Geotechnical Effects of Hurricane Florence

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Upper right: US 421 washout (Cape Fear River), New Hanover County, NC
Lower: Boiling Springs Lake Dam, Brunswick County, NC

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1. Introduction / Executive Summary

1.1 Introduction and Purpose

The Geotechnical Extreme Events Reconnaissance Association (GEER) deployed a team of engineers from academia, government, and practicing firms to southeastern North Carolina and northeastern South Carolina between September 24 and 28, 2018 following Hurricane Florence. The purpose of the GEER Florence team was to "collect perishable post-disaster data that can be useful in advancing our understanding of extreme events"[1] and, specifically, the effects of the extreme events on the geotechnical features of infrastructure. GEER's efforts were made possible because of support from the National Science Foundation. This report presents a summary of the observations and data from the GEER deployment.

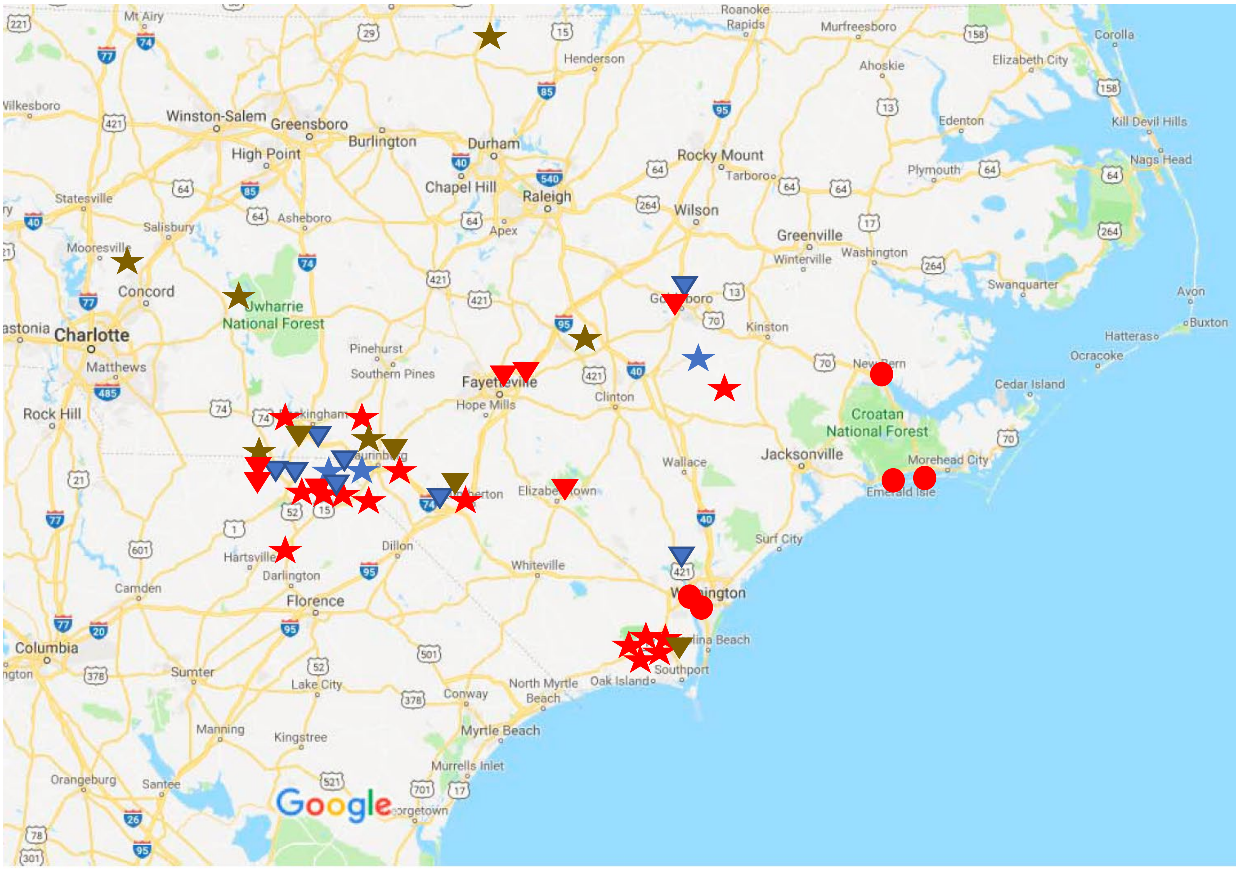
1.2 Reconnaissance Areas Covered, Time Frame of Observations, Organization of Report

The GEER Florence teams deployed about one week after the hurricane left the area. The GEER Florence group split into two initial teams, a west and an east team, to cover more area and to take advantage of the direction from which each group's members deployed. The West Team met in Charlotte and travelled to the east starting on September 24, 2018. The East Team met in Raleigh and travelled to sites south and east of Raleigh starting on September 25, 2018. The two teams rendezvoused in Fayetteville and travelled as one group on September 26, 2018. The group divided again on September 27 and 28 into three groups of two to four members to cover widely scattered sites.

Fig. 1.2-1 shows the various sites visited by the GEER Florence teams. The geographic distribution of sites provides some insight into the storm impacts. Specifically, impacts were found along the coast, along waterways, and in a cluster on the eastern edge of the Piedmont physiographic province north and south of the NC/SC border. This cluster may have been due to elevation effects on rainfall, the slow movement of the storm, a higher density of historical dam development in the hillier terrain, or increased runoff due to lower-permeability soils. We also should note that damages were very widespread and that the sites were selected based on early reconnaissance information graciously provided by state dam safety and transportation agencies and on news reports. As such, our sampling was not comprehensive or completely representative.

We have organized this report to describe observations and background about the storm (Chapter 2), the resulting hydrology (Chapter 3), dams (Chapter 4), levees (Chapter 5), transportation (Chapter 6), coastal/waterfront (Chapter 7), and other observations (Chapter 8).

[1] GEER Goals from website, http://geerassociation.org/about-geer/goals.



Map data ©2018 Google 20 mi

Fig. 1.2-1 – Observation Areas by GEER Hurricane Florence Team

★ ★ ★ = Observed dam and levee sites,
Red = breached dams and levees
Blue = overtopped, not breached
Brown = not overtopped or breached (other observations)

▼ ▼ ▼ = Observed transportation sites,
Red = Bridges
Blue = Roadways
Brown = Railroads

● = Coastal observation sites

1.3 Observation Summary

For four days, between Thursday and Sunday, September 13-16, 2018, Hurricane Florence made a slow progression from offshore across the eastern part of North and South Carolina (Fig. 1.3-1). Like 2017's Hurricane Harvey in Texas, the lingering storm dumped massive amounts of rain on the Carolinas and caused major floods in the riverways along its track. Rainfall totals of up to 34 inches were measured during the storm. Severe flooding occurred along tributaries and the rivers of the major drainage basins of the Neuse, Cape Fear, Northeast Cape Fear, Lumber, Little Pee Dee, and Pee Dee Rivers.

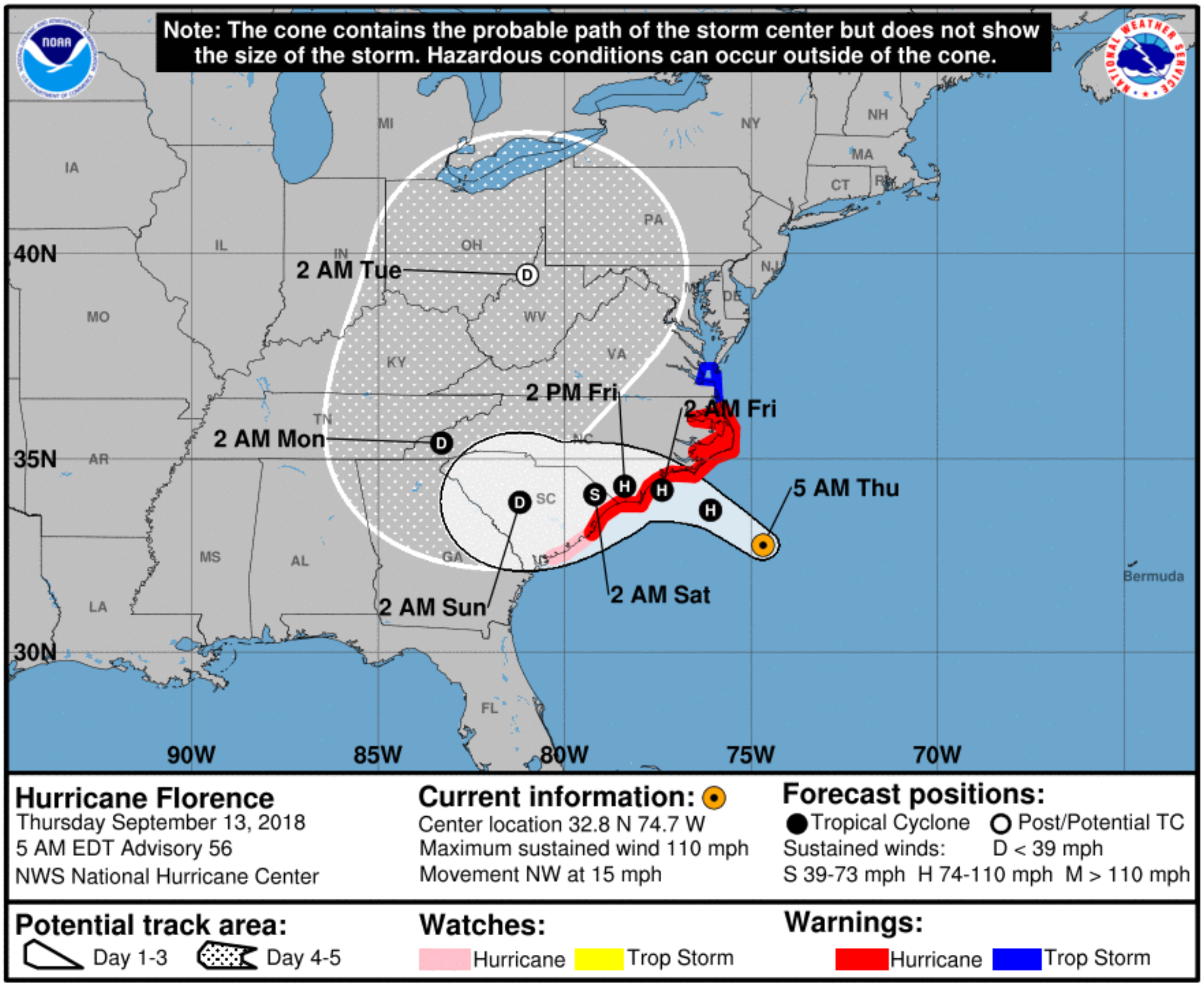


Fig. 1.3-1 – Hurricane Florence path (https://www.nhc.noaa.gov)

Of the 23 dams that we visited, flood flows overtopped 17 structures, 14 of which were breached by the overtopping. Fortunately, most of these dams were low or significant hazard such as Maxwell Mill Pond Dam (Fig. 1.3-2). However, one dam, Boiling Spring Lake Dam, south of Wilmington, NC, was classified as high hazard and was the largest overtopped dam (30-ft-high, 1584-ft-long) that we observed (Fig. 1.3-3). Four other smaller dams abutting Boiling Spring Lake area also failed (see cluster on Fig. 1.2-1). The one levee-protected area that we visited, in Lumberton, NC, flooded due to the inadequate closure of a rail and road underpass through the I-95 embankment that formed the northwestern flood barrier for the city.

Fig. 1.3-2 – Maxwell Mill Pond Dam breach, Duplin County, NC (September 25, 2018, 35.0706 N, 77.7880 W)

Fig. 1.3-3 – Boiling Springs Dam breach, Brunswick County, NC (September 26, 2018, 34.0465 N, 78.0373 W)

The storm affected all types of land transportation infrastructure – road and railroad bridges, culverts, and embankments. We saw many instances of significant scour around bridge supports (Fig. 1.3-4), and numerous failures of small bridges and road embankments downstream of breached dams (Fig. 1.3-5). Log/debris collections upstream of some bridges at two sites were large but did not appear to have overloaded piers. We saw numerous sites where scour, runoff, or overtopping eroded embankments or caused slope failures (Fig. 1.3-6). The most significant transportation failures were (1) the U.S. Route 421 washout where the Cape Fear River breached the isthmus between it and the Northeast Cape Fear River (Fig. 1.3-7) and (2) the washout of the embankment and associated railroad derailment in Anson County (Fig. 1.3-8).

Fig. 1.3-4 – Bridge pier scour, Business 95 Bridge, Cross Creek, Fayetteville, NC (September 26, 2018, 35.05507° N, 78.86251° W)

Fig. 1.3-5 – Road embankment washout downstream of Maxwell Mill Pond Dam, Duplin County, NC (September 25, 2018, 35.0701 N, 77.7876 W)

Fig. 1.3-6 – Rail line embankment washout and repair, Laurinburg, NC (September 27, 2018, 34.7936 N, 79.4619 W)

Fig. 1.3-7 – US 421 highway washout between the Cape Fear River from west (left) to the Northeast Cape Fear River on the east (right), looking northwest across washout (September 26, 2018, 34.3307° N, 77.9997° W)

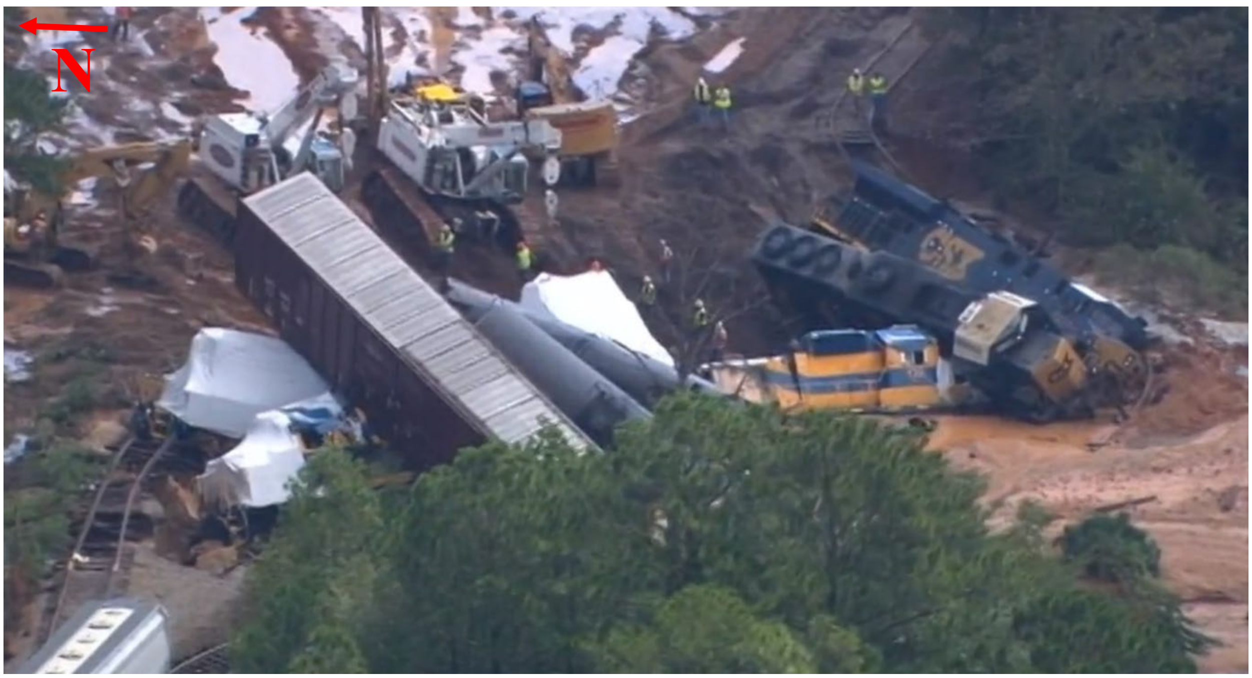


Fig. 1.3-8 – CSX Train Derailment aftermath, Anson County, NC (WSOC-TV, September 17, 2018, 34.9513 N, 79.9446 W)

One site of geotechnical interest that did not fit into our categories was the Cape Fear river bank in Elizabethtown. We observed several scarps, which were long (~500 ft) with short heights (~2 ft) in the area around a cemetery at this location indicating movement of a large part of the river bank (Fig. 1.3-9). We did not have enough information to assign a likely cause, but investigators could consider elevated seepage pressures and rapid-drawdown-induced shear stresses.

Fig 1.3-9 – Slope movement, Elizabethtown, NC (September 26, 2018, 34.6297 N, 78.60211 W)

We also made visits to the hard-hit coastal communities of New Bern, Surf City, Emerald Isle, and Wilmington. The storm surge affected all of these areas and caused severe damage to homes and businesses in those communities. The storm surge in New Bern was notably high at slightly more than 10 ft (Fig. 1.3-10) and was probably amplified by the converging mouth of the Neuse River.

Fig. 1.3-10 – Evidence of storm surge, New Bern, NC (September 25, 2018, 35.1082 N, 77.0353 W)

Overall, the infrastructure damage from hurricane Florence was significant and, while widespread, was clustered near waterways. As we have seen at other disaster sites, residents and businesses in areas of river flooding and storm surges suffered dramatic property losses (Fig. 1.3-11), especially in low-lying areas of Lumberton, New Bern, and Kinston. However, we hope and expect that the lack of area-wide devastation, such as that in New Orleans following Katrina, will allow the area to recover quickly.

Fig. 1.3-11 – Debris from residential clean-up, New Bern, NC (35.1091 N, 77.0355 W)

2. Hurricane Florence

Hurricane Florence was a powerful and long-lived hurricane, which hit the United States in September of 2018. It originated on August 30, 2018 in the Atlantic Ocean near Africa and moved towards the United States as the sixth named storm, third hurricane, and the first major hurricane of the 2018 Atlantic hurricane season. The strength of the hurricane varied from its August 30th origin until it hit the North Carolina coast on September 14, 2018. It was downgraded to Category 1 on the Saffir-Simpson wind scale when it made landfall near Wrightsville Beach early on Friday, September 14, 2018 at around 7:15 am ET. The recorded path segments of the hurricane from its origin and near the cost of Carolinas are shown in Fig. 2-1.

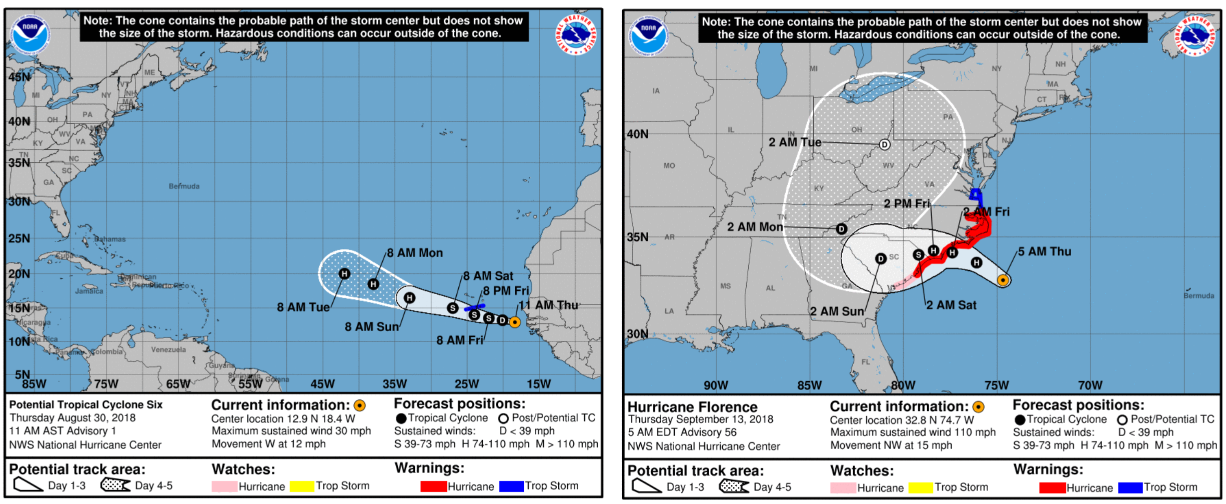


Figure 2-1 - Hurricane Florence path (https://www.nhc.noaa.gov)

Hurricane Florence produced a huge amount of rainfall that resulted in massive flooding in many parts of the Carolinas. This is a typical outcome of a slow-moving hurricane like Florence (Florence moved approximately 3 mph after made landfall). A total rainfall of 34 inches was reported in Swansboro, while the National Weather Service office in Newport recorded 25.2 inches The contour map of the recorded rainfall in the Carolinas is shown in Figure 2-2.

The hurricane produced maximum sustained wind gusts of 106 mph near Cape Lookout and 105 mph at Fort Macon. The combined effects of wind, flood and other factors resulted in extensive damage to buildings, roads, bridges, dams and other infrastructure and more than 50 fatalities in the Carolinas. The damage total is expected to be between $17 to $22 billon according to Moody's Analytics.

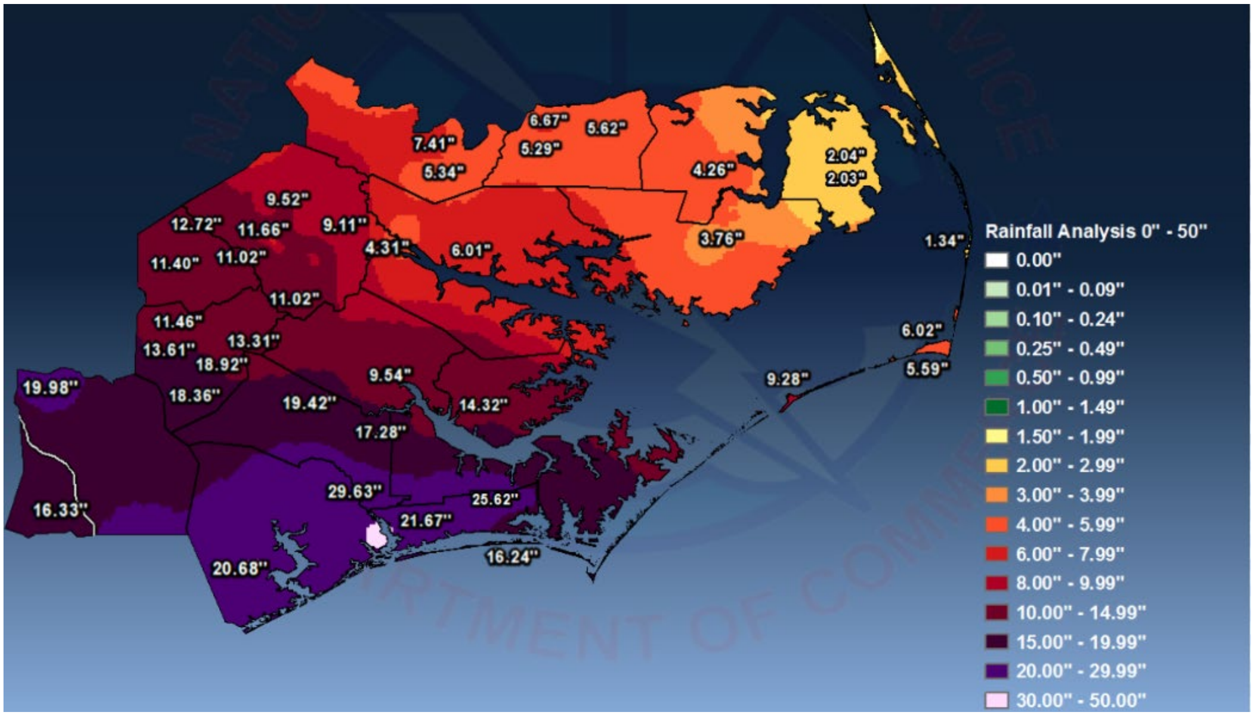


Figure 2-2 - Preliminary Hurricane Florence rainfall totals (https://www.weather.gov)

The largest storm surges reported on Friday, September 14, 2018, were in New Bern and Emerald Isle, North Carolina, where the water levels reached up to 10.1 feet and 7.0 feet above ground, respectively, according to the National Hurricane Center. Live storm surge data recorded at several other locations can be found at http://surge.srcc.lsu.edu/florence_2018.html.

References

National Weather Service. https://www.weather.gov/wrn/florence

Scism, Leslie and Ailworth, Erin (2018). “Moody’s Pegs Florence’s Economic Cost at $38 Billion to $50 Billion.” *The Wall Street Journal*. September 21.

3. Flooding / Hydrology

3.1 Precipitation

The National Weather Service published several preliminary rainfall totals from Hurricane Florence for the period of September 13 to 18, 2018. In particular, Fig. 3.1-1 shows that Wilmington and Morehead City received over 30 inches in rainfall. The 20- to 30-inch rainfall contour zone extends from the coast to Lumberton, Fayetteville, and New Bern, NC. These rainfall totals greatly exceed the normal September precipitation for the North Carolina coastline of less than 5 inches for Fayetteville and 10 inches for Wilmington (Fig. 3.1-2). Fig. 3.1-1 also shows the rainfall for South Carolina, where rainfalls in some instances reached the 20 to 30 inches contour along the border with North Carolina. This led to flooding near Florence, SC, which was observed by the GEER team as it traveled from Myrtle Beach north to visit areas of overtopped dams. Fig. 3.3-3 shows preliminary statistical analyses performed by the National Weather Service. It indicates that the region bounded by Lumberton, Fayetteville, New Bern, and Wilmington, NC experienced rainfall totals that surpass the 1-in-1000 year event (i.e., 0.1% likelihood to occur each year). The overwhelming volume of precipitation ultimately led to severe flooding within interior drainage basins of the major area river systems of the Neuse, Cape Fear, Northeast Cape Fear, Lumber, Little Pee Dee, and Pee Dee Rivers.

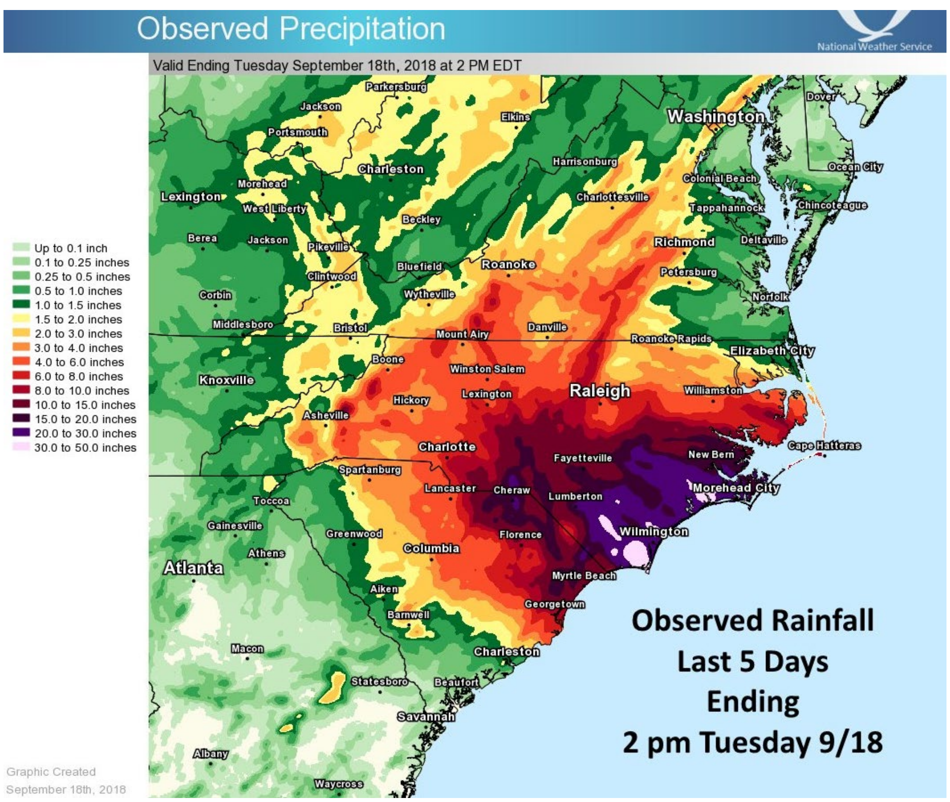


Fig. 3.1-1 - Cumulative rainfall from Hurricane Florence for North Carolina and South Carolina (https://twitter.com/NWSEastern/status/1042116250611138562)

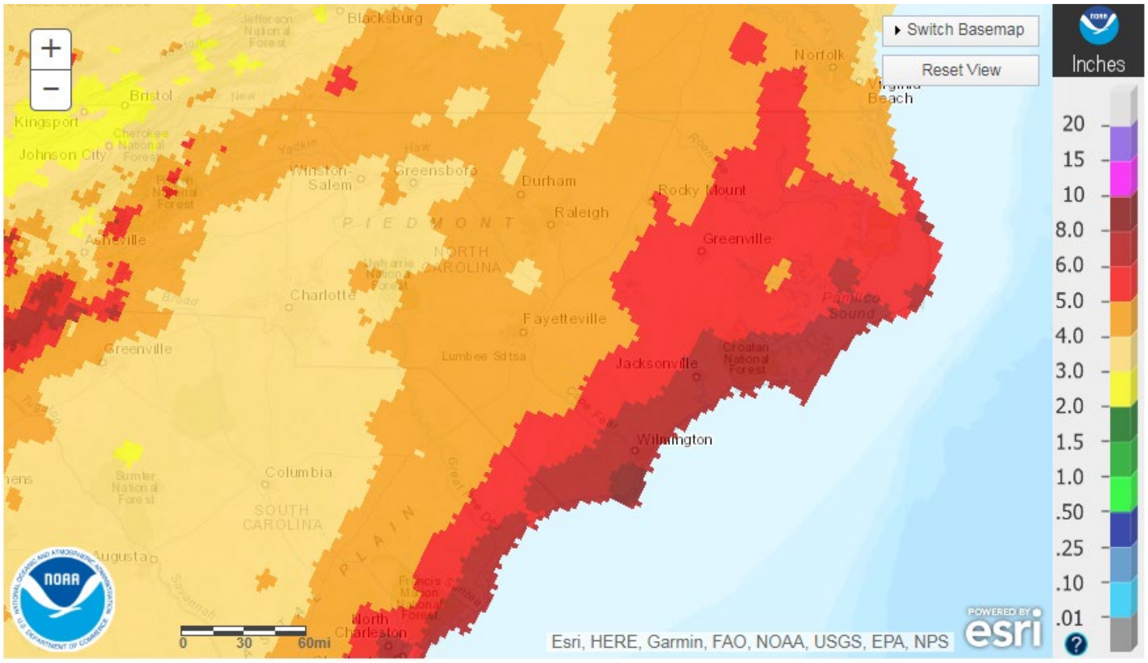


Fig. 3.1-2 - Average September rainfall for North Carolina and South Carolina coastal plains (courtesy of NOAA National Weather Service, www.weather.gov)

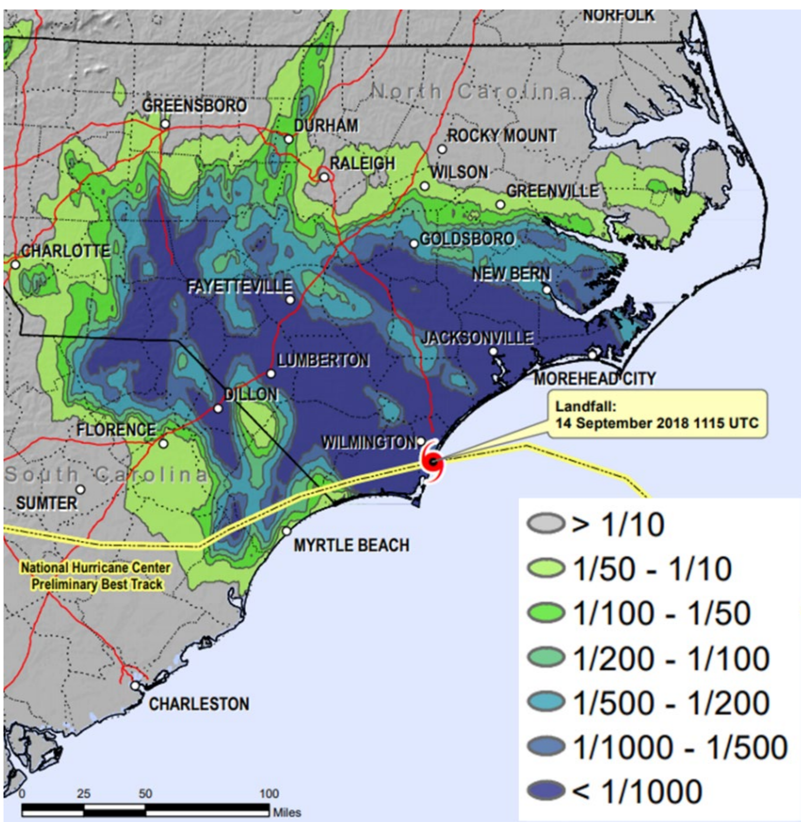


Fig. 3.1-3 - Hurricane Florence Annual Exceedance Probabilities from September 13-18, 2018 (http://www.nws.noaa.gov/oh/hdsc/aep_storm_analysis/index.html)

3.2 River Floods and Hydrographs

The river basins impacted by Hurricane Florence are identified in Fig. 3.2-1 and include, from north to south: Neuse (teal balloons), Cape Fear (orange squares), Northeast Cape Fear (red triangles), Lumber (yellow circles), Little Pee Dee (blue circles), and Pee Dee (green arrows). Figs. 3.2-2 and 3.2-3 provide an overview of the river basins for North Carolina and South Carolina, respectively. The Lumber River basin in North Carolina flows south into South Carolina and connects to the Little Pee Dee river, which subsequently flows into the Pee Dee River in South Carolina. The Pee Dee River originates in the Yadkin-Pee Dee basin in North Carolina and hence forms the larger Pee Dee basin along the northeast corridor of South Carolina. The following sections discuss each river basin and the associated hydrographs.

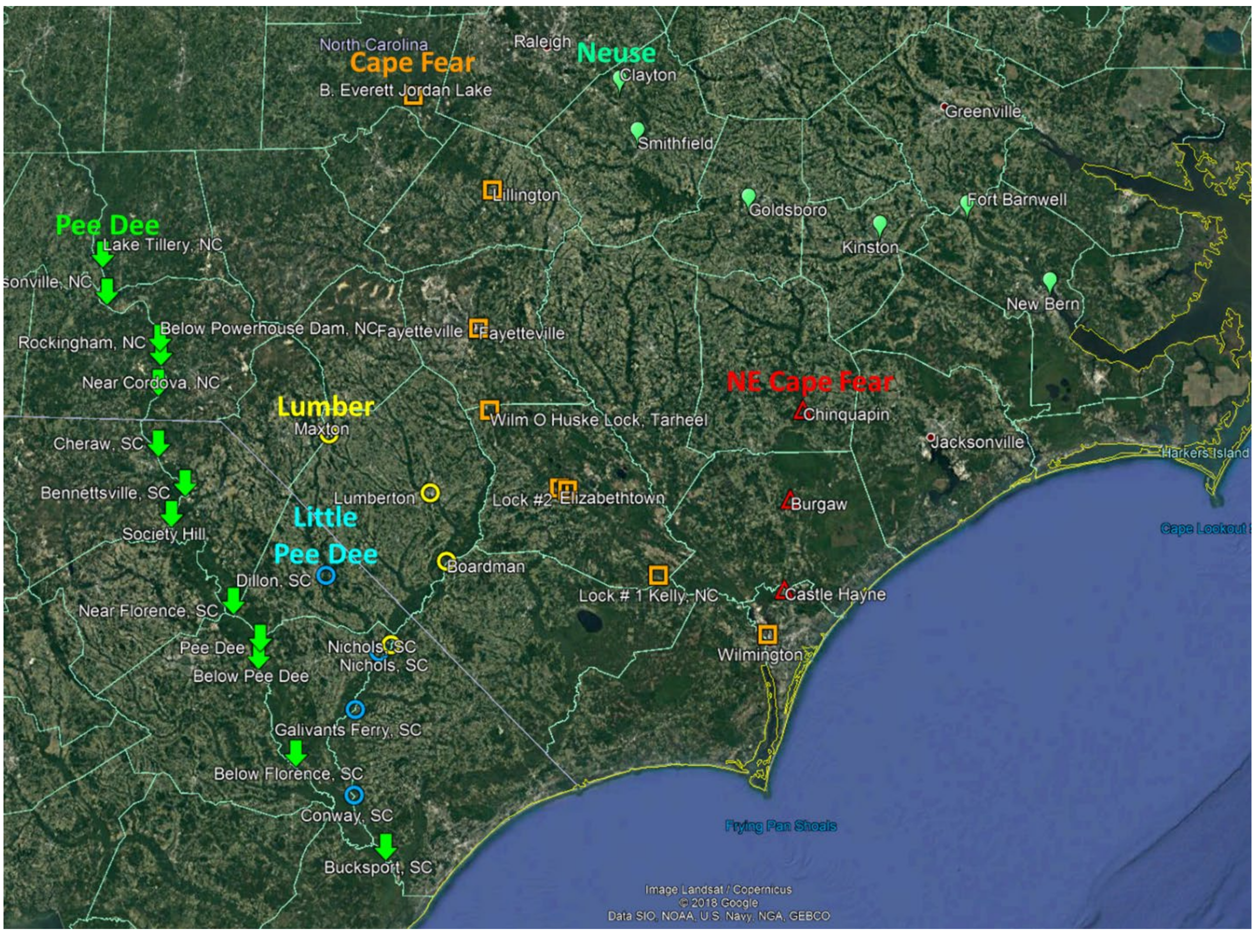


Fig. 3.2-1 – Major impacted river basins from Hurricane Florence (Google Maps for source map)

Fig. 3.2-2 - North Carolina river basins (from N.C. Division of Water Resources, https://files.nc.gov/ncdeq/Water%20Resources/files/publications/Neuse_RB_WR_Plan_20100720.pdf)

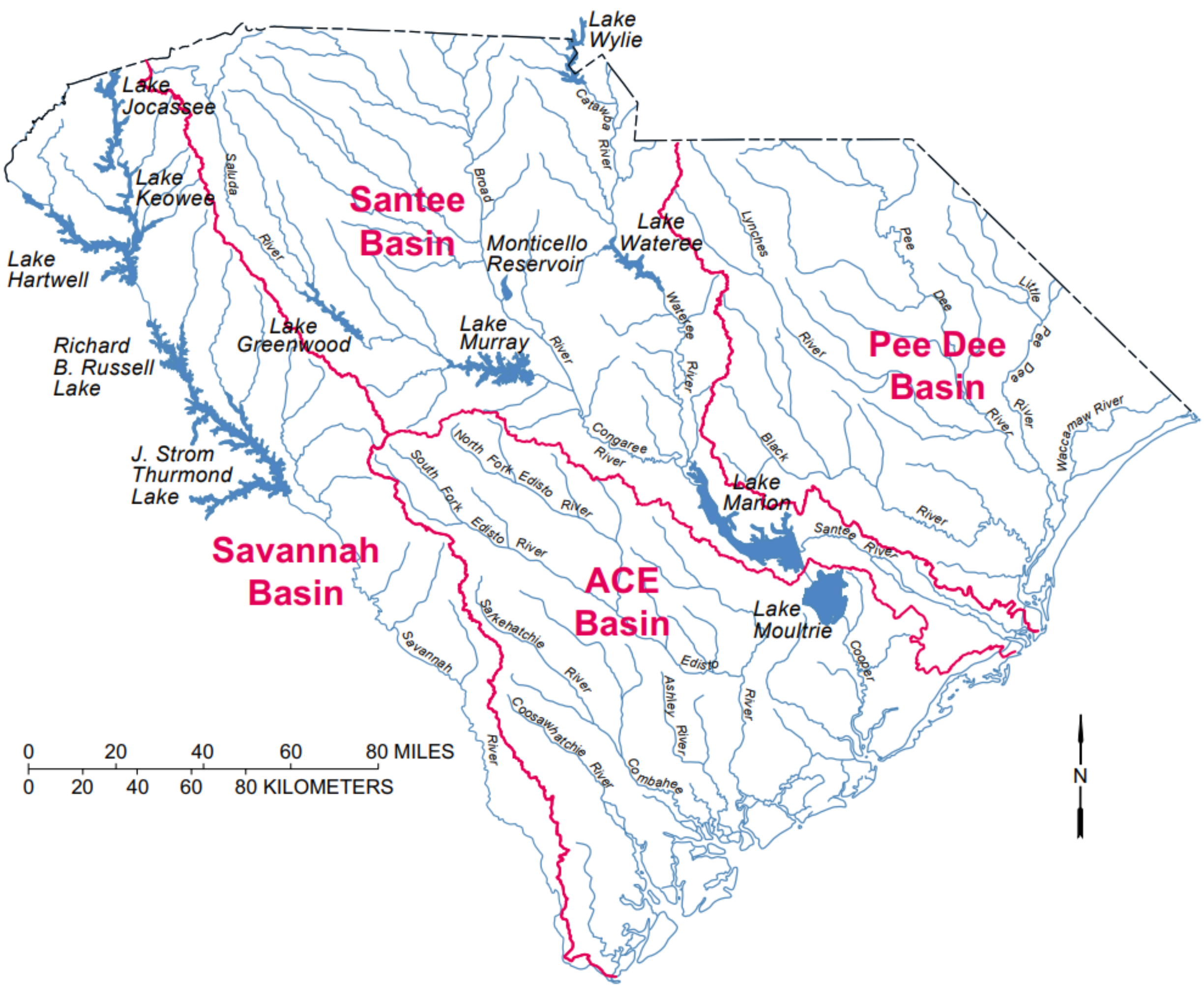


Fig. 3.2-3 - South Carolina river basins (from S.C. Department of Natural Resources, http://www.dnr.sc.gov/water/admin/pubs/pdfs/SCWaterPlan2.pdf)

3.3 Neuse River, North Carolina

The Neuse River basin is the third largest river basin in North Carolina and covers 6,235 square miles of drainage area entirely located in the state. The basin includes 3,389 freshwater stream miles, 17,902 acres of freshwater reservoirs and lakes, 143 saltwater miles, and 370,779 estuarine/saltwater acres. The headwaters of the Neuse River are northwest of Durham, where the Eno and Flat Rivers join at a location now inundated by Falls Lake Reservoir in northern Wake County. The river then flows in a southeasterly direction from the Piedmont and into the Coastal Plain regions through Goldsboro and Kinston. Contentnea Creek, a major tributary, flows into the river below Kinston. The river becomes tidally influenced upstream of New Bern, before it finally opens into the estuary leading into the Pamlico Sound. The Neuse River flows approximately 200 miles from its source in Orange and Person counties to its mouth at the Pamlico Sound.

Fig. 3.3-1 shows the hydrographs for the Neuse River during Hurricane Florence. In Fig. 3.3-1(a), the New Bern hydrograph peaks early at approximately 10 ft due to the coastal storm surge. Note that hydrograph tables and plots present gage heights that use local datums and are not common-datum water elevations. The funneling effect of the Neuse River mouth probably amplified the effects of the wind-driven storm surge off of the Pamlico Sound. Moving away from New Bern, the water levels in the Fort Barnwell, Kinston, and Goldsboro gages increased starting on September 14, 2018 due to increased river flow. The rises at these river gages were similar, with the maximum river level of ~27.5 ft on September 19 at Goldsboro (farthest inland) followed by Kinston (~25.5 ft, September 21) and Fort Barnwell (~17.5 ft, September 18). Fort Barnwell gage was the lowest water level, but it maintained this stage for about a week (September 25), as waters finally drained from the Neuse River basin. The Smithfield and Clayton gages in Fig. 3.3-1(b) show similar peaks around September 17, but the magnitude of high river stage is limited because these gages are located upriver, closer to Raleigh, NC (see Fig. 3.2-1). The latter fluctuations at these inland gages are due to post-Florence rain events.

