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Community Resilience-Focused Technical Investigation of the

The LUMBERTON, NORTH CAROLINA FLOOD of 2016, Wave 5

UNDERSTANDING RECOVERY FROM SEQUENTIAL DISASTERS

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

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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.

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Field Study Team Members

The Lumberton Wave 5 Field Study Team consisted of 36 people. Wave 5 was conducted during one trip to Lumberton. Field Study Leadership coordinated field visit planning and logistics. Field Study Team Members participated in data collection in Lumberton. Other contributors provided data collection and / or analysis support. Team affiliations are listed as of the time of Wave 5 (June 2022).

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Glossary

ACS	American Community Survey
AEO	Applied Economics Office
AMI	Area Median Income
ARC	Alternatives for Resilient Communities
BRIC	FEMA Building Resilient Infrastructure and Communities Program
CAIDI	Customer Average Interruption Duration Index
CDBG-DR	Community Development Block Grant-Disaster Recovery
CISA	Cybersecurity and Infrastructure Security Agency
CoE	Center of Excellence
CRP	Community Resilience Program
DFS	Disaster and Failure Studies
DOI	Digital Object Identifier
DPS	North Carolina Department of Public Safety
DS	Damage State
EDGe$	Economic Decision Guide Software
EL	Engineering Laboratory
FCC	Federal Communications Commission
FEMA	Federal Emergency Management Agency
FERC	Federal Energy Regulatory Commission
GIS	Geographic Information Systems
HMGP	Hazard Mitigation Grant Program
HWM	High Water Marks
HUD	Department of Housing and Urban Development
HVAC	Heating, Ventilation, and Air Conditioning
IAA	Interagency Agreement
IHP	Individuals and Households Program
IN-CORE	Interdependent Networked Community Resilience Modeling Environment
IRB	Institutional Review Board
LiDAR	Light Detection and Ranging
LP	Liquified Petroleum
NAICS	North American Industry Classification System

NCST	National Construction Safety Team
NERC	North American Electric Reliability Corporation
NIST	National Institute of Standards and Technology
NGO	Nongovernmental Organization
NOAA	National Oceanic and Atmospheric Administration
OR	Operations Research
PPP	Paycheck Protection Program
PPS	Probability Proportion to Size
PRA	Paperwork Reduction Act
SAIDI	System Average Interruption Duration Index
SAIFI	System Average Interruption Frequency Index
SBA	Small Business Administration
SCADA	Supervisory Control and Data Acquisition
TraCR	Tracking Community Resilience
USDA	United State Department of Agriculture
USGS	United States Geological Survey

Executive Summary

This is the fifth report in a series that documents the impact and recovery of Lumberton, North Carolina, following 2016 Hurricane Matthew. This fifth report captures occupancy status for housing and commercial units six years after the initial flooding in Lumberton, four years after flooding from 2018 Hurricane Florence, and two years into the COVID-19 pandemic. The longitudinal field study in Lumberton is part of the National Institute of Standards and Technology (NIST)-funded Center for Risk-Based Community Resilience Planning (Center). The Center has teamed with researchers from NIST's Community Resilience Program, Disaster and Failure Studies Program, and the Applied Economics Office to conduct the field studies since 2016. Findings from the longitudinal field study are being used by the Center and NIST team to advance the state of knowledge of community resilience and recovery.

In early October 2016, Hurricane Matthew crossed North Carolina as a category 1 hurricane with some areas receiving as much as 457 mm (18 in.) of rainfall in total for the event. In the days that followed, Lumberton, North Carolina, an inland community in Robeson County, was catastrophically flooded. The Center and NIST team conducted a quick response field study focused on housing damage, school disruption, infrastructure performance, and community-level disruption in Lumberton in October 2016. Approximately one year later (Wave 2 of data collection), the Center and NIST team returned to Lumberton to document and better understand 1) recovery progress with an emphasis on housing, schools, infrastructure, community and state-level decisions, 2) business disruption and recovery, which was newly included in the scope, and 3) the intersection of these sectors on community recovery.

In September of 2018, Hurricane Florence caused a second major flood in Lumberton. The Center and NIST team conducted a quick response field study in October 2018 to document the initial damage to the housing units and businesses in our longitudinal samples. Ultimately, the extent of flooding and its impact was quite different for Hurricane Florence than it was for Hurricane Matthew, but the compounding effect was significant, especially for those hardest hit in 2016. In April of 2019 (Wave 3), a team returned to Lumberton to document the six-month recovery from Hurricane Florence and continued recovery from Hurricane Matthew. The team was able to systematically document preparedness and mitigation actions taken by households and businesses, as well as learn about many planned capital improvement projects.

The team set intentions for a fourth wave of data collection to occur in the spring of 2020; however, due to the COVID-19 pandemic, human subjects research was shut down for NIST and universities associated with the Center. More than a year later, in the spring of 2021, the Center and NIST team were finally able to execute a remote data collection effort, termed Wave 4a. This Wave 4a expanded the longitudinal samples with a convenience sample for housing and a refreshment sample for businesses and added a new goal of documenting resilience capacity across the community. Both survey efforts produced very low response rates. The team was concerned that the large percentage of undeliverable surveys was indicative of a dire situation in Lumberton brought on by a third disaster, specifically the COVID-19 pandemic, occurring in Lumberton. Given the outcomes of Wave 4a, an additional sub-wave of data collection, termed Wave 4b, took place to document the physical existence of housing units and businesses, and to the extent possible, document occupancy status for housing and commercial units. In Wave 4b, research team members did windshield surveys of each sample unit and recorded details about the structure and perceived occupancy.

