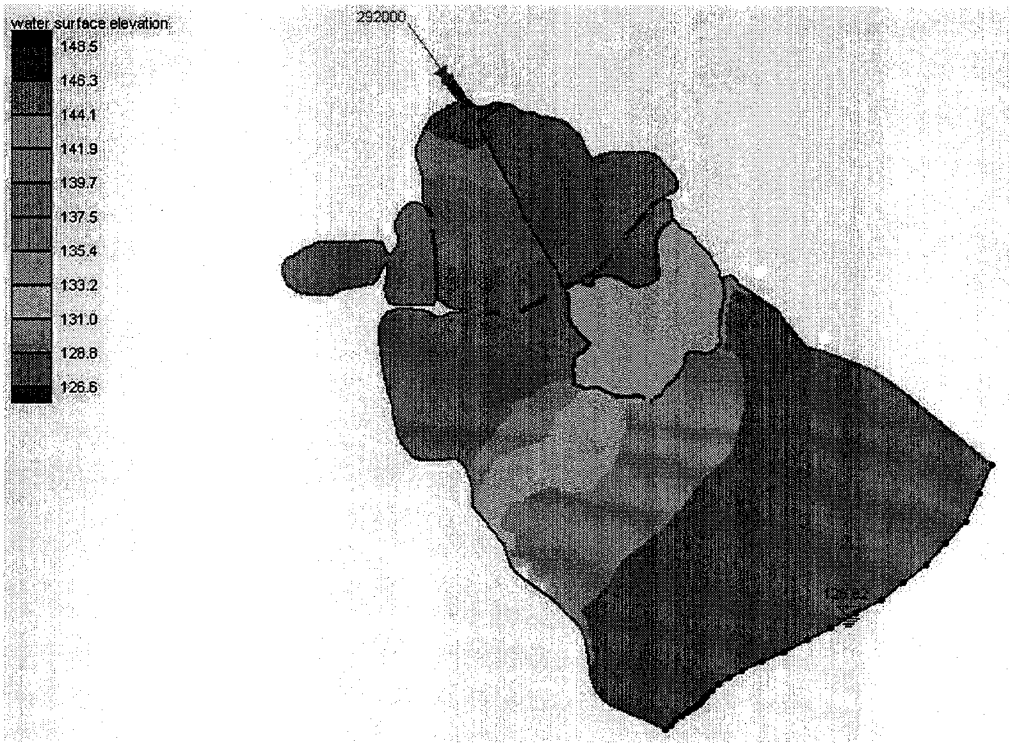


Figure 13: Water Surface Elevation "CASE 2".

CASE 3

We consider this dual inflow breach scenario to be very unlikely. When a breach occurs and begins to fill the interior area, it reduces the differential head along other parts of the levee making them less likely fail. This scenario examines the flood behavior in the event that all of the breaches are fully developed at the peak of the 100-year flood. The computed magnitudes and directions of flow still do not exhibit a floodway for this scenario. The reasons are that the velocity magnitude in the Richland County overbank is still less than 1 ft/s, and the velocity vectors indicate that some of the flow directions are opposite to the main direction of river flow. Figure 15 on the following page presents the computed water surface elevation over the mesh. Due to the presence of the double breach north of the I-77, the inflow rate is higher than in the previous scenarios and consequently the computed surface elevation is higher. An average 139 ft water surface elevation was computed in the north side of the Richland overbank. This elevation drops down to 136 ft in the area controlled by breach "C" and 134 ft at breach "D".

Outflow through the breach in the north part of the Manning levee is approximately 8,000 ft^3/sec and approximately 12,400 ft^3/sec enters the overbank from the breach behind Heathwood Hall School.