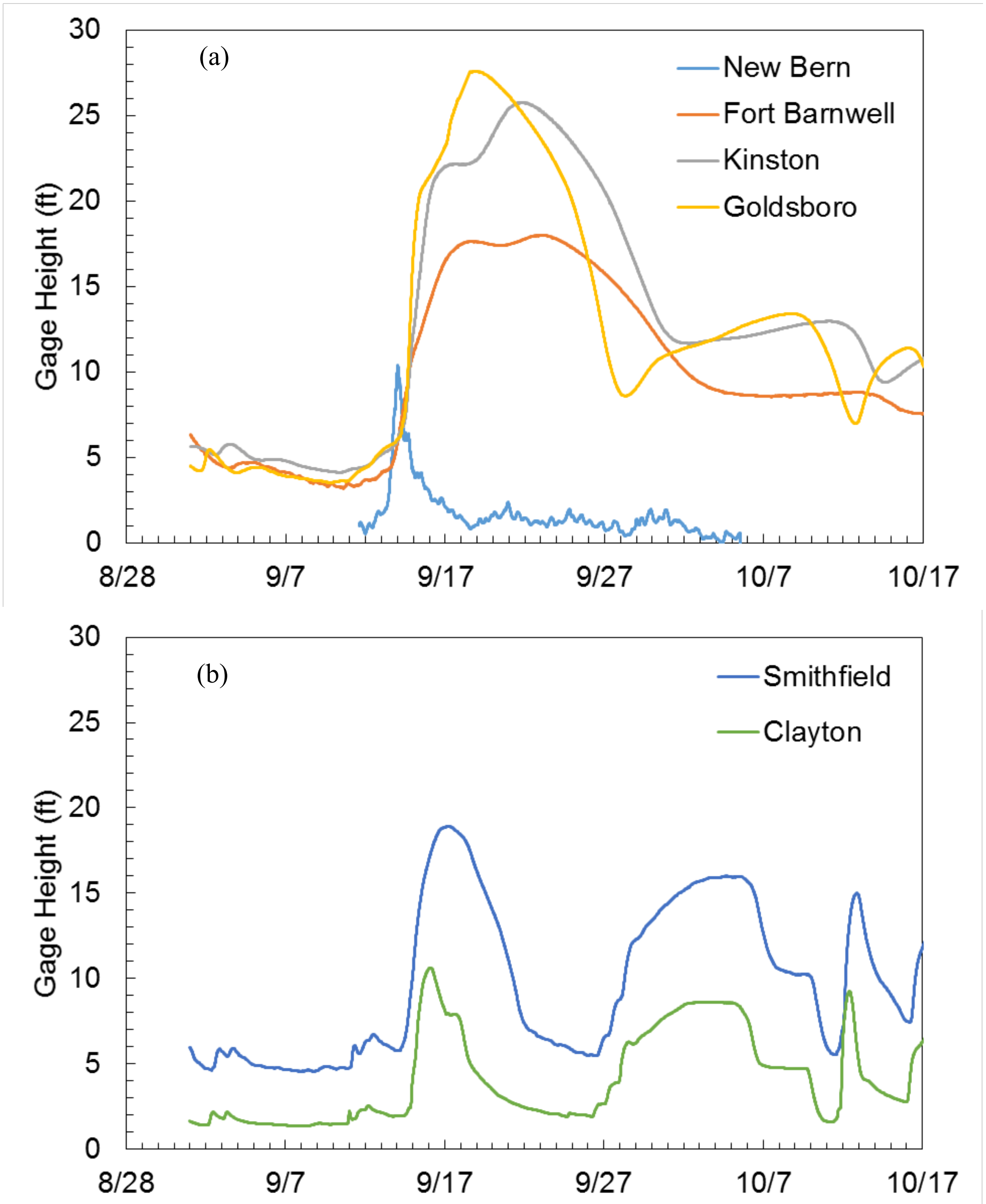


Fig. 3.3-1 - Neuse River Hydrographs: (a) Coastal plains gages, and (b) Raleigh area gages (data obtained from https://stn.wim.usgs.gov/fev/#FlorenceSep2018)

As a comparison to the river stages in Fig. 3.3-1, Table 3.3-1 summarizes the flood and major flood stages along with historic and Hurricane Florence crests. All of the gages reached flood stage and all except for Smithfield and Clayton reached major flood stage. The historic crests along the Neuse River date back to Hurricane Matthew (2016) or Hurricane Floyd (1999). The

Kinston and Goldsboro gages from Hurricane Florence were the closest to historic crests, within 2 ft to 2.5 ft.

Table 3.3-1 Summary statistics for Neuse River

Gage	Flood Stage	Major Flood Stage	Historic Crests	Hurricane Florence
Fort Barnwell	13	18 ft	22.75 ft, 9/20/1999 20.5 ft, 10/15/2016	18 ft, 9/23/2018
Kinston	14 ft	21 ft	28.3 ft, 10/14/2016 27.7 ft, 9/23/1999	25.8 ft, 9/21/2018
Goldsboro	18 ft	24 ft	29.74 ft, 10/12/2016, 28.85 ft, 9/20/1999	27.6 ft, 9/19/2018
Smithfield	15 ft	20 ft	29.1 ft, 10/10/2016 27.4 ft, 9/8/1996	18.9 ft, 9/17/2018
Clayton	9 ft	16 ft	22.1 ft, 9/19/1945 21.6 ft, 10/3/1929	10.6 ft, 9/16/2018

3.4 Cape Fear River, North Carolina

The Cape Fear Basin is the largest basin in North Carolina, draining 9,149 square miles from its headwaters in the northern Piedmont to its mouth at Cape Fear, south of Wilmington. The Haw River and the Deep River merge at the border of Lee and Chatham Counties to form the Cape Fear River, which flows southeast across the Coastal Plain past the Port of Wilmington to the Atlantic Ocean. The South River and the Northeast Cape Fear River merge with the Cape Fear near Wilmington. The New River in Onslow County is also included in the Cape Fear River Major Basin. The Haw River is impounded by the B. Everett Jordan Dam just above the confluence with the Deep River, providing storage for flood control, water supply, and releases to maintain downstream water quality. Most of the basin below the confluence of the Haw and Deep Rivers lies in the Coastal Plain.

While many rivers drain into the Cape River basin, the Northeast Cape Fear River is noted here because the GEER team traveled through this basin during the scouting of Wilmington. Three gages were found for the Northeast Cape Fear River (Fig. 3.4-1 hydrographs), located in Chinquapin, Burgaw, and Castle Hayne, upstream of the Wilmington gage, which largely reflected tidal fluctuations from the Atlantic Ocean. The Chinquapin gage unfortunately does not provide any data related to the peak of the flood event, but Table 3.4-1 likely suggests that Hurricane Florence is now the historic crest because the prior historic value was ~23.5 ft from Hurricane Floyd in September 1999. Incomplete flood levels are available for Castle Hayne, but it seems that the peak flood was ~12 ft from the fall of the hydrograph. The Burgaw gage peaks at a maximum flood level of ~25.6 ft on September 19, 2018, which is now the historic crest (previously ~22.5 ft from Hurricane Floyd) by approximately 3 ft.

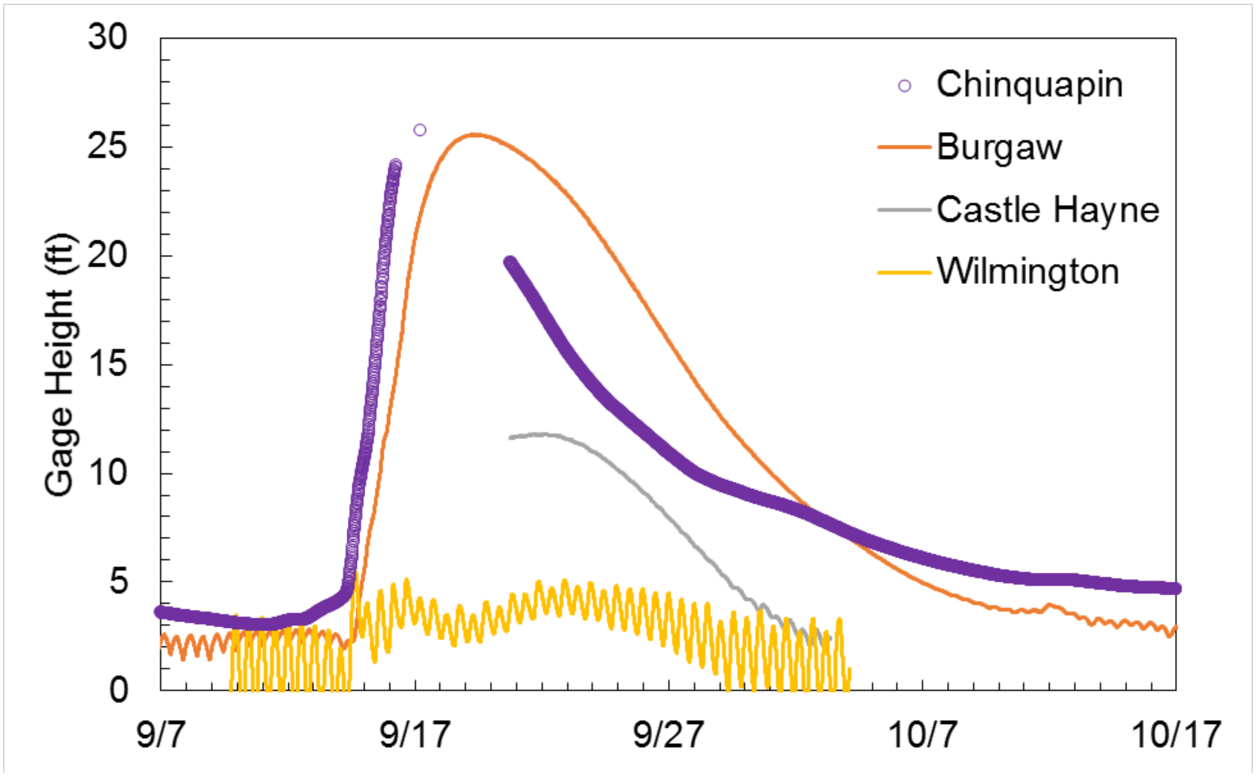


Fig. 3.4-1 - Hydrographs for Northeast Cape Fear River

Table 3.4-1 - Summary of Northeast Cape Fear River hydrograph statistics

Gage	Flood Stage	Major Flood Stage	Historic Crests	Hurricane Florence
Chinquapin	13 ft	16 ft	23.51 ft, 9/18/1999	N/A
Burgaw	10 ft	16 ft	22.48 ft, 9/19/1999 17.81 ft, 10/13/2016	25.57 ft, 9/19/2018
Wilmington	5.5 ft	6.7 ft (moderate)	8.17 ft, 10/08/2016	8.28 ft, 9/14/2018

Fig. 3.4-2 shows the hydrographs for the Cape Fear River system, starting from the north near Jordan Lake and moving to north Wilmington (Lillington, Fayetteville, W.O. Husk Lock, Elizabethtown, and Lock #1 near Kelly, NC). The Wilmington District, U.S. Army Corps of Engineers oversees the locks and dams on the Cape Fear River in North Carolina. Built between 1915 and 1935, the three locks and dams historically passed commercial traffic up and down the river. The locks and dams now rarely pass large vessels through but instead help protect water

intakes for cities and industries along the river by backing up the water. Lock and Dam 1 was originally constructed in 1915 and modified in 1934 to increase the lift by 3 ft to a total of 11 ft. The lock is 40 ft by 200 ft. William O. Huske lock and dam was constructed in 1935. The lock chamber is 40 ft by 300 ft with a total lift of 9 ft. The lower pool is at elevation +23 ft and the upper pool is maintained at elevation +32 ft. Aerial photographs of the lock and dam before (Fig. 3.4-3) and during the flooding on September 18, 2018 (Fig. 3.4-4), show that the river totally covered the structure.

The most northerly gage on Cape Fear River, at Lillington, shows that water levels were ~2 ft before dramatically increasing on September 15 to ~21.3 ft on September 18. Water levels decreased to pre-Hurricane Florence by September 23. The historic crest at Lillington is ~33.2 ft from September 1945, which corresponds to the "Homestead" Hurricane of 1945. The Fayetteville gage was at a stage of ~10 ft before Hurricane Florence. On September 15, Fayetteville started to increase, eventually reaching a major flood stage of 61.6 ft, which was still ~7 ft less than the historic crest of 68.9 ft from the Homestead Hurricane in 1945. The gage at the William O. Huske Lock shows a similar hydrograph to Fayetteville but it increases to a larger flood value because of the elevation of the lock and dam (+32 ft). While a major flood stage was observed at this lock and dam, it was ~5 ft less than the historic crest of 75.5 ft from September 1945. At Elizabethtown, the Cape Fear River rose to 42.5 ft, which was less than the major flood stage of 47 ft. Nevertheless, this flood stage still represents an extreme event because the historic crest observed during the 1945 Homestead Hurricane was 43.2 ft, i.e., less than one foot from the historic value. The Lock #1 gage near Kelly, NC, is closer to Wilmington and sea level, and the peak flood stage is slightly delayed from the rest of the gages. The drainage from upstream rivers and creeks resulted in the maximum flood stage of ~30.7 ft, which is not only above the major flood stage but also the new historic crest (previously 29.8 ft from 1945).

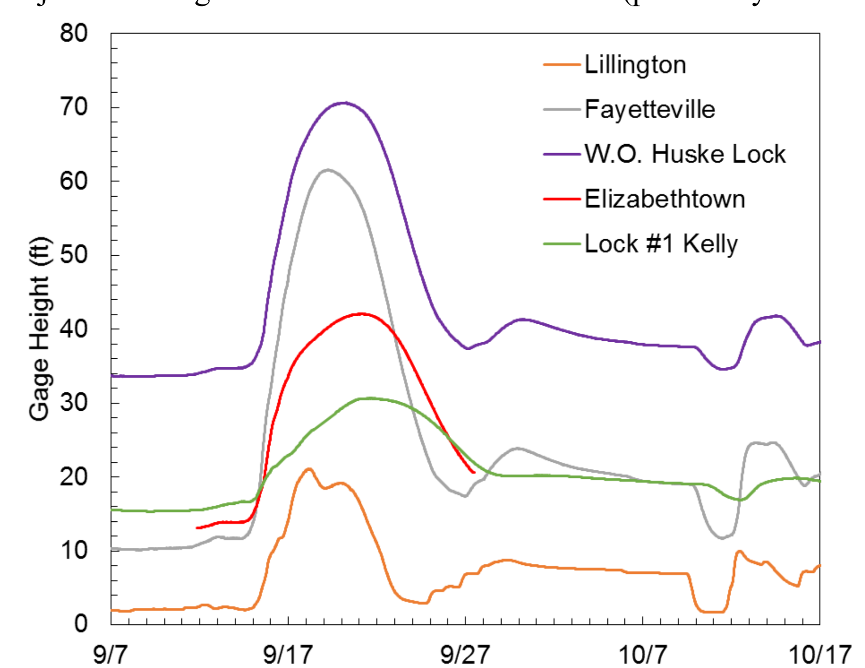


Fig. 3.4-2 - Hydrographs for Cape Fear River

Table 3.4-2 - Summary of Cape Fear River hydrograph statistics

Gage	Flood Stage	Major Flood Stage	Historic Crests	Hurricane Florence
Lillington	14 ft	27 ft	33.19 ft, 9/19/1945	21.27 ft, 9/18/2018
Fayetteville	35 ft	58 ft	68.90 ft, 9/21/1945	61.58 ft, 9/19/2018
Huske Lock	42 ft	65 ft	75.50 ft, 9/22/1945	70.73 ft, 9/20/2018
Elizabeth-town	25 ft	47 ft	43.20 ft, 9/23/1945	42.51 ft, 9/21/2018
Lock #1 Kelly	24 ft	28 ft	29.80 ft, 9/23/1945	30.68 ft, 9/21/2018

Fig. 3.4-3 – Aerial photograph of the William O'Huske Lock and Dam Number 3 before Hurricane Florence (Google Earth, March 3, 2018, 34.835 N, 78.823 W)

Fig. 3.4-4 – Aerial photograph of the William O'Huske Lock and Dam Number 3 during Hurricane Florence flooding (Google Earth, September 18, 2018, 34.835 N, 78.823 W)

3.5 Lumber River, North Carolina

The Lumber River basin encompasses an area of 3,343 square miles and flows, from upstream to downstream, through Lumberton, Laurinburg, Southern Pines, Pinehurst and Whiteville. There are four different watersheds in the Lumber River basin, i.e., Lumber River, Waccamaw River, headwaters of the Little Pee Dee, and the coastal watershed of the Shalotte/Lockwoods Folly rivers. The Lumber River begins at the headwaters known as Drowning Creek (Moore and Montgomery Counties) and flows through Lumberton, a highly-developed urban area. The river crosses the South Carolina border near Fair Bluff. Just past the border, the Lumber River joins the Little Pee Dee River, which flows to the Pee Dee River and drains to Winyah Bay.

Fig. 3.5-1 shows the hydrographs for Maxton, Lumberton, and Boardman, along with Nichols, SC. The gage at Maxton, NC starts at 7 ft before Hurricane Florence and gradually increases to a peak flood level of 17.75 ft on September 19. The Lumberton gage is also at 7 ft before Florence but dramatically increases to 22.2 ft in Fig. 3.5-1. The discrepancy between the peak stage found in Fig. 3.5-1 and the one reported in Table 3.5-1 is attributed to another nearby gage just upstream of Lumberton that reports 29 ft. This peak stage is the new historic crest compared to the previous record of 28 ft measured during Hurricane Matthew in October 2016. The Boardman gage peak for Hurricane Florence flows almost overtakes the historic crest (i.e., 14.43 ft in October 2016 and 14.36 ft on September 18, 2018). As the Lumber River flows into the Little Pee Dee near Nichols, SC, significant high gage levels of 27.4 ft on September 20 were also observed.

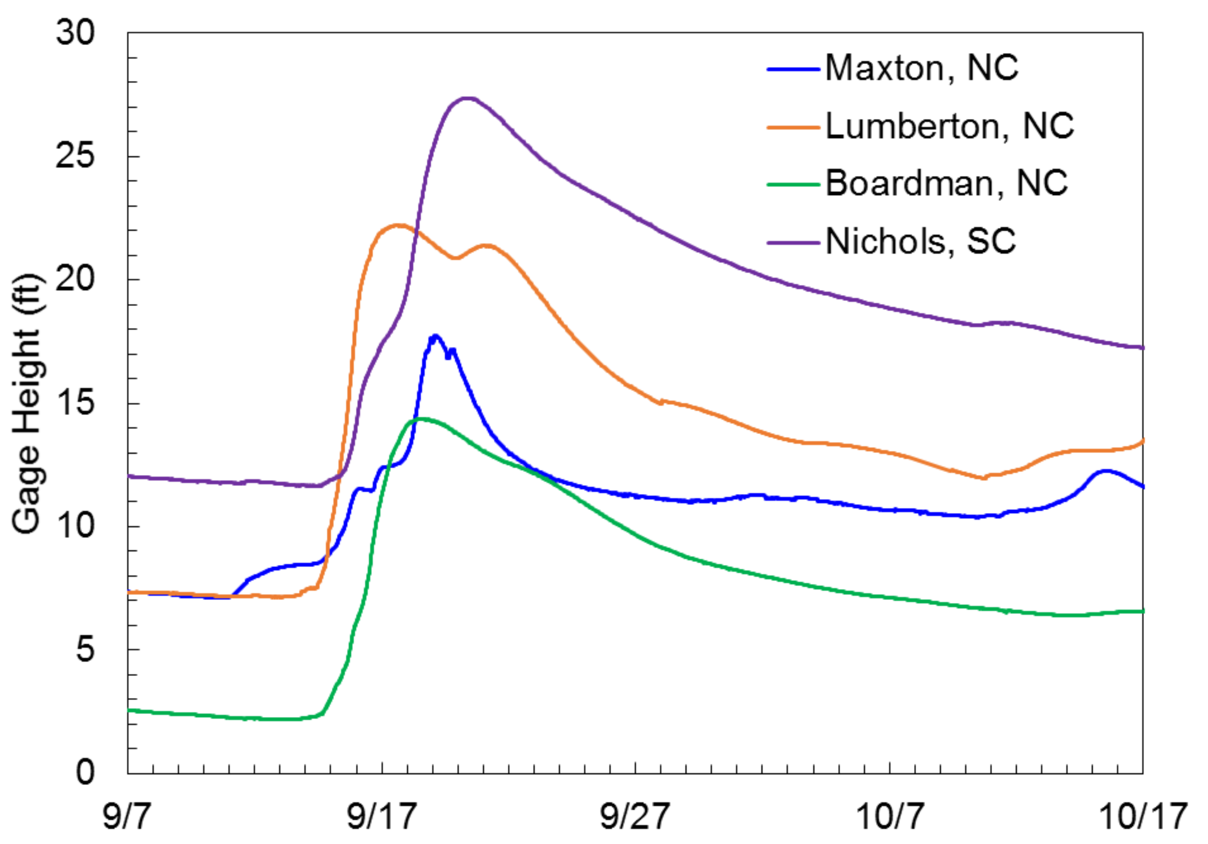


Fig. 3.5-1 - Hydrographs for Lumber River

Table 3.5-1 - Summary of Cape Fear River hydrograph statistics

Gage	Flood Stage	Major Flood Stage	Historic Crests	Hurricane Florence
Maxton, NC	N/A	N/A	15.49 ft, 10/11/2016	17.74 ft, 9/19/2018
Lumberton, NC	13 ft	17 ft	28 ft, 10/9/2016	29 ft, 9/17/2018 (nearby gage)
Boardman, NC	N/A	N/A	14.43 ft, 10/11/2016	14.36 ft, 9/18/2018
Nichols, SC	N/A	N/A	N/A	27.4 ft, 9/20/2018

3.6 Pee Dee River, South Carolina

The Pee Dee Basin incorporates 45 watersheds and some 5.5 million acres within the State of South Carolina (a portion of the basin resides in North Carolina). The Pee Dee Basin encompasses the Lynches River Basin, the Black River Basin, the Waccamaw River Basin, the Great Pee Dee River Basin, and the Pee Dee Coastal Frontage Basin. The Pee Dee River Basin extends across the Piedmont, Sandhills, Upper Coastal Plain, Lower Coastal Plain, and Coastal Zone regions. There are a total of 9,495 stream miles, 17,034 acres of lake waters, and 44,870 acres of estuarine areas in the basin.

Fig. 3.6-1 shows the hydrographs obtained for Waccamaw River, which primarily flows to the coast, from North Carolina to South Carolina. In particular, the Wacaamaw River pass through Conway, SC, which experienced severe floods, especially along Highway Route 501 where Hesco baskets were stacked to two levels along the highway. The severity of flooding that culminated in Conway is summarized in Table 3.6-1, which indicates that the Waccamaw River floods levels exceeded all historic crests by 3 ft to 4 ft. In general, the maximum flood levels were observed during the last week of September (9/24 to 9/27), which corresponds to observations from the GEER South team that visited the general area.

Fig. 3.6-2 and Table 3.6-2 summarize the relevant hydrographs for the Little Pee Dee River. Limited flood stage data is available along the Little Pee Dee, but new historic crests were observed at Galivants Ferry and Bucksport gages. The West Conway gage was a rapid deployment sensor by USGS (9/9/2018) so no flood stage information beyond the measured data is available.

Fig. 3.6-3 and Table 3.6-3 summarize the relevant hydrographs for the Pee Dee River. The Pee Dee River along with the Little Pee Dee River were important impact areas where our teams observed a number of dams near the North and South Carolinas border. In particular, Bennettsville observed a historic crest of 93.3 ft on September 18, which is 3.3 ft higher than the last historic crest of 90 ft on April 2003. It is unclear what event led to the last historic crest. Because of the lower levels of reported damage for other areas in South Carolina, the focus of GEER in South Carolina was near the North Carolina border and less along the central and southern portions of the Pee Dee River basin.

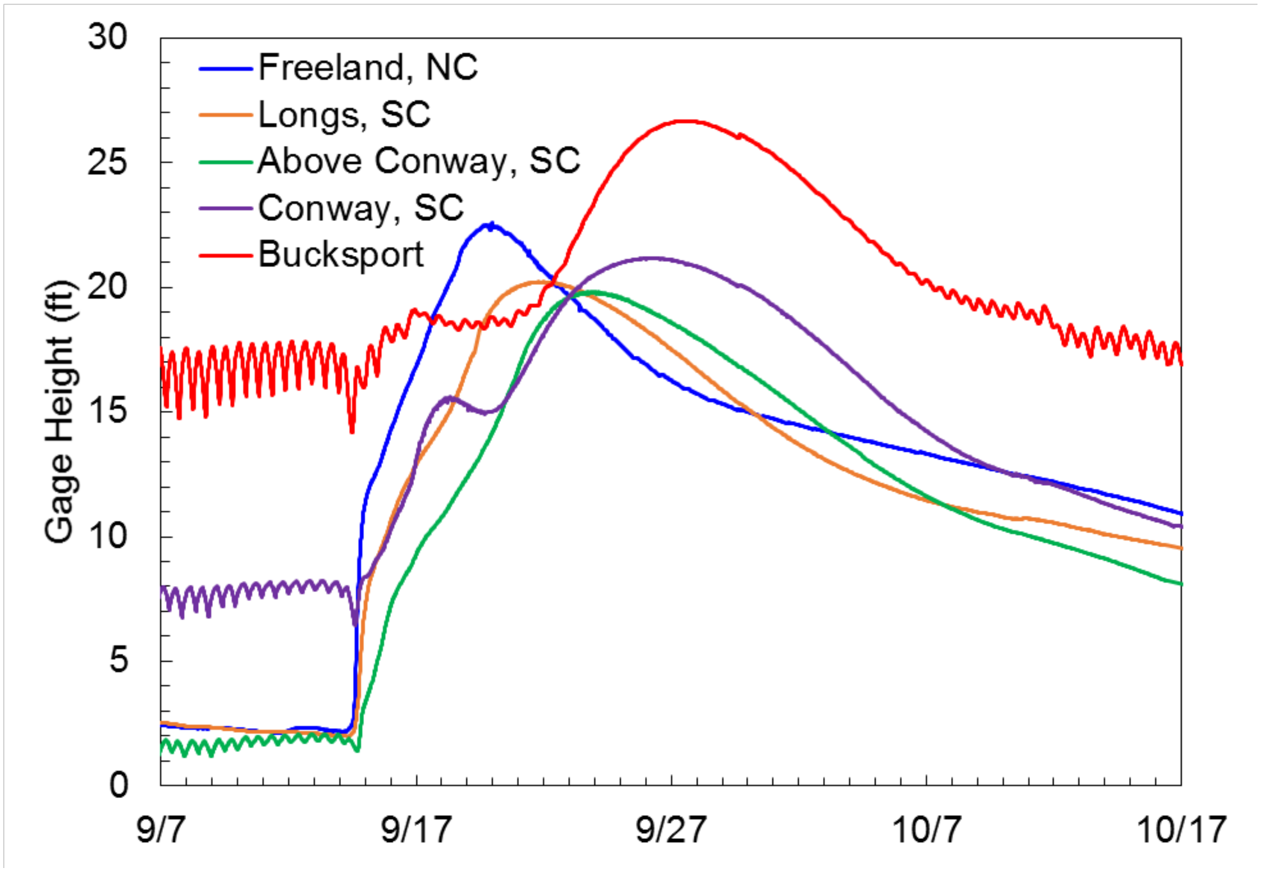


Fig. 3.6-1 - Hydrographs for Waccamaw River

Table 3.6-1 - Summary of Waccamaw River hydrograph statistics

Gage	Flood Stage	Major Flood Stage	Historic Crests	Hurricane Florence
Freeland, NC	N/A	N/A	19.30 ft, 9/21/1999	22.47 ft, 9/20/2018
Longs, SC	N/A	N/A	17.94 ft, 9/22/1999	20.22 ft, 9/21/2018
Above Conway	N/A	N/A	15.77 ft, 10/16/2016	19.82 ft, 9/24/2018
Conway, SC	11 ft	14 ft	17.87 ft, 10/18/2016	21.16 ft, 9/26/2018
Bucksport, SC	N/A	N/A	23.67 ft, 10/18/2016	26.67 ft, 9/27/2018

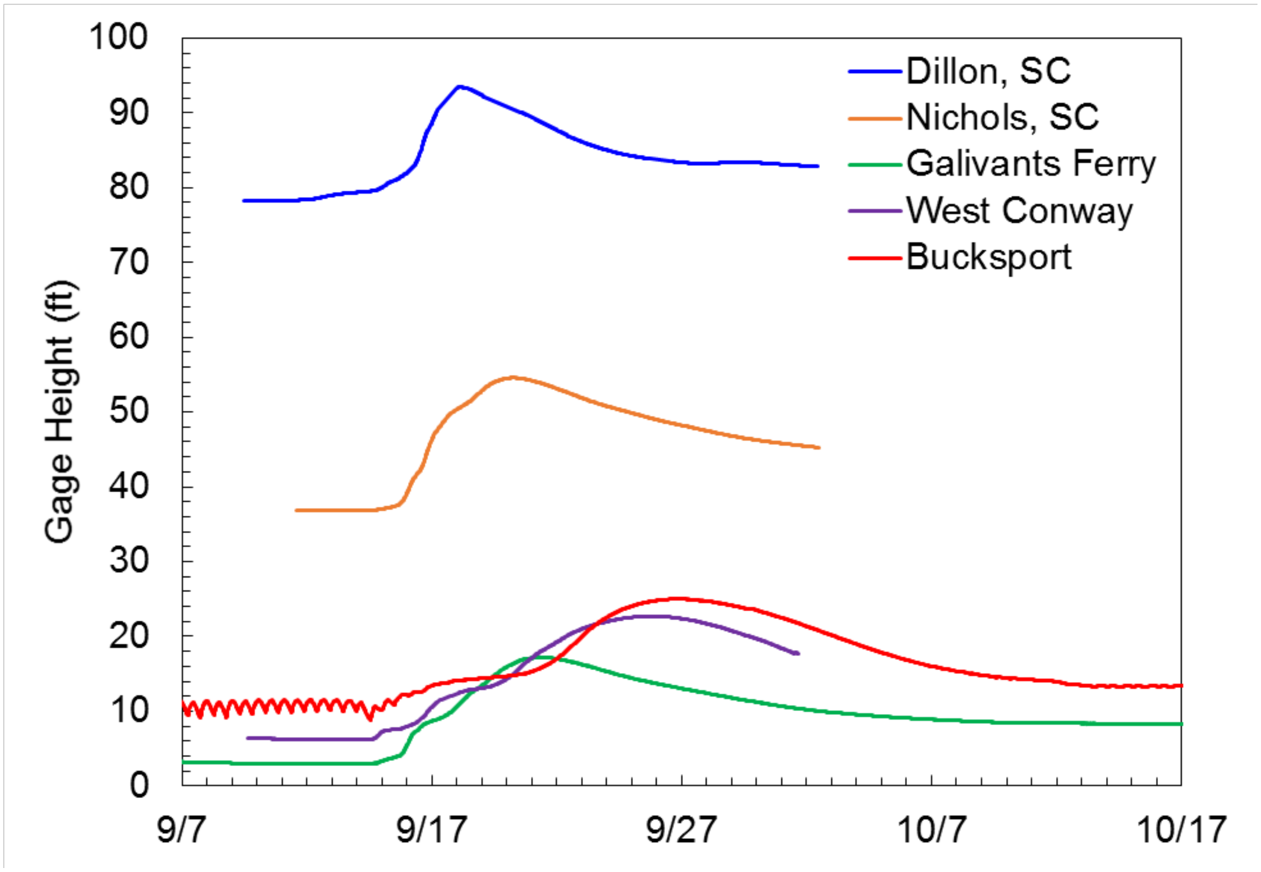


Fig. 3.6-2 - Hydrographs for Little Pee Dee River

Table 3.6-2 - Summary of Little Pee Dee River hydrograph statistics

Gage	Flood Stage	Major Flood Stage	Historic Crests	Hurricane Florence
Dillon	N/A	N/A	N/A	93.4 ft, 9/18/2018
Nichols	N/A	N/A	N/A	54.55 ft, 9/20/2018
Galivants Ferry	9 ft	12 ft	17.10 ft, 10/12/2016	17.21 ft, 9/21/2018
West Conway	N/A	N/A	N/A	21.16 ft, 9/26/2018
Bucksport	N/A	N/A	22.60 ft, 10/16/2016	25.00 ft, 9/26/2018

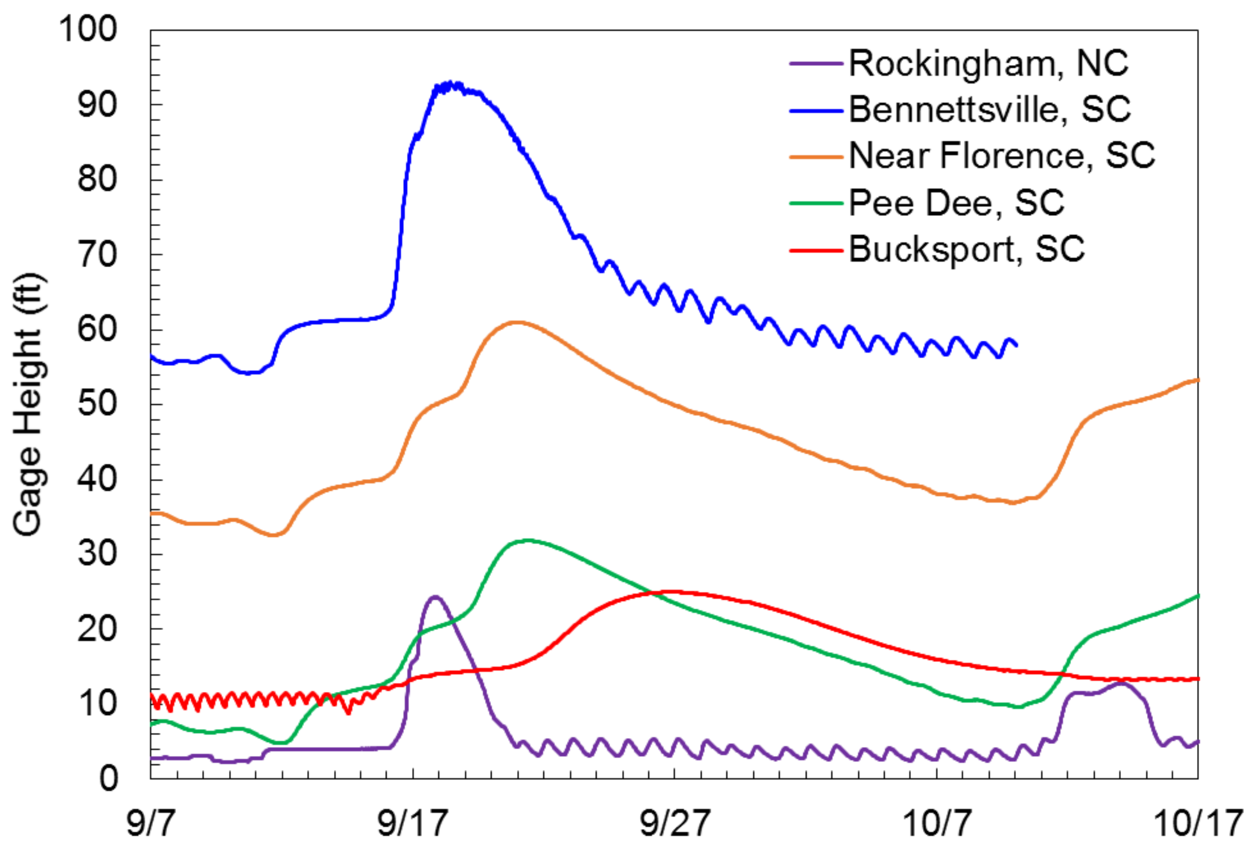


Fig. 3.6-3 - Hydrographs for Pee Dee River

Table 3.6-3 - Summary of Little Pee Dee River hydrograph statistics

Gage	Flood Stage	Major Flood Stage	Historic Crests	Hurricane Florence
Rockingham, NC	N/A	N/A	N/A	23.7 ft, 9/20/2018
Bennettsville, SC	N/A	N/A	89.94 ft, 4/12/2003	93.31 ft, 9/18/2018
Near Florence, SC	N/A	N/A	N/A	60.85 ft, 9/20/2018
Pee Dee, SC	19 ft	28 ft	33.30 ft, 9/22/1945	31.83 ft, 9/21/2018
Bucksport, SC	N/A	N/A	22.60 ft, 10/16/2016	25.00 ft, 9/26/2018

References

Google Earth aerial photography, various dates.

National Weather Service. Numerous website archive pages. https://www.weather.gov.

United States Geologic Survey, National Water Information System: Web Interface. Numerous gage station website pages. https://waterdata.usgs.gov/nwis.

4. Dams

4.1 Overview

The GEER Florence teams visited over 23 dams within the area affected by Florence. Fig. 4.1-1 shows the location of the dams that we observed, keyed to a listing of the dams in Table 4.1. We have divided our observations by the effects of the high water into three groups - breached dams (14 dams, Section 4.2), overtopped but unbreached dams (3 dams, Section 4.3), and other dam-related incidents and observations (6 dams, Section 4.4).

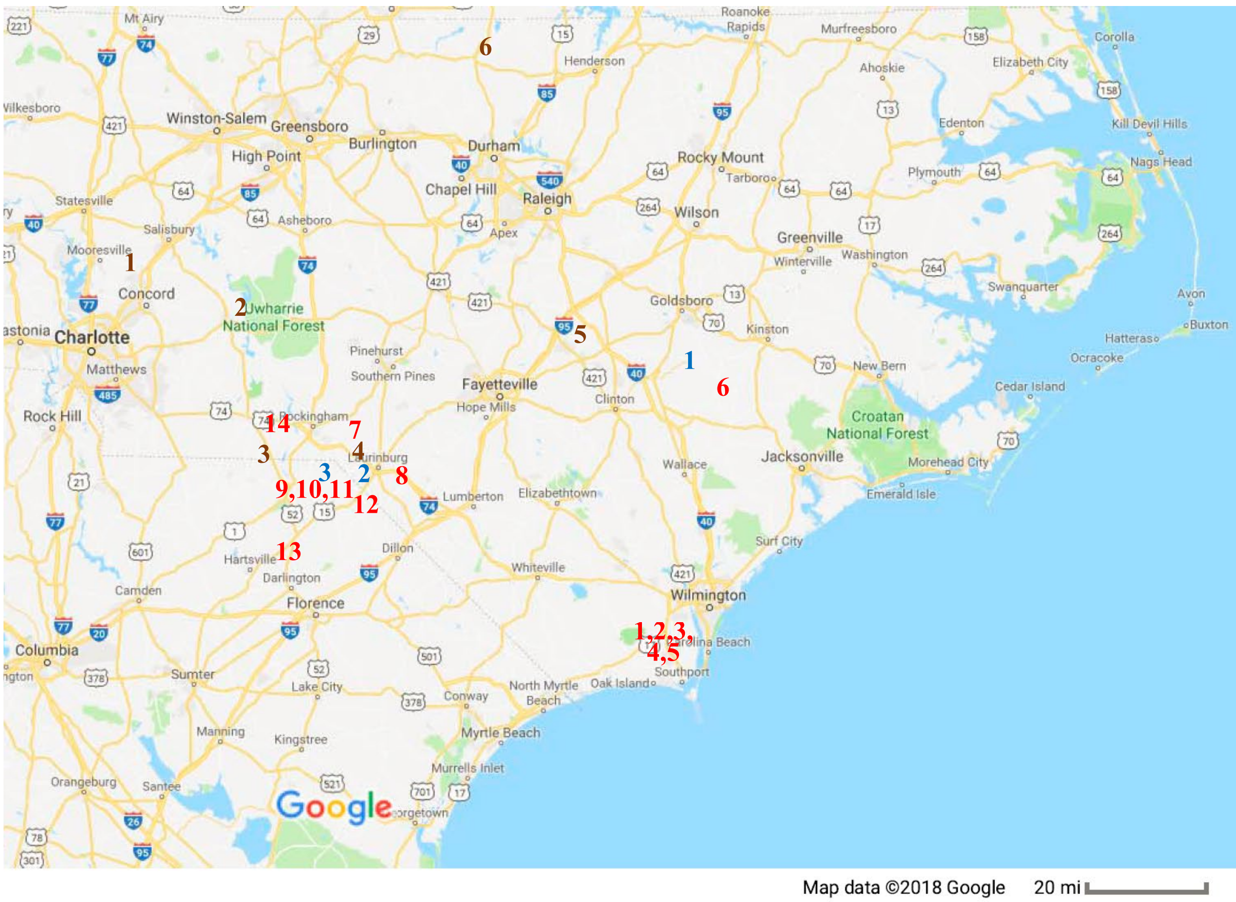


Fig. 4.1-1 – Dam sites visited by GEER Florence team (number key tabulation below, Google Maps)

<u>Breached Dams</u> (red numbers)

1. Boiling Springs Lake Dam, Boiling Spring Lakes, NC
2. Pine Lake Dam, Boiling Spring Lakes, NC
3. North Lake Dam, Boiling Spring Lakes, NC
4. Middle Dam, Boiling Spring Lakes, NC
5. Upper Dam, Boiling Spring Lakes, NC

6. Maxwell Mill Pond, Duplin County, NC
7. Gum Swamp Lake Dam, Cognac, NC
8. Cypress Creek Golf Link Pond Dam, East Laurinburg, NC
9. McMeekin Pond Dam, Wallace, SC
10. McLaurins Millpond Dam, Bennettsville, SC
11. David's Millpond Dam, Bennettsville, SC
12. Covington Millpond Dam, Bennettsville, SC
13. Lake Darpo Dam, Society Hill, SC
14. Hedrick Tailings Dike #1, Lilesville, NC

<u>Overtopped but Unbreached Dams</u> (blue numbers)
1. Williams Mill Pond Dam, Wayne County, NC
2. Fair Lake Dam, Laurinburg, NC
3. Bullards Mill Pond Dam, Marlboro County, SC

<u>Other Dam-Related Incidents and Observations</u> (dark brown numbers)
1. Landis Dam & Lake Corriher Dam, Rowan County, NC
2. Yadkin Narrows Dam, Baden, NC
3. Zoar Road, McFarlen, NC
4. Richmond Mill Pond Dam, Laurel Hill, NC
5. Bryan Lake Dam, Johnston County, NC
6. Clay Thomas Road Dam, Person County, NC

4.2 Breached Dams

Of the 14 breached dams that we visited, eight were clustered near the NC-SC border, near Laurinburg, NC. This area is on the eastern side of the Piedmont, the middle of three physiographic provinces in NC and SC. The Coastal Plain physiographic province to the east is generally flat and less than 600 feet in elevation. Circumstances that may have factored into the cluster of dam failures could include intensity of rainfall due to elevation effects, a higher density of historical dam development in the hillier terrain, and increased runoff due to lower-permeability soils. All of the eight dams in this cluster were small in size and low or significant hazard, dam categories for which state regulations allow less stringent spillway design floods (SDFs). A typical dam breach in this area is shown in Fig. 4.2-1.

Fig. 4.2-1 - McMeekin Pond Dam, Wallace, SC, looking from downstream corner of the breach upstream (September 25, 2018, 34.737 N, 79.799 W)

4.2.1 Boiling Springs Lake Dam / Sanford Dam, Boiling Spring Lakes, Brunswick County, NC

The largest and most significant of the dam breaches was that of the Boiling Springs Lake Dam, also known as Sanford Dam, located about 16 miles south of Wilmington, NC (Fig. 4.2.1-1, -2). Boiling Springs Lake Dam was a 30-ft-high, 1584-ft-long earthfill dam completed in 1964. The dam provided a recreational reservoir to the residential development around its shores, which is the central lake in a cluster of lakes formed by four other dams. These dams also failed and are discussed in subsequent sections. Based on observations of the breach, the dam appeared to be a homogeneous sand fill embankment. A local road traversed the crest of the dam. The only outlet structure noted by the team was a gated concrete structure close to the right abutment. We saw no spillway or emergency spillway.

The NC Department of Environmental Quality (DEQ) classified Boiling Springs Lake Dam as a Class C high-hazard risk dam "where failure will likely cause loss of life or serious damage to homes, industrial and commercial buildings, important public utilities, primary highways, or major railroads." The presence of a rail connection to the Military Ocean Terminal Sunny Point, "one of the largest military terminals in the world"[2] was the most apparent reason for the high-hazard classification because the rail line crosses the channel about 150 feet downstream of Boiling Springs Dam.

The breach of the dam occurred near the mid-length point of the dam and was about 200 ft wide (Fig. 4.2.1-3). We saw evidence of overtopping in the form of erosion along downstream face at multiple locations. We also observed sand deposits on the downstream slope and toe. Because there were no indications of piping on the upstream face, and no sinkholes, voids or settlements, we expect that the sand was breach erosion material left by backwater flows. We were told by a resident that on Saturday, September 15, 2018, around 11:15 p.m., the dam started to overtop and that it failed around 11:30 p.m.

