Community Resilience-Focused Technical Investigation of the
2016 LUMBERTON, NORTH CAROLINA FLOOD
MULTI-DISCIPLINARY APPROACH

EDITORS

John W. van de Lindt
Walter Gillis Peacock
Judith Mitrani-Reiser

Resilience

NIST
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Editors

John W. van de Lindt
Colorado State University

Walter Gillis Peacock
Texas A & M University

Judith Mitrani-Reiser
National Institute of Standards and Technology

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All maps in the report, except where noted, were created using ESRI ArcGIS.

Author Credits and Acknowledgements

Each section within each chapter of this report was prepared and edited by a number of different authors from the field study team and leadership. In addition, the entire study team is grateful to all those in and around Lumberton that provided their time for interviews.

Chapter 1 Authorship: John W. van de Lindt, Walter Gillis Peacock, and Judith Mitrani-Reiser

Chapter 2 Authorship: Andrew J. Graettinger, Shane Crawford, Juan Fung, Jennifer Helgeson, Maria Dillard, Jennifer Tobin, Kenneth Harrison, Nathanael Rosenheim, Bill Coulbourne

Chapter 3 Authorship: Walter Gillis Peacock, Nathanael Rosenheim, Judith Mitrani-Reiser, Derya Deniz, John W. van de Lindt, Maria Dillard, Tori Tomiczek, Maria Koliou, Andre Barbosa, Jennifer Tobin, Andrew Graettinger, Shane Crawford, Lori Peek, Mehrdad Memari, Elaina Sutley, Sara Hamideh, Donghwan Gu, Stephen Cauffman

Chapter 4 Authorship: John W. van de Lindt, Walter Gillis Peacock, Jennifer Tobin, Judith Mitrani-Reiser, Maria Koliou, Derya Deniz, Nathanael Rosenheim, Donghwan Gu, Lori Peek, Maria Dillard, Elaina Sutley, Sara Hamideh, Andrew Graettinger, Shane Crawford, Bill Coulbourne, Tori Tomiczek, Mehrdad Memari, Andre Barbosa

Chapter 5 Authorship: John W. van de Lindt, Walter Gillis Peacock, Judith Mitrani-Reiser, Maria Dillard, Jennifer Helgeson

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Executive Summary

In early October 2016, Hurricane Matthew crossed North Carolina as a Category 1 storm, with some areas receiving 0.38 m to 0.46 m (15 to 18 in) of rainfall on already saturated soil. The National Institute of Standards and Technology (NIST) funded Center for Risk-Based Community Resilience Planning teamed with researchers from NIST's Engineering Laboratory (Disaster and Failure Studies Program, Community Resilience Group, and the Applied Economics Office) to conduct a quick response field study focused on the small city of Lumberton, NC and the flooding they experienced from the Lumber River. Lumberton is an ethnically diverse community with higher than average poverty and unemployment rates, a typical civil infrastructure for a city of 22 000 residents, and possesses a small-community structured governance. The field study described in this report is the first of a series in a longitudinal study to document and better understand the impact that the riverine flooding had on Lumberton and its subsequent recovery. This type of longitudinal research is critical to better understand community resilience and ultimately provide data and insight into making U.S. communities more resilient to natural hazards. The community resilience-focused field study presented herein as a NIST Special Publication series, had two major objectives: (1) establish and document initial conditions after the flood for the longitudinal resilience field study of Lumberton's recovery with a focus on the most heavily affected area located within a particular school zone; and (2) facilitate and document the development and first application of a combined engineering-social science field study protocol that provides a quantitative linkage between flood damage and socio-economics, including race/ethnicity, income, tenancy status, and education level. Population dislocation probabilities were found to be higher for black and Native American households than for white households given the presence of the same residential damage state following the flood.

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Chapter 1: Introduction

The study of Lumberton, North Carolina described in this report is a collaboration between researchers from the National Institute of Standards and Technology (NIST) Center of Excellence for Risk-Based Community Resilience Planning, and researchers in the Engineering Laboratory at NIST.

1.1 The NIST Center of Excellence for Risk-Based Community Resilience Planning

Community resilience depends on the functioning of social, economic and public institutions, which are dependent on the performance of the built environment, and that are, individually and collectively, essential for immediate response and long-term recovery of communities following a disaster. Collective community needs and objectives (including post-disaster recovery) are not reflected in codes, standards, and other regulatory documents applied to the design of individual facilities, necessitating an approach which reflects the complex interdependencies among the physical, social, and economic systems on which a healthy community depends. Thus, modeling the resilience of communities and cities depends on many disciplines, including engineering, social sciences, and information sciences. The Center of Excellence for Risk-Based Community Resilience Planning, headquartered at Colorado State University in Fort Collins, Colorado and involving ten universities, was established by The National Institute of Standards and Technology (NIST) in 2015. The Center's overarching goal is to establish the measurement science for community resilience assessment and risk-informed decision-making. To accomplish this goal, the Center is engaged in three major research thrusts: (1) developing a community resilience modeling environment–the *Interdependent Networked Community Resilience Modeling Environment* or IN-CORE–to quantitatively assess alternative community resilience strategies, (2) developing a standardized data ontology, robust architecture, and management tools to support IN-CORE, and (3) performing a comprehensive set of disaster hindcasts to validate IN-CORE's advanced modeling environment. As part of Thrust 3, a number of field studies are planned to assist with model development of IN-CORE for different hazards. These studies will create comprehensive data sets to inform Thrust 2, and will in turn, provide the information needed in Thrust 3 for validation of the software's full architecture.

The Center of Excellence for Risk-Based Community Resilience Planning at Colorado State University works to accelerate the development of system-level models and databases that will provide the technology for enhancing community resilience. Center researchers include noted interdisciplinary experts in resilience from (in alphabetical order) the California Polytechnic University-Pomona, Colorado State University, Iowa State University, Oregon State University, Rice University, Texas A&M University, the University of Illinois, the University of Kansas, the University of Oklahoma, the University of South Alabama, the University of Colorado, and the University of Washington. Ultimately the decision framework created in the Center will provide decision-makers with a unique set of tools that can be tailored to the needs of specific communities to optimize the design and subsequent management of individual facilities and interdependent infrastructure systems to achieve resilience goals while managing life-cycle costs. Its use will provide a basis for targeting public investments and incentives for private investments, thus making it possible, for the first time, to establish a "business case" for achieving community resilience.

1.2 The Engineering Laboratory at NIST

The Engineering Laboratory (EL) at NIST promotes U.S. innovation and industrial competitiveness by advancing measurement science, standards, and technology for engineered systems in ways that enhance economic security and improve quality of life. Some of the ways that the Laboratory carries out its mission is by undertaking activities in community resilience, disasters and building failures investigations, economic analysis and life cycle assessment, wind and seismic hazards impact reduction, fire prevention and control, and engineering and manufacturing materials. Several researchers from the Applied Economics Office and the Community Resilience Program from EL participated in the Lumberton field study to advance the disaster metrology research of the EL's Disaster and Failure Studies Program.

Extreme events test buildings and infrastructure in ways and on a scale that cannot be easily replicated in a laboratory – buildings and infrastructure are built without being tested at full scale. The study of disaster and failure events is essential to improving the performance of buildings and infrastructure, the safety of building occupants, and the associated evacuation and emergency response procedures. NIST leads a multi-disciplinary Disaster and Failure Studies (DFS) Program within the Engineering Laboratory intended to standardize disaster field deployment, assessment, and reporting protocols to ultimately improve building and infrastructure performance. This program implements these goals by: (1) monitoring events using a screening tool to evaluate whether decision criteria merits the establishment and deployment of a study team, (2) coordinates the establishment, deployment, operations and reporting of study teams, (3) ensures that the study team's safety, health and environmental requirements are met including relevant hazard reviews, training, and personal protective equipment prior to deployment, (4) builds and maintains effective partnerships and communications with other federal agencies, state/local governments, stakeholders and the general public, (5) establishes and executes standard operating procedures and criteria for disaster and failure studies, (6) promotes the implementation of recommendations from all DFS investigations, (7) creates and maintains an archival data repository for DFS, (8) carries out the statutory requirements of the National Construction Safety Team (NCST) Act, which includes providing the Secretariat for the NCST Advisory Committee and annual reports to Congress, and (9) oversees a disaster metrology research program that interacts with other groups in EL, to directly inform best practices for (1)-(7).

1.3 The Scope and Audience for this Report

The purpose of this first community resilience field study is to provide a comprehensive set of initial conditions, both physical and non-physical, for a community affected by a disaster. To do this, more than 600 residential structures were assessed for damage, approximately 180 households present and neighboring households were interviewed, and several interviews were conducted with local, state and federal officials and private sector stakeholders during the week of November 29, 2016 by the field study team. This report presents background information on the flooding of the Lumber River associated with the excessive rainfall from Hurricane Matthew, in Lumberton, North Carolina, and summarizes the results of the interdisciplinary team of engineers, social scientists, and economists. The data collected from inspections and interviews will be used to establish a baseline for a longitudinal study of Lumberton's recovery over the next several years. The sampling methodology developed for this study is unique and is intended to form the basis of a new field study approach that can be used in future studies to provide data

required to calibrate models within IN-CORE and other community resilience modeling tools. Once the longitudinal study is far enough along (approximately two years), the data will be used to help validate the complex and coupled physical and non-physical modeling processes being developed within the Center of Excellence. It is envisioned that this report can also provide objective information on the impacts, response, and recovery processes as documented by an outside research team to the relevant local, state, and federal officials. Both these purposes will provide a mechanism by which to learn from the events in Lumberton and help identify mechanisms to help other communities plan, prepare for, and recover from natural hazards such as floods. Therefore, this report should be of use to researchers and practitioners interested in resilience in academia, governmental labs, industry, local and state planning, and officials in other communities interested in making their communities more resilient.

1.4 Community Based Resilience Research

As noted above, research into community resilience, particularly when considering field-based research on natural disasters, demands interdisciplinary approaches be taken to understand the factors shaping direct and indirect impacts, as well as restoration and recovery processes. Indeed, there is a growing recognition and consensus in the scientific community that natural disasters are an outcome of the interaction among biophysical systems, social systems, and their built environment (Mileti, 1999; White, Kates, and Burton, 2001; NRC, 2006, 2011a; 2011b; NWRS, 2018;). While hazards, such as a floods, hurricanes, or tornados, that strike communities might be considered a natural, impartial phenomenon, the communities they strike are far from impartial (in terms of its social systems and the built environment upon which they depend). Rather, our communities are products of history, shaped by economic, social, demographic, and environmental factors (Bates, 1972; Bates and Pelanda, 1994; Peacock and Ragsdale, 1997; Tierney, Lindell, and Perry, 2001; Tierney, 2006; Wisner et al., 2003). A community's housing stock can be quite heterogeneous in age, quality, maintenance, type (e.g., single family, multifamily, mobile homes) and that housing is often clustered into areas (neighborhoods) varying along many dimensions such as physical vulnerability (e.g., flood plains, slopes, surge zones), access to amenities (e.g., schools, health care, food retail, transportation, infrastructure), and socio economic attributes (e.g., income, wealth, social capital, power, prestige).[1] Most importantly, a household's access to these different forms of housing and neighborhoods is shaped not simply by choice, but also by factors such as wealth, income, race/ethnicity, power, and social capital.[2] The net effect of this interplay between hazards and communities as social systems and the built environment is that natural disasters in terms of their direct and indirect impacts and recovery processes, are far from *natural,* impartial events.[3] When focusing on resilience, particularly from a risk-based community planning and policy approach, our planning and policy activities requires that we better understand and investigate the physical and

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[1] Hendricks 2017; Logan 2006; Highfield, Peacock, and Van Zandt 2014; Massey, Rugh, Steil, and Albright, 2016;
[2] See for example: Foley 1980; Pendall 2000; Pendall and Carruthers 2003; Denton 2006; Choi, Ondrich and Yinger 2005; Dane 1993; Albright, Massey, Rugh, and Steil 2016; Bayer Ferrera and Ross 2014; Steil, Albright, Rugh and Massey 2018.
[3] See for example: Bates, Fogleman, Parenton, Pittman, Travy 1962; Cochran 1975; Blaikie, Cannon, Davis and Wisner 1994; Peacock, Morrow, and Gladwin 1997; Mileti 1999; Bolin and Staford, 1998; Bullard 2009; Comerio, 1998; Cutter, Schumann, and Emrich 2014; Girard and Peacock 1997; Lindell, Perry and Prater 2006; Pais and Elliot 2008; Van Zandt, Peacock, Henry, Grover, Highfield and Brody 2012.

technological factors shaping impact and recovery, but also distributional and differential consequences that social and economic factors play in shaping the resilience within our communities (Masterson et al., 2014). As a consequence, this report will at times link engineering and social science data to capture these differential and distributional aspects for direct impacts, as well as for indirect consequences like dislocation. In presenting these examples, the attempt is not to necessarily present definitive work, but much more to show by example, how interdisciplinary work might be undertaken to address resiliency issues for all facets of a community.

Chapter 2: Background

2.1 Introduction

The Center of Excellence (CoE) for Risk-Based Community Resilience Planning and NIST research team conducted a quick response field study from November 27, 2016 to December 4, 2016 in Lumberton, North Carolina. Lumberton is a small community with 21 542 residents located in the mostly rural county of Robeson (U.S. Census, 2010). In early October 2016, Hurricane Matthew crossed North Carolina as a Category 1 hurricane, including 0.38 m to 0.46 m (15 in to18 in) of rain in some areas on already saturated land, which caused major flooding in Lumberton. This chapter provides a brief description of Lumberton, including its history, and Hurricane Matthew.

2.2 Lumberton History

The City of Lumberton, named after the Lumber River, was among the most devastated communities due to flooding caused by Hurricane Matthew. Incorporated in 1859, Lumberton is the county seat of Robeson County, and is located in the coastal plains region of North Carolina. Figure 2-1 highlights the location of Robeson County in red, with the city limits of Lumberton shown in black in the insert. The City of Lumberton and its past are intricately connected to the Lumber River, which now holds both national and state designations. The Lumber River has great recreational and cultural value, as it provides for a range of activities such as canoeing, boating, fishing, hunting, and picnicking and is home to important archaeological sites. It is believed that the Indian name of Lumbee was originally used for the river, originating from an Indian word that means "black water" (Locklear, 2010). In Colonial records of 1749, Drowning Creek was the name used by early European settlers. In 1809, the name was changed by legislative action to the Lumber River. The earliest Native Americans may have lived in the region from as early as 20 000 B.C. However, by the 18th century, the river and its associated swamps were home to several Native American tribes, many displaced from other areas of the coastal region as Europeans advanced westward.
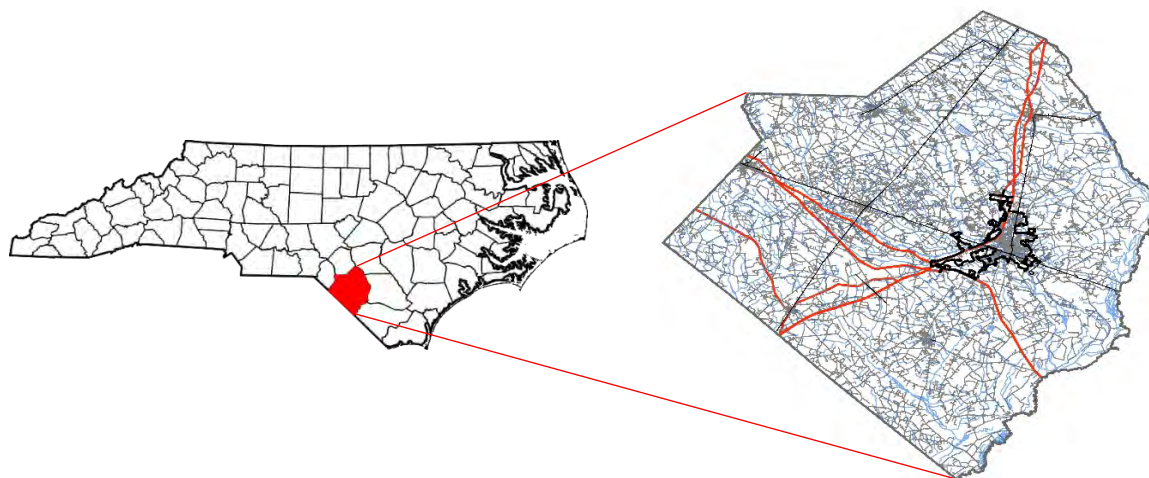
Figure 2-1. Location of Robeson County within North Carolina highlighted in red (left) and location of Lumberton city limits within Robeson County shown in black (right).

2.2.1 Geography

The city spans 15.8 square miles and is bisected by the Lumber River, which flows generally northeast to southeast through the city. Major roadways in the city include Interstate 95 (I-95) running north-south, U.S. Highway 301 running east-west through the north of the city, and U.S. Highway 74 running east-west through the south of the city. Lumberton is home to the Lumberton Municipal Airport (LBT), a city-owned airport with two runways categorized as a general aviation facility. A CSX[4] rail line runs east-west through the southern portion of the city, crossing the Lumber River at two locations as well as going under I-95.

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[4] Certain commercial products are identified in this paper in order to specify the experimental procedure adequately. Such identification is not intended to imply recommendation or endorsement by the National Institute of Standards and Technology, nor is it intended to imply that products identified are necessarily the best available for the purpose.
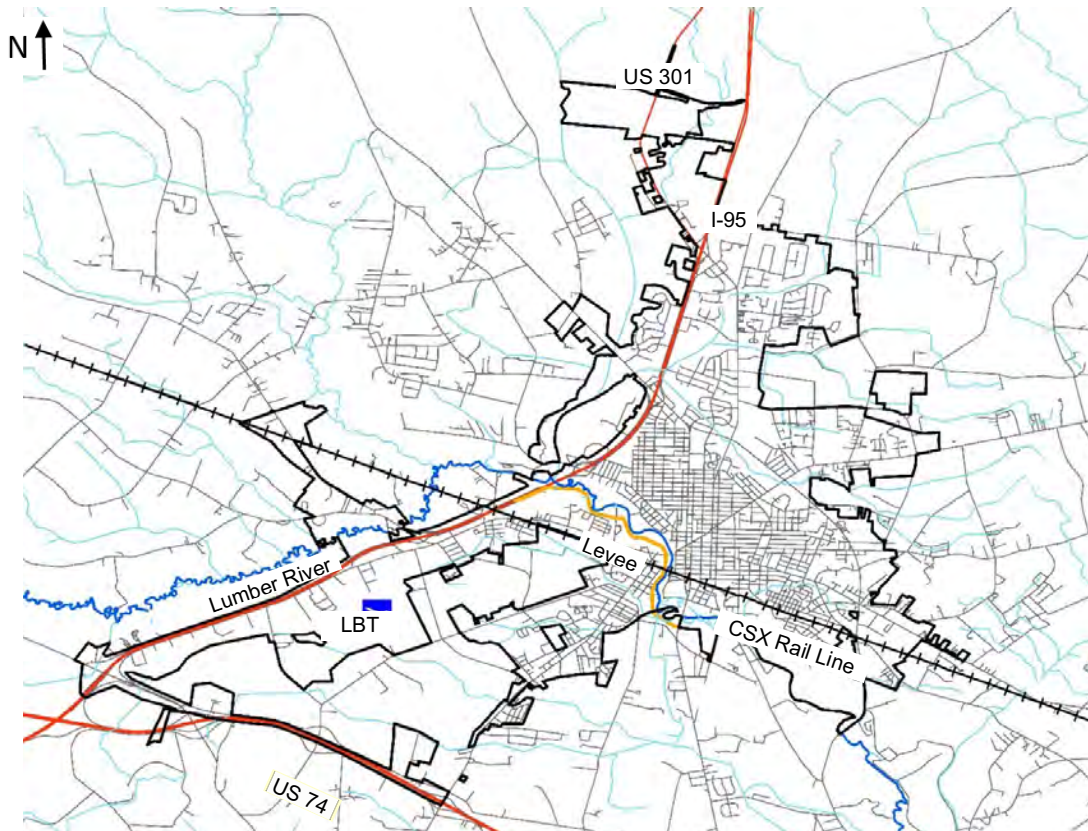
Figure 2-2. Lumberton city limits in black, overlaid with major transportation infrastructure.

Figure 2-2[5] shows the city boundaries along with major infrastructure including major roadways in red, all other roadways in gray, CSX rail line denoted with a black ticked line, Lumberton Municipal Airport with an airplane symbol, and levee denoted with an orange line. The Lumber River is denoted with a dark blue line in Figure 2-2 and minor waterways are shown in light blue. A portion of the city sits in the floodplain of the Lumber River, which extends for the most part to the southern sections of the river. The area north of the river sits at a higher elevation while the southern portion of the city is only slightly above the river elevation. A levee system was designed to protect areas of the city south of the Lumber River.

Robeson County covers 949 square miles, the largest county in North Carolina, and is designated as 70 % rural (American Community Survey, 2015). However, increases in developed land cover from the mid-1990s on has been occurring in Robeson County (NOAA C-CAP, 2017). Much of this development was concentrated in Lumberton. Between 2001 and 2011, there was a 21 % increase in acres of medium or high intensity developed land cover in Lumberton, based on data reported in the National Land Cover Database provided by the U.S. Department of Interior Multi-Resolution Land Characteristics Consortium (MRLC, 2018). Among types of development, high intensity had the greatest increase (24 %) for the ten-year period.

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[5] Unless otherwise noted, all maps were created by the CoE/NIST researchers using ESRI ArcGIS software. Certain commercial products are identified in this paper in order to specify the experimental procedure adequately. Such identification is not intended to imply recommendation or endorsement by the National Institute of Standards and Technology, nor is it intended to imply that products identified are necessarily the best available for the purpose.

2.2.2 City Government

The City of Lumberton is governed by a council/manager form of government, in which elected officials carry out legislative duties through the establishment of laws and policies while a city manager, who is appointed by the city council, acts as chief administrator and ensures laws and policies are followed. The city council is made up of eight council members, representing different precincts of the city, as well as the city mayor who presides over the council and does not vote except in the case of a tie. The city manager is responsible for the coordination and management of all city government activities, including policy development and project management. The city manager is aided by a deputy city manager and an assistant to the city manager (City of Lumberton, NC Website).

2.2.3 Demographics

Robeson County, North Carolina is known for being minority-majority and "tri-racial," with 39.9 % of the population identifying as American Indian, 32.2 % as White, and 24.4 % as Black (American Community Survey, 2015). The City of Lumberton is also a highly diverse community with 39.0 % of the population identifying as non-Hispanic White, 36.7 % as non-Hispanic Black, and 12.7 % as American Indian according to the 2010 U.S. Census (see Figure 2-3). These percentages remain essentially the same based on 2015, 5-year American Community Survey (ACS) estimates. The relatively large population of American Indian residents in the county and city is due to the presence of the Lumbee Tribe of North Carolina. The tribe, which is now the largest east of the Mississippi River with 55 000 members, has inhabited Robeson County since the early eighteenth century. This tribe has been recognized by the state of North Carolina as a Native American tribe since 1885 and by the federal government since 1956, but the tribe did not receive the full benefits of federal recognition until 2009 (LumbeeTribe, 2016).

Based on the 5 year ACS[6] estimates (2011 to 2015), 24.8 % of the population of Lumberton is under the age of 18, while 20.1 % is above the age of 60, which is consistent with national averages. Lumberton also has a substantial portion of its community, 34.8 %, living at or below poverty levels. This is more than double the national average of 13.5 %. The poverty rate in Robeson County is even more extreme for children: in 2011, 43 % of those under the age of 18 were in poverty and this rose to 45.2 % for children under the age of 5 (Kids Count, 2017). The unemployment rate for the civilian labor force age 16 and older is 10.2 %, as compared to 8.3 % nationally. The median household income is $31 245. Nearly one third (30.1 %) of the population is receiving social security income, 19.7 % are also receiving retirement income, and 20 % of the population had no health insurance coverage.

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[6] The ACS 5 year estimates are period estimates reflecting the conditions for the 5 year period ending in 2015.

Lumberton: Racial/Ethnic Composition

Legend:
- Hispanic
- NH White
- NH Black
- Am. Indian
- NH Other

Values shown: 6.7%, 39.0%, 36.7%, 12.7%, 4.8%
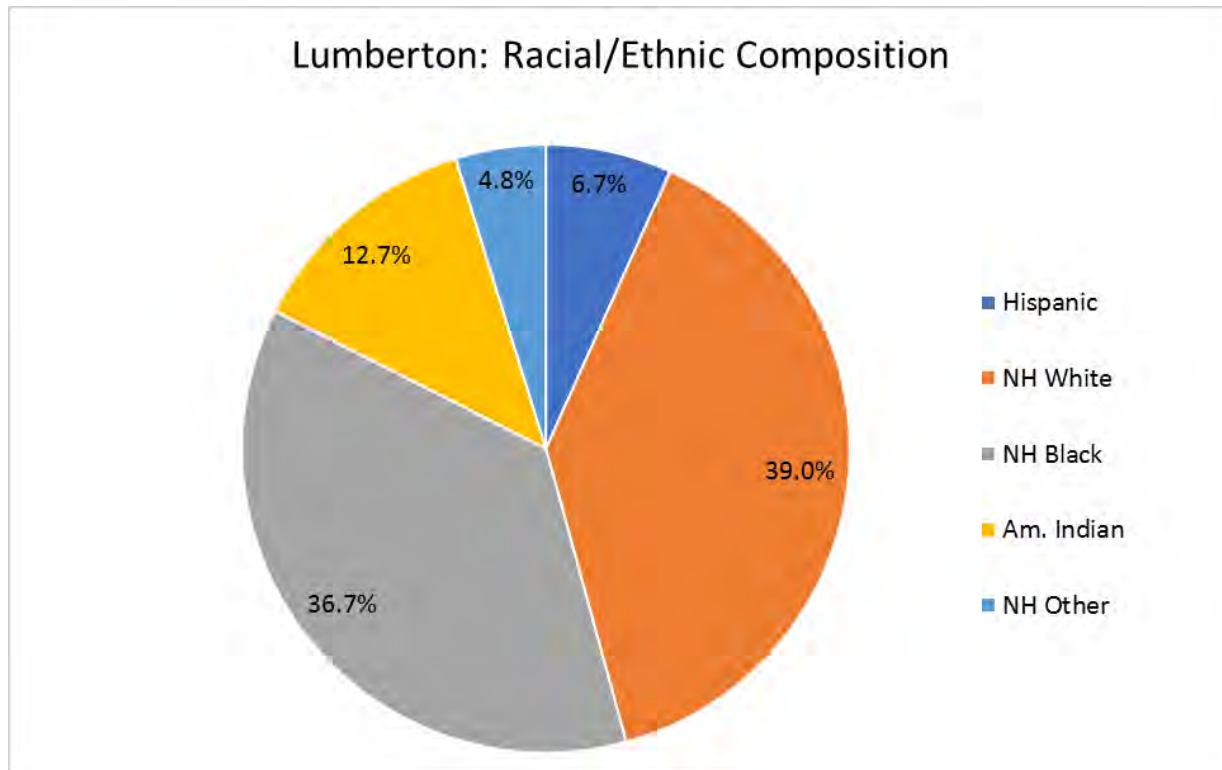
Figure 2-3. Racial/ethnic composition of Lumberton, based on 2010 Census.

Clearly Lumberton is a highly diverse community in terms of its racial and ethnic composition relative to most communities in the United States, with substantial proportions of its population below 18 or over 60. While Lumberton might be considered a "minority-majority community" this observation does not necessarily reflect a reversal of general patterns of inequalities and their consequences found elsewhere in the United States. Indeed, the general patterns of traditional minority racial/ethnic status (i.e., Black and American Indian) are still disproportionately associated with poverty and unemployment and these patterns of inequalities can have major consequences in disasters. In Lumberton, for example, 5 year (2011 to 2015) ACS estimates report that 44.8 % (± 5.4) of African Americans and 48.4 % (± 8.7) of American Indians are below the poverty level compared to 18.5 % (± 3.7) of Whites. Similarly, the ACS**Error! Bookmark not defined.** unemployment estimates for individuals 16 years or older in the same period in Lumberton are 16.6 % (± 5.2) for African Americans and 20.0 % (± 7.0) for American Indians compared to 4.5 % (± 1.6) for Whites. The disaster literature has long found that minority and low-income populations are often disproportionately impacted (in terms of property damage and permanent dislocation) by natural disasters and experience greater difficulties in responding to and overcoming these impacts (Peacock et al., 1997; Van Zandt et al., 2012; Bolin and Kurtz, 2018); these difficulties can be particularly pronounced for children (Fothergill and Peek, 2015; Peek et al., 2018). These factors will be important to consider when analyzing the impacts and response to Lumberton's flooding. The next sections, however, will continue to explore and better understand Lumberton's economy and the economic characteristics of its population.

2.2.4 Economic Background

A comparison of selected economic statistics for Lumberton and Robeson County, based on ACS 5 year estimates for 2010 and 2015 are presented in Table 2-1. While economic conditions were often better in Lumberton when compared to the county as a whole during the period ending in 2010, both experienced declines over these 5-year periods. Comparing the two periods we can see that per capita incomes (in 2015 US dollars) fell 18.3 %, from $21 462 to $17 528, in Lumberton and by 6.6 %, from $16 650 to $15 559, in Robeson County as a whole. The unemployment rates climbed as well from 6.2 % in the 2010 period to 10.2 % in 2015 period and from 9.2 % to 12.1 % over the same periods in Robeson County as a whole.

Table 2-1. Select economic statistics for the City of Lumberton and Robeson County, 2010 and 2015.

	Lumberton		Robeson	
	2006-2010	2011-2015	2006-2010	2011-2015
Per capita income	$21 462	$17 528	$16 650	$15 559
Unemployment Rate	6.2 %	10.2 %	9.2 %	12.1 %
Poverty Rate	29.9 %	34.8 %	30.2 %	31.6 %

* 2010 data are from the 2006 to 2010 5 year ACS estimates, and 2015 data are from the 2011 to 2015 ACS 5 year estimates.

The poverty rate increased during both time periods in the city. In Lumberton poverty rates increased by 4.9 %, moving up to 34.8 %. While the rate of increase was not as high for the county, 1.4 %, the rate was still a very high 31.6 % in Robeson county as a whole. It should be remembered that many areas throughout the United States experienced economic slowdowns and increases in unemployment and poverty rates as a result of the national economic recession that occurred in 2008. Nevertheless, it is evident that these impacts were quite significantly felt in Lumberton and Robeson County.

2.2.4.1 Economic Structure

The largest industries, by share of employed workers, in Lumberton are: education and health (28.2 %), manufacturing (20.5 %), retail (11.9 %) and construction (5.7 %). Together, these industries comprise 66.3 % of employment in Lumberton. For comparison, these industries comprise approximately the same percentage of employment in Robeson County (65.6 %). Education and health, manufacturing, retail, and construction industries in Robeson County over time show the following:

- Construction, manufacturing, and retail employment shares were falling well before the 2007-8 recession, both in Robeson and across the state.

- Since around 1975, the manufacturing industry in Robeson County employed substantially more workers than the state average. That share has fallen since the mid-1990s, as it has nationally.

- Since 2001, health services (health care and social assistance) in Robeson employed more workers than the state average, while the education industry employs less than half the state average.
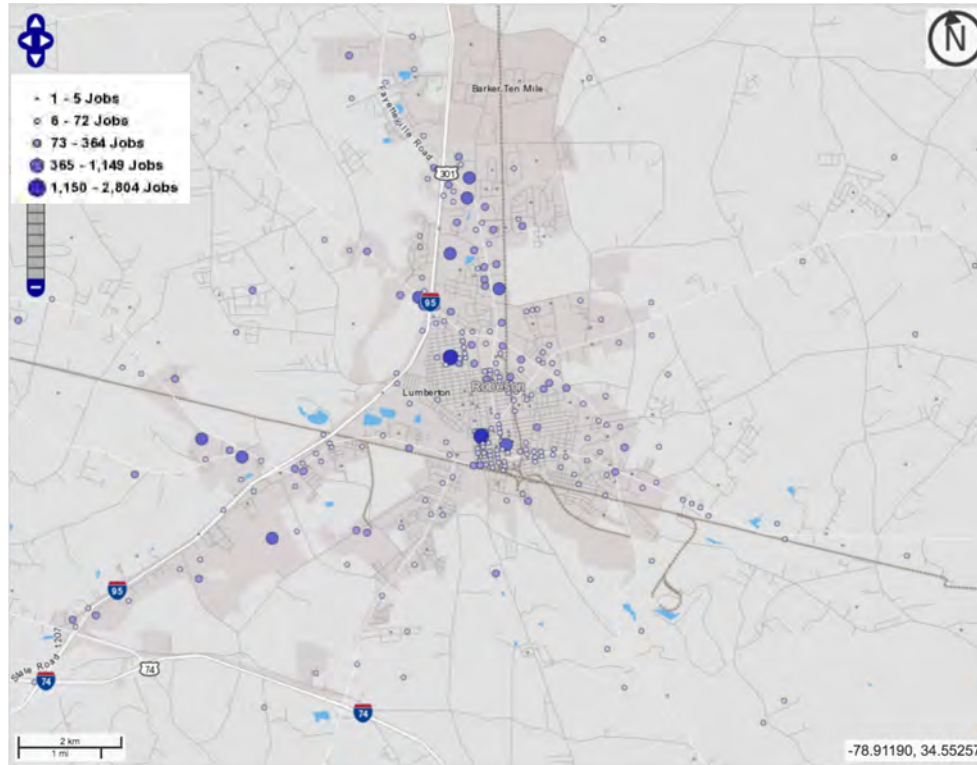
Figure 2-4. Map of job locations in and around Lumberton city limits in 2015.[7]

Figure 2-4[7] displays a map of the locations of all primary and secondary jobs held by employees in and around the Lumberton city area of Robeson County in 2015. Most jobs and hence business locations are in areas north of the Lumber River and east of I-95. As will be discussed below, it is fortunate that most employment activities are north of the river and east of I-95, since most of the significant flooding occurred in areas primarily south of the river and west of I-95.

2.2.4.2 Trends in Income and Government Transfers

It can be revealing to examine trends in *per capita* personal income (total personal income divided by the area's population) through time and in comparison, to state per capita measures to get a sense of the relative economic well-being of an area's population. Figure 2-5 compares per capita income in Robeson county to both the state means and medians from 1969 to 2015. Robeson County's income per capita (shown in black), since 1969, has consistently fallen below the state's average (shown in orange) and median values (shown in blue).

