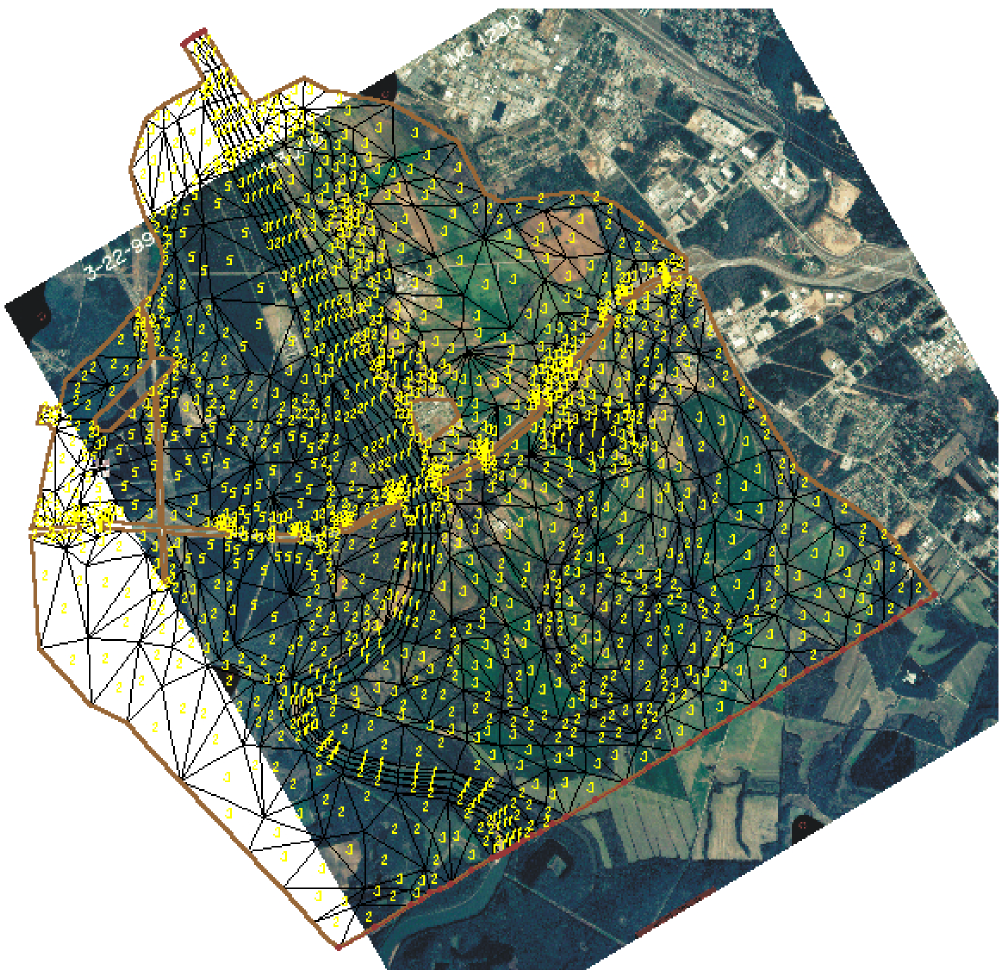
Appeal Resolution for Congaree River in Richland and Lexington Counties, South Carolina



September 26, 2000

Executive Summary

On August 12, 1999, the Federal Emergency Management Agency (FEMA) issued revised preliminary Flood Insurance Studies (FISs) and Flood Insurance Rate Maps (FIRMs) for Lexington County, South Carolina and Incorporated Areas, and for Richland County, South Carolina and Incorporated Areas to reflect a revised study of the Congaree River. FEMA received a large quantity of correspondence on these draft FISs and FIRMs, and in a letter dated March 17, 2000, FEMA officially recognized three parties as appellants under Part 67 of the NFIP regulations. Please note that Part 67 of the NFIP regulations applies only to Base Flood Elevations (BFEs); the floodway cannot be appealed. Each of these three parties provided detailed technical data and alternative analyses of the Congaree River floodplain. These parties are: Dr. John Grego, University of South Carolina; Dr. Paul A. Sandifer, South Carolina Department of Natural Resources; and Ms. Deborah A. Hottel, McNair Law Firm, P.A.

Dr. Grego and the SCDNR appealed the assumptions and methods used to determine the 1% annual chance (100-year) discharge, which in turn is used to determine the BFEs. Both appellants asserted that the entire record for the USGS gage for the Congaree River at Columbia from 1892 to the present should be used, and each provided an alternative statistical analysis of the data.

The SCDNR also appealed assumptions made in the HEC-2 hydraulic model of the Congaree River, which affect both BFEs and the floodway delineation. Specifically, the SCDNR appealed the assumption that no conveyance would occur landward of Manning's dike.

The report prepared by Braswell Engineering, Inc., submitted by Ms. Hottel, appealed roughness coefficients used in the HEC-2 hydraulic model of the Congaree River, which affect both BFEs and the floodway delineation.

Due to the complexity of the technical issues involved and the amount of data received, it was necessary for FEMA to perform additional analyses and develop a new HEC-2 hydraulic model of the Congaree River to resolve the appeals.

Discharge

The 1% annual chance (100-year) discharge for the Congaree River at the Columbia gage has been revised from 253,000 cfs to 292,000 cfs. The revised discharge is based on a weighted frequency curve that combines analyses based on two different methods and data sets. The first method was based on a Bulletin 17B analysis that used the Maintenance of Variance Extension (MOVE.2) to estimate regulated peak flows for 1926-29 and used the observed regulated peak flows from 1930 to 1998. The second method was also based on a Bulletin 17B analysis that used MOVE.2 to estimate regulated peak flows from 1892 to 1929 and used the observed regulated peak flows from 1930 to 1998. The two frequency curves were combined by weighting the flood discharges of the two methods inversely proportional to their variances. This approach is consistent with Equation 8-1 of Appendix 8 of Bulletin 17B.

In the determination of the revised discharge, FEMA performed flood frequency analyses for the Congaree River using four different methods and summarized these results in a July 21, 2000 report. This report was reviewed by the U.S. Geological Survey (USGS) and their recommendation was to weight the results from the two methods described above. FEMA provided the results of the weighted frequency computation to the USGS and they concurred that 292,000 cfs is a valid estimate of the 1-percent annual chance discharge for the Congaree River at Columbia, South Carolina.

BFEs

Due to the width of the floodplain, the presence of uncertified dikes and multiple openings in Interstate 77, the lower Congaree River floodplain is difficult to model. These complexities were addressed by using a two-dimensional steady flow model, which can determine water-surface elevation and velocity at any point in the floodplain. The two-dimensional steady flow model used in this appeal resolution is based on earlier models created by the U.S. Geological Survey and the South Carolina Department of Transportation to design Interstate 77 and the 12th Street Extension. This two-dimensional model was used to analyze flow patterns and conveyance landward of Manning's. This tool allowed us to model a variety of likely dike failure scenarios during the base flood. The results showed that a significant amount of flow could be expected behind the breached dike during a 100-year flood.

In this situation, our guidelines require that we show different BFEs landward of the breached dike than riverward of the dike. This is because the highest water-surface elevations in Lexington County will occur before the dike breaches, while water-surface elevations across the floodplain will be lowered after the dike breaches. The highest water-surface elevations in Richland County will occur after the dike breaches. BFEs landward of the dike are 1 to 2 feet lower than those riverward of the dike.

Based on these new hydraulic analyses and the discharge of 292,000 cfs, BFEs were computed using a one-dimensional hydraulic model. The one-dimensional model was calibrated to reproduce two-dimensional results. BFEs on the landward side of the dike are 1 to 2 feet lower than those shown on the August 12, 1999 preliminary FIRMs. BFEs on the riverward side of the dike are 1 to 2 feet higher than those shown on the August 12, 1999 preliminary FIRMs.

Floodway

Using the computed discharge of 292,000 cfs and the two-dimensional model previously mentioned, it was determined that significant conveyance of flow behind Manning's dike is likely. As such, FEMA guidelines require that the floodway be computed using the equal conveyance reduction method. The results show the floodway both widening and narrowing in Lexington County when compared to the August 12, 1999 preliminary FIRMs. The widening in Lexington County is approximately 1,000 feet, and the maximum narrowing is approximately 500 feet. On the Richland side, the floodway primarily widens; the average widening is on the order of 4,500 feet, and the maximum increase in width is approximately 7,200 feet.

Conclusion

Based on the revised hydrologic and hydraulic analyses for the Congaree River, the FISs and FIRMs have been revised to show a generally wider floodway, decreased BFEs in Richland County, and increased BFEs in Lexington County.

Contents

Introduction

On August 12, 1999, the Federal Emergency Management Agency (FEMA) issued revised preliminary Flood Insurance Studies (FISs) and Flood Insurance Rate Maps (FIRMs) for Lexington County, South Carolina and Incorporated Areas, and for Richland County, South Carolina and Incorporated Areas. These FISs and FIRMs reflect a revised study of the Congaree River. Following the issuance of these FISs and FIRMs, the affected counties and communities were provided 30 days in which to comment on their FISs and FIRMs, which was followed by a 90-day appeal period. This was done in accordance with Section 67.5 of the National Flood Insurance Program (NFIP) regulations. The appeal period ended on December 13, 1999.

FEMA received a large quantity of correspondence following the issuance of the revised preliminary FISs and FIRMs on August 12, 1999. In a letter dated March 17, 2000, FEMA officially recognized three parties as appellants under Part 67 of the NFIP regulations. Each of these three parties provided detailed technical data and alternative analyses of the Congaree River floodplain. These parties are Dr. John Grego, University of South Carolina; Dr. Paul A. Sandifer, South Carolina Department of Natural Resources (SCDNR); and Ms. Deborah A. Hottel, McNair Law Firm, P.A. While only these three parties were formally recognized as appellants, all of the comments received were taken into consideration in resolving the recognized appeals. Please note that under Part 67 of the NFIP regulations, only flood elevations may be appealed. Therefore, FEMA has considered concerns with the floodway delineation as "protests." The floodway is provided as a tool for floodplain management.