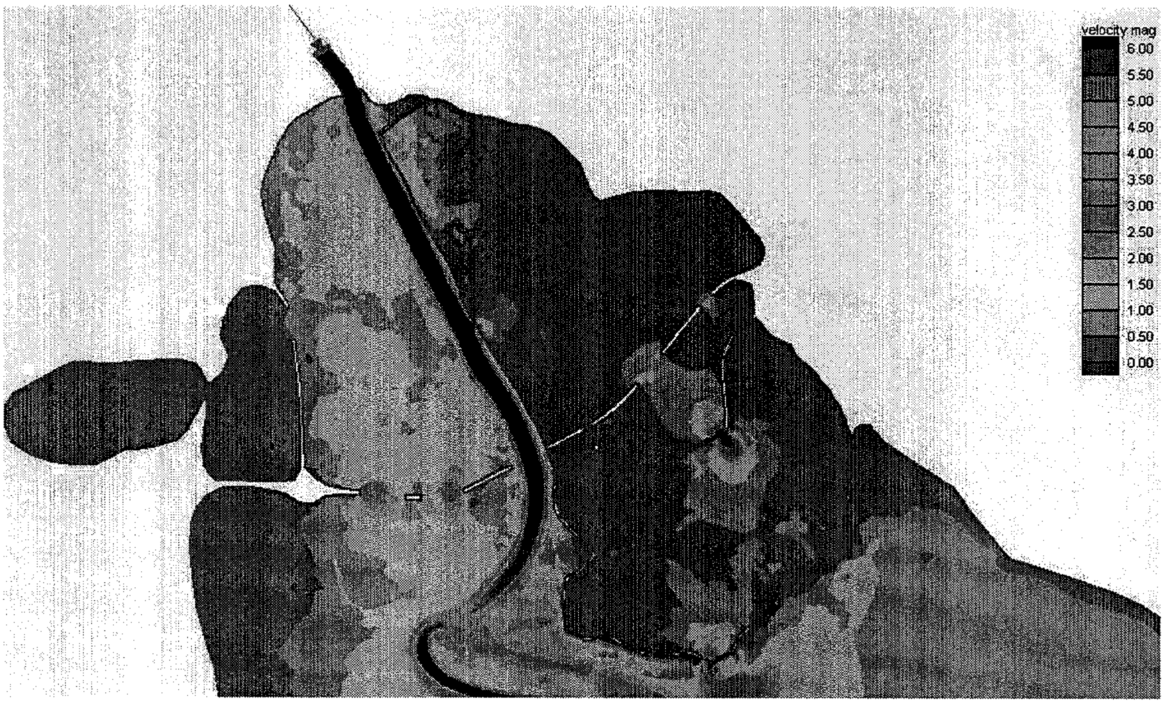


Figure 14: Velocity Magnitude "CASE 3".