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[7] The data displayed in this map are created by the Economic Research Services of the U.S. Census and are made available through its mapping service website: https://onthemap.ces.census.gov/
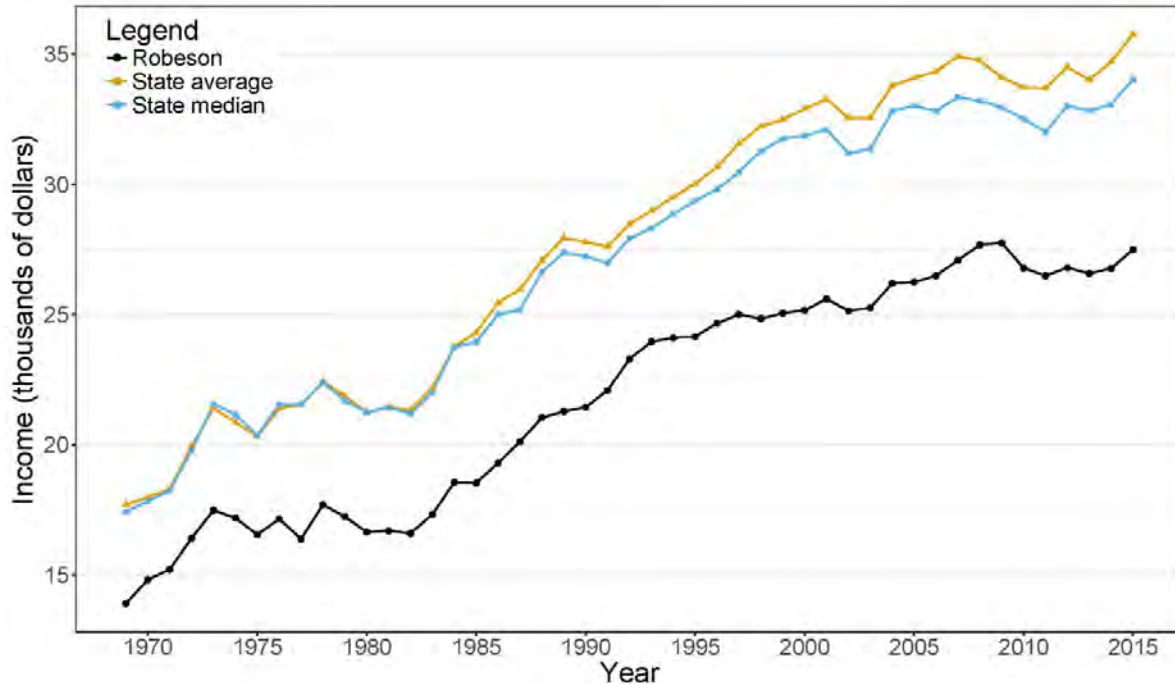
Figure 2-5. Per-capita personal income (in 2015 USD) for Robeson County and North Carolina: 1969 to 2015.

In order to better assess the economic well-being of Robeson county's population and the different income sources, the fraction of income derived from transfer payments was considered. As defined by the Bureau of Economic Analysis (BEA), these government payments include sources such as Social Security payments, retirement and disability insurance benefits, medical benefits (such as Medicare), and supplemental income benefits (such as the Supplemental Nutrition Assistance Program, or SNAP). Figure 2-6 shows government program money as a share of personal income over time in Robeson County compared to the average across other counties in North Carolina. The most striking trend is the growth of transfer payments as a share of personal income in Robeson County relative to the state average. While transfers make up 10.6 % of the personal income in Robeson County in 1969, by 2015 transfers account for 38 % of personal income. This share is much higher (90 %) than the state average.
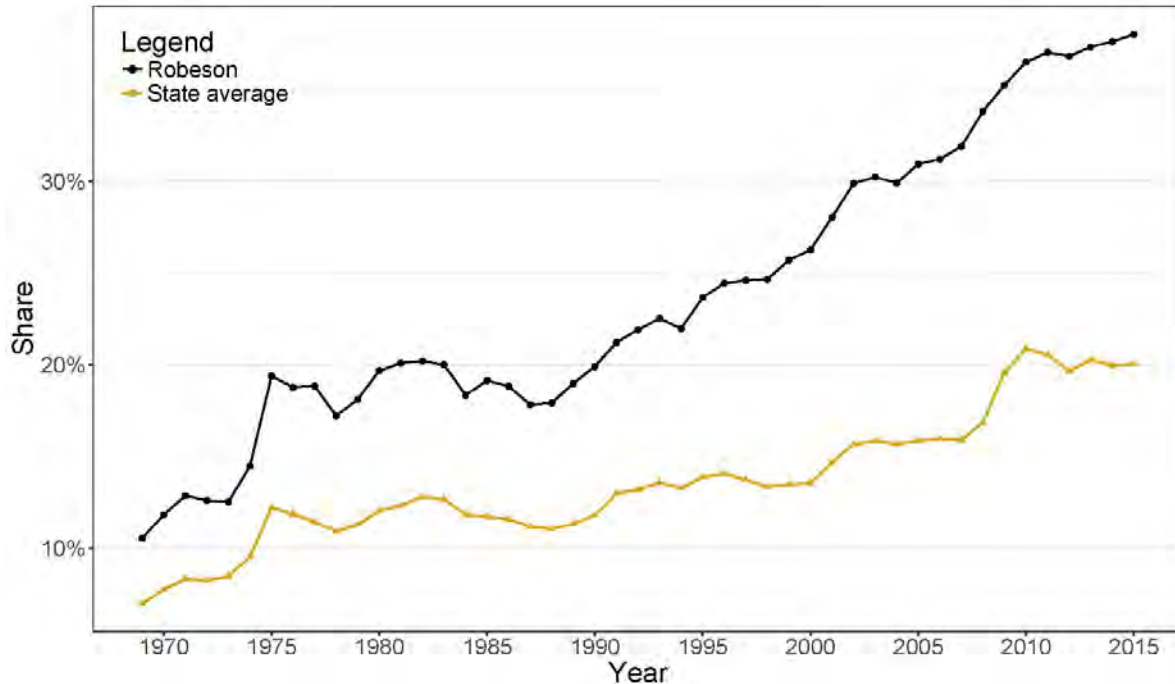
Figure 2-6. Personal transfer payment as a percent of personal income (in 2015 USD) over time in Robeson County compared to North Carolina.

By investigating the sources of transfer payments, some additional noteworthy trends are identified:

- Retirement and disability benefits (excluding Social Security) account for a small portion of personal income (although this source has been growing since 2001).

- Social security, medical, and supplemental income benefits account for larger portions of personal income, with these shares continuing to grow above the state average in recent decades.

- Medical benefits, in particular, are growing much more rapidly than the state average since the mid-1990s.

The economic data provides a comprehensive picture of households in the Lumberton area when attempting to address the impacts of a significant flooding event. The per-capita income data suggests that, in general, individuals and households have lower economic resources on average when compared to many areas across the state. However, there is a need for caution, in that the trend data are for the county as a whole; while the ACS data suggests relatively higher per-capita income levels in Lumberton proper. Nevertheless, the very high poverty rates (greater than 30%) for Lumberton and the county, particularly for households with children, suggest that a substantial proportion of households will have severely limited, if any, economic resources with which to overcome the impacts of the flooding should their homes be impacted. Similarly, the substantial and increasing dependence on transfer payments as an ever-increasing component of personal income clearly suggest that many individuals and households are dependent on potentially limited, fixed incomes with limited surplus to address the acute needs generated by a flood event. The consequences, of course, will depend upon which kinds of households that are

impacted and, importantly, the degree to which post disaster aid might overcome the relative lack of economic resources that some households may face.

2.2.5 Housing Stock

According to the 5 year ACS estimates for 2015, there were 8 668 (±295) housing units in the city, with a 85.4 % occupancy rate. Lumberton has a much higher renter-occupancy rate, 52.3 %, compared to the state (34.9 %) and national (36.1 %) rates.
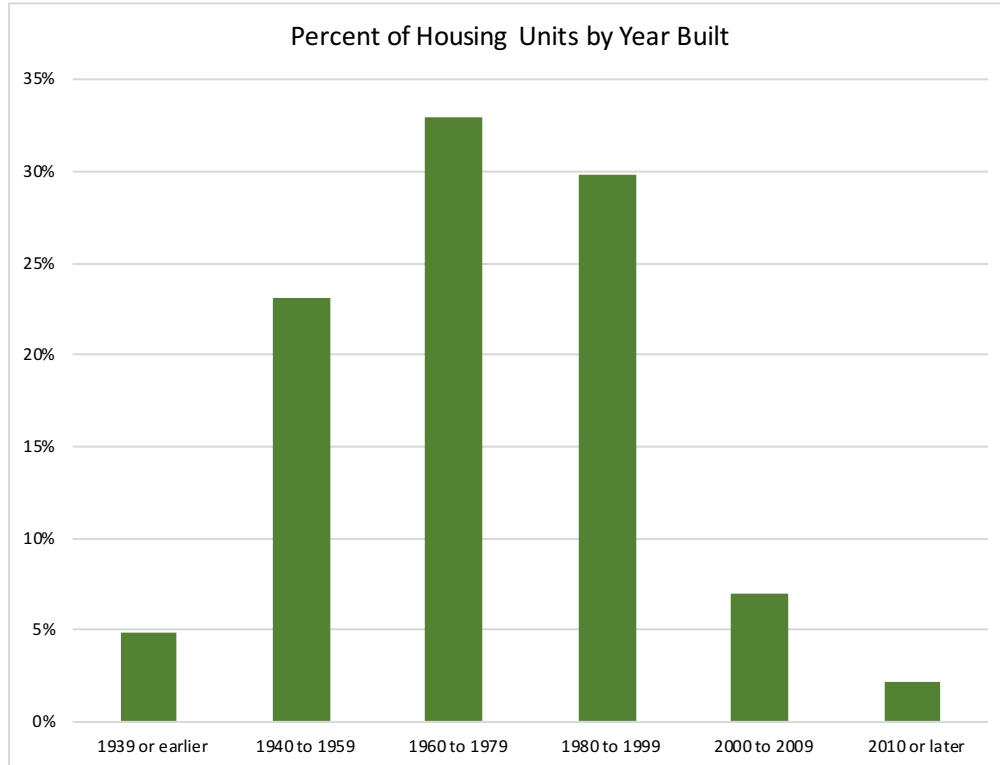
Figure 2-7. Lumberton housing data broken down incrementally by year built.

Lumberton's housing stock is composed of 64.0 % single-family detached housing units, where 67.9 % of those are owner-occupied and 32.1 % are renter occupied. Mobile homes make up 9.8 % of Lumberton's housing units, where 74.7 % are renter occupied. The remaining housing, approximately 26 %, is generally found in some form of multi-family housing with the majority consisting of 2-, 3-, or 4-unit apartment buildings with 94 % being rental units.

The majority of housing units are located in structures built 20 or more years ago. More specifically, Figure 2-7 provides data on the percentage of housing units constructed in different periods. About 28 % of housing was built prior to 1960, 33 % was built between 1960 and 1979, nearly 30 % built between 1980 and 1999, and less than 10 % has been built since 2000. These percentages generally hold for rental and owner-occupied housing, although owner occupied housing tends to be slightly older with relatively higher percentages falling into the three older categories. The median value of owner-occupied housing units in Lumberton is $102 500, with approximately 48.5 % of this housing owned without a mortgage. The median rent for rental housing is estimated to be $649 per month (American Community Study, 2015).

The relatively high proportion of rental housing does have the potential for generating important post-disaster consequences for population dislocation, household and housing recovery, and overall community resilience. The literature on population dislocation due to natural disasters has generally found that renters tend to dislocate from their residences more often than do home owners (Girard and Peacock, 1997; Lin et al., 2008; Esnard and Sapat, 2014 & 2017). Depending on the actual nature of flooding associated with Hurricane Matthew, the high levels of rental housing in Lumberton suggests the potential for relatively high level of population dislocation, at least temporarily following the event. Dislocation in turn will result in hardships for dislocated individuals and households and, depending on how long it lasts, the potential for negative consequences to local businesses that lose their employees and customers. Similarly, the literature has also found that housing recovery for rental housing is a much longer and more protracted process (Comerio, 1998; Zhang and Peacock, 2010; Peacock et al., 2014 and 2018). The consequences of a lengthy and protracted housing recovery process can extend population dislocation and the negative consequences for displaced households and families, as well as put local businesses at risk of failure.

2.2.6 Schools

Lumberton's children attend the Public Schools of Robeson County, a county-wide school system made up of 44 schools with a student population over 24 000. There are 2 100 certified employees and 1 100 classified employees, which makes the district the largest employer in the county (Public Schools of Robeson County, 2016). There are also 7 private or alternative schools in Robeson County, three of which are located in Lumberton. There are 17 public schools that serve the students of Lumberton, including 11 elementary, 3 middle, and 3 high schools. During the 2011 to 2012 school year, Robeson County had the second lowest per pupil spending in the state (Robesonian, 2014). Many students come from low-income families; as a consequence, 83.8 % of students have access to free or reduced lunch, compared to 56 % statewide (Kids Count, 2017).
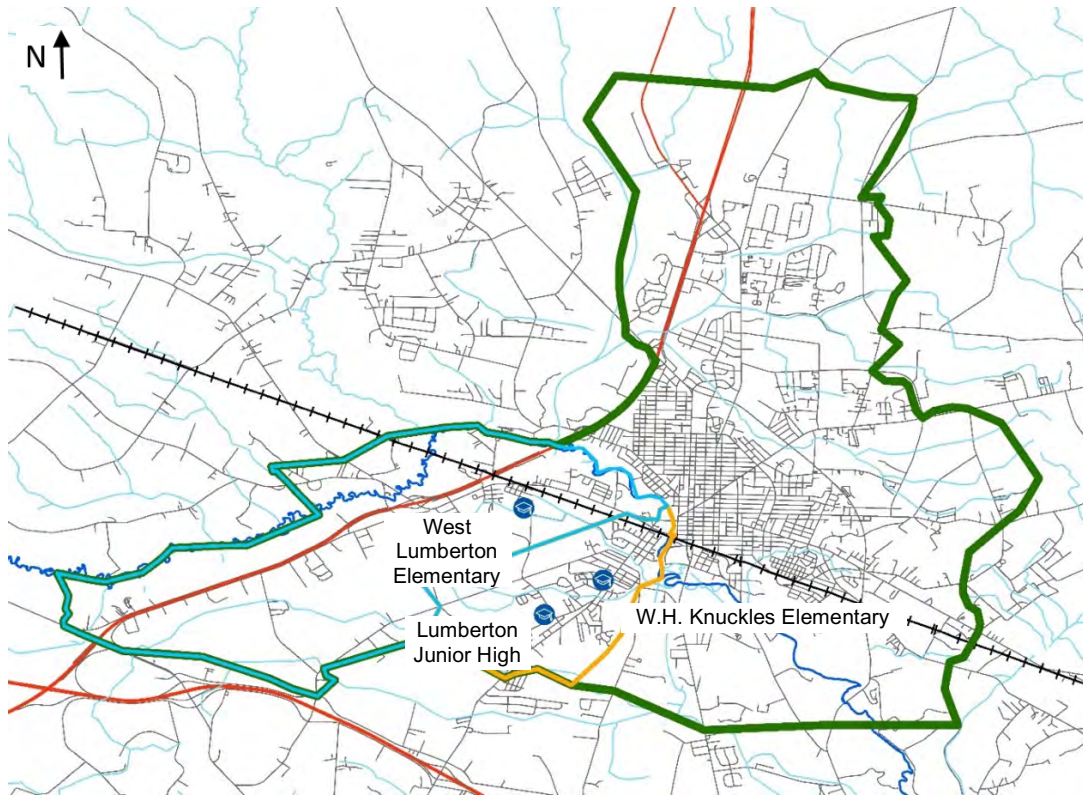
Figure 2-8. Lumberton flooded school locations and boundaries.

Table 2-2. Racial/ethnic composition of three target schools in Lumberton and Robeson County (NCES, 2018).

	W.H. Knuckles Elementary.	West Lumberton Elementary	Lumberton Junior High
White	4	7	80
%	1.4 %	5.0 %	15.9 %
African American	253	71	240
	85.5 %	50.7 %	47.8 %
Native American	29	47	83
	9.8 %	33.6 %	16.5 %
Hispanic	5	8	46
	1.7 %	5.7 %	9.2 %
Asian/Pacific Islander	0	0	17
	0.0 %	0.0 %	3.4 %
Two or more races	5	7	36
	1.7 %	5.0 %	7.2 %
Total Enrollment	296	140	502

Figure 2-8 displays the districts of the three public schools that were flooded during the Hurricane Matthew flooding experienced by Lumberton, with school boundaries obtained by the National Center for Education Statistics (NCES, 2018). The schools impacted are two elementary schools (W.H. Knuckles and West Lumberton), and one junior high (Lumberton Junior High). All three schools were south of the Lumber River and the levee. West Lumberton school boundary is denoted in light blue, W.H. Knuckles boundary denoted in orange, and Lumberton Junior High boundary denoted in dark green. It should be noted that the Lumberton Junior High Boundary encompasses the boundaries of the other two elementary school boundaries. Hence, children attending the two elementary schools will eventually matriculate to Lumberton Junior High.

Table 2-2 displays the race/ethnicity of students at the three schools. All three schools are composed of very high percentages of African American students with substantial percentages of American Indian students as well. W. H. Knuckles student body is 85.5 % African American and 9.8 % American Indian and West Lumberton's students are 50.7 % African American and 33.6 % American Indian. Lumberton Junior High is 47.8 % African American and 16.5 % American Indian. The only school with a somewhat significant percentage of non-Hispanic White students is Lumberton Junior High, with 15.9 % of its student body being identified as White. This relatively low percentage of white students in Lumberton Junior High might be surprising since its district encompasses most of Lumberton which itself is nearly 40 % non-Hispanic White.

2.2.7 Levee

Construction of the levee system in Lumberton was completed in September 1974 to protect the low-lying areas south of the Lumber River (Federal Emergency Management Agency, 2014). The levee system consists of a raised section along the river, connecting to I-95, which acts as part of the levee on the west side of the city and Alamac Road acting as levee to the east. Figure 2-9 displays a more detailed map of the southern sections of Lumberton showing the location of the levee system with an orange line. The levee was built by the U.S. Department of Agriculture, and the City of Lumberton manages and maintains the levee. However, the Jacob-Swamp District manages water movement in channels around the City of Lumberton. Just prior to Hurricane Matthew the city was going to work with the Army Corps of Engineers to certify the levee at the Corps' request.

Figure 2-9. Southern Lumberton with the levee system denoted with an orange line.

2.2.8 Floodplain Development

Flood maps are developed by overlaying rainfall events of varying magnitudes on top of a selected watershed using the topographical information pertinent to that watershed. The maps are generated by computer models that use the flood events of various magnitudes to develop flood elevations of varying annual probabilities. The flood elevation and flood extent that represents the 1% annual chance event (base flood elevation or BFE) is used to create the 100-year flood map since the 1% annual chance event is the regulatory flood elevation.

The Federal Emergency Management Administration (FEMA) allows some protective measures, such as levees, to modify the extent of a floodplain by requiring that the protective measures meet certain criteria including additional height of the top of the levee above the BFE. When the criteria are met, the area protected by the levee is then considered outside the floodplain and the flood insurance requirement for properties protected by the levee is eliminated. The primary building construction requirement in the floodplain is that the top of the lowest floor of the building be at or above the BFE. Areas below the BFE can only be used for parking, access, or storage and foundation walls must include flood vents to relieve hydrostatic pressure caused by flood water.
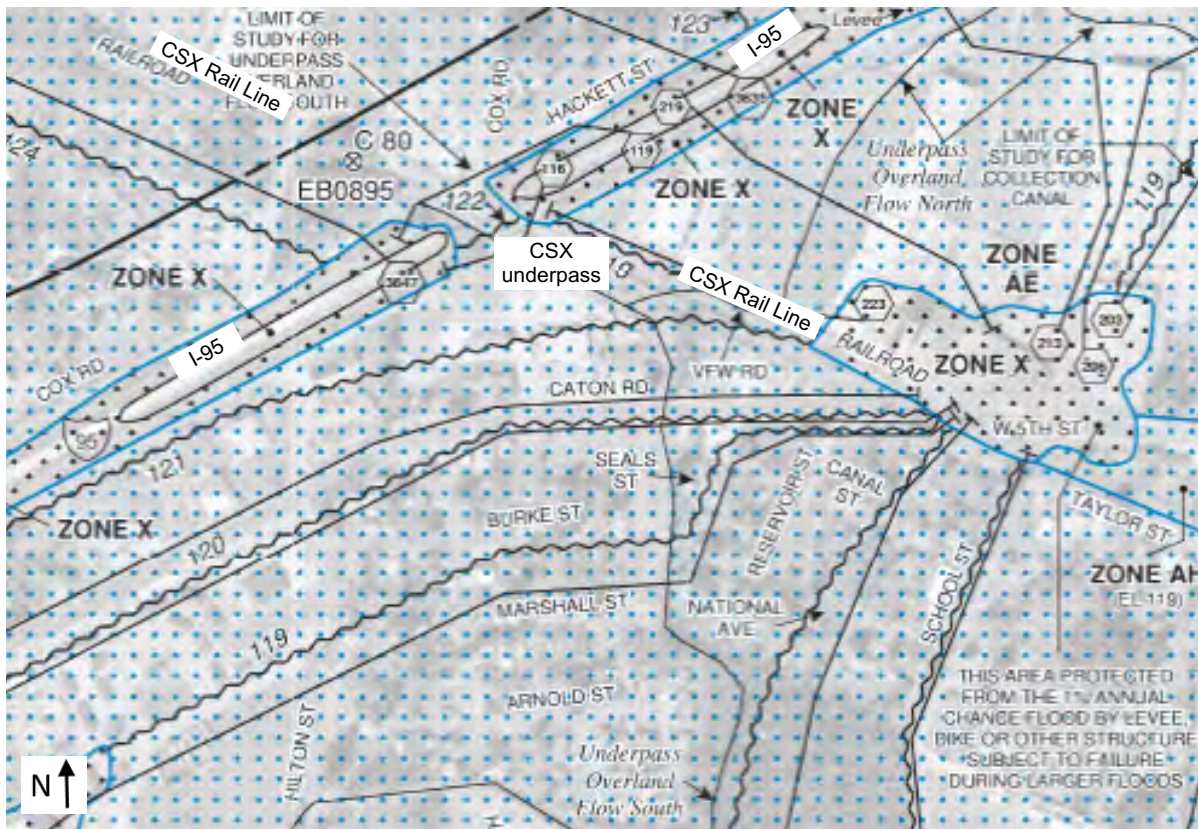
Figure 2-10. Insurance map showing Zone X, or the 500 year flood zone and Zone AE, or the 100 year flood zone (FEMA, 2014).

In 1977, after the levee was constructed in Lumberton, FEMA revised the Flood Hazard Boundary Map to reflect the area protected by the levee (FEMA, 2014), shown in Figure 2-10 as Zone X. Within this zone, homeowners who bought homes or refinanced their mortgages were no longer required to maintain flood insurance. This revision was based on the levee meeting FEMA criteria for a change of the floodplain.

2.3 Hurricane Matthew

2.3.1 Hurricane Path and Timeline

At the time that Hurricane Matthew occurred, it was considered one of the worst storms in recent history, killing over 1 000 people and causing damage estimated by Goldman Sachs at a minimum of $10 billion (Drye, 2016). It was classified as a Category 1 hurricane on September 29, a Category 2 hurricane early on September 30, a Category 3 the same afternoon, a Category 4 that evening, and a Category 5 in the early morning of October 1. The hurricane was downgraded to a Category 4 before affecting nations in the Caribbean Sea. Hurricane Matthew made landfall in Haiti on October 4 with wind speeds up to 257 km/h (160 mph) and torrential rainfall. The storm next hit the Bahamas on October 5 and 6, with wind speeds up to 233 km/h (145 mph). It was downgraded to a Category 3 before skirting the east coast of the United States, with the eye of the storm 120.7 km (75 miles) offshore from West Palm Beach, Florida. Florida received damage due to storm surge in St. Augustine, Jacksonville, and Ormond Beach on October 7, with relatively minor wind damage but including 5 reported deaths. As the storm moved north on

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October 7 it was downgraded to a Category 2 with winds up to 177 km/h (110 mph). The storm tracked through Georgia, flooding parts of Savannah and Saint Simon Island, and parts of Interstate 95 in South Carolina. On October 8 at around 11 a.m. Matthew made landfall in the U.S. as a Category 2 hurricane approximately 48.3 km (30 miles) north of Charleston. Storm surge damaged areas of Charleston and Myrtle Beach before being downgraded to a Category 1 in the afternoon of October 8.

Figure 2-11. Rainfall for Hurricane Matthew with Lumberton evident in the highest rainfall area (Climate, 2017). [1 in = 25.5 mm].

Some areas in North Carolina received more than 380 mm (15 in) of rainfall, with total precipitation shown in Figure 2-11, causing flooding that was exacerbated by already saturated ground due to heavy rains in September. Hurricane Matthew was downgraded to a Post-Tropical

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Cyclone the morning of October 9 as the storm turned eastward toward the Atlantic Ocean. Due to the intense rainfall, riverine flooding continued days after the hurricane passed, especially in areas of North Carolina, which resulted in 25 direct deaths (and additional 6 indirect deaths) statewide including four in Robeson County (NOAA, 2017; Wright, 2016).

2.3.2 Lumberton Flood Timeline

The Lumber River experienced historic flooding due to Hurricane Matthew. Stream gage data were collected at the West 5th Street Bridge, shown as a red-and-white circle in Figure 2-9. Figure 2-12 shows the stream gage data for October, including the large rain event in early October, which led to increased flooding from Hurricane Matthew. The Lumber River crested at almost 6.7 m (22 ft) above the gage datum, which is 2.74 m (9 ft) higher than the National Weather Service flood threshold of 3.96 m (13 ft). The previous maximum flood level occurred in 2004 at just over 5.49 m (18 ft).

The river reached flood stage in Lumberton on October 3rd due to local heavy rains. It reached a local maximum on October 5th and began to decrease for three days (USGS National Water Information System's Web Interface, 2017). On October 8th, rain from Hurricane Matthew began to fall and once again the stream gage height rose drastically for two days until it peaked at a gage height of 6.7 m (22 ft) (36.12 m [118.5 feet] above the NAVD88) on October 11th. The water level began to fall slowly, eventually dropping below flood level on October 23rd.
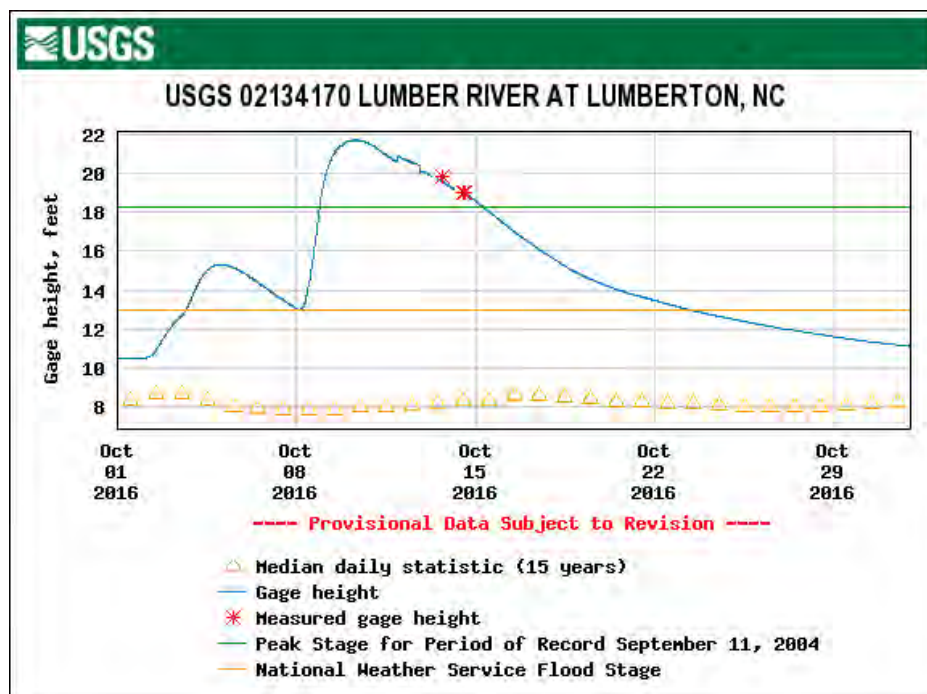
Figure 2-12. A hydrograph reporting river levels at the Lumberton gage location during October 2016 (USGS National Water Information System's Web Interface, 2017). [1 ft = 328 mm]

The North Carolina Flood Inundation Mapping and Alert Network (FIMAN), an advanced flood monitoring tool used by first responders and emergency managers, allows users to monitor flood levels and predict damage to communities using NOAA stream gage data (Flood Inundation Mapping and Alert Network, 2017). A FIMAN report, shown in Figure 2-13, estimated the

Lumber River would crest at 6.55 m (21.5 feet) above the datum and predicted damage to an estimated 882 buildings totaling an estimated $23.9 million in damage. It should be noted that the FIMAN tool only estimates damage within certain distances from the gage location (approximately 2.4 km [1.5 miles] upstream and 1.6 km [1 mile] downstream), which underrepresents the actual inundation area in Lumberton.

FIMAN Scenario Flood Report

Lumber River at Lumberton
Site ID: 02134170

Major Flooding Scenario

Scenario at 119 ft
Major Flooding

21.5 ft	882 Buildings
119 ft (NAVD 88)	$23,860,000
Scenario Stage / Elevation	**Impacted Structures / Damages**

Scenario Stream Elevation compared to Risk Ratings

LEGEND
- Major Flooding
- Moderate Flooding
- Minor Flooding
- Monitor
- Normal Conditions
- Scenario Flood Elevation

Estimated Damages based on a Scenario. The Elevation for this scenario is 119 ft.

Estimated Scenario Building Damages

DEPTH	Total Damages	Total Count	Residential Damages	Count	Public Damages	Count	Commercial Damages	Count
Sub Structure	$1,821,000	481	$1,786,000	468	$0	0	$35,000	13
0 - 1 ft	$1,994,000	134	$1,584,000	118	$18,000	1	$392,000	15
1 - 2 ft	$4,025,000	136	$2,652,000	118	$0	0	$1,373,000	18
2 - 3 ft	$4,603,000	90	$3,526,000	75	$0	0	$1,077,000	15
3 - 4 ft	$1,249,000	31	$798,000	24	$152,000	1	$299,000	6
4 - 5 ft	$10,093,000	7	$46,000	2	$0	0	$10,047,000	5
> 5 ft	$77,000	3	$77,000	3	$0	0	$0	0
TOTAL	$23,860,000	882	$10,468,000	808	$170,000	2	$13,222,000	72

Impact Summary

Road Impact: Numerous roads are closed and many areas are isolated. Water begins to also flood along the right bank from W 2nd St to Chicken Foot Rd. Water **Building Impact:** 882 Buildings impacted. $23,860,000 Est. Damages. **Utilities Impact:** Water Treatment Plant property along Lowery St begins to flood. **Other Impact:** Low land flooding will occur along the river.

Note: Additional buildings may be impacted outside of flood inundation extent. Damages do not include content and inventory.

Figure 2-13. North Carolina Flood Inundation Mapping and Alert Network (FIMAN) estimates for the Lumber River gage in Lumberton (Flood Inundation Mapping and Alert Network, 2017). [1 ft = 328 mm]

2.3.3 CSX and VFW I-95 Underpass

An underpass exists at the intersection of I-95 and the CSX railroad as indicated by the green star in Figure 2-8. At this location, the CSX railroad and VFW Rd go under I-95, which is acting as the northwest arm of the levee system. An aerial view of the CSX and VFW Rd underpass of I-95 taken on October 11th during the flood is shown in Figure 2-14 (NOAA Hurricane Matthew
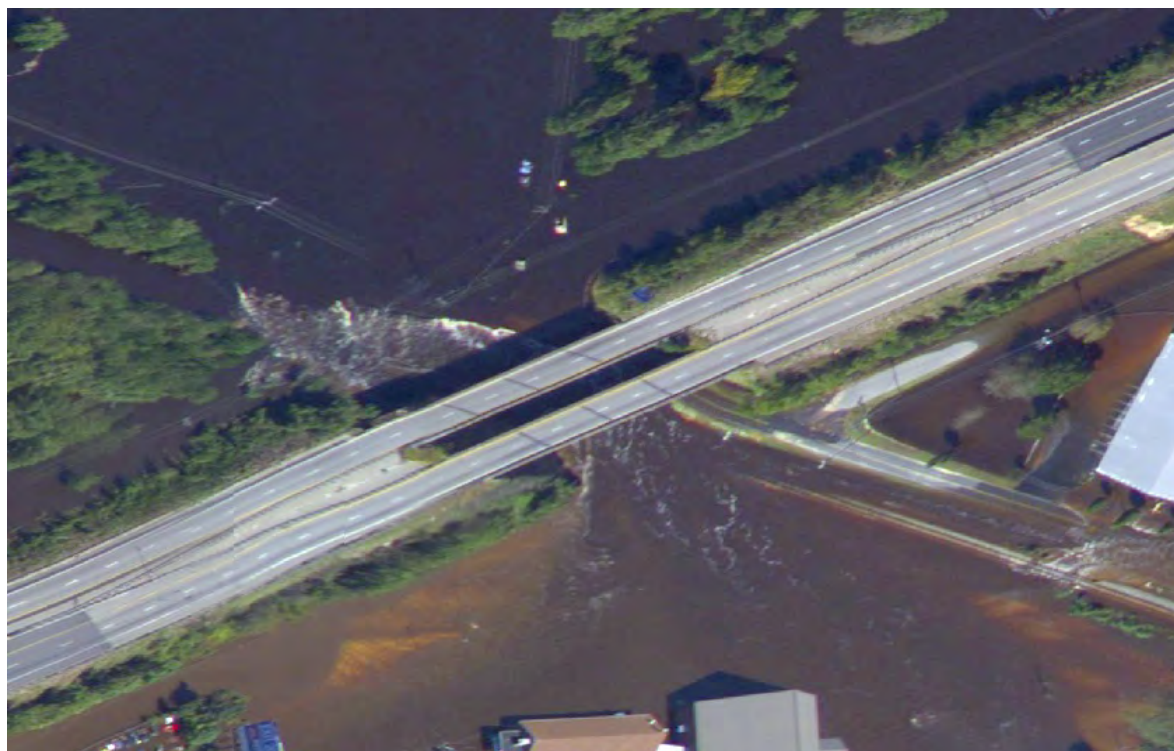
Figure 2-14.   Lumberton levee system at the location of the CSX underpass showing flood waters moving through the underpass (NOAA Hurricane Matthew Imagery, 2016).

Imagery, 2016). The image shows water flowing through the underpass covering both the railroad tracks and the road. It should be noted that no water typically flows under I-95 at this location. A Digital Elevation Model (DEM) was obtained from the USGS National Elevation Dataset to determine elevation values along the levee system. The elevation of the levee on the north side is typically 37.2 m to 37.5 m (122 ft to 123 ft). To the west, where the levee merges with I-95, the elevation ranges from 37.5 m (123 ft) on the low end and crests at around 44.2 m (145 ft), on either side of the CSX overpass. On the eastern edge of the levee where the river turns south and curves around the city, the elevation is consistent with the northern elevations and gradually drops to around 35.1 m (115 ft) as the distance between the levee and river increases.