FEMA received the following information, which was used in resolving the appeals:

- a report, dated December 3, 1999, revised on December 13, 1999, and January 28, 2000, prepared by Dr. Grego, titled Appeal of FEMA's Draft Flood Insurance Study for Richland County, providing an alternative statistical analysis of the Congaree River gage at Columbia;

- a report, dated November 30, 1999, prepared by Braswell Engineering, Inc., titled Proposed Revision to the Congaree River Floodway, including a HEC-2 hydraulic model modified to reflect field-observed Manning's "n" values;

- a report, dated December 10, 1999, prepared by the SCDNR, titled SCDNR Appeal of Preliminary Flood Insurance Study-Richland/Lexington Counties, South Carolina, including a Bulletin 17B frequency analysis (computer program PEAKFQ) of the Congaree River gage at Columbia;

- a letter and untitled report, dated April 13, 2000, prepared by SCDNR, including a Bulletin 17B frequency analysis (computer program PEAKFQ) of the Congaree River gage at Columbia and a HEC-2 hydraulic model of the Congaree River that allows conveyance landward of Manning's levee;

- a trial transcript dated 1987 for Burwell Manning, Jr., et. al., v. City of Columbia, describing a levee failure and flood damage that occurred in 1976;

- a report, dated December 9, 1976, by Law Engineering Testing Company, titled Report of Geotechnical Investigation of Dike Failure – Metropolitan Wastewater Treatment Plant, City of Columbia, SC, investigating the dike failure that occurred in 1976;

- an undated videocassette of flooding on the Congaree River in April 1964;

- copies of articles from The State newspaper, dated August 26, 1908; August 30, 1908; July 17, 1916; August 18, 1928; August 19, 1928; and October 4, 1929; reporting the stages of major floods on the Congaree River between 1840 and 1888;

- a copy of the data sheet from SCANA's Federal Energy Regulatory Commission license, showing the storage capacity of Lake Murray Reservoir;

- printouts of RMA-2 two-dimensional hydraulic models of the Congaree River, prepared by the U.S. Geological Survey (USGS) and the South Carolina Department of Transportation (SCDOT) as part of USGS Open-File Report 81-1194; and

- digital copies of FESWMS two-dimensional hydraulic models of the Congaree River, prepared by the USGS and SCDOT as part of USGS Water Resources Investigations Report 90-4056.

Dr. Grego and the SCDNR appealed the assumptions and methods used to determine the 1% annual chance (100-year) discharge, which in turn is used to determine the Base (1% annual chance) Flood Elevations (BFEs). Both appellants asserted that the entire record for the USGS gage for the Congaree River at Columbia from 1892 to the present should be used, and each provided an alternative statistical analysis of the data. In addition, Dr. Grego provided historical flood information dating back to 1840 from newspaper articles and asserted that the upper 95% confidence limit of the statistical analysis of the Congaree River gage should be used as the discharge in hydraulic calculations rather than the point estimate from the same statistical analysis.

The SCDNR also appealed assumptions made in the HEC-2 hydraulic model of the Congaree River, which affect both BFEs and the floodway delineation. Specifically, the SCDNR appealed the assumption that no conveyance would occur landward of Manning's dike.

The report, prepared by Braswell Engineering, Inc., submitted by Ms. Hottel, appealed roughness coefficients used in the HEC-2 hydraulic model of the Congaree River, which affect both BFEs and the floodway delineation.

Due to the complexity of the technical issues involved and the amount of data received, it was necessary for FEMA to perform additional analyses and develop a new HEC-2 hydraulic model of the Congaree River to resolve the appeals. This report describes these additional analyses, development of the new HEC-2 model, and summarizes FEMA's appeal resolution.

Background

The Congaree River originates at the confluence of the Broad River (drainage area = 5,240 square miles) and the Saluda River (drainage area = 2,520 square miles), flows southeast for 51.5 miles, and joins the Wateree River near the head of Lake Marion to form the Santee River. Numerous dams on the Saluda and Broad Rivers influence flow in the Congaree River. The largest of these structures, Lake Murray Dam, was completed in 1930 and is located 12 miles above the mouth of the Saluda River. Congaree Creek (drainage area = 136 square miles) and Gills Creek (drainage area ≈ 5 square miles) join the Congaree River in Lexington and Richland Counties. River mile zero for the Congaree is at the mouth of the Santee River. The Congaree River also forms much of the corporate boundary between Lexington and Richland Counties.

The Congaree River floodplain expands from a width of approximately 1,000 feet in the upper reach (from its origin to river mile 173.1) to a width of nearly four miles in its lower reach (between river miles 173.1 to 166.9). The channel bed generally consists of alluvial sands blanketed with finer soils. The floodplain is generally covered with a combination of dense timber with underbrush, mature pine forests, and cultivated fields interspersed among wooded areas.

The following topographic features define the lower Congaree floodplain:

1. Residential and Industrial buildings:
   - River Bluff Estates, a residential subdivision in the City of Cayce, Lexington County, is at the location where the Congaree River floodplain begins to become flat and wide (River Mile 173).
   - Developments between river miles 170.5 and 171.5.
     - Caycee wastewater treatment plant in Lexington County.
     - Heathwood Hall Episcopal school in Richland County.
     - City of Columbia wastewater treatment plant and sewage lagoon in Richland County.

2. Pine Forests:
   The Congaree River floodplain in Lexington County has pine forests. These pine trees were planted in the mid-1970s and are now mature.

3. Quarry Operation:
   A large depression just upstream of the River Bluff Estates in Lexington County and adjoining high grounds exist on either side of the floodplain. A comparison with the 1966 topographic data indicates that these high grounds have grown in both area and height since 1966.

4. Earth-Fill Dikes:
   Although the floodplain of the lower reach has limited residential and commercial development, the Richland County side of the floodplain is partially protected by an earth-fill dike near the Congaree River bank (Manning's dike) and along Gills

Creek (ring dike). These dikes do not satisfy the minimum structural and safety requirements of Subparagraph 65.10 of the NFIP regulations needed to provide 100-year floodplain protection for the landward side of the levees.

5. Road Embankments:
Road embankments for Interstate 77, Route 48, Seaboard Coast Railroad, and 12th Street Extension cross the lower Congaree River floodplain. Interstate 77, a six-lane divided highway and a part of the Southeastern Beltway system, crosses the Congaree River floodplain between river miles 170 and 171. In addition to the main bridges over the Congaree River and Congaree Creek, I-77 consists of five flood relief bridges and a reinforced concrete culvert to discharge the Congaree River flood. In the lower reaches, the Congaree River floodplain is contained in the eastern (Richland County) side by the Route 48 road embankment and on the western (Lexington County) side by the Seaboard Coast Railroad. The recent addition to the western side of the floodplain is the road embankment for the 12th Street extension, which runs in a north-south direction parallel to the direction of flow for the Congaree River.

Approximately 9.3 miles of the Congaree River, from the Richland County boundary to its origin is studied for the FIS. The Congaree River RMA-2 model developed during this study covered approximately 6.2 miles of the lower Congaree River floodplain.

The Congaree River has a USGS gage station near Columbia at river mile 174.8 (station number 02169500) and a staff gage near the City of Cayce (station number 02169603) at the Carolina Eastman Kodak Company, at river mile 164.5. The Columbia gage is within the study reach and the Cayce staff gage is approximately 2.5 miles downstream.

Annual peak flow records at the Columbia gage location (drainage area = 7,850 square miles) are available from 1892 to present. In addition, the USGS has published a discharge-rating table that relates Congaree River discharge to the stage measured at this gaging station. The discharge rating was established using current meter measurements and, more recently, with an Acoustic Doppler Current Profiler.

The highest recorded peak flow occurred at the Columbia gage location in 1908. The recorded peak flow was 364,000 cfs. Nine major flood events have been recorded in 1908, 1912, 1916, 1928, 1929, 1936, 1964, 1976, and 1990, with peak discharges varying between 135,000 cfs and 364,000 cfs.

High-water marks have been established at seven locations along the lower study reach for the 1976 flood event with a peak flow discharge of 155,000 cfs. These data are published in the USGS Open File Report 81-1194 titled A finite-element model study of the impact of the proposed I-326 crossing on flood stages of the Congaree River near Columbia, South Carolina. In addition, one high-water mark is observed at the eastern boundary of the Congaree River flooding at the Route 48 Crossing of the Gills Creek. Manning's dike failed during this flood; this failure is described in a 1976 report by Law Engineering.

The USGS has published three reports documenting a steady-state, two-dimensional, depth-averaged, finite-element model study of the lower reach of the Congaree River (from river mile 166.9 to 173.1). They are USGS Open File Report 81-1194, USGS Water-Resources Investigation Report 84-4280, titled Impact of the proposed I-326 crossing on the 500-year flood stages of Congaree River near Columbia, South Carolina, and USGS Water-Resources Investigation Report 90-4056, titled Simulation of the effects of proposed construction of Twelfth Street extension and floodplain reforestation on flood elevations, Congaree River near Columbia, South Carolina. These studies were conducted to evaluate the effects of highway embankments for I-77 and the 12th Street extension on the 100-year and 500-year flood elevations of the Congaree River. The finite element model RMA-2 was used in the 1981 and 1984 USGS analyses to model the floodplain. The 1990 analysis was developed using the RMA-2 data; however, the USGS 2-dimensional model FESWMS was used in the analysis. The study results were used to model the flow through the I-77 bridge across the Congaree River floodplain. These models were calibrated to the 1976 flood event and used a 100-year peak flow discharge of 364,000 cfs and a 500-year peak flow discharge of 630,000 cfs.