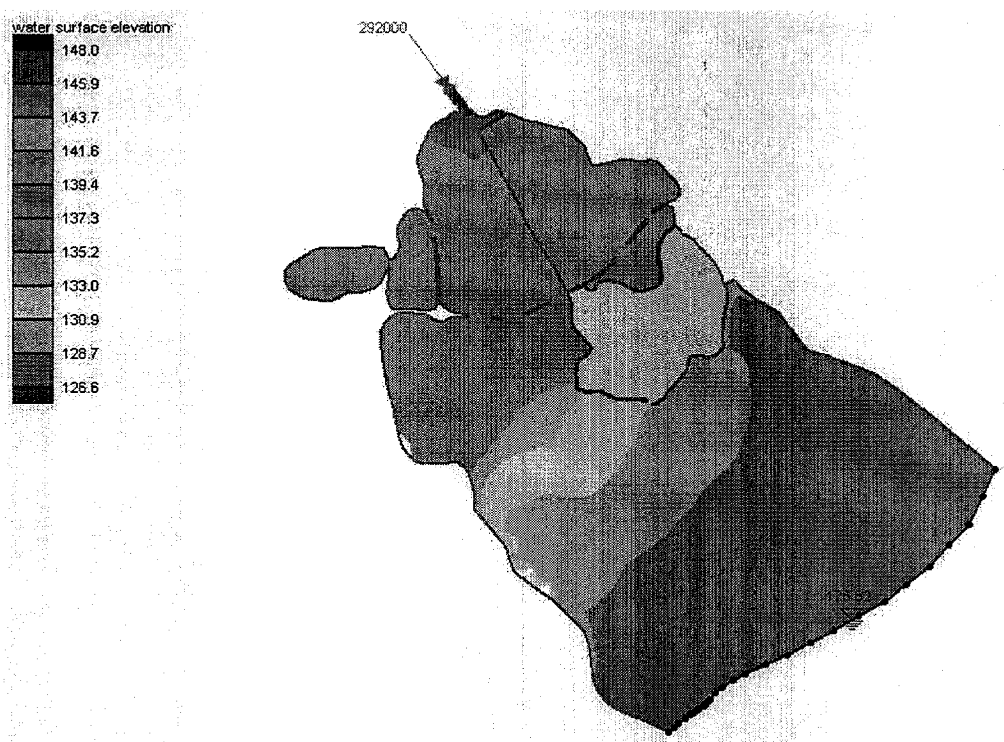


Figure 15: Water Surface Elevation "CASE 3".

CASE 4

This scenario presents breaches at the same location as CASE 3 except the 12th Street embankment was excluded from the study and the additional bridge under Interstate 77 was added. The pre-road ground elevations were assigned to the mesh nodes in that area. The existing bridge opening along the Interstate increases the amount of water circulation on the west overbank.

The computed results in the Richland County overbank are substantially unchanged from the previous scenario. In the Lexington County overbank area, the absence of 12th Street slightly decreases the computed water surface elevations compared to the previous scenarios.

Figure 16 and Figure 17 displays these results. Table 3 summarizes computed flux through different openings and breaches. Additional plots are attached to this report in appendix C.

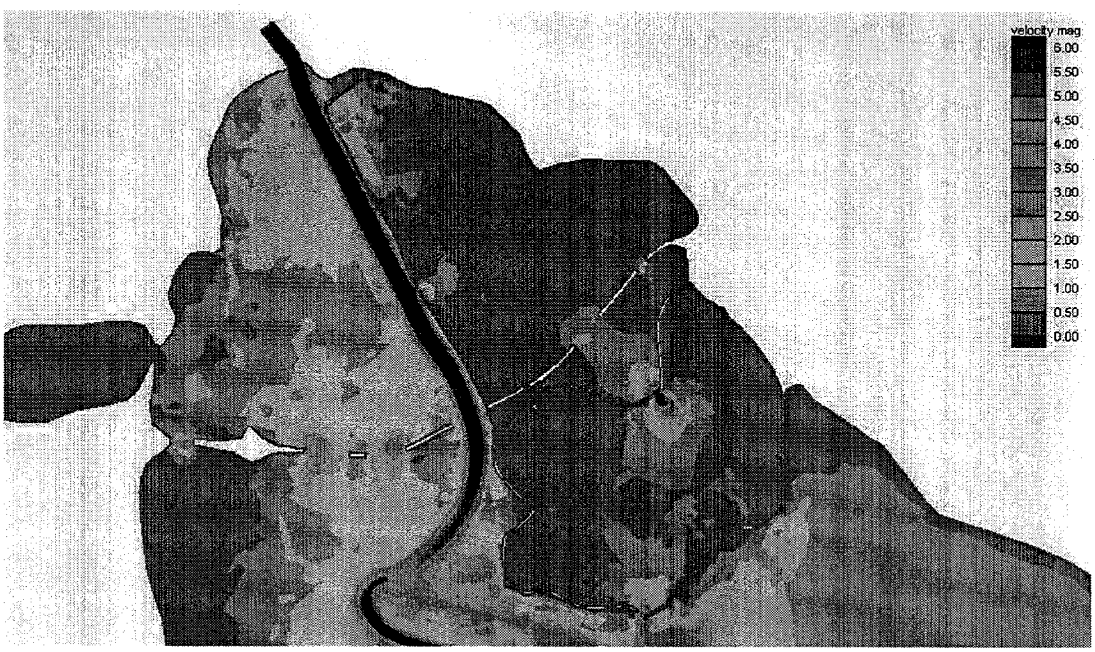


Figure 16: Velocity magnitude "CASE 4"