According to a Flood Insurance Study compiled in 2014 by a cooperative partnership between the State of North Carolina and FEMA, "To provide safe flood protection and be mapped as such, FEMA specifies that all levees must: have a minimum of three feet of freeboard against the 1 % annual chance flood event; be equipped with closure devices at every opening; be constructed with embankments and foundations that are certified not to fail due to erosion, seepage, or instability; and be certified against future loss of freeboard due to settling" (FEMA, 2014 p.15). The study goes on to say "A 2003 survey of the I-95 bridge opening for Seaboard

Coastline Railroad and VFW Rd revealed that it was not constructed in accordance with requirements of the accepted drainage project agreement with NRCS. Also, the plan does not meet the current FEMA regulations for the structure closures. Therefore, at this time it must be assumed that the bridge opening cannot be adequately blocked to prevent flow from the Lumber River into the levee-protected area" (FEMA, 2014 p. 27).

A collection of photos describing flooding at the CSX railroad underpass of I-95 is shown in Figure 2-15 to detail the flood through time. These photos are compared to stream gage data from the Lumber River and elevation data from the underpass. Aerial imagery of the underpass captured on October 11, the day the stream gage indicated the crest of the flood, is shown in Figure 2-15(a). The arrows and letters on the aerial image in Figure 2-15(a) indicate the location and directions of photographs presented in Figures 2-15 (b)-(h). Figure 2-15(b) shows the underpass in its pre-flood state. Figure 2-15(c) shows mitigation efforts implemented before the flooding including sandbags in the ditches surrounding the railroad tracks and VFW Rd. The photo shown in Figure 2-15(d) was taken at 3:44 PM on October 11, with a water depth estimated to be 0.3 m to 0.6 m (1 ft to 2 ft) above the roadway. This estimated depth closely matches the National Elevation Dataset DEM which estimates the ground elevation near 35.6 m (120 ft) and the USGS stream gage which estimates the water elevation near 37.2 m (122 ft) at that time. The hydraulic jump shown in the picture is also evident in the aerial image, and is attributed to roadway blowout.

The roadway blowout below I-95 can be seen in Figure 2-15(e), which was taken on October 15 when the water elevation had dropped approximately 4 feet as shown on the hydrograph in Figure 2-12. A vertical drop caused by erosion along the roadway is clearly visible. Figure 2-15(f) shows erosion of the I-95 bridge abutment exposing the foundation. This photograph was taken on October 16, after repair work on the abutment had begun. Figure 2-15(g), taken on October 17, shows erosion under the rail line, which is seen hanging where the base material was washed away. This photo also shows blowouts and sediment that was eroded from the underpass and washed into the city.

Based on correspondence with Ken Murphy, the North Carolina Department of Transportation regional maintenance engineer, abutments on both sides of the underpass were effected and toe slopes were undercut. Repairs to I-95 included removing approach slabs, driving sheet piles to both driving directions on the South side of the overpass, placing riprap to build the toe slopes for the abutments, and repairing several hundred feet of railroad tracks. Figure 2-15(h) shows the underpass on November 29, after structural repairs were completed and the rail line and roadway above were both functioning properly. Less than $2 million of flood-related repairs were performed on I-95 at this location, which took less than a week to complete. During the time that the Interstate was closed, traffic was diverted through Fayetteville.
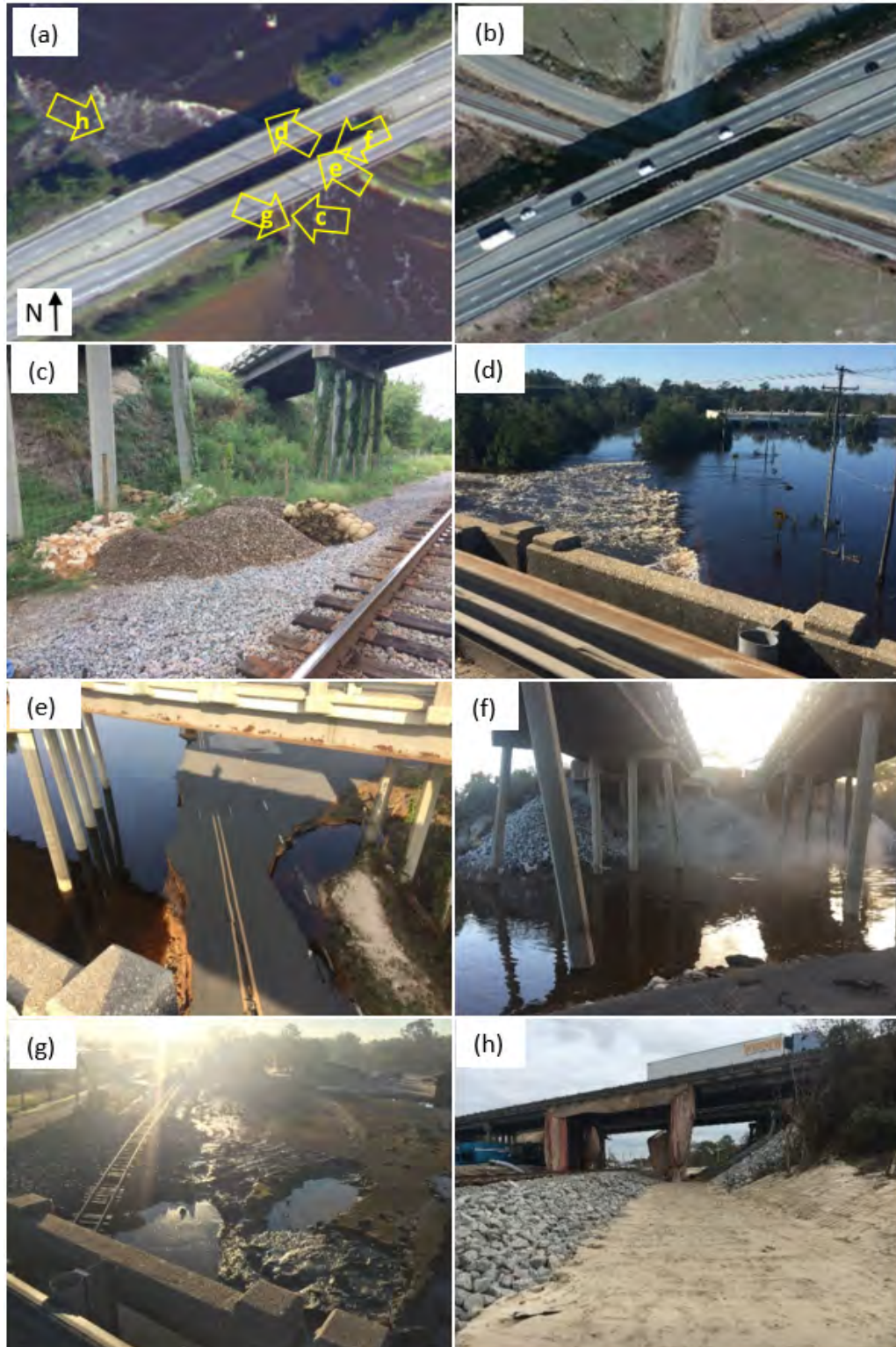
Figure 2-15. Imagery of the CSX and VFW Road - I-95 underpass. Photo (a): NOAA Hurricane Matthew Imagery, 2016. Photo (b): Esri, DigitalGlobe, GeoEye, i-cubed, USDA FSA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community. Photo (c): Robert Armstrong, Lumberton Public Works. Photos (d), (e), (f), (g), (h): Ken Murphy, NCDOT.

2.3.4 Lumberton Flood Inundation

An aerial image mosaic captured by NOAA on October 11th is shown in Figure 2-16. The flooding to neighborhoods south of the river is visible along with some flooding to the north due to stream overflow. The water reached the Lumberton Municipal airport (LBT) but no damage was recorded there.

Figure 2-16. Aerial imagery of inundation of Lumberton on October 11, 2016. Photo: NOAA Hurricane Matthew Imagery, 2016.

2.3.5 Affected Networked Systems

The geographically distributed infrastructure systems—transportation, power, water and wastewater—are similar to those found in most communities. Therefore, the features that distinguish them from normal communities are the focus of this discussion. Interstate 95, which largely skirts Lumberton to the west of the city, averages approximately 50 000 vehicles per day at Lumberton. The counts were approximately 57 000 in Lumberton near the Lumber River crossing in 2015, which when compared to the traffic counts of approximately 47 000 two interchanges to the north and 41 000 two interchanges to the south, suggest that potentially some of the Lumberton counts are due to local traffic usage (North Carolina Department of Transportation, 2017). There are few alternatives to I-95, when traveling north/south in Lumberton. For example, travel from Fayetteville, NC, which is the next major city to Lumberton's north on I-95, to Florence, SC, the next major city to Lumberton's south on I-95, would require a minimum of 45 minutes additional driving time if utilizing major roads (US numbered routes) instead of the Interstate. However, local roads were used as an alternative affecting response and recovery efforts due to traffic congestion (EM, 2016).

The electrical power in Lumberton is supplied by Duke Energy and, as with all large systems, is managed by separate transmission and distribution groups. The electrical power network consists of substations owned by Duke Energy as well as the City of Lumberton. Electrical power was lost to many residents of Lumberton due primarily to downed trees and some substation flooding. Electrical power to Lumberton was completely restored by December 9, 2016. Drinking water and wastewater services are managed by Lumberton Public Works. The water network was built in 1992 with funding from the Environmental Protection Agency (EPA) (Armstrong, 2016). A levee was in place to protect Lumberton where the water treatment plant was located, but the water treatment plant remained inside the 100-year floodplain. The water intake to the plant is 60 % from the Lumber River and 40 % from 8 deep-water wells and approximately 5-6 million gallons of water is required for the city's daily functions. Only 6 % of U.S. public water systems with their own water sources are supplied by both surface and groundwater (National Service Center for Environmental Publications, 2017).

Hurricane Matthew disrupted water service in Lumberton (Armstrong, 2016) on October 10th, when the river intake pump suffered damage, a treatment plant generator failed, and the sole water treatment plant was inundated. Limited service was able to be resumed by October 15th, when 4 trailers carrying portable membranes were brought in to treat up to 6 MGD of water pumped directly from the groundwater wells, bypassing the treatment plant. Still, the wells began losing capacity after days of flushing an empty distribution system. A water conservation notice was issued to build up enough capacity to flush pipes and backwash the treatment filters. The conservation notice was lifted October 20th, but a boil water advisory for the city was active until the 25th. The treatment plant was operational by the end of the month, though the generator was still broken. Subsequent detection and repair of leaks in the distribution system revealed less subgrade damage than anticipated, with only one under-river main repair needed. The wastewater treatment plant was not damaged, although sanitary sewer overflows compromised the Lumber River water quality from upstream sources. Figure 2-17(a) indicates locations of failed networked systems for the city of Lumberton. Figure 2-17(b) and (c) show the drinking water plant serving the city before and during flooding, and Figure 2-17(c) and (e) show an electrical substation before and during flooding. The failed water intake was not visible in aerial imagery.
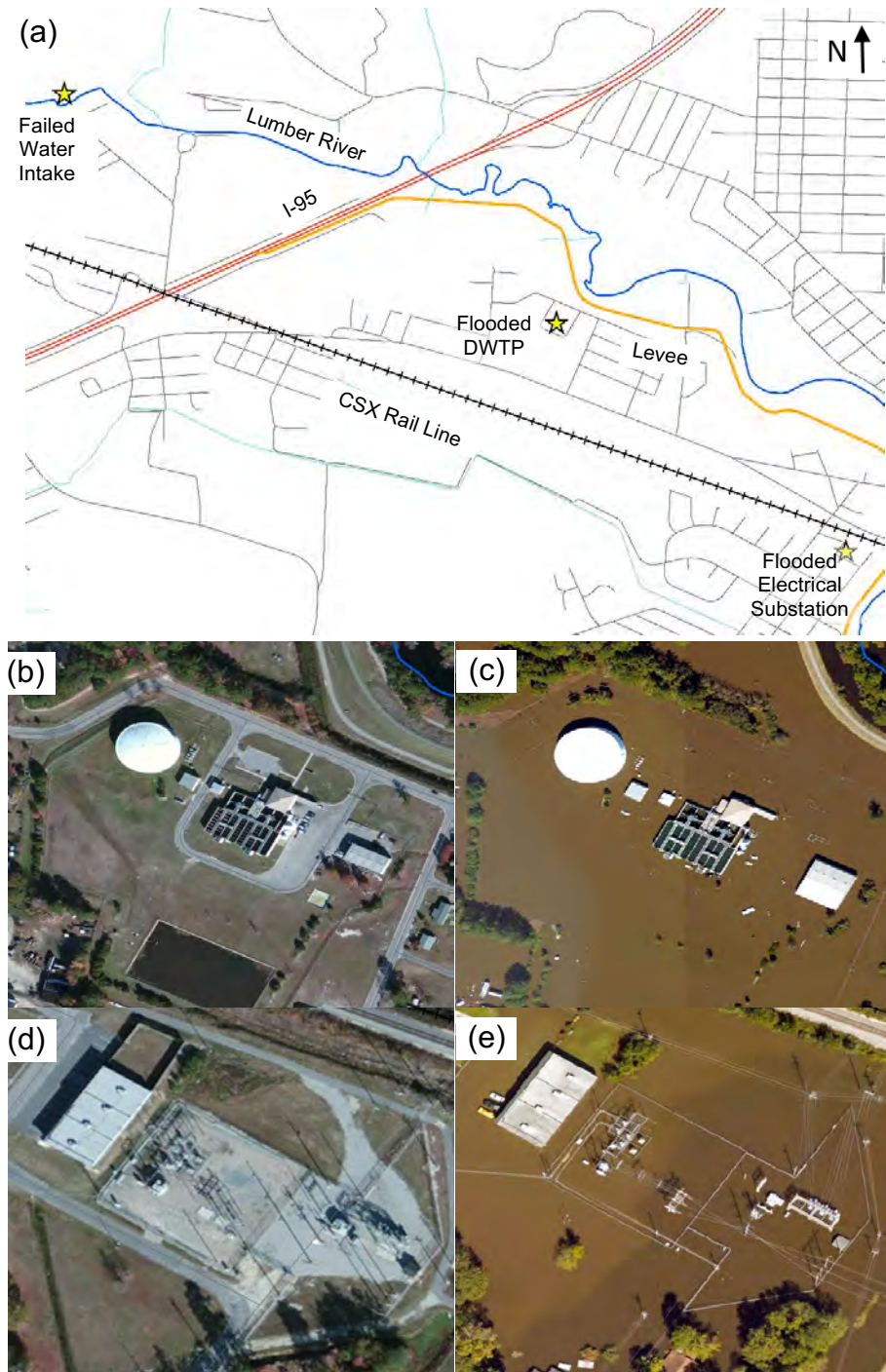
Figure 2-17. (a) A map of the flooded network infrastructure nodes, (b and d) aerial imagery of drinking water treatment plant (DWTP) and electrical substation before, and (c and d, respectively) during flooding. Photos: Esri, DigitalGlobe, GeoEye, i-cubed, USDA FSA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community.

2.3.6 Overall Impacts of Matthew

An estimated $1.5 billion worth of damage to an estimated 100 000 homes, businesses, and government buildings were reported in North Carolina. Across the state there were 26 deaths, mostly due to motorists being swept away while driving. On October 10th, FEMA approved a major disaster declaration for 10 counties in North Carolina, including Robeson. The federal assistance includes grants for temporary housing, home repairs, and low-cost loans to cover uninsured property losses as well as other programs to aid in the recovery of individuals and businesses (NCEM/Reuters, 2016).

2.3.6.1 Evacuation and Sheltering

Across North Carolina, there were over 600 rescue missions saving more than 2 300 people (Wright, 2016). In Lumberton and other low-lying areas in Robeson County, the flood water rose quickly. This resulted in approximately 1 500 citizens being stranded in their homes and on rooftops waiting to be rescued by helicopter and boat (Wright, 2016). Many people who evacuated early were able to leave town, however, the flooding damaged or destroyed approximately 5 000 vehicles, which made it difficult for many others to get to safety (Gellatly, 2016).

In Robeson County, shelters were opened at five locations: South Robeson High School, Purnell Swett High School, Red Springs High School, St. Pauls High School and the Bill Sapp Recreation Center. Another shelter opened at Gilbert Carroll Middle School, but had to be moved quickly as floodwater began to threaten the building. These shelters served nearly 1 800 evacuees in the early days following the storm. In Robeson County, over 5 000 people were placed in hotels and other temporary housing provided by FEMA (Gellatly, 2016). Mayor Bruce Davis reported that as of early January 2017 there were still 695 families not living in their homes and 500 still living in hotels awaiting an option for more permanent shelter (Brown, 2017; Gellatly, 2016).

2.3.6.2 School Damage and Student Displacement

The flooding that followed Hurricane Matthew had a major impact on the Public Schools of Robeson County. All 42 schools, serving 24 000 students in the district, were closed for three weeks due to a combination of road closures, loss of electricity, damaged water systems, flooded buildings, contaminated kitchens from rotting food, need for air quality testing, and displaced students and staff members. Students and staff returned to some schools on October 31, 2016 with students from schools remaining closed being placed into other schools.

The central office building for the school district suffered a total loss due to flooding and contamination from fuel tanks forced off of their foundations during the flood (Willets, 2016). Other buildings nearby were damaged as well, including the Program Services Department, Maintenance Department, and the Planetarium. Many of the school district supplies housed in these buildings were damaged or destroyed (Willets, 2016).

Lumberton fared the worst in terms of school damage. W.H. Knuckles Elementary experienced flood damage in the cafeteria and kindergarten classrooms, Lumberton Junior High suffered damage to the auditorium, and seven additional schools needed food removal and clean-up services due to weeks with no electricity. West Lumberton Elementary School was completely flooded and remained uninhabitable as of February 2017; all of their 130 elementary students,

teachers, and staff occupied a wing of Lumberton Junior High School until further notice (Public Schools of Robeson County, 2016; Willets, 2016).

2.3.6.3 Population and Housing

As was briefly discussed above, the population and housing characteristics of Lumberton are rather unique and depending on the actual areas impacted by the flooding, these characteristics may have consequences for population displacement and housing restoration and recovery. More specifically, the disaster literature suggests that minority and low income populations live in the highest hazard areas (e.g., FEMA, 2018), and are likely to experience higher levels of displacement, particularly longer-term displacement. In addition, rental housing is often slower to restore and recover.
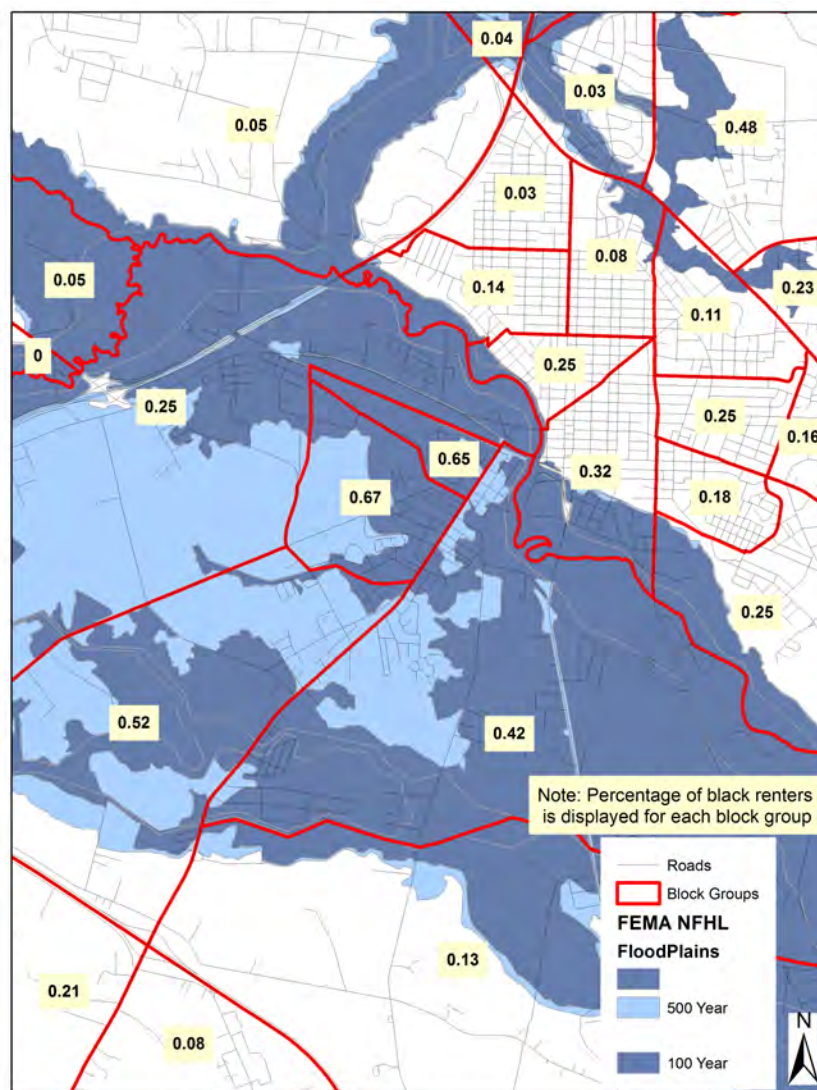
Figure 2-18. Black population concentrations in Lumberton relative to inundation areas based on 2010 Census data.

Figure 2-18 presents a map overlaying US Census block data for 2010 on concentrations of Lumberton's Black population (approximately 38 %) relative to the 100 year and 500 year flood plains (shown in dark blue and light blue, respectively, in Figure 2-18), which capture areas that likely experienced flooding. The map clearly suggests that there were substantial concentrations of Lumberton's Black population within areas experiencing high levels of flooding (see Figure 2-16). Figure 2-19 displays concentrations of households that rent their homes in Lumberton, again based on US Census block data. Given the rather large percentage of rental housing in Lumberton, it is not surprising that rental housing is found throughout the community. However as displayed in the map, there was a particularly significant area of rental housing found within the flood inundation area. Figure 2-20 displays data on minority (non-White population) rental households with children–some of the most vulnerable households with respect to dislocation and other post-disaster issues. Clearly, there are significant concentrations of these households within the areas experiencing flooding.
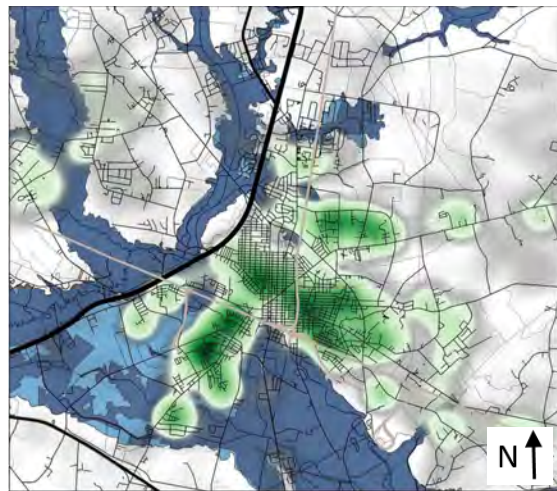
Figure 2-19. Renters concentrations in Lumberton based on 2010 Census data.
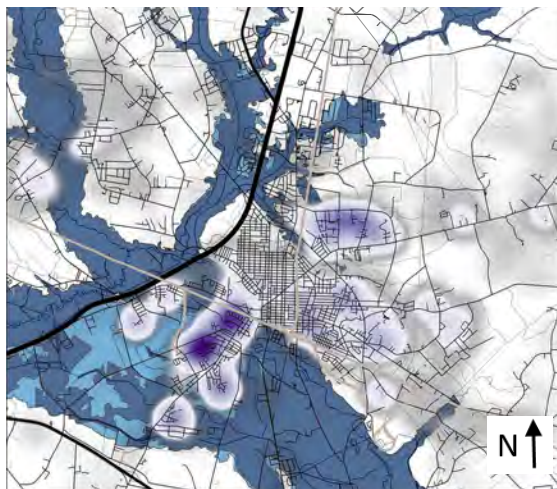
Figure 2-20. Concentrations of minority renters with children based on 2010 Census data.

Chapter 3: Field Study Methodology

3.1 Introduction: Study Goals and General Strategies

In order to understand community resilience from empirical data, researchers need comprehensive baseline data on the community's key social, economic, environmental and built environmental characteristics prior to a hazard event. Researchers would then need to gather data on how the community and its constituent elements (e.g., households, businesses, governmental organizations) prepared for, were impacted by, responded to, and ultimately recovered from the event. Therefore, researchers need data on community functioning before the event plus data over time, collected at strategic points in time, so that impact, response, and recovery can be understood as these stages unfold. Together these data can help us understand what makes a community "resilient" or what attributes facilitate "bouncing back" from disasters.

Unfortunately, most communities are not equipped to collect thorough data on pre-event functioning of their key social, economic, environmental and built environmental characteristics. Furthermore, the expense, time, and personnel necessary to gather scientifically valid and reliable data in the immediate aftermath of an event as well as through the response and recovery period on even a few, much less all key dimensions of community, make it challenging and prohibitively expensive. Consequently, researchers typically narrow the scope of their investigations by specifying a more limited range of key community characteristics they are seeking to study. Additionally, where possible they gather secondary data on pre-existing conditions and retrospective data from respondents in order to reconstruct the "baseline" situation of a community prior to impact.

The general goals of the Lumberton field investigation were twofold. First, the investigators set out to learn as much as possible about impacts to and the post-disaster recovery of a specific part of the Lumberton school system, focused on the households, residential building stock, and critical infrastructure (electric power network, water, and gas) within the boundaries of the specific school districts. Second, investigators gathered representative data that could be utilized to improve flood hazard fragilities for residential housing, develop population dislocation models, better understand issues confronting local school districts impacted by disasters, and establish baseline data for housing recovery modeling. The intent is to use these data to improve the modeling and algorithms included in IN-CORE that will ultimately enable researchers and community stakeholders to optimize investments in community resilience related to flooding events.

An important addition to these general goals was to develop field research strategies for undertaking systematic interdisciplinary engineering *and* social science data gathering activities that can be replicated and improved upon in the future. There are some examples of interdisciplinary field research, such as the National Oceanic and Atmospheric Administration's National Weather Service Assessment teams (www.weather.gov/publications/assessments) that gather field data to evaluate the utility of NWS products and services related to severe weather events and post-earthquake research teams deployed by the Earthquake Engineering Research Institute (EERI) Learning from Earthquakes (LFE) program that deploys interdisciplinary field reconnaissance teams to gather data on lessons that might reduce future earthquake losses (https://www.eeri.org/projects/learning-from-earthquakes-lfe/). However, few teams attempt to gather systematic random samples that are representative of their studies' communities or areas

of focus. Random sampling strategies better ensure that the data gathered are representative of the population under study and the nature of the event's impact on the built and social environments within the area of interest. The goal of developing a strategy as part of this field study it to facilitate the development of resiliency modeling, which is a fundamental and core goal of the Center of Excellence (CoE). Furthermore, this field study is intended to be an example of a collaborative field effort between NIST and CoE researchers, focused on developing a framework for conducting interdisciplinary field investigations.

3.1.1 Research Objectives

The major research objectives of the Lumberton field study are to:

1. Improve the understanding of how public schools cope and respond to the impacts and disruptions resulting from the flooding;
2. gather information on flood impacts to private sector businesses, particularly those involved in critical infrastructure (e.g., electric power network), and document major decisions by Local, State, and Federal agencies during the response and recovery phases of the disaster;
3. improve damage assessment instruments and subsequent fragility functions related to flooding damage of residential structures;
4. improve household dislocation models by collecting data on household dislocation and factors shaping dislocation such as damage to a household's residence, household socio-economic and tenure characteristics, and damage/disruption to critical infrastructure;
5. gather data on households that will provide an opportunity to assess the utility of stochastic population inventory estimation methods[8] being developed as part of COE testbed activities; and
6. model long-term housing and household recovery, using collected baseline data to set the initial conditions for quantitatively assessing the community recovery over time.

3.2 Sampling Methodology and Strategies

Two distinct data collections activities were undertaken to meet the above objectives for the Lumberton field study: a household/housing survey and qualitative interviews with community leaders/stakeholders. The goal of the housing/household survey was to obtain data on a representative sample of housing units with respect to flood damage and, where possible, obtain data on the individuals that occupied these housing units. The qualitative leader/stakeholder

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[8] Some of the social science algorithms, such as one of the population dislocation algorithms, being incorporated into IN-CORE, are based on household characteristics which are generally not available at the housing unit level. However, there is a growing literature in both the social science and health science areas for generating synthetic household data utilizing a variety of secondary data sources that offer solutions for generating these data and incorporating them into improved algorithms. Researchers in the CoE are also developing these methods and the data being gathered as part of the Lumberton fieldwork may provide an opportunity to assess the utility of these methods.

interviews sought to obtain contextual information on how the community, schools, businesses and officials responded to the event, particularly flooding impacts, addressed restoration activities and began to address recovery. Since each activity had different objectives, it dictated two distinct sampling strategies.

3.2.1 Housing/Household Survey

A number of factors were used to develop the sampling strategy for the housing/household survey. This work arises out of research objectives related to improving damage residential housing assessment instruments and fragilities for flooding, gathering household and housing data to improve dislocation models, assess stochastic population inventory estimation methods, and establishing baseline data for housing and household recovery, and understanding how flooding based disruptions impacted schools -- particularly with respect to households dependent on those schools. As a result, the primary sampling goal for the housing/household survey was to obtain a representative sample of housing units and, where possible, the households occupying those units within the study area which was defined by the school attendance zone for Lumberton Junior High, which includes the attendance zones for two elementary schools. This school attendance zone (the dark black boundary line) is identified in Figure 3-1 along with the city boundary (black dashed line). As can be seen, the school boundary includes most of Lumberton along with areas adjacent to the city, with the exception of some minor appendages that extend beyond the attendance zones to the northwest, west, and southwest of the city. The school attendance zone also includes both areas inundated by flooding as well as areas not directly impacted by the flooding. It was paramount for the sample to have variability and representativeness of Lumberton with respect to damage (flood heights and structural damage), socio-demographic characteristics of the population (race/ethnicity, income, and tenure), and housing types (single family detached and attached, and various forms of multi-family structures).
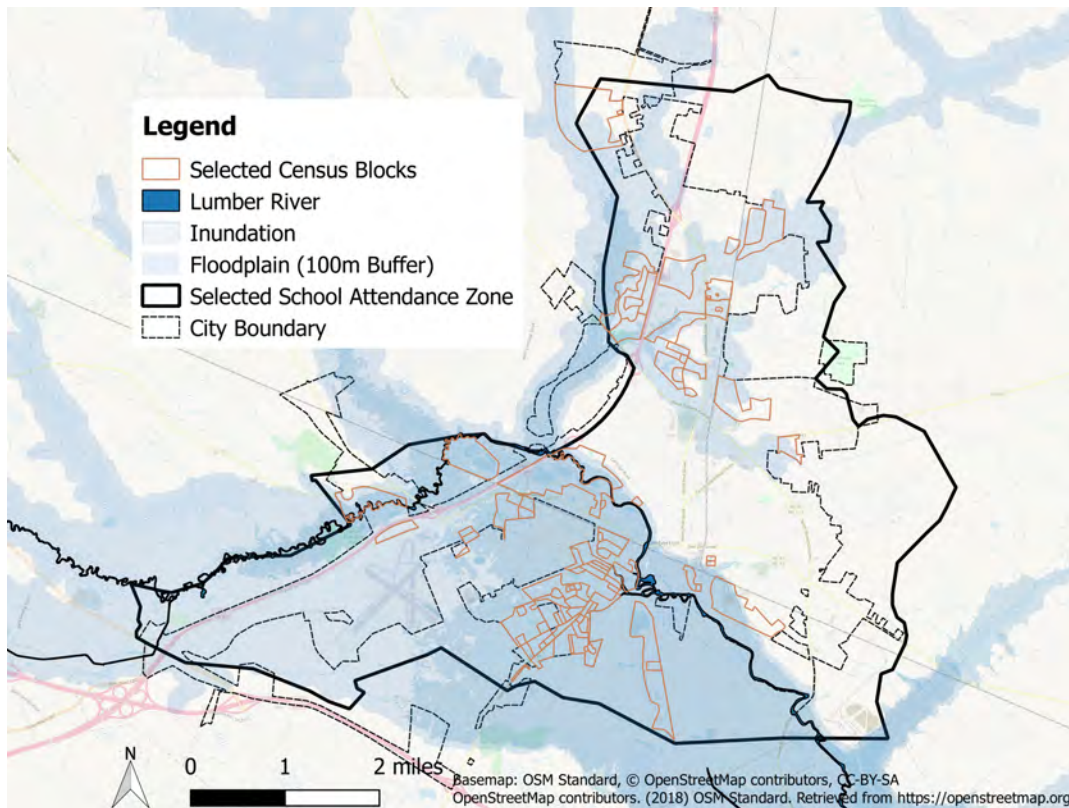
Figure 3-1. Target sampling area with sampled blocks. [1 mile = 1.61 km]

We wanted to ensure that all levels of flooding damage to residential housing were captured, ranging from no damage to the highest levels of damage. Unfortunately, highly accurate inundation data, particularly with respect to residential structures were not available. Hence, we attempted to identify areas with relatively high probabilities of having been flooded and those with relatively low, but some probability of flooding. Areas with lower probability of flood damage were identified as the areas outside of the predicted inundation area, but in FEMA's designated 100 year or 500 year floodplains plus a 100 m buffer around this area. These low probability areas are identified by the lighter blue shading. Areas with a higher probability of flooding damage were identified based on the University of Alabama's predicted flood inundation. These predicted inundation areas appear in slightly darker blue shading on the map because they overlaid within the 100 or 500-year flood plain.

Since one goal was to model population dislocation due to the flooding, pre-event baseline data for the population of individuals and households in our focus areas prior to the event were needed. The only reliable, valid data to employ as baseline data are the US Census data. Specifically, baseline data for pre-event household counts and occupancy, are derived for the dislocation models by employing U.S Census block data from the 2010 decennial census, updated where possible by the 5 year American Community Survey (ASC) estimates (2011-2015).

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Based on the above factors and goals of the fieldwork, a two-stage non-proportional stratified cluster sampling strategy[9] was designed: the penultimate sampling units were census blocks, and the primary sampling units were housing units and the households residing in those units. Utilizing the census block as a penultimate sampling unit has advantages for face-to-face survey work, particularly over a spatially dispersed area, including logistical efficiency and safety management. To fully develop the sampling strategy, data on all blocks for Lumberton were gathered.[10] These data included the boundary files for block and census data on the number of individuals, households, race and ethnicity, housing units, and housing types. Based on these data, the penultimate sampling units (blocks) were selected utilizing a probability proportion to size (PPS) random sampling procedure, with blocks in high probability flooding areas selected 3-to-1 over low probability flooding areas. Housing units would then be randomly selected on a fixed rate of 8 random units per block. The combination of PPS selection with a fixed number of primary or housing unit selection, after weighting, assures a representative sample of the area (Kish, 2004).