Wave 5, documented in this report, captured the return to in-person data collection for the longitudinal study following the onset of the COVID-19 pandemic. The longitudinal housing and business samples were revisited using measures of recovery or stagnation similar to previous waves, along with additional information on utility and infrastructure-related needs at the house or business level. Wave 5 of the longitudinal study introduced semi-structured interviews with utility service providers to systematically learn more about their resilience planning and recovery decision processes, an area which is not well documented yet critical for future decision support tools. In earlier waves, this kind of information was less systematically collected through informal discussions with utility service providers. City government officials also shared their views as in previous waves through informal discussions at the Lumberton City Hall.

The return to in-person data collection was fruitful with similar response rates for the business and housing unit samples as those experienced before the research interruption caused by the pandemic. The housing survey collected data on recovery processes from Hurricanes Matthew and Florence as well as the impact of the COVID-19 pandemic. Dislocation, which has been measured throughout the longitudinal data collection effort, showed a common pattern for post-disaster return to permanent housing with most respondents returning within 1-2 years post-disaster, but a long tail of slow return for a small portion of the population. Those housing units that were perceived abandoned in 2022 (n = 137), including those that were marked as abandoned during every data collection since Hurricane Matthew (n = 35 housing units), may represent households still searching for permanent housing or households that have permanently relocated elsewhere.

Wave 5 highlighted the compounded effects of successive disasters on households' recovery processes. While a majority of survey respondents reported that their housing repairs were complete, repair was more likely to be completed for those who had damage from only one hurricane compared to those who reported damage from both hurricanes. While COVID-19 did not directly affect house repairs for most residents, those households who reported employment disruption from COVID-19 also reported greater effect of the pandemic on their ability to complete hurricane repairs.

The Wave 5 business survey also continued the collection of recovery metrics from Hurricanes Matthew and Florence–including employment size, profitability, capacity, and self-reported recovery–as well as collected information on the impacts of COVID-19 on that process. The survey found that most businesses reported being recovered from the hurricanes, but over half were still dealing with the effects of COVID-19. For businesses that were still recovering from the hurricanes, COVID-19 exacerbated recovery challenges. In previous waves, few businesses in Lumberton participated in disaster recovery programs. When asked how businesses financed their recovery from Hurricanes Matthew and Florence, personal savings was the most commonly used resource. Businesses also used insurance in some instances and/or creative sources of funding, including deals with suppliers, mortgage refinancing, and changes in budgeting. However, when it came to COVID-19 approximately 43 % of businesses applied for financial assistance, primarily from Federal programs. COVID-19 saw the introduction of the Paycheck Protection Program (PPP), which offered forgivable, rather than low-interest loans, which may have been more appealing to businesses than loans offered at the Federal level during previous disasters.

Responses to interviews with several critical infrastructure operators and institutions, including power transmission, power distribution, water distribution and public works, transportation, and

the county extension, revealed several trends to manage contingencies by making decisions under uncertainty and constraints. They expressed a shared goal of reducing the impact of flooding on customers through interventions such as hardening assets or restoring system operation without safety incidents, augmenting capacity of systems to satisfy end-users' demands, enabling re-routing or adding redundancies to balance the supply/demand dynamics among providers and users, and stockpiling spare parts and equipment while securing personnel and assistance pre-event. In parallel, infrastructure sectors have already started significant capital investment projects, including the elevation of interstate 95 (I-95), the relocation of wells, the flood protection of substations, and the development of an industrial park, among others. In addition to shovel-ready interventions and bold capital improvements, infrastructure sectors also have a heightened interest in renewable energy, decentralized operation of systems, expanded use of contingency impact assessments, and adoption of technology for improved task reliability, coordination, documentation, and asset management.

In survey responses about infrastructure, households and businesses reported their protective actions in terms of redundancies to utility service outages, where a third of the respondents have power generators. However, other critical services are hard to back up at scale, including sewer for business continuity and telecommunications for the community.

During informal discussions, representatives of the City of Lumberton reported progress and ongoing challenges for recovery. Funding rules and application procedures, including changing application processes, complicated recovery for a city staff that is the same size it was before Hurricane Matthew. City revenues have dropped, causing continued concerns for recovery coordination and efforts. Several planned large mitigation projects, including a flood gate, are still in progress but the City is optimistic about improved coordination with the network of stakeholders involved in these efforts. Housing recovery remains a challenge for the City, with high vacancy rates and housing with remaining damage. Hurricane Florence flood buy-outs are continuing while Hurricane Matthew buy-outs are completed for damaged houses. Additional state managed housing programs have been slow to tackle housing repair and rebuilding in the City. Several preparedness actions that improved resilience during Hurricane Florence have continued, including a recovery center near City Hall that is available for the public, and supplies stored for creating temporary flood barriers during future events.

This report concludes that a sixth wave of data collection should be conducted in-person to systematically document the recovery status and establish a baseline for future events that may affect Lumberton housing, businesses, schools, infrastructure, and government, including an update on where capital improvements and recovery funded projects stand and how they align with an assessment of their resilience benefits and co-benefits.

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1. Chapter 1: Introduction

The longitudinal study of Lumberton, North Carolina described in this report is a collaboration between researchers from the National Institute of Standards and Technology (NIST)-funded Center of Excellence for Risk-Based Community Resilience Planning (Center), and researchers in the Engineering Laboratory (EL) at NIST. This is the fifth report in a series that documents the impact and recovery of Lumberton, North Carolina, following the 2016 Hurricane Matthew.

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

Collective community needs and objectives, including post-disaster recovery goals, are not reflected in codes, standards, and other regulatory documents applied to the design of individual facilities. This necessitates 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 against the disruption caused by natural hazards and disasters depends on many disciplines, including engineering, social sciences, and information sciences. In the wake of climate change, it is becoming more likely and more common for communities to be faced with a major disaster before being able to fully recover from the previous disaster. Providing detailed and community-specific guidance on how to better prepare for and recover from disasters is the impetus for the Center's research.