The U.S. Army Corps of Engineers (USACE) prepared the effective FIS for the Congaree River floodplain using the HEC-2 backwater program. FEMA contracted Hayes, Seay, Mattern and Mattern to update the FIS for the Congaree River, and issued a preliminary FIS and FIRM for Lexington County on September 26, 1997. A revised preliminary FIS and FIRM were issued for Lexington County on February 12, 1998, to reflect a SCDOT interchange project. A preliminary FIS and FIRM were issued for Richland County to reflect the updated studies on June 5, 1998. Based on comments received from the counties, revised preliminary FISs and FIRMs were issued for both counties on February 25, 1999, and August 12, 1999, respectively.

Hydrologic Analysis

Resolution of the appeals of the hydrologic analysis was accomplished by close coordination and consultation with the USGS. The exchange between FEMA and USGS is documented on the enclosed compact disc.

Bulletin 17B guidelines (Interagency Advisory Committee on Water Data, 1982) were used to estimate flood discharges for the Congaree River; however, there is some regulation in the watershed. The annual peak flows are regulated to some degree, but the Pearson Type III distribution fits the logarithms of the regulated data reasonably well. Issues related to the flood frequency analysis are:

- the appropriate length of record or database to use;
- the effect of Lake Murray on peak flows;
- the utility or applicability of historical peak flows;
- use of weighted or station skew; and
- appropriate record extension techniques.

Another issue that complicates the frequency analysis is time sampling error as more major floods occurred prior to 1930 than after this date. The paucity of major floods since 1930 makes it more difficult to estimate the effect of regulation from Lake Murray using observed data.

Flood frequency analyses were performed for the Congaree River using various analysis methods and data sets to define the 1-percent annual chance (base) flood discharge for floodplain mapping.

Based on data submitted by the appellants, FEMA initially developed four different methods to analyzing Congaree River gage data. These methods are summarized below, and results are shown in Table 1.

Method 1 with weighted skew uses linear regression to estimate the regulated record for 1926-30. While technically accurate, this method for record extension may be less appropriate than MOVE.2. The use of weighted skew is considered less appropriate than the station skew for the Congaree River due to the size of the watershed (greater than 3,000 square miles) and the regulated nature of peak flows.

Method 2 estimates the extended record (1926-29) using MOVE.2 and the unregulated peak flows for the Broad River at Richtex. The correlation coefficient between the concurrent Congaree and Broad River peak flows is 0.960. This provides confidence that the estimated peak flows are reasonable from a statistical perspective. Also, the use of station skew is considered more appropriate for the Congaree River analysis because of the size of the watershed and the regulated nature of the peak flows. One weakness with this method is that it does not use the entire period of record (1892 to 1998).

Method 3 uses data from 1892 to 1998, including the adjusted systematic data prior to construction of Lake Murray. This makes this method very attractive, but the weakness of this method is that the method for adjusting the peak flows from 1892 to 1925 may underestimate the effect of Lake Murray. In other words, the adjusted peak flows may be too high. Methods 3a and 3b differ only in the number of major floods for which the historical adjustment was applied. For Method 3a, the historical adjustment was applied to the 1908, 1928, and 1930 floods. For Method 3b, the historical adjustment was only applied to the 1908 flood. The latter method may be slightly superior because it is more certain that the 1908 flood is higher than any flood that occurred in the 1840 to 1892 period.

Method 4 uses data from the Tar River at Tarboro, North Carolina, and MOVE.2 to estimate regulated peak flows for the Congaree River back to 1897. The weakness of this method is that the correlation between the Congaree and Tar Rivers is only 0.455. While this is sufficiently high to acquire improved estimates over using the shorter record, the low correlation coefficient lessens our confidence in the results.

Table 1. Summary of Base Flood Discharges for the Congaree River using Different Data Sets

Analysis Method	**Base Flood Discharge (cfs) (Weighted skew)**	**Base Flood Discharge (cfs) (Station skew)**
1. August 1999 Analysis Regression for 1926-30 Observed data 1931-96	253,000 (0.299)	265,000 (0.430)
2. MOVE.2 for 1926-29 Observed data 1930-98	262,000 (0.328)	275,000 (0.471)
3a. MOVE.2 for 1926-29 **Adjusted** data for 1892-1925 Observed data 1930-98 Hist. adj. 1908, 1928, 1930	285,000 (0.289)	292,000 (0.355)
3b. MOVE.2 for 1926-29 **Adjusted** data for 1892-1925 Observed data 1930-98 Hist. adj. for 1908 flood	296,000 (0.317)	304,000 (0.390)
4. Tar River extension MOVE.2 1897-1929 Observed data 1930-98	269,000 (0.471)	285,000 (0.643)

These initial analyses are summarized in a FEMA report dated July 21, 2000, titled Flood Frequency Analysis for the Congaree River at Columbia, South Carolina. This report was transmitted to the USGS, which provided comments on July 30, 2000. The USGS comments provided suggestions for improving the analysis, including the use of gage data from Broad River at Alston (station 02161000). The USGS also suggested that "…it may be appropriate to weight the more defensible method and less complete data of Method 2 and the more questionable and more comprehensive data of Method 3B."

The method was to develop a combined frequency curve by weighting the flood discharges of Methods 2 and 3B inversely proportional to their variances. This method is consistent with Equation 8-1 of Appendix 8 of Bulletin 17B, Guidelines For Determining Flood Flow Frequency (Interagency Advisory Committee on Water Data, 1982). The flood discharges for various percent chance exceedances for Methods 2 and 3B are given in the following table.

Table 2. Summary of Flood Discharges for Methods 2 and 3B and the Weighted Flood Discharges

Percent chance exceedance	Method 2 (cfs)	Method 2 Variance (log units^2)	Method 3B (cfs)	Method 3B Variance (log units^2)	Weighted frequency curve (cfs)
50 (2-year)	70,060	0.000771	72,960	0.000560	71,700
20 (5-year)	109,100	0.001103	116,900	0.000835	114,000
10 (10-year)	140,700	0.001781	152,600	0.001316	148,000
4 (25-year)	187,900	0.003550	206,000	0.002551	198,000
2 (50-year)	228,800	0.005673	252,200	0.004017	242,000
1 (100-year)	274,900	0.008550	304,400	0.005988	292,000
0.5 (200-year)	327,200	0.012236	363,400	0.008500	349,000
0.2 (500-year)	406,900	0.018433	453,400	0.012695	434,000

The variances in the above tabulation were estimated using procedures in Kite (1988). The equation for the variance of a flood discharge for a given percent chance exceedance has the following form:

$$\text{Var (p)} = [\text{Var} / N] / R_p^2 \qquad (1)$$

where

Var (p) is the variance in log units squared of the flood discharge with p-percent chance of exceedance in any given year,

Var is the variance of the annual peak flows in log units squared [0.046829 log units^2 $(0.2164)^2$ for Method 2 and 0.053870 log units^2 $(0.2321)^2$ for Method 3B,

N is the length of record or sample size in years, and

R_p^2 is a Pearson Type III frequency factor for a given skew coefficient [0.417 for Method 2 and 0.390 for Method 3B; and p-percent chance flood.

The frequency curve for Method 2 was based on 73 years of record (1926-98); so N in Equation 1 was 73. The frequency curve for Method 3B was based on 107 years of record (1892 to 1998), with the 1908 flood considered the highest since 1852 (highest in 146 years). Although an historical adjustment was applied to the 1908 flood, 107 years was used for N in computing the variance in Equation 1.

The weighted flood discharges in Table 1 were computed from the following equation also given in Appendix 8 of Bulletin 17B.

$$Q_w = [Q_{m2} * Var_{m3B} + Q_{m3B} * Var_{m2}] / Var_{m2} + Var_{m3B} \qquad (2)$$

where

Q_w is the weighted flood discharge in cubic feet per second (cfs);

Q_{m2} is the flood discharge from Method 2 in cfs;

Q_{m3B} is the flood discharge from Method 3B in cfs;

Var_{m2} is the variance of Method 2 in log units^2; and

Var_{m3B} is the variance of Method 3B in log unit^2.

Equation 2 was applied for each p-percent chance flood in the above tabulation. A weighted frequency curve was also obtained by converting the flood discharges for Methods 2 and 3B to log units before weighting them according to Equation 2. The same weighted frequency curve was obtained when flood discharges were rounded to three significant figures. The weighting in log units is actually more logical since the flood discharges and variances are computed in log units. However, since the same frequency curve resulted, Equation 2 is shown in cfs units.

Figure 1 shows the weighted frequency curve by weighting flood discharges from Methods 2 and 3B.

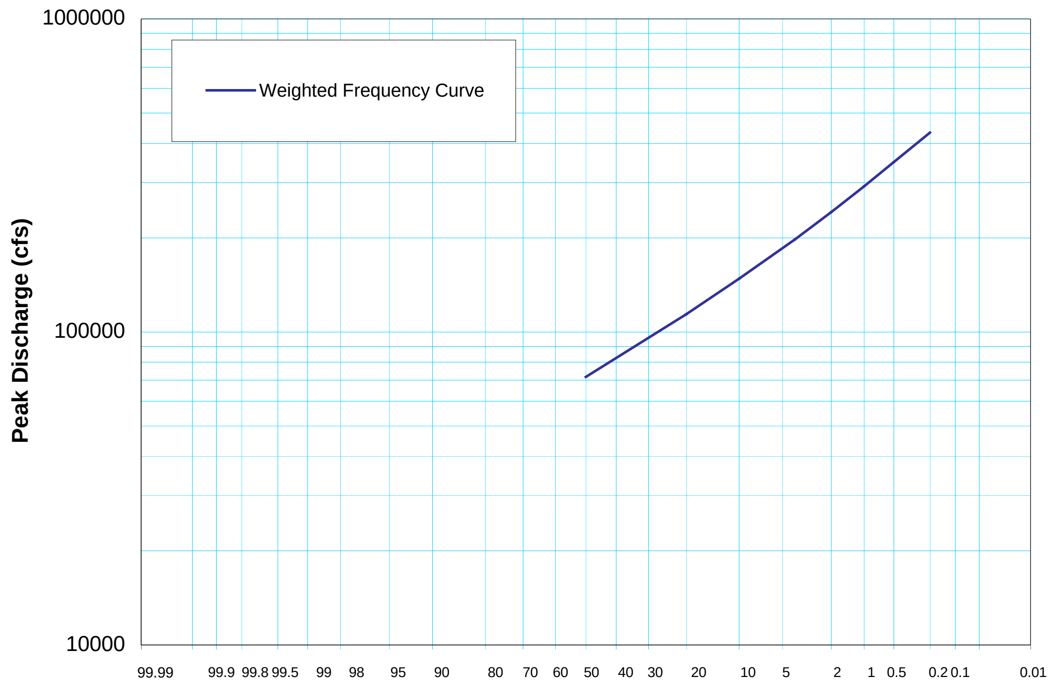


Figure 1. Weighted Frequency Curve

The 1-percent annual chance flood discharge for the weighted frequency curve in Figure 1 and in Table 1 is 292,000 cfs. The standard error of this discharge was not estimated because we do not know the equivalent years of record of the weighted flood frequency curve. However, it is likely that the standard error of the weighted 1-percent annual chance discharge is in the range 18-22 percent, the standard errors for Methods 3B and 2, respectively.