We observed five areas of interest around the dam – (1) the ~200-ft-wide breach section, (2) the right side of the dam where overtopping eroded part of the downstream slope around the outlet works without breaching the dam, (3) an eroded section of the downstream slope on the embankment to the left of the breach, (4) the left abutment contact where local responders attempted to create an emergency spillway to divert and reduce overtopping flows, and (5) the apparent robust response of the downstream rail structures to the high flows.

The breach bisected the embankment, washing out the entire height of the structure, leaving only the crest road guard rail to dangle over the breach (Figs. 4.2.1-4, -5, -6, -7). Because of the obvious evidence of overtopping along the entire dam, it is most likely that the breach resulted from simple surface erosion. Given the high permeability of the embankment sands, seepage forces could have also contributed to instability of the downstream slope.

The occurrence of overtopping on each side of the breach was evident because of the severe erosion on the downstream slopes. The paved crest road provided an erosion retardant at the locations of severe erosion on the embankment to the right (Fig. 4.2.1-8, -9) and left (Fig. 4.2.1-10) of the breach.

At the left abutment, we observed that the crest road had been excavated and that small berms had been constructed on either side of the excavated road in a failed attempt by municipal workers to save the dam by constructing an emergency spillway that would divert the overtopping flows (Fig. 4.2.1-11).

The heavy rainfall and the high flows from the dam breach eroded a significant amount of the abutments around the downstream railroad (Fig. 4.2.1-12, 13). The designers of the railroad, perhaps with the benefit of Defense Department funding, appear to have anticipated such flows by supporting the railroad on large beams spanning support piers that extended a significant depth into the abutments.

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[2] Wikipedia, "Military Ocean Terminal Sunny Point," https://en.wikipedia.org/wiki/Military_Ocean_Terminal_Sunny_Point.

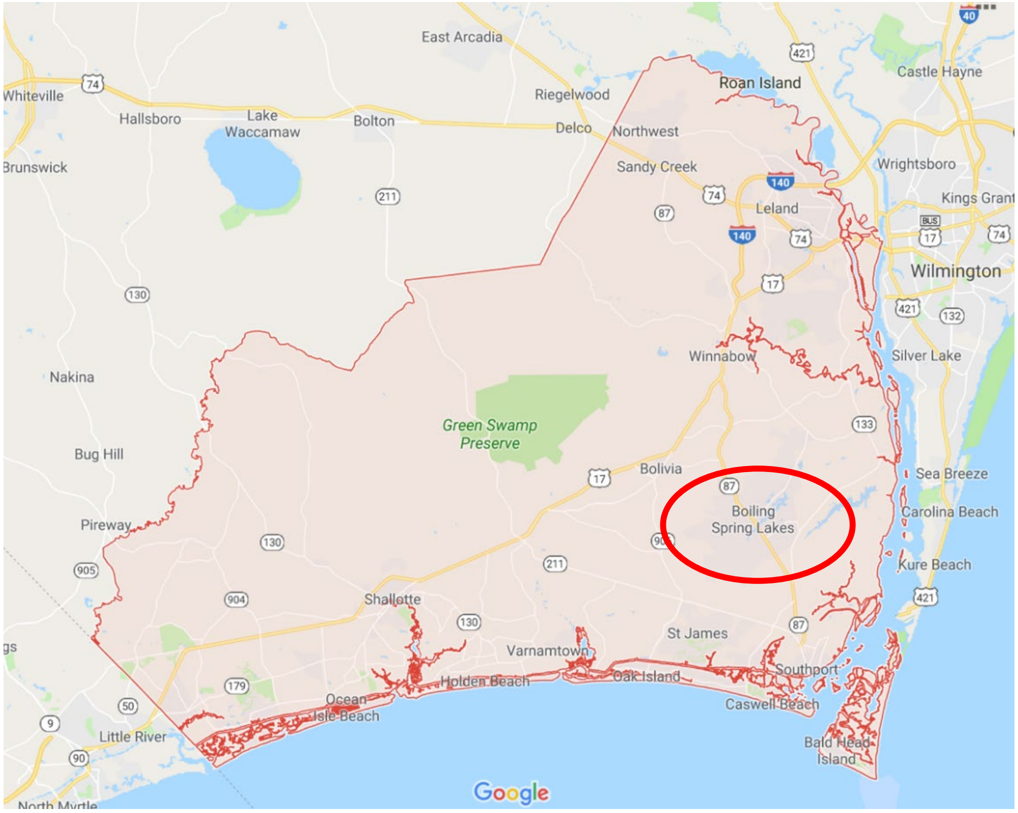

Fig. 4.2.1-1 – Brunswick County, Boiling Spring Lake Dam Location (Google Maps)

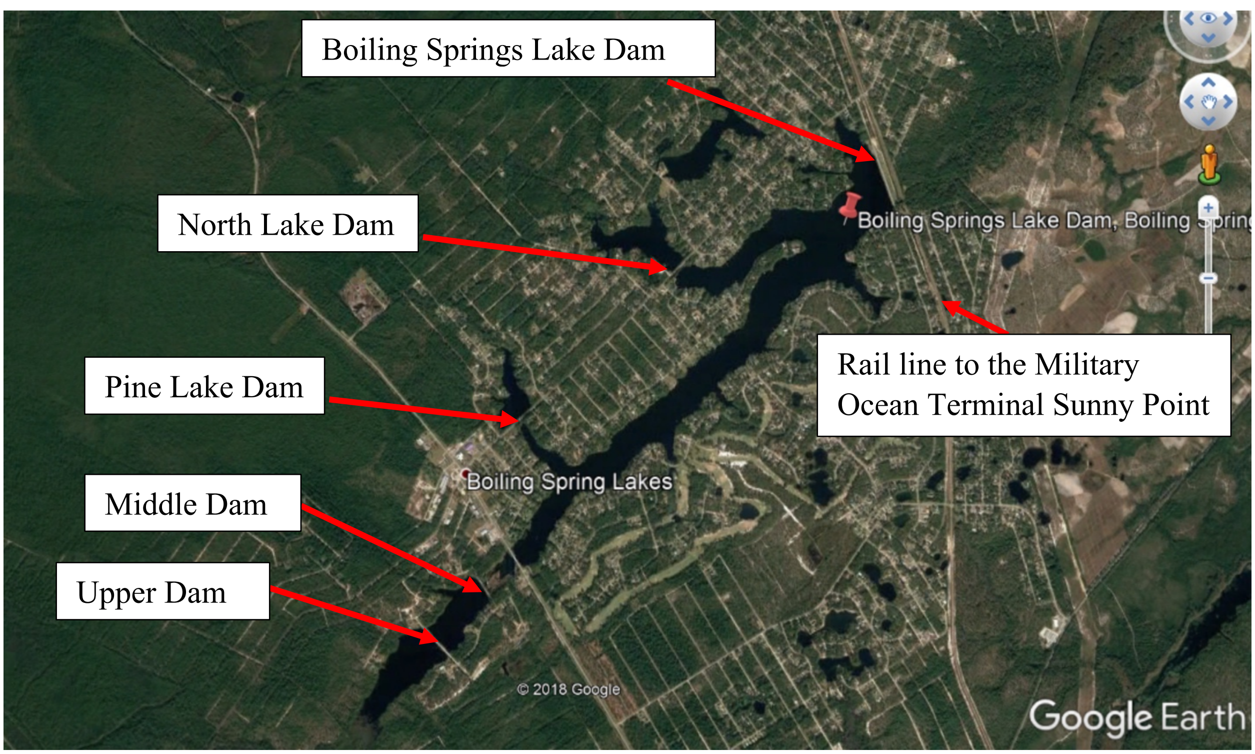

Fig. 4.2.1-2 – Aerial image of Boiling Spring Lakes complex, October 2016 (Google Earth)

Fig. 4.2.1-3 – Post-failure aerial photograph (Google Earth September 19, 2018, 34.046 N, 78.037 W)

Fig. 4.2.1-4 – Breach, right side of dam, and outlet structure (September 26, 2018, 34.0462 N, 78.0373 W)

Fig. 4.2.1-5 – Breach from right side (September 26, 2018, 34.0465 N, 78.0373 W)

Fig. 4.2.1-6 – Looking to breach from empty reservoir (September 26, 2018, 34.0469 N, 78.0395 W)

Fig. 4.2.1-7 – Looking to breach from downstream (September 26, 2018, 34.0473 N, 78.0373 W)

Fig. 4.2.1-8 – Downstream right slope erosion, looking across to left abutment (September 26, 2018, 34.0462 N, 78.0371 W)

Fig. 4.2.1-9 – Downstream right slope erosion, facing right abutment (September 26, 2018, 34.0466 N, 78.0373 W)

Fig. 4.2.1-10 – Downstream left slope erosion, facing left abutment (September 26, 2018, 34.0476 N, 78.0378 W)

Fig. 4.2.1-11 – Attempted emergency spillway construction, left abutment (September 26, 2018, 34.0500 N, 78.0388 W)

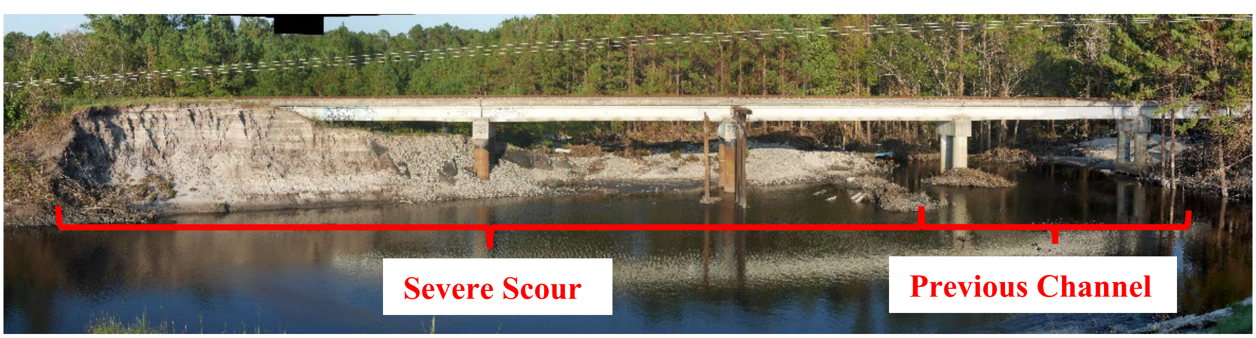

Fig. 4.2.1-12 – Rail line to Military Ocean Terminal Sunny Point showing scour due to breach flows (September 26, 2018, 34.0465 N, 78.0374 W)

Fig. 4.2.1-13 – Scour along rail line to Military Ocean Terminal Sunny Point about 250 ft from channel on right abutment, likely due to abutment overtopping (September 26, 2018, 34.0457 N, 78.0363 W)

4.2.2 Pine Lake Dam, Boiling Spring Lakes, Brunswick County, NC

Boiling Springs Lake Dam impounded the main reservoir of the Boiling Springs Lakes complex (Fig. 4.2.1-2), which included four other dams that failed during Florence – Pine Lake Dam, North Lake Dam, Middle Dam, and Upper Dam.

Pine Lake Dam was a 10-ft-high earthfill dam, which, like Boiling Springs Dam, was completed in 1964. It was an unregulated low hazard recreational dam. The only outlet appeared to be a low-level pipe. Pine Lake Dam impounded water at a 5-ft-higher elevation than Boiling Springs Lake, and it served as a causeway for East Boiling Spring Road that traversed its crest.

The breach occurred at the location of the low-level pipe (Figs. 4.2.2-1, -2, -3). We observed indications of overtopping and toe cutting downstream of dam at multiple locations. NC DEQ informed us that the dam failed after the failure of downstream Boiling Springs Dam. The sudden drawdown of Boiling Springs Lake and the added exposure of the downstream slope to overtopping erosion without the cover of the downstream lake may have contributed to the dam failure.

Fig. 4.2.2-1 – Post-failure aerial photograph (Google Earth, September 19, 2018, 34.034 N, 78.064 W)

Fig. 4.2.2-2 – Looking from downstream left abutment to overtopping erosion, breach and empty reservoir (September 28, 2018, 34.0334 N, 78.0635 W)

Fig. 4.2.2-3 – Looking from downstream right abutment to partially filled breach and empty reservoir (September 28, 2018, 34.0334 N, 78.0635 W)

4.2.3 North Lake Dam, Boiling Spring Lakes, Brunswick County, NC

North Lake Dam in the Boiling Springs Lakes complex (Fig. 4.2.1-2) also failed during Florence. North Lake Dam was a 10-ft-high earthfill dam, also completed in 1964, and like Pine Lake Dam was an unregulated low hazard recreational dam traversed by the same East Boiling Spring Road. We observed remnants of multiple plastic and steel corrugated pipes through the dam. The water level of North Lake, upstream of the dam, was normally 5 ft higher than the downstream level in Boiling Spring Lake. As with Pine Lake Dam, the sudden drawdown of Boiling Springs Lake and the added exposure of the downstream slope to overtopping erosion without the cover of the downstream lake may have contributed to the dam failure.

In addition to the breach near the right abutment (Figs. 4.2.3-1, -2), we observed indications of severe overtopping erosion and toe cutting near the left abutment (Figs. 4.2.3-3, 4). We also noted the possibility that part of dam toe may have eroded due to drainage pipe discharge.

Fig. 4.2.3-1 – Looking from upstream right abutment to overtopping erosion and empty North Lake reservoir (September 28, 2018, 34.0412 N, 78.0528 W)

Fig. 4.2.3-2 – Looking downstream from right abutment to breach and erosion downstream (September 28, 2018, 34.0421 N, 78.0530 W)

Fig. 4.2.3-3 – Looking from downstream left abutment to overtopping erosion and empty reservoir (September 28, 2018, 34.0430 N, 78.0517 W)

Fig. 4.2.3-4 – Looking from left abutment to overtopping erosion and possible culvert discharge erosion (September 28, 2018, 34.0430 N, 78.0517 W)

4.2.4 Middle Dam, Boiling Spring Lakes, Brunswick County, NC

The Middle Dam sits at the southwest end of Boiling Spring Lake and normally impounds water at a level 5 ft higher than the main part of the lake. The dam is not included in the NC Dam

Safety Inventory. From Google Earth aerial and street view imagery, it appears that the dam was about 10 ft high and had at least one low-level outlet pipe and a broad-crested concrete spillway about 40 ft wide. Like the other dams in the complex, Middle Dam appeared to be largely a sand embankment. Unlike the other Boiling Spring Lakes dams, Middle Dam did not have a local road on its crest.

Fig. 4.2.4-1 shows the Google Earth aerial photograph of the dam breach taken on September 19, 2018. Fig. 4.2.4-2 shows the breach from ground level at the time of our visit. Figs 4.2.4-3 and -4 show evidence that the dam was overtopped, which, in possible combination with the rapid drawdown of Boiling Spring Lake downstream and lack of backwater to mitigate erosion, was a likely cause of the breach.

Fig. 4.2.4-1 – Middle Dam aerial image (Google Earth, September 19, 2018, 34.024 N, 78.066 W)

Fig. 4.2.4-2 – Middle Dam breached embankment close to northwest abutment and the concrete culvert structure, looking at left abutment (September 26, 2018, 43.024 N, 78.066 W)

Fig. 4.2.4-3 – Middle Dam overtopping downstream slope erosion close to right abutment, looking at right abutment (September 26, 2018, 43.024 N, 78.066 W)

Fig. 4.2.4-4 – Middle Dam overtopping downstream slope erosion of embankment, looking at northwest abutment (September 26, 2018, 43.024 N, 78.066 W)

4.2.5 Upper Dam, Boiling Spring Lakes, Brunswick County, NC

The Upper Dam is located about ¼ mile southwest and upstream of the Middle Dam and normally impounds water at a level 3 ft higher than the Middle Dam impoundment. Unlike the Middle Dam, the Upper Dam is included in the NC Dam Safety Inventory and is listed as a high hazard dam having a height of 9 ft and a length of 600 ft. From Google Earth aerial imagery, it appears that the dam may have had two drop intake outlets and no spillway. Like the other dams in the complex, Middle Dam appeared to be largely a sand embankment. An dirt/gravel road traversed the dam crest.

Fig. 4.2.5-1 shows the Google Earth aerial photograph of the dam breach taken on September 19, 2018. Fig. 4.2.5-2 shows the breach from ground level at the time of our visit. Fig 4.2.4-3 shows evidence that the dam was overtopped, which, in possible combination with the rapid drawdown of the Middle Dam impoundment downstream and lack of backwater to mitigate erosion, was a likely cause of the breach.

Fig. 4.2.5-1 – Upper Dam aerial image (Google Earth, September 19, 2018, 34.022 N, 78.070 W)

Fig. 4.2.5-2 – Upper Dam breached embankment looking at northwest abutment (September 26, 2018, 43.022 N, 78.069 W)

Fig. 4.2.5-3 – Upper Dam overtopping downstream slope erosion and new fill, looking toward northwest abutment (September 26, 2018, 43.022 N, 78.069 W)

4.2.6 Maxwell Mill Pond Dam, Duplin County, NC

Maxwell Mill Pond Dam was a 14-ft-high earth embankment dam located in Duplin County, NC, near the town of Pink Hill, on Big Creek, within the Cape Fear River basin (Figs. 4.2.6-1, -2). The earth embankment was about 840 ft long and, based on our observations, consisted of a clay shell cover of varying thickness over a core and foundation consisting of the native fine sand (Fig. 4.2.6-3). The NC DEQ classified the dam as a low hazard dam exempt from regulation. The dam features included a concrete weir spillway near the right abutment and the remnants of an old mill structure with low level outlets near the left abutment. Maxwell Mill Road is located 25 to 100 ft downstream of the dam and has two bridges to cross the mill outlet and the spillway outlet channels. One major feature of the dam was the presence of numerous large trees all along the dam.

The dam failed during Florence, creating an embankment breach about 100 ft to the left of the spillway (Figs. 4.2.6-4, -5). We observed evidence of overtopping, the most likely cause of the failure. The breach and overtopping flows severely scoured the upstream side of Maxwell Mill Road along the right abutment of the mill outlet bridge (Figs. 4.2.6-6). Spillway and overtopping flows also overwhelmed the spillway outlet and channel and severely scoured along both sides of the outlet structure (Figs. 4.2.6-7, -8).

Overtopping flows eroded the embankment at numerous other locations. We observed a pattern of scour on the downstream side of the trees on the embankment, presumably due to the turbulence induced below the trees (Figs. 4.2.6-9). Felled trees were also noted in the dam breach. While tree roots were present in all scoured areas and may have provided some hinderance to erosion, in general, it appears that the mature tree growth on the dam was most likely a contributing or accelerating factor to the breach.

Fig. 4.2.6-1 – Duplin County and Maxwell Mill Pond Location (Google Maps)

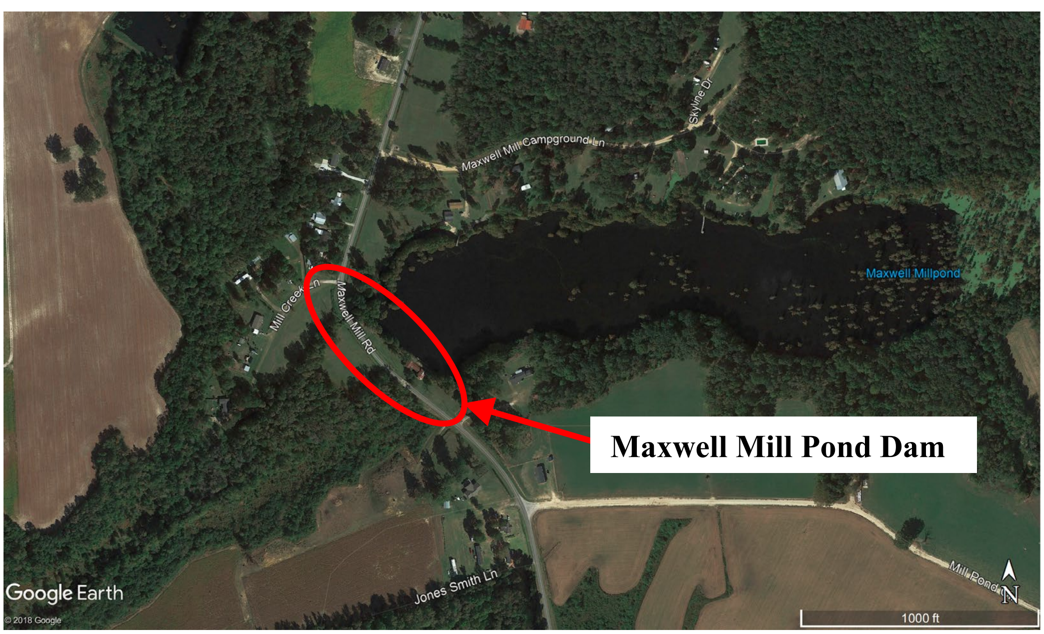

Fig. 4.2.6-2 – Aerial photo of Maxwell Mill Pond and Dam (Google Earth, September 9, 2017, 35.070 N, 77.788 W)

Fig. 4.2.6-3 – Scour near breach at Maxwell Mill Pond Dam showing embankment materials (September 25, 2018, 35.0706 N, 77.7879 W)

Fig. 4.2.6-4 – Maxwell Mill Pond Dam breach from downstream (September 25, 2018, 35.0706 N, 77.7880 W)

Fig. 4.2.6-5 – Maxwell Mill Pond Dam breach from upstream (September 25, 2018, 35.0706 N, 77.7875 W)

Fig. 4.2.6-6 – Maxwell Mill Road scour at outlet channel bridge abutment (September 25, 2018, 35.0701 N, 77.7876 W)

Fig. 4.2.6-7 – Maxwell Mill Pond Dam spillway from upstream (September 25, 2018, 35.0708 N, 77.7882 W)

Fig. 4.2.6-8 – Maxwell Mill Pond Dam spillway from downstream (September 25, 2018, 35.0708 N, 77.7883 W)

Fig. 4.2.6-9 – Maxwell Mill Pond Dam embankment scour near left abutment (September 25, 2018, 35.0700 N, 77.7868 W)

4.2.7 Gum Swamp Lake Dam, Cognac, Richmond County, NC

Gum Swamp Lake Dam, located on the Richmond and Scotland County line, NC (Fig. 4.2.7-1), also failed during the storm. The dam was a 12-foot-high earthfill dam, which was constructed in 1934 and is owned by the North Carolina Wildlife Resources Commission. The NC DEQ classifies the dam as an exempt low-hazard dam. Outflow from the dam was controlled by three stop log gates upstream of a box culvert. There does not appear to be another outlet or spillway. The dam is located upstream of an unpaved road (Fig. 4.2.7-2) and normal outflow from the dam passes under the road via corrugated metal pipe culverts (Fig. 4.2.7-3).

The dam appeared to have been overtopped at multiple locations, and the breach occurred over and on both sides of the outlet structure (Fig. 4.2.7-4, -5, -6, -7). The flood flow also breached the downstream road, resulting in a displaced automobile (Fig. 4.2.7-8).

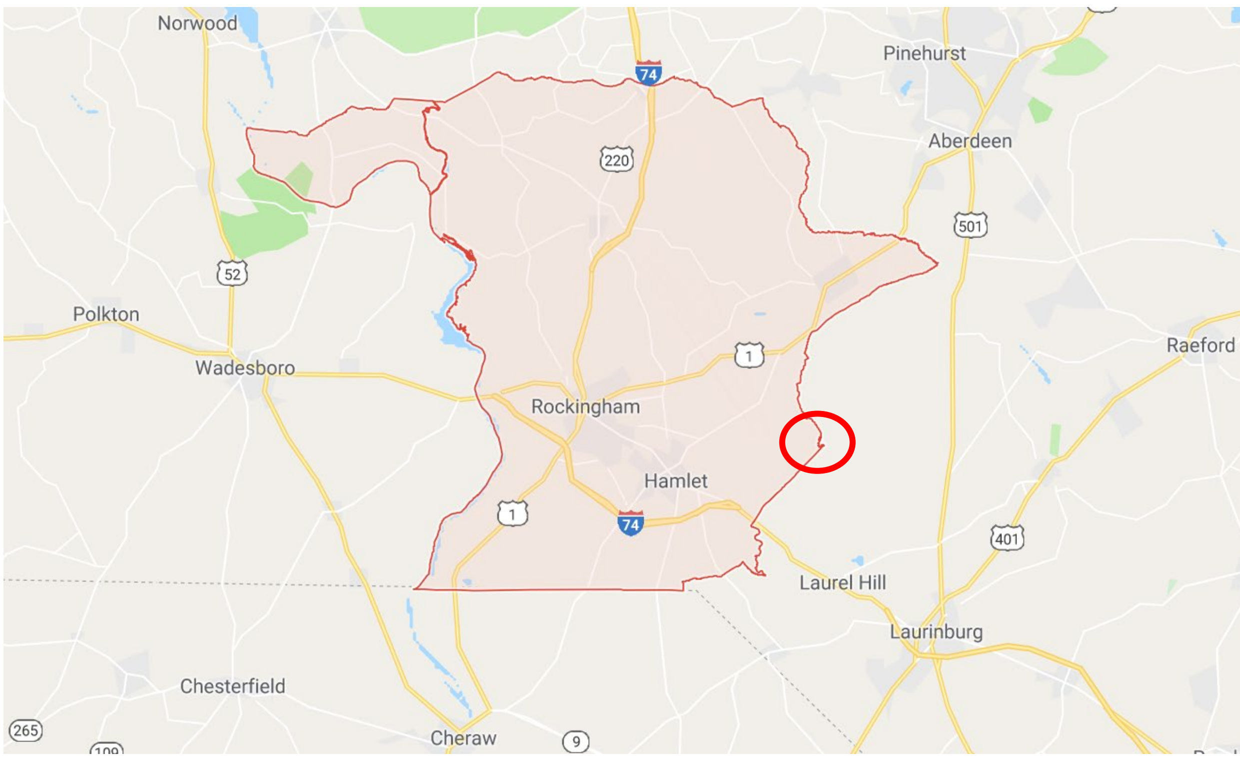

Fig. 4.2.7-1 – Richmond County and dam location (Google Maps for source map)

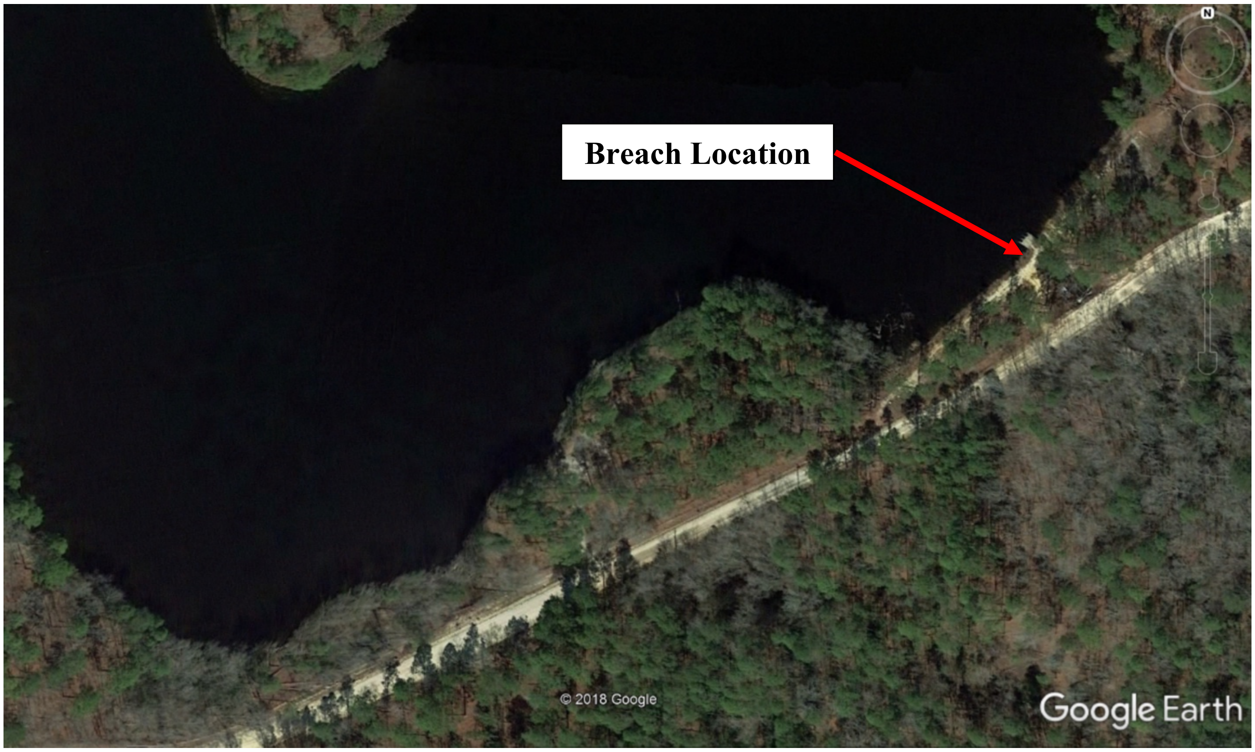

Fig. 4.2.7-2 – Gum Swamp Lake Dam before the breach (Google Earth, 34.910 N, 79.562 W)

Fig. 4.2.7-3 – Dam and culvert at Gum Swamp Lake, pre-breach (Google Street View, 34.9104 N, 79.5619 W)

Fig. 4.2.7-4 – Dam crest, looking toward breach from right abutment with multiple overtopping areas (September 24, 2018, 34.9103 N, 79.5624 W)

Fig. 4.2.7-5 – Upstream view of dam and breach (September 24, 2018, 34.9106 N, 79.5621 W)

Fig. 4.2.7-6 – Empty reservoir, outlet structure and breach from downstream (September 24, 2018, 34.9106 N, 79.5621 W)

Fig. 4.2.7-7 – Dam breached and destroyed at Gum Swamp Lake (September 24, 2018, 34.9106 N, 79.5621 W)

Fig. 4.2.7-8 – Downstream eroded dirt road and flooded / displaced vehicle (September 24, 2018, 34.9104 N, 79.5619 W)

4.2.8 Cypress Creek Golf Links Pond Dam

Fig. 4.2.8-1 shows the location of the dam breach on the Cypress Creek Golf Links near Laurinsburg, Scotland County, NC. The year-round 18-hole Cypress Creek Golf Links is a public golf course, which opened in 1981 and was designed by Tom Jackson. Cypress Creek Golf Links measures 6,222 yards from the longest tees and has a slope and USGA rating of 115 and 68.7, respectively (www.cypresscreekgolflinks.com). Fig. 4.2.8-2 shows a 2017 aerial image of Cypress Creek Golf Course (see red pin).

The golf course includes a water hazard, which was created by the impoundment of a small stream by an earthen dam about 7 ft high and 450 ft long. Outflow from the dam was controlled by corrugated metal pipe (CMP) drop inlet with an upstream slide gate attached to a conduit that traversed through the embankment. The dam did not include another outlet or spillway.

Fig. 4.2.8-3 shows the progression of the lake with historical imagery for 2000, 2008, 2013, and 2017. Fig. 4.2.8-3(a) shows a primarily water filled reservoir in 2000 and vegetation starting to impact the lake in 2008 and 2013. Fig. 4.2.8-3(d) shows a 2017 image from Google Earth that shows the heavy vegetation that filled the reservoir area. Fig. 4.2.8.4 shows the emptied reservoir on September 27, 2018 and some of the exposed cypress trees after draining of the reservoir due to the breach.

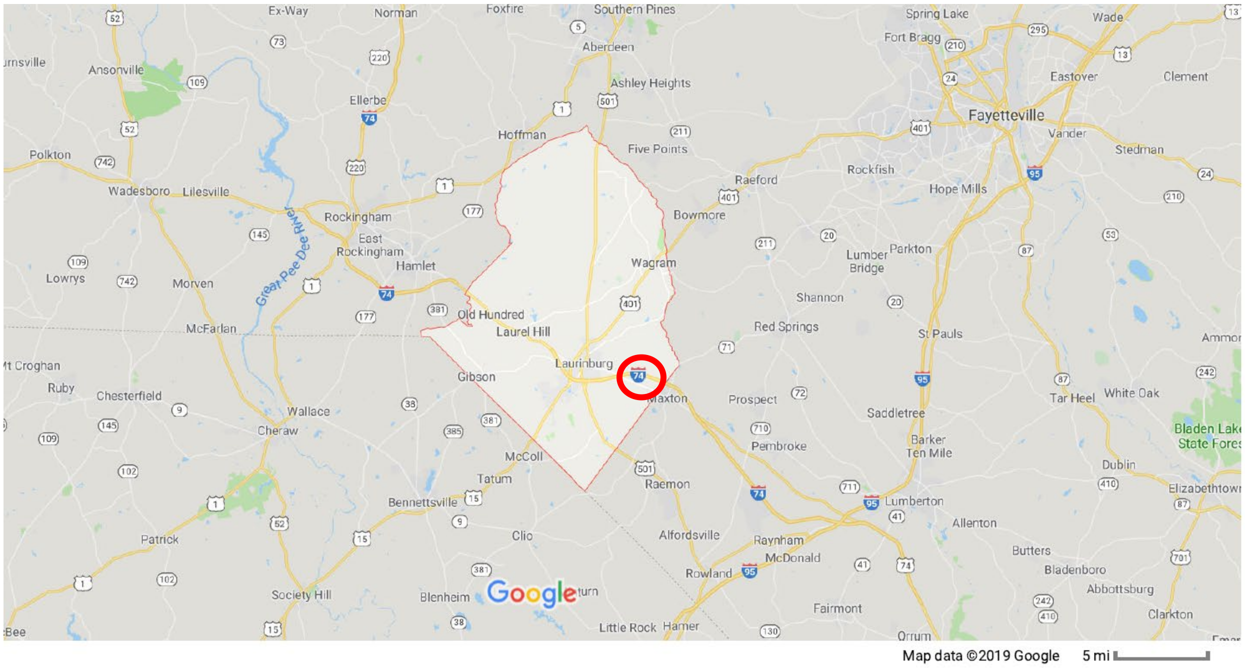

Fig. 4.2.8-1 - Location of Cypress Creek Golf Links near Laurinburg, North Carolina (Google Maps, 34.758 N, 79.415 W).

Fig. 4.2.8-2 - Aerial imagery of the site showing: golf course at red pin and dam and reservoir in red dashed circle (Google Earth, 34.7576 N, 79.4145 W).


Legend
Cypress Creek Golf Link
Line Measure
Cypress Creek Golf Link
Google Earth
1000 ft
N

(a)


Legend
Cypress Creek Golf Link
Line Measure
Cypress Creek Golf Link
Google Earth
1000 ft
N

(b)

(c)

(d)

Fig. 4.2.8-3 Aerial imagery of the site showing the golf course and reservoir (red circle) from: (a) 2000, (b) 2008, (c) 2013, and (d) 2017 (Google Earth, 34.758 N, 79.415 W)

(a) (b)

Fig. 4.2.8-4(a) - Emptied reservoir and (b) - Exposed cypress trees showing level of reservoir water on root system (September 27, 2018, 34.7516 N, 79.4145 W).

Fig. 4.2.8-5 shows photos of the crest of the dam from the right abutment looking towards the left abutment. Fig. 4.2.8-5(a) provides an overview of the straight axis of the dam and the main breach (see yellow arrows). Fig. 4.2.8-5(b) provides a close-up of the failed area from the crest of the dam with the yellow arrow pointing to the main breach location. A second breach area was developing near the main breach (see red arrow in Fig. 4.2.8-5(b)).

(a)

(b)

Fig. 4.2.8-5(a) - Overview of the axis of the dam from the right abutment and the failure area (see yellow arrow) and (b) - Close-up of the failed area (yellow arrow) and a partial breach (red arrow) (September 27, 2018, 34.7509 N, 79.4150 W)

Fig. 4.2.8-6 presents photos along the crest of the dam from the left side of the breach, which also show that the downstream side of the dam was covered with bamboo trees and other vegetation. Fig. 4.2.8-7 shows photos of the breach from upstream. The dam in this location had a height of about 7 ft. The dam was comprised of a sandy clay soil with an asphalt pavement on the crest. Fig. 4.2.8-7(a) shows water flowing from the reservoir under the downstream slope. The downstream slope did not appear to have collapsed due to the underseepage because of the thick and strong root mat created by the dense bamboo trees growing on the downstream slope. A PVC water pipe was installed in the embankment and exposed by the breach.

(a)

(b)

Fig. 4.2.8-6(a) - Overview of the axis of the dam looking towards the right abutment and the failure area and (b) - Close-up of the failed area from the crest of the dam (September 27, 2018, 34.7509 N, 79.4150 W).

(a)

(b)

Fig. 4.2.8-7(a) - Water flowing through the breach area and (b) - Close-up of significant settlement of the crest where the dam was breached (September 27, 2018, 34.7509 N, 79.4150 W).

Fig. 4.2.8-8(a) is a closeup of the thick and strong bamboo root mat that supported the remaining portion of the downstream slope. Fig. 4.2.8-8(b) is a closeup of the seepage occurring under the remaining portion of the downstream slope. There was a clear breach from upstream to downstream near the center of this photograph where the water flowed under the root mat. This seepage was observed exiting the downstream slope on the other side of the dam.

(a) (b)

Fig. 4.2.8-8(a) - Close-up of significant vegetation and settlement of the downstream slope due to underlying seepage and erosion and (b) - Water flowing through the breach area and under the downstream slope at the base of the dam (September 27, 2018, 34.7509 N, 79.4150 W).

An interesting aspect of this dam failure is that the seepage, erosion, and eventual breach did not occur along the nearby outlet conduit. Fig. 4.2.8-9(a) shows the outlet conduit to the left of the breach and water flowing along the conduit to about the edge of the crest asphalt pavement and then flowing to the right where the breach occurred. The observed flow path through the breach paralleled the conduit until about the center of the dam, at which point the breach and flow diverted toward the right abutment. Conduit leakage is a common problem with earth dams because of the difficulty in compacting around and under a round pipe. In this case, the construction was tight enough to prevent seepage erosion along the downstream part of the conduit. Fig. 4.2.8-9(b) shows a closeup of the conduit and the tightness between the right side of the conduit and the embankment materials. No seepage or erosion was observed on the left side of the conduit.

(a) (b)

Fig. 4.2.8-9(a) - Water flowing through the breach area and (b) - Close-up of significant settlement of the crest where the dam was overtopped (September 27, 2018, 34.7509 N, 79.4150 W).

Finally, Fig. 4.2.8-10 shows the condition of the outlet intake controls. The outlet system consists of a CMP riser with the top of the riser located at an elevation that was below the dam crest. As a result, the CMP riser acted as a "glory hole" or drop intake, which allowed flow when the pond level reached top of the CMP riser. This type of outlet system was observed in other small dams visited during this reconnaissance. Fig. 4.2.8-10(a) shows that the top of the 3-ft-high CMP riser pipe was about 4 ft below the dam crest. Fig. 4.2.8-10(b) is a closeup of the damaged CMP riser pipe. It is likely that the CMP riser rusted away or was severely weakened before the flood because only one significant piece of CMP was found in the upstream breach area (see yellow arrow in Fig. 4.2.8-10(b)), and this piece was much smaller than the missing portion of the CMP riser. Forces from flood flows into the riser or through the breach could have contributed to the damage.

(a)

(b)

Fig. 4.2.8-10(a) - Water flowing into the outlet conduit and the upstream slope of the dam area and (b) - Close-up of damaged riser pipe for the outlet conduit with the flow gate in the background (September 27, 2018, 34.7509 N, 79.4150 W).

In summary, this dam breach was interesting because (1) the breach appeared to be seepage induced even though the hydraulic head was less than 7 ft and (2) conduit leakage did not appear to have caused the breach but may have facilitated initiation of the breach. CMP riser and conduit pipes for reservoir outlet systems should be inspected and, if needed, repaired or replaced to ensure that seepage and overtopping issues do not develop.

4.2.9 McMeekin Pond Dam, Wallace, Marlboro County, SC

Multiple dam failures and overtopping incidents were reported near Bennettsville, SC, in Marlboro County, which abuts the NC border west of Lumberton and Laurinburg, NC and north of Florence, SC (Fig. 4.2.9-1). We visited five of these dams, four of which were breach failures and are described in this and the next three sections. One dam, Bullards Millpond Dam, experienced overtopping without failing and is described in Section 4.3.3.

McMeekin Pond Dam is a 9-foot-high earthfill dam completed in 1950, which is classified as a low hazard recreational dam. The dam and pond are along Phils Creek, in the drainage basin of the Great Pee Dee River. Old Wire Road West / State Road S-35-165, a two-lane road, crosses the crest of the dam (Fig. 4.2.9-2). The normal outlet for the pond is a gate or stop-log slot in the middle of a drop spillway located upstream of a large box culvert or bridge supporting the road.

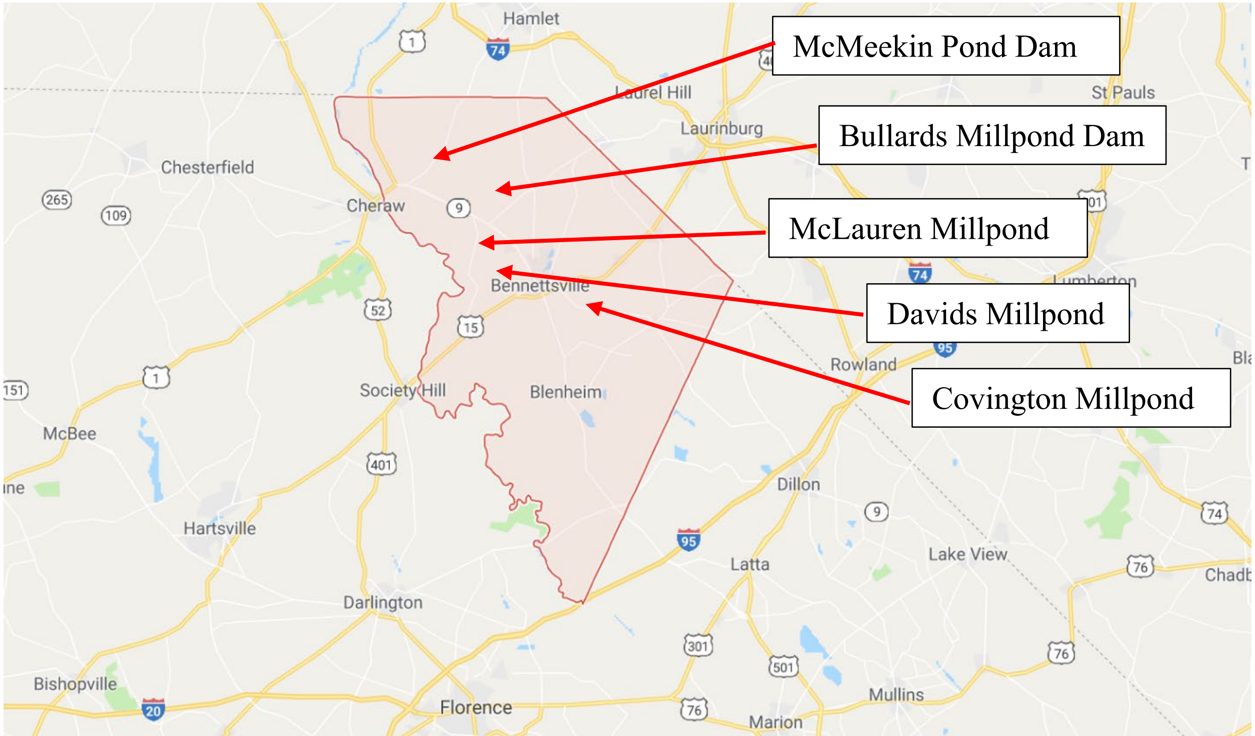

Fig. 4.2.9-1 – Dams visited in Marlboro County (Google Maps)

Fig. 4.2.9-2 – McMeekin Pond Dam Area (Google Earth, 34.738 N, 79.799 W)

The dam appeared to have overtopped at multiple locations and failed along the side of the box culvert (Figs. 4.2.9-3, -4, -5). A complete breach to the base of the dam was eroded on the left side of the culvert, and a shallower channel was eroded on the right side of the box culvert. In addition, the overtopping flows eroded the downstream embankment in one location about halfway across the crest road (Figs. 4.2.9-6, -7).