The Center, headquartered at Colorado State University in Fort Collins, Colorado, involves twelve additional universities at the time of Wave 5, was established by 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 aimed at: (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. A longitudinal field study is planned and executed approximately every 12 months in the same location with the same sample of housing units and businesses to support the following phases of resilience model development within IN-CORE: impact, disruption, dislocation, recovery, decision, and interdependency. The Lumberton field study will provide comprehensive data sets to evaluate the information needed for validation of the full architecture. Additionally, Lumberton now serves as a testbed or a platform for testing both the models and function of IN-CORE. Specifically, the models focused on infrastructure networks for water, transportation, and electricity offer local utility providers a new tool for supporting resilience decisions and investments under uncertainty.

The Center works to accelerate the development of system-level models and databases that will provide the technology for enhancing community resilience. Team members from the Center, at the time of Wave 5, include noted resilience experts from Colorado State University, East Carolina University, Rice University, Texas A&M University, the University of Florida, the University of Illinois, the University of Kansas, Stony Brook University, Texas Tech University, and the U.S. Naval Academy. Ultimately, the decision framework created by the Center will provide decision-makers with a unique set of tools that can be tailored to the needs of individual communities. These tools will 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 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. In support of this mission, EL is conducting research in community resilience, disasters and building failure investigations, economic analysis and life cycle assessment, wind and seismic hazard impact reduction, fire prevention and control, engineering, and manufacturing materials. Researchers from EL's Applied Economics Office (AEO), the Community Resilience Program (CRP), and the Disaster and Failure Studies (DFS) Program have participated in the Lumberton field study. This work seeks to advance the disaster metrology research as well as to advance measurement and modeling needed to support community resilience planning.

Hazard events stress buildings and infrastructure in ways and on a scale that cannot be easily replicated in a laboratory. Field studies of disaster and failure events are essential to improving the performance of buildings and infrastructure, the safety of building occupants, and associated evacuation and emergency response procedures. NIST's DFS Program seeks to standardize disaster field deployment, assessment, and reporting protocols to improve building and infrastructure performance. DFS implements these goals through the following activities: (1) monitoring disaster events to evaluate whether an event meets decision criteria for the establishment and deployment of a study team, (2) coordinating the establishment, deployment, operations and reporting of study teams, (3) ensuring 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) building and maintaining effective partnerships and communications with other federal agencies, state/local governments, stakeholders and the general public, (5) establishing and executing standard operating procedures and criteria for disaster and failure studies, (6) promoting the implementation of recommendations from all DFS investigations, (7) creating and maintaining an archival data repository for DFS, (8) carrying 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) overseeing a disaster metrology research program that interacts with other groups in EL, to directly inform best practices for DFS program activities. The Lumberton field study directly supports the disaster metrology research activity of the DFS Program and has repeatedly served as a space for developing and/or testing new technology, data collection instruments, and methodologies. For example, in Wave 1, the team developed an integrated sampling methodology that prioritized both engineering and social science research questions and created data collection instruments to assess physical and socioeconomic impacts of Hurricane Matthew. The sampling methodology and data collection instruments are published on *DesignSafe*-CI (van de Lindt et al. 2021; Tobin et al. 2021; Peacock et al. 2020; Deniz et al. 2020; Sutley et al. 2020; Xiao et al. 2020; Sutley et al. 2021; Crawford et al. 2021). In Wave 4, the team employed new technology to collect data on housing and business occupancy status using ESRI®'s *Survey123 Connect* survey design application. The team continued the use of

these tools to support both sample tracking and data collection in Wave 5. The contribution of the new technology to the field study continues to be evaluated to inform recommendations associated with future disaster and failure studies.

Community Resilience Planning Guides – NIST also manages a multi-faceted program aimed at assisting communities and stakeholders on issues related to buildings, the interdependencies of physical infrastructure systems, and the social and economic functions they support. NIST CRP released the *Community Resilience Planning Guide for Buildings and Infrastructure Systems* in 2015 to help communities plan and implement prioritized measures for the built environment to strengthen their resilience to hazard events. Since 2016, NIST has been working to develop science-based tools for communities, professionals, and researchers to assess resilience and to support informed planning and decision making at the community scale for improving resilience in communities of all sizes. The three following Community Resilience Program research projects are directly supported by the field study in Lumberton.

Community Resilience Systems Model – In the development of community plans (e.g., land use management, emergency response, economic development), the formidable challenges inherent in both the analysis and design of the resilience systems must be addressed. This project focuses on the development of a model to support community resilience decision-making. The NIST Alternatives for Resilient Communities model, or NIST ARC, is an interactive screening tool that is designed to assist communities in resilience planning. In its application of operations research methods, NIST ARC addresses many of those challenges related to the breadth, large scale, and interdependencies of the physical, social, and economic systems that determine a community's resilience. Given hazard and interdependency information, and socio-economic data, NIST ARC outputs alternative sets of actions across the community that can be taken to meet user-specified resilience and other targets (e.g., cost). The goal of NIST ARC is to decrease a community's burden in developing viable, sound alternatives for stakeholder consideration and to provide useful starting points for further, more detailed analysis. NIST ARC is designed to assist a collaborative planning team in the identification of solutions as outlined in NIST's *Community Resilience Planning Guide for Buildings and Infrastructure Systems*. The target user is an analyst facilitating the collaborative planning team's interactive use of the tool. The analyst assists in the refinement of targets and imposition of new constraints to address comments or concerns, and to explore tradeoffs between competing objectives. Data and information obtained throughout the Lumberton field study provided the foundational case study for the development of NIST ARC.