The weighted frequency computations were transmitted to the USGS, which concurred with FEMA's approach for weighting two different methods for determining the base flood discharge. In a letter dated August 17, 2000, USGS agreed that 292,000 cfs is a valid estimate of the base flood discharge for the Congaree River at Columbia.

Geotechnical Investigation

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. Therefore, land behind these dikes is shown in the floodplain.

When preparing the August 12, 1999, FIRMs, FEMA considered Manning's and Gill's Creek dikes to have an effect on flow conveyance. At that time, FEMA assumed that while these dikes would partially fail, they would still block conveyance through the Richland County floodplain. The appeals received argued for reconsideration of the dikes' effect on flow conveyance. A significant portion of this assumption lies with geotechnical evaluation of the dikes' stability.

The data which FEMA had to consider in geotechnical evaluation include a report dated August 10, 1999, prepared by S&ME, Inc., titled Report of Geotechnical Exploration, Congaree Levee Sections 1 and 2, and a report dated December 9, 1976, prepared by Law Engineering Testing Company, titled Geotechnical Investigation of Dike Failure, Metropolitan Wastewater Treatment Plant, Columbia, South Carolina.

FEMA had these reports while preparing the August 12, 1999 FIRMs, and at that time used them to conclude that the dikes would likely fail in a 100-year flood. Since receiving appeals, FEMA decided to take a more detailed approach, asking the following three main questions:

1. Where are the dikes most likely to breach?
2. What width of breach is likely to occur?
3. How many breaches are likely to occur during a 100-year flood?

The first question was answered by investigating the potential for failure by piping. Piping is the most likely mode of failure, as demonstrated by the two areas that failed in 1976. Shear failure itself is not a likely cause of breaching because of the relatively low height of the levees to the ground, and the fact that they have gained some degree of stability through consolidation over many years. It is possible that there could be some sloughing and sliding of the steeper landside slopes, but this would probably be due to the effect of seepage causing piping and removal of some landside toe support, as is suspected in the south failure during the 1976 flood. Dike sections that had conditions conducive to piping failure were identified; these are shown in Figure 2.

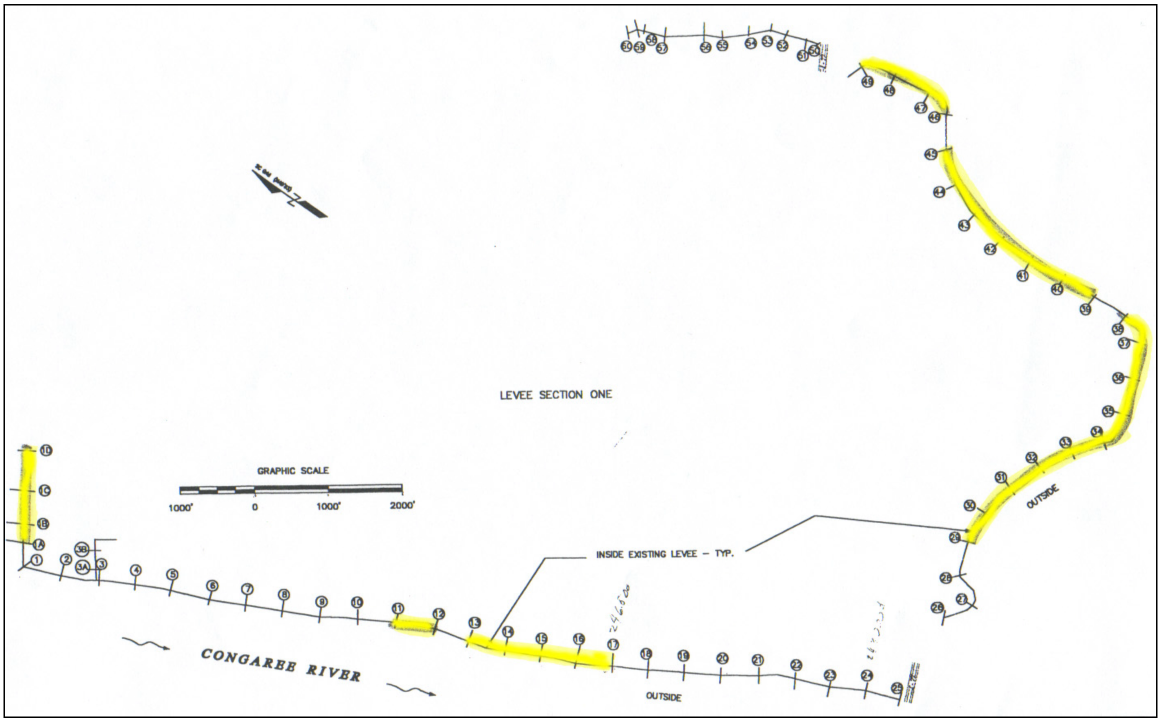


Figure 2. Dike Sections Conducive to Piping Failure

The second question was answered by considering the breaches that occurred in 1976, and considering the ratio of hydraulic head across the levee to the base width of the levee, H/L. In 1976, one breach had a width of 110 feet, while another had a width of 95 feet. The H/L ratios for a 100-year flood would be greater than those experienced in 1976. Based on the relative H/L ratio and extensive engineering experience, it was determined that a breach would likely be about 120 feet wide.

The third question was answered by analogy to the 1976 flood. Based on the experience of the two failures in 1976, it would be reasonable to assume that the levee could fail by piping at two or possibly three weak locations during a single occurrence of the 100-year flood.

Two-Dimensional Model Investigations (RMA-2)

Background

A lack of detailed topographic data and historic flood information for the Congaree River floodplain in Richland County, South Carolina, has led to the use of various hydraulic modeling assumptions regarding the effective flow path in the floodplain. New topographical and geotechnical data available for the floodplain in Richland County and two-dimensional model simulations of the flow have provided the opportunity to examine different flow scenarios and determine the most appropriate effective flow path for Congaree River flow in this area.

Hard copies of the RMA-2 model simulations originally prepared by the USGS and SCDOT, with and without the I-77 road embankment, were used to generate the finite element mesh that covered the entire lower Congaree River floodplain in Richland and Lexington Counties. The 1981 USGS models simulated flow in the Congaree River channel and assumed flow in either Richland-side floodplain to be active or Lexington-side floodplain to be active. Separate finite element meshes were used in the 1981 study due to limitations in computers of that time. The graphical interface program Surface-Water Modeling System (SMS) was used to merge the Richland-side and Lexington-side meshes used by the USGS. However, both the Richland-side mesh and the Lexington-side mesh were retained and the latter was used for calibration purposes. As in the USGS analysis, steady-state flow simulations were used in this study.

Mesh Development

The finite element mesh of the Congaree River floodplain was generated using the data available in the output files of the RMA-2's mesh generation program GFGEN. The finite element mesh used six-noded isoparametric triangular elements. The topographic information coded into the USGS finite element mesh was checked and updated using the following topographic data.

- Spot elevation and 1-foot contour data for the Richland-side floodplain provided by Lockwood & Greene. This data was dated, March 22, 1999.
- Spot elevation and 2-foot contour data for the Lexington-side floodplain prepared by HSM&M for FEMA.
- Cross section data coded into the HEC-2 model used to generate the August 12, 1999, revised preliminary FIS.

The high grounds, road embankments, and the dikes within the floodplain were modeled using the internal boundary option available in the RMA-2 program. The 12th Street extension and the wastewater treatment plant in Richland County are two high-ground internal boundaries that were also added to the mesh. The 12th Street data were taken from the USGS 1990 model. Figure 3 illustrates the finite element mesh of the Congaree River floodplain without the dikes.

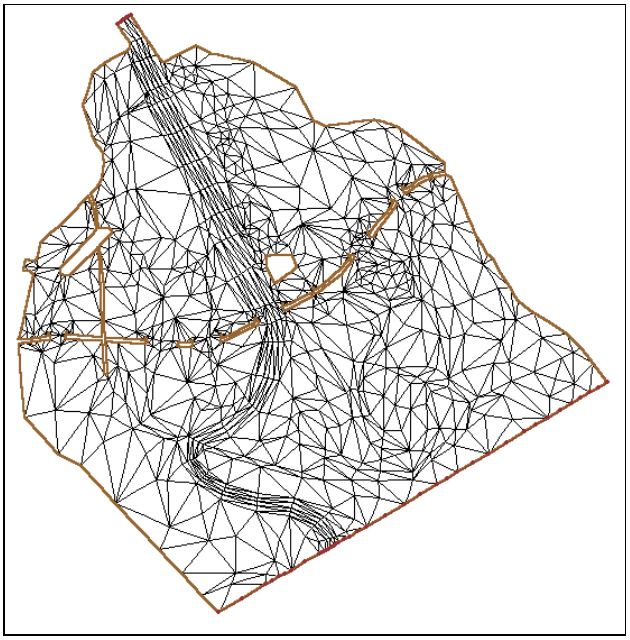


Figure 3. The Finite Mesh Element without Dikes

The levee configuration on the Richland side floodplain is shown in Figure 4. The sensitivity tests conducted with various levee breach scenarios were modeled by modifying the geometry of the internal boundary to reflect the levee breach.