The above sampling strategy was implemented using the following steps. First, all census[10] blocks were identified within the attendance zones of the target schools and within the 100 year and 500 year floodplains, supplemented by additional information regarding likely inundation areas within the school attendance zones. Based on the criteria above, we identified 1 153 blocks falling completely or intersecting with the Lumberton Junior High school boundary area; there are a total of 9 714 housing units within these blocks. A number of these blocks (323) had very few housing units (< 5) and were, therefore, dropped from the sample. In total, there were 830 blocks with 5 or more occupied housing units. Of these, 168 blocks fell completely or partially into the high- or low-probability flooding areas within the school district, with the remaining 662 falling outside of our focus areas. In other words, 168 blocks were within our sample frame, with 79 considered low probability and 89 considered high probability of experiencing flooding. From this sample frame, we drew a random sample of 80 blocks based on a probability of selection proportionate to size (proportion of the sampling area's housing units (HUs), and oversampling blocks in high probability flooding areas. The final sample included 56 census blocks in the high probability areas and 24 in the low probability areas. These census blocks are also identified in Figure 3-1. Based on US Census data these blocks contained 3 617 housing units of which 3 320 (91.8 %) were occupied and 297 (8.2 %) were vacant. Once the blocks were selected, the US Census data on HUs from these blocks was combined with *Google[11]* mapping data, *Google*

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[9] A two staged non-proportional stratified cluster sample is a sampling procedure consisting of two random sampling stages. The first stage entailed randomly selecting "clusters" of housing units where the clusters were census blocks which were randomly selected with a probability proportionate to size defined as the number of housing units per block. The second stage consisted of randomly selecting a fixed number of housing units in each block sampled during the first stage. Additionally, during the first stage, blocks were selected non-proportionately, selecting 3 blocks in high probability flooding areas, to every one block selected in low probability areas. This latter step was taken to enable the field team's limited time and resources to be expended most efficiently to gather data on damage residential structures, rather than non-damage structures.

[10] Census data, boundary files, and supporting documentation were obtained from the US Census website.

[11] Certain commercial products are identified in this paper in order to specify the experimental procedure adequately. Such identification is not intended to imply recommendation or endorsement by the National Institute of Standards and Technology, nor is it intended to imply that products identified are necessarily the best available for the purpose.

Street View[12], and tax portfolio parcel data to identify the numbers and locations of structures and identify housing units within structures located in the block. Within each of these 80 blocks of the primary sample, a fixed number of eight housing units (HU) were randomly selected along with additional random selection of two HUs that served as replacements. These replacements are required if initially selected HUs are not actual residential HUs or if households could not be located or surveyed (e.g., hard refusals, no adult, no access).
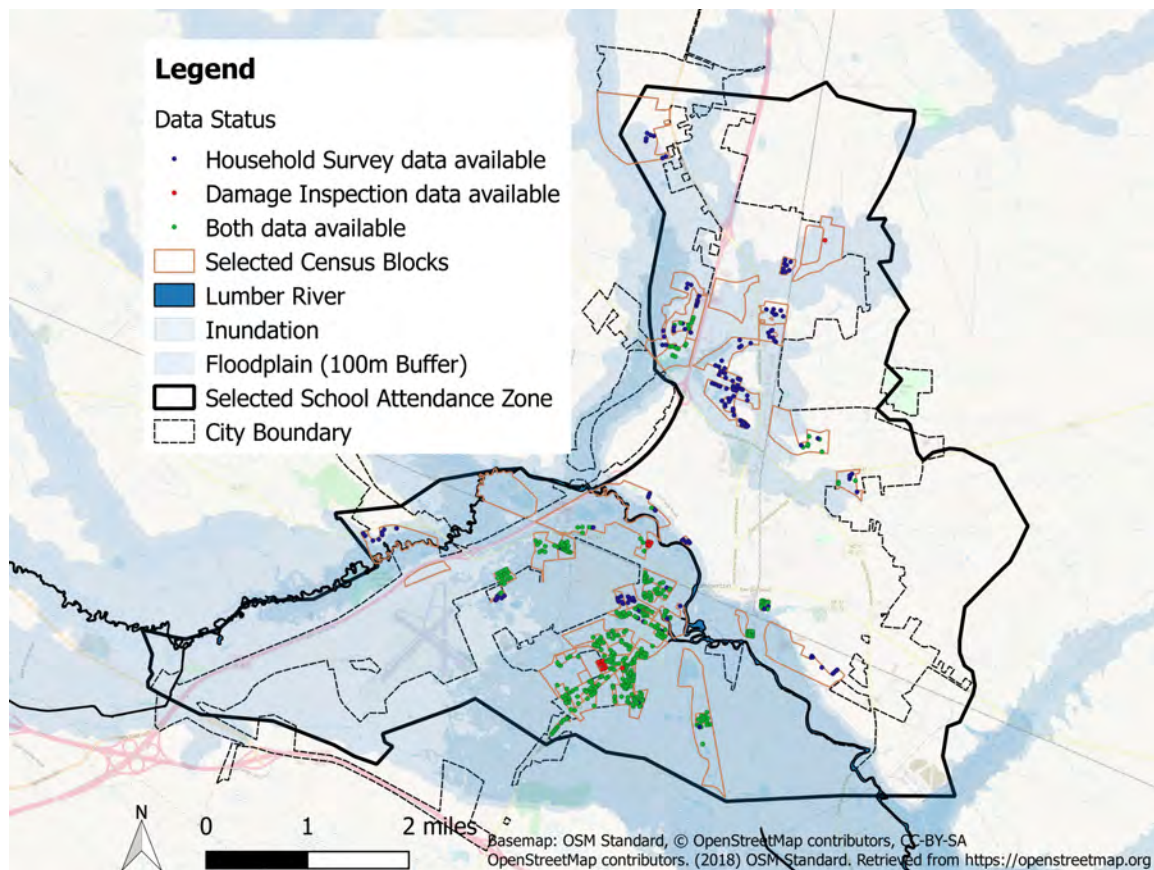
Figure 3-2. Housing units and census blocks sampled and final data status indicated.
[1 mile = 1.61 km]

An advance team adjusted the sample, both with respect to blocks and housing units, by visiting sampled blocks prior to sending interview teams into the field. A critical part of the advance team's activities was to verify that structures identified as residential structures were indeed residential and, most importantly, the identification of housing units within structures to ensure that primary unit sampling was undertaken correctly. This was particularly important when it came to large multi-family structures, which are only a very small proportion of structures in Lumberton. The advance team also made determinations about the safety of sending survey teams into blocks and prioritized field team surveying efforts.

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[12] Certain commercial products are identified in this paper in order to adequately specify the experimental procedure. Such identification is not intended to imply recommendation or endorsement by the National Institute of Standards and Technology, nor is it intended to imply that products identified are necessarily the best available for the purpose.

After the advance team's assessments, it was determined that two census blocks needed to be dropped from the high flooding probability areas: one block was deemed unsafe for teams to enter, and one block, despite census information to the contrary, had no housing units. In addition, a number of blocks in the low probability flooding areas, mostly in the northern section, were well away from inundation areas and had no risk of flooding. It was clear that with or without assessments in these areas, the overall sample would provide good coverage of impacted and non-impacted households. These blocks were, therefore, given low priority for data collection, particularly with respect to damage inspections; if the main teams ran short of time in the field, they were instructed to prioritize other areas first. In the final analysis, 75 of 80 census blocks were visited in the final sample, including 54 of 56 in the high probability of flooding damage areas and 21 of 24 blocks in the low probability areas.

Figure 3-2 displays the target area (or the attendance zones for the schools of interest) and the locations where data were collected (including damage assessment data and/or direct [from household] or indirect [from neighbor] household data) for each housing unit in each of the census blocks included in the sample. As will be discussed below, survey teams included both engineers and social scientists undertaking both damage assessments and household surveys. While the intent was to conduct household surveys and damage assessments in parallel, often times damage assessments went more quickly than household surveys. Therefore, teams would at times split-up, with part focusing on damage assessments while others focused on household surveys. In the final analysis, 568[13] valid primary housing units were visited, yielding an average of 7.6 housing units per block.

3.2.2 Qualitative Interviews

The goal of the qualitative interviews was again, to obtain detailed information on how local officials and stakeholders in the community, schools, and businesses responded to the flood event, and addressed restoration activities and began to address recovery. Since most of these interviews needed to be conducted with leaders in local government, the business community, or local school officials, newspaper and Internet searches were mainly used to identify a purposive sample of these individuals. Hence, most of the recruited participants were contacted through targeted emails and phone calls based on their job titles and involvement in the response and recovery efforts. Qualitative interviews were conducted with 22 community leaders and key stakeholders including:

- eight representatives in the school district, including representatives from student services, public relations, and transportation as well as school counselors and school principals;
- infrastructure (electric power, water, and transportation) managers;
- Local Officials and key stakeholders/leaders of response and recovery organizations; and
- State and Federal Officials.

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[13] Of these households, only 13 refused to participate when contact was made. Additionally, there were two households that were new to the residence (post flooding) and hence did not qualify for inclusion, one did not have an adult available to answer the survey, and 259 were either not occupied or household members were not present. This yields a cooperation rate of 94 % and a more conservative response rate of just over 50 %. Damage assessments were not undertaken for all 568 of these housing-units in the case that the residence was out of the flooding area and clearly had no flooding so damage.

Key stakeholder interviews were conducted by at least two members (one lead and at least one assistant) of the team, working together to ensure complete data collection and maximal safety of all team members. The interviews, which lasted between 30 minutes to 1.5 hours each, were documented through audio recordings and field notes. Upon returning from the field all written and audio recorded data were compiled into one master *Fieldnotes document* for analysis.

At each face-to-face interview, the NIST Community Resilience Program was described, as well as the NIST Disaster and Failure Studies program and the NIST Center of Excellence. In particular, the objectives of the Center of Excellence were explained, with an emphasis on the broader societal goal to utilize Lumberton's recent experience to educate other communities. The introduction by team members typically concluded with a summary of using the collected data to inform models under development, which may eventually be used by other communities to better protect them from disasters and improve their recovery. Each participant signed a consent form (see Appendix 1). Additionally, participants were offered a flyer with mental health resources for Lumberton and surrounding areas as well as a compiled list of current disaster recovery resources (see Appendix 2).

Interviews were conducted using a semi-structured interview guide (see Appendix 3) that asked questions about damage, infrastructure, response efforts, organizational decision-making, evacuation and displacement, and community recovery. These interviews provided important context and real-time documentation of the decision-making processes that influence recovery outcomes.

3.3 Housing/Household Survey Instruments

The following sections provide information on the damage assessment instrument (employed to assess damage to residential housing) and household survey instruments. Each instrument was designed to gather specific types of information on either the physical structure of the housing unit itself or on the household (social unit) that occupied the housing unit at the time of the flooding. The damage assessment and household survey instruments can be found in Appendix 4 and 5, respectively.

3.3.1 Damage Assessment Instrument

The damage assessment survey was designed with three main goals: (1) inspect the general physical condition of buildings, such that a general damage state assessment ranging from 0 to 4 could be provided for correlation with other engineering and social science parameters, (2) record the high-water mark location observed on the structure or another nearby physical reference point, and (3) gather more specific assessments of the external and the internal damage sustained by the structure and its contents. In general, flooding without significant velocity results in damage to contents and non-structural components in buildings, and Lumberton was no different. The Lumberton floods mostly caused damage to non-structural building components (e.g., flooring, drywall, and façade), equipment (e.g., heat, vacuum, and air conditioning systems), and contents (e.g., furniture, electronics, clothing). A flood damage assessment methodology was established with a focus on post-flood conditions of non-structural building components in residential buildings. This methodology relied on damage descriptions for each identified damage state. The survey instrument employed for the damage assessments can be found in Appendix 4.

The damage assessment survey was undertaken for each housing unit sampled, following the four steps outlined below:

Step (1): Building Information. A general perimeter check of the structure was conducted to gather data related to the building characteristics, such as: building type (single-family or multi-family), construction type (wood, concrete, masonry, steel), house dimensions (length and width), number of stories, year built (if available), foundation type (crawlspace or slab on grade), construction quality and maintenance condition (from low to very good). These parameters were selected in order to describe the physical variability of the housing stock, as well as to investigate the impacts of the selected parameters on the flood damage assessment of structures. Note: basement type foundations are not common in Lumberton, and none were encountered during the field investigation.

Table 3-1. Overall damage description for residential structures.

Damage State Level	Description
0	No damage: water may enter crawlspace or touch foundation (crawlspace or slab on grade) but water has no contact to electrical or plumbing, etc. in crawlspace, and no or limited contact with floor joists. No sewer backup into living area.
1	Minor water enters house; damage to carpets, pads, baseboards, flooring. Approximately 25.4 mm (1 in), but no drywall damage. Touches joists. Could have some mold on subfloor above crawlspace. Could have minor sewer backup and/or minor mold issues.
2	Drywall damage up to approximately 0.3 m (2 ft) and electrical damage, heater and furnace and other major equipment on floor damaged. Lower bathroom and kitchen cabinets damaged. Doors or windows need replacement. Could have major sewer backup and /or major mold issues.
3	Substantial drywall damage, electrical panel destroyed, bathroom/kitchen cabinets and appliances damaged; lighting fixtures on walls destroyed; ceiling lighting may be ok. Studs reusable; some may be damaged. Could have major sewer backup and/or major mold issues.
4	Significant structural damage present; all drywall, appliances, cabinets etc. destroyed. Could be floated off foundation. Building must be demolished or potentially replaced.

Table 3-2. Detailed damage descriptions for external and internal building components.

Damage State	0	1	2	3	4
Interior Damage Assessment	Water enters the foundation but no contact or no visible damage to electrical, plumbing, or floor joists.	Water enters house; damage to carpets, pads, baseboards, flooring, but no drywall damage. Touches joists. Could have some mold on subfloor above crawlspace.	Drywall damage up to 2 feet and electrical damage, heater and furnace and other major equipment on floor damaged; Lower bathroom and kitchen cabinets damaged. Doors need replacement.	Substantial drywall damage, electrical panel destroyed, bathroom/kitchen cabinets and appliances damaged; lighting fixtures on wall destroyed; ceiling lighting may be ok.	All drywall, ceiling lights, appliances, cabinets etc. destroyed and need replacement.
Exterior Damage Assessment — Attachments or Detached Structures	Water touches exterior of garage or porch but no visible damage.	Visible damage or water marks/mud.	Minor damage to garage door/ minor damage on decks.	Major damage on garage door or on decks (i.e. garage door needs replacement).	Major or significant structural damage present; floated away or destroyed.
Walls	Water may or may not touch walls but no visible damage.	Water touches walls but no damage on the wall or cladding or insulation, just aesthetic marks/mud.	Need to clean and dry the wall out. Slight damage on insulation or cladding which need partial replacement.	Water penetration through holes or cracks on the walls. Or water penetration through broken windows. Studs reusable when dried.	Significant structural damage present or collapse; majority of walls damaged beyond the point of reuse.
Foundation	Water enters crawlspace or touches foundation but no visible damage.	Waters enters crawlspaces but not any significant damage. Just water marks/ mud.	Minor cracks on foundation stem walls.	Cracks or holes on foundation stem walls.	Major structural damage on foundation. Differential settlement or the structure floated off the foundation.

Step (2): Flood Information. The goal of this step is to record the flooding conditions present at home during the event to the best of the damage inspectors' ability, by measuring the high-water mark that remained on the façade of the home or on a nearby structure was measured with respect to first floor elevation (FFE), which corresponds to the threshold of the front or the rear doors. Where possible, this was confirmed with the homeowner or a neighbor. It should be noted that this level could have corresponded to standing water and the actual flooding could have reached a higher location than this level for a shorter period of time and thus leaving no watermark for measurement. Also, the ground level next to the building with respect to FFE, and the location of the high-water mark observed in the house (i.e., foundation, first floor, or second floor), and flood source (i.e., surface flooding from a nearby ditch or river, sewer back-up, drain pipe) were recorded for further analysis of the flooding conditions.

Step (3): Overall Damage Assessment. Most of the damage observed in the flooding was due to water contacting non-structural building components. Therefore, the following factors were considered to describe the damage states: condition of damageable building items (e.g., carpet, electrical outlets, flooring and major appliances on flooring), severity of mold, flooding source (sewer backup or not), condition of studs (reusable or damaged), and a possible depth range. While damage state zero (DS0) indicates no damage to the structure even if the water had come into contact with the building, damage states 1 to 3 (DS1, DS2, & DS3) focus more on the condition of non-structural and content items, where damage state 4 (DS4) represents structural failure with enough building components destroyed that the house will likely require demolition. Table 3-1 offers a general description for the various damage states for residential structures.

Table 3-3. Interior components considered for damage assessment.

Interior Items

Plywood Subfloor	Base Cabinets (Kitchen)
Flooring	Upper Cabinets (Kitchen)
Carpet Pad	Countertop (Kitchen)
Base Trim	Appliances (Kitchen)
Water Heater	Electrical Panel
Furnace	Staircase
HVAC equipment	Front door
Water Softener	Interior doors
Drywall	Windows
Electrical Outlets	Lighting fixtures
Base Cabinets (Bathroom)	Ductwork
Upper Cabinets (Bathroom)	Furniture
Countertop (Bathroom)	

Step (4): Component-Based Damage Assessment. Detailed damage assessments were conducted separately for building exteriors and interiors to analyze physical damage to the buildings. Table 3-2 offers a description for exterior and interior components associated with each damage state rating. Exterior assessments were conducted for foundations, walls, and any attachments such as the garage, porches, and sheds. Interior damage assessments recorded the condition of the interior building contents and non-structural components, whenever possible (either through permissible entry to the home, visibility through windows, or by inspection of removed contents). The existence of any visible mark/mud or hole/crack or deterioration was considered to determine five damage levels (from DS0 to DS4) for external components (see Table 3-2).

Similarly, varieties of interior components vulnerable to damage based on flood levels were considered to determine the interior damage state from DS0 to DS4. Interior damage assessment was especially important to quantify non-structural flood losses, which can be significant: non-structural components represent a large portion of the construction cost of buildings. Therefore, where possible, specific data on interior damage sustained to specific building contents (i.e., carpet, cabinets, see Table 3-3) was assessed at three levels: no damage, lightly damaged but still repairable, or ruined and requiring full replacement. For the condition of furniture and walls, the amount of the damage was described by an ordinal assessment (i.e.: *some, most*, or *all*) or quantitatively (i.e., percentage damaged) with supporting notes.

3.3.2 Household Survey Instrument

The household survey instrument was designed to collect information on a number of features of the housing unit's occupancy status, either based on determinations[14] made by the interviewing team or on the basis of information obtained from surrounding neighbors, property managers (or some other source), or adult members of the occupying household. The survey instrument was designed to collect information on: (1) disruption of major lifeline utilities (e.g., electricity, natural gas, and water) and communications (phone and internet), (2) an enumeration of household members along with basic demographic information (gender and age), (3) dislocation/displacement with respect to each household member, (4) employment and student status of each member, (5) amount of time each member missed work or school; (6) if others joined the household due to the flooding, (7) tenure status (i.e., rental vs owner), (8) applications to disaster assistance programs (insurance, FEMA, SBA), and (9) additional household socio-economic and -demographics (e.g., highest education status, race/ethnicity, and annual income).

The household survey instrument was developed and modified based on an instrument that had been developed, fully tested, and used to assess the impact of Hurricane Andrew on households in southern sections of Miami-Dade County (Peacock et al., 1997: 246-248). The survey instrument utilized in the Lumberton field study can be found in Appendix 5.

As part of the survey process, households were asked to verbally consent to participate in the research. Potential interviewees were given a verbal description of the project, and provided with information about the project, including the types of information that would be collected. They were explicitly told that their participation was voluntary and that they could withdraw their

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[14] Teams were asked to, where possible, assess whether or not the housing unit appeared to be currently occupied or in use, versus potentially occupied at the time of the flood, but now abandoned, if there were no occupants or neighbors available to interview.

consent at any time. The verbal consent form can be found in Appendix 6. There was also an information sheet providing more detailed information about the study that was provided to participants (see Appendix 7).

3.3.3 Institutional Review Board Protocol Approval Process

Prior to initiating the Lumberton Field Study, a small task group of the field study team submitted the field study design and associated protocol to the IRB[15] at Colorado State University (CSU) and NIST, and received approval to conduct the Lumberton field study. All of the other universities involved in the field study effort had previously signed an IRB Authorization Agreement, or IAA, designating the CSU and NIST IRBs as the lead institutions for the field study protocol review and approval.

The IRB process contained many steps. First, the members of the field study team responsible for the research protocol design and IRB approval met with representatives of the CSU IRB and NIST IRB prior to seeking approval for the Lumberton field study. These initial meetings were focused on briefing the IRBs regarding the broader scope of the NIST Center of Excellence and the specific purpose of associated field study tasks. In addition, at these early meetings, the research team and the IRB representatives agreed that the CoE/NIST research team would draft a hypothetical field study protocol, which would offer a framework for future community-resilience focused field study efforts. In the instance of an actual field study effort, that base protocol would then be updated with specifics on the disaster type and the location of the event. The communication and pre-disaster protocol development were crucial, allowing the research team and the IRB representatives to establish a mutually agreeable process for seeking IRB approval in the case of a future disaster event.

Once the research team decided to focus on Lumberton for a field study effort, the small group of team members who had responsibility for the IRB began drafting the full research protocol along with all associated instruments, including interview guides and the survey questionnaire that would be used in the field study effort. Once these materials were completed, they were then circulated to the entire field study team for review and comment.

After all comments from the research team had been addressed regarding the research design and instruments, the study protocol was uploaded into the CSU IRB portal. The protocol was simultaneously submitted to the NIST IRB team for review and comment. The CSU and NIST IRB leadership had committed to a less than 48 hour turnaround for IRB review. The research team then integrated all suggested changes into the IRB protocol and resubmitted. The field study protocol was ultimately approved; only after receiving that approval was the team allowed to begin the work.

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[15] Institutional Review Boards (IRBs) may include faculty, professional researchers, administrative staff, and community members that have been designated to oversee biomedical research and studies involving human subjects (which includes interviews). The IRB on any given campus has the authority to approve research protocols, to require modifications to such protocols, or to disallow research in the case of approaches that pose too great of a risk without commensurate benefit.

In addition to IRB approval, all federal employees who wish to collect information from the US public (including the NIST researches that were part of the team) must adhere to the Paper Reduction Act (PRA), which is intended to reduce the paperwork burden the federal government imposes on private businesses and citizens. PRA approval is required when identical questions are asked of ten or more persons, whether such collection of information is mandatory, voluntary, or required to obtain or retain a benefit. The structured household survey was not submitted for PRA-approval due to the short turnaround required for this field study. Therefore, NIST researchers did not participate in the household interviews for this first wave of the Lumberton field study.

3.4 Data Collection Process and Procedures

The following sections provide an overview of the compositions and of field teams, the organization of daily activities, and the use of technology to facilitate data collection and interactions across a large team with varying areas of expertise.

3.4.1 Team Compositions

For the Lumberton field study, the Center of Excellence and NIST collaborative research team investigated the interconnectivity of the physical and social systems that influenced community recovery and resilience in the aftermath of Hurricane Matthew. As a consequence, the goal was to create a fully integrated interdisciplinary field team. The first step in assembling the team was to identify a group of potential field researchers based on the following criteria: (1) pre-completion of the required CITI ethics training and institutional completion of the IAA paperwork; (2) completion of the CoE-led field research methods workshops;[16] (3) proximity[17] to the disaster site; (4) availability to travel to the disaster site with the team during a specified period of time; (5) area of expertise as related to disaster type (e.g., including a mix of engineers and social scientists); (6) interest in the disaster event; and (7) the principal investigators' judgment regarding the size and best composition of the team.

After inquiring with the larger team, 24 individuals self-identified as available to travel to Lumberton and were selected for inclusion in the field study. These are researchers with varying backgrounds (e.g., engineering, sociology, planning) who have all completed the required CITI ethics training. The final field study team was comprised of two professors and five researchers from CSU who led the engineering team, seven researchers from NIST who led the interdisciplinary field protocol, a professor and research scientist from Texas A&M who led the social science team, a professor and a graduate student from University of Alabama with a focus on digital imagery and mapping, a professor and a postdoc from Oregon State University with a focus on building damage assessment, a professor from the University of Kansas with a focus on modeling housing dislocation, a professor from Iowa State University with a focus on planning, a structural engineer who serves on the COE's assessment panel, and a professor and COE assessment panel member from East Carolina University with a focus on economics that provided local knowledge and helped secure contacts for our study.

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[16] A field research methods workshop was conducted by CoE researchers to provide field teams with general knowledge and best practices for field work.
[17] Where possible we tried to encourage CoE researchers at universities closer to the field cite location to participate in order to reduce costs.

In order to prepare the team for the field investigation, we held weekly conference calls with all members of the team to solidify the data collection plan and ethics requirements. These frequent team calls helped to prepare the researchers for the realities of conducting post-disaster field investigations with human subjects, the need for following IRB protocols, and field research protocols. In addition, and as mentioned above, field team members undertook training on field research and survey methodologies and trained on the survey and assessment instruments. The actual field study took place in Lumberton, North Carolina in 2016, from November 28-December 5. The research team traveled to the study site in waves depending on their data collection goals, expertise, and availability.

3.4.2 Types of Survey Field Teams

An advance team arrived in Lumberton on the evening of November 27, 2016 to perform an initial survey of the study locations selected from the random sample as discussed above. The *Google My Map* Application, described in Section 3.4.5 below and that was developed to indicate sample locations, was tested by this advance team. Each of the census blocks was visited by the advance team members to: (1) assess the accessibility and safety issues that might be encountered by the survey teams, (2) assess the sampled blocks and ensure the sample procedures provided accurate information about the housing units, and (3) identify the levels and nature of flooding damage experienced by residential structures. The goal of the latter assessment was to identify areas with no flooding damage from those with more significant exterior or interior damage to prioritize field activities and maximize the efficiency of the engineering damage assessment surveys from household surveys. As noted before, one block was removed for difficulty in access, and another because of a mismatch with census data. In summary, the advanced team led the sample verification procedure, and laid the groundwork on November 28th for the main team who arrived later on November 28th, and the closing team who arrived December 3rd. The staggering of teams proved to be an effective and safe way to carry out these large-scale investigations, allowing researchers to share insights and leads with one another as the week progressed.

3.4.3 Interdisciplinary Survey Field Teams

Our goal had been to have each field team participating in this field study consist of one to two engineers, and one social scientist. The teams were intended to also be balanced between NIST researchers and CoE researchers. Engineers from NIST and the CoE completed damage assessments and photo documentation. Simultaneously, teams including at least one social scientist conducted the structured interviews with the building occupants. When building occupants were not available, some of the needed information was collected by interviewing neighbors or building managers. Given that damage assessments could often be undertaken more quickly than interviews, engineering teams were dispatched to many census blocks to do damage assessments, independent of household survey teams. Similarly, even when a full interdisciplinary team was sent into a block, the damage assessment sub-teams would often complete their assessments more quickly than the household survey sub-teams; often the damage assessment sub-teams would either return to help in the household survey sub-teams or move onto the next block.

It should also be noted that disciplinary distinctions became blurred in the data collection process as the fieldwork progressed. For example, social scientists were involved with and assisted in

many of the damage assessment activities. Engineers supported the household survey activities by supporting the social scientist conducting the interviews, and also by directly interviewing households. By the end of the week, all field team members were focused almost entirely on household survey activities, regardless of the disciplinary affiliation.

3.4.4 Daily Operations

Each day before departing into the field, the entire team met to discuss daily operations. During this meeting, survey instruments and damage assessment forms were distributed as needed, as were the other field equipment (e.g., tape measures and clipboards). After returning from the field each day, the entire team met again to report findings, review their data, enter preliminary data into the shared *Google* spreadsheet (which automatically updated the *Google My Maps* tool), and plan for the next day. During the evening meetings, any problems that arose throughout the day were shared, and the team would discuss strategies for addressing these problems. For example, some team members expressed their feelings of discomfort when asking respondents about their age and/or household income. In response, other team members were able to stress the importance of these data and provided their strategies for asking these questions.

Daily reports of progress in each cluster were recorded during team evening meetings on large note paper mounted on easels along with updates of qualitative interviewing activities. This information was then used to prioritize which block groups should be revisited by which teams the next day, and determine which meetings were scheduled for qualitative interviewing. A broad strategy for the rest of the week was also discussed in the evening meetings, and revisited daily. Criteria for determining who, if, and when to revisit a cluster included the number of outstanding sample points, the average damage level of previously visited samples in the cluster visited, the presence of household members with whom to conduct interviews (some areas were mostly abandoned), and the safety of the area.

3.4.5 Google Mapping Services Assist Field Teams

Google mapping services*, Google My Maps & Google Street View*[18]*,* were extensively employed to develop the housing units/household sample and ultimately to develop a mapping tool that could be used by field teams to navigate to, and locate, primary HUs to conduct damage assessments and household interviews. More specifically *Google My Maps* provided a platform to create web-accessible, detailed sample maps of Lumberton, allowing each team member to use their personal internet-enabled smartphone to view the locations of their assigned housing units.

To develop the sample (described in Section 3.2.1) and ultimately the field mapping tool used by the deployed teams, a number of steps were undertaken by the team. First, the University of Alabama (UA) team used ArcGIS software to spatially place data identification points on all structures within the study area. These data were then provided to the Texas A&M University (TAMU) team. The TAMU team first visually confirmed the locations of structures that were

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[18] Certain commercial products are identified in this paper in order to adequately specify the experimental procedure. Such identification is not intended to imply recommendation or endorsement by the National Institute of Standards and Technology, nor is it intended to imply that products identified are necessarily the best available for the purpose.

identified by the UA team, and then the 2010 Decennial Census and tax portfolio data were used to estimate the actual number of HUs in each of the 80 identified blocks in the sample. The two datasets differed in cases where individual structures identified by the UA team contained multiple housing units, as would be the case for apartment buildings, duplexes and other forms of attached housing. *Google Street View* and *My Maps* made it possible for the UA team to determine the actual number of HUs in each structure. Physical clues, such as multiple sidewalks, mail boxes, front doors, electric meters, and roof exhaust vents, along with information from tax data were used to estimate the number of housing units. Where necessary, spatial location of data points created by the UA team were moved to the center of the structure roofline in the case of single family units. Additional data points were created and placed over likely locations for multiple HUs within structures. These maps, with updated data points, helped the teams identify their HUs of interest and assisted in making daily operations more efficient.

After the sample of eight primary and two alternate HUs were drawn for each sample block, a new *Google* spreadsheet of sample housing units was created. This spreadsheet includes details about each housing unit, such as location, address found in the county parcel database, geocoded latitude and longitude, and data collection status (e.g., completed or possible revisit). The spreadsheet was then imported into *Google My Maps*, which maps each point based on the latitude and longitude variables. *Google My Maps* allows for the user to define the style of each point based on a variable in the spreadsheet. For example, during the field study, the spreadsheet and maps were updated as teams completed a damage assessment and/or household survey. This facilitated daily operations planning and increased situational awareness in the field.
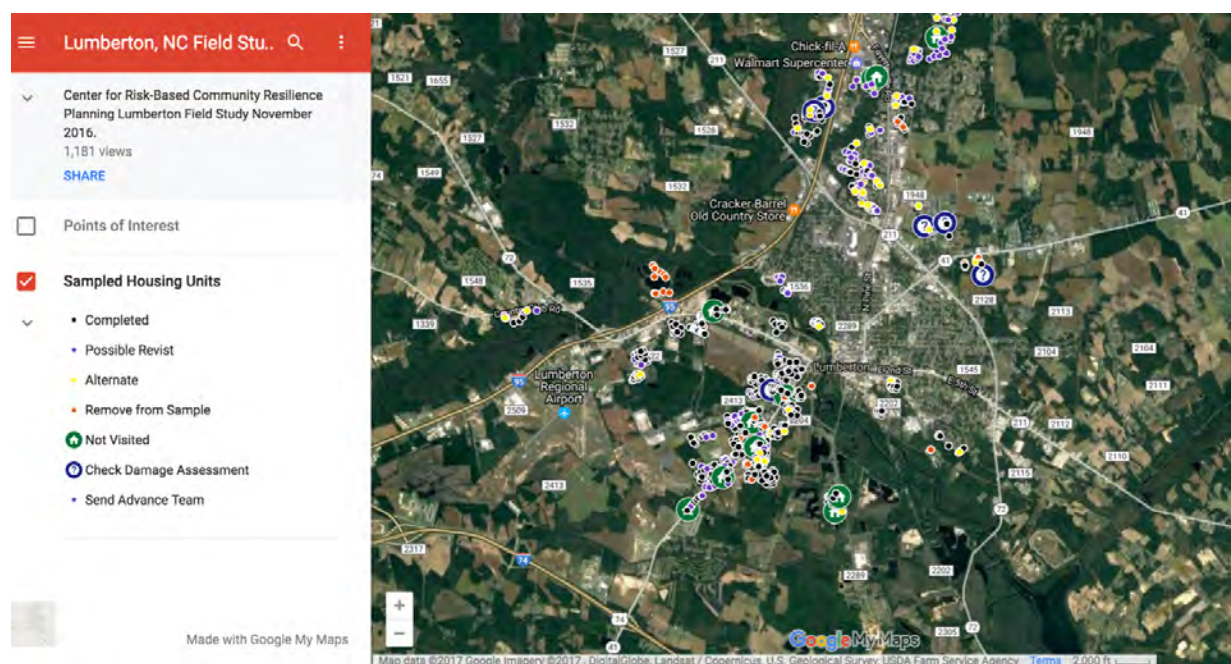
Figure 3-3. Screenshot of *Google My Map* for the Lumberton area.[19]

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[19] Certain businesses or municipal landmarks are identified in commercial software. Such identification is not intended to imply recommendation or endorsement by the National Institute of Standards and Technology.

Once the *Google My Map* is generated, a link was shared to provide access to the map using a device that has Internet access, such as a smartphone or a laptop. If the device also has GPS, the location of the device can be displayed on the map. Figure 3-3 shows examples of the *Google My Map* displays on a laptop; displays on a smart phone were essentially the same. The satellite image overlay provides visual evidence for team members to determine the location of the sampled housing unit. Additionally, a user can select an individual data point to see a list of all of the variables from the imported spreadsheet within the *Google My Maps* application. Overall, the field study team members provided positive feedback on the *Google My Map* tool. Most team members were familiar with using *Google Maps* on their smartphone and found that the *Google My Map* tool had a similar interface. Consequently, the tool required minimal training and increased the effectiveness of the survey effort.

3.5 Data Management and Integration

The following sections provide an overview of the data collection, visualization, and archiving methods used in the field study.