Community Resilience Assessment Methodology – Community resilience is a complex, multi-dimensional problem that relies on engineering, social sciences, earth sciences, and other disciplines to improve the way communities prepare for, resist, respond to, and recover from disruptive events, whether those events are due to natural or human-caused hazards. This project will develop tools and metrics for communities to measure resilience at the community-scale. The assessment methodology will employ a complex systems perspective to make linkages between social and physical systems and will address resilience over time in order to provide useful information to inform an understanding of the factors influencing recovery following a disruptive hazard event. The goal of this research is to develop a simplified, science-based community resilience assessment methodology that can be applied to communities of any size for the purpose of assessing baseline resilience and changes in resilience over time. The Tracking Community Resilience (TraCR) methodology will ultimately be coupled with NIST ARC to

provide a means of evaluating decisions for their contribution to resilience, among other factors. Field studies including Lumberton provide essential datasets for supporting multivariate analyses examining relationships between indicators of resilience and recovery, sensitivity and uncertainty analyses, and validation studies.

Cost-Effective Resource Allocation Strategies to Enhance Community Resilience - Advancements in measurement science are needed to estimate the economic impact associated with community resilience planning for natural and human-made hazards. In addition to the development of 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, this project includes a focus on the measurement of disaster losses, focusing on major indirect losses, such as business interruption, and distributional effects —through the use of both data gathered in the field through surveys and interviews as well as secondary data sources. These data ultimately support measurement of the 'resilience dividend,' the (non-disaster related) community co-benefits from investing in disaster resilience and can be used to provide guidance to communities on approaches to assess the net co-benefits associated with resilience planning. Since Wave 2, the Lumberton field study has included a formal business recovery component to establish data collection tools and methods for measuring indirect losses, like business interruption, associated with hazard events.

1.3. Overview of Hurricanes Matthew and Florence and Previous Waves

In early October 2016, after devastating parts of the Caribbean, Hurricane Matthew struck Florida and continued up the eastern seaboard before turning out into the Atlantic Ocean off the coast of North Carolina and Virginia. More than 170 counties in Florida, Georgia, South Carolina, and North Carolina were included in Presidential Emergency Declarations and/or Presidential Disaster Declarations between October 6th and 11th, 2016. Economic loss estimates exceeded $10 billion (NOAA NCEI 2018).

More than a week after the storm turned out to sea, parts of North Carolina had yet to experience flood crests, with many communities experiencing flood levels at or higher than those associated with Hurricane Floyd in 1999.[1] The Lumber River reached flood stage in Lumberton on October 3, 2016, due to local heavy rains. On October 11, 2016, the Lumber River crested at almost 22 ft (6.7 m) above the gauge datum. The water level slowly fell, dropping below flood level on October 23, 2016.

As described in van de Lindt, Peacock, Mitrani-Reiser et al. (2018), the Center Field Study team selected Lumberton for longitudinal study for many reasons, including the moderate population size of approximately 21 000 residents (US Census Bureau 2016), the diverse socio-demographic makeup of primarily three race and ethnicity groups (White, Black, and Lumbee Indian), and

[1] At its peak, Hurricane Floyd was recorded as a Category 4 hurricane. It was reduced to a Category 2 by early September 1999 when it impacted North Carolina with a storm surge height exceeding 9 feet causing 51 fatalities and billions in damages. Flooding damage was tremendous with as much as 20 feet of floodwater staying for over a week in some areas and exacerbated due to Hurricane Dennis which hit North Carolina just a few weeks prior.

because flood waters entered the City through a gap in the levee system that, 13 years prior, was reported to not meet the current Federal Emergency Management Agency (FEMA) regulations.

The Center and NIST conducted a quick response field study focused on Lumberton and the flooding experienced from the Lumber River. This first field study was performed during the week of November 29, 2016. Denoted here as Wave 1, it was the first of a series of approximately annual field studies to document and better understand Lumberton's recovery. Table 1-1 shows each field study wave by date, purpose, and report.

Table 1-1. Lumberton longitudinal field study timeline and report publications.

Wave	Dates	Purpose	Report Publication
1	Nov. 27 - Dec. 4, 2016	Initial impact after Hurricane Matthew	van de Lindt, Peacock, Mitrani-Reiser, et al. (2018)
2	Jan. 19 - 29, 2018	1-yr recovery after Hurricane Matthew	Sutley, Dillard, Hamideh, et al. (2020)
3a	Oct. 16 - 19, 2018	Initial impact after Hurricane Florence	Helgeson, Hamideh, Sutley, et al. (2021)
3b	Dec. 2 - 5, 2018	Decision-making regarding public housing	
3c	Apr. 11 - 21, 2019	6-mo recovery after Hurricane Florence	
4a	Feb. 1 - Jul 1, 2021	Virtual impact during COVID-19 pandemic	Watson, Crawford, Sutley, Loerzel, et al. (2022)
4b	Dec. 1 - 4, 2021	In-person operational/occupancy status during COVID-19 pandemic	
5	Jun. 17 - 27, 2022	Recovery after Hurricanes Matthew, Florence, and COVID-19 pandemic	Meyer, Duenas-Osorio, Dillard, Sutley, et al. (2023)

Data collection during Wave 1 focused on the residential housing sector with two primary objectives: (1) to establish and document initial conditions 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) to 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 housing damage state following the flood. See van de Lindt, Peacock, Mitrani-Reiser, et al. (2018) for the Wave 1 field investigation report.