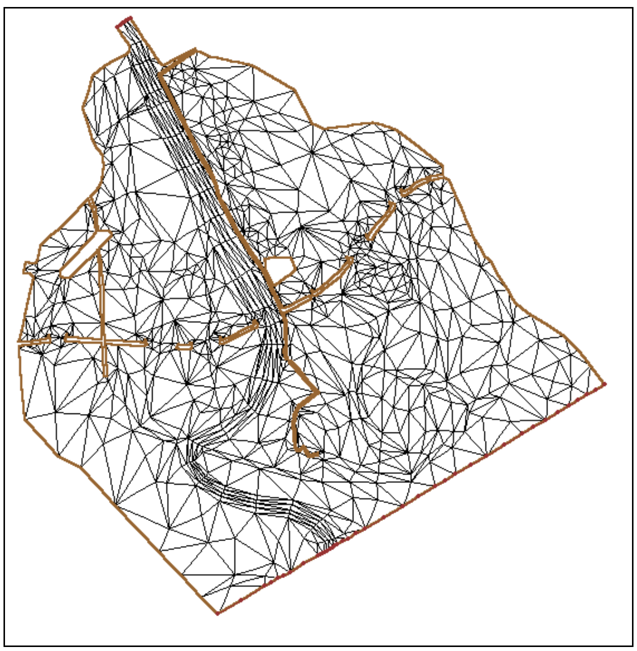


Figure 4: The Finite Element Mesh with Manning's Dike

Congaree Creek and Gills Creek flow through the floodplain were not considered for the RMA-2 analysis, and the channel geometry of these streams is not reflected in the finite element mesh. Since the Congaree River drains a much larger watershed than Gills Creek or Congaree Creek, it is reasonable to assume that the flow carrying capacity of these streams will have an insignificant effect in passing the Congaree River flood.

Roughness Coefficients and Calibration

The roughness coefficients were assigned as Manning's roughness coefficients. Because the 1981 USGS analysis assigned roughness coefficients as Chezy coefficients, the following equation was used to transform the set of Chezy coefficients used in the 1981 USGS analysis to Manning's roughness coefficients.

$$n = \frac{1.49R^{1/6}}{c}$$

where: n = the Manning's roughness coefficient
c = corresponding Chezy coefficient
R = Hydraulic radius
(Source: USGS Water Resources Investigation Report 90-4056)

This initial estimate was modified during the calibration of the RMA-2 model to high-water marks obtained during the 1976 flood event. The roughness coefficients were reviewed and updated using a current aerial photograph (flown on March 22, 1999) of the lower Congaree River floodplain. Major changes to the roughness coefficients occurred in the areas of the planted pine forest in Lexington County. The Manning's roughness coefficients were revised to reflect the mature pine trees existing in this area.

The final set of roughness coefficients used in the RMA-2 model are provided in Table 3. Figure 5 illustrates the distribution of the different roughness coefficients within the finite element mesh superimposed on an aerial photo of the lower floodplain.

Table 3. Roughness Coefficients Used in the Existing Conditions Model

Number	Type	Manning's Roughness Coefficient	Remarks
1	River Channel and Open Water	.038	Congaree River, ponds in Richland side
2	Vegetation	.12	dense hard wood
3	Grass land	.06	cleared areas
4	Structures	.175	River Bluff Development
5	Vegetation	.12	dense pine trees

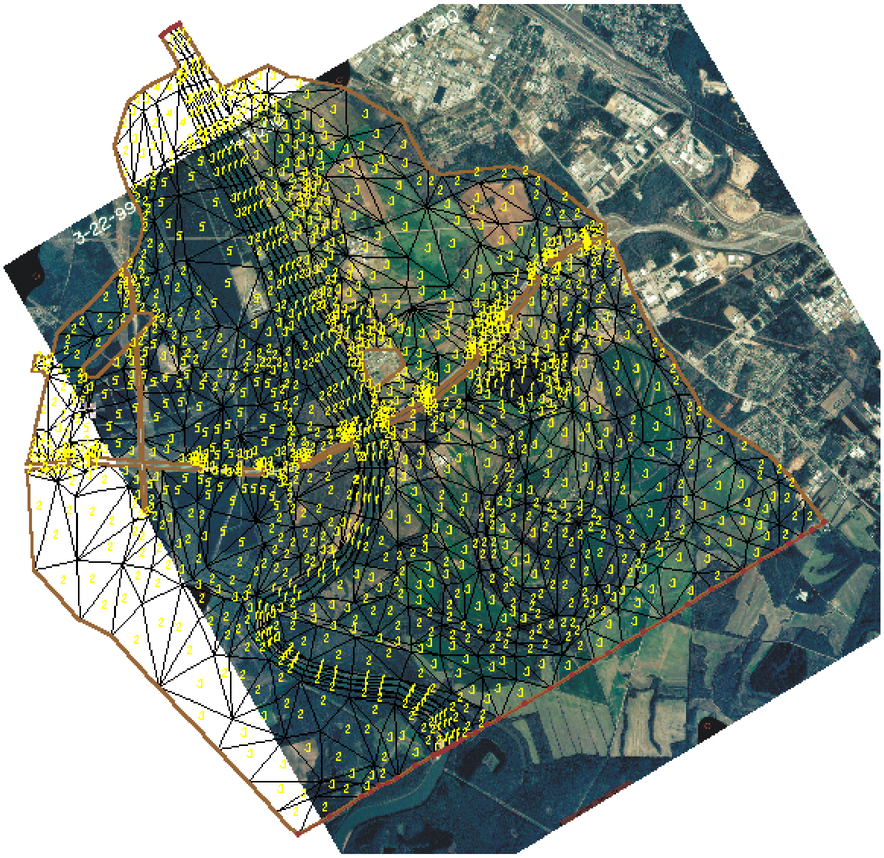


Figure 5. Roughness Coefficients – Material Properties

The model was calibrated and verified to the flood of 1976. This is the only flood on record that has good flood elevation data throughout the study area, but only in Lexington County; therefore, the Lexington grid duplicated from the USGS data was used for the calibration. Since the I-77 bridge did not exist in 1976, the grid was modified for the verification and calibration runs to exclude the I-77 bridge. The calibration results of the RMA-2 model are presented in Table 4. The results of the USGS simulation are given in this table for comparison. The downstream water-surface elevation observed during the 1976 flood was 127 feet. The USGS used a downstream water-surface elevation of 129 feet because it was not possible for the model to converge on a solution using 127 feet. Due to improvements in the RMA-2 model, it is now possible to use the 127 feet downstream water-surface elevation in the calibration to the 1976 flood.

Table 4. Congaree River - Calibration Results of the RMA-2 Model to the 1976 Flood

Location No.	Location	HEC-2 Cross Section	Lexington Mesh Node Number	Observed Elevation ft. NGVD	2000 RMA-2* Model ft. NGVD	2000 HEC-2* Model ft. NGVD	1981 USGS Model ft. NGVD
1	River Bluff Estates- right channel bank	254500	160	138.0-139.6	138.09	137.48	139.0
2	Cayce Waste water treatment plant-right channel bank	246700	418	135.4	134.97	134.46	135.9
3	Old State Road bridge. Congaree Creek-right over bank	245800	544	133.2-133.4	133.68	134.30	133.2
4	Left Channel bank where I-77 crosses now	242440	1239	134.0-134.2	133.88	133.58	134.6
5	Old State Road-right over bank.	241500	1177	130.5-130.6	133.10	133.27	133.1
6	Old state road - right over bank	239370	631	130.2-130.8	133.02	133.04	133.1
7	Power line -right over bank	215700	1027	129.7	129.15	130.70	130.1
8	Columbia gage 2169500	266750	-	142.72		142.72	-
9	Gage 2169603 down stream study limit	212950	-	127.0		128.51	-

* No conveyance is assumed in Richland County and the I-77 bridge was removed from the model.

As demonstrated in Table 4, the model verified fairly well with the observed water-surface elevations except at locations 5 and 6. The USGS suggested that the storage at these two locations is not accurately accounted for by the steady state analysis, hence the under-estimation of the water-surface elevations. This explanation appears to be accurate when considering that these two observations are located a good distance from the Congaree River and that the effects of Congaree Creek that flows through the area are not accounted for in this analysis.

Ineffective Flow Areas

While the flow in the lower Congaree floodplain has an overall flow direction along the Congaree River's main channel, the flow is two-dimensional in the vicinity of the I-77 bridge and embankment. Therefore, in order to model the two-dimensional flow phenomenon using the one-dimensional HEC-2 model, it was necessary to make assumptions regarding the effective flow areas in the vicinity of the I-77 road. This study used RMA-2 model simulations to determine the ineffective flow areas of the floodplain.

Areas with water velocity below 1 foot/second in a simulation with no dikes and Q=364,000 cfs, were considered to be ineffective flow areas. Figure 6 shows a sample plot of the entire floodplain without Manning's levee of the areas with a velocity below 1 foot/second.