3.5.1 GIS Platform, Photo Integration, and Data Updates

The collection, handling, and long-term storage of spatially collected data can be difficult for large field teams using various types of equipment and multiple sensors to capture data. The field team used geolocation approaches to aggregate collected data onto a map of the affected area using geographic information system (GIS) software. Additionally, a GIS-enabled web viewer was used to preserve the data, creating a baseline of damage for the sample in Lumberton. Longitudinal visits to the area are planned for one year from this initial field deployment and regularly afterward, to collect recovery data and compare to the data collected on this reconnaissance trip. Hundreds of photographs of building and community damage were taken and combined with global positioning system (GPS) location data using two methods: (1) automated extraction of smartphone location values embedded in the photograph's metadata, and (2) paired photographs with GPS track data captured by an external GPS unit. For the latter method, GPS location values were assigned to each photograph by comparing the time between each camera and paired GPS unit and synchronizing the two if necessary, as shown in

Figure 3-4(a). This method was employed for team members who opted to use high resolution digital cameras instead of smartphones. The GPS units collected data passively, allowing team members to collect data while only intermittently ensuring that the GPS device was powered on and calibrated with a satellite constellation as shown in Figure 3-4(a). Recent increases in smartphone accuracy provide an acceptable level of uncertainty in spatial accuracy and available in camera resolution provides an acceptable quality for photographs. However, the GPS-unit pairing method provides a higher level of spatial accuracy in the data, but requires more steps to add geolocation to the data. Figure 3-4(c) provides a map of geolocated photograph data collected in Lumberton.

57
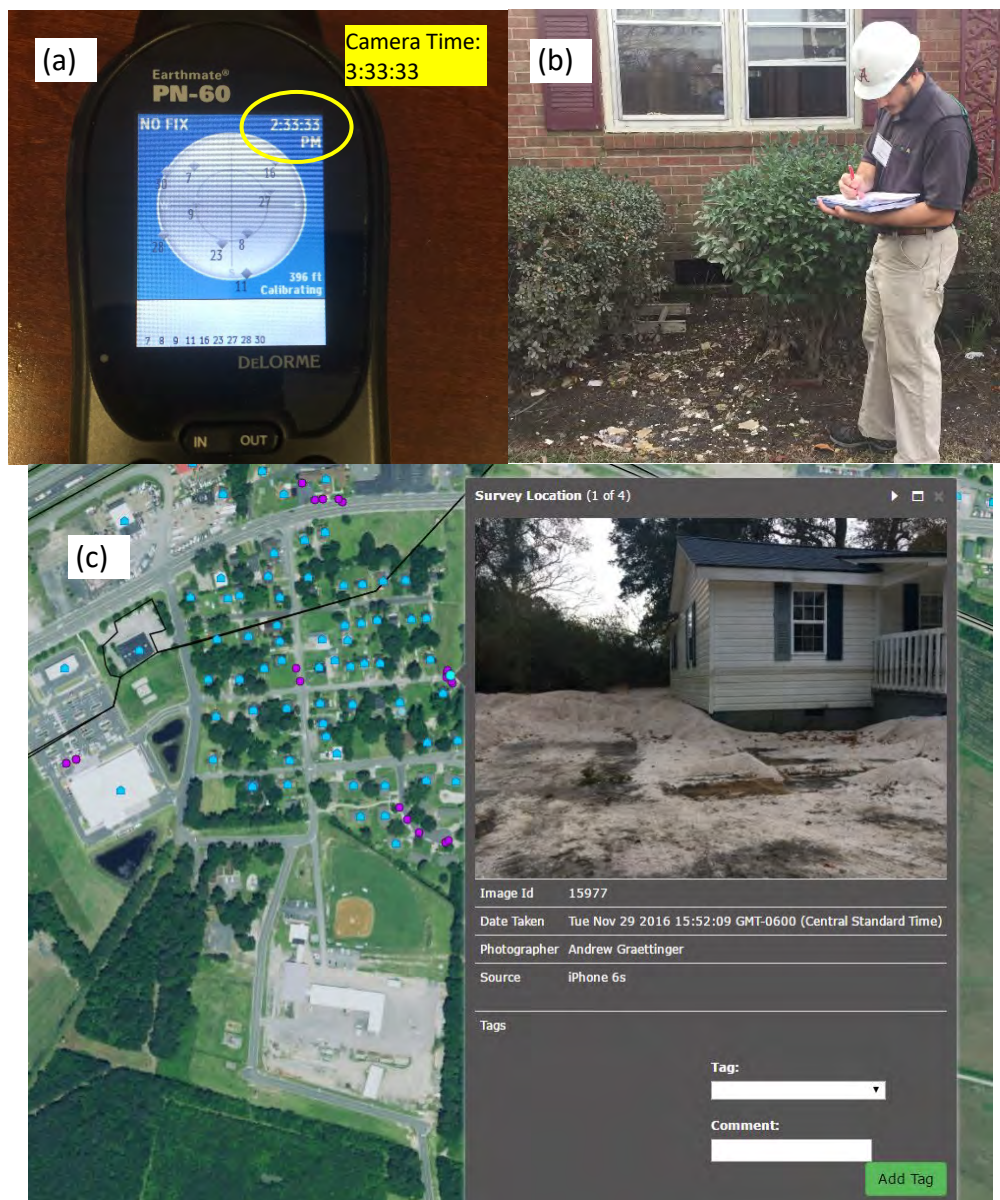
Figure 3-4. GPS-aided photograph geolocation methodology: (a) photograph of an external GPS unit used by the field team; (b) field team member collecting field data; and (c) visualization of aggregated data, by geolocation, on the GIS-enabled web viewer.

An alpha-version of the GIS-enabled web viewer, called the *Extreme Events Web Viewer*, was created to display, annotate, and store the perishable data collected during this trip as well as future recovery data for Lumberton. This web viewer also contains damage data collected from the 2011 Tuscaloosa, AL and Joplin, MO tornadoes, as well as the 2013 Moore, OK tornado. Geolocated photographs were uploaded to the web portal each night in order to provide an overview of the areas visited each day and create a deployment plan for the following day. As described in the previous section, building points were added to the web viewer before the team arrived in Lumberton.
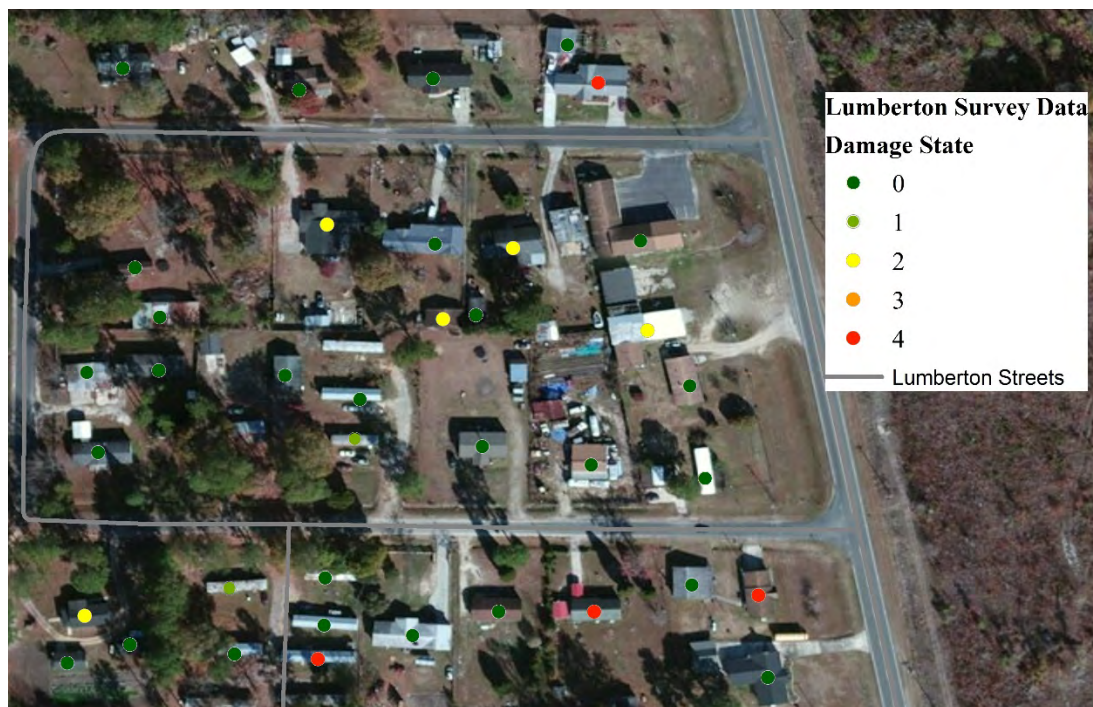
Figure 3-5. Lumberton desktop viewer with damage state information.

In addition to storing the data captured in the field, the web viewer allows users to augment the collected data via tags. For example, attribution can be added to collected photos via a tagging tool which allows researchers to create a *tag* or *label* that correspond to research topics that can be applied to selected photographs. Hence, a user could create a "measured inundation level" data tag, select photographs which show measurements taken at water lines and enter the height of inundation in the comment line, shown in Figure 3-5(c), of each photograph. Photographs are aggregated at the camera location so that multiple photos could be associated with an individual building.

A desktop version of the web application contains more data and functionality and is being implemented to test concepts for the web viewer. One example of desktop functionality is querying capabilities for the data tags to quickly find relevant research data, create thematic maps based on the tags, and apply expanded geospatial analyses. An example thematic map is shown in Figure 3-6, where a neighborhood with associated overall damage states for HUs are shown in the web viewer. In addition to added functionality, the desktop version can store more types of data, such as 360° videos collected from a vehicle-mounted camera. Figure 3-6 shows a video centerline along with the video data corresponding to the location highlighted on the centerline. Figure 3-6 also shows the vehicle path and time mapped to correlate map position with timing position in the videos. Additional functionality will be applied to the web viewer in the future to account for the desktop version functionality as well as expanded capabilities.

Figure 3-6. Map of 360° video path with arrows indicating direction and time labels.

3.5.2 Collection of Data Forms

At the end of each working day, the members of each team involved in either the damage assessment or household surveys, reviewed the forms they completed and made any adjustments based on comments or quick annotations they used in the field. Once the forms were reviewed, a set of summary data (e.g. overall building damage state, water height, days the household was out of their home) was entered into the *Google* spreadsheet for viewing. This process automatically updated the daily and total data sheet as well as the *Google My Map*, which served two purposes: (1) create a systematic approach to uploading the data, and (2) provide direction for teams on subsequent days. For example, if only a portion of samples were visited in a block, the *Google* spreadsheet provided a summary on the percent complete and the levels of damage captured by the data. The field investigation team would then determine a priority strategy for revisiting that cluster (versus other clusters) to complete the samples.

After the data forms were completed and checked, the damage assessment and household survey forms were collected by the assigned field lead and were sorted by cluster zones. The Colorado State University team led the entering and cleaning of the damage assessment sheets and the

Texas A&M team led the entering and cleaning (editing and verifying accurate data entry) the household survey forms. These two activities were done in series. The TAMU team subsequently created merged data files, linking the damage assessment and household survey data for each HU into a single data file for further processing.

3.5.3 Data Management

Raw data access is limited to project investigators who have completed the IRB training and whose universities have signed the IAA agreement. The raw data will be maintained for the three-year archive period following the conclusion of the study. All CoE investigators have been notified that only those who have completed the required ethics training and who are listed as part of the potential field study team will have access to this data.

All physical data (e.g., completed survey forms) will be stored in a locked file cabinet and all electronic media will be saved in locked offices on the password protected computers of the principal investigators. A linked-list will be created, where all identifiable information will be replaced with code numbers. The same codes will be used to link audio recordings, field notes, and photographs from each site. No names will be attached to this documentation.

Audio recordings that contain identifiable information will only be seen/heard by team members. Photos produced through the fieldwork that contain identifiable information will only be seen/viewed by team members, unless written permission is provided by anyone identifiable in those images. Household survey data must be reported in accordance with the IRB approved protocol.

Chapter 4: Field Study Results

Section 3.3.1 specifies the joint CoE/NIST objectives for the field study. These objectives include improving our understanding of how public-school systems cope and respond to flooding events, gathering information on how the private sector and local/State officials responded, developing flood related fragilities, and creating household dislocation models by combining engineering and social science data. To achieve the outlined objectives, two data collection activities (qualitative and quantitative surveys) were undertaken as part of this field study to provide these data.

This chapter summarizes field study results, with respect to four of the six objectives. Chapter 2 summarizes the data from qualitative interviews with individuals managing private and public-sector utilities in and around Lumberton. Additional summaries from qualitative surveys conducted by interviewing local/State officials and businesses, with respect to public schools, are also presented in this chapter. The results from the household and damage surveys are then discussed with respect to developing epistemic residential flood damage fragilities and linking damage and social characteristics to model household dislocation.

4.1 Qualitative Interviews

The following sections provide an overview of interviews with local/State officials, community organizations, public schools, and businesses. These interviews were all completed using unstructured survey methods as described in Section 3.2.3. The summary results of these

interviews are presented here to provide a background of the response and recovery stages when this field study took place. This includes a number of people still being displaced from their homes, schools still being closed, and financial aid still outstanding to the majority of residents as explained below.

4.1.1 Local Governmental and Community Organizations

As mentioned in Chapter 3, this field study was conducted more than a month after major flooding in Lumberton, North Carolina. Therefore, many of the local government and community organizations we spoke with were transitioning out of the response phase of the event and trying to plan for the longer-term recovery. Hundreds of residents were still living in hotels or staying with relatives, houses were still being cleaned, and schools had been reconvened for several weeks. In this section, we draw from qualitative data collected by attending two community disaster recovery meetings and interviewing key stakeholders representing the non-profit and faith-based communities, the City of Lumberton government officials, and Robeson County Emergency Services.

As of February 13, 2017, FEMA had received 81 855 applications for assistance across North Carolina and had granted over $93 million to individuals, with another $9.3 million offered in public assistance grants (NC Public Safety, 2017). Robeson was the hardest hit county in terms of FEMA registration numbers, with 18 372 being filed and $23.4 million being paid out as of January 17, 2017 (Hunter, 2017). The deadline to apply for FEMA assistance was January 23, 2017. In Robeson County alone, approximately 1 400 people were displaced from their homes and staying in shelters and other temporary locations. By February 2017, this number had dropped to 355 families, who were still living in motels and hotels in the area while they searched for more permanent housing options (Futch, 2017).

After a federally declared disaster, a FEMA liaison is assigned to the county to assist the community in establishing its own Long-Term Recovery Group (LTRG). These groups are largely made up of representatives from community and faith-based organizations, emergency management, and local governments. The FEMA liaison guides the group to democratically organize, vote on positions such as a Chair, co-Chair, Secretary, and establish multiple committees to oversee major areas of disaster recovery (i.e., volunteering, construction, housing, community outreach, donations, and unmet needs). When we visited the Robeson County LTRG, they were still in the early stages of planning and had not yet voted on their leadership. We intend to learn more about this Group and associated recovery process as we document the recovery in Lumberton.

4.1.2 State Emergency Management

In addition to local governments, the state also plays a key role in the response and recovery of localities that have experienced an emergency. The North Carolina Emergency Management Agency provides key services to citizens in the State: emergency preparedness programs (e.g., family emergency plans), emergency management operations (e.g., EM training, coordination of Federal and State mitigation grant programs, and coordinate mutual aid system), chemical accident prevention and response programs (e.g., guidance on how to select cleanup contractors), search-and-rescue programs, floodplain mapping, disaster recovery programs (e.g., individual and public assistance), and message development for the emergency alert system (NC Public Safety, 2017). Like the documentation of the recovery from a local government perspective

(Section 4.2.1), it is important to capture what happens at the state level in the early stages of recovery to better understand decision-making across jurisdictional scales. Therefore, in this section, we provide a summary of the qualitative data collected by interviews conducted at an in-person meeting in Raleigh, at North Carolina's Emergency Operations Center (EOC).

The meeting at the EOC included two of the Lumberton field study team members, as well as the Director of Emergency Management, Operations Chief, Assistant Directors of Logistics and Plans, the Recovery Chief, Critical Infrastructure and Key Resources Planner, Hazard Mitigation Supervisor, State Economist, State Meteorologist, and the Public Assistance Manager. The heterogeneity in points-of-view provided a holistic picture of the State's role in responding to Hurricane Matthew and supporting recovery activities across the State, including Lumberton. The State was monitoring Hurricane Matthew for days before it made landfall, although there was a general lack of confidence in the predictions because of Matthew's erratic track changes. The attention on Matthew's impact remained focused along the coast, where the hurricane was expected to potentially make landfall. Although the inland communities were not the pre-event focal points, there were some conversations before Matthew hit between the State and the local communities in Robeson County to monitor the levee. By Thursday, October 6, 2016 the National Weather Service declared that the storm could produce a flood event similar to the one produced by Hurricane Floyd more than fifteen years earlier. The reality surpassed expectations when Hurricane Matthew's extreme rainfall caused severe flooding in North Carolina, resulting in 28 peak flood records (USGS, 2016). The flooding was exacerbated by beaver-built dams and the lack of drainage caused by the buildup of sediment and debris due to the Lumber River's history of harvesting and transporting of timber centuries ago (NC State Parks, 2017).

Although Lumberton did not have a long history of experiencing hazards before Hurricane Matthew, the State's experience with Hurricane Floyd prompted them to take protective measures before the event and altered the focus of recovery efforts. For example, before the storm hit, the State placed emergency personnel at key locations and prepared for swift water rescues. This preparation turned out to be necessary given the hundreds of people that required rescuing, including 1 500 Lumberton residents who were stranded in their homes after the storm. Based on interviews with state officials, the response for Matthew was a much larger effort in terms of personnel, compared to the hurricane Floyd response effort (Sprayberry, 2016). As the State was transitioning from a response phase and into a recovery phase, lessons from Floyd continued to resonate across many State-level programs. State officials told us that the recovery from Floyd did not focus on economic rebuilding, which caused some permanent impact in the State. Therefore, there will now be an economic focus for rebuilding communities in North Carolina after the storm.

4.1.3 Schools

The Public Schools of Robeson County (PSRC) is the largest district in North Carolina, serving 24,000 students. Hurricane Matthew and the subsequent flooding caused extensive damage to physical infrastructure across the county. In this section, we outline the ways that Hurricane Matthew affected the school system and highlight the interconnectedness of infrastructure failures, community response efforts, displacement, and student recovery. We draw from qualitative interviews with key stakeholders within the PSRC, including representatives from student services, public relations, and transportation as well as school counselors and school principles. Secondary data were also collected and analyzed in the form of local news media

coverage related to the impact of flooding on schools, as well as documents provided by interviewees.

4.1.3.1 Physical Damage to Schools

The school district suffered major building damage at their central offices, supplies warehouse, testing department, computer services, program services, maintenance department, a print shop, child nutrition, planetarium, and an art building in addition to damage to schools. The district staff members relocated district offices to a temporary location until they could repair/rebuild. Eight schools, including those with the most damage, are located in the city of Lumberton. W. H. Knuckles and West Lumberton Elementary Schools sat in the worst part of the floodplain and had the most severe damage. W. H. Knuckles received approximately 1 m to 2 m ($\approx$ 3 ft to 6 ft) of water, damaging one wing of the school and the gymnasium. All of West Lumberton Elementary was under 0.6 m to 0.9 m ($\approx$2 ft to 3 ft) of water for at least one week. While students at W. H. Knuckles were able to return after some minor renovations, West Lumberton students will remain displaced at Lumberton Jr. High School until the school district can decide if it is possible to rebuild in the same location.

In addition to building damage, the schools in Lumberton lost power and water for one to three weeks. Many schools reopened needing to get bottled water shipped, as there was still a boil water advisory in many areas, during the time of the field deployment. In addition, the loss of power caused cafeteria food to spoil. Prior to reopening the schools, the district had to completely remove all rotting food and clean the kitchens to ensure they met safety standards. In fact, some of the schools reopened and had lunch brought in from the outside while kitchen repairs were ongoing. Power and water outages also affected high schools that were used as temporary shelters. Fortunately, efforts were taken to get back-up generators for these schools, since they were considered high priority while temporarily housing community members. Schools also needed to have the air quality tested due to mold growth prior to students returning.

Damage to roads and bridges complicated the recovery process for PSRC schools. Each day, approximately 16 000 students were transported by 268 buses in Robeson County (Public Schools of Robeson County, 2017). Because of widespread financial need, the school district procured additional funding through grants to provide free transportation to and from school as well as for after school activities. In the weeks following the flood, school district officials met with the North Carolina Department of Transportation (NC-DOT) to get a road damage assessment and evaluate if it was possible to get children to school safely. After the flooding, there were over 100 roads either partially or completely damaged. Given that the PSRC buses drive on 269 roads across 181.3 square km (70 square miles) to transport children to schools, they could not continue operations until the roads were repaired or alternate pathways were mapped out. Two weeks after the schools closed, the district transportation department sent out bus drivers in their privately-owned vehicles to document areas that were unsafe and map possible alternatives for bus stops and driving routes. When schools reopened three weeks after the flood, they were on a two-hour delay to accommodate new and longer routes. The transportation department used privately contracted vans to help transport students safely to schools from shelters and hotels. These vans are federally paid for under the McKinney Vento Act, which offers additional resources to students who are homeless or displaced due to a disaster. Many children also had to walk up to a half of a mile to get to new bus stops.

In addition to road damage, the district struggled with the loss of many of their vehicles to floodwaters. A total of 96 district vehicles were damaged in the flood including driver's education cars, vehicles used for maintenance and delivery services, and 15 activity buses valued at $100K each. Many employees are now being asked to use their own vehicles for work-related activities (with expense reimbursement), given that the school district has not received adequate funding to replace all lost vehicles. The district transportation offices were also inundated with over a foot of water, which destroyed all paper records and transportation logs that are needed to legally document student transportation services to the State. Funding of school bus operations is determined by ratings of efficiency of fuel use, hours driving, and mileage. Loss of documentation and less efficient transportation routes may negatively impact the District's budget.

The flood forced the costly restructuring of bus drivers' schedules, compensation, and benefits. Given that bus drivers are paid hourly, many of them are typically ineligible for employee benefits. When the drivers worked additional hours due to longer route times, many met the 4 hours/day requirement to receive benefits, such as overtime, health insurance, and retirement plans. Prior to the flood, only about ten percent of bus drivers received benefits; this figure jumped to seventy percent once school was back in session. In addition, other transportation department employees lost their offices and were working out of their cars or temporary spaces, which reportedly decreased productivity by approximately thirty percent. This will certainly cost the school district and it is still uncertain how much reimbursement for employee benefits the district can expect to get refunded.

4.1.3.2 Schools and Evacuation, Sheltering, and Displacement

On Friday, October 7, 2016, the Public Schools of Robeson County announced that students would be released early with all afternoon activities cancelled as Hurricane Matthew was approaching and expected to bring heavy rains to the area. The following day, the District opened the first five schools for sheltering evacuees: South Robeson High School, Gilbert Carroll Middle School, St. Pauls High School, Purnell Swett High School, and Red Springs High School. By October 12, Gilbert Carroll Middle School was closed due to flooding, many of these schools used for shelters were at capacity, and additional shelters were needed and being opened across the county. District officials were making updates every few days about school closures, but did not know the extent of the damage until two weeks after, when the floodwaters crested and began to subside. On October 20 and 21, the principals, assistant principals, and custodial staff returned to work to prepare the buildings and make plans for bringing students back. On October 31, three weeks after the flooding began, students and staff were able to return to school on a two-hour delay. Staff members continued to receive their full income while schools were closed.

The flood waters rose quickly and unexpectedly in Lumberton. Many people were still in their homes and needed to be rescued by boat or helicopter. Eighteen state-owned school buses were commissioned to help rescue and transport approximately 1 800 evacuees to shelters. Many students and families stayed at school shelters, local motels and hotels, or left the area to seek refuge with family and friends. During the weeks that the students were out of school, key employees at the school district worked tirelessly to locate their students. They went to shelters and hotels to document who was there, used email, Facebook message groups, the school website, phone calls, text messages, and word of mouth to reach out to parents and communicate with staff about locating students and/or their family members. Many of those who were able to

remain in their homes were without power and all homes were without water for one to three weeks. Breakfast and lunch were provided for free to all students prior to the floods. Based on the low-income status of most families, they were able to get a grant that has been covering these costs for 2 to 3 years. However, many students went without this service while the schools were closed for three weeks, which placed an additional hardship on families.

On October 31, when most students were returning to their home schools, the prekindergarten through fourth grade students at West Lumberton Elementary had to temporarily occupy a new location at Lumberton Junior High School. Even with the major transition and an estimated 90 % to 95 % of the student body still out of their homes, 127 out of 151 West Lumberton Elementary students returned to school by the end of November 2016. This was explained by a staff member who said, "I believe it's a testament to the kind of school community we have. Parents are doing everything they can to get the kids back to this school." The decision to relocate the students to Lumberton Junior High was much deliberated. The key decision makers at the school and district level explored relocation options such as mobile units and splitting the children across multiple schools, but ultimately decided to prioritize keeping students together and getting back to classes as soon as possible. One school official explained it this way:

> *'Cause it was really important to keep everyone together and that's really what guided that whole decision, you know? 'Cause it would have been a lot easier to have said, 'you know we are gonna send this group here, we are gonna send this teacher there', 'cause there are small segments, places we could have gone to other schools around the county. But that was never a consideration...Because what happened was just too traumatic and then having to come back and go to some place where you don't even recognize the adults, that just would have not been fair to our students and our families.*

4.1.3.3 Returning to School and Responding to Needs

For many students and staff at West Lumberton Elementary, losing their homes as well as their school and workplace, made the impact to their lives even more severe. Therefore, interviewees were relieved to be able to return to school together. When asked about how the children responded on their first day back, one school employee assured us, "The kids know that when they are at school they are taken care of. They are warm, they are fed. They are going to have two meals. It was just so good for them to get back to their normal day." The school district was able to organize donations and provide students with free breakfast and lunch; counseling services and creative recovery activities; material donations such as clothing, toiletries, holiday presents, backpacks, and school supplies; and adult and peer-to-peer support.

There are many factors that may compromise the mental health of children, including witnessing a death or injury of a loved one; losing a family pet, personal belongings, or a home; living in shelters or other temporary circumstances; and/or being exposed to increased stress within the family due to displacement, job loss, or other disaster-related circumstances. In disaster literature, children are described as being part of a vulnerable population and at the same time, exceptionally resilient (Fothergill and Peek 2015; Masterson et al., 2014). According to respondents, children in Lumberton experienced a similar juxtaposition of vulnerability and resilience. For example, although the children in this area would be considered "vulnerable" by most metrics, one school counselor explained, "Kids are resilient, but they are still in shock. They are just trying to get through the day" and another commented, "Kids have been very

resilient and have bounced back, especially after the first week." Many of the respondents did not see mental health as a top concern for students. Yet, they did acknowledge that no outside mental health resources were brought in and that school counselors were overwhelmed as they had to spend much of their time doing disaster-related jobs (i.e., organizing donations), instead of working directly with children.

While it is likely too early in the recovery process to diagnose trauma, school leadership did acknowledge that some children and staff members were suffering more than others. In one classroom, the students were coloring in district-provided recovery notebooks, when the school counselor noticed one little boy turned and looking down. Upon further investigation, the counselor noticed the boy was crying.

Principals and counselors explained that they were also worried that children were losing focus in the classroom, that fighting had increased amongst high school students, that they may not have access to food on evenings and weekends because they are living in hotels, that physical problems such as asthma and colds were being exacerbated by mold exposure, and that the parents were still struggling to find houses and get basic needs met.

School officials were getting increasingly concerned about the stress experienced by teachers as well. One principal explained, "Some staff members, I am concerned that they are right on the brink, you know, to losing it. Everyone is just exhausted, just tired. Everyone is still carrying the emotional part of that." Even though resources were limited, principals explained that they were doing many things to try to reduce everyone's stress levels such as limiting or forgiving homework, tardiness, and absences; letting teachers leave early to meet with FEMA or when they have other disaster-related needs; counseling teachers to be more compassionate with students; and reducing the trainings and expectations put on teachers outside of school hours.

4.1.3.4 Preparedness of Schools and Staff

Every disaster comes with significant challenges that school districts face in the weeks and months following an event. At the PSRC, key employees were working around the clock to manage the unfolding crisis. In the early days, the main challenges were organizing buses for evacuations, setting up evacuation shelters, and trying to locate students. Unlike many school districts, PSRC does not have a full-time emergency or crisis management person. This meant that many of the Ddistrict employees were struggling to learn how to manage a disaster in real time and found themselves overwhelmed by needing to educate themselves on disaster response strategies as the event was unfolding. One district representative explained:

> We did not have a crisis unit already in place prior to Matthew. Therefore, while everyone was out of school, we had to spend that time coming together, form a crisis team, identify all the steps that needed to be taken and the resources that were available, and then begin working on recovery. If we would have had that in place already, it would have saved a lot of time.

After the immediate response phase passed, the main challenges faced at the District level were managing student withdrawals, new registrations, overcrowding at intake schools, and documenting displaced student services that are required by the McKinney Vento Act.

Both the individual schools and the District were overwhelmed with outside donations and the process of trying to match supplies with families in need. Many employees had to put their regular duties on hold to assist with fundraising, communication, and other disaster relief efforts,

which meant that they got behind in managing daily operations and found themselves with a much larger workload as time went on. All of the respondents commented on how grateful they were for the many material donations and generous offers for services and assistance, but acknowledged that they needed additional help in trying to organize these efforts.

When students and staff returned, it was necessary that schools were adequately stocked with the materials necessary for teaching. Unfortunately, many of the paper materials, extra supplies, and printing services were located in the central offices and district warehouse that were inundated with flood water. In addition, delayed supply chains due to road closures and loss of district delivery vehicles made it particularly challenging for the district to replace and deliver supplies to schools. The many challenges faced by the PSRC, and more specifically the Lumberton schools, have highlighted areas where disaster planning could be improved.

4.1.4 Non-Residential Interviews

The research team visited 14 businesses (including one church) based on availability at the time in the southeastern section of Lumberton along 5th Street, with eight being fully documented. This street parallels I-95 to the west and turns to parallel the CSX rail line that went under I-95. Figure 4-1 shows the flooded area and the locations of the businesses visited. The depth of flooding in the buildings varied from 0 m (0 in) to just over 1.22 m (48 in) depending on the elevation of the site and building floor compared to the flood elevation (BFE was approximately 37.2 m [122.0 ft]). Table 4-1 lists a select group of the businesses and the approximate flood elevation at those sites. Note that all businesses surveyed were flooded to the same approximate BFE of 37.2 m (122.0 ft) above mean sea level. All businesses lost power and all had some contents damaged or lost.

Table 4-1 Approximate flood elevations of surveyed non-residential buildings.
[1 ft = 0.30 m; 1 in = 25.4 mm]

Location	Ground Elev. (ft.)[1]	Depth of Flooding (in.)[2]	Approx. Flood Elev. (ft.)	Time to Reopen
(a) Bank	120	12	121	4 weeks
(b) Small retail store	119	24	121	2 weeks
(c) Big box store	119	1	119	3 mo. (expected)
(d) Gas station	119	0	119	2 weeks
(e) Furniture store	118	16	119	3 weeks
(f) Propane distributor	117	48	121	Moved
(g) Liquor store	117	22	119	2.5 weeks
(h) Church	114	59	119	Unknown

[1] The elevation is taken at the lowest adjacent grade around the building from Google Earth.
[2] The depth of flooding is taken from the ground to a high-water mark on the building or is taken from owner interviews when a high-water mark was not visible.
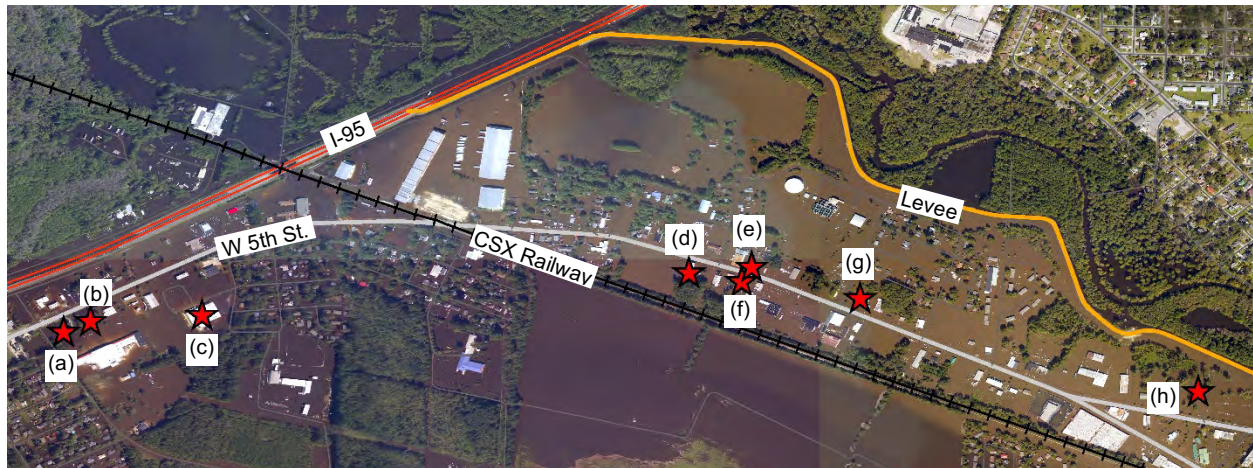
Figure 4-1. Location of select non-residential buildings.

The business sizes and types varied significantly. The non-residential inspections included two banks, three small retail stores, one big box retail store, two gasoline and convenience (small retail) stores, a propane distribution station, a produce center, a liquor store, a church, and a furniture store. Because all of these businesses were closed during the flood and for several weeks post-flood, most employees were not able to work. Many of the businesses adapted their locations and/or that of their employees to best continue operations: the big box store moved employees to other stores in the area; two of the small retail stores allowed employees to work in other locations; one of the banks shifted employees to another location; and the propane distribution center moved the entire operation to another rented location and will permanently close the location on 5th Street. The buildings inspected are shown by location in Figure 4-1 and a front view of each of the sites listed is presented in Figure 4-2.

Observations from the investigations of commercial businesses include:
- Many chain establishments were able to send workers to other locations while fewer local businesses were able to relocate employees.
- Chain establishments typically filed insurance claims for lost inventory, while smaller establishments typically were not insured.
- Interviews showed that looting was a consistent problem. Small items such as cigarettes, alcohol, and soft drinks were typical items stolen.
- Small businesses expressed large financial burden relative to their resources and a lack of support from government.

Figure 4-2. Front view of selected businesses.

4.2 Survey Results

4.2.1 Damage Surveys: Empirical Flood Damage Fragility Analyses for Residential Buildings

In this section, the damage states associated with physical damage to residential buildings and certain contents and personal property are considered in the analysis. An initial dataset of 469[20] entries for residential buildings was considered. However, before the analysis, data (approximately 14 %) associated with incomplete assessments were eliminated. This generally included entries with missing information, inconsistent recordings of high-water mark locations and foundation types, or incomplete assessments due to access challenges (e.g., team member could not access crawl space to properly assess the damage). The elimination of these points reduces the total number of data points, but avoids introducing bias likely from using incomplete or erroneous entries. This data organization produced a final dataset of 402 damaged properties. The updated dataset was considered for the social vulnerability analyses presented later in this chapter.