Approximately one year after Hurricane Matthew, during the period January 19 - 29, 2018, the Center and NIST researchers returned to Lumberton for Wave 2 of the longitudinal study. As indicated in Sutley, Dillard, van de Lindt et al. (2020), the overall purpose of Wave 2 was to (1) support on-going research at the Center and NIST through the collection of the necessary data to build and/or validate community-resilience models for business, housing, social institutions, and building functionality; and (2) advance understanding on the factors that influence recovery for two specific community sectors, namely housing and business, as well as to gain

information on the recovery status of schools, households, public works, and the community as a whole.

In support of the overall purpose of the longitudinal study, the same housing sample from Wave 1 was adopted for subsequent waves, and as a new feature, a sample of 453 businesses was added. For housing, one housing unit was dropped due to a hard refusal during Wave 1, resulting in a sample of 567 housing units for structured surveys in Wave 2 and on. Of these 567 housing units, the team was able to survey more than 227 household respondents. For businesses, a stratified random sampling approach resulted in a sample of 350 businesses drawn from the *ReferenceUSA* database (now *InfoGroup*). While in the field, an additional sample of 103 businesses was drawn to address possible coding errors in *ReferenceUSA*, business closures, and response rates. The final sample resulted in 453 businesses, where 164 business owners and managers were surveyed. The business survey instrument used in Wave 2 assessed the damage caused to commercial buildings from Hurricane Matthew through a series of questions built on damage state descriptions developed for residential buildings. Both the housing and business surveys included questions on physical repair and sector-specific recovery indicators to document recovery progress and asked about the availability and timing of a range of financial recovery resources. For the public sector data collection, meetings were held with four city representatives and four state representatives, including both government and the water utility, to understand the context for recovery of the community. Likewise, to understand the context for school recovery, interviews were conducted with nine school district representatives. At the time of Wave 2, recovery was still pronouncedly on-going for Lumberton households and businesses, with much Federal money having not yet arrived, and many rebuilding decisions yet to be made.

Hurricane Matthew was widely reported to be a 500-year rainfall event, but only two years later, Hurricane Florence resulted in another low annual exceedance probability (1000-year) rainfall event that inundated Lumberton along with many areas in North Carolina. After reaching peak intensity and Category 4 status on September 11, 2018, Hurricane Florence made landfall on the US Eastern Coast on September 14, 2018, as a weakened Category 1 hurricane, bringing six days of heavy rainfall to North and South Carolina. The storm eventually lost strength over West Virginia and was downgraded to a post-tropical cyclone on September 17, 2018. Hurricane Florence inundated the city of Lumberton with 165 mm (6.5 in.), 380 mm (15 in.), and 350 mm (13.8 in.) of rain on the 15th, 16th, and 17th of September 2018, respectively. Due to its slow forward motion and heavy rains, the storm caused significant coastal and inland flooding. In North Carolina, 22 stream gauges measured record peak flood stages due to the storm, with many breaking records previously set by Hurricane Matthew. Post-Hurricane Florence flooding significantly affected businesses, housing, and agriculture in many areas that were still recovering from the 2016 flooding.

The Center and NIST team conducted a quick response field study October 16 -19, 2018 to document the initial physical damage from Hurricane Florence to the longitudinal sample of housing units and businesses, denoted as Wave 3a. As critical decisions were being made by the City on whether or not to rebuild vacant and damaged housing units since Hurricane Matthew, a small team of Center researchers returned to Lumberton December 2 - 5, 2018, to conduct focused interviews with key decision makers and public housing residents, denoted as Wave 3b. During April 11 - 21, 2019, the Center and NIST team returned to Lumberton to execute two systematic surveys – one to households and one to businesses – and conduct semi-structured interviews with City contacts to learn more about the impact and disruption caused by Hurricane

Florence, and the progress of recovery from Hurricane Matthew. This latter trip was denoted as Wave 3c.

The Wave 3a damage surveys revealed approximately two-thirds of the sampled housing units that were damaged after Hurricane Florence experienced more severe damage after Hurricane Matthew. In total, approximately 18 % of sampled housing units and 15 % of sampled businesses were damaged by Hurricane Florence. The fact that significant proportions of the sampled housing and businesses were not damaged in Hurricane Florence was due to differences between the two flood events and inundation areas, as well as differences in the city's preparation for Hurricane Florence compared to Hurricane Matthew. The Wave 3a team observed different mitigation actions that had been taken at the city-level, as well as by individuals. These observations made for important follow-up questions the team would ask about in future waves.

Individual level mitigation measures were only captured anecdotally in Wave 3a and used to inform survey design for Wave 3c. In the surveys conducted during Wave 3c there was systematic data collection about mitigation to understand the extent of these actions and to understand whether they may have reduced property loss and collective damage.

The Wave 3c household survey documented that 33 % of households who completed the survey still had unrepaired damage from Hurricane Matthew at the time of Hurricane Florence. Because of Hurricane Florence, nearly two-thirds of respondents were dislocated from their home for at least one day, where the majority of households who responded to the survey returned home within two weeks. Although recovery was still an active process, 85 % of respondents reported intentions of remaining in their home for the next year, and more than 80 % indicated having the same access to school and grocery stores when comparing post-Hurricane Florence with pre-Hurricane Matthew.

Similar to observations in Wave 2, in Wave 3c small proportions of respondents had received insurance payouts and other recovery support. The Wave 3c survey asked about positive impacts of the two disasters as well, where approximately one-third of respondents indicated increased community involvement and approximately 40 % indicated increased contact with neighbors and extended family since before Hurricane Matthew.