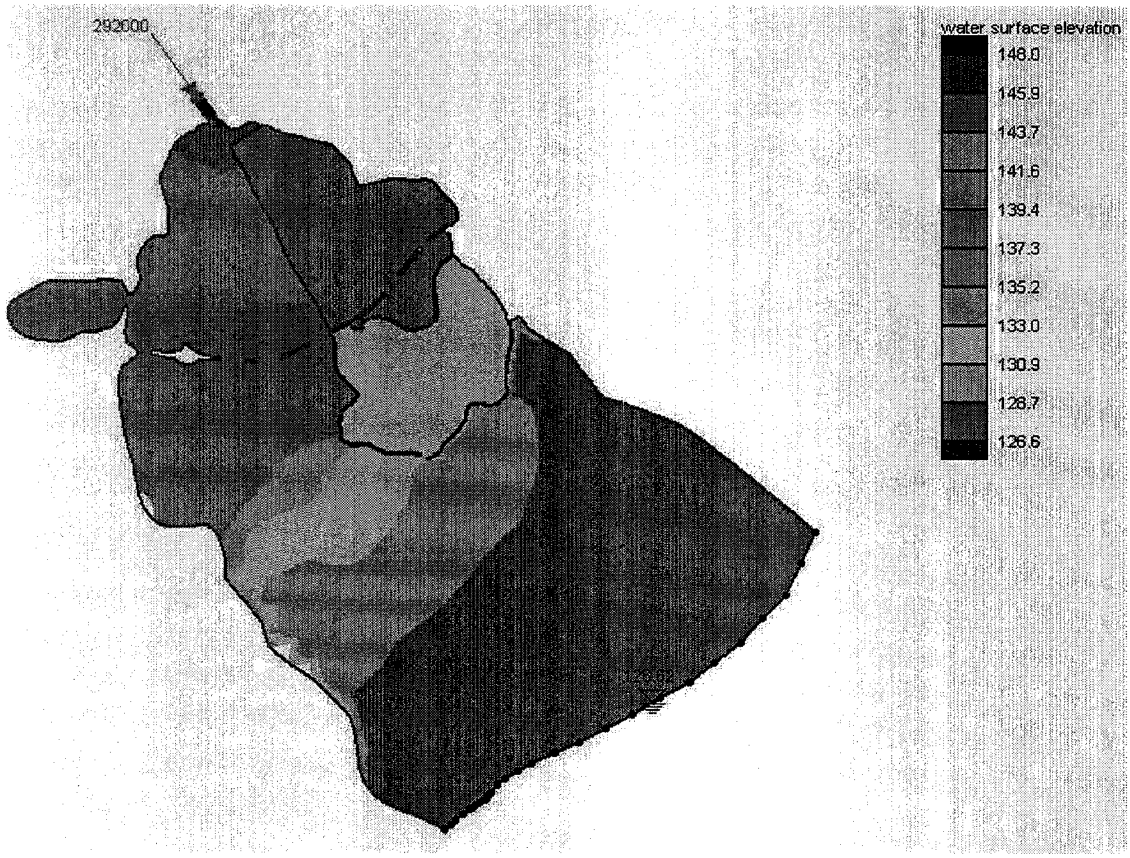


Figure 17:Water Surface Elevation "CASE 4".

CASE 5

For this scenario it is assumed that a breach occurs only at location "B" behind Heathwood Hall School. A second breach ("D") is left open at the downstream side of the model geometry to avoid the presence of disconnected area from the main mesh. In this case, the 100-year peak flow value of 259,000 cfs is used. For this condition velocities in the Richland County overbank area are basically 0. The water surface elevation in the ponding area for this reduced flow is not high enough to cause overtopping failure of the ring levee. It would have to fail via a piping mechanism in order to achieve a flow through situation. Figure 18 and Figure 19 graphically presents results for this scenario.