Fig. 4.2.9-3 – Looking from upstream to overtopping erosion and breach next to concrete outlet structure (September 25, 2018, 34.7375 N, 79.7997 W)

Fig. 4.2.9-4 – Looking from downstream corner of the breach to concrete outlet structure, left abutment (September 25, 2018, 34.7375 N, 79.7997 W)

Fig. 4.2.9-5 – Scour of bridge abutment and breach of McMeekin's Pond Dam (September 25, 2018, 34.7375 N, 79.7997 W)

Fig. 4.2.9-6 – Looking from upstream to overtopping erosion, left abutment (September 25, 2018, 34.7376 N, 79.7991 W)

Fig. 4.2.9-7 – Erosion due to overtopping at McMeekin's Pond Dam (September 25, 2018, 34.7376 N, 79.7991 W)

4.2.10 McLaurins Millpond Dam, Bennettsville, Marlboro County, SC

McLaurins Millpond Dam is located about 5.5 miles north of the center of Bennettsville, SC, again in Marlboro County (Fig. 4.2.9-1) on Naked Creek, a tributary of the Great Pee Dee River. The dam is an 11-foot-high earthfill structure completed in 1900 and is classified as a significant hazard recreational dam. The significant hazard classification may be due to the downstream Brickyard Road / Route 36. We did not have access to dam but were able to photograph it using a drone. The drone photography showed that the dam breached across the center of the dam (Fig. 4.2.10-2) on either side of the outlet structure, which can be seen in the pre-breach Google Earth aerial photograph (Fig. 4.2.10-1).

Fig. 4.2.10-1 – McLaurins Millpond before Florence (Google Earth, 34.675 N, 79.759 W)

Fig. 4.2.10-2 – Aerial photograph of left abutment, spillway structure and breach (September 25, 2018, 34.675 N, 79.759 W)

4.2.11 Davids Millpond Dam, Bennettsville, SC

Davids Millpond and the associated dam are located 4 miles northwest of Bennettsville, SC, and about 2 miles south and downstream from McLaurins Millpond Dam on Naked Creek (Fig. 4.2.9-1). The earth embankment dam is a former roadway embankment with a linear layout, about 1700 ft long parallel to Davids Mill Pond Road / State Road 35-33, which is located about 140 ft south and downstream of the dam (Fig. 4.2.11-1). The dam had a concrete spillway with stoplogs located about mid-length.

Flood flows destroyed the spillway (Fig. 4.2.11-2) and scoured the piles for the bridge immediately downstream of the spillway such that it was failing. At the time of our visit the pond was largely drawn down by the breach but still draining. We also observed that Davids Mill Pond Road was breached at a location 0.5 mile east of the dam (Figs. 4.2.11-3 and -4).

Fig. 4.2.11-1 – Aerial photograph of David's Millpond Dam (Google Earth, February 18, 2017, 34.644 N, 79.748 W)

Fig. 4.2.11-2 – View of destroyed spillway at Davids Mill Pond (September 25, 2018, 34.6440 N, 79.7482 W)

Fig. 4.2.11-3 - Scour and breach of Davids Millpond Road 0.5 mile east of the dam ((September 25, 2018, 34.6432 N, 79.7356 W)

Fig. 4.2.11-4 – David's Mill Pond Road culvert washout from above (September 25, 2018, 34.6432 N, 79.7356 W)

4.2.12 Covington Millpond Dam, Bennettsville, SC

Covington Millpond Dam is located about 3 miles east southeast of Bennetsville, SC (Fig. 4.2.9-1) on Cottingham Creek, a tributary of the Great Pee Dee River. Based on aerial imagery (Fig. 4.2.12-1), the earth embankment dam appears to be about 770 ft long with two corrugated metal pipe drop intakes. The dam is immediately upstream of Covington Millpond Road / State Road 356.

We observed a breach of the dam about 200 feet to the west of the intakes. Figs. 4.2.12-2 and -3 show the breach from the vantage point of the downstream road. In addition to the breach, other areas of the crest were eroded, indicating that the dam was overtopped.

Fig. 4.2.12-1 - Aerial photograph of Covington Millpond Dam (Google Earth, February 18, 2017, 34.6077 N, 79.6314 W)

Fig. 4.2.12-2 - Covington Millpond Dam breach looking northeast (September 25, 2018, 34.6079 N, 79.6317 W)

Fig. 4.2.12-3 – Covington Millpond Dam breach looking east (September 25, 2018, 34.6079 N, 79.6317 W)

4.2.13 Lake Darpo Dam, Society Hill, SC

Lake Darpo Dam is located about 4 miles south of Society Hill, SC in Darlington County, along Bucholtz Creek, which feeds into the Great Pee Dee River from the south (Fig. 4.2.13-1). Based on Google Earth aerial imagery (Fig. 4.2.13-2), the earth embankment dam appears to be about 700 ft long. We observed the breach of the dam (Fig. 4.2.13-3) and the drained lake (Fig. 4.2.13-4). We understand from SC Department of Health and Environmental Control (DHEC) records that the dam breached at a 36-inch corrugated metal pipe outlet that served as the auxiliary spillway.

Fig. 4.2.13-1 - Location, Lake Darpo Dam (Google Maps, 34.457 N, 79.880 W)

Fig. 4.2.13-2 Aerial photograph of Lake Darpo Dam (Google Earth, February 18, 2017, 34.4575 N, 79.8805 W)

Fig. 4.2.13-3 - Lake Darpo Dam breach (September 25, 2015, 34.4578 N, 79.8805 W)

Fig. 4.2.13-4 - Lake Darpo remnants (September 25, 2015, 34.4583 N, 79.8806 W)

4.2.14 Hedrick Tailings Dike #1, Lilesville, NC

The BV Hedrick Gravel & Sand mining facility in Lilesville, NC (Fig. 4.2.14-1) suffered greatly from the Florence flooding. The plant, along Island Creek, a tributary of the Great Pee Dee River, mined and refined quartzite sand and gravel. The plant features included numerous tailings ponds with impounding dams or dikes, haul road embankments, and railroad embankments.

The Florence flooding breached the main haul road and a haul road embankment and caused a train derailment (Fig. 4.2.14-2). We discuss observations of the breach of the main haul road and the train derailment in Chapter 6. The breach of the haul road appears to have released flooding that breached Hedrick Tailing's Dike #1, which was completely destroyed (Fig. 4.2.14-3), and flooded out the downstream mining operation, submerging the office facility to near the roofline (Fig. 4.2.14-4).

Fig. 4.2.14-1 - Location, BV Hedrick Gravel & Sand (Google Maps, 34.45731 N, 79.8804 W)

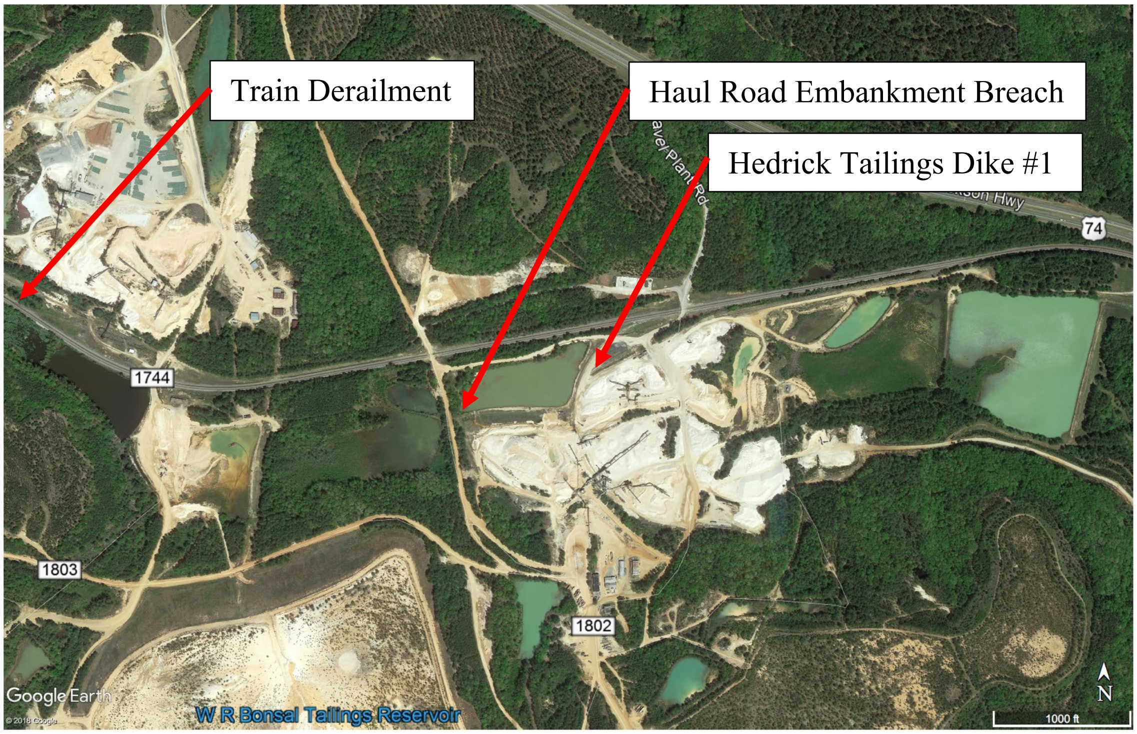

Fig. 4.2.14-2 – Aerial view, BV Hedrick Gravel & Sand (Google Earth, April 20, 2018, 34.95 N, 79.93 W)

Fig. 4.2.14-3 – View of breached dike at the Hedrick Tailing's Dike #1 (September 24, 2018, 34.9498 N, 79.9316 W)

Fig. 4.2.13-4 – View downstream of breach – note office structure on left, circled (September 24, 2018, 34.9498 N, 79.9316 W)

4.3 Overtopped but Unbreached Dams

Not all dams that were overtopped breached. We visited three dams that managed to survive overtopping as described in the following sections.

4.3.1 Williams Mill Pond Dam, Mount Olive, Wayne County, NC

Williams Millpond dam (2169 NC Highway 55 East) is a state-owned earthen dam located in Mt. Olive, NC (Fig. 4.3.1-1), and was constructed in 1938 for recreational purposes. The dam is 850 ft long and 13.6 ft high with 2H:1V upstream and downstream slopes (NC Dam Inventory, 2018). The dam previously served as the highway crossing of Lewis Branch, which connects with the Northeast Cape Fear River about 0.2 miles south of the dam. Fig. 4.3.1-2 shows an aerial image from Google Earth of Williams Millpond dam before Hurricane Florence (January 2018). Fig. 4.3.1-3 shows a Google Street View of the dam in 2013.

On September 25, 2018, we observed evidence of the overtopping due to the Hurricane Florence. Although the dam did not breach, erosion occurred adjacent to both ends of the spillway bridge.

Figs. 4.3.1-4, -5, -6, -7, -8, and -9 show the damage to the dam from the flooding and the emergency repairs.

The dam appeared structurally sound and functional at the time of our visit. Compared to the pre-hurricane condition (Fig. 4.3.1-3), the soil at downstream slope and part of the crest adjacent to the east end of the bridge appeared to have eroded by several feet (Fig. 4.3.1-5). The broken laggings on the wooden soldier post retaining wall might have had a role in dam erosion during the hurricane (Fig. 4.3.1-6), and as a result, the integrity of the wall could be a source of potential future issues. The upstream slopes at each end of the bridge also experienced some erosion (Fig. 4.3.1-7, -8). Flood flows overtopping the adjacent downstream Highway 55 East appeared to have caused no observed effects on the highway upstream slope (Fig. 4.3.1-9) but eroded part of the downstream lane, which had been repaired at the time of our visit. (Fig. 4.3.1-10).

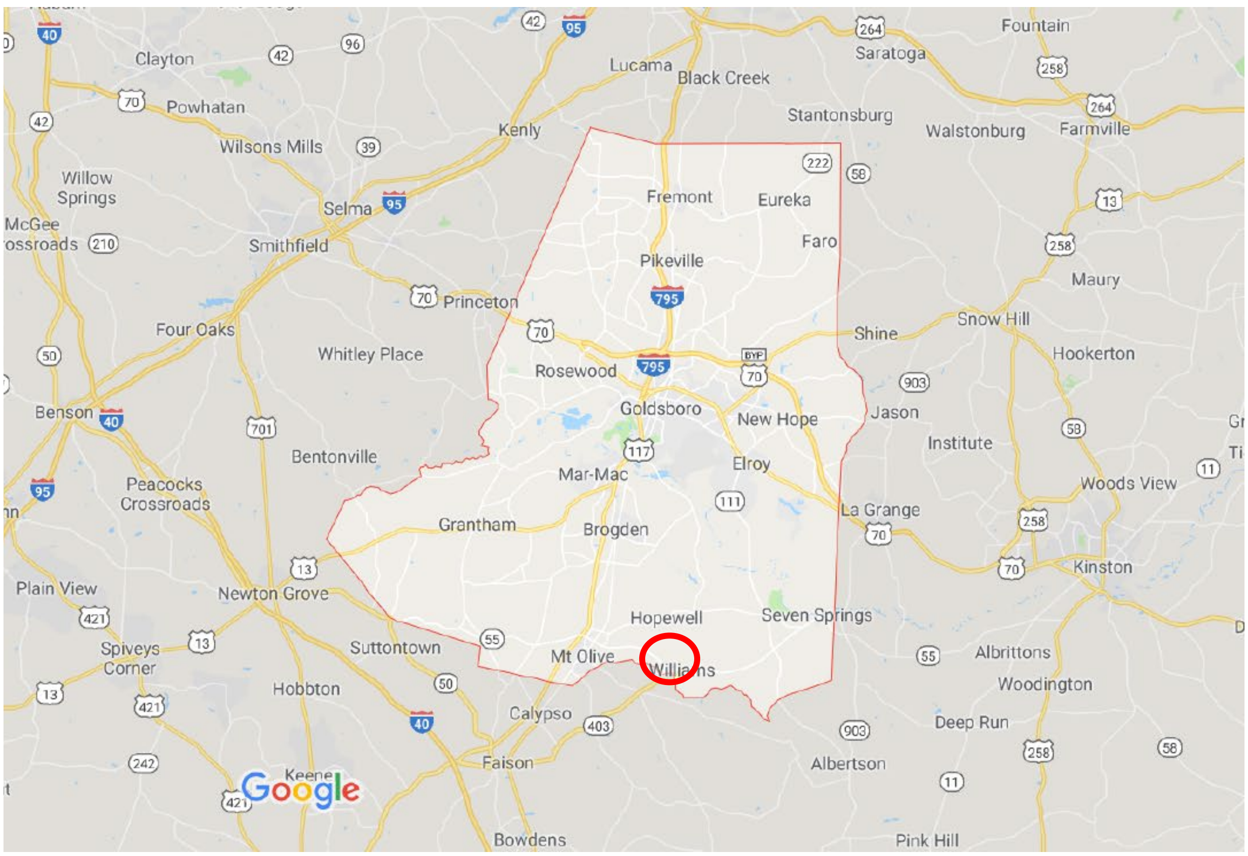

Fig. 4.3.1-1 - Location Williams Millpond Dam, Wayne County (Google Maps)

Fig. 4.3.1-2 - Aerial image of Williams Millpond dam in January 2018 (Google Earth)

Fig. 4.3.1-3 - Williams Millpond dam in December 2013 (Google Street View, 35.1866 N, 77.9841 W)

Fig. 4.3.1-4 - Williams Millpond dam after hurricane Florence (September 25, 2018, 35.1867 N, 77.9844 W)

Fig. 4.3.1-5 - Downstream slope and part of the crest adjacent to the east end of the bridge showing eroded embankment repair (red soil, September 25, 2018, 35.1867 N, 77.9841 W)

Fig. 4.3.1-6 - Timber soldier post retaining wall at the east end of the bridge shows some damages of lagging panels, which contributed to erosion. Geotextile and temporary wooden boards were recently added. One post shows some sign of failure (September 25, 2018, 35.1867 N, 77.9841 W)

Fig. 4.3.1-7 - Upstream slope (near east end of the bridge) covered with rockfill riprap underlain by geotextile, likely recent repair (September 25, 2018, 35.1868 N, 77.9840 W)

Fig. 4.3.1-8 - Upstream slope erosion (adjacent to the west end of the bridge) (September 25, 2018, 35.1868 N, 77.9843 W).

Fig. 4.3.1-9 - The upstream slope of the NC Highway 55 East was covered with grass and did not experience erosion. The riprap shows three different colors (September 25, 2018, 35.1867 N, 77.9844 W)

Fig. 4.3.1-10 – Repair of downstream slope of the NC Highway 55 East (September 25, 2018, 35.1865 N, 77.9839 W)

4.3.2 Fair Lake Dam, Laurinburg, NC

Fair Lake Dam is a 14-ft-high, 521-ft-long earthfill dam in Laurinburg, Scotland County, NC (location - Fig. 4.3.2-1, aerial – Fig. 4.3.2-2). The dam was built in 1952 and is classified as a high hazard recreational dam. Fair Lake Dam is situated inside of a residential development. The surrounding homeowners had only recently taken ownership of the structure after a foreclosure.

During the hurricane, the impoundment overtopped at multiple locations and eroded the embankment at two locations. Flood flows also scoured around the spillway structure. The National Guard patched the erosion during the storm. There may have been some internal erosion parallel to the concrete structure. The dam was saved from breaching by combined efforts of the dam owner, emergency managers, state dam safety, and the National Guard. Figs. 4.3.2-3 through 4.3.2-6 show evidence of the overtopping and emergency repairs that were visible when we visited the dam.

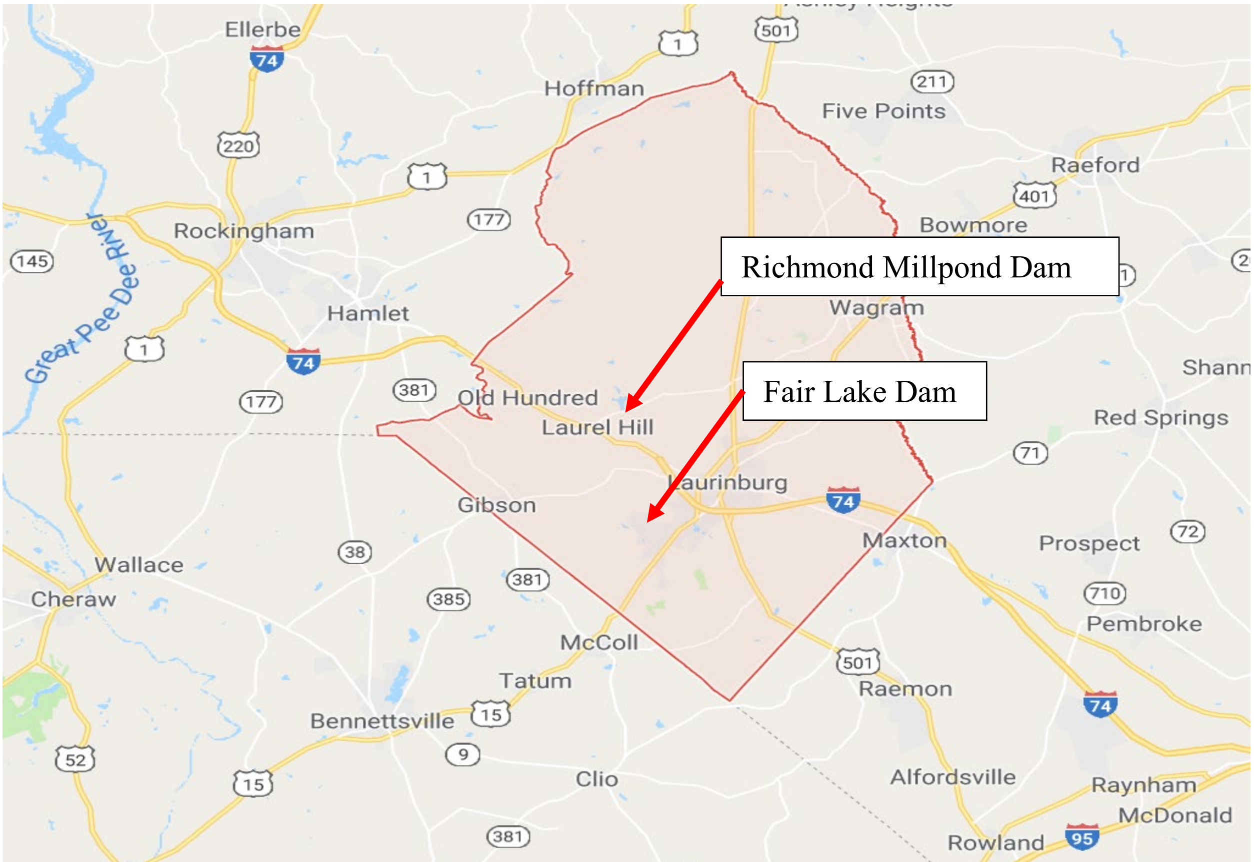

Fig. 4.3.2-1 – Locations of Fair Lake Dam and Richmond Millpond Dam, Scotland County, NC (Google Maps for source map)

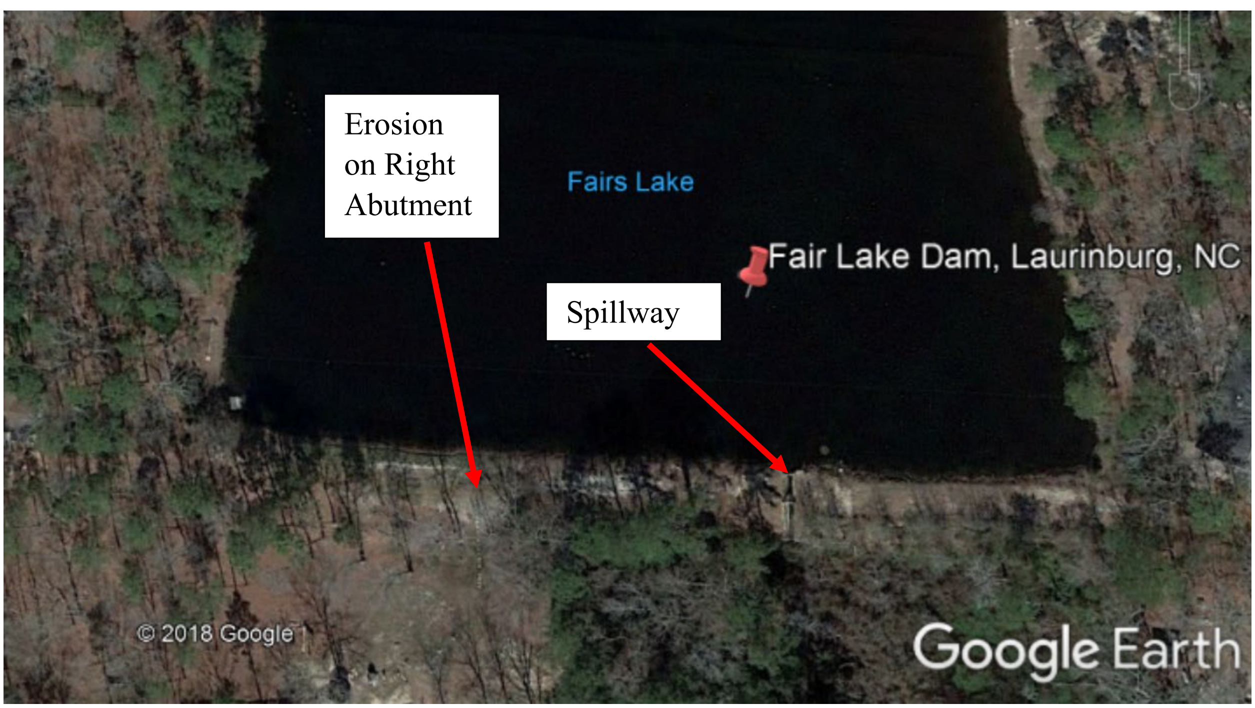

Fig. 4.3.2-2 – Fair Lake Dam area (Google Earth, 34.742 N, 79.517 W)

Fig. 4.3.2-3 – Temporary fix at the right side of spillway (September 24, 2018, 34.7418 N, 79.5167 W)

Fig. 4.3.2-4 – Looking to dam and spillway from the right abutment temporary fix at the toe of the right abutment (September 24, 2018, 34.7419 N, 79.5178 W)

Fig. 4.3.2-6 – Overtopping erosion failures where riprap is visible at Fairs Lake (September 24, 2018, 34.7418 N, 79.5168 W)

Fig. 4.3.2-6 – Erosion repairs around spillway structure at Fairs Lake (September 24, 2018, 34.7418 N, 79.5168 W)

4.3.3 Bullards Millpond Dam, Marlboro County, SC

Bullards Millpond Dam is a 12-ft-high earthfill dam completed in 1900 and is located in Marlboro County, South Carolina (Fig. 4.2.9-1), along Naked Creek, a tributary of the Great Pee Dee River. It is a state regulated significant hazard recreational dam used primarily for fishing and recreational activities. The pond is stocked with fish, and local residents pay a small fee to fish in the pond. The pond has an outlet structure and a make-shift emergency spillway as shown in photographs below. Fig. 4.3.3-1 is a photograph showing the large reservoir created by the dam.

Fig. 4.3.3.1 - Bullards Millpond in Marlboro County, South Carolina (September 27, 2018, 34.704 N, 79.731 W)

Fig. 4.3.3-2 includes historical Google Earth aerial images from for 2003, 2011, and 2017 that show the development of the lake as a recreational facility. Figs. 4.3.3-2(a) and (b) show a smaller reservoir on June 25, 2003 and June 28, 2011. Fig. 4.3.3-2(c) shows a larger reservoir on December 18, 2011. We do not know if the impounding structures were enlarged for the expanded reservoir. Fig. 4.3.3-2(d) shows that the larger reservoir was maintained through February 18, 2017, a similar configuration and size as encountered during the GEER reconnaissance trip on September 27, 2018. The red circle shows the location of the fishing club house on the right abutment of the dam.

(a) 6/25/2003

(b) 6/28/2011

(c) 12/18/2011

(d) 2/18/2017

Fig. 4.3.3-2 - Historic aerial imagery of Bullards Millpond from: (a) June 25, 2003, (b) June 28, 2011, (d) December 18, 2011, and (d) February 18, 2017 (Google Earth, 34.703 N, 79.731 W)

Fig. 4.3.3-3 shows a closer aerial view of the dam with the locations of the main features – the spillway and outlet works at the right abutment, the main earth embankment, and a crude emergency spillway at the left end of the embankment. The dam is about 8 ft high near the outlet structure and varies between 8 ft near the outlet works to 4 feet at the emergency spillway and is about 850 ft long.

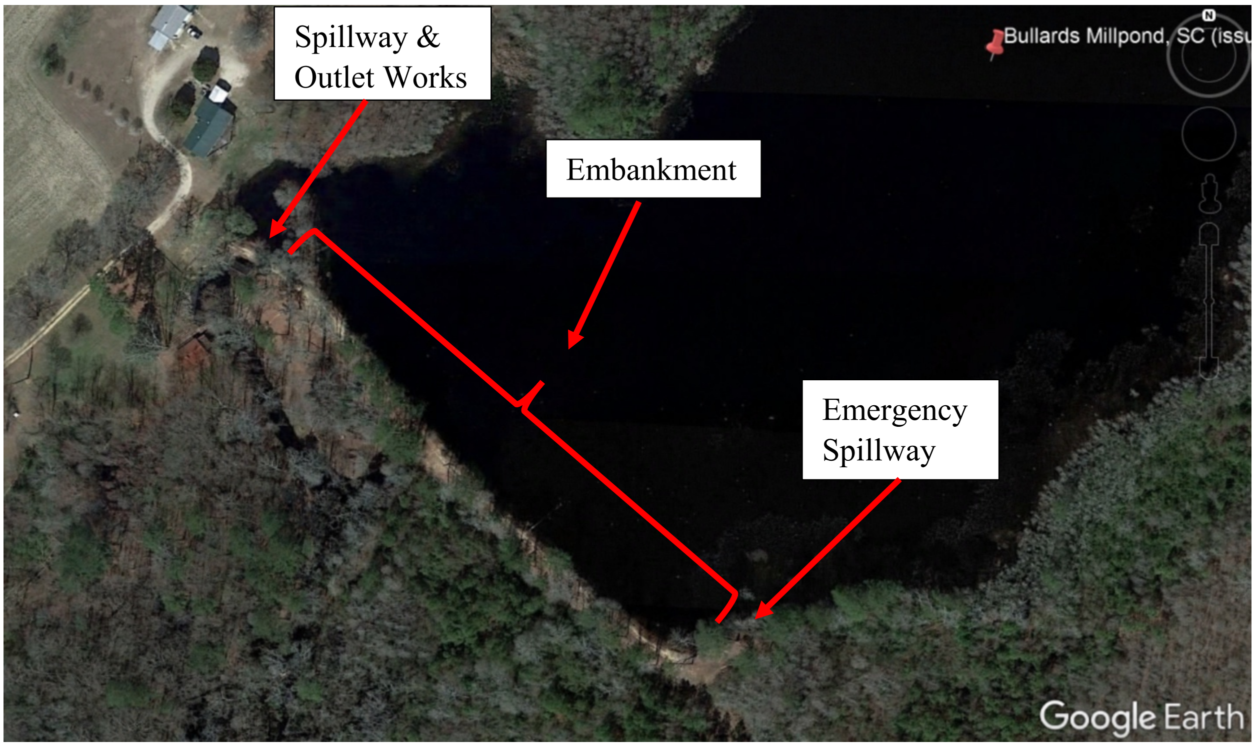

Fig. 4.3.3-3 – Bullards Millpond Dam Area (Google Earth, February 18, 2017, 34.703 N, 79.731 W)

During Florence, the dam was overtopped at multiple locations along the length of the embankment. Fig. 4.3.3-4(a) shows the dam from the right abutment and surrounding forest. Near the left abutment area, discussed below, the height of the dam is about 4 ft high. Fig. 4.3.3-4(a) also shows trees, which could be found along most of the dam. Erosion was observed around a few, but not most tree roots. Fig. 4.3.3-4(b) shows the dam from the left abutment looking back towards the clubhouse and parking area.

(a) (b)

Fig. 4.3.3-4(a) - Dam crest from right abutment and surrounding forest and (b) Dam crest looking toward right abutment showing clubhouse and parking area (September 27, 2018, 34.7041 N, 79.7312 W)

Fig. 4.3.3-5(a) shows the outlet structure weir (see yellow arrow). The outlet structure was functioning properly but part of the dam near the outlet was overtopped. Fig. 4.3.3-5(b) shows flow exiting the concrete outlet structure on the downstream side of the dam.

(a) (b)

Fig. 4.3.3-5(a) - Outlet structure weir (yellow arrow shows inflow slot) and (b) Outlet structure outflow (September 27, 2018, 34.7042 N, 79.7315 W)

Fig. 4.3.3-6(a) and (b) show the stream bank downstream of the outlet structure. In the left portion of Fig. 4.3.3-6(a), the stream bank has been protected with previously placed rock rip-rap. Fig. 4.3.6(b) shows recently eroded fine-grained stream bank material and slope failure slide debris in the stream channel.

(a) (b)

Fig. 4.3.6(a) - Stream bank erosion transition from prior stream bank erosion (see previously placed rock rip-rap) and more recent erosion and (b) - Recently eroded fine-grained stream bank material, accompanying slope failures, and resulting slide debris in stream channel (September 27, 2018, 34.7042 N, 79.7315 W)

Fig. 4.3.3-7 shows a make-shift emergency spillway and downstream channel at the left abutment, about one-quarter of a mile from the outlet structure. The emergency spillway appeared to be an earth channel slightly lower than the dam crest that was covered with concrete rubble riprap. Fig. 4.3.3-7 also shows more of the extensive tree growth on the dam.

Fig. 4.3.3-7 - Emergency spillway, downstream channel and left end of embankment (September 27, 2018, 34.7030 N, 79.7295 W)

Fig. 4.3.3-8(a) shows overtopping about 100 ft from the emergency spillway with the spillway channel flow on the right side of the photo on September 17, 2018. Fig. 4.3.3-10(b) shows the resulting erosion at the same location.

(a) (b)

Fig. 4.3.3-8(a) - Overtopping on September 17, 2018 and (b) - Erosion on September 27, 2018 at the same location about 100 ft from the emergency spillway (see yellow arrow) (September 17 & 27, 2018, (a) courtesy of SCDHEC, 34.7029 N, 79.7297 W)

Fig. 4.3.3-9 shows another area of obvious overtopping erosion on the downstream side of the embankment about 200 ft from the outlet works. Overtopping flows at this location eroded around trees on the embankment and created scour holes at the toe of the embankment.

Fig. 4.3.3-9 - Overtopping erosion about 200 ft from the outlet works (September 27, 2018, 34.7042 N, 79.7314 W)

In summary, this dam did not breach and offered the following observations of interest:

- The embankment was overtopped in several areas, resulting in some erosion on downstream slope, especially around roots and trees.
- We did not observe indications of seepage or seepage damage associated with the extensive tree growth. However, the trees likely induced turbulence in areas of overtopping flow, which exacerbated embankment erosion.
- The outlet structure worked well but some downstream erosion of the downstream channel bank occurred.
- The makeshift emergency spillway near the left abutment reduced the overtopping flows, and, if eroded, would have been a more favorable location for a breach than locations along the taller embankment.

4.4 Other Dam-Related Incidents and Observations

We also visited other dams that were not overtopped. These dams ranged from large hydroelectric power dams to a small unnamed dam. As expected, the large hydroelectric dams performed well, and flood flows were managed by spillways designed for larger events. The following sections describe our observations at six of these dams.

4.4.1 Lake Corriher Dam and Landis Lake Dam, Rowan County, NC

The Town of Landis, NC, owns two dams, Lake Corriher Dam and Landis Lake Dam, which are in series along the Flat Rock Branch, in Rowan County, NC (see Figs. 4.4.1-1, -2 and -3). The dams fall in the Yadkin/Pee Dee River basin.

Lake Corriher Dam is a 23-ft-high earthfill dam completed in 1953 (see Fig. 4.4.1-4). Landis Lake Dam is a 25-ft-high earthfill dam completed in 1955. Both dams are state-regulated high-hazard water-supply dams. There is a long dike or levee on the north side of the Lake Landis reservoir that extends to the upstream Lake Corriher.

Neither dam failed. According to dam caretaker, Lake Corriher Dam had regular spillway operation during the event and had no issues. However, the Lake Corriher Dam spillway outflow appeared to have caused erosion along the Landis Lake levee (see Fig. 4.4.1-5 and -6). According to dam caretaker, the Landis Lake level was reduced before the event with a syphon. The operators of Landis Lake continued to drain the pool level after the event to allow the erosion to be inspected.

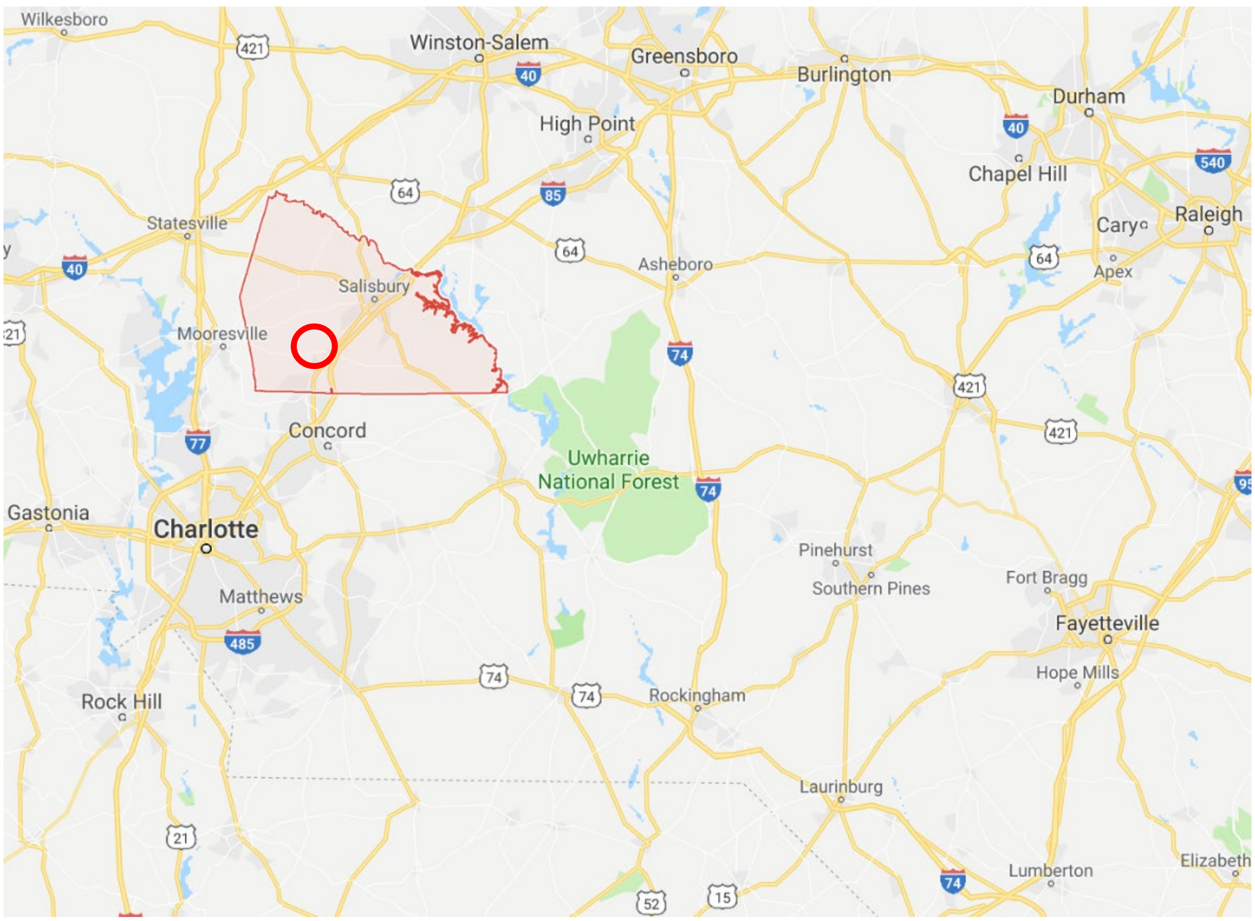

Fig. 4.4.1-1 – Lake Corriher Dam and Landis Lake Dam locations, Rowan County, NC (Google Maps)

Fig. 4.4.1-2 – Relative locations of Lake Corriher and Landis Lake (Google maps)

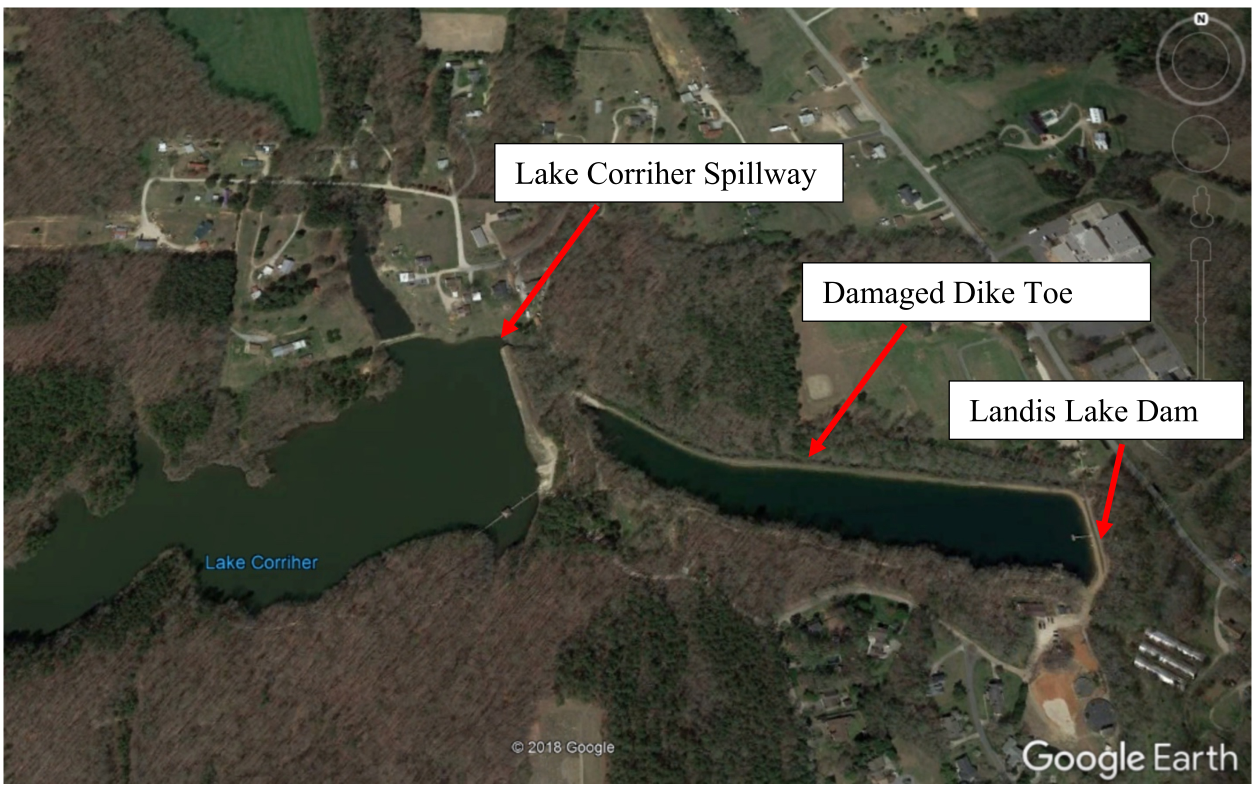

Fig. 4.4.1-3 – Landis Lake and Lake Corriher Area (Google Earth. March 30, 2018, 35.563 N, 80.602 W)

Fig. 4.4.1-4 – Lake Corriher Spillway on left Abutment (September 24, 2018, 35.566 N, 80.608 W)

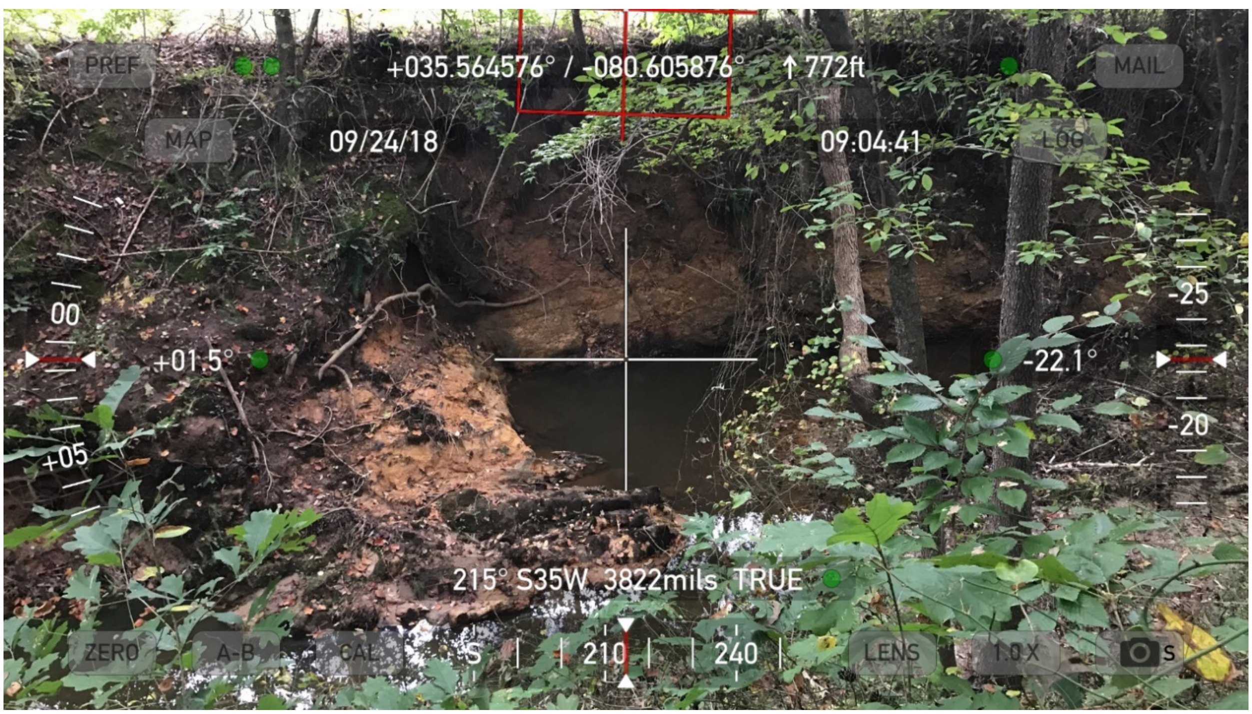

Fig. 4.4.1-5 – Erosion observed on Landis Lake levee (September 24, 2018, 35.5646 N, 80.6059 W)

Fig. 4.4.1-6 – Erosion observed on Landis Lake levee (September 24, 2018, 35.5649 N, 80.6068 W)

4.4.2 Yadkin Narrows Dam, Badin, Stanly County, NC

Yadkin Narrows is one of four dams operated by Cube Hydro Carolinas along the Yadkin River, which forms the east boundary of Stanly County, NC (Fig. 4.4.2-1 for location). These dams are regulated by FERC. The Yadkin Narrows Dam is large structure (207 ft high, 1654 ft long) with a high hazard rating. According to the dam engineer whom we interviewed, the Emergency Action Plan was activated but the spillway safely passed the high flows.