The Wave 3c business survey documented that 17 % of businesses that completed the survey reported unrepaired damage from Hurricane Matthew at the time of Hurricane Florence. Due to Hurricane Florence impacts, 80 % of businesses reported losing electricity for at least one day, which was the most frequently reported utility loss. Furthermore, over 40 % of businesses experienced interrupted operations for at least one week. When asked to report their perception of their recovery, over half of businesses (58 %) reported being fully recovered relative to their state prior to Hurricane Florence. The Wave 3c survey asked business representatives to indicate mitigation and preparedness actions they have taken. Fewer businesses reported taking these actions compared to households. Overall, the field team concluded that two years after Hurricane Matthew, and six months after Hurricane Florence flooded Lumberton, recovery was underway with a long road of continued recovery ahead for the community of Lumberton. See Helgeson, Hamideh, Sutley et al. (2021) for the Wave 3 field study report.

Wave 4 took place during the COVID-19 pandemic. Lumberton was still recovering from 2016 Hurricane Matthew and 2018 Hurricane Florence and waiting on significant federal recovery resources when the COVID-19 pandemic started. Findings from Wave 3c revealed increased mitigation and preparedness employed by individuals, businesses, and the City for Hurricane

Florence compared to Hurricane Matthew. Thus, there was still much to learn from Lumberton's recovery, despite the pandemic. Both the household and business data collection focused on longitudinal recovery from the hurricanes as well as mitigation and impacts from the COVID-19 pandemic.

Plans for Wave 4 of the longitudinal field study were heavily adapted in response to the evolving pandemic guidance and restrictions provided by the institutions involved. Both in-person interaction with study participants and work-related travel were restricted during the early phase of the pandemic, which delayed the planned fieldwork for Wave 4 until 2021. Data collection for Wave 4 was executed in two parts, Wave 4a (electronic surveys) and Wave 4b (windshield surveys).

In Wave 4a, postcards were mailed to the longitudinal housing sample with a link for the electronic survey. These postcards were followed by paper surveys if the household did not respond to the electronic survey. Additionally, the household survey was opened up to a convenience sample and shared with institutional partners in Lumberton to share through their member listservs and on their websites. Business surveys were also conducted online in the same manner with an additional refreshment sample due to low response rates. Both surveys were open from February 1 to July 1, 2021. The electronic survey resulted in an only 6 % response rate, and so the results were not analyzed. Instead, the team summarized important methodological lessons from this data collection in the Wave 4 report (Watson, Crawford, Sutley, and Loerzel et al. 2022). For example, the team recommended that: both housing and business survey collection should continue in-person every 12 to 16 months particularly where internet access is not available to all respondents; interviews with key community stakeholders should continue at the same frequency as these data provide important context for field observations and structured data collections; and ongoing analysis, with regular feedback from NIST and Center researchers, should continue to ensure the field study continues to align with what is needed for measurement and modeling of community resilience and for the advancement of IN-CORE and the Lumberton testbed.

Because response rates were extremely low in Wave 4a, windshield surveys were conducted as Wave 4b to assess perceived occupancy of housing units and operational status of businesses within the longitudinal sample. Teams of two drove around Lumberton from December 1 to 4, 2021. Of the 567 housing units, the team estimated that 67 % were occupied, 7 % were likely occupied, 12 % were vacant, 5 % were likely vacant, 2 % had no building on the lot, and 8 % were unable to be determined from the street. A total of 309 businesses were assessed in Wave 4b (of the full sample of n=461). Most commercial units were reported as occupied or probably occupied by a business, representing 86 % of the Wave 4b sample in total. Approximately 10 % of the commercial units were vacant and 1.6 % were probably vacant. Only 2.6 % of the commercial units had an occupancy status that was unable to be determined.

1.4. Overview of Wave 5 (2022) Lumberton Field Study

The Center and NIST teams returned to Lumberton during June 17 - 27, 2022 to execute two systematic surveys – one with the housing sample and one with the business sample – and conduct semi-structured interviews with City and infrastructure officials to learn more about the progress and challenges with recovery from Hurricanes Matthew and Florence, the impact of the COVID-19 pandemic on recovery, and new mitigation and preparedness activities undertaken.

Figure 1-1 provides the timeline of Lumberton field studies executed by the Center and NIST team to date.

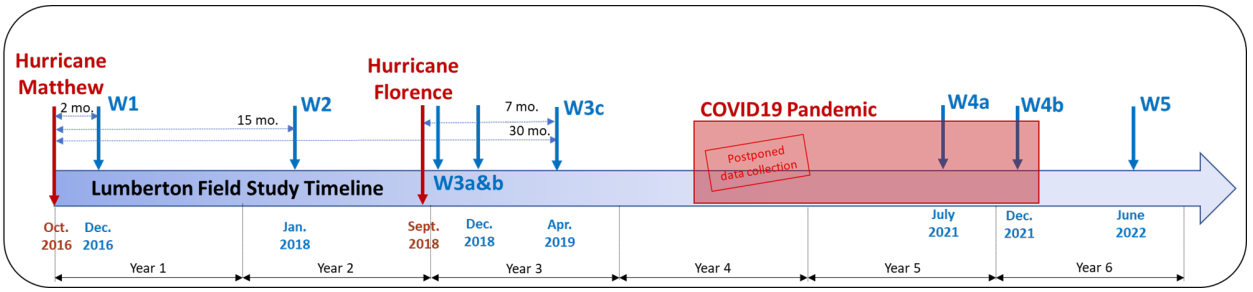

Figure 1-1. Timeline of Lumberton field study.

This report is organized as follows: Chapter 2 provides a summary of the assessment of housing impacts and household disruption and recovery from the successive flood events and COVID-19, including specific study goals, team training and deployment, data collection methods, and results. In Chapter 3, the business survey results on disruption and recovery from successive flood events is provided in a similar fashion as Chapter 2. Chapter 4 provides findings from the interviews with utility service providers and meetings with city officials. Finally, Chapter 5 includes conclusions on the previous chapters' findings and next steps for the longitudinal field study.