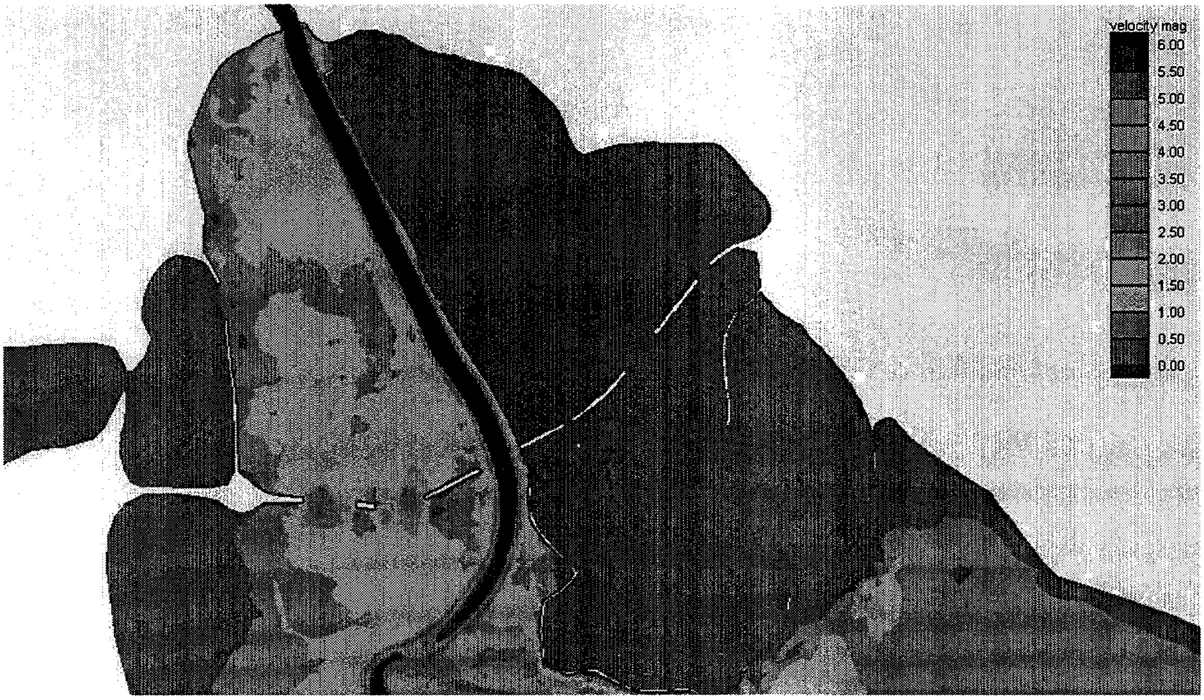


Figure 18: Velocity Magnitude "CASE 5".