Table 4-2. Summary of empirical dataset, including breakdown by foundation type, building type, and number of stories

Foundation type (# of bldgs)	Type of building	Distribution	Number of stories			
			1 story	2 stories	≥3 stories	split/other
Slab (116)	Single Family	33.6 %	97.4 %	0.0 %	0.0 %	2.6 %
	Multi family	64.7 %	80.0 %	20.0 %	0.0 %	0.0 %
	Other	1.7 %	50.0 %	50.0 %	0.0 %	0.0 %
Crawlspace (272)	Single Family	96.7 %	95.4 %	2.7 %	0.0 %	1.9 %
	Multi family	1.8 %	80.0 %	0.0 %	0.0 %	20.0 %
	Other	1.5 %	25.0 %	0.0 %	0.0 %	75.0 %
Other (14)	Single Family	100.0 %	100.0 %	0.0 %	0.0 %	0.0 %
	Multi family	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %
	Other	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %

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[20] This number is smaller than the 568 housing units visited as part of the surveying process (see section 3.2.1). The reason this number is smaller is because damage assessments were not undertaken in areas clearly not inundated by flood waters and many housing units were located in various forms of multi-family structures.

Table 4-3. Summary of empirical dataset, including breakdown by foundation type, building type, and construction type

Foundation type (# of bldgs)	Type of building	Construction type (%)					
		Wood	Concrete	Masonry	Steel	Wood/ Masonry	Other
Slab (116)	Single Family	15.5	0.0	9.5	0.0	6.0	2.6
	Multi family	22.4	0.0	15.5	0.0	26.7	0.0
	Other	1.7	0.0	0.0	0.0	0.0	0.0
Crawlspace (272)	Single Family	62.5	0.0	21.3	0.0	11.8	1.1
	Multi family	1.5	0.0	0.4	0.0	0.0	0.0
	Other	0.7	0.0	0.0	0.0	0.7	0.0
Other (14)	Single Family	35.7	0.0	0.0	0.0	0.0	64.3
	Multi family	0.0	0.0	0.0	0.0	0.0	0.0
	Other	0.0	0.0	0.0	0.0	0.0	0.0

4.2.1.1 Statistics of Data Parameters

More than 25 variables were collected from the engineering inspection data to be used in the development of the physical damage fragility curves. These variables are classified into four groups: 1) flood intensity information such as flood depth (quantified as inundation depth above the first floor elevation (FFE) and the ground) and flood source type (*e.g.,* sewer backup vs. proximity to nearby streams); 2) building properties such as occupancy type (*e.g.* single-family residence versus multi-family), foundation type, floor area, number of stories, construction and maintenance quality, as well as construction year where possible; 3) overall damage assessment that identifies the damage state of a structure from damage state zero (DS0) to damage state four (DS4), based on the condition of the affected building items and structural integrity (see Section 3); and 4) a detailed damage assessment of external and internal components to better record the damage of the residential structures (again from DS0 to DS4; see Section 3). Tables 4-2 and 4-3 summarize the key characteristics of the buildings in the dataset, and Figures 4-3 and 4-4 present histograms of flood depth for each damage state by foundation type. Most of the damaged homes were wood light-frame structures (many with brick veneer), of typical maintenance for their age, and typically one to two stories. Almost two-thirds of the homes have crawlspaces while the rest were built with slab-on-grade foundations. Figures 4-3 and 4-4 show: skewed distributions for DS1 and DS2 for all homes with crawl spaces where the flood is measured with respect to the FFE; normal distributions for DS1 and DS2 for all homes with crawl spaces where the flood is measured with respect to the ground; skewed distributions for DS1 and DS2 for all homes with slab-on-grade foundations, for both datum types; approximately a bimodal distribution for homes with slab-on-grade foundations, for both datum types; and flat distributions for DS3 for all types of foundations and datums. Figure 4-3 shows that the inspection data for buildings with crawlspaces experienced flood levels up to 1 220 mm (48 in) above the first-floor elevation (corresponding to 1 950 mm [77 in] above the ground). Figures 4-4 shows that the inspection data for buildings with slab-on-grade foundations experienced flood levels up to 1 220 mm (48 in) above the first-floor elevation (corresponding to 1 270 mm [50 in] above the ground). Most

of the damaged homes were found to be in damage states from DS0 to DS2. The depths for each damage state are highly variable (i.e., have a large value of standard deviation changing from 130 mm [5 in] to 430 mm [17 in]), even for a given foundation type, which is due to a number of factors ranging from the inspected damage to the flood characteristics themselves. It should be noted that the damage assessment of buildings with crawlspaces were challenging due to the reduced accessibility in parts of the inspected buildings with crawlspaces. These measurement challenges may have resulted in variability of flood depth for all the damage states.
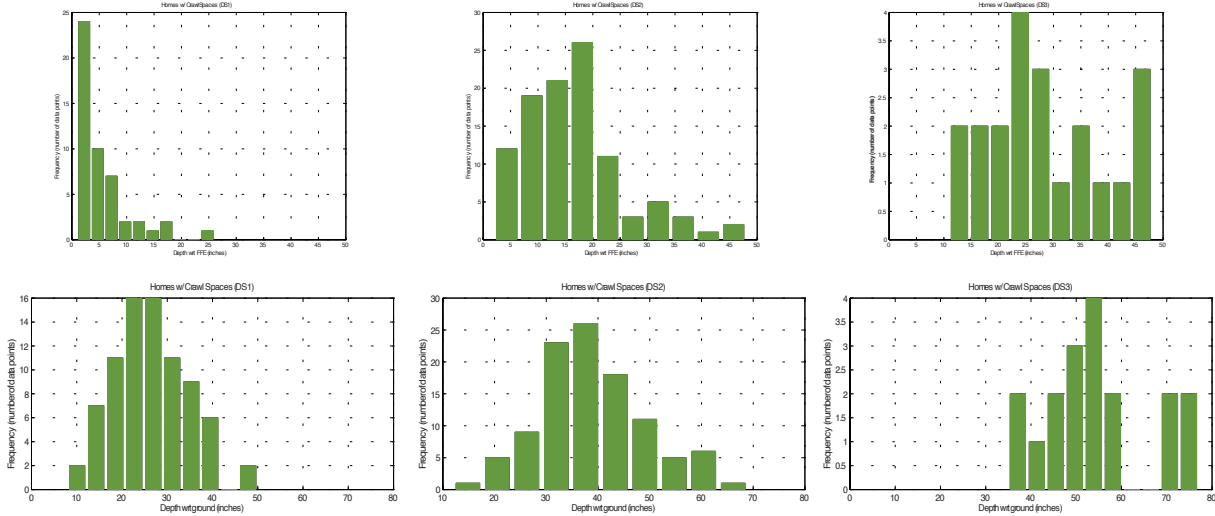

Figure. 4.3. Histograms of damage states for homes with crawlspaces using the first-floor elevation as the datum (top row) and the ground as the datum (bottom row). [1 in = 25.4 mm]
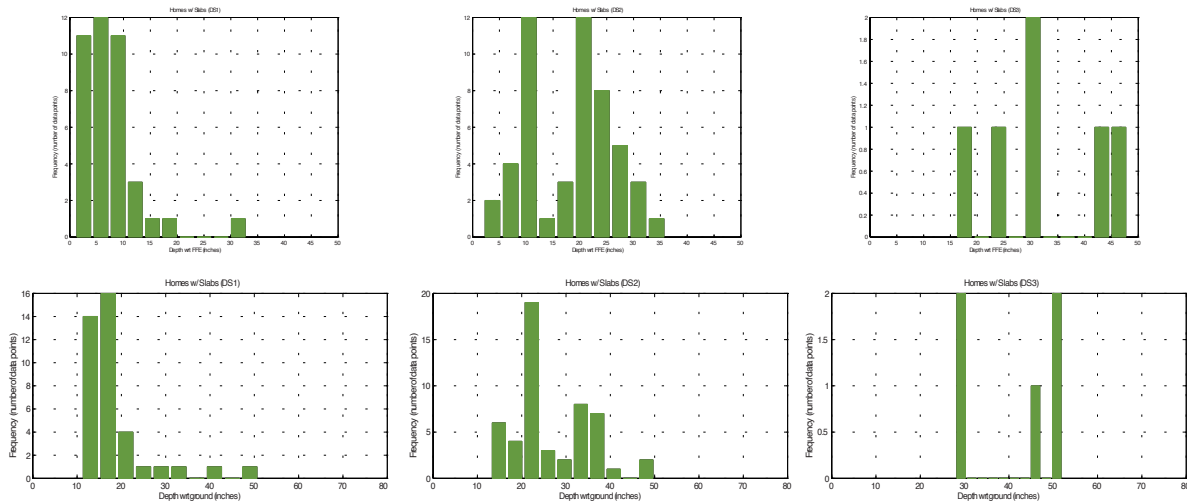
Figure. 4.4. Histograms of damage states for homes that have slab-on-grade foundations using the first-floor elevation as the datum (top row) and the ground as the datum (bottom row). [1 in = 25.4 mm]

4.2.1.2 Development of Empirical Fragility Curves

Significant variability was observed in flood damage estimates for the residential buildings, and therefore, a probabilistic model was used to characterize the uncertainty in the damage suffered by residential structures, conditioned on flood depth. Damage is characterized for these residential homes using fragility functions, or cumulative distribution functions (CDF). Lognormal distributions are often used in engineering fields because they have simple parametric forms to characterize uncertainty and only take on positive values.

Lognormal distributions were considered to be appropriate for characterizing exceedance probabilities of damage for flooded homes after performing goodness-of-fit tests for the empirical fragility curves. The widely used Kolmogorov-Smirnov (or K-S) goodness-of-fit test was used in this study. The basic premise of this test is to compare the collected cumulative frequency with the CDF of the assumed theoretical distribution (lognormal for this study). If the maximum discrepancy between the observed (from damage assessments) and theoretical (lognormal) frequencies is larger than normally expected for a given sample size, the theoretical distribution is not acceptable for modeling this specific problem. On the other hand, if the discrepancy is less than a critical value, the theoretical distribution is acceptable at the prescribed significance level *a*. In this study, a significance level of 5 % (*a* = 0.05) was considered for the sample size of the dataset considered in the analyses. For buildings with crawlspaces, all models passed the K-S test for all considered damage states. For buildings with slabs on grade, the models for damage states 1 and 3 passed the K-S test, however, the model for DS2 did not pass the K-S test for the specified significance level. Given the high degree of variability due to uncertainty factors involved in damage evaluation such as building properties, flood characteristics, and data collection variability (human error) and the fact that majority of the models passed the K-S test, the lognormal distribution was selected as appropriate for the data of the present study. Therefore, the probability that the uncertain damage state, *D*, is greater than or equal to specific damage state, *d*, conditioned on the uncertain flood depth with respect to FFE, X, taking on flood height, x, is given by:

$$P[D \geq d | X = x] = F_d(x) = \Phi\left(\frac{\ln(x) - \lambda_d}{\xi_d}\right) \tag{4.1}$$

which is the fragility function of damage state, *d*, evaluated at *x*, where *x* is the water depth above a datum (either FFE or the ground as shown in Figures 4.5 (a) and (b)) in inches, and where λ_d is the median capacity of homes to resist damage state, *d*, measured in units of flood depth, *D*, and ξ_d is the standard deviation of the natural logarithm of the capacity of homes to resist damage state, *d*. The values of λ_d and ξ_d for each damage state considered in this study are given in Table 4.3 for structures with slabs on grade and those with crawlspaces. Using the cleaned set of data (excluding erroneous measurements or missing data fields), damage fragility functions were developed for the homes in our sample. These fragilities are shown in Figures 4-5 (c) and 4-5 (d) for residential buildings with crawl-spaces, and in Figures 4-5 (e) and 4-5 (f) for residential buildings with slab-on-grade foundations. Since flood depth is relative to the chosen datum, the fragilities are shown for two datums typically used to characterize floods in buildings: the first-floor elevation and the ground. Since the damage states considered in this study are sequential (i.e., DS1 must be surpassed before reaching DS2), the probabilities of reaching or exceeding a damage state, *D*, is given by the following set of equations:

$$P[D = d|X = x] = 1 - P[D \geq 1|X = x] = \Phi\left(\frac{\ln(x) - \lambda_1}{\xi_1}\right) \qquad d = 0$$

$$= P[D \geq d|X = x] - P[D \geq d + 1|X = x]$$
$$= \Phi\left(\frac{\ln(x) - \lambda_d}{\xi_d}\right) - \Phi\left(\frac{\ln(x) - \lambda_{d+1}}{\xi_{d+1}}\right) \qquad \begin{array}{l} 1 \leq d \\ \leq n_D \end{array} \qquad (4.2)$$

$$= P[D \geq d|X = x] = \Phi\left(\frac{\ln(x) - \lambda_d}{\xi_d}\right) \qquad d = n_D$$

where n_D is the largest damage state. These probabilities of exceedance or shown in the shaded regions in between the fragility curves in Figures 4-5 (a) and 4-5 (b). For example, for buildings with slab-on-grade foundations that experience a flood depth of 508 mm (20 in) with respect to the FFE have the 16%, 49%, 28%, and 7% probability of being in DS3, DS2, DS1, and DS0, respectively. It should be noted that no DS4 observations were reported for the inspected buildings with slabs, while only 5 cases of DS4 were reported for buildings with crawlspaces. Given the small sample and potential bias on data collection, DS3 and DS4 were merged into a single damage state, DS3+, and shown in the fragility functions as the exceedance probability of reaching DS3.

The damage fragilities presented herein may be used to predict damage probabilities and estimate damage by future flooding events. They can also be integrated with flood hazard models for life-cycle performance assessments of similar structure types as well as be used as predictive tools for other U.S. communities, which show similar residential construction practice across the country for community resilience studies.
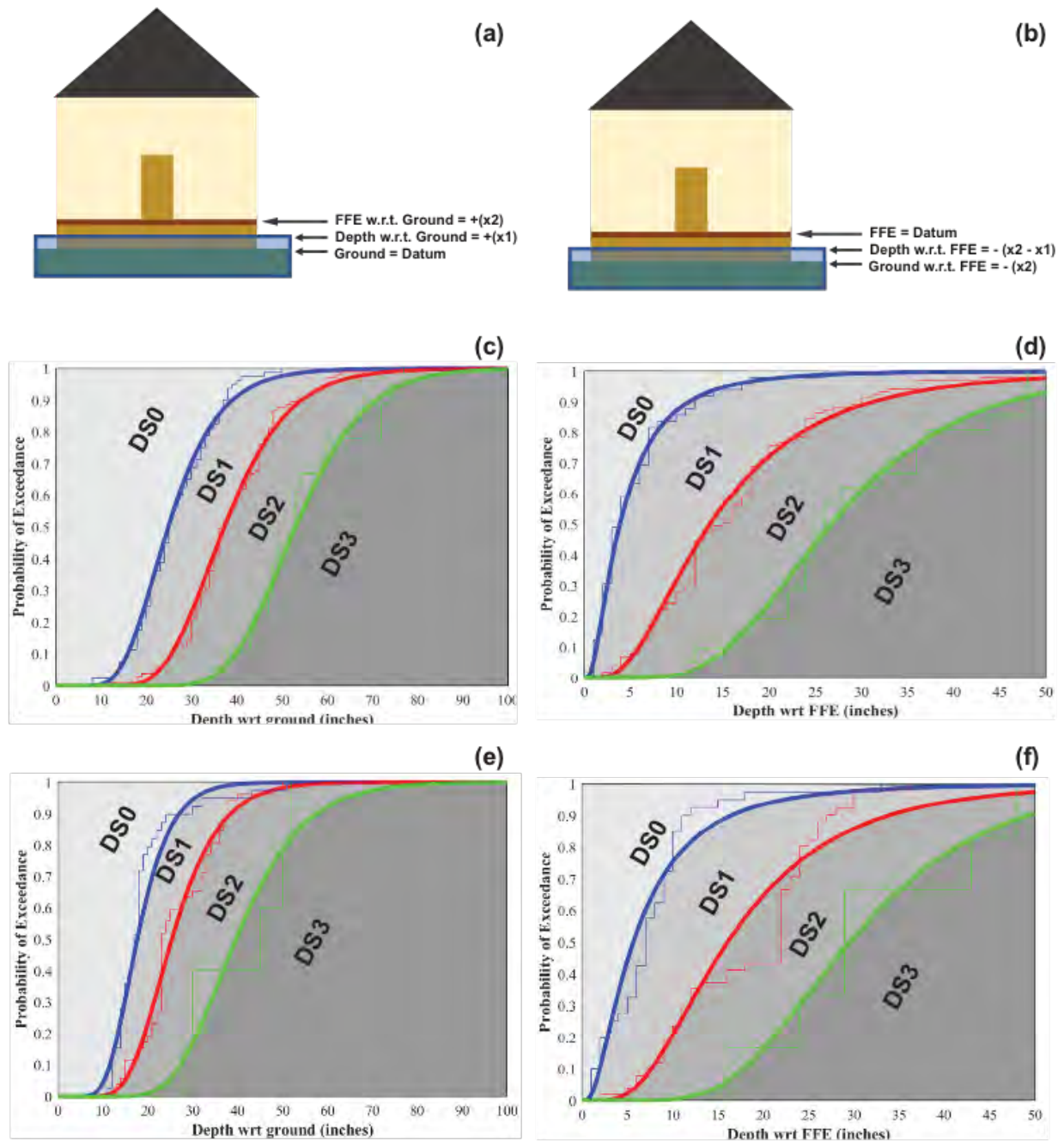
Figure 4-5. Flood depth measurements taken in the field with respect to the (a) ground and (b) first floor elevation (FFE), and associated fragility curves as a function of: (c) flood depth w.r.t. the ground for homes with crawlspaces; (d) flood depth w.r.t. the FFE for homes with crawlspaces; (e) flood depth w.r.t. the ground for homes with slabs-on-grade; and (f) flood depth w.r.t. the FFE for homes with slabs-on-grade. [1 in = 25.4 mm]

Table 4-4. Summary of lognormal fragility parameters

Datum	Damage State	Crawlspace		Slab-on-Grade	
		Mean (λ)	Standard deviation (ξ)	Mean (λ)	Standard deviation (ξ)
FFE	DS1	1.36	0.84	1.73	0.83
	DS2	2.61	0.65	2.78	0.58
	DS3	3.29	0.42	3.39	0.40
Ground	DS1	3.21	0.35	2.87	0.33
	DS2	3.62	0.29	3.23	0.32
	DS3	3.97	0.22	3.58	0.29

4.2.2 Household Survey Results: Damage, Disruption, and Dislocation

As discussed in Section 3.3, the housing unit/household survey was designed to gather representative information on the damage to residential housing, the consequences of the flood for household residents (including dislocation – whether forced or voluntary – and lifeline disruptions) and other consequences. This chapter will present preliminary findings with respect to these data focusing on damage, lifeline disruption, and dislocation. As each of these topic areas are explored, we will combine data from the damage assessments with relevant socio-economic and demographic data from the neighborhood (census block) and the household to better understand the overall picture of the impacts on the Lumberton area.

4.2.2.1 Flooding Damage to Residential Structures

Figure 4-6 displays a map of Lumberton, with the boundary of our primary focus area, the attendance zone for Lumberton Junior High and the damage-state assessments for residential housing units. Not surprisingly given the discussion in Chapter 2 about the flooding, we see much higher damage states in areas south of the Lumber River, in the area that was supposed to be protected by the levee, as well as a few structures that were impacted in northern sections of Lumberton, east of I-95.[21] However, it should be noted that the predominate damage-state ratings are the DS1 and DS2 levels, indicating minor to major damage particularly to the contents of these structures, but not substantial internal nor structural impacts to the residence. It should also be noted that simply because a structure was rated at DS0, it does not necessarily mean that there was no damage. Particularly in structures with crawl spaces, a DS0 means could mean that water did not likely touch floor joists, but damage could have occurred to central air-conditioning units, storage areas behind carports which may have contained hot-water heaters, etc.

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[21] For the purposes of this discussion and in subsequent dislocation analysis structures that were well out of the inundation areas and did not, therefore, receive formal damage assessments have been classified as DS0.
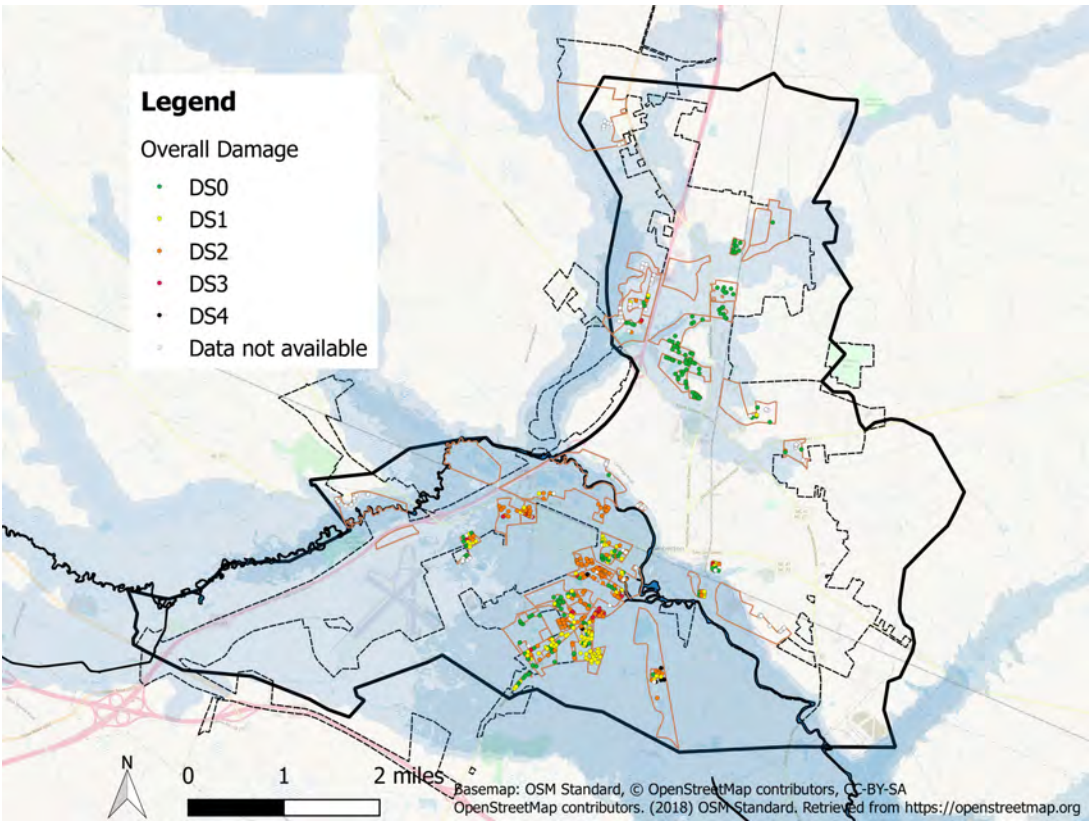
Figure 4-6. Overall damage state rating of residential housing units. [1 mile = 1.61 km]
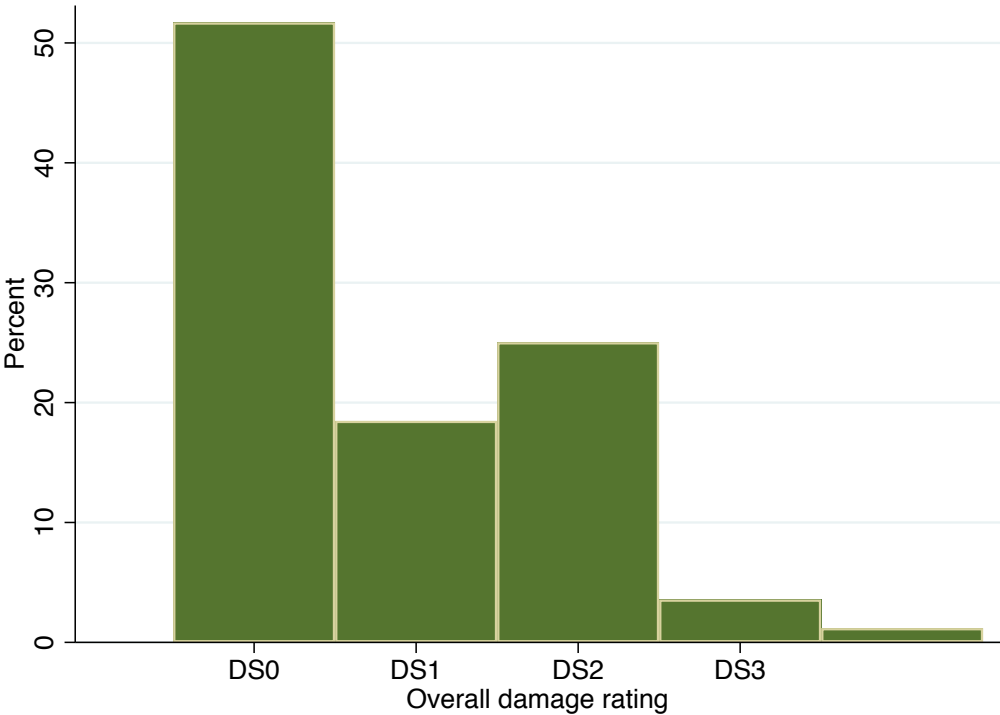
Figure 4-7. Overall damage state ratings of residential housing units.

Recall that Figures 4-3 and 4-4 presented histograms for each foundation type and damage level as a function of depth. Figure 4-7 combines all this data into one histogram, which displays the survey data appropriately weighted to better reflect the estimated impacts on residential housing for the study area. Overall, approximately 52 % of the housing units received no direct physical impacts from the flooding. However, 18.5 % were rated DS1, 25 % were rated at DS2, and 3.6 % and 1.2 % were rated at DS3 and DS4, respectively.

To obtain a picture of the economic consequences of these damage states for the residential owner, we were able to merge in tax appraisal data for structures before and after the flooding with our data. Tax appraisal data has been employed in the research literature to assess not only disaster impacts with respect to housing, but also to track housing restoration and recovery after a disaster (Bin and Kruse, 2006; De Silva et al., 2006; Zhang and Peacock, 2010; Peacock et al., 2015; Hamideh et al., 2018). Table 4-5 presents the average percentage in appraised value loss across structures for each damage state. There were so few observations at DS3 and DS4, that their margins of errors were quite large, meaning that statistically speaking, there were no differences between these two categories. Because of this, observations in DS3 and DS4 categories were collapsed into one category, DS3+, and their average percentage damage loss, along with the margin of error are presented in the last row of Table 4-5. Figure 4-8 shows the averages and confidence intervals for each damage state, utilizing the collapsed DS3+ category.

Table 4-5. Average appraisal value loss and margin of error by damage state.

Damage State	Average % Value Loss	95 % Margin of Error
DS0	4.4	2.1
DS1	16.6	4.6
DS2	25.5	5.9
DS3	40.8	11.2
DS4	45.0	18.1
DS3+[*]	41.9	9.6

*The final row, DS3+, collapses DS3 and DS4 observations into a single category
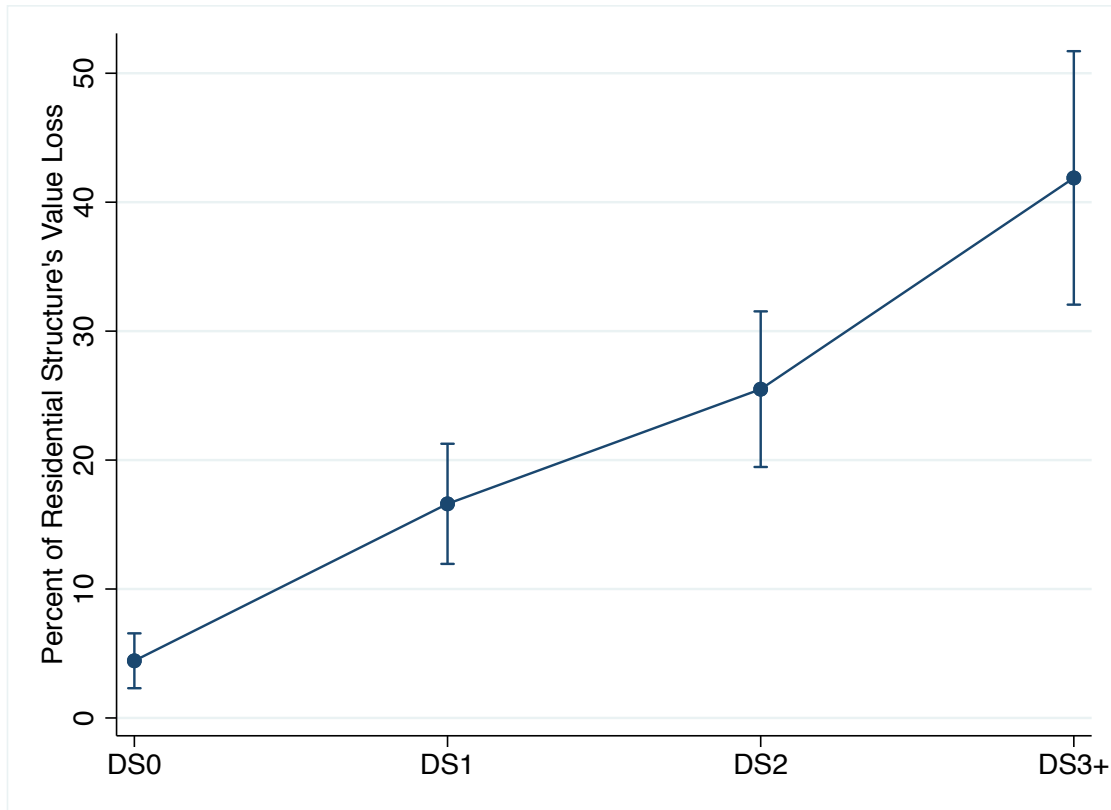
Figure 4-8. Average value loss by damage state and 95 % confidence intervals.

As would be anticipated, as damage state increases, so too do the percentage of pre-flood value lost. Specifically, on average DS1 homes lost 16.6 % (±4.6) when comparing their pre-event tax assessed value with their post event assessment. For DS2 houses the average percentage loss was 25.5 % (±5.9) and at DS3+ the loss was 41.9 % (±9.6). It may seem strange at first blush to have a percentage loss of 4.4 % (±2.1) for houses in the DS0 category. However, it should be remembered that simply because a structure was rated at DS0, does not necessarily mean that there was no damage to the property. Hence, while substantially smaller, there were nevertheless some economic impacts registered amongst these structures as well.

Remembering the discussion in Chapter 2 regarding the racial and ethnic composition of Lumberton, it will be recalled that there were substantial percentages of what are often categorized as minority populations in Lumberton, particularly African American and American Indian populations. Furthermore, these populations were highly concentrated within the flood plains in and around Lumberton, particularly in southern sections of Lumberton, below the Lumbee River. Consequentially, it would not be surprising to find that minority populations were disproportionally impacted by this flooding event. Figure 4-9 presents the damage state data broken down for each of the three-primary racial/ethnic populations found in Lumberton: non-Hispanic White, non-Hispanic Black, and American Indian.
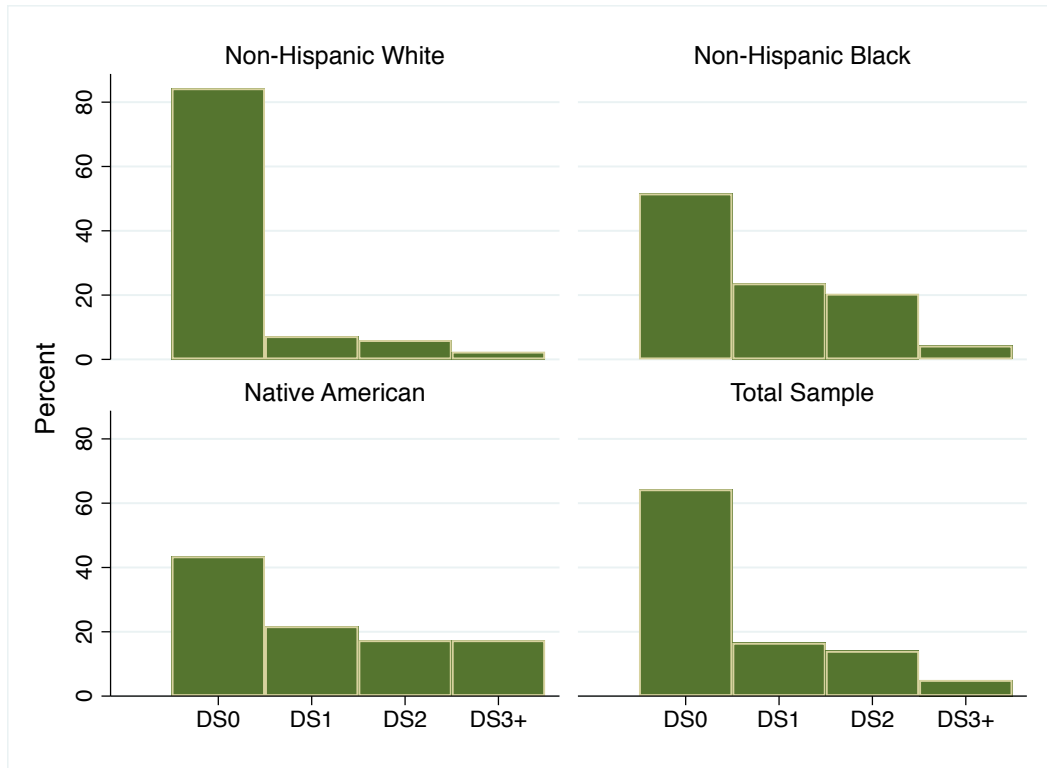
Figure 4-9. Damage state by racial/ethnic category.

As seen in Figure 4-9, the percentages of housing falling into different damage states is quite different when comparing non-Hispanic white households (upper left panel) to non-Hispanic Black (upper right panel) and American Indian (lower left panel) households. While 84 % of white households fell into the DS0 category, the percentages were 52 % for non-Hispanic Blacks and 43.5 % for American Indian Households. Similarly, while just over 7 % and 6 % of white households fell into DS1 and DS2 states, the percentages for Black households was 23.7 % and 20.4 % and for American Indian households the percentages were 21.7 % and 17.4 % respectively. In terms of percent value loss, the percentages for non-Hispanic white households was 3.7 % ($\pm$2.1), while for non-Hispanic Black households it was 15 % ($\pm$5.2) and for American Indian it was 12.8 % ($\pm$8.8). The latter two percentages were statistically different than the percentage for non-Hispanic white household, but not statistically significant than each other.

Clearly, as is so often found in the disaster literature, the Lumberton flooding event was not a so called "equal opportunity" event when it comes to damage and economic impacts. Rather, the nature of our communities not only in how we build but also the historical legacy of where we do and can build and what populations tend to be found in different locations shapes the outcomes of disaster events.