2. Chapter 2: Housing Disruption and Recovery

2.1. Goals and Objectives

This chapter presents the Housing Study for Wave 5, including goals, planning and coordination, data collection, and findings. The goals of the Wave 5 household surveys were to document the recovery of housing and households from both hurricanes, how the COVID-19 pandemic affected said recovery and the associated hurricane recovery trajectories, perceptions and needs for utility service provision, and implemented mitigation strategies since the hurricanes. The housing component of the Wave 5 field study supports housing unit and household-level impact and recovery modeling efforts in the Center, and quantifies linkages and interdependencies across housing, households, schools, and business recovery. A number of key housing recovery metrics have been collected through all waves of the Lumberton field study, including repair, re-occupancy, restored accessibility of critical services, and restored stability (of housing). The field study continues to be a valuable source of information about types of mitigation adopted, and the types of resources available to households to help them with their housing recovery. Following the COVID-19 study pause, it was imperative to return in-person to the longitudinal study's housing sample to document and understand the on-going recovery from Hurricanes Matthew and Florence.

Wave 5 used a structured questionnaire (i.e., survey) executed with residents in the housing units of the longitudinal sample. This chapter presents the research methods and findings from Wave 5 as well as a snapshot of longitudinal recovery across Waves.

2.2. Housing Sampling Procedure

The longitudinal housing sample was originally developed by Center researchers for Wave 1. This section briefly reviews sample development; further detailed information on sampling strategy can be found in the Wave 1 report (van de Lindt, Peacock, and Mitrani-Reiser et al. 2018). A number of factors were used to develop the sampling strategy for the household survey. The primary sampling goal for the household survey was to obtain a representative sample of housing units and, where possible, the households occupying those units within the study area. The study area was defined by the school attendance zone for Lumberton Junior High, which also encompasses the attendance zones for two elementary schools. This school attendance zone is identified in Figure 2-1 (the dark black boundary line) along with the city boundary (black dashed line). The school attendance zone also includes both areas inundated by flooding from Hurricane Matthew 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). Floodplains, predicted inundation zones, and U.S. Census data were used to develop the two-stage non-proportional stratified cluster sampling strategy.

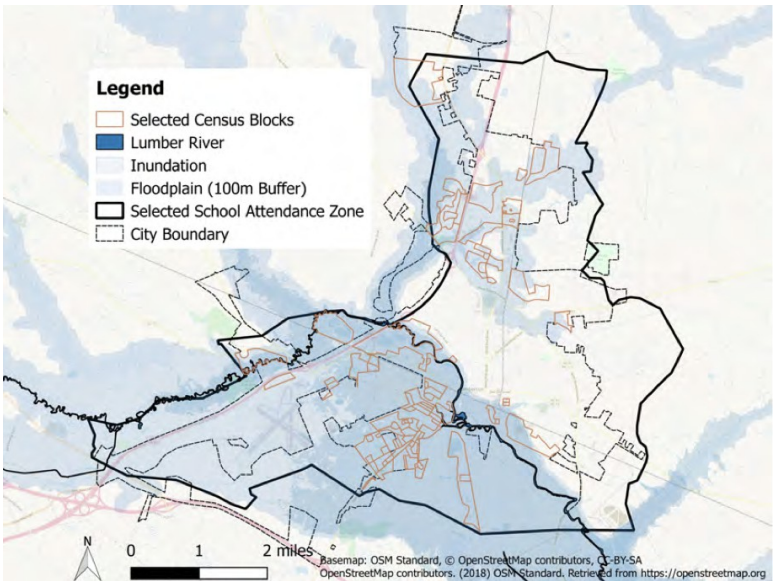

Figure 2-1. Target sampling area with sampled blocks [1 mile = 1.61 km].

The two-stage non-proportional stratified cluster sampling strategy was designed with the first sampling units as Census blocks, and the primary sampling units as housing units and the households residing in those units. Based on the sampling information discussed above, the Census blocks were selected through 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 were then randomly selected on a fixed rate of eight random units per block (with two alternates selected). 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). In Wave 1, which solidified the sample for the continuing waves, 568 valid primary housing units were visited, yielding an average of 7.6 housing units per block. There was one hard refusal to participate in Wave 1, thus 567 housing units were considered as the longitudinal sample and used for each following wave, including Wave 5.

2.3. Survey Instrument Development

Multiple researchers from the Center and NIST, each with unique expertise and interest in community resilience and disaster recovery, participated in developing the survey for Wave 5. Having a multidisciplinary team helped ensure inclusion of different dimensions of household and community recovery in conjunction with housing recovery and in the wake of successive catastrophic flooding events. During development, the survey instrument underwent several rounds of review both internally and through training by researchers within the Center and at NIST, specifically in the Community Resilience Group of NIST's Engineering Laboratory (EL).

The final household survey instrument also went through review required by the Paperwork Reduction Act (PRA). The purpose of the PRA review is to: "ensure the greatest possible public benefit from and maximize the utility of information created, collected, maintained, used, shared, and disseminated by or for the Federal Government;" and to "improve the quality and use of Federal information to strengthen decision-making, accountability, and openness in Government and society" (1995, Pub. L. Count 104-13, 109 Stat 163). The instrument and data collection

methodology for the household survey and the full Wave 5 Lumberton study were approved by the Institutional Review Board (IRB) at Colorado State University, which oversees the Center's human subjects research through an IRB Authorization Agreement with the participating institutions, including NIST.

The Wave 5 survey built upon the surveys utilized in previous waves, with particular interest in continuing to understand recovery processes. Additional questions on mitigation, preparedness, and the COVID-19 pandemic were drawn from Wave 4. New sections of the survey were developed to capture information on decision-making processes of infrastructure and utility service providers in order to support the modeling of infrastructure services.