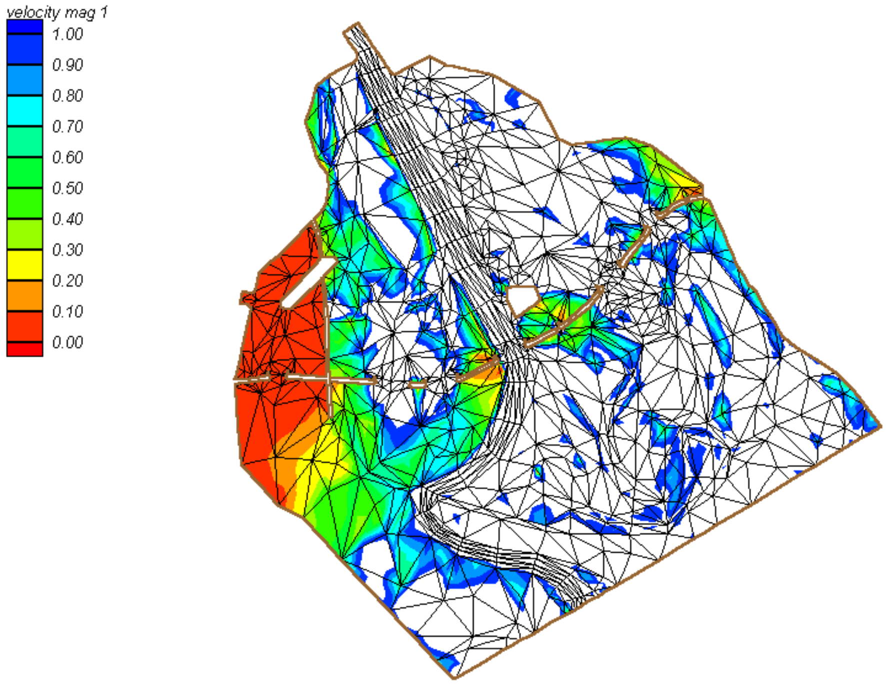


Figure 6. Areas of Velocity below 1 foot/second (Q=364,000 cfs)

Two Breach Scenario

The geotechnical evaluation previously discussed above identified two locations as having the highest likelihood of breach by piping. One location is on the northernmost end of the levee where it runs in an east-west direction just before the levee turns south. The other location is approximately 3,000 feet upstream of the I-77 crossing. Both breaches would have a width of approximately 120 feet. The grid was adjusted by inserting elements in the location of the breaches along the levee and refining the grid around these locations. An area of high ground on the Richland County side that would be dry with the levee in place was taken out of the model in order to get better convergence of the model in the area of the breach. The model was run assuming both breaches would occur simultaneously. The results can by seem in Figures 7 and 8.

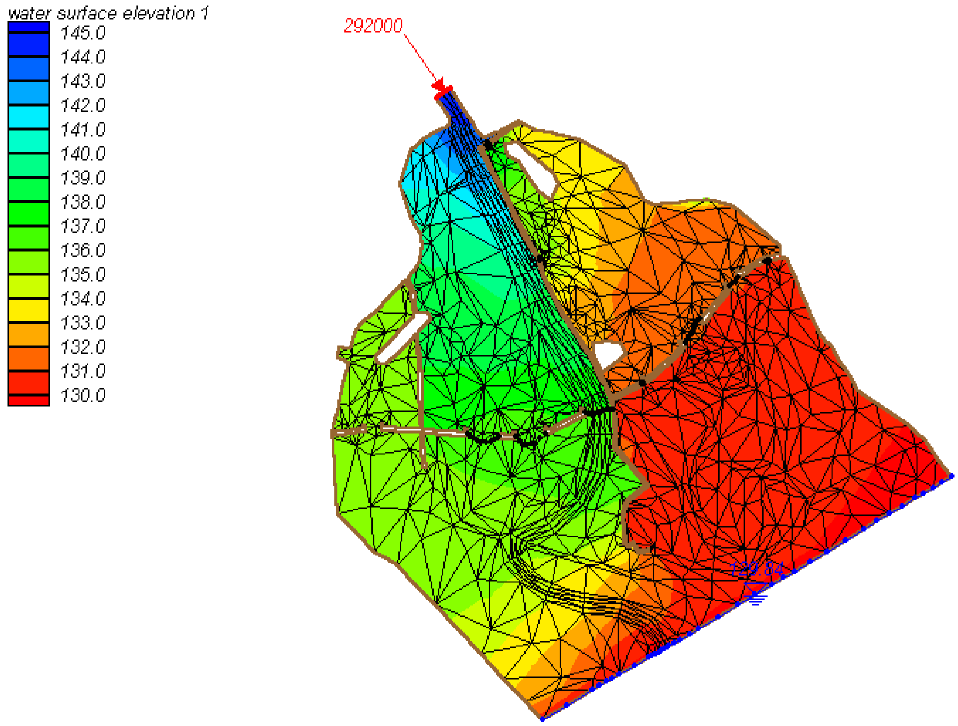


Figure 7. Water Surface Elevation; Manning's Levee with Two Piping Breaches

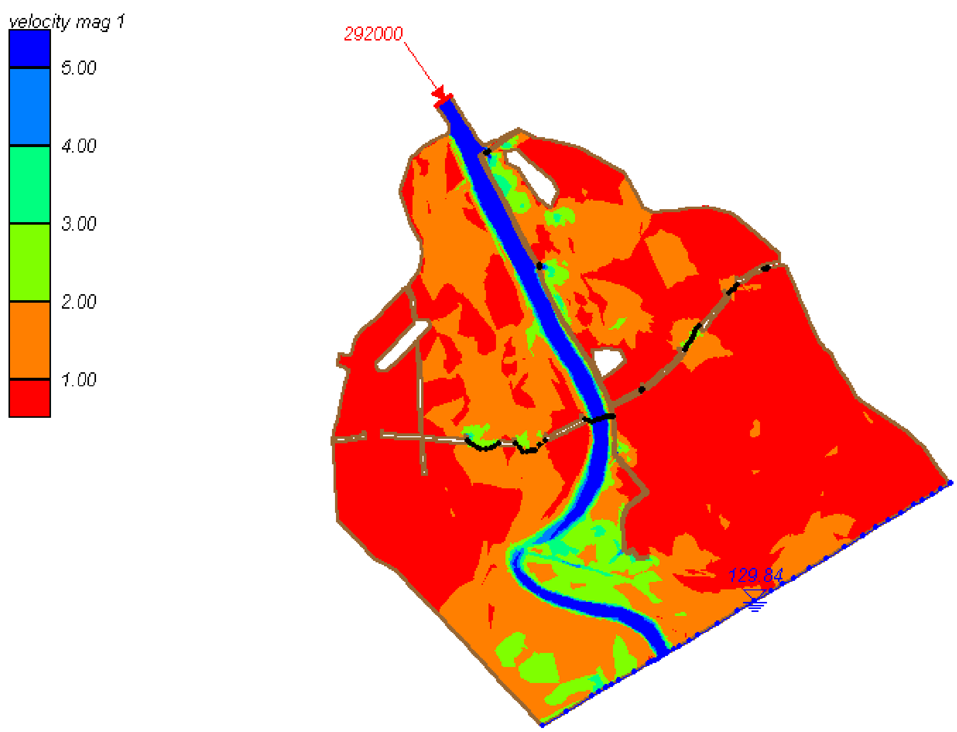


Figure 8. Velocities; Manning's Levee with Two Piping Breaches

The results show that approximately 9.6 percent of the total Congaree River discharge will enter the Richland County side of the floodplain through the two breaches.

One Breach/Varying Width Scenario

In addition to the breach scenario determined by geotechnical evaluation, Manning's dike was also breached at a low point of the levee just upstream of the City of Columbia wastewater treatment plant in Richland County in order to investigate the relationship between breach width and percentage of total Congaree River flow through the Richland County floodplain. Figure 9 is an example of the unbreached levee, and Figure 10 is an example of a 600 foot breach in the Manning's dike.