4.2.2.2 Lifeline Disruption
Households were also asked about disruption to their utilities: power, water, natural gas, phone and internet service. The vast majority of households reported losing power (99.4 %) and water (94.7 %) and a correspondently high percentage (96.4 %) reported having to boil when their service returned. Significantly fewer of households that had natural gas, reported losing access (63.8 %). Similarly, much fewer households that had either phone or cell phone service, reported

losing phone service (46.2 %), although many that never lost service reported difficulties with getting calls out. Finally, the percentage of households that had internet service and reported losing that service (89 %) was just slightly lower than the percentages reporting losing power or water.

Table 4-6. Average days without lifeline service.

Days Without	Average	Margin of Error	Median	Minimum	Maximum*	N
Electricity	10.9	1.4	7	2	61	280
Water	14.6	1.6	10	1	61	265
"Safe" Water	27.2	2.5	21	1	61	248
Natural Gas	27.7	6.7	16	3	61	44
Phone Service	11.3	2.2	7	1	61	136
Internet	13.9	2.0	8.5	1	61	190

For those households reporting losing any of their utility or communication services, the number of days they were without services varied considerably depending on the utility/service. Table 4-5 presents the descriptive statistics for the number of days households reported being without specific utility or communication services. The lowest average time household reported being without service was for electricity, where household reported an average of 10.9 d ± 1.4 d without service, with a median of 7 d. Similarly, phone service was out for an average of 11.3 d ±2.2 d, also with a median of 7 d. Water service disruption averaged 14.6 (±1.6) days, although the average time for having safe water was 27.2 d ±2.5 d. Interestingly, while fewer households that had natural gas reported disruption in service, the average days without service was the longest for any of these services at 27.7 d ± 6.7 d. It is also worth mentioning that some of these figures are higher than those officially reported by utility service providers. Part of the reason for this discrepancy is that the data in Table 4-6 represent days that a given residential structure was without a service which is often much longer than the time it takes to have transmission lines or pipes into a neighborhood active. When considering community resilience, it may well be important to consider these differentials, because they can have consequences for household themselves.

4.2.2.3. Population Dislocation

As noted above, in addition to gathering data to improve damage fragilities for residential housing, one of the other objectives of the Lumberton field study was to collect data to improve population dislocation modeling. Population dislocation has become increasingly important over the last decade in the United States as the issue was magnified after natural disasters, such as Hurricane Katrina in 2005. There is increasing recognition that dislocation is likely to continue with climate change and sea-level rise. Currently attempts to develop population dislocation algorithms have been based on an earthquake cased study, as in HAZUS Multi-Hazard (HAZUS-MH), or on a hurricane case study, as in MAE-Viz. Both of these have been incorporated into IN-CORE. This section will discuss preliminary findings based on the Lumberton field study.

As discussed in Section 3.3.2 the survey instrument was designed to collect both direct and indirect information about household dislocation. Direct information was obtained by actually interviewing an adult member of the household regarding the displacement of any or all

members of the household. In the case where no household was present, indirect information regarding household displacement was obtained from neighbors, managers, as well as assessments made by the survey team as to whether or not the housing unit appeared to have been occupied. Based on these data, determinations were made as to whether some household members were displaced or the entire household was dislocated. In general, as is often found in the disaster literature, households in Lumberton tended to dislocate as a unit, rarely did only some members displace, leaving others at the home. Hence our focus is on household dislocation.

Based exclusively on interview data with household or neighbors, we estimated that 69.8 % (±4.3) of households dislocated; extending our estimate to include survey team assessments, the estimated dislocation rate was 75.6 % (±3.6). On the whole, we feel that the latter estimate is a reasonable estimate that makes full use of the data collected by field survey teams. The length of dislocation ranges between 0 d to 61 d, where the maximum is set by the fact that the interview team completed its survey work 61 d after the flood. So, it is possible, that with the next round of survey work, this maximum will be much larger. Nevertheless, based on this survey the average days of dislocation was 34.4 d ±2.4 d, with a median of 61 d. If we focus only on those households that were available to interview, the average was 26.8 d ±2.7 d, with a median of 9. Clearly, the dislocation process has impacted a substantial proportion of households in Lumberton, and for many families this has been a protracted process.

Figure 4-10 is a map of Lumberton identifying the sampled units and the dislocation status of households. The red dots reflect housing units in which their household dislocated after the storm, with green dots indicating housing units whose occupying household did not dislocate. Clearly there are much higher frequencies of dislocated households in areas that experienced some flooding, although this is not exclusively the case for either likely or unlikely flood areas.

Legend

Dislocation

- Not dislocated
- Dislocated
- Data not available
- Selected Census Blocks
- Lumber River
- Inundation
- Floodplain (100m Buffer)
- Selected School Attendance Zone
- City Boundary

N

0   1   2 miles

Basemap: OSM Standard, © OpenStreetMap contributors, CC-BY-SA
OpenStreetMap contributors. (2018) OSM Standard. Retrieved from https://openstreetmap.org
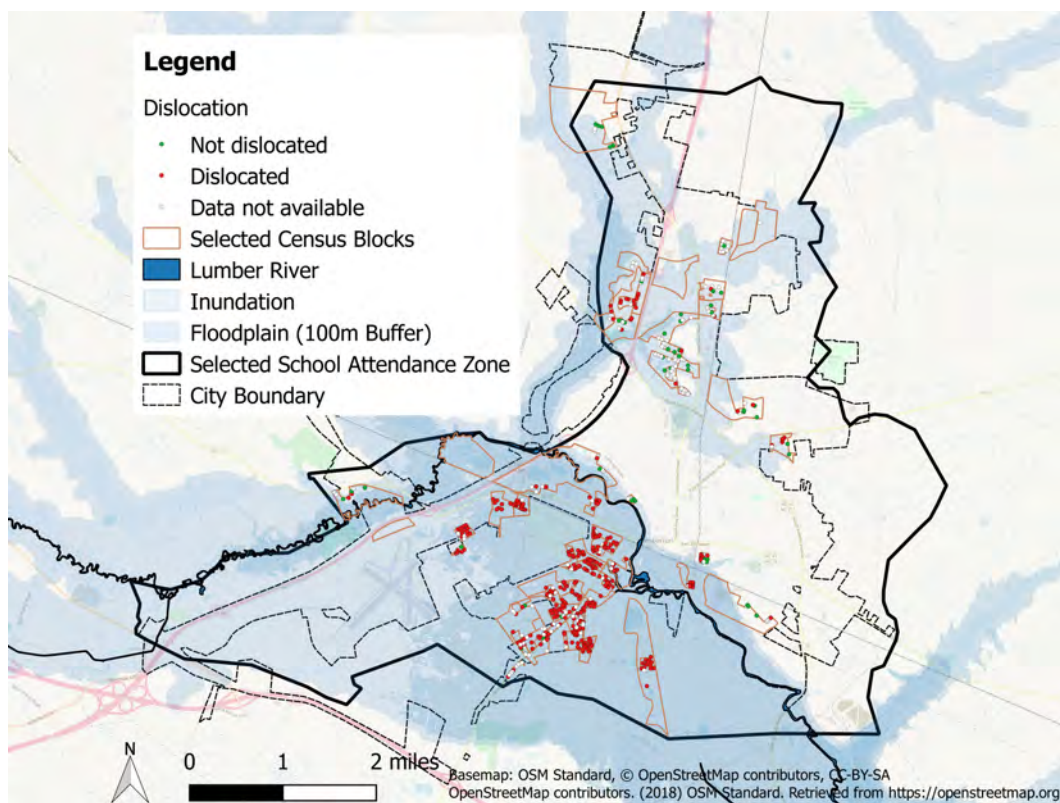
Figure 4-10. Estimated dislocated households for sampled housing/household units.
[1 mile = 1.61 km]

Legend

Days of dislocation

- Not dislocated
- less than 7 days
- 7 d to 13 d
- 14 d to 20 d
- 21 d to 27 d
- 28 d to 34 d
- 35 d to 41 d
- 42 d to 48 d
- 49 d to 55 d
- More than 56 days and not returned

N

0   1   2 miles

Basemap: OSM Standard, © OpenStreetMap contributors, CC-BY-SA
OpenStreetMap contributors. (2018) OSM Standard. Retrieved from https://openstreetmap.org
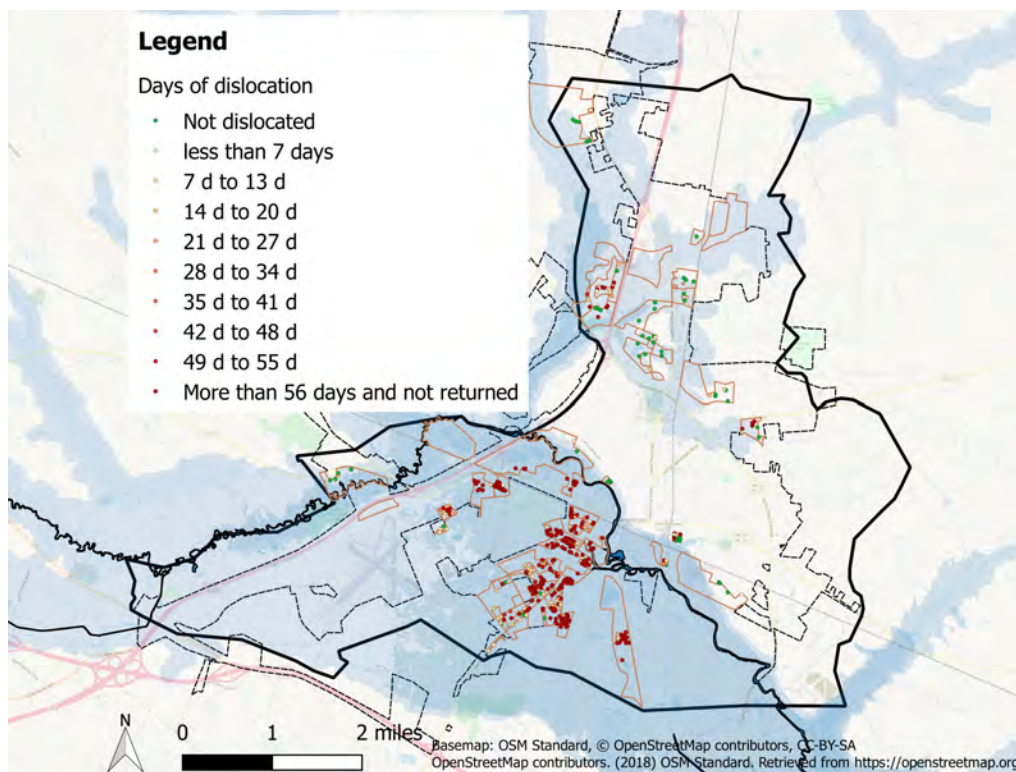
Figure 4-11. Estimated days of dislocation for sampled housing/households.
[1 mile = 1.61 km]

Figure 4-11 displays the estimated days of dislocation for sampled housing units. While it is a bit difficult to distinguish, in general as the dots go from green, through tan, and to red, the higher the number of days a household is estimated to be dislocated. Not surprisingly the darker dots, indicating a greater number of days of dislocation tend to be found in areas south of the Lumber River and east of I-95 to the north. Again, however, there are also many tan and green dots south of the river indicating that many households did not dislocate or were only away for relatively short periods of time.

As discussed in other sections, the literature on dislocation has noted that there are many factors that can influence dislocation. The obvious factor is, of course, damage to the housing unit, with the general expectation being at higher levels of damage will force households to leave their homes for safety and certainly discomfort reasons. However, other factors have been shown to have consequences as well. Tenure is another factor often cited. In general, renters have been found to dislocate at higher levels. Since renters do not own their home they do not have the same levels of property rights and can be asked or forced to leave by the owners of the property who are potentially liable should the renters be hurt or somehow harmed by the damaged property or may simply want to affect repairs. Homeowners, on the other hand own their properties and tend to want to stay, even with badly damage property, although this is most likely the case with low income households that have fewer resources. Figure 2-18, for example, showed much higher concentrations of rental properties in neighborhoods south of the river, hence this may well be a factor shaping dislocation. The literature also suggests that households with higher incomes, particularly if insurance will cover the extra-living expenses associated with hotels or short-term rentals, will leave their homes temporarily, for a short period of time, until repairs can be started. The literature has also shown that other factors such as race/ethnicity, social networks, discrimination, etc. can also have consequences for dislocation.

$$\ln\left(\frac{P_i}{1-P_i}\right) = \beta_0 + \beta_1 X_1 + \cdots + \beta_k X_k + u_i \tag{4.2}$$

With the data collected as part of the field work, combined with census and other data we can develop more comprehensive models to better understand the consequence of these different factors for shaping dislocation. More specifically, in this case logistic regression can be employed to fit a model predicting the log odds of a household being dislocated. A general form of the model is offered in Equation 4.2, where P_i is the probability that a household is dislocated from its housing unit, $1-P_i$ is the probability that it does not, β_k are coefficients representing the change in the logged odds given a unit change in a set of independent variables, X_k. These equations are estimated using a maximum-likelihood estimation procedure. This chapter presents preliminary examples of findings employing this form of analysis to predict household dislocation. Specifically, these examples will utilize damage state, race/ethnicity, and percent renter in the block in which the housing unit is located to predict household dislocation.

Table 4-7 presents the results from three models predicting household dislocation. Model 1 employs only damage state data, with DS0 being the comparison and DS3 and DS4 are collapsed into a single category capturing DS2 or above damage. Model 2 adds household racial/ethnic variables in which non-Hispanic Whites are the comparison group, and Model 3 adds the percentage of rental housing units in the block that the housing unit is located as an indicator of the likely tenure of housing occupants. All models are statistically significant, with pseudo-R^2s suggesting that the base model accounts for 25% of the variance, climbing to just over 31% in the final model. Logit coefficients are presented in the shaded rows and the coefficients

representing the change in logged odds are presented in the unshaded rows. The standard errors were estimated using robust estimation to account for mixing individual and block measure in the equations.

Table 4-7. Logistic regression results predicting household dislocation.

	Model 1	Model 2	Model 3
Constant	-0.49**	-1.08**	-1.46**
	0.61	0.34	0.23
Damage State 1	2.47**	2.18**	2.20**
	11.88	8.86	9.04
Damage State 2+	4.10**	3.83**	3.88**
	60.62	46.09	48.58
non-Hispanic Black		1.10**	0.98**
		3.00	2.67
American Indian		1.66**	1.79**
		5.25	6.00
Proportion renters			1.06*
			2.88
Log Likelihood	-99.0973	-93.0922	-91.3985
χ^2	32.97**	44.72**	43.25**
Pseudo R^2	0.2532	0.2984	0.3112
AIC	204.2	196.2	194.8

** = two tail significance at ≤.05; * = one tail significance at ≤.05; N = 195

The results from Model 1 suggest that, as would be expected, households located in structures with higher damage are indeed more likely to dislocate. Households in homes classified as DS1 have odds of dislocating by nearly 12 times than households in DS0 structures and those in DS2+ were nearly 61 times more likely to dislocate. These shifting odds can clearly be seen in Figure 4-12, which displays the probabilities of households living in housing units with different damage states of dislocating. At DS0 the probability of dislocation is approximately .38 with a margin of error (MoE) of ±.09, at DS1 the probability rises to .88 (MoE of ±.11), and at DS2+ it is .97 (MoE of ±.05). As can be seen in Model 2, when household race/ethnic indicators are added to the equation, there is an attenuation in the odds associated with the two damage states, when compared to Model 1, but we also find that both minority households, non-Hispanic Black and American Indian, have statistically significant elevated odds of dislocation when compared to non-Hispanic White households. More specifically, the odds for non-Hispanic Black households are 3 times the odds of non-Hispanic White households and for American Indian households the odds are 5.25 times the odds of a non-Hispanic White households. These differentials are illustrated in Figure 4-13, which presents the probabilities of dislocating at each damage state for each type of household. The navy-blue line is for non-Hispanic White households, the maroon line for non-Hispanic Black households, and the green line for American Indian households. Again, we see higher dislocation probabilities as damage state increases, but consistently non-Hispanic White probabilities are the lowest, with American Indian households having the highest probabilities, and non-Hispanic Black households falling in between. It should

be noted, that the probabilities of all three types of households converge with higher levels of damage, and there are not statistical differences between the two minority households.
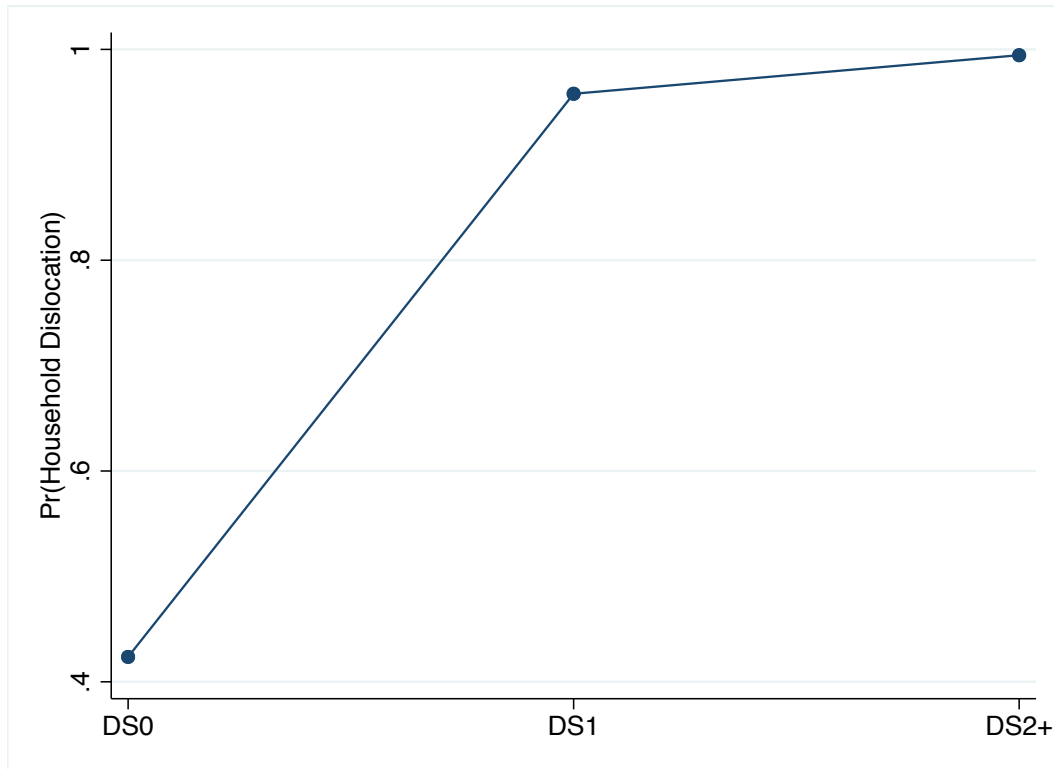
Figure 4-12. Probability of household dislocation by different damage states.
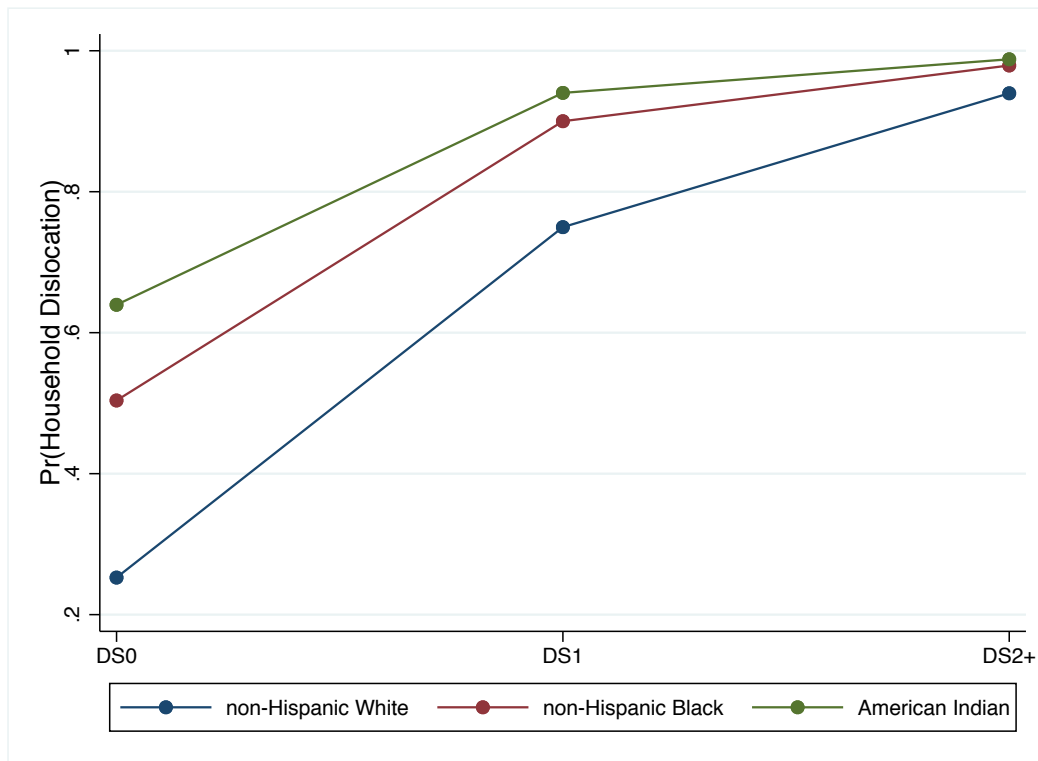
Figure 4-13. Probability of household dislocation by damage state and race/ethnicity.
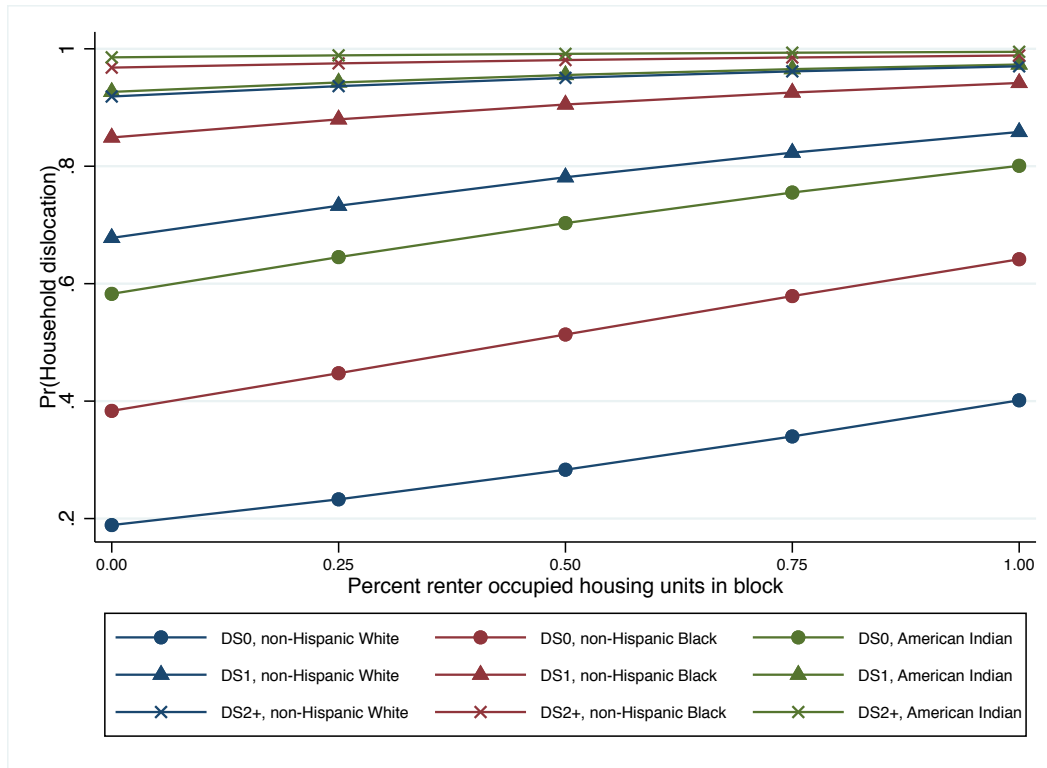
Figure 4-14. Probability of household dislocation by damage state, race/ethnicity, and tenure.

In the final model of Table 4-6, the percent renter in the block the housing unit is located is included as an indicator for likely tenure status of households within the block. As noted above the literature has generally found that renters dislocate at higher rates than do homeowners, hence the expectation would be that this measure should have a positive effect on dislocation, which indeed we see in the model. Figure 4-14 displays the predicted probabilities for each ethnic category, at each damage state, for various proportions of rental units on the block. The color scheme is the same as above with non-Hispanic Whites in navy-blue, non-Hispanic Blacks in maroon, and American Indian in green and now lines with circles are for DS0, triangles for DS1, and "X" for DS2+. We see the same pattern with non-Hispanic Whites having the lowest probability regardless of damage state, with non-Hispanic Black having higher probabilities, and American Indian household the highest probability. However, now we see that probabilities increase with the proportion renters on the block, indicating higher likelihoods that the household is a renter. For example, among non-Hispanic White households in housing units in the DS0 state, the probabilities of dislocation range from only .19 in blocks with no renters to .40 with renters.

As noted above, our goal with this analysis is to develop new dislocation algorithms for incorporation into IN-CORE that will better capture dislocation for flood events. We are currently examining a variety of models employing alternative measures suggested by the literature. There are, of course, many issues that arise with applying these epistemic probabilities based on a single case study for applications in other situations. However, it should be recalled that current practice, for those employing HAZUS-MH dislocation algorithms for example, are based on the limited observational data undertaken after the Northridge earthquake and expert opinion. Our hope is that by developing post disaster survey techniques that will allow for more

representative data collection in which state of the art engineering and social science survey techniques are employed, that a host of post event data collection field studies will generate data and subsequently findings that can be combined to develop more robust and generalizable models upon which to base future algorithm development.

CHAPTER 5: Discussion and Future Directions

This chapter presents a summary of the lessons learned and overall observations from the basic statistical analysis and the qualitative interviews presented in Chapter 4. In addition, a detailed assessment of the data collection methodology is included for both quantitative and qualitative information collected during this initial Lumberton field study. The chapter concludes with future plans for a longitudinal study and the integration of the findings of this field study into NIST/CoE work such as improvement and validation of the Interconnected Network Community Resilience Modeling Environment (IN-CORE).

5.1 Observations and Lessons Learned

Two primary data collection activities were undertaken in this initial Lumberton field study: a household/housing survey and a series of qualitative interviews with community leaders and stakeholders. The latter provided community-level qualitative interview data on how the community, state, federal, and local governments and utility managers responded to the flooding event, with a focus on how the local school system was impacted and responded. The housing/household survey provided engineering damage assessment data about the housing unit and social science data about the household that occupied the housing unit.

At the core of this interdisciplinary field study is the ability to fully integrate the physical building damage data with the socio-economic demographics of households to better understand how the combination of measurable parameters (e.g. building damage state, tenure, race/ethnicity) affect probability of dislocation following a disaster event such as the flooding associated with Hurricane Mathew in Lumberton. In order to understand how these physical and non-physical parameters affect households, we have considered them independently, as well as in combination. Additionally, since the housing/household survey was undertaken employing a random sampling procedure, the data can be utilized to generalize to residential housing units and households within the Lumberton school systems boundary area which included nearly all of the populated areas within Lumberton's city limits and surrounding neighborhoods.

The building damage data for more than 400 houses in Lumberton were presented in Section 4.2.1 in Chapter 4. The dispersion of the fragility curves for buildings with crawl spaces and building with slabs on grade were comparable (i.e., their logarithmic standard deviations are approximately equal for each damage state) for damage states 1 and 3, but the dispersion was 12 % greater for homes with slabs for damage state 2. The empirical fragility curves show that there were many flood depth observations (with respect to FFE) concentrated at 0.56 m (22 in). The median values of reaching and or exceeding each damage state were also quite close for damage states 2 and 3 (i.e., within 3 % to 6 % of each other, respectively) for the two foundation types. The fragilities developed with respect to the FFE are effective at portraying content damage, while the fragilities with respect to the ground provide overall damage for the housing units (including damage limited to crawl spaces and/or detached structures).

The building damage fragilities are general enough such that they can be used to predict damage states[22] for wood, light-frame residential single and multi-family buildings in North America. Although it may be possible to further sub-divide the damage data, given the size of the data set, this is not recommended given that only the uncertainties in the data collection methodology and not uncertainties in construction quality or modeling are included in the lognormal standard deviations shown in in Table 4-3. It is also important to note that the fragilities should only be used for static or slow-moving flood waters, since these were the conditions that occurred in Lumberton. These fragility functions are an important contribution to the literature to help predict residential damage in flooding events. However, future waves of the longitudinal study that collect damage impacts from more household surveys will further provide context to these fragility functions, including losses and household dislocation.

When considering residential housing in the Lumberton survey area, we found that 52 % of the area's housing units were rated as DS0, suggesting they were not substantially impacted by flood waters. However, 18.5 % of residential housing units were rated at DS1, 25 % were rated at DS2, and only 3.6 % and 1.2 % were rated at DS3 and DS4, respectively. We were able to link each residential structure to the tax assessor's appraisal data allowing us to assess the economic losses associated with each damage state as captured by losses to a property's assessments. More specifically our focus here was on losses to the "improvement" values of residential parcels, not the assessment value associated with a parcels land. We found that on average parcels whose structures were assessed in damage states 1 through 4 lost an average of 16.6 %, 25.5 %, 40.8 % and 45 % of their pre-flood appraised values respectively. Interestingly, housing rated as DS0, was not unscathed; on average they lost 4.4 % of their assessed improvement values.

We also found that housing occupied by minority households, both non-Hispanic Black and American Indian, were much more likely to be rated in higher damage states and hence suffered higher levels of damage, when compared to housing occupied by non-Hispanic White households. These findings were primarily due to the fact that minority households were much more likely to be residing in housing located in the Lumberton's flood zones south of the river (see Figures 2-18 and 2-19). This finding is consistent with much of the disaster literature, which has all too often noted that disaster impacts are rarely equal opportunity events; rather, impacts are shaped by the historical legacies of our communities and social processes that often place minorities in more vulnerable locations, particularly as it relates to flooding.

The household survey enabled the collection of data related to a number of factors including dislocation as a function of several variables, lifeline and work/school disruption, and early recovery activities, along with socioeconomic and demographic data. These data, along with the damage assessment data allows for the development of models predicting household responses due not only to physical damage to residential structures, but also socio-economic factors that can shape these responses. For example, we examined the relationship between household dislocation and damage state, along with various combinations of socio-economic and demographic factors in analyses present in section 4.2.2.3 (see also Table 4-6 and Figures 4-12-4-14). Our preliminary analyses found that household dislocation was indeed driven by damage, but damage was not the only factor influencing the likelihood of dislocation. Specifically, we

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[22] Damage state predictions for flood provide a probability of a building being in or exceeding each damage state as a function of flood depth with respect to FFE.

found that a model containing damage state, race/ethnicity measures, and data on tenure (renters/homeowner) performed better than models including only damage state data. The findings suggest that households in structures rated as DS1 were nine (9) times more likely to dislocate than were household in structures rated as DS0 and those in structures rated DS2 or higher were nearly 49 times more likely to dislocate. However, even after controlling for damage state, non-Hispanic households were 2.7 times more likely to dislocate when compared to non-Hispanic White households. Similarly, American Indian households were six (6) times more likely to dislocate, than non-Hispanic white households. It should be noted that the overall probabilities of dislocation rise and converge across all groups with higher levels of damage, but there were significant and pronounced differentials at lower levels of damage. The analyses also suggest that housing in areas with higher percentages of rental housing had higher probabilities of dislocation, net of damage and race/ethnic factors. This finding is also consistent with the literature that has shown that households in rental properties are often required to leave their homes by the owners and managers of those properties due to safety, liability, and other issues (Girard and Peacock, 1997; Esnard and Sapat, 2017), while households that own their homes are not as readily displaced.

Thus, our preliminary results suggest that our goals of combining both engineering-based damage assessment data, along with measurable socioeconomic and demographic data will allow us to improve the modeling of important dimensions of community resilience, such as population dislocation in the wake of natural disasters. Our goal will be to continue to refine our fragility analyses for residential structures along with the dislocation and other models of key resiliency metrics for inclusion in IN-CORE. Furthermore, our preliminary success at integration suggests future possibilities of capturing the complexities of recovery trajectory of households based upon a combination of measurable parameters (e.g., housing repairs, financial assistance, race/ethnicity, insurance, income). This expectation provides further basis for a longitudinal study.

5.2 Methodology Assessment

In order to capture recovery data, community resilience is best understood and studied over time in a series of field studies. The results of this field study provide the initial conditions that resulted from a natural disaster (flood), i.e. recovery initial conditions, and the first of a series of field studies for Lumberton by the CoE and NIST. The concept of a longitudinal field study is that the same cases will be observed over time to track changes, both positive and negative, in the post-disaster experience of a community and its constituent parts - households, schools, businesses, buildings and supporting infrastructure. Because the social impacts of a disaster unfold slowly, longitudinal studies provide a mechanism of tracking the same variables through time using standardized data collection instruments. In addition, the ability to document disaster impacts to a local community, including population loss/gain, business disruption, housing recovery, and financial loss, requires the assessment of change over time. Thus, the joint CoE/NIST research team expects to study Lumberton over a duration of 3 to 5 years with data collection waves approximately one year apart with the addition of business disruption to the investigation. Through repeated observations of a sample of housing units, schools, and businesses, the physical, social, and economic recovery of Lumberton can be assessed.

5.3 Connections to the Community Resilience Planning Guide

As part of the broader program focused on community resilience, NIST has produced guidance and tools to support resilience planning in communities like Lumberton. The NIST *Community Resilience Planning Guide for Buildings and Infrastructure Systems* (CRPG) provides a practical and flexible approach to help communities improve their resilience. Communities are encouraged to use the CRPG to develop a stand-alone resilience plan or, more commonly, to fold the concept of resilience into existing plans (e.g., hazard mitigation plan, economic development plan, emergency management plan). For example, Lumberton could use the six-step process to work towards increased resilience to future hurricane and associated flood events. Whether or not Lumberton faces another flooding event like that following Hurricane Matthew, resilience planning can address a range of hazard events as well as chronic stressors such as crime, economic decline, and poverty. There are benefits to the physical, social, and financial services in the community of planning ahead to reduce impacts and recover better.

Following the development of a collaborative planning team, the second step in the CRPG calls for the community to "understand the situation." Information presented in this report helps provide the basis for understanding the constituent social dimensions and the built environment in the community of Lumberton. While there is further work to be done in linking social systems (e.g., families, households, businesses) and the built environment, this field study provides a foundation for the discussion of these linkages. The flooding associated with Hurricane Matthew and the observed impacts on the community documented in this study highlight how damage to buildings and physical infrastructure can impact a range of social functions of importance to a community, including education, the economy, participation in church and other community organizations, and the usual activities of daily life.

The NIST *Community Resilience Economic Decision Guide for Buildings and Infrastructure Systems* (EDG) and the accompanying Economic Decision Guide Software (EDGe$) Tool provide a standard economic methodology for evaluating investment decisions aimed at improving the ability of communities to adapt to, withstand, and quickly recover from disruptive events. The EDG is designed for use in conjunction with the companion CRPG. Findings from the household surveys and community interviews indicate information that could be useful in assessing potential resilience options Lumberton may identify. Similar survey work to that completed for households aimed at businesses could be an important element of describing the cost and benefits for a variety of resilience options (e.g., higher levee, elevated buildings, raised controls for utility plants) a community like Lumberton may consider.