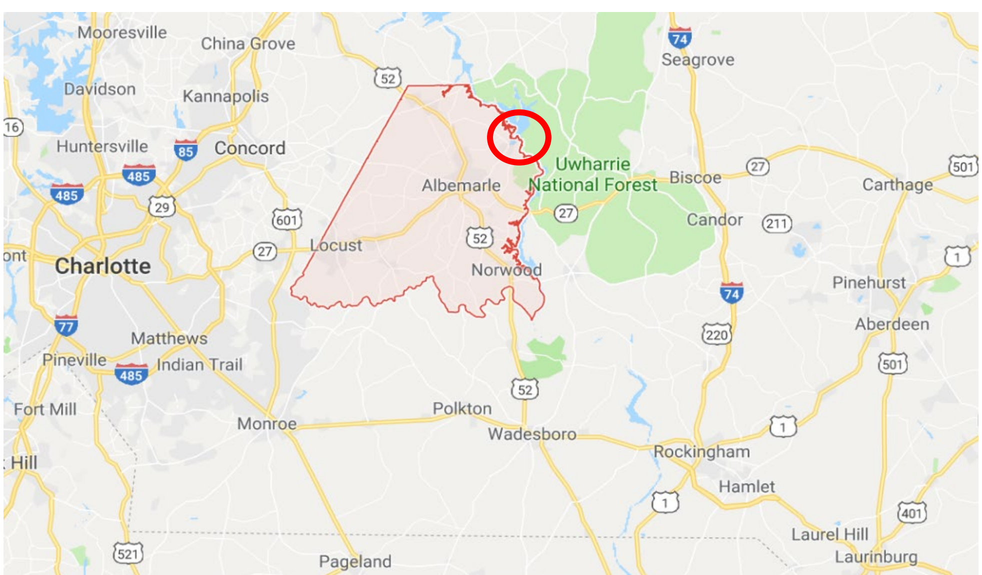

Fig. 4.4.2-1 – Yadkin Narrows Dam location, Stanley County, NC (Google Maps)

Fig. 4.4.2-2 shows a Google Earth aerial photograph of the dam. Figs. 4.4.2-3, -4, and -5 show the dam on the day of our visit.

Fig. 4.4.2-2 –Yadkin Narrows Dam Area (Google Earth, 35.419 N, 80.093 W)

Fig. 4.4.2-3 – Upstream view of Yadkin Narrows Dam (September 24, 2018, 35.4186 N, 80.0950 W)

Fig. 4.4.2-4 – Downstream view of Yadkin Narrows Dam (September 24, 2018, 35.4183 N, 80.0928 W)

Fig. 4.4.2-5 – Dam and powerhouse at Yadkin Narrows (September 24, 2018, 35.4186 N, 80.0950 W)

4.4.3 Zoar Road Dam, Anson, NC

We observed a small, unregulated dam along Zoar Road in Anson, NC. The dam was located about 700 ft north of the NC/SC border, immediately north of Zoar Road (Figs. 4.4.3-1, -2). The dam is about 500 ft long and appeared to be about 5 to 7 ft high (Fig. 4.4.3-3). The most notable observations at the dam was the active seepage on the downstream slope (Fig. 4.4.3-4).

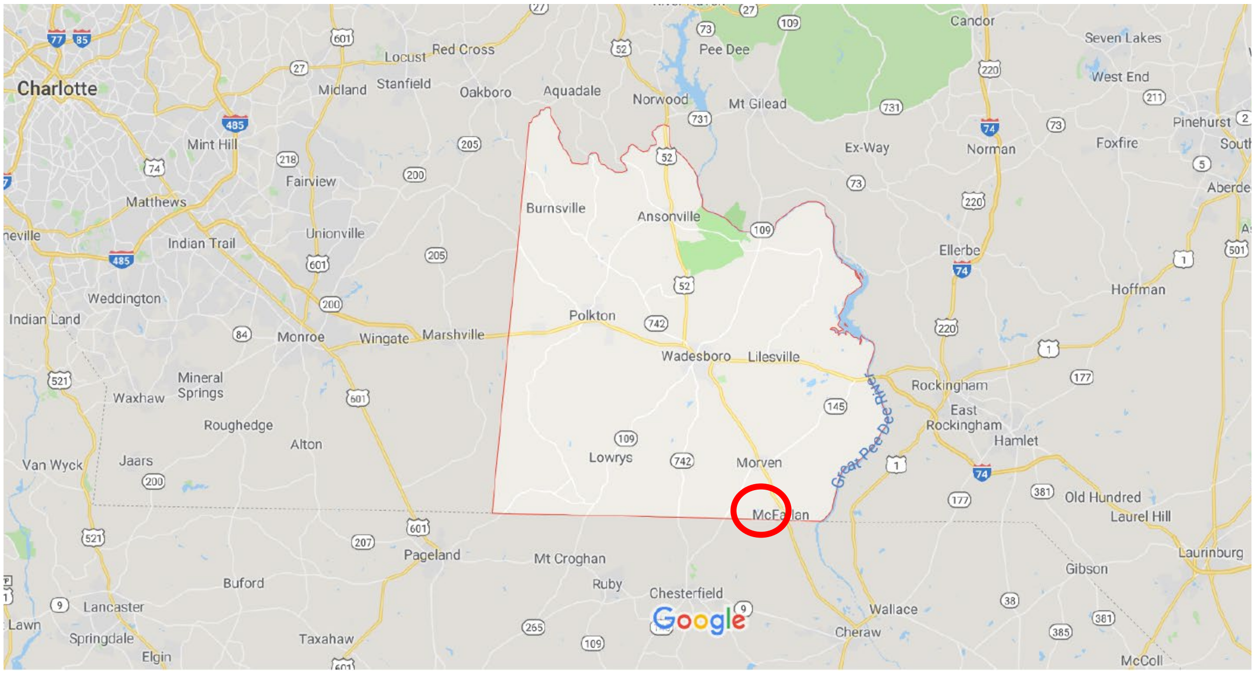

Fig. 4.4.3-1 – Site location, Anson County, NC (Google Maps)

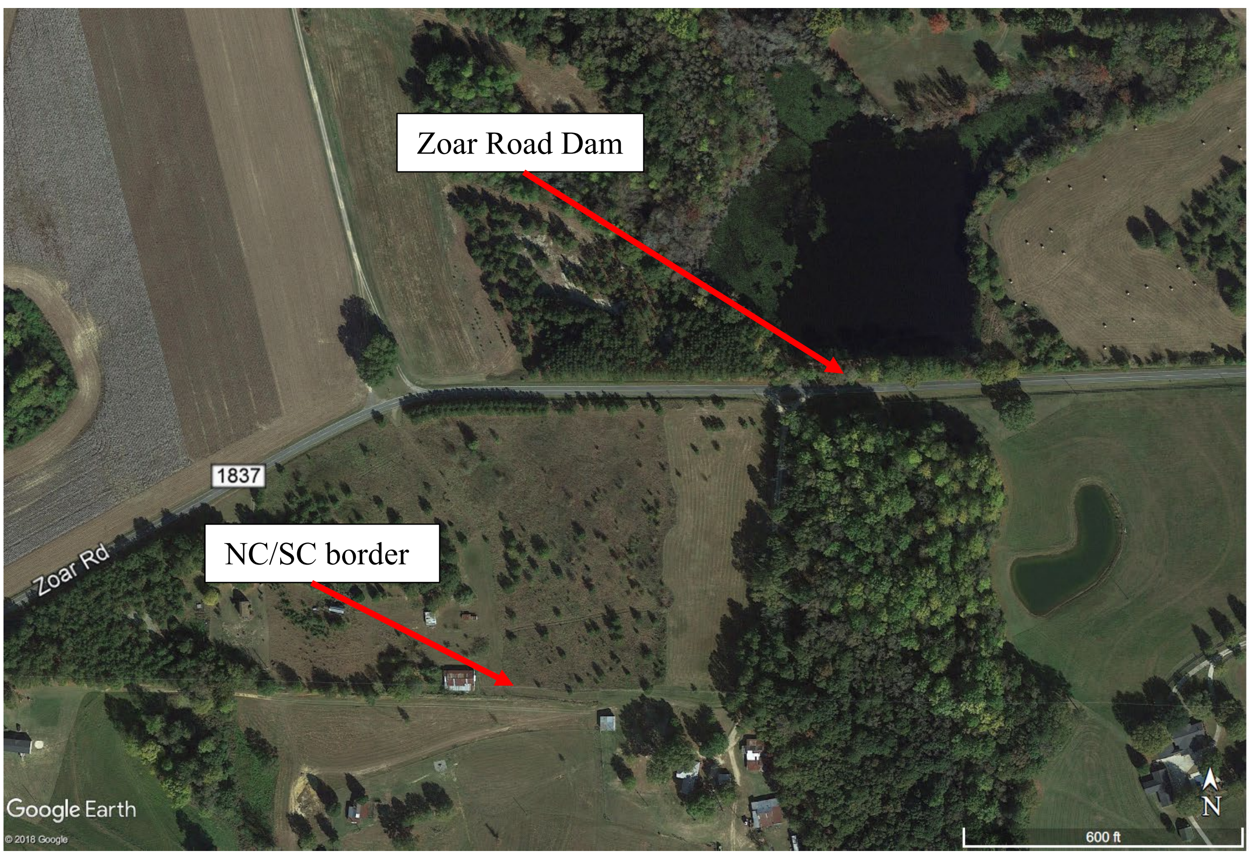

Fig. 4.4.3-2 – Aerial photograph Zoar Road Dam (Google Earth November 2, 2014, 34.810 N, 79.987 W)

Fig. 4.4.3-3 – Crest of unnamed dam off Zoar Rd in Anson, NC (September 25, 2018, 34.8097 N, 79.9874 W)

Fig. 4.4.3-4 – Seepage at unnamed dam off Zoar Rd in Anson, NC (September 25, 2018, 34.810 N, 79.987 W)

4.4.4 Richmond Millpond Dam, Laurel Hill, NC [West Team]

The Richmond Millpond Dam is a privately-owned high hazard structure located in Laurel Hill, Scotland County, NC, on Gum Swamp Creek, in the Lumber River basin (Fig. 4.4.4-1). The dam is located 100 ft upstream of Old Wire Road / State Route 144. The dam has a listed length of about 700 ft (Fig. 4.4.4-2). The sharp-crested concrete-weir spillway has a rectangular footprint that extends about 85 ft into the pond to provide an enhanced crest length and spillway capacity (Figs 4.4.4-3 & -4).

The team visited this dam based on a report of overtopping. At the time of our visit, the spillway was active and performing as designed. The operator was onsite and described recent remediation measures implemented based on flooding during a previous hurricane. The most significant remedial measure was the installation of a 70-ft-deep sheet-pile cutoff wall. It did not appear that the dam was overtopped.

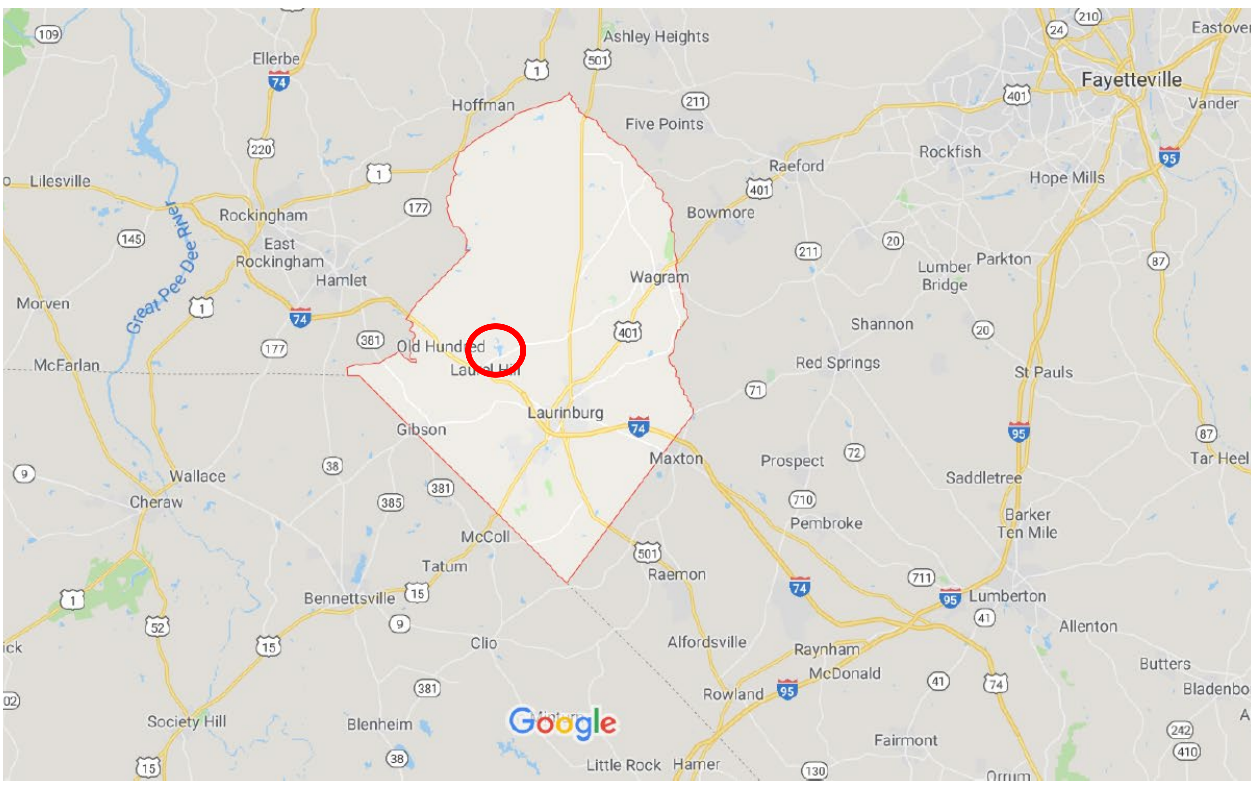

Fig. 4.4.4-1 Location Map, Scotland County, NC (Google Maps)

Fig. 4.4.4-2 – Aerial photograph of Richmond Millpond Dam (Google Earth, September 30, 2018, 34.821 N, 79.530 W)

Fig. 4.4.4-3 – Richmond Millpond Dam spillway (September 24, 2018, 34.8203 N, 79.5303 W)

Fig. 4.4.4-4 – Richmond Millpond Dam spillway and dam (September 24, 2018, 34.8207 N, 79.5302 W)

4.4.5 Bryan Lake Dam, Johnston County, NC

Bryan Lake Dam is a low hazard embankment dam on Jumping Creek in the Neuse River basin in Johnston County, NC (Fig. 4.4.5-1). The dam has a listed height and length of 12 ft and 675 ft respectively and is privately owned. Holly Grove Road / State Route 1113 runs immediately downstream of the dam (Figs. 4.4.5-2 for aerial, -3 for view from road).

We visited the dam because of an incident report. A sinkhole developed above the reinforced concrete pipe (RCP) barrel behind the headwall (Fig. 4.4.5-4). Additional signs of erosion were observed behind the block headwall; voids were observed behind the outlet headwall (Fig. 4.4.5-4). No signs of overtopping were observed, the spillway was intact (Fig. 4.4.5-5), and the dam appeared to be stable. There were signs of road damage due to spillway channel flows on Holly Grove Road, along with fresh straw on the shoulder of the roadway (Fig. 4.4.5-6). An 8-ft by 6-ft cutout with recently placed gravel on the road (Fig. 4.4.5-6) appeared to be a temporary repair of the damage. New riprap over woven geotextile had also been placed along the roadway embankment.

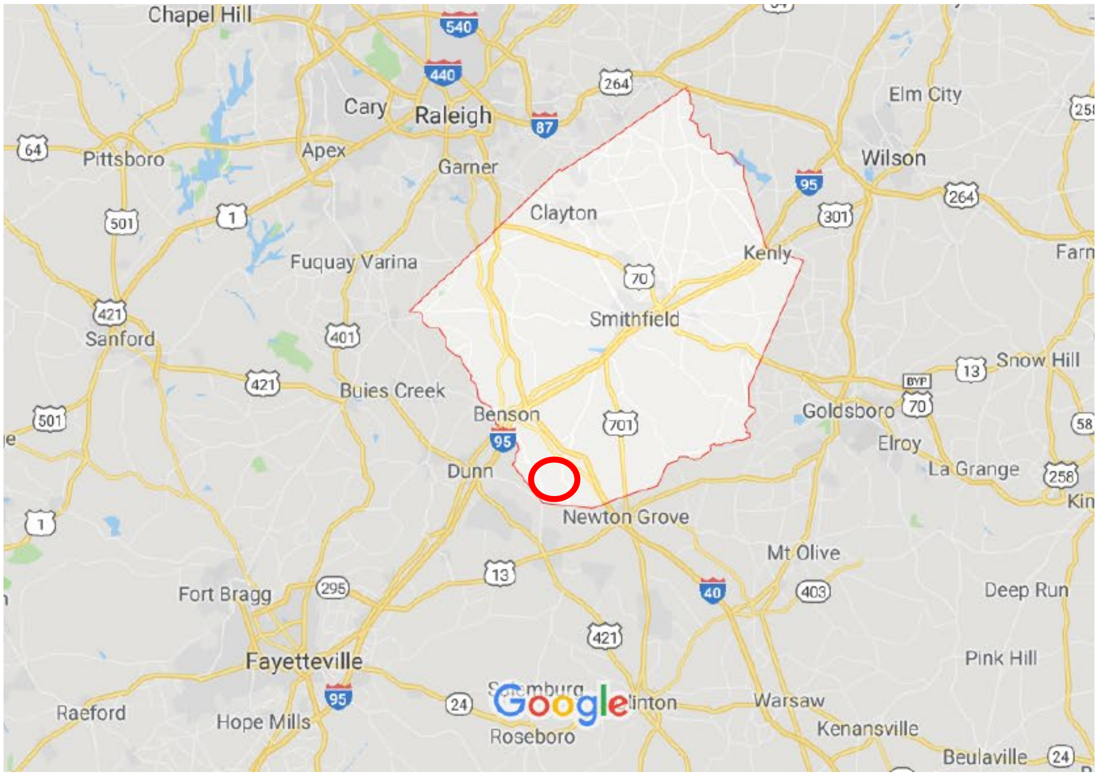

Fig. 4.4.5-1 Bryan Lake Dam location, Johnston County, NC (Google Maps)

Fig. 4.4.5-2 – Aerial image of Bryan Lake Dam, March 4, 2018 (Google Earth, 35.291 N, 78.477 W)

Fig. 4.4.5-3 – Holly Grove Road in front of Bryan Lake Dam (September 27, 2018, 35.2905 N, 78.4765 W)

Fig. 4.4.5-4 – Sinkhole developed above reinforced concrete pipe in earthen dam, and signs of erosion behind the block outlet headwall (September 27, 2018, 35.2909 N, 78.4765 W)

Fig. 4.4.5-5 – Spillway of dam (September 27, 2018, 35.2905 N, 78.4769 W)

Fig. 4.4.5-6 – Road damage, fresh straw, and new riprap on Holly Grove Road (September 27, 2018, 35.2909 N, 78.4765 W)

4.4.6 Clay Thomas Road Dam, Person County, NC

We made a visit near an unregulated dam in Person County, NC, along Clay Thomas Road and US 501 (Fig. 4.4.6-1, -2) because of a report that the spillway was activated. We could not get access to the privately-owned earthen dam; however, neighbors downstream of the spillway were interviewed. The reservoir is below the elevation of US 501, which was built in about 2013, and according to interviewed residents acts as a retention basin for surface water from the highway. However, the impoundment predates the highway by more than 10 years.

When the spillway was activated, the downstream drainage ditch through a private residence overtopped and water backed up along Clay Thomas Road. The drainage ditch flooded the grass areas shown in Figs. 4.4.6-3 and -4. The interviewed residents advised us that no flooding was experienced by the structures adjacent to the drainage ditch.

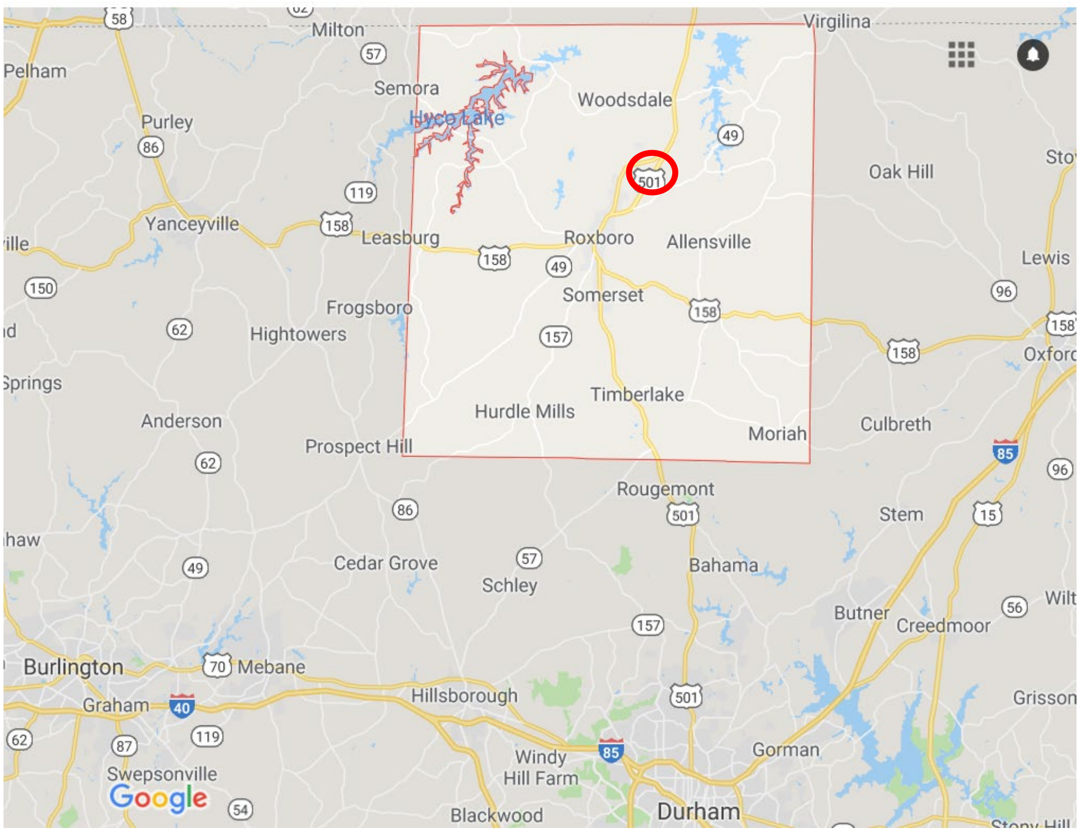

Fig. 4.4.6-1 Clay Thomas Road dam, Person County, NC (Google Maps)

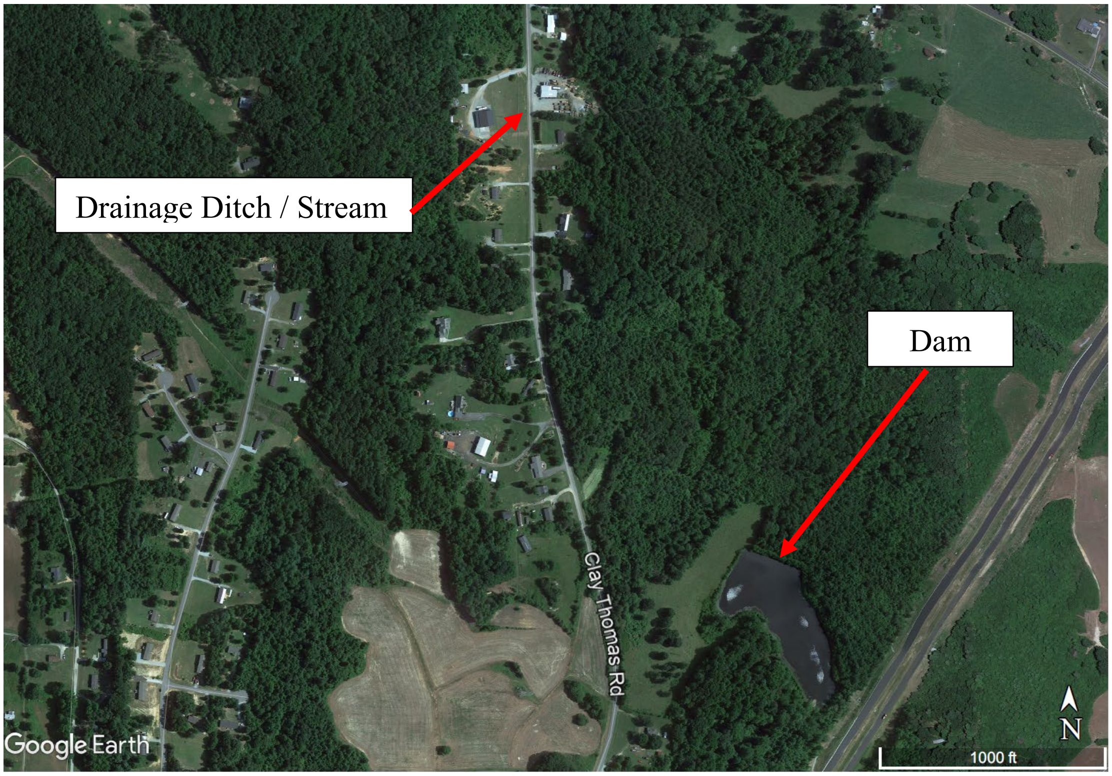

Fig. 4.4.6-2 – Aerial image of reservoir along Clay Thomas Road and US 501, June 13, 2016 (Google Earth, 36.434 N, 78.942 W)

Fig. 4.4.6-3 – Private residence along Clay Thomas Road downstream of dam spillway (September 27, 2018, 36.4406 N, 78.9458 W)

Fig. 4.4.6-4 – Private residence along Clay Thomas Road downstream of dam spillway (September 27, 2018, 36.4407 N, 78.9456 W)

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5. Levees

5.1 Lumberton Levee System Observations, Lumberton, North Carolina

Lumberton Levee System Description and Flooding

The Lumber River flows though the southern part of Lumberton, NC, from northwest to southeast. The river is a tributary of the Little Pee Dee River within the Pee Dee watershed and is designated a natural and scenic river. An earth embankment levee system protects the low-lying section of Lumberton on the south side of the river. The westernmost section of the levee is the I-95 highway embankment. Fig. 5.1-1 shows the location of the Greenway System Lumberton Riverwalk / Lumber River Bike Trail (green line on map), which is the paved walk/bike way along the crest of the levee embankment.

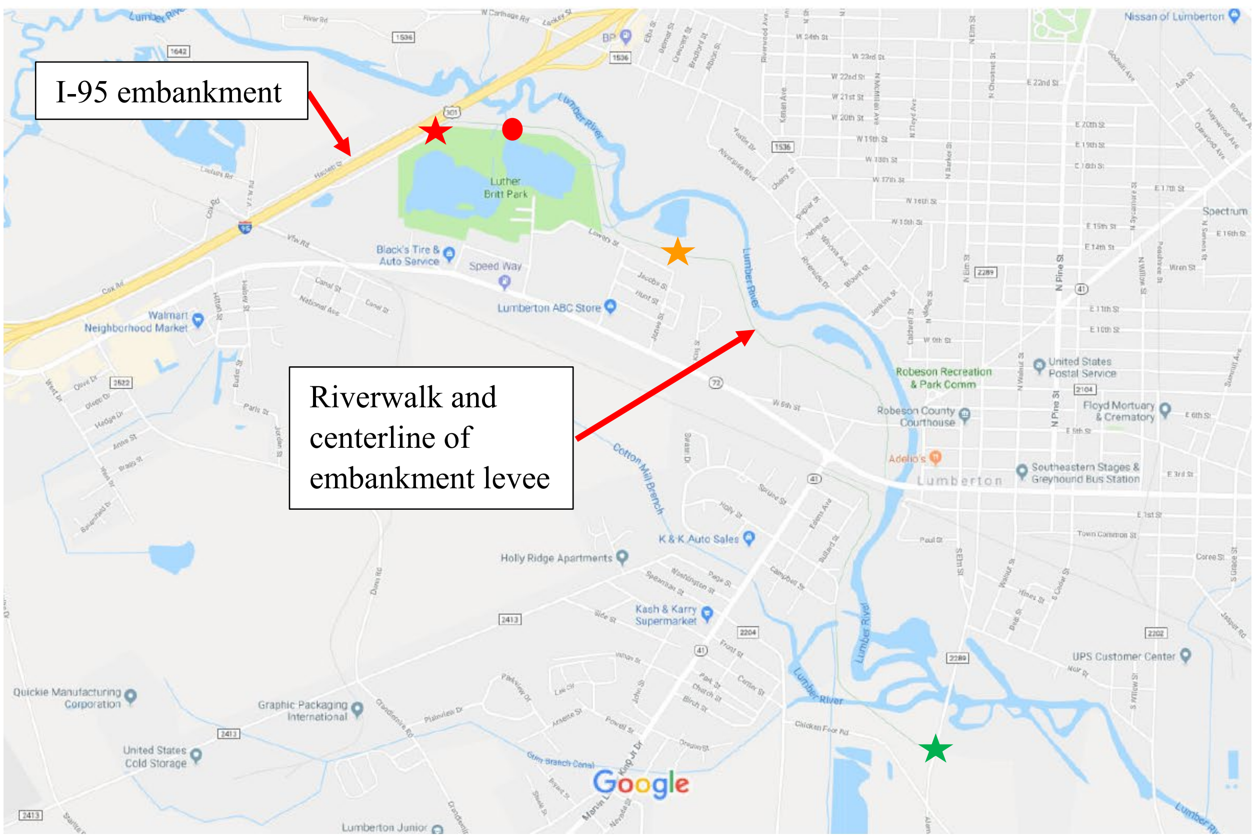

Fig. 5.1-1 – Lumberton Levee System (Google Maps, 34.62 N, 79.02 W)

The GEER team walked the top of the levee from the end of Crystal Road (red star in Fig. 5.1-1) to the intersection of Lowery and Jacobs Streets (orange star) and made additional spot observations along the southeastern part of the levee to its terminus at South Chestnut Street / State Route 2289 (green star). Figs. 5.1-2(a) and (b) are aerial photographs of this section of

Lumberton taken on March 4, 2018 before the flood and September 18, 2018 during the flood, respectively. The brown areas in Fig. 5.1-2(b) are the flooded areas of south Lumberton.

Figs. 5.1-2(a), top, and (b), bottom – Aerial photographs of south Lumberton before (a) and during (b) the Florence flooding (Google Earth, March 4, 2018 and September 18, 2018, 34.62 N, 79.02 W)

At the time of our visit, the levee was in excellent condition and appeared to range in height from a few ft to about 25 ft (estimated). We noted high water marks on the levee about 4 to 5 ft below the crest. Fig. 5.1-3(a) shows the Lumberton Levee at the western end of the Riverwalk with the river still at flood stage but receded from its maximum height. Fig. 5.1-3(b) shows a park bench near the bend in the levee in the background of Fig. 5.1-3(a) (orange dot) to give an indication of the level of flooding still present during the reconnaissance. Fig. 5.1-4 shows some residual flood water or possible underseepage on the protected side in Luther Brit Park. There was no visible seepage occurring at the time of the reconnaissance. The location of this wet area is given by the red dot in Fig. 5.1-1. We noted that several trees along this levee had fallen and pulled down telecommunication and/or power lines (Figs. 5.1.5(a) and (b)).

(a) (b)

Fig. 5.1-3(a) - Lumber River Levee at the end of Crystal Street and (b) - Park bench still flooded near the orange dot in (a) in the Riverwalk Area (September 27, 2018, (a) 34.6312 N, 79.0309 W, (b) 34.6311 N, 79.0271 W)

Fig. 5.1-4 – Protected side ponding along Lumber River Levee in Luther Britt Park (September 27, 2018, 34.6309 N, 79.0284 W)

(a) (b)

Fig. 5.1-5 - Photographs of fallen trees damaging telecommunications and/or power lines along Lumber River Levee (September 27, 2018, (a) 34.6311 N, 79.0271 W, (b) 34.6308 N, 79.0259 W)

CSX I-95 Underpass

South Lumberton has experienced flooding with regularity because of its low elevation relative to the river, because of runoff within the protected side of the levee, and, significantly, because of inflows through an underpass opening in the levee system where a CSX rail line and the VFW Road pass below I-95. The I-95 underpass is shown by the red dashed rectangle in Fig. 5.1-6 and is located near the intersection of Crystal Road and VFW Road in southwest Lumberton.

Hurricane Matthew in 2016 caused high levels along the Lumber River that flowed from the northwest side of I-95 through this underpass, flooding South Lumberton, displacing more than 1,500 city residents for months. Consequently, residents and officials expected a similar occurrence from the anticipated Florence flood levels. Local officials had asked for funding for permanent floodgates at the underpass following Matthew, but such funding had been delayed. A study completed in May 2018 concluded that a floodgate would save about 2,000 buildings from flooding and the $232.6 million of damage that was caused in 2016 by Hurricane Matthew.

To prepare for the expected high water from hurricane Florence, officials asked for and received a special order from the North Carolina governor to construct a temporary levee at the underpass. Various news reports noted that CSX tried to prevent the temporary levee across the rail line but relented in the face of the special order. A workforce of National Guardsmen, city employees, and civilian volunteers erected the temporary levee across the opening using sandbags, soil, stones, and Jersey barriers and positioned eleven pumps along the levee capable of moving 30,000 gallons per minute from low areas across the levee into the river. The temporary levee was completed on Friday, September 14th. On Sunday afternoon, September 16th, about 2 p.m., the temporary barrier at the underpass gave way and the Lumber River poured into south

Lumberton. Fig. 5.1-7 is an aerial photograph of this area from September 18, 2018. Flood flows through the underpass are visible in Fig. 5.1-7 on the southeast side of I-95.

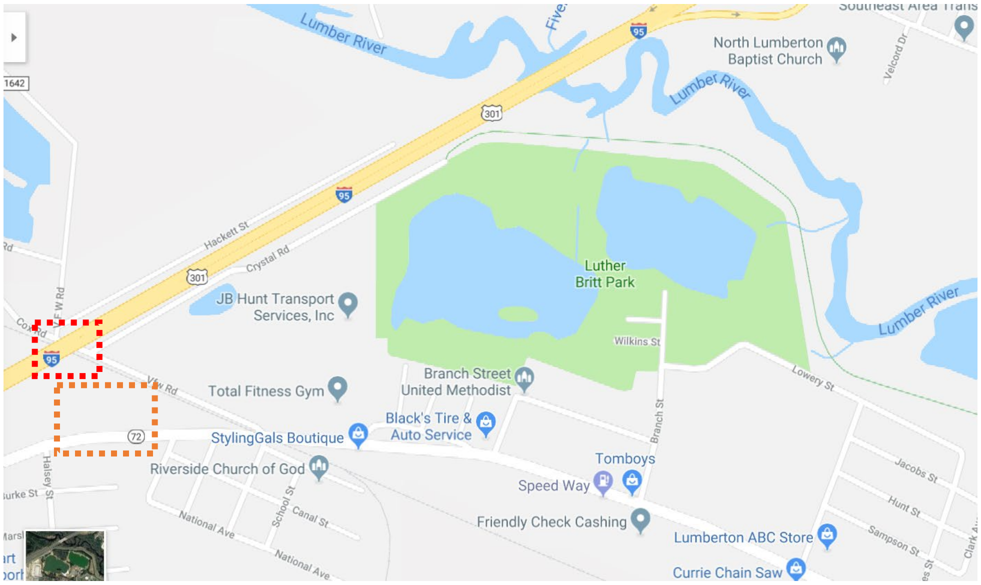

Fig. 5.1-6 – Location map- I-95 underpass (red rectangle) and West Lumberton Baptist Church (orange rectangle) (Google Maps, 34.627 N, 79.40 W)

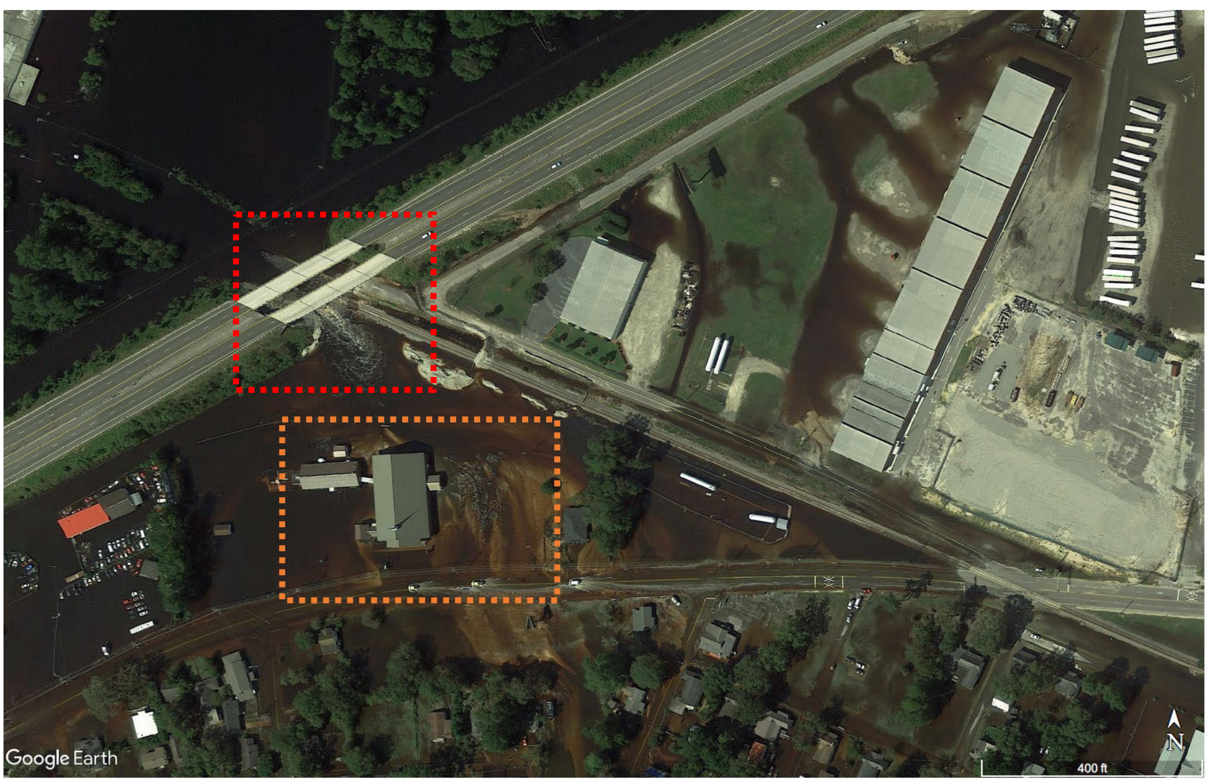

Fig. 5.1-7 - Google Earth view of I-95 underpass (red rectangle) and Riverside Church of God (orange rectangle) (Google Earth, September 18, 2019, 34.627 N, 79.039 W)

Fig. 5.1-8 shows the resulting flood levels and flows at the nearby West Lumberton Baptist Church. Fig. 5.1-9(a) shows the portion of the temporary levee on VFW Road under the northbound lanes of I-95 that was present at the time of our visit. Fig. 5.1.9(b) from September 27, 2018 shows the top of the sandbag levee, the uncovered CSX Railway, the flood level on bridge embankment, and a portion of the West Lumberton Baptist Church.

Fig. 5.1-8 - Flooding of the West Lumberton Baptist Church (Huffington Post, Joseph Rushmore, article dated September 20/21, 2018, 34.6273 N, 79.0389 W)

(a)

(b)

Fig. 5.1-9(a) - Temporary levee at VFW Road/ CSX Railway underpass of northbound I-95 and (b) - View from on top of temporary levee on VFW Road, uncovered CSX railway, flood level on bridge embankment (blue dashed line), and West Lumberton Baptist Church (red arrow) (September 27, 2018, (a) 34.6273 N, 79.0390 W, (b) 34.6276 N, 79.0396 W)

The full layout and configuration of the temporary levee was not in place or completely apparent at the time of our visit. The levee elements under I-95 that we saw were only across the VFW Road and not on the CSX rail line, most likely because the rail line had been cleared for traffic. Additional temporary levee elements appeared to have been placed along and across VFW Road and the CSX line forming a U-shape in plan that extended about 250 ft inboard / east of I-95. The inboard temporary levee may have been a second line of defense or a second attempt to contain or direct flood flows. The temporary levee(s) did allow residents some additional time to protect their property and move some items and property to higher ground, but significant property damage still occurred to houses, churches, vehicles (see Fig. 5.1.10), and businesses.

Fig. 5.1-10 – Vehicle with flood level marks in front of an auto parts store about 0.4 mile west of the I-95 underpass (September 27, 2018, 34.6236 N, 79.0452 W)

The City of Lumberton has secured a $1.25 million FEMA grant to build a permanent floodgate under the I-95 underpass, and construction is slated to begin in 2019. Lumberton and CSX are cooperating to implement a permanent solution to this opening in the levee protection system.

The flooding through the underpass confirms the importance of surveying a levee protection system and identifying and sealing all possible openings before a major storm arrives. Possible failure mechanisms for the temporary levee(s) include overtopping and underseepage erosion. The riprap in the underpass drainage channels and the coarse gravel ballast of the rail line would have provided little impedance to underseepage at the temporary levee. Construction of a permanent floodgate with appropriate seepage cutoffs certainly makes sense as a way to prevent repeats of the 2016 and 2018 flooding.

5th and 2nd Street Crossings

We also made observations at other locations along the levee including road crossings at 5th Street and 2nd Street (Fig. 5.1-11). The area near these crossings appeared to be about the lowest in south Lumberton and was the location where the city positioned some of the temporary pumping stations. Fig. 5.1-12 is an aerial photograph taken on September 18, 2018, during the flooding. The brown flood waters can be seen covering most of this area.

Fig. 5.1-13 shows the numerous temporary pumps that the city set up adjacent to the 5th Street levee crossing during the flooding. At the time of our visit, some of the pumps were still set up (Fig. 5.1-14). The high flows and velocities from some of the pumps resulted in erosion on the riverside of the levee (Fig. 5.1-15(a)). We also noted that the street level at the 5th Street crossing was lower than the rest of the levee by about 2 ft (Figs. 5.1-14 and Fig. 5.1-15(b)), but flood levels did not reach this street elevation.