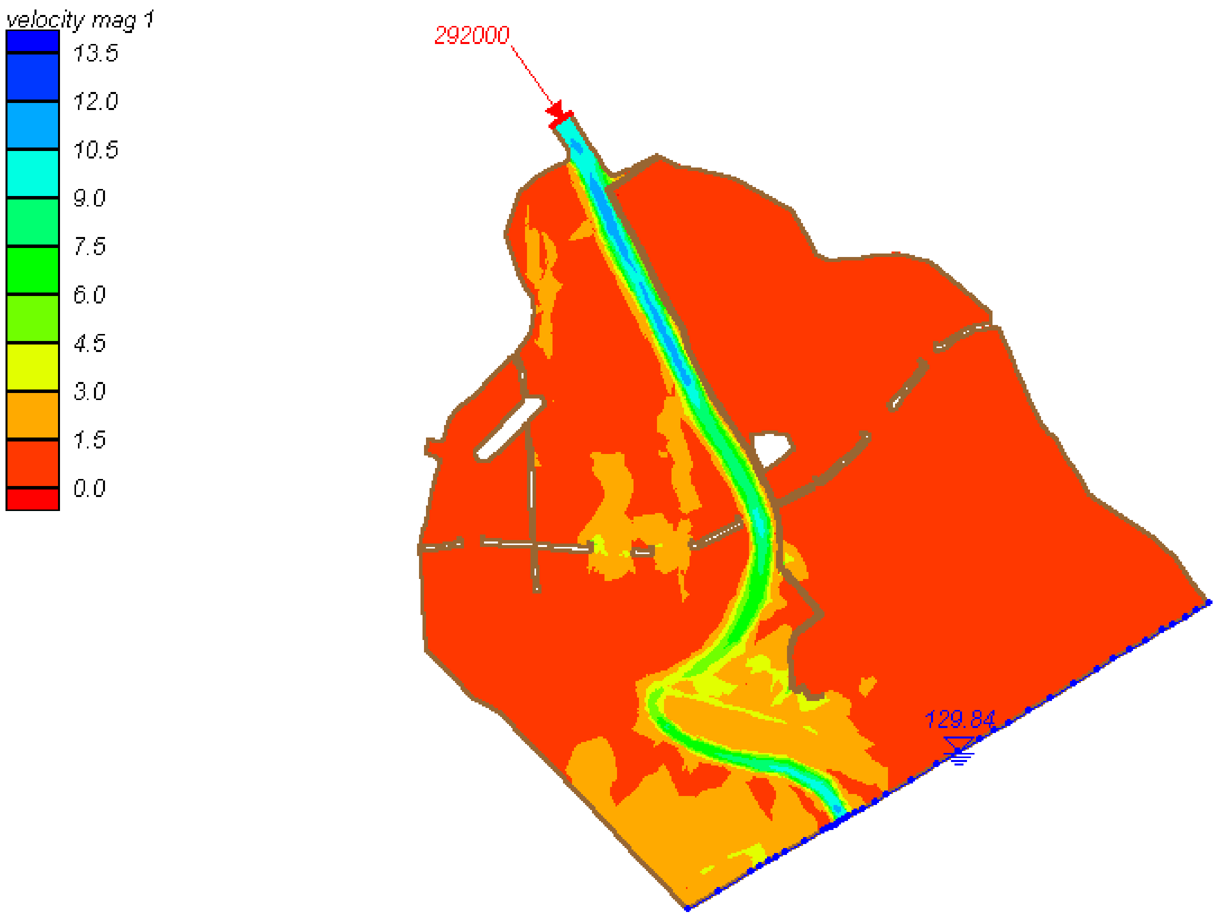


Figure 9. Flow in Richland County without Gills Creek Ring Levee

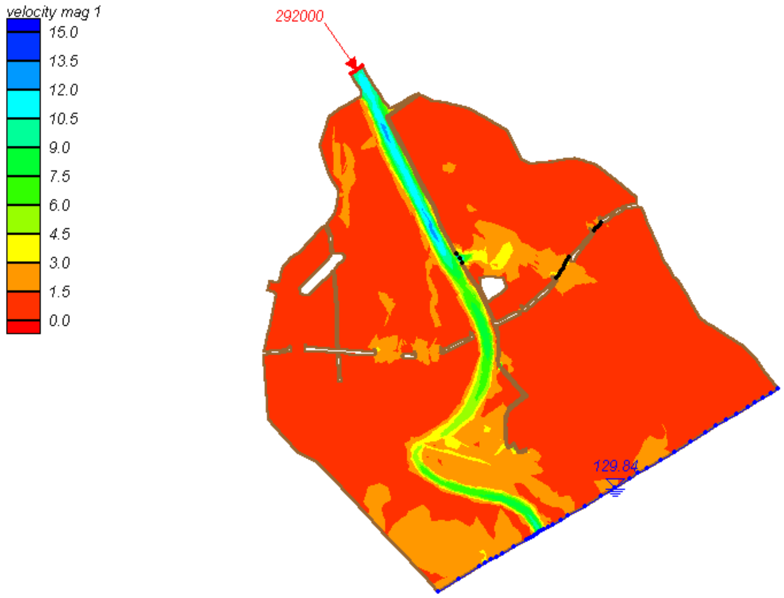


Figure 10. Flow in Richland County with Breached Manning's Levee

A range of breach widths was simulated with RMA-2 to determine the percentage of flow that would enter the Richland County floodplain with each different breach width. The results are shown on Figure 11.

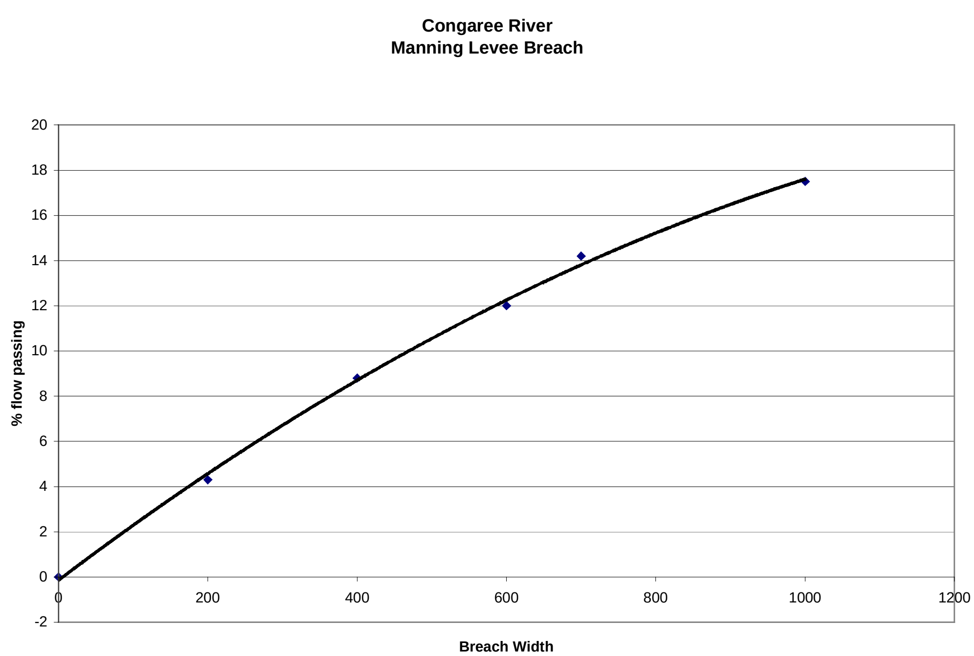


Figure 11. Percent Flow Passing versus Single Breach Width

Using the HEC-2 model with the Manning's dike in place, it was determined that allowing 5.5 percent of the total flow to enter the Richland County floodplain would decrease water-surface elevations in the Lexington County floodplain by approximately 1 foot. Using Figure 11, the 5.5 percent flow in Richland County floodplain would correspond to a breach width of approximately 250 feet. This means that if Manning's dike were considered to restrict flow in Lexington County, a breach greater than 250 feet wide would lower water-surface elevations by more than 1 foot in Lexington County.

Based on these investigations with the RMA-2 model, it was concluded that the Richland County floodplain would convey a significant amount of flow in a 100-year flood. Specifically, it was determined that the large (1,320 feet wide) relief bridge is critical to conveying the Congaree River flow during a 100-year flood. Therefore, based on the two-dimensional model investigation, it was determined that the floodway should extend landward of Manning's dike in Richland County, and should allow for flow through the large relief bridge.

Hydraulic Modeling (HEC-2)

The two-dimensional flow model (RMA-2) was used as a decision-making tool, however, the BFEs shown on the FIRMs are based on a one-dimensional flow model (HEC-2). This was done because HEC-2 is the most common hydraulic program used in FISs nationwide. HEC-2 is available free of charge, and a large number of engineers are familiar with it, facilitating future revisions. While RMA-2 provides more detail about flow on a wide floodplain, HEC-2 can be calibrated to closely match these results. Most significantly, HEC-2 has established, equitable methods for determining a floodway, while RMA-2 has no floodway determination tools.

The Congaree River HEC-2 hydraulic model was calibrated to the RMA-2 model for the 1976 flood (peak flow of 155,000 cfs at Columbia gage) and ineffective flow areas for the Richland County floodplain were determined using an RMA-2 simulation for the largest flood of record, the 1908 flood with a peak discharge of 364,000 cfs. (Figure 6) Areas where RMA-2 indicated velocities less than 1 foot per second were coded as ineffective in the HEC-2 model.

During the 1976 flood, Manning's dike was breached near the City of Columbia wastewater treatment plant. Even though the floodplain in Richland County was flooded during this event, observations indicate that a significant portion of the Congaree River floodwaters were conveyed by the Lexington County-side floodplain. Therefore, the HEC-2 model used to model the 1976 flood event assumed no conveyance in Richland County. Sensitivity tests with the HEC-2 backwater model indicated that the Manning's levee along the left overbank of the Congaree River was overtopped for peak flow discharges of more than 200,000 cfs. Therefore, it was assumed that for the higher flood events that occurred prior to 1936, the flood will also be conveyed by the Congaree River floodplain in Richland County. The HEC-2 model that was used to model high flood events reflects this condition.

In addition, this HEC-2 backwater model reflected the floodplain conditions that existed prior to and in 1976 by not having the cross sections associated with the I-77 bridge model. It was evident from a 1966 topographic map that the high grounds that currently exist on the floodplain between the River Bluff Estates and the Railroad Bridge upstream (near the quarry) were lower in 1966 than they are today. The effective FIS HEC-2 model prepared by the USACE in 1978 reflected lower high grounds for this area. Therefore, both HEC-2 models that were used for calibration used cross sections taken from the effective FIS HEC-2 model.

The flood levels computed by the hydraulic model (1976 conditions) compared well to five of the high-water marks published and the water level measured at the Columbia gage. The large differences between the observed and computed water-surface elevations at two locations may have been due to the steady flow assumption used in the hydraulic model.

Table 5. Congaree River Model: 1908 Flood RMA-2 Simulations Compared with HEC-2 Model Results

Location	HEC-2 cross section	2000 HEC-2* Results	2000 RMA-2 Results	Remarks
FIS A	226700	133.12	134.36	Downstream RMA-2 study limit
FIS B	234100	135.22	136.48	Downstream of Congaree Creek
	238900	136.72	136.51	
	239800	136.83	136.54	
	241500	136.81	136.67	
	247000	137.32	138.67	
FIS D	249300	139.67	139.35	
	249590	139.59	139.57	Columbia sewage lagoon
	250770	139.84	140.30	Upstream of Heathwood Hall School
FIS E	253400	142.48	141.72	
	254500	143.15	142.58	Downstream of River Bluff Estates
	254600	143.32	143.05	
	255100	144.10	144.13	
FIS F	256100	145.42	145.14	Upstream of River Bluff Estates

*Results were from Finalhgh.018. This model assumed conveyance in Richland (2000 feet), no I-77 bridge or 12th street extension, and used effective FIS cross sections for upstream of River Bluff Estates up to the USGS gage (254500 to 266750).