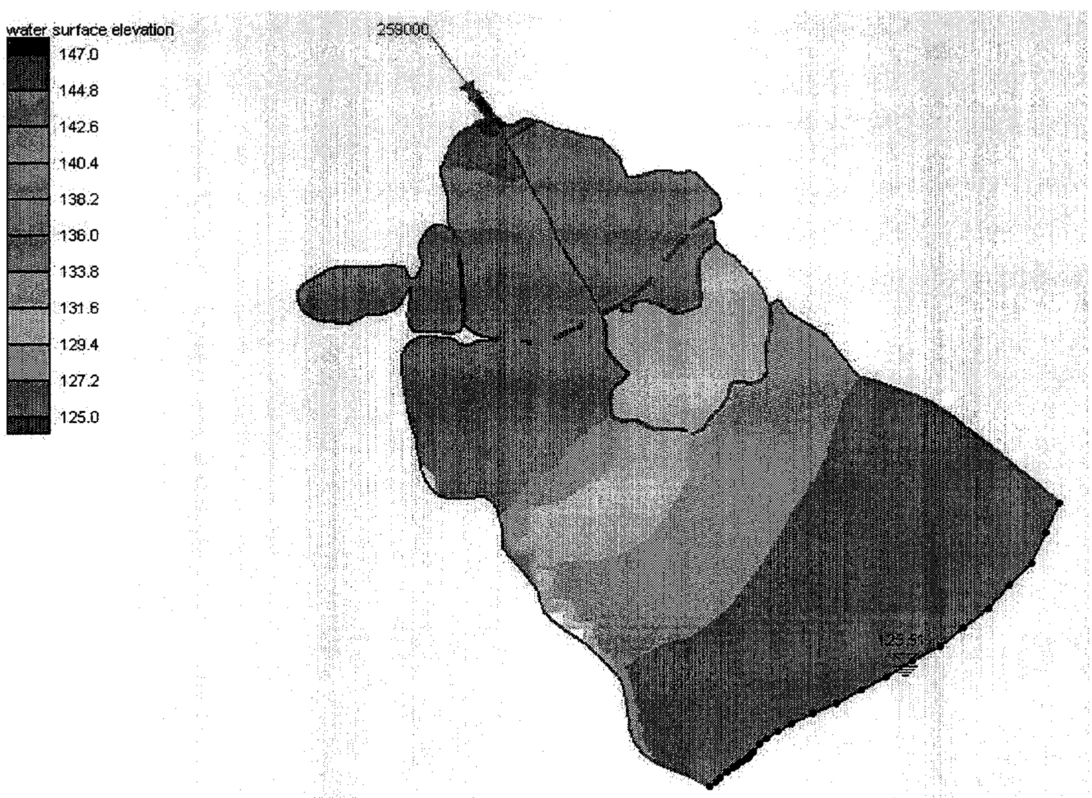


Figure 19: Water Surface Elevation "CASE 5".

In Table 3, continuity flux check line results are displayed for each opening for all scenarios. Reference for locating openings is found in Figure 6 and in Figure 9. The continuity check line is part of the RMA-2 print out result and it is reported in Appendix B.

A negative number in the table indicates that flux was traveling in a reverse direction through the continuity check line.

FLUX LINE	DESCRIPTION	WIDTH [ft]	CASE 1	CASE 2	CASE 3 [ft^3/sec]	CASE 4	CASE 5
1	*Inflow BC*	495	292,000	292,000	292,000	292,000	259,000
2	*Outflow BC*	28305	292,018	292,018	292,023	292,014	259,033
3	*Breach "A"*	130	8,308	***n/a***	7,975	7,837	***n/a***
4	*Breach "B"*	205	***n/a***	20,184	12,372	12,236	-101
5	*Breach "C"*	250	16,388	23,693	27,733	27,267	***n/a***
6	*Breach "D"*	430	13,698	20,826	24,821	24,364	-820
7	*Opening 1*	1560	42,385	40,722	39,645	40,690	38,102
8	*Opening 2*	1440	52,327	50,527	49,536	48,445	48,099
9	*Opening 3*	1350	168,820	165,137	163,296	158,670	161,264
10	*Opening 4*	210	104	352	528	506	3
11	*Opening 5*	1380	11,885	17,344	20,035	19,717	-8
12	*Opening 6*	535	1,983	3,298	4,173	4,078	4

Table 3: Continuity flux check line result along the model

Conclusion

Based on the definition and purpose of a floodway, and the results of this expanded two dimensional flow analysis, this study concludes that there is no floodway on the Richland County, South Carolina side of the Congaree River downstream of the City of Columbia. It was necessary to analyze flow characteristics on both sides of the Congaree River floodplain. However, no change to the Lexington County floodway delineation as shown in the September 26, 2000 map by FEMA occurs as a result of this study. The floodplain on the Richland County side of the river is not an unobstructed waterway and the analysis reinforces this fact. The only way for water to enter the floodplain is via a flood-caused levee breach. Considering worst-case conditions, the flow patterns are divergent, and the floodplain areas with flow velocities greater than one foot per second are discontinuous. No coherent corridor to convey floodwaters exists on the Richland County side of the Congaree River.

This study was prepared by [redacted], Registered Civil Engineer No. [redacted] as conferred by the State of California, Board of Registration of Professional Engineers.