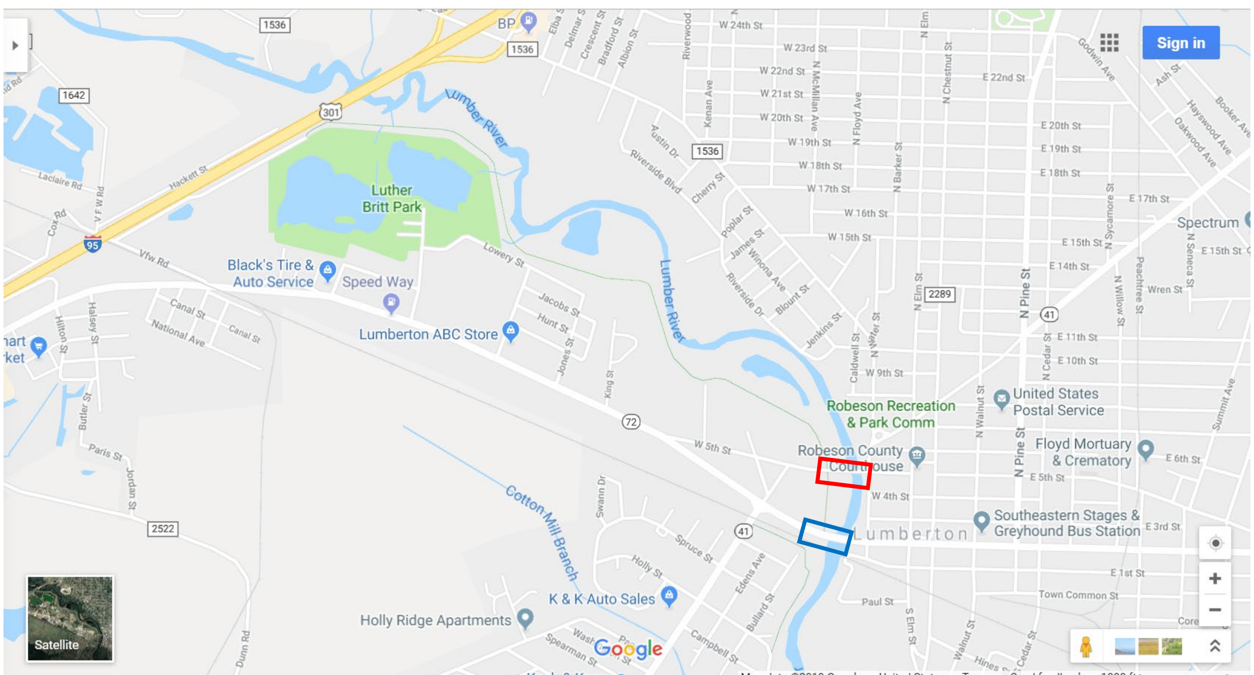

Fig. 5.1-11 - Locations of 5th Street and 2nd Street levee crossings (red and blue rectangles, respectively) (Google Maps, coordinates 34.6193 N, 79.0118 W)

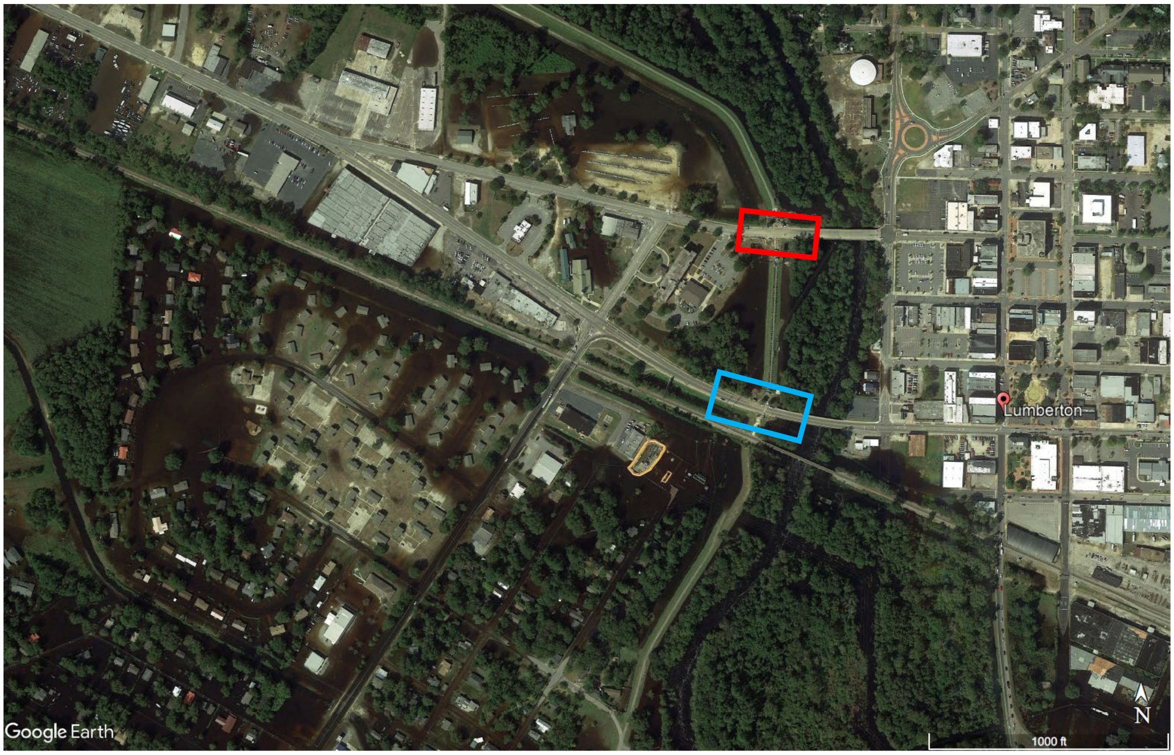

Fig. 5.1-12 – Aerial photograph – low areas of south Lumberton near 5th and 2nd Street levee crossings (see red and blue rectangles, respectively) during Florence flooding (September, 18, 2018, Google Earth, 34.6193 N, 79.0118 W)

Fig. 5.1-13 – 5th Street levee crossing (Google Earth, September 18, 2018, 34.62.02 N, 79.0118 W)

Fig. 5.1-14 – 5th Street levee crossing of levee (September 27, 2018, 34.6202 N, 79.0113 W)

(a) (b)

Fig. 5.1-15(a) - Erosion on river side of levee due to pumping at the 5th Street levee crossing, (b) - View across 5th Street levee crossing showing higher levee level (September 27, 2018, (a) 34.6202 N, 79.0113 W, (b) 34.62.02 N, 79.0118 W)

The 2nd Street levee crossing is about 750 ft downriver of the 5th Street crossing as shown in Figs. 5.1-11 & -12. Fig. 5.1-16 is an aerial photograph from September 18, 2018, during the flooding, showing the 2nd Street levee crossing, numerous temporary pumps, the CSX levee crossing located about 130 ft south, and an electrical substation where the power company had installed an orange Tiger Dam™ temporary flood barrier. Fig. 5.1-17 shows the 2nd Street and CSX rail levee crossing at the time of our visit.

The Tiger Dam™ System used at the substation is a portable system consisting of tubes that can be shipped uninflated and then filled with water to form a temporary flood barrier. Standard tubes are 100 ft long and between 3 ft and 12 ft high. The Tiger Dam™ at the Lumberton substation appeared to use the 3-ft-high tubes, stacked in some locations, with adjacent gravel berms for stability (Figs. 5.18(a) & (b)). The system was used around two of the substation transformer groups, presumably with interior pumping to remove underseepage.

Fig. 5.1-16 – 2nd Street and CSX levee crossings area with electrical substation (Google Earth, September 18, 2018, 34.6180 N, 79.0121 W)

Fig. 5.1-17 - 2nd Street and CSX levee crossings area with electrical substation (Google Earth, September 27, 2018, 34.6179 N, 79.0218 W)

(a) (b)

Fig. 5.1-18(a) & (b) - Tiger Dam temporary flood barrier a substation near 2nd Street levee crossing (September 27, 2018, (a) 34.6179 N, 79.0136 W, (b) 34.6177 N, 79.0133 W)

The residents in the area south of 2nd Street appeared to be in a particularly low area and, consequently, suffered damages, most likely for the second time in two years (Fig. 5.1-19).

Fig. 5.1-19 – Residential damage, south Lumberton (September 27, 2018, 34.61 N, 79.01 W)

References

Bock Clark, Doug (2018). "Two Years after a Devastating Hurricane, a North Carolina Town is Again at the Center of the Flood." *The New Yorker*. September 2018. https://www.newyorker.com/news/dispatch/two-years-after-a-devastating-hurricane-a-north-carolina-town-is-again-at-the-center-of-the-flood.

D'Angelo, Chris, and Jamieson, Dave (2018). "CSX Railroad Fought a North Carolina City's Desparate Attempt to Prevent Devastating Flooding." *Huffington Post*. September 20/21. https://www.huffpost.com/entry/lumberton-north-carolina-flooding-florence-csx-railroad_n_5ba286a0e4b09e34df25f6f0.

Google Earth aerial photography, various dates.

Google Maps, selected areas. https://www.google.com/maps.

U.S. Flood Control (2018). Tiger Dams website, https://usfloodcontrol.com/super-tiger-dams/.

6. Transportation

6.1 Overview

The GEER Florence teams visited seven bridge sites, eight roadways sites, and two railroad sites affected by Florence. Fig. 6.1-1 shows the location of the transportation sites observed. The bridge sites all experienced high water, as expected, and scour around the foundations and river banks was observed at many of the sites. Debris piles were also observed at several of the sites. Detailed descriptions of the bridge-related observations are included in Section 6.2. Many of the roadways visited by the GEER Florence teams were undermined from overwash. Roadways supported on embankments were also damaged by slope failures related to weakened soil from poor drainage. Detailed description of the observations of the damage to the roadways are included in Section 6.3. Four railroad sites were visited by the GEER Florence teams to observe the damage to the rail tracks from the flood waters. The damage to the railroad in Anson County, NC lead to a train derailment. Detailed description of the visits to the undermined railroads are included in Section 6.4.

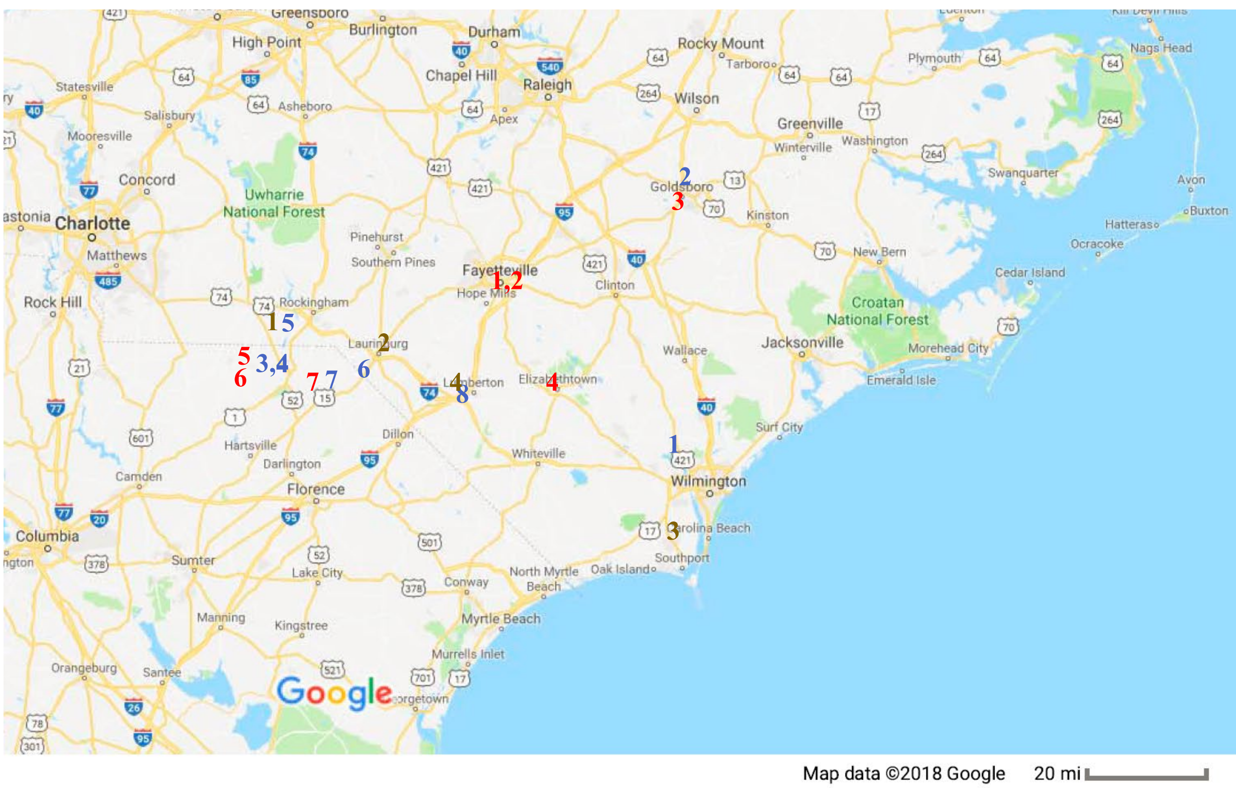

Fig. 6.1-1 – Transportation sites visited by GEER Florence team (number key tabulation below) (Google Maps)

Bridges (red numbers)

1. Business 95 Bridge at Cross Creek, Fayetteville, NC
2. Business 95 Bridge at Cape Fear River, Fayetteville, NC
3. I-795 Brudge at Neuse River, Goldsboro, NC
4. US 701 Bridge at Cape Fear, Elizabethtown, NC
5. Davis River Road Bridge, Chesterfield, SC
6. H.F. Bell Bridge, Chesterfield, SC
7. David's Millpond Bridge, Bennettsville, SC

Roadways (blue numbers)

1. US 421 Wilmington Washout by Cape Fear, Wilmington, NC
2. I-795 Embankment Slope Failure, Goldsboro, NC
3. SC 145 Culvert Washout Location 1 East, Chesterfield, SC
4. SC 145 Culvert Washout Location 2 West, Chesterfield, SC
5. Hendrick Haul Road,Anson County, NC
6. US-15 Roadside Repair
7. David’s Millpond Road, Marlboro County, SC
8. US-95 Roadside Repair, Lumberton, Robeson County, NC

Railroads (dark brown numbers)

1. Old Castle/Bonsal CSX Derailment, Anson County, NC
2. CSX Rail Culvert, Laurinburg County, NC
3. Rail Line to Military Ocean Terminal Sunny Point
4. Rail Line / I-85 Underpass and Temporary Closure Structure

6.2 Bridges

6.2.1 Business 95 Bridge at Cross Creek, Fayetteville, NC

In Fayetteville, NC, we observed significant scour at the bridge foundations of Business 95 across Cross Creek (location and aerial - Fig. 6.2.1-1 and 6.2.1-2). The bridge is about four years old, and the riprap along the slopes and settling pond were installed at that time. The foundation system of the bridge consists of four steel pipe piles in each pile cap embedded in stiff clay (Fig. 6.2.1-3). The original grade of the soil at the base of the creek was approximately 18 inches above the pile caps. After Hurricane Matthew in 2016, the initial pile cap and about 12 inches of the piles were exposed. Approximately 24 to 36 additional inches of scour was observed after Hurricane Florence and scour extended across the majority of the pile caps along the southern bank of the creek (Fig. 6.2.1-4). Insignificant scour around the foundations was observed along the northern bank of the creek.

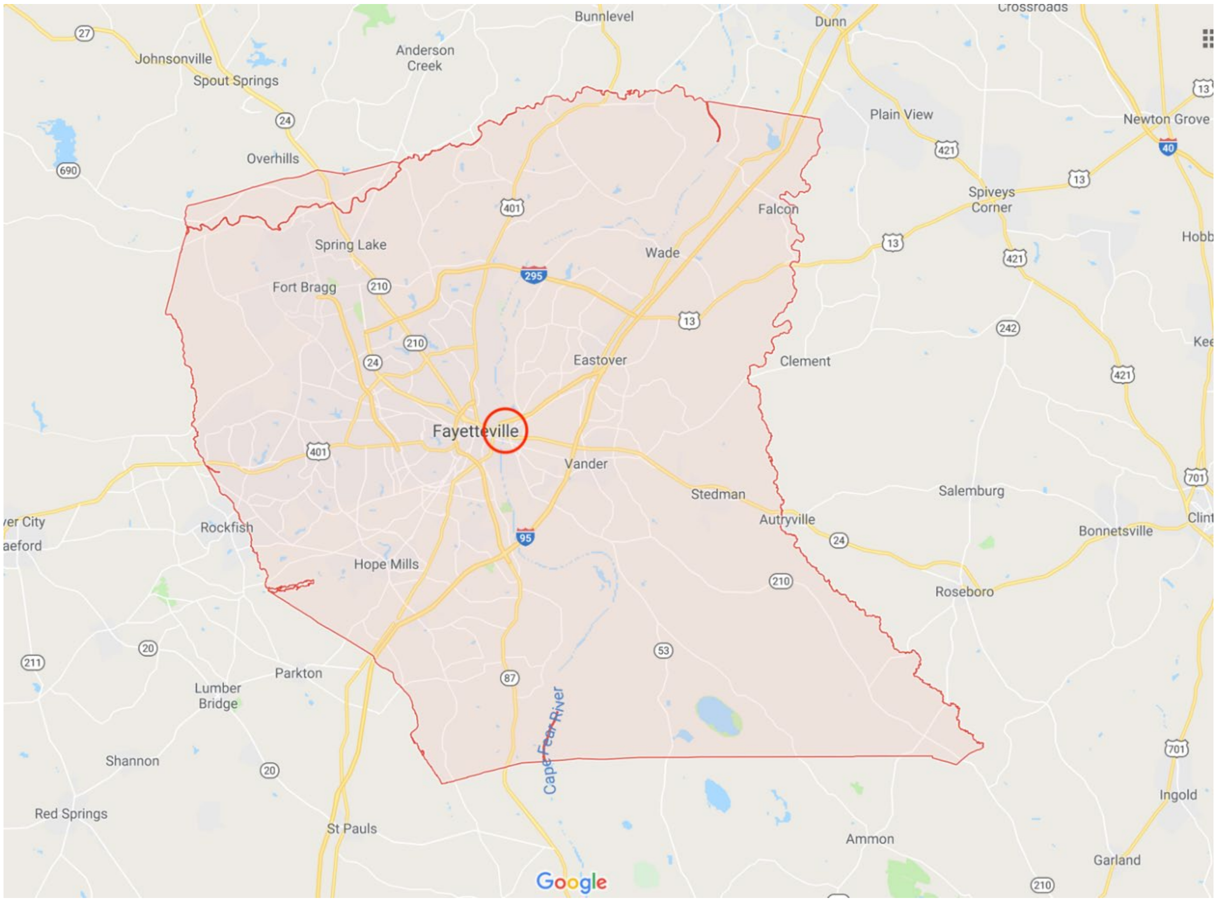

Fig. 6.2.1-1 – Cumberland County, NC (Google Maps)


Fig. 6.2.1-2 – Aerial image of Business 95 Bridge at Cross Creek, February 17, 2018 (Google Earth, 35.055 N, 78.862 W)

Fig. 6.2.1-3 – Business 95 Bridge at Cross Creek, looking north across Cross Creek at the high-water elevation (shown by muddied vegetation) and bridge foundation (September 26, 2018, 35.05453 N, 78.86315 W)

Fig. 6.2.1-4 – Business 95 Bridge at Cross Creek, looking south across Cross Creek at the exposed pile caps and pile foundations (September 26, 2018, 35.05507 N, 78.86251 W)

6.2.2 Business 95 Bridge at Cape Fear, Fayetteville, NC

The Business 95 Bridge over the Cape Fear River in Fayetteville, NC, is about a half mile away from the Business 95 Bridge over Cross Creek (Fig. 6.2.1-1). The Business 95 Bridge over the Cape Fear River, as seen in Fig. 6.2.2-1, was exposed to significant high water, as indicated by the muddied water mark on the bridge columns (Fig. 6.2.2-2). The bridge foundations over the water consist of drilled shafts, approximately 6 ft in diameter. Hollow pipe piles supported the bridge of the southern river bank (Fig. 6.2.2-3). The shallow sloping ground beneath the bridge on the southern bank was under water for at least a week (Fig. 6.2.2-4) due to the prolonged flooding of the Cape Fear River. The river bank beneath the bridge was reinforced with riprap after Hurricane Matthew in 2016 (Figs. 6.2-1 - 6.2-4). The armoring of the river bank resulted in no additional erosion observed after Hurricane Florence.

Fig. 6.2.2-1 – Aerial image of Business 95 Bridge at Cape Fear River, February 17, 2018 (Google Earth, 35.059 N, 78.855 W)

Fig. 6.2.2-2 – Business 95 Bridge at Cape Fear River, looking northeast across Neuse River (September 26, 2018, 35.0582 N, 78.8557 W)

Fig. 6.2.2-3 – Business 95 Bridge at Cape Fear River, looking southwest at southern bridge abutment (September 26, 2018, 35.0582 N, 78.8559 W)

Fig. 6.2.2-4 – Business 95 Bridge at Cape Fear River, looking north at southern bridge abutment; view from Fayetteville Technical Community College Horticulture Educational Center (September 21, 2018, 35.0575 N, 78.8571 W)

6.2.3 I-795 Bridge at Neuse River, Goldsboro, NC

The East Team visited the I-795 Bridge at the Neuse River in Goldsboro, NC (location and aerial - Fig. 6.2.3-1 and Fig. 6.2.3-2). We observed evidence of flood levels up to the bridge deck (Fig. 6.2.3-3) and erosion of the river bank upriver of the bridge in several locations (Fig. 6.2.3-4), with erosion scarps several yards in length. The flood stranded large catfish along the western riverbank (Fig. 6.2.3-5).

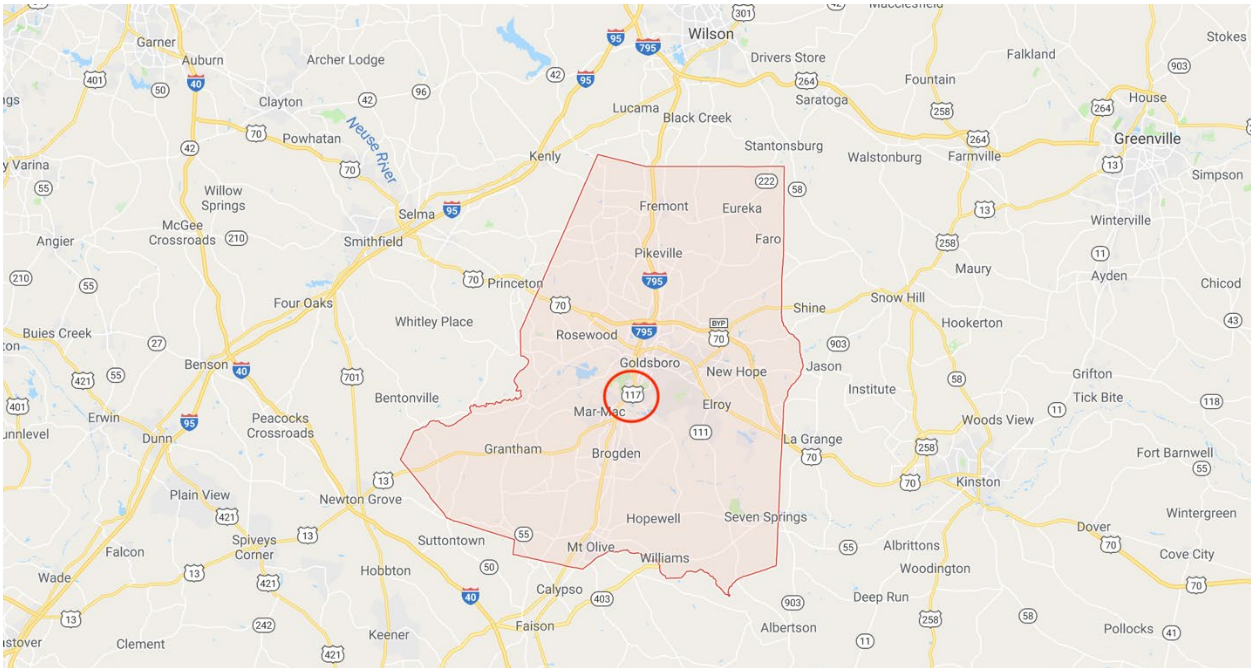

Fig. 6.2.3-1 – Wayne County, NC (Google Maps)


Fig. 6.2.3-2 – Aerial image of I-795 Bridge at Neuse River, May 14, 2016 (Google Earth, 35.344 N, 78.027 W)


Fig. 6.2.3-3 – I-795 Bridge at Neuse River, looking down river (September 25, 2018, 35.3443 N, 78.0277 W)

Fig. 6.2.3-4 – I-795 Bridge at Neuse River (right image) looking downriver with bank scour ahead of bridge pilings, and (left image) view of upstream bank scour from bridge elevation (September 25, 2018, 35.3442 N, 78.0277 W)

Fig. 6.2.3-5 – I-795 Bridge at Neuse River, beneath western bridge approach, evidence of high water with stranded multiple large catfish (September 25, 2018, 35.3441 N, 78.0276 W)

6.2.4 US 701 Bridge at Cape Fear, Elizabethtown, NC

We visited the US 701 Bridge that crosses the Cape Fear River in Elizabethtown, NC (Fig. 6.2.4-1 for location on county map and Fig. 6.2.2-2 for pre-flood aerial) because of its proximity to a river bank slope that had started to slide toward the river. The bridge did not appear to be affected by the slope movements, which created numerous scarps and slope cracks of up to 1 to 2 ft in height and along a length of the slope in excess of 500 ft (Fig. 6.2.4-3 for location). We describe observations about the slope in Chapter 8.

The notable observation about the bridge was the large debris pile, which had collected against the bridge supports of the southbound lane of US 701. The debris pile could be seen in the September 18, 2018 aerial photograph (Fig. 6.2.4-3) and on September 26, 2018 when we visited (Fig. 6.2.4-4). The bridge supporting the southbound lane (upstream side) of US 701 was still closed on September 26.

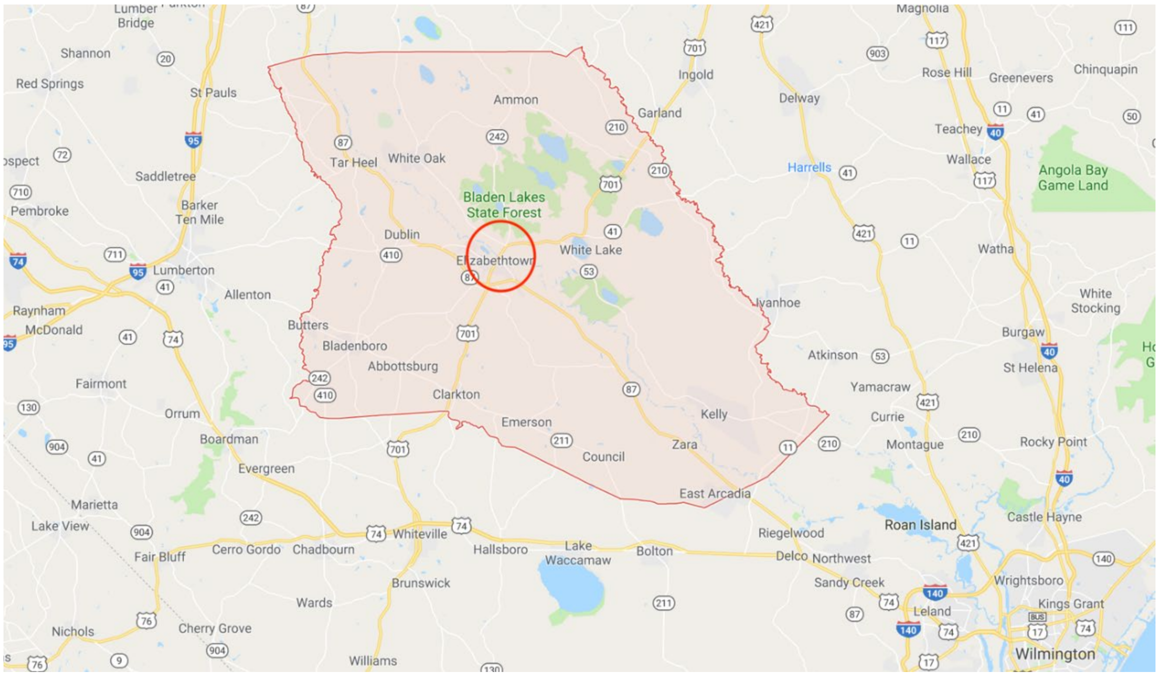

Fig. 6.2.4-1 – Bladen County, NC (Google Maps)

Fig. 6.2.4-2 – Aerial image of I-795 Bridge at Neuse River, March 4, 2018 (Google Earth, 34.632 N, 78.604 W)

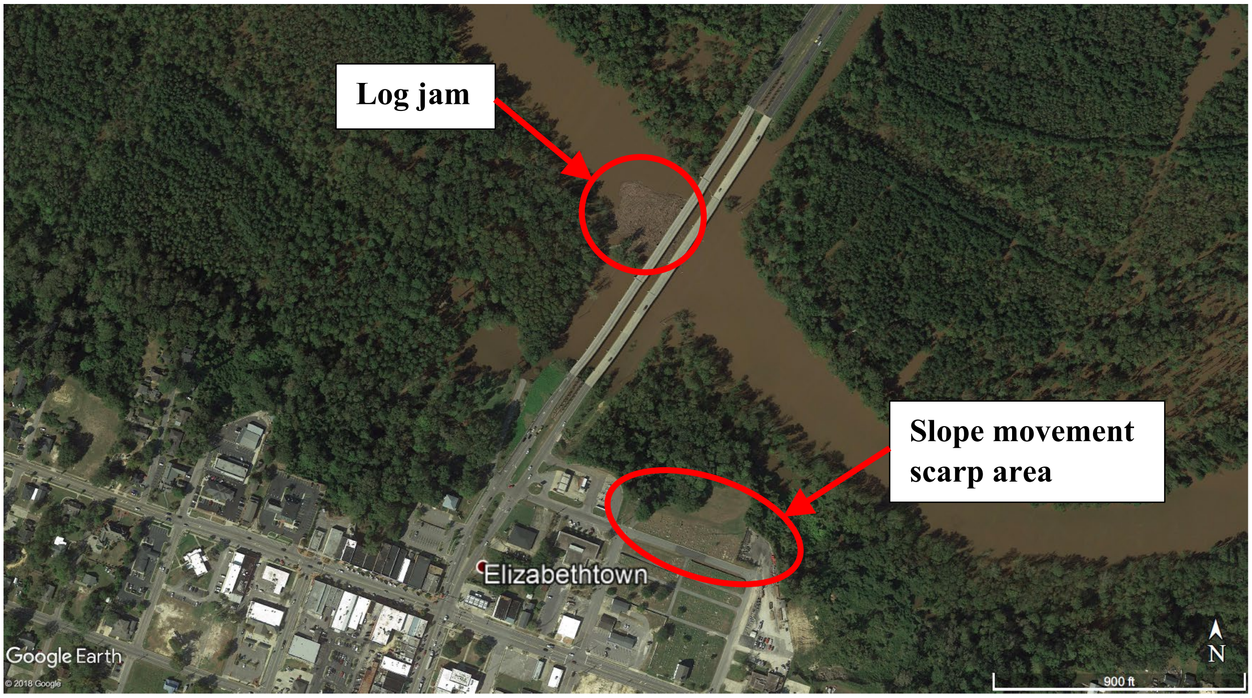

Fig. 6.2.4-3 – Aerial image of I-795 Bridge at Neuse River (Google Earth, September 18, 2018, 34.632 N, 78.604 W)

Fig. 6.2.4-4 – US 701 Bridge at Cape Fear in Elizabethtown, NC, looking north at the debris pile (September 26, 2018, 34.6321° N, 78.6036° W)

6.2.5 Davis River Road Bridge, Chesterfield County, SC

The West Team visited the Davis River Bridge in Chesterfield County, SC (Fig. 6.2.5-1) on September 25, 2018. The bridge carries Davies River Road over Jimmies Creek in the Pee Dee River Basin. The bridge was closed due to scour observed around the eastern bent (Fig. 6.2.5-2 and 6.2.5-3).

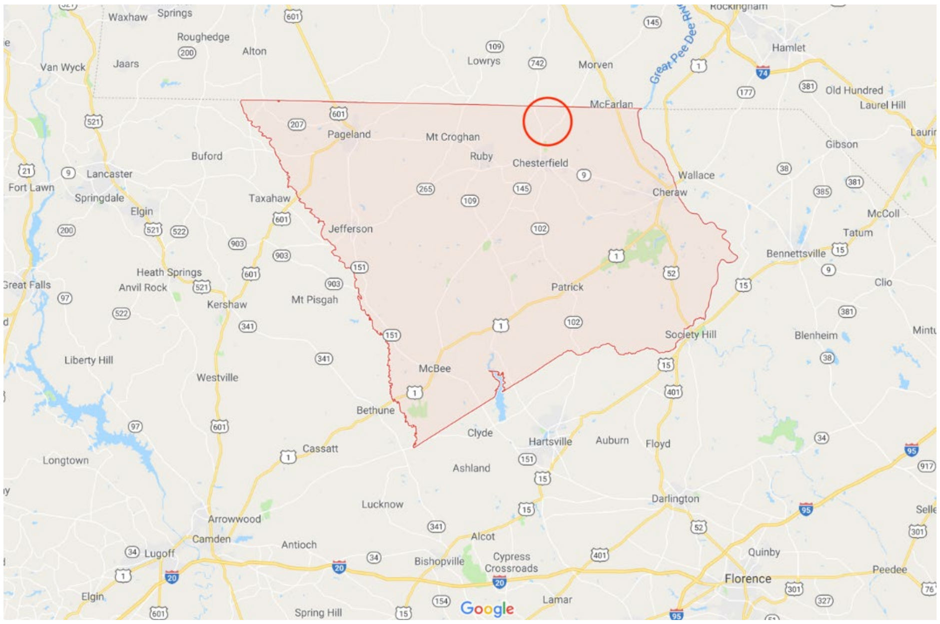

Fig. 6.2.5-1 – Chesterfield County, SC (Google Maps)


Fig. 6.2.5-2 – Davis Road Bridge looking south (September 25, 2018, 34.7883 N, 80.0802 W)

Fig. 6.2.5-3 – Davis Road Bridge scour hole (September 25, 2018, 34.7883 N, 80.0802 W)

6.2.6 H.F. Bell Bridge, Chesterfield County, SC

The West Team visited the H.F. Bell Bridge over Little Carr Creek in Chesterfield County, SC (Fig. 6.2.6-1 and Fig. 6.2.6-2), while traveling along SC9. The team stopped to document an extremely large debris pile that had collected at the bridge (Fig. 6.2.6-3). The bridge appears to have historically collected debris.

Fig. 6.2.6-1 – Chesterfield County, SC (Google Maps)

Fig. 6.2.6-2 – H.F. Bell Bridge (Google Earth, 34.7286 N, 80.0638 W)

Fig. 6.2.6-3 – H.F. Bell Bridge debris pile (September 25, 2018, 34.7286 N, 80.0638 W)

6.2.7 David's Millpond Bridge, Bennettsville, SC

The breach of David's Millpond Dam near Bennettsville, SC (see Section 4.2.11) caused significant scour of the bridge piles just downstream of the dam (Fig. 6.2.7-1 - location and Fig. 6.2.7-2 - aerial). The bridge deck settled on the order of 2 to 3 ft (Fig. 6.2.7-3). The depth of scour was approximately 11 ft and likely completely undermined the piles (Fig. 6.2.7-4). The bridge carried David's Millpond Road / State Road S-35-33 across Naked Creek.

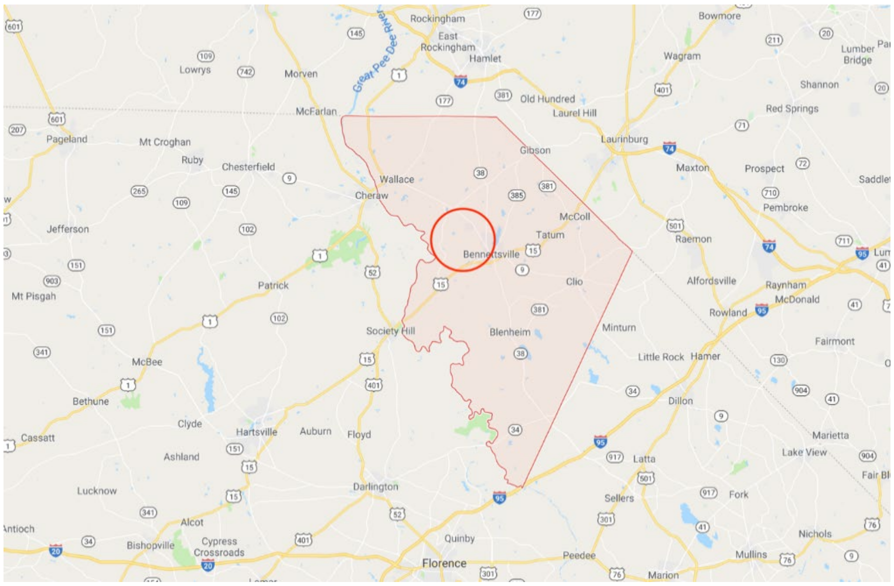

Fig. 6.2.7-1 – Marlboro County, SC (Google Maps)

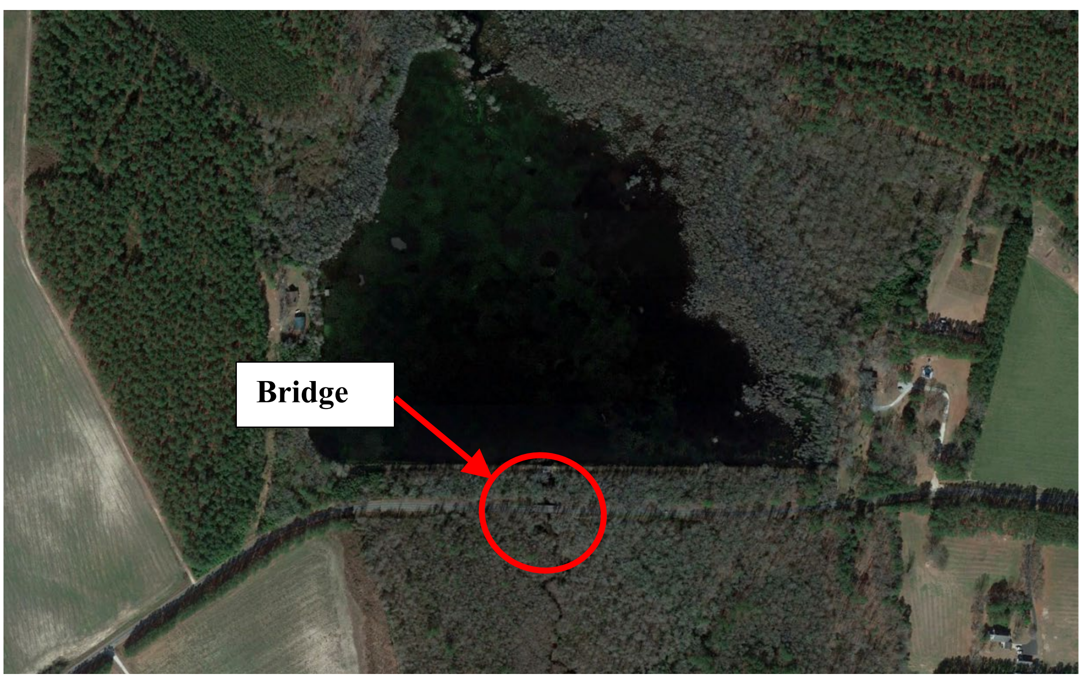

Fig. 6.2.7-2 –Aerial image of David's Mill Pond Bridge, February 18, 2017 (Google Earth, 34.6443 N, 79.7482 W)

Fig. 6.2.7-3 – David's Mill Pond Bridge deck subsidence (September 25, 2018, 34.6443 N, 79.7482 W)

Fig. 6.2.7-4 – David's Mill Pond Bridge pile settlement (September 25, 2018, 34.6443° N, 79.7482° W)

6.3 Roads

6.3.1 US 421 Wilmington washout by Cape Fear River, New Hanover County, NC

A section of US 421 north of Wilmington, in New Hanover County, NC (location - Fig. 6.3.1-1) was washed out by flow between two branches of the Cape Fear River. High water levels on the main branch of Cape Fear River on the southwest side of the highway overtopped the highway and created a breach or washout to the Northeast Cape Fear River on the northeast side of the highway (Figs. 6.3.1-2, -3). The foundation soil was significantly undermined and a large section of the roadway, estimated to be about 500 ft in length, was washed away (Fig. 6.3.1-4). Water was still flowing eastward across the site, and, based on highwater marks on the pavement, the peak flood water level reached a level about 6 ft higher than the observed water elevation at the time of our visit.

The sandy soil beneath the pavement eroded about 4.5 ft below the pavement elevation at the southern bank of the washout (Figs. 6.3.1-5 – 6.3.1-7). Additional erosion was observed further south of the washout on the northbound side of the road where the shoulder of the roadway was undermined as the flood water connected to an existing slough (Fig. 6.3.1-8).