The calibrated hydraulic model results were verified for the high-water marks available at the Route 48 crossing historic floods of 1908, 1930 and 1936. In addition, the flood elevations computed for all of the historic flood events at the USGS Columbia stream gage location matched closely with those published by the USGS. The flood elevations computed by the HEC-2 model at the Columbia USGS stream gage are summarized in Table 6 below. In addition, the flood elevations computed by the RMA-2 and HEC-2 models for the 1908 flood event compared well. These results are presented in Table 5 above.

Table 6. HEC-2 Model Results at Columbia Gage

Discharge Cfs	Year	From rating curve at Gage	2000 HEC-2*
364,000	1908	152.82	152.35
256,000	1912	148.32	147.49
272,000	1916	149.12	148.47
311,000	1928	150.72	150.39
303,000	1929	150.42	150.01
231,000	1936	147.22	146.21
142,000	1964	141.62	141.32
155,000	1976	142.72	142.51
135,000	1990	140.92	140.65

*Finalhgh.018 model was used to calibrate the flood events with peak flow discharges higher than 200,000 cfs. For lower flooding events (1964, 1976 and 1990 and 10-year) Finallow.018 model was used.

The I-77 bridge was removed from both of these calibration models. Both models used effective FIS cross sections (1978) upstream of the River Bluff Estates up to the USGS gage (254500 to 266750). The model (Finalhgh.dat) assumes conveyance on the landward side of Manning's dike in Richland County. The model (Finallow.dat) assumes no conveyance landward of Manning's dike. Both these models used cross section 258400 from the effective FIS model.

Base Flood Elevations

The highest water-surface elevations will occur at different times for a floodplain with a dike that does not withstand a 100-year flood. Manning's dike and the Gill's Creek ring dike are both expected to breach in a 100-year flood. Manning's dike will constrict flow along the Congaree River, increasing water-surface elevations above what they would be without a dike or levee in place. When Manning's dike breaches, a large volume of water will leave the Congaree riverbed area and enter the Richland County floodplain. Two-dimensional models indicate that roughly 10 percent of the total flow through the Congaree River will be conveyed through Richland County following a breach of Manning's dike. As water flows through the breaches, it will fill the Richland County floodplain, and eventually the water level on both sides of the dike will equalize. Hydraulic analyses indicate that water-surface elevations are expected to decrease 2- to 4-feet in Lexington County after a breach occurs. Therefore, the worst flooding in the riverbed area and in Lexington County will occur before the dike breaches, while the worst flooding in Richland County will occur after the dike breaches.

The existing conditions HEC-2 model, which was used to determine BFEs, was developed by reflecting the following features of the floodplain that were added to the floodplain after 1976:

- I-77 road bridge and embankment;
- 12th Street extension; and
- Pine reforestation in Lexington County.

The Manning's dike along the Congaree River does not meet the minimum NFIP requirements to consider it to provide 100-year flood protection. Furthermore, breach scenarios using RMA-2 indicate a likelihood of conveyance behind the dike. Therefore, the effective HEC-2 model assumed flow to exist behind the Manning's dike on the floodplain in Richland County. The ineffective flow areas for the floodplain were developed using the RMA-2 model simulation.

The existing conditions model assumes that the Gills Creek ring levee does not have the structural strength to hold the 100-year flood waters that enter the Richland-side floodplain. The available geotechnical exploration results and the fact that the flood events in the Congaree River watershed last for 3 to 4 days adds credibility to this assumption.

The Manning's dike has not met the minimum NFIP requirements to provide protection from the 100-year flood event, and it is evident that the maximum flood elevations for the Congaree River floodplain in Lexington County will occur prior to the breach of Manning's dike. In order to simulate this scenario, the existing conditions model for Lexington County considered no conveyance behind the Manning's dike in Richland County.

Floodway

The floodway analysis is based on the model for the landward side of Manning's dike, which assumes conveyance behind Manning's dike. This floodway was computed in accordance with the general guidelines adopted by FEMA nationally. (FEMA 37) The national guidelines require the retention of the effective floodway, wherever possible. In addition, the definition of new floodway boundaries satisfies the following general criteria:

- maintaining equal conveyance reduction on both sides of the flooding source;
- maintaining the resulting flood elevation increase to be less than the maximum allowable, 1.0 foot for South Carolina; and
- obtaining a final floodway configuration that is hydraulically smooth.

The dike configuration was not removed from the cross section geometry in this floodway model. The Method 4 floodway option available in the HEC-2 program was used to determine the floodway boundaries for the remaining portion of the Congaree River floodplain. The Method 4 floodway option reduces the conveyance of the natural floodplain equally on either side of the river to establish floodway stations that assure flood elevation surcharges are held to less than the maximum allowable (in this case, 1 foot).

The floodway computed by the HEC-2 Method 4 option was modified in two locations (in the vicinity of the I-77 bridge and just downstream of the River Bluff Estates) to obtain a hydraulically smooth floodway configuration. The final floodway configuration for the Lexington side generally matches that shown on the August 12, 1999 preliminary FIS. However, the floodway boundary in the Richland side has been widened to include the largest I-77 relief bridge opening on the Richland side.

Conclusions

Based on the information submitted and the additional analyses described above, FEMA concluded that revisions to the August 12, 1999, revised preliminary FISs and FIRMs for Lexington County and Incorporated Areas and Richland County and Incorporated Areas were warranted. The peak 1% annual chance flood discharge for the Congaree River at the gage has been revised to 292,000 cfs. BFEs for the area landward of Manning's dike are now computed by a HEC-2 hydraulic model using the revised discharges and assuming flow conveyance landward of Manning's dike.

Subsequently, BFEs are 1 to 2 feet lower than those shown on the August 12, 1999, revised preliminary FIRM in Richland County. BFEs riverward of Manning's dike are based on a hydraulic model that assumes no conveyance landward of Manning's dike. This assumption, coupled with the increase in discharge has resulted in BFEs which are 1 to 2 feet higher than those shown on the August 12, 1999, revised preliminary FIRM for Lexington County.

Furthermore, the floodway in Richland County is wider than that shown on the August 12, 1999 revised preliminary FIRM. The floodway in Lexington County shows both widening and narrowing when compared to the August 12, 1999, revised preliminary FIRM.

The report prepared by Braswell Engineering, Inc., submitted by Ms. Hottel, appealed roughness coefficients used in the HEC-2 hydraulic model of the Congaree River, which affect both BFEs and the floodway delineation. The HEC-2 hydraulic model submitted in support of this appeal changed Manning's "n" values at cross-section 226700, which is located on property owned by Blanchard Investments, Inc., who is represented by McNair Law Firm. The apparent intent of this appeal was to narrow the floodway on Blanchard Investments, Inc.'s property.

Review of the data indicates that the Manning's "n" values submitted may accurately reflect field conditions at the indicated cross section. No photographs supporting data were provided, other than the statement of a registered Professional Engineer. However, the Manning's "n" values submitted were inconsistent with those used in the rest of the study, and they cause upstream water-surface elevations to increase by as much as 1.5 feet. These water-surface elevations do not compare well with the calibration data discussed previously. Therefore, the proposed Manning's "n" values were not used.

While FEMA seeks to use caution when determining flood hazards, we must disagree with Dr. Grego's assertion that the upper 95% confidence limit of the statistical analysis of the Congaree River gage should be used as the discharge in hydraulic calculations rather than the point estimate from the same statistical analysis. The NFIP is based upon the 100-year flood as the standard level of risk. Using the upper 95% confidence limit rather than the point estimate is the same as using a less probable flood as the standard for flood insurance rates and floodplain management. Mapping flood hazards based on a flood less probable than the 100-year event would contradict the NFIP's statutory mandate and be inconsistent with decades of nationwide practice.

Resources

NFIP Regulations are available at:
http://www.access.gpo.gov/nara/cfr/waisidx_99/44cfr67_99.html

Guidelines and Specifications for Study Contractors (FEMA 37) area available at:
http://www.fema.gov/fhm/dl_scg.shtm

The following digital files used in formulating the appeal resolution are provided on the included compact disc:

- 🗀 **HEC-2 Models:** One-dimensional hydraulic models
  - 🗀 **Calibration HEC-2:** Models used to calibrate to 1976 flood
    - Finalhgh.* Calibration model for Q>200,000 cfs
    - Finallow.* Calibration model for Q<200,000 cfs
  - 🗀 **Final HEC-2:** Models used to determine BFEs
    - CongFW2K.* Model used to determine floodway
    - CongLx2K.* Model used to determine Lexington County BFEs
    - CongRc2K.* Model used to determine Richland County BFEs
  - 🗀 **Sensitivity HEC-2:** Models used to show sensitivity to assumptions
    - Conglexs.* Model used to determine sensitivity to assumptions
- 🗀 **Hydrology Reports:** Reports and correspondence between FEMA and USGS
  - FEMA Report 7-21-00.doc
  - FEMA Report 8-10-00.doc
  - USGS Comments 7-30-00.doc
- 🗀 **RMA-2 Models:** Two-dimensional hydraulic models
  - 🗀 **1908 Flood:** Old topo with no Interstate bridge
  - 🗀 **Existing:** Existing conditions model of 100-year flooding with updated topo and 12th street included
    - 🗀 **Manning Levee:** Existing conditions model of 100-year flood with Manning's dike
      - 🗀 **Breach widths:** Existing conditions model of 100-year flood with breach at low area of Manning's dike
        - 🗀 **200br:** 200 foot breach
        - 🗀 **400br:** 400 foot breach
        - 🗀 **600br:** 600 foot breach
        - 🗀 **700br:** 700 foot breach
        - 🗀 **1000br:** 1000 ft breach
      - 🗀 **Piping Breach**
  - 🗀 **Lexington:** Reproduction of USGS grid and simulation
    - 🗀 **Verification:** Simulation of 1976 Flood
  - 🗀 **Richland:** Reproduction of USGS grid and simulation

Congaree-Smallerfile.tif: Aerial photograph of study area
existing.img: SMS input file for superimposing aerial photo with mesh