5.4 Data Uses for Future CoE/NIST Work

Improved understanding is needed on how mitigation, preparedness, and response decisions impact the recovery process for a community and its constituent parts – households, schools, and businesses. This field study data is helping to improve this understanding. The data is being used, by the CoE and NIST, to make better predictions of the impacts and recovery from disaster events. More specifically, the data are being used to ground-truth computer-based simulations of recovery. These simulations and other tools are key to the evaluation and comparison of resilience-improving decisions for communities implementing resilience plans.

The CoE has a specific hindcasting task which focuses on validation of models and algorithms using the prediction of past disasters with only the use of information available prior to the event. The longitudinal Lumberton field study presents a unique opportunity to help identify exactly

which recovery data are tracked over time such that they align with the community level resilience and recovery metrics being used for risk-informed decision support in IN-CORE 2.0. This will allow the results of the field study to serve as another validation of predictive algorithms within IN-CORE which includes financial infusion, community and regional decisions, and changes in governance.

This field study is the first to inform the development of a NIST systems model to support community resilience decision-making. A case study is being patterned after the experience of Lumberton, relying heavily on the field study data and post-event decision-making. The Lumberton field study data will also be used as part of studies to test and validate community resilience metrics that address the built environment, as well as the social and economic systems. Among its methodological contributions, the Lumberton field study informs NIST researchers' development of standards and best practices for disaster failure studies including sampling design, damage assessment, survey and interview instruments, and data collection procedures.

The Lumberton Field Study and resulting reports will help similar communities anticipate and plan for the physical damage and associated societal impacts of hazard events, which in turn may improve the recovery of such communities. More broadly, this field study contributes to an improved understanding of the longer-term effects of a disaster on a community when recovery resources are limited. Although the focus is on flood, it is hoped that the recovery study portion of this report can be extended to other hazards such as tornado and earthquake.

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Appendix 1
Signed consent form used with Qualitative surveys
Consent to Participate in a Research Study
Colorado State University

Title of study:
Center of Excellence for Risk-Based Community Resilience Planning

Principal Investigators:
This project is led by Dr. John van de Lindt and Dr. Bruce Ellingwood, both Professors from the Civil and Environmental Engineering Department at Colorado State University. Dr. van de Lindt can be reached at 970-491-6697 or via email at jwv@engr.colostate.edu and Dr. Ellingwood can be reached at 970-491-5354 or via email at bruce.ellingwood@colostate.edu.

Who is doing the study?
This five-year project is funded by the National Institute of Standards and Technology (NIST). Our research team is made up of professors, postdoctoral fellows, and graduate students across 14 universities. Two or more of our field research team members will be interviewing you for this project.

What is the purpose of this research and why am I being invited to take part in this study?
You have been chosen to be part of this research study because of your experience with the 2016 flooding that occurred in Lumberton, N.C. following Hurricane Matthew. We would like to speak with you about the choices that you made before, during, and after the flood so we can learn more about how people responded to and are beginning to recover from the event. Up to 200 people from your community may be invited to be interviewed for this study; however, the team will begin interviews, initially, with a smaller group of community leaders and key informants.

What will I be asked to do and how long will it take?
You will be asked to answer questions about what happened before, during, and after the flood. We are interested in your experiences with preparedness, evacuation, damage, loss, and rebuilding. The interview will be held in a mutually agreeable, private location. With your permission, each interview will be audiotaped and will take about 30 minutes of your time. We would also like to speak to you in the future to learn more about your experiences as they unfold. Also with your permission, the research team may take photos or videotape of you or your home.

What will it cost me to participate?
There is no cost to you for being part of this study and you will not be paid for your time.

What are the possible risks, discomforts, and benefits?
It is not possible to identify all potential risks during a research project, but our team has taken reasonable safeguards to minimize any known and potential risks. The potential risks associated with this study are difficult emotions such as anger and sadness. There is no known benefit in

participating. We hope, however, this will provide a space for reflection and an opportunity to make a difference for others by sharing your knowledge and experiences.

Do I have to take part in the study?
Your participation in this project is completely voluntary. You may withdraw your consent and stop participating at any time. You have the right to refuse to answer any question(s) for any reason. You also have the right to refuse to be photographed or audio/video recorded.

Who will see the information that I give?
We will keep private all research records that identify you, to the extent allowed by law. Anything that you share during our interview will be kept confidential. In addition, your privacy will be maintained in all written and published documents resulting from this study. However, if any abuse or illegal activity is discussed, we will have to report that information to the authorities. Any reports created from this study will use fake names in place of real names of people and organizations.

Other identifying features may be altered as well to protect your confidentiality. Audio files will be stored in a secure location. They will be marked with an interview number separate from your name. At the end of the study, all audio files will be erased and all other written materials will be permanently stored in a secure location. This data will be kept for future use. We may be asked to share the research files for audit purposes with the CSU Institutional Review Board and the NIST Human Subjects Protection Office.

If you have questions about this study, you should ask the researcher before you sign this consent form. If you have questions regarding your rights as a participant, any concerns regarding this project, or any dissatisfaction with any aspect of this study, you may contact the Colorado State University Institutional Review Board at: RICRO_IRB@mail.colostate.edu; or 970-491-1381.

A signed copy of this three-page consent form and Photo/Video-release form will be provided to you at the time of the interview.

Participant's Initials _____ Date _____

I agree to be audio recorded for this study (please initial):

Yes ☐   No ☐

If you are willing, we may want to conduct 1-2 more interviews with you over the next two years so that we can follow changes in recovery. We have asked for your address below so that we may contact you again. I am willing to be contacted again to participate in similar studies related to disaster recovery (please initial):

Yes ☐   No ☐

I have read this paper about the study or it was read to me. I know the possible risks and benefits. I know that being in this study is voluntary. I choose to be in this study. I know that I

can withdraw at any time. I know that it is my choice to be audio taped. I know that any contact information I provide is optional and will only be used to follow up on the community recovery process following Hurricane Matthew. I have received, on the date signed, a copy of this document containing two pages.

Signed:_____   Date:_____

Name:_____   Phone:_____

Address:_____

_____

Email:_____

_____   _____
Signature of Research Staff   Date

Please direct follow-up questions to:

Dr. van de Lindt, Department of Civil Engineering Room A201, Colorado State University, Fort Collins, CO 80523-1301, 970-491-6697

Appendix 2
Mental Health Resources for Lumberton

Mental Health Resources
Robeson County

Should you need additional assistance, the following local resources are available to provide timely services.

Phone Access:
Eastpointe Access Center is available 24 hours a day, 7 days a week. Customer Service Specialists will assist you to find a crisis provider that is well-matched with your needs. Your local number is: 800-913-6109 or for TTY 888-819-5112
If you already have a service provider, <u>call them first</u>. Providers who know you are usually best prepared to assist you in a crisis.

In-home:
Crisis situations are often best resolved at home. Mobile Crisis Teams are available 24 hours a day in all counties. Professional counselors will speak with you and your family during a visit. They have an average response time of 2 hours. This service is provided by:
Monarch
910-618-5606

Crisis Center:
Many counties have a specialized crisis center where you can walk in for a crisis assessment and referrals to additional services. Appointments are not needed. The crisis center in your county is provided by:

Monarch
207 W. 29th St, Lumberton NC
910-618-5606
Monday - Friday, 8:00 a.m. - 5:00 p.m.

Crisis Services for Robeson County are managed by: Eastpointe

Appendix 3
Semi-Structured Interview Guide

Interview Guide

Thank you for meeting with us today. My name is [XX] and my associate is [XX]. We are part of a research team funded by the National Institute of Standards and Technology (NIST), which is a federal agency within the U.S. Department of Commerce. NIST's mission is to promote innovation by advancing science, standards, and technology in ways that enhance economic security and improve our quality of life.

This project is focused on learning about disaster recovery and community resiliency. We are here to learn about decisions people made before, during, and after the flooding that occurred in Lumberton following Hurricane Matthew in October of 2016. We will use this information to help build models that communities can use to better prepare for, respond to, and recover from future disasters.

We have a series of questions that we would like to ask you. The interview should take about 15-30 minutes to complete. We will also ask you to complete a short survey at the close of the interview.

Do you have any questions about the interview or the project before we begin?

[Note: give interviewee your business card when you first meet]

Interview Questions:	Probes:
1. **Personal Information** First, will you please say your name, title, and the name of your organization OR name and the city you live in?	
2. **Disaster** Tell me about you / your organization's experience during the 2016 flooding?	Mitigation Efforts, Information Received, Preparedness, Evacuation, Impact, Response, etc.
3. **Damage to Home/Business/Organizations** What types of damage happened to your home/business/school/other organization? What type of damage happened to your local utilities (water, electric, sewage, communication, etc.)	What things were you able/ unable to do after the disaster occurred? What day-to-day activities did you alter?
4. **Post-Disaster Decisions**	

What decisions have you made so far regarding rebuilding/ restoration/ relocation/ work/ school/ health, etc. thus far? Why? Who has made those decisions?	
5. **Evacuation /Displacement** Were you, your staff/employees evacuated or displaced for any period of time following the disaster? If so, can you tell me about that?	For how long? Did you seek temporary shelter in the community, or were friends able to assist you? What sort of response was offered by local churches? By the local chapter of the Red Cross?
6. **Community Recovery** What factors have slowed your community's recovery so far? What do you think has accelerated or helped with the recovery so far?	How responsive has the municipal government been to requests for assistance? What sort of support has been offered by local utilities – water, gas, electricity? Has the municipal government established contacts with FEMA/SBA counselors, who can help navigate the application process for Federal or State assistance?

Now we are going to give you a short survey that asks shorter more specific questions. This should only take a few minutes to complete, and then we will talk about your responses. [Give respondent demographic questionnaire.]

Interviewee Completes Demographic Questionnaire [keep recorder on unless the interviewee seems to be taking an unusually long time and isn't speaking]

This has been exceptionally helpful, and we are grateful for your time. Are there any final thoughts or comments that you would like to add?

Ask interviewee to complete demographic form for demographic reporting purposes and future follow-up interviews.

Thank respondent. [turn off recorder]

Appendix 4.
North Carolina Flood Field Study Damage Inspection Tool
Draft developed by Derya Deniz, Tori Johnson, and John van de Lindt
Draft developed on November 16, 2016

Please fill in the fields and circle the option that best identifies the condition for multiple-choice questions.

BUILDING INFORMATION:			FIRM Zone and BFE: _____	
Address:_____ __	**Date/Time:**_____ _		**GPS-N:**_____	**GPS-E:**_____
ID Photo #:	(1) _____	(2)_____	(3)_____ (4)_____	(5)_____
Building Type:	Single Family	Multi-Family	Other: Explain	
Number of stories:	1	2	3 or More Split	
Construction Type:	Wood Concrete	Masonry Steel	Other: Explain	
Foundation Type:	Slab on grade	Crawlspace	Other: Explain	
House Dimensions:	Length ___ft	Width ____ ft	**Garage Dimension** Length ___ft	Width ____ ft
Building Year:_____	**Quality:** Excellent Good		Ave Low	

FLOOD INFORMATION:				
Flood source:	Surface flooding	Sewer backup	Drain pipes	Other: Explain
Flood level w.r.t first floor elevation (FFE*):	_____ft _____in		**Ground level next to bldg w. r. t FFE***	_____ft _____in
High water mark location (HWM)	Foundation	First Floor	Second Floor	Other: Explain _____

FFE* : The threshold of the front or rear door
Check the Table 1 below and circle the appropriate damage state level

OVERALL DAMAGE DESCRIPTION:					
	DS0	DS1	DS2	DS3	DS4
REPAIR STARTED:	YES Date_____	NO	**RELOCATED/EVACUATED:**	YES	NO
DID HOMEWONER START	YES Date_____	NO	**DOES MOLD APPEAR TO BE A PROBLEM?**	YES	NO

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DS Level	Description
0	No damage; water enters crawlspace or touches foundation (crawlspace or slab on grade). No contact to electrical or plumbing, etc. in crawlspace. No contact with floor joists. No sewer backup into living area.
1	Water touches floor joists up to minor water enters house; damage to carpets, pads, baseboards, flooring. Approximately 1" in house but no drywall damage. Could have some mold on subfloor above crawlspace. Could have minor sewer backup and/or minor mold issues.
2	Water level approximately 2 feet with associated drywall damage and electrical damage, water heater and furnace and other major equipment on first floor damaged. Lower bathroom and kitchen cabinets damaged. Doors or windows may need replacement. Could have major sewer backup and /or major mold issues.
3	Water level 2 feet to 8 feet; substantial drywall damage, electrical panel destroyed, bathroom/kitchen cabinets and appliances damaged; lighting fixtures on walls destroyed; ceiling lighting may be ok. Studs reusable; some may be damaged. Could have major sewer backup and/or major mold issues.
4	Significant structural damage present; all drywall, appliances, cabinets etc. destroyed. Could be floated off foundation. Building must be demolished or potentially replaced.

Table 1. Overall damage description for the residential structures

Check the Table 2 on next page and circle the appropriate damage state level:

EXTERIOR DAMAGE:	Foundation:	DS0	DS1	DS2	DS3	DS4
	Walls:	DS0	DS1	DS2	DS3	DS4
	Attachments or Detached Structures:	DS0	DS1	DS2	DS3	DS4
INTERIOR DAMAGE:		DS0	DS1	DS2	DS3	DS4

DS Level		0	1	2	3	4
Exterior Damage	**Foundation:**	Water enters crawlspace or touches foundation but no visible damage	Waters enters crawlspaces but not any significant damage. Just water marks/ mud.	Minor cracks on foundation stem walls.	Cracks or holes on foundation stem walls	Major structural damage on foundation. Differential settlement or the structure floated off the foundation.
	Walls:	Water may or may not touch walls but no visible damage	Water touches walls but no damage on the wall or cladding or insulation, just aesthetic marks/mud.	Need to clean and dry the wall out. Slight damage on insulation or cladding which need partial replacement.	Water penetration through holes or cracks on the walls. Or water penetration through broken windows. Studs reusable when dried.	Significant structural damage present or collapse; majority of walls damaged beyond the point of reuse.
	Attachments or Detached Structures: Garage/ Porches/Sheds…	Water touches exterior of garage or porch but no visible damage	Visible damage or water marks/mud	Minor damage to garage door/ minor damage on decks	Major damage on garage door or on decks (i.e. garage door needs replacement)	Major or significant structural damage present; floated away or destroyed.

Interior Damage		Water enters the foundation but no contact or no visible damage to electrical or plumbing, or floor joists	Water enters house; damage to carpets, pads, baseboards, flooring, but no drywall damage. Touches joists. Could have some mold on subfloor above crawlspace.	Drywall damage up to 2 feet and electrical damage, heater and furnace and other major equipment on floor damaged; Lower bathroom and kitchen cabinets damaged. Doors need replacement.	Substantial drywall damage, electrical panel destroyed, bathroom/kitchen cabinets and appliances damaged; lighting fixtures on wall destroyed; ceiling lighting may be ok.	All drywall, ceiling lights, appliances, cabinets etc. destroyed and need replacement

	No Damage	Lightly Damaged	Ruined
Interior Items			
Plywood Subfloor			
Flooring			
Carpet Pad			
Base Trim			
Water Heater			
Furnace			
HVAC equipment			
Water Softener			
Drywall			
Electrical Outlets			
Base Cabinets (Bathroom)			
Upper Cabinets (Bathroom)			
Countertop (Bathroom)			
Base Cabinets (Kitchen)			
Upper Cabinets (Kitchen)			
Countertop (Kitchen)			
Electrical Panelboard			
Staircase			
Front door			
Interior doors			
Windows			
Lighting fixtures			
Ductwork			
Kitchen appliances (dishwasher…)			
Furniture			

Table 2: Detailed damage descriptions for external and internal building components

Mark the damage level (no damage, lightly damaged but still repairable, or ruined which requires full replacement) for the interior items below:

EXTRA NOTES:
Explain condition of the drinking water well if there is any around the house: _____

Appendix 5.
North Carolina Flood Field Study: Household Survey

North Carolina Flood Field Study: Household Survey
November 24, 2016

CODE INFORMATION ON HU, POSSIBLE HOUSEHOLD OCCUPANCY AND INTERVIEW ATTEMPTS:

Housing Unit/Sample Unit Description:		Address:_____
		Verified by Respondent? YES NO

Building Type:	1. Single Family	2. Multi-Family: # of HUs _____	3. Mobile home	4. Other:_____
Interview Attempt 1: interviewer _____ Date/Time:_____		Interview Attempt 2: Interviewer _____ Date/Time:_____	Interview Attempt 3: Interviewer _____ Date/Time:_____	
Result of Interview attempt 1: _____ Comments:		Result of Interview attempt 2: _____ Comments:	Result of Interview attempt 3:_____ Comments:	

Result/completion codes	1. Completed interview 2. Incomplete/partial - 3. Not available or inconvenient (note best time to return)	4. Soft refusal – closing team assignment. 5. Hard Refusal – contact captain, perhaps replacement	6. No Answer or response, but evidence or confirmed occupied 7. Ineligible, (needs follow interview attempt)	8. Ineligible (with information about previous residents 9. Ineligible total – new construction – post HM 10. Ineligible property – structure not a residence 11. Bad address – could not locate HU.	12. Not occupied residence, abandoned property, home destroyed. 13. No access. Gated community or safety fence preventing entry to damage residence(s).

Code for occupancy status of Housing Unit

Housing Unit (HU) Occupancy status:	YES: household present interviewed or attempted	YES, evidence of current habitation	DK: indeterminate/ uncertain	NO: not occupied, appears abandoned	NO, damage and not habitable
	Yes, occupied confirmed by neighbor	Yes, occupied, confirmed by management		NO: not occupied, under repair/reconstruction.	

IF INTERVIEW NOT POSSIBLE BUT NEIGHBORS, APARTMENT MANAGERS, OR OTHERS CAN PROVIDE INFORMATION ABOUT HU AND HOUSEHOLD RECORD HERE:

If Neighbor, manager, or other person can provide information:	Was the HU occupied at time of HM?: YES NO	If YES: # of persons _____
	Is same household there now? YES NO DK	If No: Will former HH return? YES NO DK
Type of informant: Neighbor Manager Other: (specify) _____	If NO: New residents in HU? YES NO DK	If YES: # of persons _____
Space for Additional Comments/Observations:		

1

Hello, my name is *(interviewer name)* and I am a researcher from *(name of university)* in the *(department name)*. We are conducting a research study on the flooding that occurred in Lumberton, N.C. in the days following Hurricane Matthew in early October. We would like to speak with you about how this event affected your household. In particular, we are interested in learning if there were any changes in where you and members of your household lived and any disruption to work and/or school schedules.

This study is part of a larger project led by Center of Excellence for Risk-Based Community Resilience Planning at Colorado State University. This project is led by Drs. John van de Lindt and Bruce Ellingwood, both Professors from the Civil and Environmental Engineering Department at Colorado State University. This five-year project is funded by the National Institute of Standards and Technology (NIST).

We would like you to answer some brief survey questions about your household's decisions before, during, and after the flood as well as some details about your home during this time. Participation will take approximately fifteen minutes, depending on what happened to your household. Your participation in this research is voluntary. If you decide to participate in the study, you may withdraw your consent and stop participation at any time without penalty.

We will be collecting information about the damage to your home and how the flood disrupted your household's daily routines, such as going to work and school. When we report and share our findings, we will combine the data from all participants into summary statistics and tables so no unique individual or household can be identified. There are NO KNOWN RISKS or direct benefits to you, but we hope to gain more knowledge on how you were affected by Hurricane Matthew and the flooding so that we can learn from your experiences to help communities better prepare for similar events in the future.

So again, we would like to speak with an adult member of the household that was here at the time of Hurricane Matthew and the flooding OR is knowledgeable about what happened to the household around that time. Would that person be you and would you be willing to participate?

This first set of questions is about electricity, gas, and water utilities during and after Hurricane Matthew and associated flooding.

Did your home lose electric power?		YES	NO	DK*	If yes, for how long?	Record in hours or days* _____ Hrs. _____ Days	Or,	still don't have power
Did your home lose water?		YES	NO	DK*	If yes, for how long?	Record in hours or days* _____ Hrs. _____ Days	Or,	still don't have water
Was your water unsafe to drink (under a boil water order)?		YES	NO	DK*	If yes, for how long?	Record hours or days* _____ Hrs. _____ Days	Or,	still under boil water order
Did you home lose gas (LP)?	YES	NO	NA	DK*	If yes, for how long?	Record hours or days* _____ Hrs. _____ Days	Or,	still don't have gas

Coding notes: NA = not appropriate question, did not have gas
DK* = don't know because were out of their home when utility may have been off.

*Coding notes: record hours or days, but not both. Record hour, if utility disruption for less than a day.
Record days, to nearest day, if disruption over a day.

Next we are going to ask about communications during and after the disaster.

Did your Household lose all phone service (cell and land lines)?	YES	NO	NA	DK*	If yes, for how long without?	Record in hours or days* _____ Hours _____ Days	Still don't have power
Did your home/household lose all internet connectivity from your home?	YES	NO	NA	DK*	If yes, for how long without	Record in hours or days* _____ Hours _____ Days	Still don't have water

Coding notes: NA = not applicable because did not have any phones or internet
DK = don't know because were out of their home when utility may have been off.

*Coding notes: record hours or days, but not both.
Record hour, if less than a day or record days, to nearest day, if disruption over a day.

2

Ok, now we are going to ask about how Hurricane Matthew affected your household in terms of disruption in work or school schedules and leaving. Since not all household members may be impacted the same, it is easier to record this information for each member of your household and to find out a little about them. So let me begin by asking, including yourself, how many people were regularly living in your household when Hurricane Mathew and the flooding impacted Lumberton?

Number of household members at time of HM: _____

Thank you. Now I am going to ask you to list all household members starting with you, and then followed by others in terms of their relationship to you….

	List HH members based on Relationship to respondent Note, it will be easier/quicker to complete each column.	Sex	Age (age at last birthday)	Member's employment (16+ years), student, or day care status at time of HM. (Day Care = nursery, pre-school, after school, business, individual service, or friend/relative)	Member out (or missed) work, school, or day care for more than a day due to HM? (Day Care = nursery, pre-school, after school, business, individual service or friend/relative)	How may days were members out (or missed) work, school, or Day Care due to HM and Flooding.			Did member leave home for a day or more (over night) due to HM?	How many days was each member away of from home?	There can be many reasons why household members may have left home due to Hurricane Matthew and the flooding afterward. I would like to record reasons why individual members left your home. (Hand then the REASON CARD and record up to four reasons)			
						Work	School	Day Care			1st	2nd	3rd	4th
1	Respondent													
2														
3														
4														
5														
6														
7														
8														
9														
10														
11														
12														
13														
14														
15														
	1) Spouse/partner 2) Son/daughter (biological or adopted) 3) Brother/sister 4) Parent 5) Parent in law 6) Grandparent 7) Grandchild 8) Other relative 9) Non-relative	1) Female 2) Male 3) Trans 4) Prefer not to answer	Age at last birthday. 1 ≤ 1 year 99 = DK NOTE: approx., if needed.	1) Full-time 2) Part-time 3) Retired, disabled 4) Unemployed 5) Student 6) Student & employed 7) Student & day care 8) Homemaker 9) Child in daycare or daycare service 10) Child not in daycare. 11) Other	1) Yes: work. 2) Yes: school 3) Yes: day care* 4) Yes: work & school 5) Yes: School & day care 6) No	Enter number of days or if still out or missing school 77) If still out of work, school or daycare 88) If lost job due to flooding			1) Yes 2) No	Enter approximate number of days or if not yet returned code: 77) Still out, but plan on returning 88) Still out, and may not return.	1) Risk of flooding 2) Flooding 3) Evacuation order 4) Asked to leave by owner 5) Evicted by owner 6) Schools not opened 7) Day care issues 8) Utilities out		9) Damage to home 10 Damage to neighborhood 11) Local business closed 12) Unsafe neighborhood 13) Not applicable – never left home. 14) Other: Specify _____	

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We have asked about people leaving your home, but now we would like to ask about people joining your home.:

Did anybody join or move in to your home because of HM or flooding?	NO	YES, how many:_____	Are any still staying with you?	NO	YES, how many: _____

Now I have a few general questions about your home, insurance, and FEMA assistance:

Does your household Own or Rent?	OWN				RENT				OTHER: Specify
	If OWN, do you have a mortgage?	YES	NO	DK	If RENT, do you have a flood insurance rental policy?	YES	NO	DK	
	If OWN, do you have Flood Insurance?	YES	NO	DK					

If damage to home or contents not obvious ask: Did your home or contents sustain any damage? YES NO	Filed a claim for damages?	YES	NO	DK	If no, do you plan to in the future?	YES	NO	DK
	Applied for FEMA assistance	YES	NO	DK	If no, do you plan to in the future?	YES	NO	DK
	Applied for and SBA (Small Business Association) Loan?	YES	NO	DK	If no, do you plan to in the future?	YES	NO	DK

Finally, Just four questions about your household in general:

When considering all of the members in your household, what is the highest number of years of schooling completed by a household member?	Enter number of years _____ and indicate type of diploma or degree	High School Associate degree Bachelors Masters or higher degree
While we often ask about each household member, in general, when considering your household how would you characterize its racial make up?	1) White 2) Black or African American 3) American Indian or Native American 4) Asian (Asian Indian, Chinese, Korean, etc.) 5) Native Hawaiian or other Pacific Islander	6) More than one race (specify - codes): _____ _____ 7) Other (Specify): _____
Are members of your household of Hispanic or Latino origin?	1) NO, none of Hispanic or Latino origin 3) Yes, Mexican, Mexican Am., Chicano 2) Yes, Hispanic or Latino 4) Yes, Puerto Rican	5) Yes, Guatemalan 7) Yes, Other Hispanic or Spanish 6) Yes, Cuban
Finally, I don't want to know exactly, but would you simply identify the letter associated with the category that best captures your combined household annual income? *(hand respondent the card)*	A. $1 to $3,999 E. $10,000 to $11,999 I. $25,000 to $29,999 L. $50,000 to $74,999 B. $4,000 to $5,999 F. $12,000 to $14,999 J. $30,000 to $39,999 M. $75,000 to $99,999 C. $6,000 to $7,999 G. $15,000 to $19,999 K. $40,000 to $49,999 N. $100,000 to $149,999 D. $8,000 to $9,999 H. $20,000 to $24,999 O. $150,000+	

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Appendix 6
Verbal Consent Form
Consent to Participate in a Research Study
Colorado State University

Hello, my name is *(interviewer name)* and I am a researcher from *(name of university)* in the (*department name*) department. We are conducting a research study on the flooding that occurred in Lumberton, N.C. in the days following Hurricane Matthew in early October. We would like to speak with you about how this event affected your household. In particular, we are interested in learning if there were any changes in where you and members of your household live and any disruption to your work and/or school schedules.

This study is part of a larger project led by Center of Excellence for Risk-Based Community Resilience Planning at Colorado State University. This project is led by Dr. John van de Lindt and Dr. Bruce Ellingwood, both Professors from the Civil and Environmental Engineering Department at Colorado State University. This five-year project is funded by the National Institute of Standards and Technology (NIST).

We would like you to answer some brief survey questions about your decisions before, during, and after the flood as well as some details about your home during this time. Participation will take approximately take approximately fifteen minutes, depending on how much information you would like to share. Your participation in this research is voluntary. If you decide to participate in the study, you may withdraw your consent and stop participation at any time without penalty.

We will be collecting information about the damage to your home and how the flood disrupted your household's daily routines, such as going to work and school. When we report and share our findings, the data will combine all of the participants into summary statistics and tables that and not identifiable in terms of an unique individual or household. There are no known risks or direct benefits to you, but we hope to gain more knowledge on how you were affected by Hurricane Matthew and the flooding so that we can learn from your experiences to help communities better prepare for similar events in the future.

Would you like to participate?

If yes: Proceed.

If no: Thank you for your time.

Offer to give the participant your contact information and the Participant's Rights contact information (If you have questions about your rights as a volunteer in this research, contact the CSU IRB at: RICRO_IRB@mail.colostate.edu; 970-491-1553.).

If you have any questions about this study, please contact:

Dr. van de Lindt, Department of Civil Engineering Room A201, Colorado State University, Fort Collins, CO 80523-1301, 970-491-6697

Appendix 7

Center for Risk-Based Community Resilience Planning
A NIST-funded Center of Excellence
Webpage: resilience.colostate.edu; Email: resilience@colostate.edu

Information about the Lumberton, North Carolina
Hurricane Matthew Field Study

Researchers affiliated with the Center for Risk-Based Community Resilience Planning, at Colorado State University, are conducting a study on the flooding that occurred in Lumberton, N.C. in the days following Hurricane Matthew in early October. The researchers will be surveying a scientifically drawn, random sample of homes and households assessing the damage to homes and speaking to households about how this event affected their households.

This study is part of a larger project led by Center of Excellence for Risk-Based Community Resilience Planning at Colorado State University (CSU). The Center is directed by Drs. John van de Lindt and Bruce Ellingwood, who are professors in the Civil and Environmental Engineering Department at Colorado State University. The National Institute of Standards and Technology (NIST) is funding the Center at CSU.

The Lumberton field study is collecting information about damage to homes and how the flood disrupted household daily routines, such as going to work and school, as well as living patterns. The interviews will take approximately fifteen minutes, depending on what happened to the household and its members. Participation in this research is voluntary and household informants participating in the survey can withdraw consent and stop participation at any time.

When the Center reports and shares the findings, the data from all participants will combine into summary statistics and tables that are not identifiable in terms of unique individuals or households. There are no known risks or direct benefits for participating in the study, but we hope, through household participation, to gain knowledge on how households were affected by Hurricane Matthew and the flooding so that lessons can be learn from Lumberton's experiences to help Lumberton and other communities better prepare for similar events in the future.

If there are questions about the rights of participants as volunteers in this research, please contact Colorado State University's Institutional Review Board (IRB) at: RICRO_IRB@mail.colostate.edu; 970-491-1553.

If there are questions about the study, please contact: Dr. John van de Lindt, Department of Civil Engineering Room A201, Colorado State University, Fort Collins, CO 80523-1301, 970-491-6697
The field team will be in Lumberton, conducting research during the week of Monday, November 28th through Sunday, December 4th.

AUTHOR AFFILIATIONS

JOHN W. VAN DE LINDT
Howard H. Short Endowed Chair and Co-Director – Center of Excellence for Risk-Based Community Resilience Planning, Dept. of Civil and Environmental Engineering, Colorado State University, Fort Collins, CO, 80523, U.S.A., E-mail: jwv@engr.colostate.edu

WALTER GILLIS PEACOCK
Professor, Department of Landscape Architecture and Urban Planning and Director – Hazard Reduction and Recovery Center, Texas A&M University, College Station, TX, 77843, U.S.A., E-mail: peacock@tamu.edu

JUDITH MITRANI-REISER
Director of Disaster and Failure Studies, Community Resilience Group, Engineering Laboratory, National Institute of Standards and Technology, Gaithersburg, MD, 20899, U.S.A., Email: judith.mitrani-reiser@nist.gov

NATHANAEL ROSENHEIM
Associate Research Scientist, Department of Landscape Architecture and Urban Planning, Hazard Reduction and Recovery Center, Texas A & M University, College Station, TX, 77843, U.S.A., E-mail: nrosenheim@arch.tamu.edu

DERYA DENIZ
Assistant Professor, Department of Civil Engineering, Özyeğin University, Cekmekoy- Istanbul, 34794, Turkey, Email: derya.deniz@ozyegin.edu.tr

MARIA DILLARD
Research Social Scientist, Community Resilience Group, Engineering Laboratory, National Institute of Standards and Technology, Gaithersburg, MD, 20899, U.S.A., Email: maria.dillard@nist.gov

TORI TOMICZEK
Assistant Professor, United States Naval Academy, Naval Architecture & Ocean Engineering, Annapolis, MD, 21402, U.S.A., E-mail: vjohnson@usna.edu

MARIA KOLIOU
Assistant Professor, Zachry Department of Civil Engineering, Texas A & M University, College Station, TX, 77843, U.S.A., E-mail: maria.koliou@tamu.edu

ANDREW GRAETTINGER
Professor, Department of Civil, Construction and Environmental Engineering, Director of Graduate Programs, University of Alabama, Tuscaloosa, AL, 35401, U.S.A., E-mail: andrewg@eng.ua.edu

SHANE CRAWFORD
Post-Doctoral Scholar- Center of Excellence for Risk-Based Community Resilience Planning, Dept. of Civil and Environmental Engineering, Colorado State University, Fort Collins, CO 80523, U.S.A., Email: Shane.Crawford@colostate.edu

KENNETH HARRISON
Operations Research Analyst, Community Resilience Group, Engineering Laboratory, National Institute of Standards and Technology, Gaithersburg, MD, 20899, U.S.A., Email: kenneth.harrison@nist.gov

ANDRE BARBOSA
Assistant Professor, Oregon State University, Corvallis, OR, 97331, U.S.A., E-mail: Andre.Barbosa@oregonstate.edu

JENNIFER TOBIN
Deputy Administrator, Natural Hazards Center, University of Colorado, Boulder, CO, 80309, U.S.A., E-mail: Jennifer.L.Tobin@colorado.edu

JENNIFER HELGESON
Economist, Applied Economics Office, Engineering Laboratory, National Institute of Standards and Technology, Gaithersburg, MD, 20899, U.S.A., E-mail: jennifer.helgeson@nist.gov

LORI PEEK
Professor, Department of Sociology and Director, Natural Hazards Center, University of Colorado, Boulder, CO, 80309, U.S.A., E-mail: lori.peek@colorado.edu

MEHRDAD MEMARI
Senior Research Scientist, Research and Development, American International Group, Inc., Philadelphia, PA, 19103, U.S.A., E-mail: mehrdad.memari@aig.com.

ELAINA SUTLEY
Assistant Professor, Department of Civil, Environmental and Architectural Engineering, University of Kansas, Lawrence, KS, 66045, U.S.A., E-mail: enjsutley@ku.edu

SARA HAMIDEH
Assistant Professor, Community and Regional Planning, Iowa State University, Ames, IA, 50011, U.S.A., E-mail: shamideh@iastate.edu

DONGHWAN GU
Department of Landscape Architecture and Urban Planning, Hazard Reduction and Recovery Center, Texas A & M University, College Station, TX, 77843, U.S.A., E-mail: dgu@tamu.edu

STEPHEN CAUFFMAN
Research Engineer, Community Resilience Group, Engineering Laboratory, National Institute of Standards and Technology, Gaithersburg, MD, 20899, U.S.A., E-mail: stephen.cauffman@nist.gov

JUAN FUNG
Economist, Applied Economics Office, Engineering Laboratory, National Institute of Standards and Technology, Gaithersburg, MD, 20899, U.S.A., E-mail: juan.fung@nist.gov