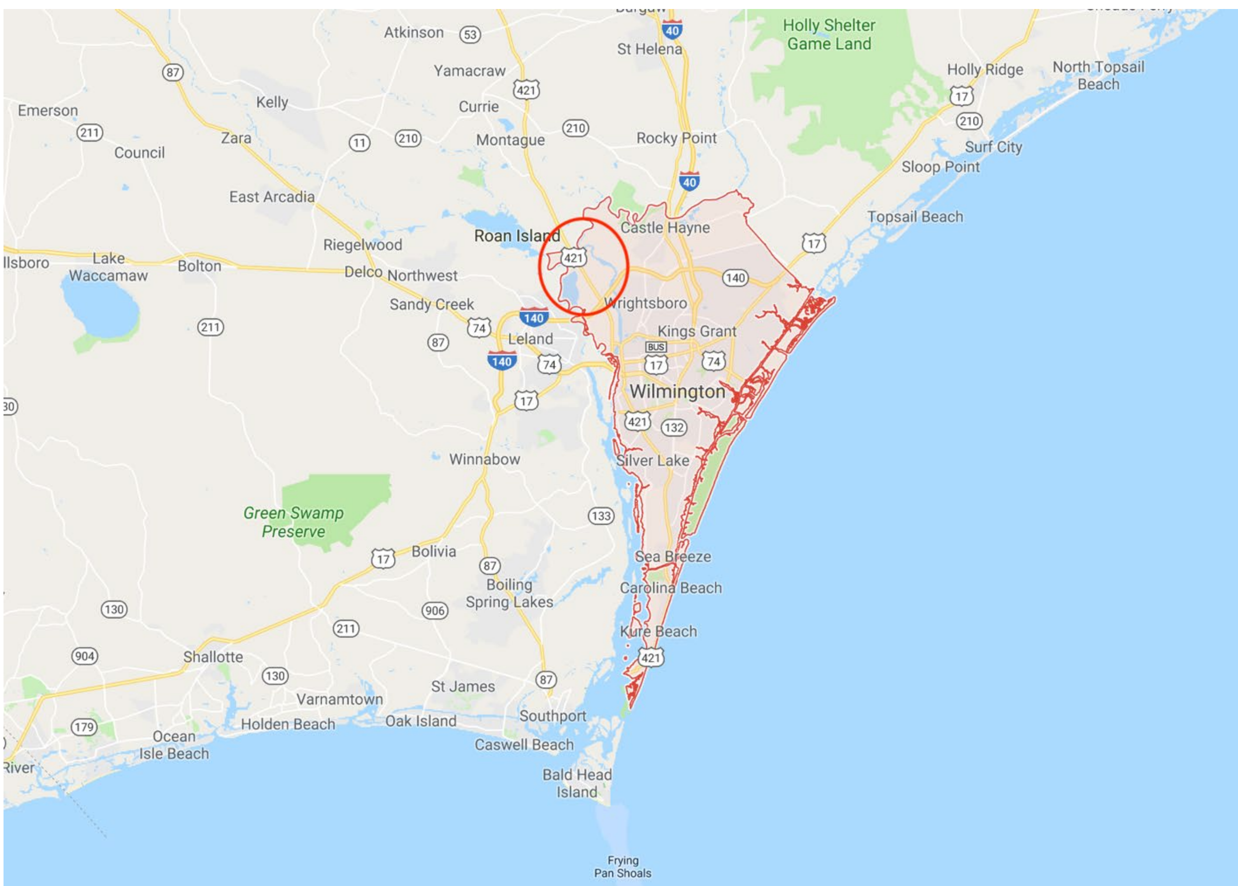

Fig. 6.3.1-1 – New Hanover County, NC (Google Maps)

Fig. 6.3.1-2 – Preflood aerial image of US 421 between Cape Fear River (river on left of image) and Northeast Cape Fear River (river on right of image); site of washout indicated by circle, October 29, 2016 (Google Earth, 34.331° N, 78.000 W)

Fig. 6.3.1-3 – Preflood aerial image of US 421 where the washout occurred (Google Earth, October 29, 2016, 34.331° N, 78.000 W)

Fig. 6.3.1-4 – US 421 washout by Cape Fear River, looking northwest across washout (September 26, 2018, 34.3308 N, 77.9996 W)

Fig. 6.3.1-5 – US 421 washout by Cape Fear River, looking northwest across washout, undermined roadway and foundation soil in foreground (September 26, 2018, 34.3304 N, 77.9993 W)

Fig. 6.3.1-6 – US 421 washout by Cape Fear River, looking northwest across washout, undermined roadway and foundation soil in foreground (September 26, 2018, 34.3306 N, 77.9995 W)

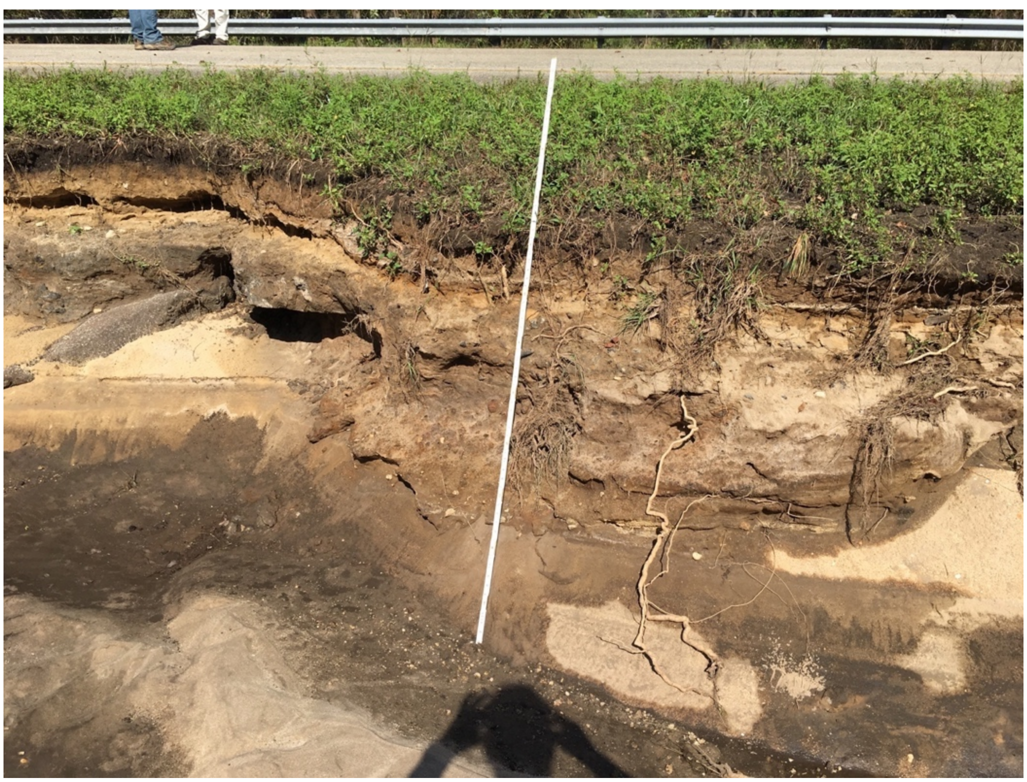

Fig. 6.3.1-7 – US 421 washout by Cape Fear River, about 4.5 ft of soil eroded, measured between the northbound and southbound lanes (September 26, 2018, 34.3306 N, 77.9995 W)

Fig. 6.3.1-8 – US 421 eroded by Cape Fear River flood water (September 26, 2018, 34.3306 N, 77.9993 W)

6.3.2 I-795 embankment slope failure, Goldsboro, NC

The East Team visited a section of I-795 US 421 north of Goldsboro, NC (Figs. 6.3.2-1) that was damaged due to an embankment slope failure (Figs. 6.3.2-2 through 6.3.2-4). The roadway embankment, estimated to be more than 20 ft high, was built across the flood plain of the Smith Mill Run stream, which is located at the toe of the slope and drains into the Little River and eventually into the Neuse River about 6 stream-flow miles / 3.3 straight-line miles south of the slope failure.

The slope failure appeared to have extended across the breakdown lane into the right lane of the highway a distance of about 15 ft from the top of slope. The slope failure had been repaired at the time of our visit and the highway restoration was underway. Road runoff had eroded a significant gully just south of the slope failure (Fig. 6.3.2-5), which was indicative of the rainfall intensity in the area. Contributing factors to the failure could have included saturated soil conditions, varying or perched pore pressures in the embankment soils, which include a range of silty and clayey sands, foundation soil conditions, or effects from the rise and drawdown of the adjacent stream.

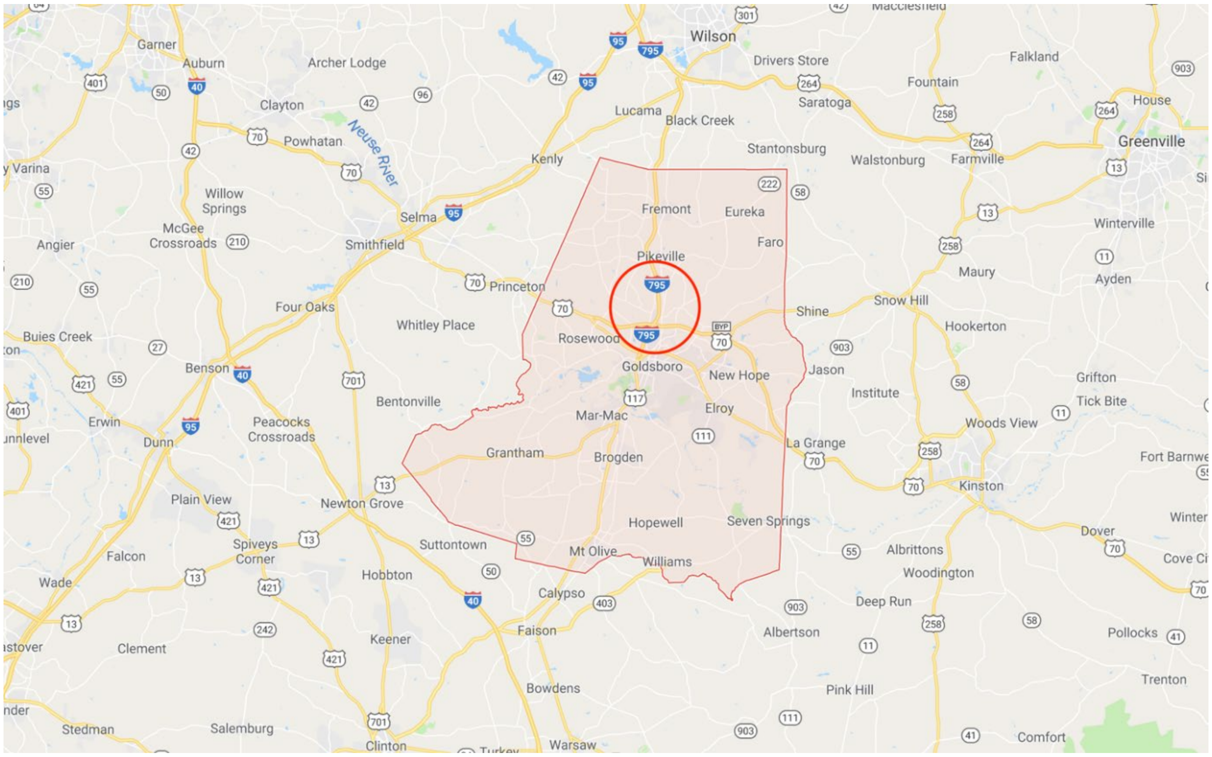

Fig. 6.3.2-1 – Wayne County, NC (Google Maps)

Fig. 6.3.2-2 – Preflood aerial image of I-795, October 25, 2016 (Google Earth, 35.4201 N, 77.9976 W)

Fig. 6.3.2-3 – I-795 slope failure at northbound lane (September 25, 2018, 35.4201 N, 77.9976 W)

Fig. 6.3.2-4 – I-795 slope failure at northbound lane (September 25, 2018, 35.4201 N, 77.9976 W)

Fig. 6.3.2-5 – Erosion gully immediately south of slope failure (September 25, 2018, 35.4199 N, 77.9980 W)

6.3.3 SC 145 Culvert Washout Location 1 East, Chesterfield, SC

The West Team travelled Highway 145 in Chesterfield County, SC, about 0.1 mile south of the NC-SC border (Fig. 6.3.3-1) and stopped at a repair of a highway washout. One lane of the road embankment (downstream side) had been washed out at a box culvert crossing of a tributary of Westfield Creek. The washout was likely caused by overtopping of the embankment.

Fig. 6.3.3-1 – Chesterfield County, SC (Google Maps)

Fig. 6.3.3-2 – Failed culvert off SC 145 Location 1 East with repairs (September 25, 2018, 34.8090 N, 80.0432 W)

6.3.4 SC 145 Culvert Washout Location 2 West, Chesterfield County, SC

The West Team also visited a second site along Highway 145 in Chesterfield County, SC (Fig. 6.3.3-1) about 3 miles south of the previous site (Section 6.3.3). At this site, scour around a culvert at Jimmies Creek created a severe washout of the roadway. The Figure 6.3.4-1 image became viral after a social media post from the truck driver's wife. The site was under construction when the GEER Florence team visited on September 25, 2018 (Fig. 6.3.4-2).

Fig. 6.3.4-1 – Failed culvert off SC 145 Location 2 West (source WSOC TV)

Fig. 6.3.4-2 – Repairs to failed culvert off SC 145 Location 2 West (September 25, 2018, 34.7747 N, 80.0763 W)

6.3.5 Hedrick Haul Road, Anson County, NC

As noted in Section 4.2.14, the BV Hedrick Gravel & Sand mining facility in Lilesville, Anson County, NC suffered a dike failure, haul road embankment breach, and a train derailment (locations – Figs. 6.3.5-1 and -2). The derailment occurred on the upstream property of Oldcastle Stone Products, another mining company. We present information about the train derailment in Section 6.4.1.

B.V. Hedrick haul road was an elevated embankment that crossed the Hedrick Tailings Pond #1 / Recirculating Pond along the Island Creek floodway and may have been created by the mining operations. The haul road was not intended to be a water retaining structure and had 48-inch and 36-inch culverts to allow flow through the embankment. During the storm the 48-inch culvert became plugged, and 36-inch culvert did not have sufficient capacity to discharge flood flows., We understand that flood water overtopped and breached the road embankment around 4:30 PM on September 17, 2018 (Figs. 6.3.5-3, -4, -5), causing the Tailings Pond #1 to overtop and breach. Upstream releases or breaches from holding ponds may have contributed to the flood flows.

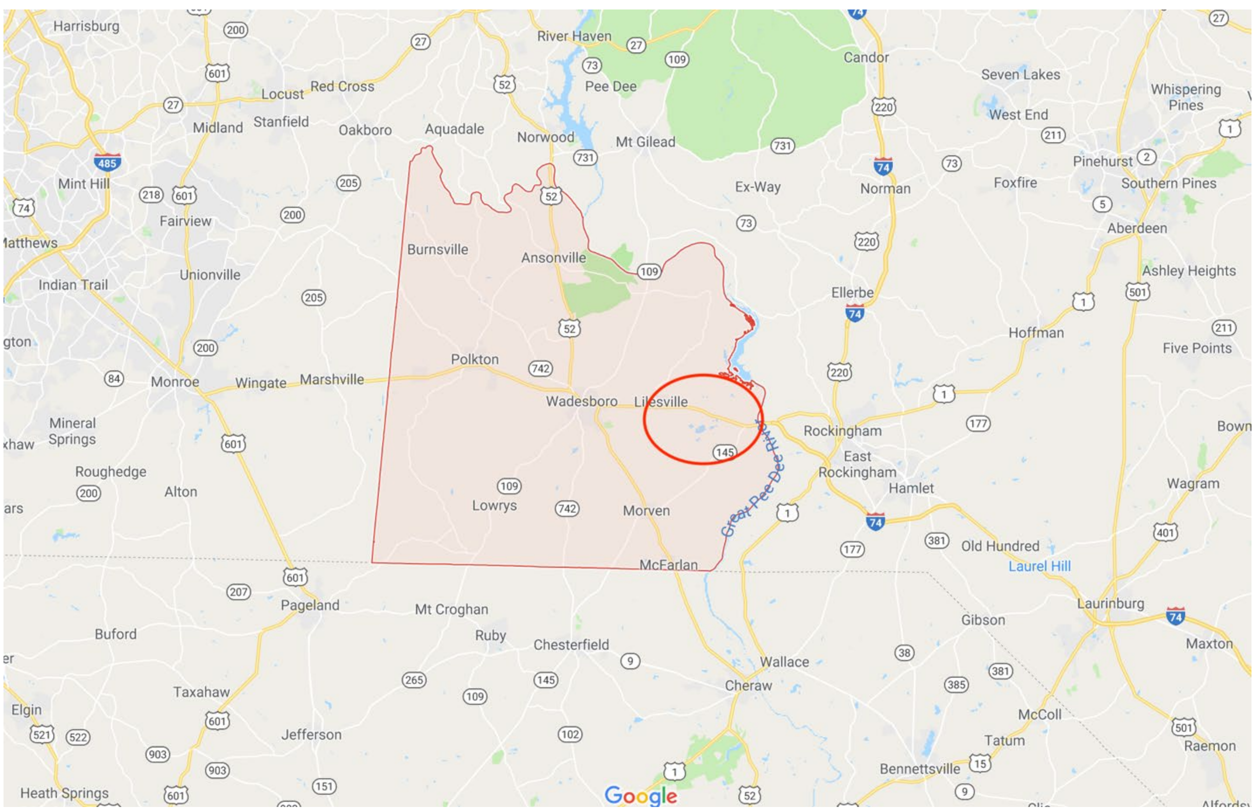

Fig. 6.3.5-1 – Site location, Anson County, NC (Google Maps)

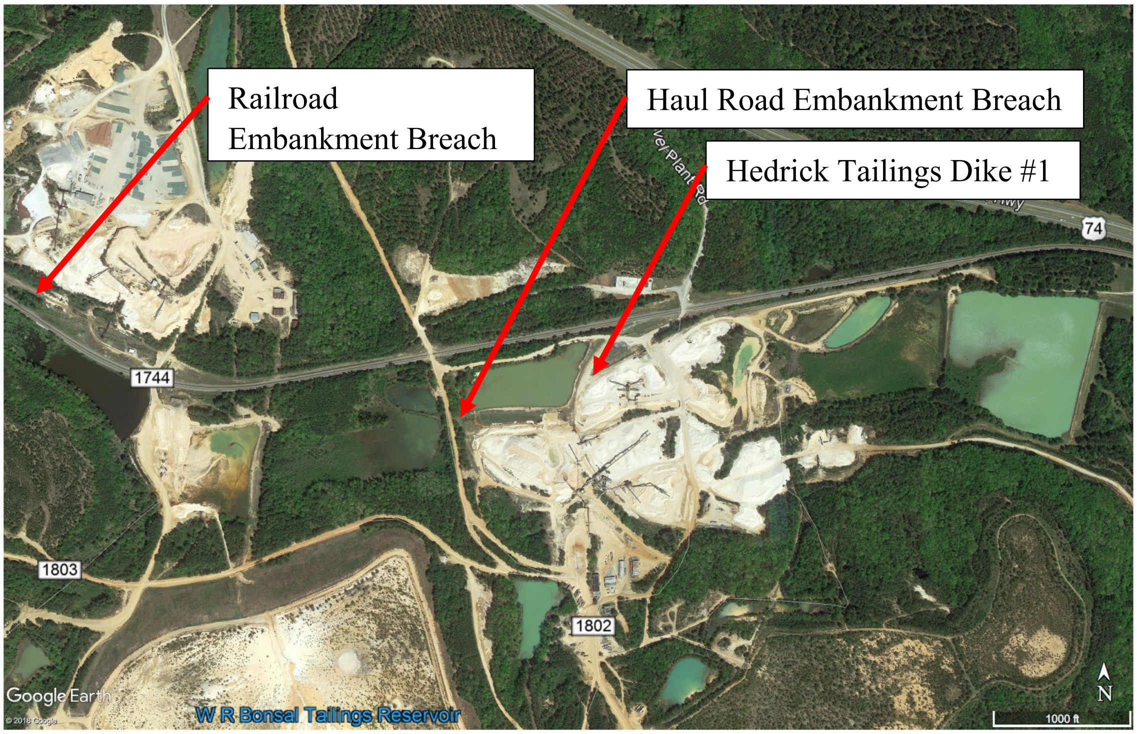

Fig. 6.3.5-2 – Aerial view, BV Hedrick Gravel & Sand (Google Earth, April 20, 2018, 34.95 N, 79.93 W)

Fig. 6.3.5-3 – B.V. Hedrick Haul Road breach looking downstream towards the Tailings Pond # 1 / Recirculating Pond (September 24, 2018, 34.950 N, 79.935 W)

Fig. 6.3.5-4 – Hedrick Haul Road breach (September 24, 2018, 34.950 N, 79.935 W)

Fig. 6.3.5-5 – Hedrick Haul Road (September 24, 2018, 34.950 N, 79.935 W)

6.3.6 US 15-501 Highway Repair

We visited the site of a combined railroad and road washout at a railroad crossing along US 15-501 in Laurinburg, NC, which we describe in Section 6.4.2.

6.3.7 David's Millpond Road

The West Team observed two road damage locations near David's Millpond Dam – a bridge immediately downstream of the dam that had settled due to pile scour and a culvert-crossing road washout 0.5 mile east of the dam. We describe these in Section 4.2.11.

6.3.8 US-95 roadside repair, Lumberton, Robeson County, NC

GEER Florence team visited Lumberton, NC on September 27, 2018. While driving on Crystal Road along the southeast side of I-95 (Figure 6.3.8-1), we observed a repair (Fig. 6.3.8-2) of the I-95 embankment southeast slope. At the time the team was traveling between a temporary closure levee constructed under the I-95 overpass bridge and the permanent levee to the east. The road damage was at the 18-mile marker along the south side of the I-95 embankment near a roadside drainage gutter and catch basin (Fig. 6.3.8-3). We expect that the highway catch basin did not have the sufficient capacity for stormwater flow running down the highway, which slopes down to the east from the overpass bridge, and that storm water on the road poured over and eroded the embankment slope. Gravel was placed in the area as a temporary protection and repair. The embankment damage did not appear to extend to the roadway.

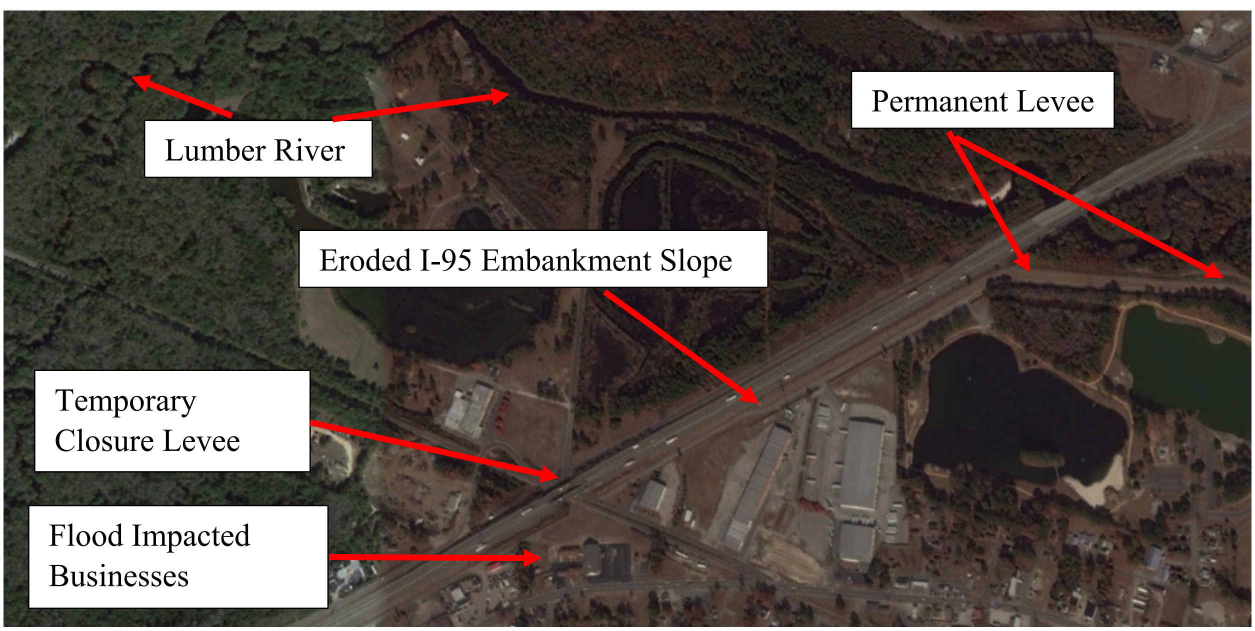

Fig. 6.3.8-1 – Aerial image of US-95 18-mile marker, November 2013 (Google Earth, 34.629 N, 79.036 W)

Fig. 6.3.8-2 – Damaged slope and dumped gravel for repair, (September 27, 2018, 34.6289 N, 79.0361 W)

Fig. 6.3.8-3 – US-95 looking Northeast, marker 18 and catch basin, (September 27, 2018, 34.6289 N, 79.0361 W)

6.4 Railroads

6.4.1 Old Castle/Bonsal CSX Derailment

A CSX train derailed on the evening of September 16, 2018 in Anson County, NC (Fig. 6.4.1-1), just to the west of the Hedrick Tailings Dike #1 failure described in Section 4.2.114 and the road embankment failure described in Section 6.3.5. The train was transporting recently refurbished locomotives to Hamlet, NC, and derailed on the Old Castle/Bonsal property, another gravel mining operation immediately west of the BV Hedrick Gravel & Sand operation. The aerial photo from Google Maps (Fig. 6.4.1-2) shows the proximity of the derailment to the Hedrick Tailings Dike and the haul road embankment failures.

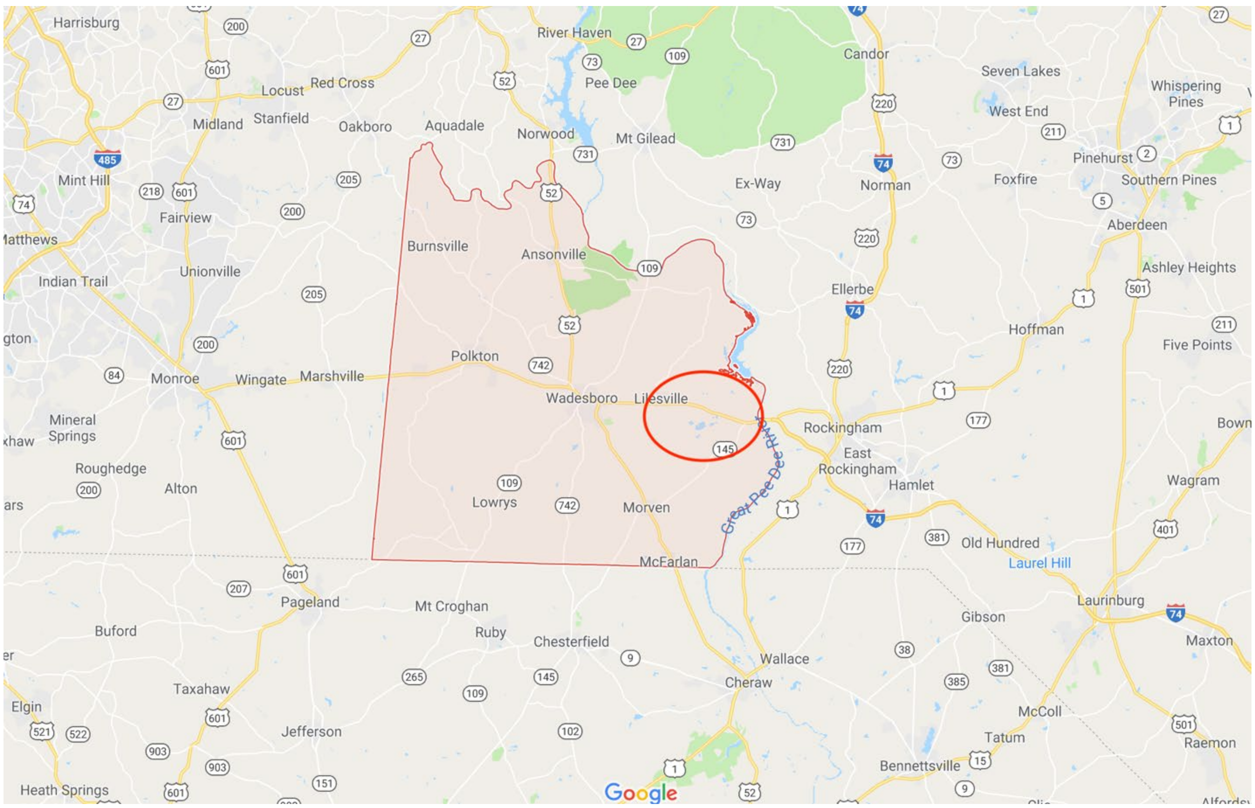

Fig. 6.4.1-1 – Anson County, NC (Google Maps)

The team was unable to access the site, but the derailment was well documented by WSOC from Charlotte, NC. The GEER team walked the railroad just to the east of the Old Castle/Bonsal property. The derailment site tracks were located on the north side of a pond impounded by the Bonsal Tailings Dam along Island Creek. It appears from the April 20, 2018 Google imagery that there had been a significant ballast repair immediately east of the derailment site (Fig. 6.4.1-3). Aerial photographs (Figs. 6.4.1-4, 6.4.1-5) after the storm show significant erosion of the ballast in that section.

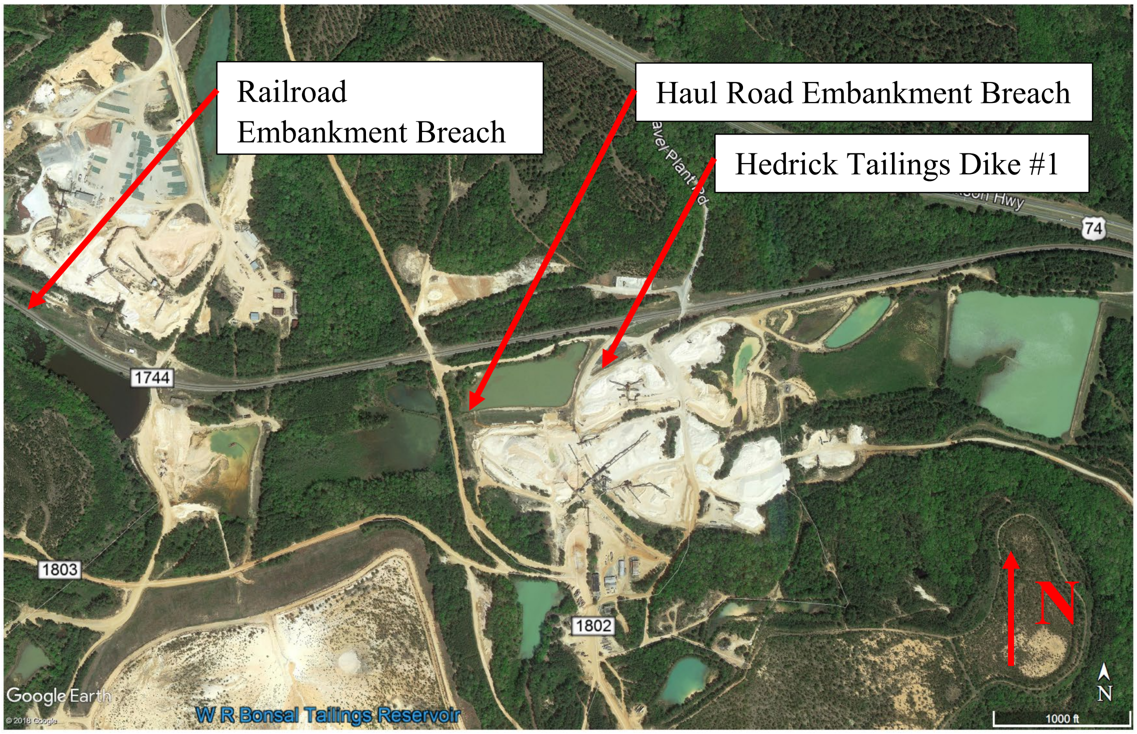

Fig. 6.4.1-2 – Aerial view, failure sites along Island Creek (Google Earth, April 20, 2018, 34.950 N, 79.937 W)

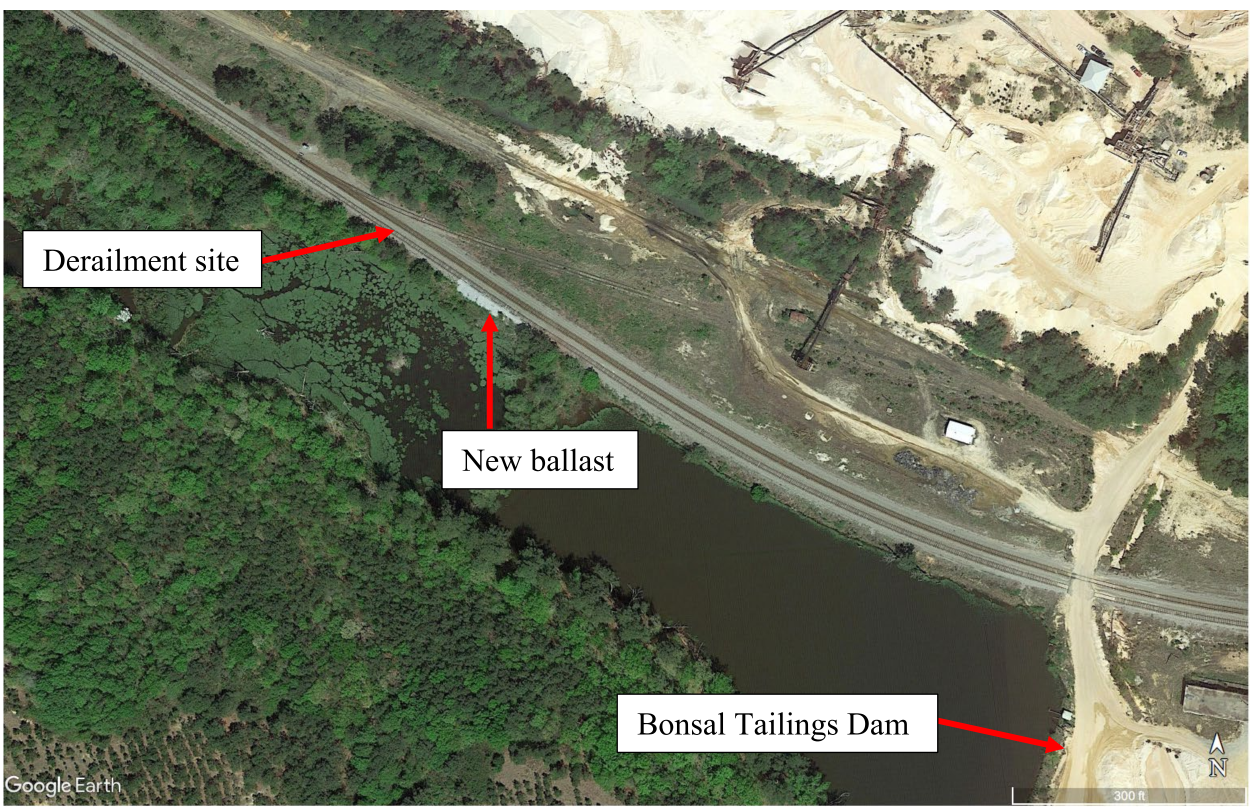

Fig. 6.4.1-3 – Aerial view, Old Castle/Bonsal train derailment site (Google Earth, April 20, 2018, 34.9513 N, 79.9446 W)

Fig. 6.4.1-4 – CSX Train Derailment (WSOC-TV, September 17, 2018, 34.9511 N, 79.9443 W)

Fig. 6.4.1-5 – CSX Train Derailment (WSOC-TV, September 17, 201834.9511 N, 79.9443 W)

The pool of the Bonsal Tailings Dam impoundment just south of the railroad was elevated after the storm and continued to drain for several days. The water released by the dam was the event that triggered failure of the Hedrick Haul Road and the Hedrick Tailings Dike. Figures 6.4.1-6 through 6.4.1-8 show the impoundment, dam, and drainage in relation to the derailment.

Fig. 6.4.1-6 – CSX Train Derailment (WSOC-TV, September 17, 2018, 34.9511 N, 79.9443 W)

Fig. 6.4.1-7 – CSX Train Derailment (WSOC-TV, September 17, 2018, 34.9511 N, 79.9443 W)

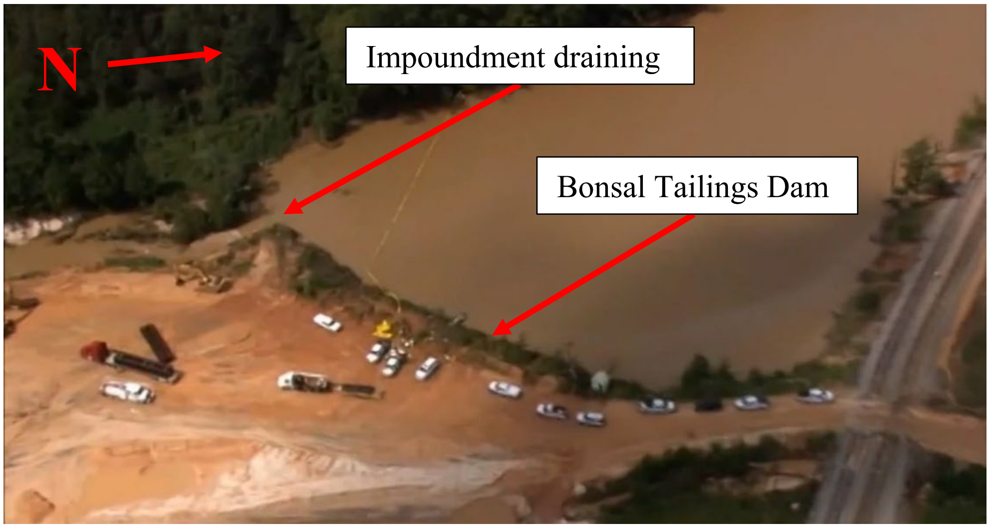

Fig. 6.4.1-8 – Bonsal Tailings Dam draining (WSOC-TV, September 17, 2018, 34.9494 N, 79.9418 W)

In total, nine locomotives and five rail cars derailed in the incident. By the time the GEER team visited the site on Monday, September 25, CSX had established a mobile command center and was working to clear the rolling stock and repair the main line. Rail traffic was diverted to a side track. Fig. 6.4.1-9 shows the impact of the derailment on the train and the recovery effort.

Fig. 6.4.1-9 – CSX Train Derailment aftermath (WSOC-TV, September 17, 2018, 34.9513 N, 79.9446 W)

Possible causes for the derailment include reduced bearing capacity or embankment stability due to the high water, groundwater flow and associated internal erosion, embankment scour, and overtopping erosion. The embankment appeared to fail to the south side abutting the west end of the impoundment based on the soil fan or failure mass on that side of the tracks.

6.4.2 CSX Rail Culverts and Embankments, Laurinburg/East Laurinburg, Scotland County, NC

The CSX rail lines in the Laurinburg / East Laurinburg area of Scotland County, NC (Fig. 6.4.2-1) cross Leith Creek in numerous locations and suffered washouts at four or more of these crossings. GEER teams visited four locations along the CSX line where repairs were either underway or had been performed (Fig. 6.4.2-2). We have labelled the washout locations with the nearest road or feature.

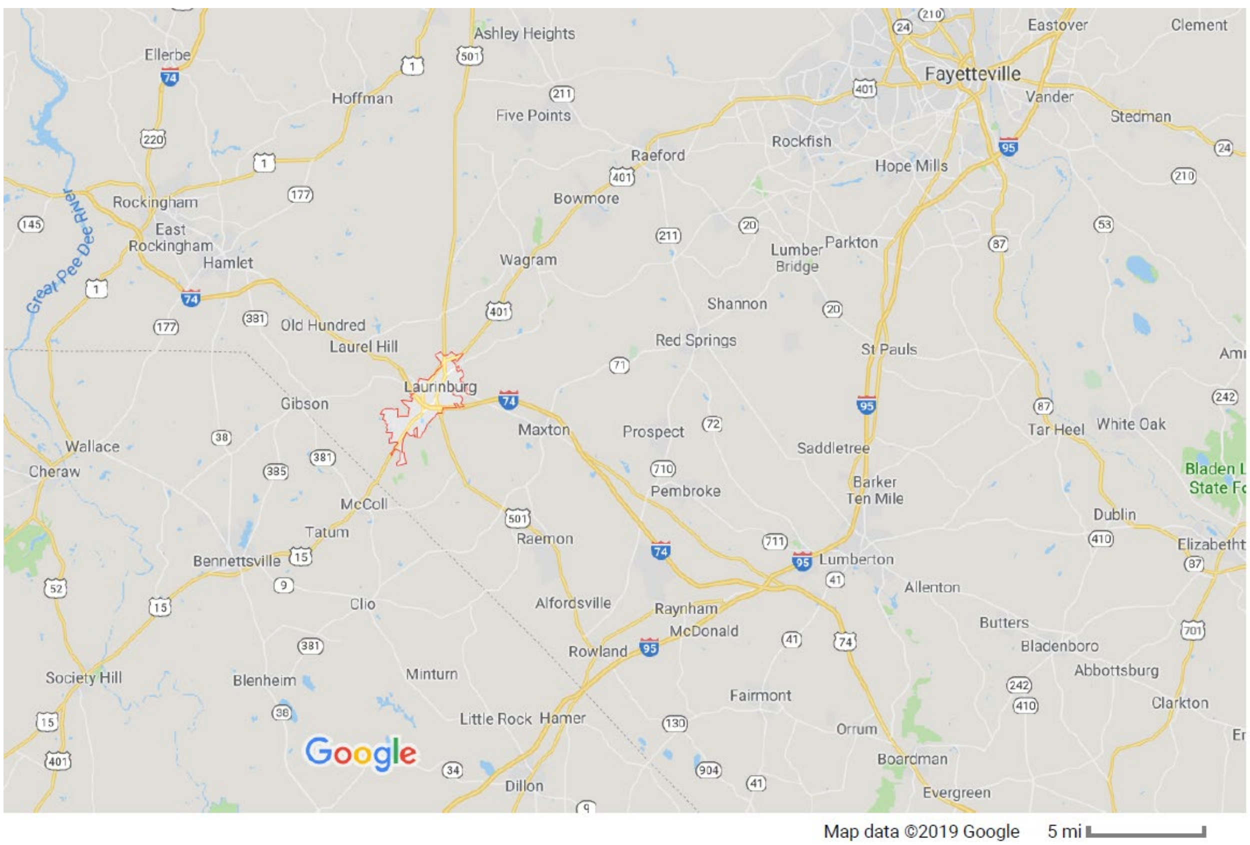

Fig. 6.4.2-1 – Laurinburg location (Google Maps)

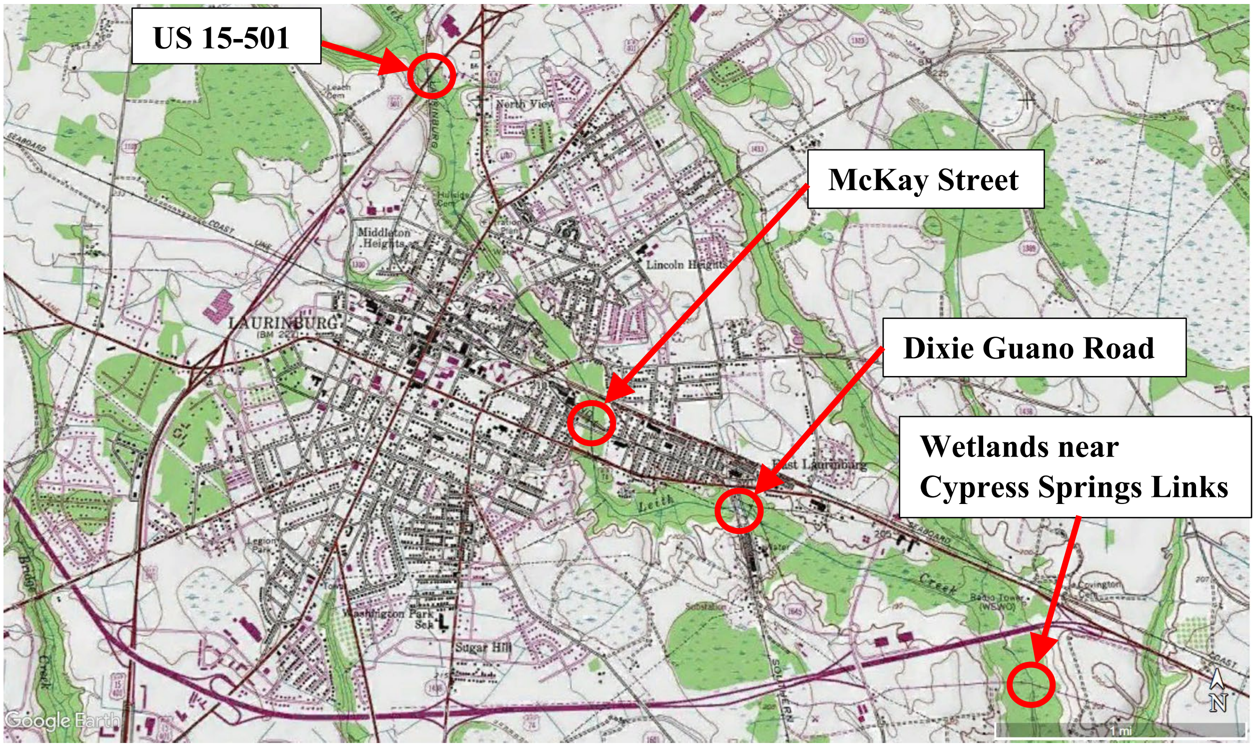

Fig. 6.4.2-2 – Rail line flood damage observation locations, Laurinburg / East Laurinburg, Scotland County, NC (Google Earth with USGS map overlay)

US 15-501 Site Washout - The washout at US 15-501was the location of two Leith Creek culverts, one beneath the highway and one below the CSX rail line. The embankment on both sides of the rail line culvert on the west side of US15-501 was washed away (Figs. 6.4.2-3 and -4). There was also significant damage to the ballast on the east side of US 15-501 and, based on the pavement repairs, damage to the highway (Fig. 6.4.2-5).

Fig. 6.4.2-3 – Rail line washout and repair at US 15-501 (September 27, 2018, 34.7936 N, 79.4619 W)

Fig. 6.4.2-4 – View of US15-501 and rail culverts looking south (September 25, 2018, 34.7936 N, 79.4619 W)

Fig. 6.4.2-5 – Washout and partial repairs northbound of US 15-501 looking south (September 25, 2018, 34.7930 N, 79.4621 W)

<u>McKay Street Site Washout</u> – The rail line crosses Leith Creek again just north and upstream of McKay Street. Leith Creek in this area forms the boundary between Laurinburg and East Laurinburg. The washout at this location was at a culvert crossing and, based on the new ballast to the east, washed out the embankment over a length of about 400 ft, most likely due to overtopping (Figs. 6.4.2-6, -7). The downstream culvert road crossing at McKay Street did not wash out, possibly because the rail line culvert prevented significant debris from reaching the McKay Street culverts (Fig. 6.4.2-8).

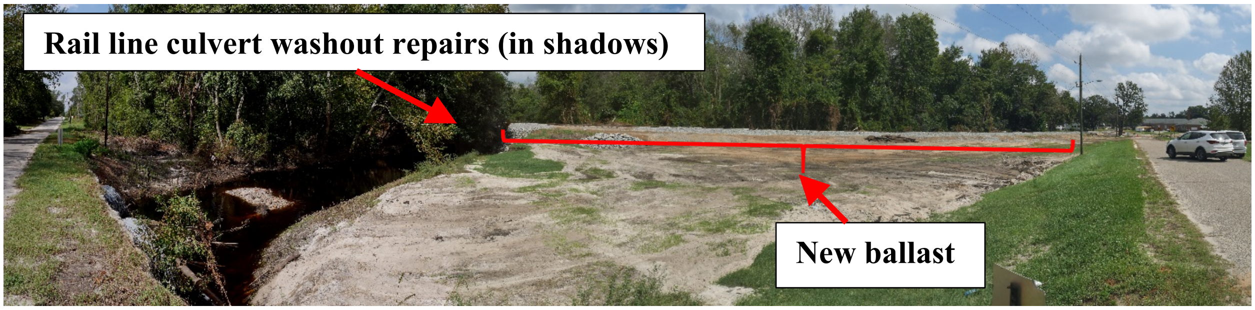

Fig. 6.4.2-6 – Looking upstream from McKay Street toward rail line (September 27, 2018, 34.7713 N, 79.4495 W)

Fig. 6.4.2-7 – Looking upstream from the rail line culvert crossing (September 27, 2018, 34.7717 N, 79.4495 W)

Fig. 6.4.2-8 – Looking downstream across rebuilt rail line embankment toward the McKay Street culvert crossing (September 27, 2018, 34.7717 N, 79.4495 W)

Dixie Guano Road Site Washout – Leith Creek also washed out the rail line stream crossing just to the east of Dixie Guano Road in East Laurinburg (Fig. 6.4.2-9). Flood flows downstream (west) also eroded ballast and the side of the road next to the rail line crossing of Dixie Guano Road (Fig. 6.4.3-10).

Fig. 6.4.2-9 – Rebuilt rail line crossing of Leith Creek east of Dixie Guano Road (September 27, 2018, 34.7665 N, 79.4391 W)

Fig. 6.4.2-10 – Erosion on upstream side of Dixie Guano Road looking south on north side of Leith Creek (September 27, 2018, 34.7671 N, 79.4389 W)

<u>Cypress Springs Links Wetland Site Washout</u> – The most downstream rail line washout that we visited was west of the Cypress Springs Links in a wetlands area east of Laurinburg (Figs. 6.4.2-11 and -12). Like two of the other rail line crossings, repairs had been performed prior to our visit.

Fig. 6.4.2-11 – Looking east across the Leith Creek crossing repair in the Cypress Springs Links wetland (September 27, 2018, 34.7665 N, 79.4188 W)

Fig. 6.4.2-12 – Looking west across downstream side of Leith Creek crossing in the Cypress Springs Links wetland (September 27, 2018, 34.7564 N, 79.4135 W)

6.4.3 Rail Line to Military Ocean Terminal Sunny Point

The failure of the Boiling Springs Lake Dam released large flood flows toward the Military Ocean Terminal Sunny Point rail line and bridge that was located about 250 ft downstream of the dam. Refer to our write up in Section 4.2.1 for more information.

6.4.4 Rail Line / I-85 Underpass and Temporary Closure Structure

The VFW Road and a rail line pass under the I-85 embankment on the northwest side of Lumberton. The underpass is a gap in the protection that the I-85 embankment provides between south Lumberton and the Lumber River. Failure of the temporary closure structure / levee in this gap resulted in flooding of Lumberton. At the time of our visit on September 27, 2018, the rail line at this location appeared to be intact and ready for traffic with no trace of either damage or temporary levee remnants. Refer to our write-up in Chapter 5 concerning the Lumberton Levee for more information.

References

Google Earth aerial photography, various dates.

Google Maps, selected areas. https://www.google.com/maps.

WSOC-TV (2018). Chopper 9 flies over Anson County CSX train derailment. September 17. https://www.wsoctv.com/video?videoId=836198913&videoVersion=1.0

7. Coastal and Waterfront

7.1 Overview

The eye of Hurricane Florence made landfall in New Hanover County between Wrightsville and Carolina Beaches. However, the first effects of Hurricane Florence were along the Cape Lookout and Crystal Coast area, then, subsequently, the Onslow County Beaches and eventually New Hanover. While the eye of the storm stayed offshore to the south of the beaches, there was significant sound side surge due to rising water in the sounds and wind driven waves. As with the effects documented in previous chapters, the more acute impacts were along the waterfronts along rivers upstream of the area. New Bern, in Craven County about 45 miles to the north, is situated along the Neuse River and received significant impact to structures due to the storm surge. Many of the coastal and waterfront communities to the south of the Cape Lookout area incurred significant structural damage due to wind and storm surge. However, there was minimal geotechnical damage documented. This chapter documents observations of impacts in Carteret, Craven, New Hanover, and Craven Counties.

7.2 Carteret County, NC

The path of Hurricane Florence brought heavy rains and winds from the north to the Crystal Coast communities in Carteret County. As shown on Fig. 3.1-1, rainfall totals from Hurricane Florence in the Carteret County Area were between 20 and 30 inches. The communities of Atlantic Beach, Pine Knoll Shores, Indian Beach, and Emerald Isle are all situated on a east-to-west-oriented barrier island separated from the mainland by Bogue Sound. All along the island, there was significant damage to structures situated on the sound side. The GEER team visited two locations in Carteret County, the Washington Street Residence and the Iron Steamer Pier mapped in Fig.7.2-1.

7.2.1 Emerald Isle/Washington Street Residence

The Washington Street residence that we visited was located on the sound side of the barrier island. Many sound side homeowners constructed seawalls to increase their shoreline acreage (Fig.7.2.1-1). The retaining structure at the Washington Street residence was 80% destroyed (Fig.7.2.1-2 and Fig.7.2.1-3). The failure mode appeared to be erosion from overtopping. The wall failed into the sound due to the combination of hydrostatic pressure and wave action.

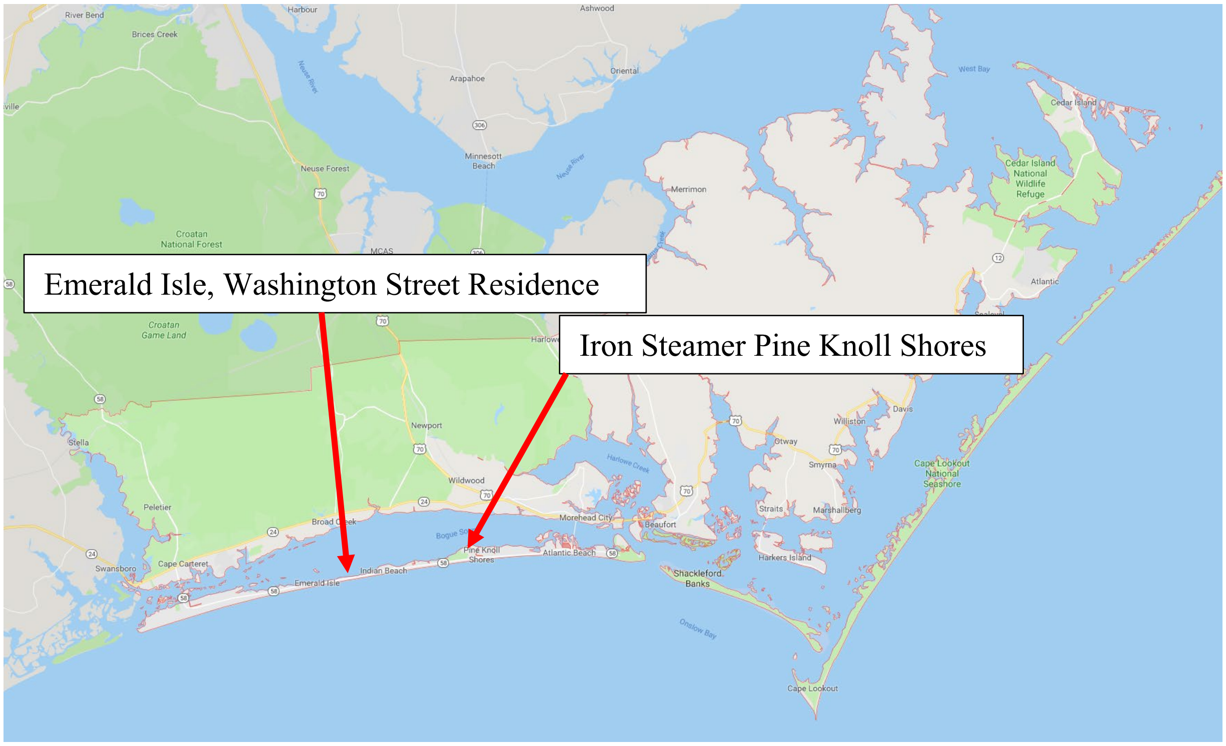

Fig. 7.2-1 – Emerald Isle Washington Street Residence before hurricane (Google Earth, February 9, 2017, 34.68 N, 76.93 W)

Fig. 7.2.1-1 – Emerald Isle Washington Street residence before hurricane (Google Earth, February 9, 2017, 34.6822 N, 76.9280 W)

Fig. 7.2.1-2 – Emerald Isle Washington Street residence after Florence (NOAA, September 17, 2018, 34.6822 N, 76.9280 W)

Fig. 7.2.1-3 – Emerald Isle Washington Street residence failure looking west (September 27, 2018, 34.6822 N, 76.9280 W)

7.2.2 Pine Knoll Shores/Iron Steamer Pier

The Iron Steamer Pier was formerly located on the ocean side of the barrier island at the site of the wreck of the Civil War blockade runner SS Pevensey in Pine Knoll Shores, NC (Fig. 7.2.2-1-). An anchored concrete-panel seawall at the site failed due to overtopping and erosion of the wall backfill (Fig. 7.2.2-2). We saw no other damage around that structure save for beach erosion. The wall may be salvageable.

Fig. 7.2.2-1 – Iron Steamer public beach access (Google Earth, February 9, 2017, 34.6930 N, 76.8289 W)

Fig. 7.2.2-2 – Washed out seawall with anchors visible (September 27, 2018, N34.6930 N, 76.8289 W)

7.3 New Bern, Craven County, NC

New Bern in Craven County, has a long history as North Carolina's second oldest continuous European settlement and its colonial and first state capital, owing primarily to its coastal location off the Pamlico Sound at the confluence of the Neuse River from the northeast and the Trent River from the east (Fig. 7.3-1, -2). Unfortunately, the upriver narrowing of the sunken river channel of the Neuse River resulted in amplification of Florence's storm surge from the Pamlico Sound and the highest storm surge along the North Carolina coast.

The Trent River flows from west to east from a smaller drainage basin than the Neuse River. The blue outlines in Fig. 7.3-2 demarcate water bodies in the region. The hydrology of the upper Neuse River is described in Chapter 3, and Chapter 2 covers the storm surge hydrograph. As described in this section, the storm surge was responsible for the high level of flooding experienced by New Bern.

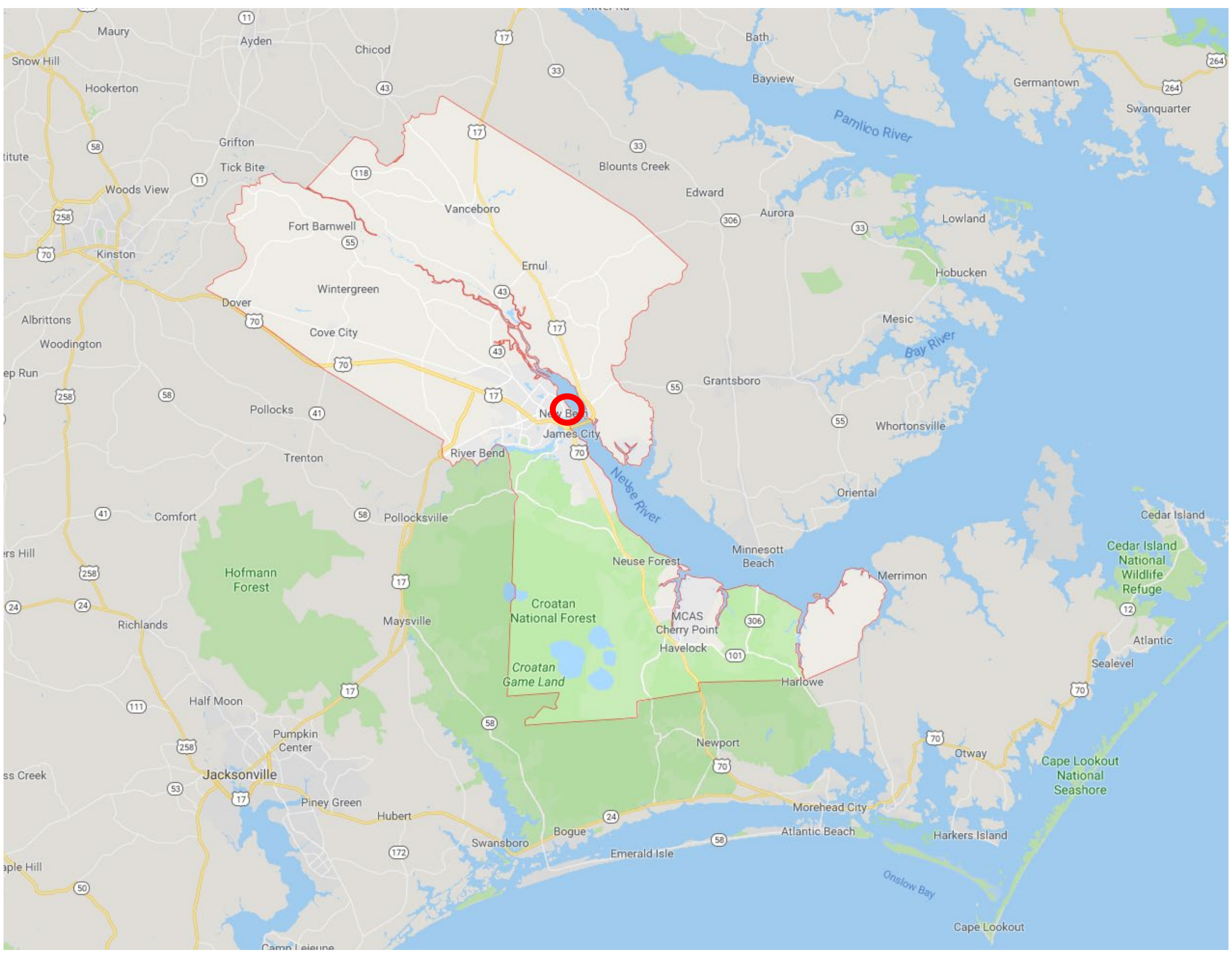

Fig. 7.3-1 – New Bern waterfront observations location, Craven County, NC (Google Maps, 34.105 N, 77.035 W)

Fig. 7.3-2 – New Bern and area water bodies, Craven County, NC (modified from Google Earth, December 30, 2014, 34.105 N, 77.035 W)

Fig. 7.3-3 shows the NC State DOT mapping of the 10-ft-elevation contour (red line) with high water observations reported during and after Hurricane Florence (blue symbols). The 10 ft elevation corresponds with the storm surge peak along the Neuse River and Trent River (see Fig. 7.3-4(a)-(b)). Consequently, the blue shading bounded by the red line and water bodies is an indication of severity of flooding in New Bern, NC. As shown by the mapping, most of the flooding in New Bern occurred to the north and south of the downtown area. The cause of flooding was the wind-driven storm surge from the Pamlico Sound moving up the narrowing mouth of the Neuse River.

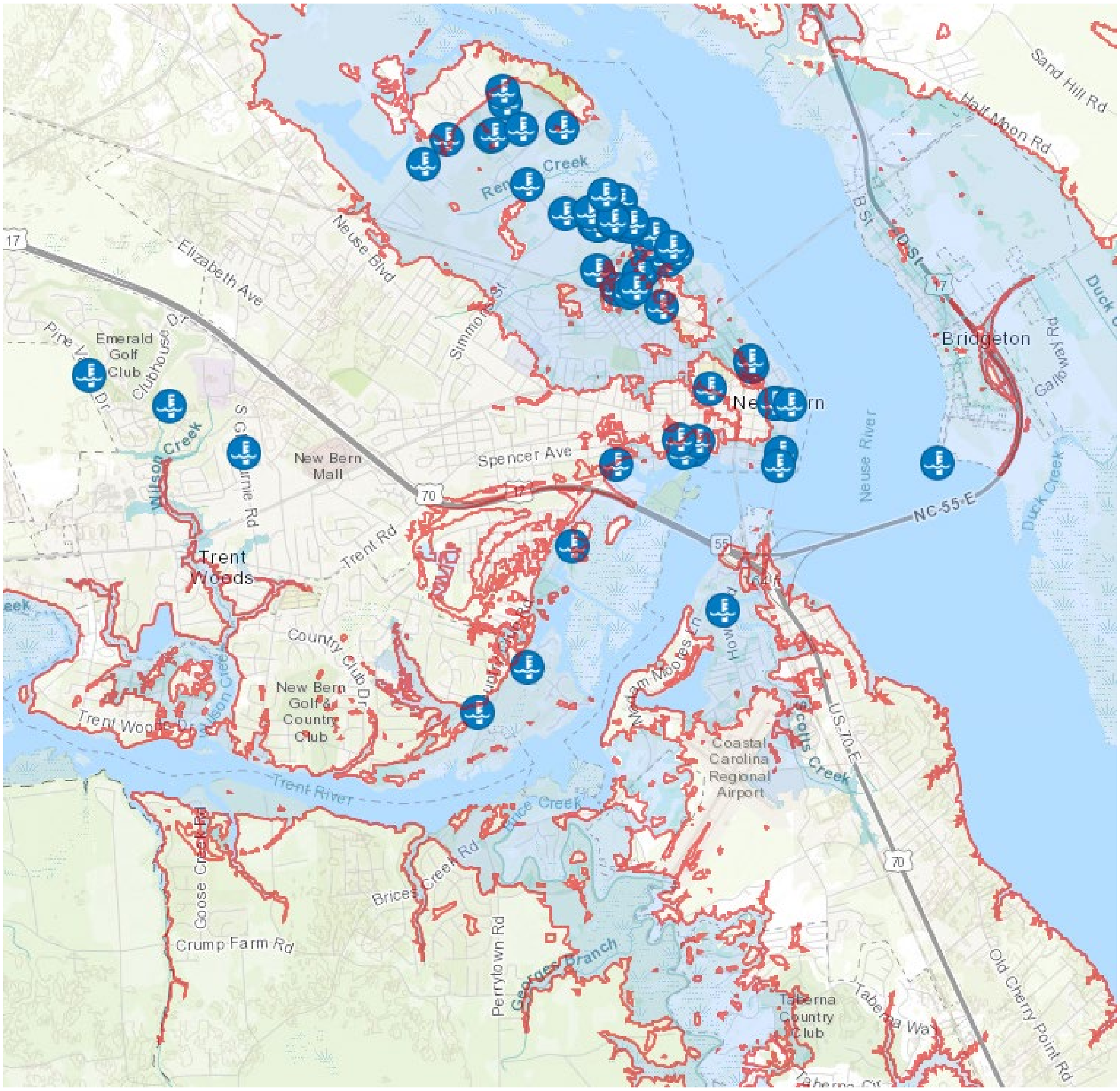

Fig. 7.3-3 - Overlay- high water observations (blue) and extent of flooding (red outline), New Bern, NC
(https://www.arcgis.com/apps/View/index.html?appid=158479a2afec4529836b67f7b91d2111)

Fig. 7.3-4(a) and (b) show that water levels increased from customary tidal conditions to peak surge in about 18 hours, i.e., a rise of 8 ft or ~0.45 ft/hr. The fall of the hydrograph occurred in stages. For example, the surge began to recede immediately after the peak water level and reached about 6 ft in elevation after 8 hours (0.75 ft/hr). Around mid-day on September 14 and early morning hours on September 15, the water levels remained at constant values. This may be explained by interactions between the receding surge, tidal cycle, rainfall, Neuse River, Palmico Sound, and Trent River. Based on the Fig. 7.3-4 data, approximately two days lapsed before water levels fell to the pre-Florence elevation of 2 ft. Nevertheless, the fall of the hydrograph occurred much slower than the rise and delayed recovery.

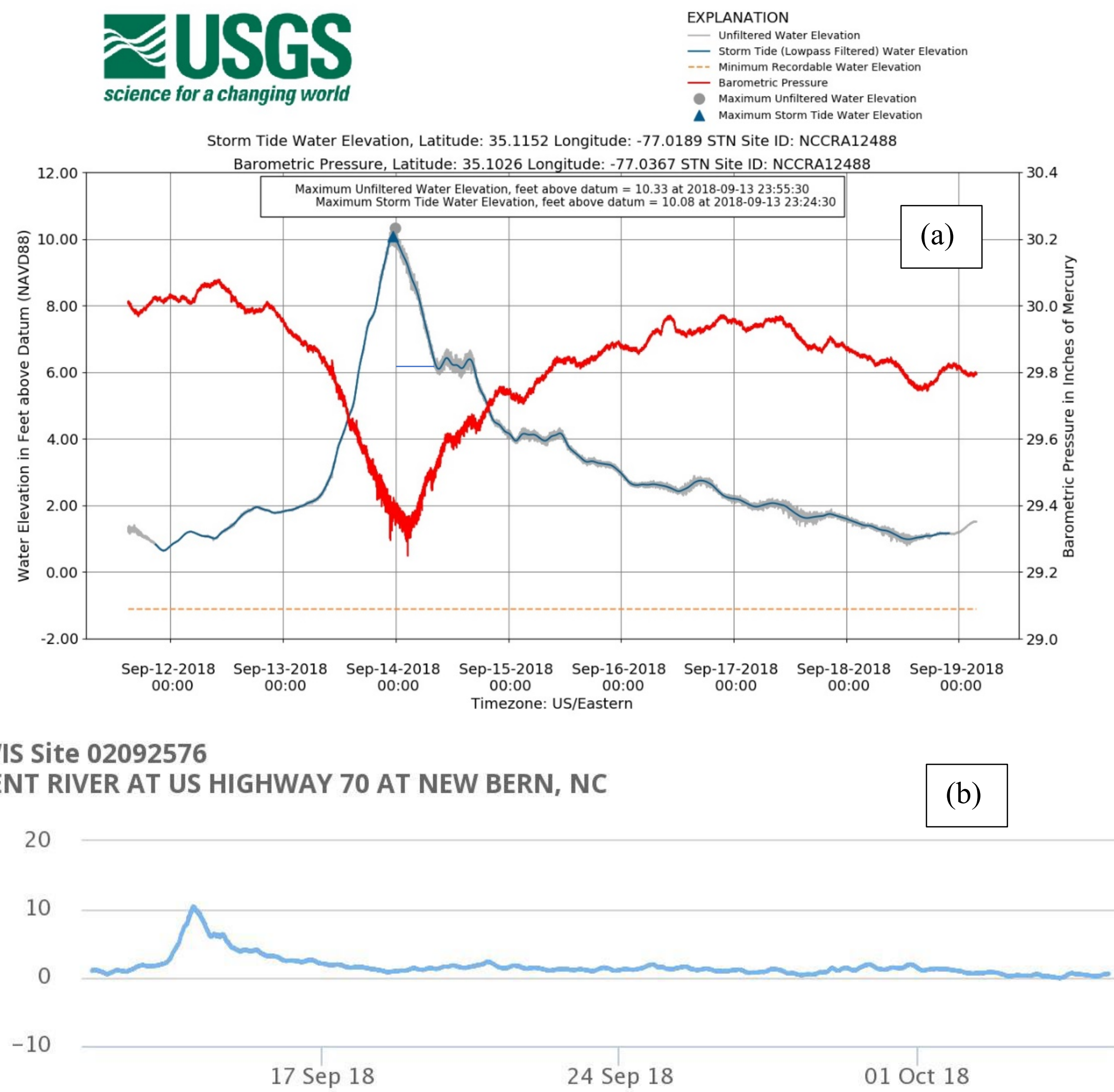

Fig. 7.3-4 - Hydrographs for New Bern, NC: (a) Neuse River, and (b) Trent River (https://stn.wim.usgs.gov/STNServices/Files/102258/Item https://stn.wim.usgs.gov/FEV/#FlorenceSep2018)

The GEER team arrived at New Bern on the afternoon of September 25, 2018. The team walked the downtown area and drove around the city documenting the effects of urban flooding. Fig. 7.3-5 shows the entrance to a locally owned business, where the depth of flooding was ~3.5 ft. Near the coast at the Union Point Park, the damage caused by high winds was evident from uprooted trees (Fig. 7.3-6) and downed a light pole (Fig. 7.3-7). Uprooted trees in the waterfront park resulted from a combination of factors – the force of the winds and waves and the shallow root system, possibly the result of brackish groundwater at the river's edge. Uprooted trees are typically important factors in disasters because they down power lines, hinder emergency responses by blocking roads, damage buildings and cars, and potentially injure or kill people. The understanding of tree uprooting will require better data collection, which will have value for predicting structure and infrastructure damage. Integrating structural (wind) and geotechnical teams with landscape architects could enhance that data collection and understanding.

Fig. 7.3-5 - Evidence of flooding to a relative depth of 3.5 ft in downtown New Bern, NC (September 25, 2018, 35.10484 N, 77.03856 W).

Fig. 7.3-6 - Evidence of tree uprooting near the shore (September 25, 2018, left: 35.10419 N, 77.03544 W, right:35.10371 N, 77.03546 W)

Fig. 7.3-7 - Downed light pole at Union Point Park (September 25, 2018, 35.1033 N, 77.0354 W).

The GEER Team also observed significant amounts of flood debris from residential and commercial buildings piled on the curbside (Fig. 7.3-8). Hurricane Florence made landfill on September 14th, and the debris piles were still being placed or not collected on September 25. Rapid removal and disposal of disaster waste debris is important for facilitating community recovery. Most of the debris was composed of home furnishings, electronics, interior building materials, kitchen appliances, cabinets, among many other. The vegetation debris was mostly located near the coast where the highest wind fields likely occurred.

Fig. 7.3-8 - Disaster debris piles located at the curbside that were yet to be collected 10 days after Hurricane Florence made landfall (September 25, 2018, Photo A: 35.10557 N, 77.04676 W) (Photo B: Latitude 35.10489 N, 77.03888 W, Photo C: N/A)

At the New Bern Grand Marina, the storm surge damaged a number of recreational boats (Fig. 7.3-9(a)). Moreover, the surge was sufficiently powerful to lift a sailing boat and place it adjacent to a nearby building (Fig. 7.3-9(b)). Local scouring around the foundation of the same building was observed in Fig. 7.3-9(c). The uniformity of the scour along the porch and lawn interface suggests that the large eddies that imparted the erosive forces reached a steady state level of erosion. This is somewhat similar to the backside scour found of the I-wall floodwall along the Inner Harbor Navigational Canal at the Lower Ninth Ward, New Orleans, LA after Hurricane Katrina.

Fig. 7.3-9 - Damage to the New Bern Grand Marina: (a) Recreational boats, (b) Scour at building foundation, and (c) Displaced sailing boat adjacent to building. (September 25, 2018, Photo A: 35.10054 N, 77.03888 W) (Photo B and C: 35.09923 N, 77.03925 W)

The following links connect to the NOAA imagery taken after Hurricane Florence and can be used to investigate changes further in New Bern and other affected areas.

- https://www.arcgis.com/apps/MapSeries/index.html?appid=8ed79d19f6654464a4d77b8e6126b42b
- https://storms.ngs.noaa.gov/storms/florence/index.html#19/35.09974/-77.03828
- https://scemd.maps.arcgis.com/apps/webappviewer/index.html?id=76582b9b6616439eafc2612242348d38

In the aftermath of a disaster, citizens look to the local, state, and federal governments for assistance. Fig. 7.3-10 shows a business owner's message that plays off a Trump campaign slogan. Understanding how impacted communities and individuals act upon their socioeconomic status and political tendencies to respond to natural disasters is also important for improving our ability to develop community resilience. Collecting post-disaster social information is another form of perishable data gathering that can have similar or greater importance to infrastructure data collection for understanding recovery efforts.

Fig. 7.3-10 - Political / social statement by local business owner (September 25, 2018, 35.10502 N, 77.03857 W)

7.4 New Hanover County, NC

As stated previously, the hurricane made landfall between Wrightsville and Carolina Beaches. The City of Wilmington is situated on the banks of the Cape Fear River just to the west (Fig. 7.4-1). Previous discussions of bridges and hydrology noted the volume of water that passed through the Cape Fear watershed. In addition to the river flow, the hurricane brought more than 30 inches of rain to the area. The GEER team visited New Hanover County on September 27, 2018. As in Carteret County, we noted few geotechnical impacts. The Cape Fear River crested at about 7 feet (1.5 ft is considered flood stage) in Wilmington. The extreme precipitation caused water damage to many structures in the downtown area, but no observed damage appeared to result from rising river levels. The GEER team documented the lack of major impacts at two locations along the Wilmington Riverfront – River Place and the slopes near historic residences.

Fig. 7.4-1 New Hanover County, NC (Google)

7.4.1 River Place Wilmington, NC

River Place is a mixed-use condominium development being constructed between Front and Water streets in Wilmington, NC. Water Street faces the Cape Fear River. There were excavations shored with soldier and sheet pile retaining structures for construction of the lower floors of the structures. Water pumps were running to dewater the excavation, but the site seemed minimally affected by the storm. Figs 7.4.1-1 and 7.4.1-2 show the dewatering work.

Fig. 7.4.1-1 – River Place development on Water St. Wilmington, NC looking southeast. (September 27, 2018, 34.2385 N, 77.9505 W)

Fig. 7.4.1-1 – River Place development on Water St. Wilmington, NC looking northeast. (September 27, 2018, 34.2376 N, 77.9503 W)

7.4.2 Old Slopes Downtown Wilmington

Houses facing Front Street just south of downtown Wilmington back up to the Cape Fear River with steep grassed slopes. Many of these homes are historic. The steep slopes behind these homes were unaffected by the rain.

Fig. 7.4.2-1 – Steep slopes behind historic homes off Front Street Wilmington, NC looking east. (September 27, 2018, 34.2308 N, 77.9491 W)

References

Google Earth aerial photography, various dates.

Google Maps, selected areas. https://www.google.com/maps.

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8. Other Observations

8.1 Elizabethtown Slope, Elizabethtown, NC

Fig. 8.1-1 shows the location of a slope failure / movement that the team observed in Elizabethtown, North Carolina. The slide mass is located near the intersection of West Broad Street and Highway 701 (see section 6.2.4 for observations of the adjacent US 701 bridge). The Cape Fear River borders the site, forming a tight concave bend. Historical imagery from Google Earth suggests that the first aerial to show indications of a slide was taken on October 2016 because of a scarp forming through the cemetery and cracks penetrating through the pavement. The subsequent aerial images show that the cracked road was repaved (Fig. 8.1-3(a) March 2018) and that the new cracks and scarps were apparent at the time of the flooding (Fig. 8.1-3(b) September 2018).

Figure 8.1-1 - Site location, Elizabethtown, NC (Google Maps, 34.6297 N, 78.6027 W)

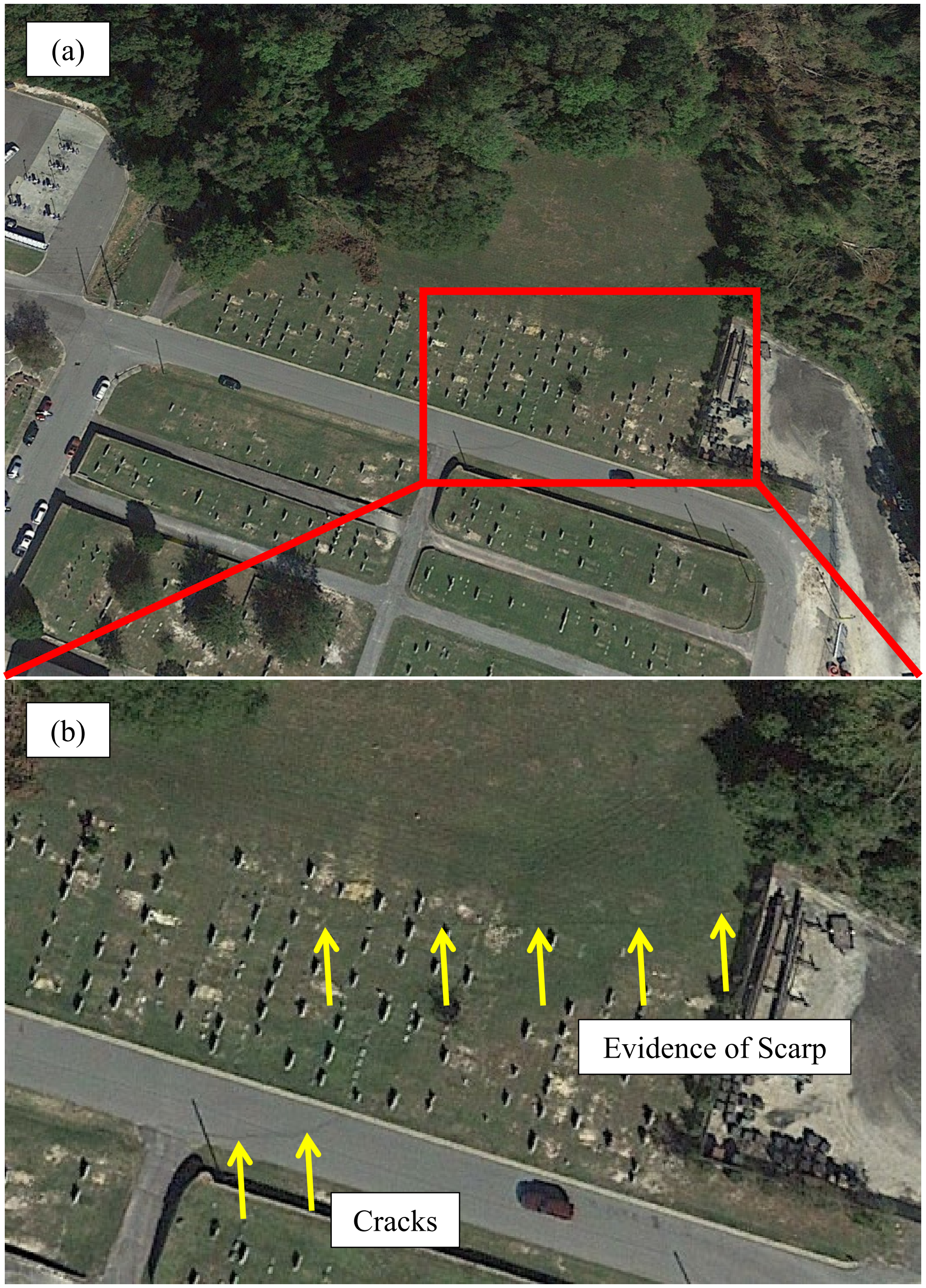

Figure 8.1-2 - Aerial imagery of the site: (a) cemetery and road, (b) inset showing evidence of pavement cracks and a scarp (Google Earth, October 25, 2016, 34.6297 N, 78.6027 W)

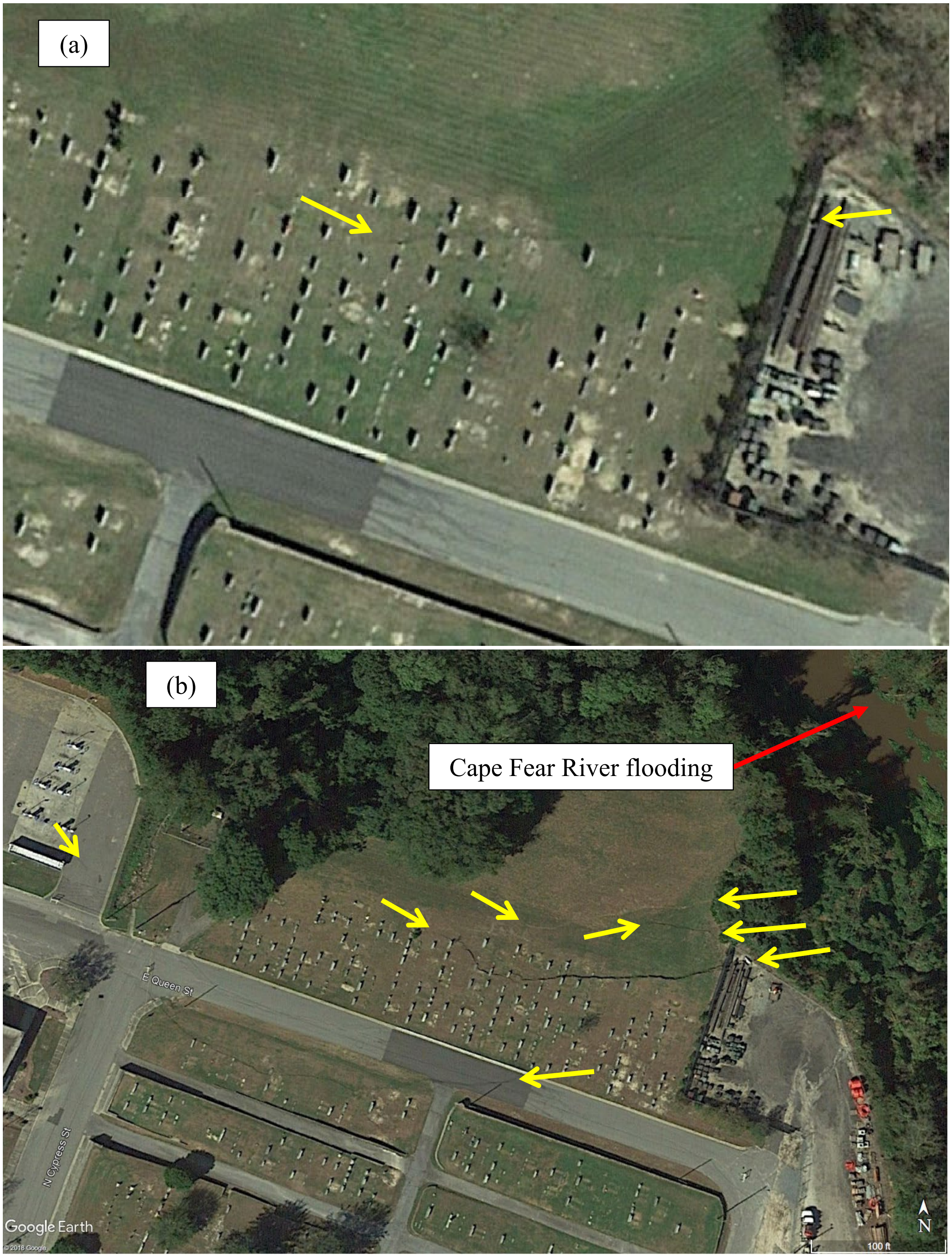

Figure 8.1-3 - Progressive aerial imagery of the site: (a) March 4, 2018 with repaved road and scarp, (b) September 18, 2018 during Florence flooding, yellow arrows show visible ends of cracks/scarps (Google Earth, March 4, 2018, September 18, 2018, 34.6297 N, 78.6027 W)

Fig. 8.1-4 shows the general surface geology at the site, which is characterized by Kt and Qwb deposits. The Kt symbol indicates the Tarheel Formation and consists of very fine to coarse-grained sand that has some silt and clay. It is also interbedded with silt, clayey pyritic soils. The soil is typically olive gray with deposits up to 265 ft thick. The Qwb symbol indicates the Bahramsville unit and consists of very fine to fine-grained sand with silt and clayey soils. Around Elizabethtown, this unit typically includes up to 22 ft of very shelly basal sand in paleochannels. The deposit color is typically reddish brown with deposits are up to 62 ft thick. In other words, the soil near the Cape Fear River is likely coarse-grained sands with silt and clay fines.

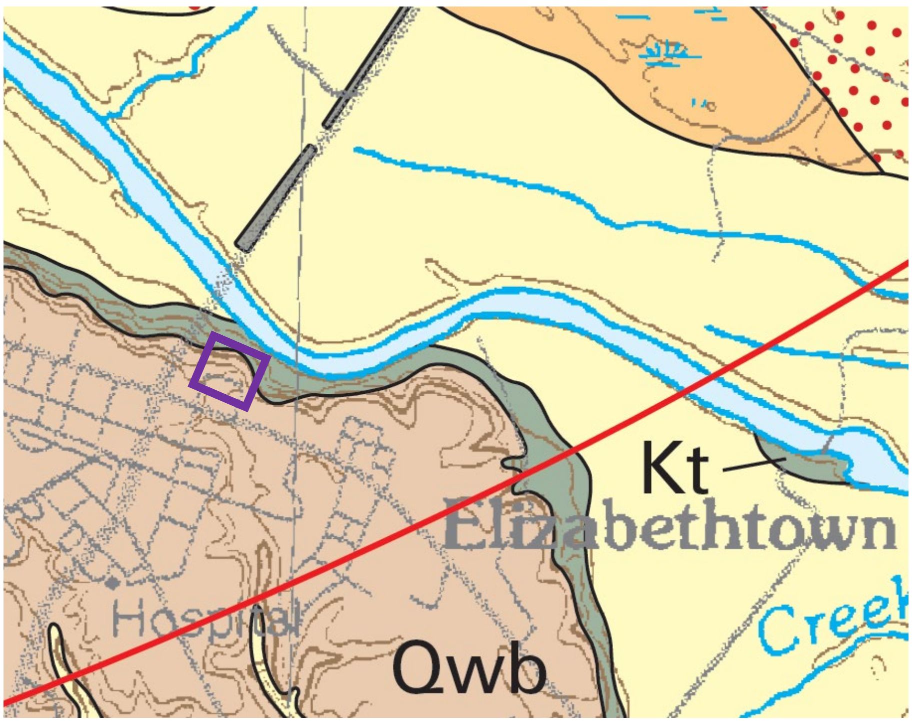

Figure 8.1-4 - Surficial geologic map of Elizabethtown with purple box representing the cemetery and slide location (obtained from Weems et al. 2011 at https://pubs.usgs.gov/of/2011/1121/ElizabethtownNCGeologicMap.pdf)

Figures 8.1-5 and 8.1-6 show photos of the general area. These images were obtained using an Insta360® (near 360-degree view video), which was uploaded into the Insta360 studio editor to pull snapshots highlighting specific aspects of the slide. Figure 8.1.5 was captured at the location of North Cypress St. and East Queen St. where we observed two tension cracks extending along the pavement (East Queen St) and about 20 ft above it in the cemetery. The slide mass appeared to extend upslope to this point and to wrap back downslope towards the Cape Fear River on either side of this high point. Figure 8.1-6 shows cracks that penetrate through the cemetery section below East Queen Street. The offset along the larger and uphill crack was about 1 ft, while the lower crack was a few inches. The land between the two scarps was slightly sunken, forming a small graben. It may also be that the first crack in Figure 8.1-6 is where the failure initiated before retrogressively growing to the larger crack in Figure 8.1-6 and then to the cracks located at the pavement.

The drone photographs in Fig. 8.1-7 show the maximum extent of flooding along the Cape Fear River by the discoloration of the trees and vegetation near the toe of the slope. Based on the hydrograph of the Cape Fear River, the maximum elevation of flooding occurred at approximately 45 ft.

Figure 8.1-8 shows additional photos taken by a drone. These photos provide an aerial view of the slide mass and the interconnectedness of the tension cracks. In the first figure, it seems a graben formed when the first slide mass moved. The scarp offset was greatest at the east border of the cemetery. The bottom two photos show cracks through the pavements. The fact that the pavement was resurfaced in one location indicates that the slide mass had previously moved before Hurricane Florence.

Figure 8.1-5 Scarp or cracks of the Elizabethtown slide along East Queen St and just north in the cemetery (September 26, 2018, ~34.6295 N, 78.6032 W)

Figure 8.1-6 - Scarp or cracks of the Elizabethtown slide along across the cemetery and midslope towards the Cape Fear River (September 26, 2018, ~34.6297 N, 78.6023 W)

Figure 8.1-7 - Drone photographs showing the vegetation browning indicative of the inundation extent by the Cape Fear River at peak flow (September 26, 2018, ~34.630 N, 78.602 W)

Figure 8.1-8 - Drone photographs showing the tension cracks across the site (September 26, 2018, ~34.630 N, 78.603 W)

References

Google Earth aerial photography, various dates.

Google Maps, selected area. https://www.google.com/maps.

Weems, Robert E., Lewis, William C., and Crider, E. Allen (2011). "Surficial Geologic Map of Elizabethtown 30' x 60' Quadrangle, North Carolina." U.S. Department of the Interior, U.S. Geological Survey. https://pubs.usgs.gov/of/2011/1121/ElizabethtownNCGeologicMap.pdf.

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