There were 7 main sections in the Wave 5 household survey. These included (in the order they appear in the survey instrument):

1. occupancy, study eligibility and survey completion,
2. general questions regarding the household, impacts, dislocation/return, recovery status, and recovery funding related to Hurricanes Matthew or Florence,
3. household's current and future insurance and mitigation strategy use,
4. perceived status of recovery regarding the housing unit, household, neighborhood, and community,
5. currently adopted or planned mitigation and preparedness strategies,
6. impacts of COVID-19 on the household and their recovery efforts, and
7. general questions regarding household socio-demographic characteristics.

Appendix A includes the full Wave 5 household survey and Appendices B and C includes the consent script and information sheet.

2.3.1. Establishing Occupancy and Study Eligibility

As in previous waves, when approaching a household, the surveyors observed the housing unit for safety, accessibility, and occupancy. The occupancy status, which focused on occupancy rather than survey completion, could have been marked as: A) yes, the household was present, B) household not present but evidence of habitation, C) household not present with occupancy confirmed by a neighbor or management, D) don't know / uncertain, or D) no the housing unit was not occupied and was abandoned, under repair, or damaged and therefore not habitable. Surveyors recoded a "survey completion" code for each address that included: completed interview, ineligible respondent, bad address, incomplete/partial survey, not occupied residence, no answer or response, no access to property (due to gate or fence), and dropped off survey (which was added in Wave 5). Notes about any of these completion codes were recorded on the paper survey forms for review during data cleaning.

If an eligible household member was present (i.e., over 18 years of age) and provided consent to be surveyed, they were asked to provide the number of adults and children currently living in the household and the month and year the household moved into the home. Households that moved into the housing unit after Hurricanes Matthew or Florence were still asked about their knowledge regarding the possible impacts of the events on the housing unit.

2.3.2. State of Repair and Recovery Following Hurricanes Matthew and Florence

To understand long-term recovery in Lumberton, survey participants were asked if the home was damaged by either Hurricane Matthew or Hurricane Florence and the status of repairs. In addition, participants were asked to think about the recovery status of their home (the structure itself), household (the people), neighborhood, and Lumberton as a whole, and categorize each as fully recovered, partially recovered, still in survival or response mode, or will never recover. If they selected fully recovered, they were asked to specify the year recovery was reached. Following the questions about recovery at different scales, respondents were asked about their recovery in-place. These questions were carried over from Wave 3c and included asking whether the household had the same access to school, work, grocery stores, and other essential needs as they did before the hurricanes. To understand future household stability and place attachment, they were also asked if they intended to move in the next year.

For homes that were damaged during either hurricane, the residents were asked about funding they received, where it came from, and whether the funding was used for repairs or complete rebuilding. Many of the funding options in the survey were the same as used in previous surveys (e.g., FEMA individual assistance, personal insurance, Small Business Association (SBA) Loans, friends or family, nonprofit aid). However, the Wave 5 survey added assistance from the Rebuild North Carolina homeowner recovery program using Department of Housing and Urban Development (HUD) Community Development Block Grant for Disaster Recovery (CDBG-DR) grant funds.[2] This program was still open for applications at the time of Wave 5. The program offered different options to homeowners who were at or below 150 % of the Area Median Income (AMI) including buyouts of properties in flood zones and elevation of existing or new structures.

Survey participants were again asked if their household was displaced from the home during either Matthew or Florence, how many different places they lived before returning, and the month and year they moved back into a permanent home. Unlike surveys conducted in previous waves that closer in time to the hurricanes, this survey did not ask about the nature of the damage sustained, the loss of specific utilities, or the reasons why the households were displaced.

2.3.3. Household Perceived Preparedness Following Hurricanes Matthew and Florence

The next survey section asked a few questions to understand the household's perceived preparedness following Hurricanes Matthew and Florence. Similar to previous waves, households were first categorized as owners or renters, and owners were then asked if they had flood insurance, homeowner's insurance, or a mortgage. In addition, the Wave 5 survey introduced questions asking survey participants if they believed that they had adequate insurance coverage for a flood event, how many major floods or hurricanes they have experienced first-hand in their lifetime, how likely they thought their home is to be damaged during a major flood event in the future, and how likely they were to evacuate their home during a future major flood if given evacuation orders.

[2] https://www.rebuild.nc.gov/homeowners-and-landlords/homeowner-recovery-program

2.3.4. Preparedness, Mitigation, and Social Capital

This section of the survey aimed to collect data on preparedness and mitigation actions taken by households. As with Wave 3c, respondents were asked whether they had elevated their hot water heater and/or heating/ventilation/air conditioning (HVAC) units, re-routed ductwork from below the floor to attic space, and developed an emergency plan with household members. In addition, this wave's survey added additional preparedness items including: whether they had gathered supplies to last three or more days, sought information on mitigation or preparedness, and set money aside for recovery or repairs. For any action that had not been completed, the survey participant was asked if they planned to complete the action in the next six months.

Two new questions aimed to understand the household's ability to provide utility services themselves in the event of an outage and how various utility outages or disruptions are perceived to impact their ability to stay in the home. For the first question, the respondent was asked if they had any of the following alternative sources for utility services: power generator, gas tanks, solar panels, community wi-fi, community information hub, and water storage tanks. Then they were asked for the number of days they could stay in their home without each of the following: electricity, water, wastewater, natural gas, internet, or phone/cell phone service.

The participants were asked whether their involvement with neighborhood and/or community groups, as well as with neighbors and extended family had changed. These questions were also asked in Wave 3c and are used as proxies to understand changes in social capital.

2.3.5. Household Impacts from COVID-19

In addition to Hurricanes Matthew and Florence, the COVID-19 pandemic was another disaster that impacted households in Lumberton. Therefore, Wave 5 included questions from Wave 4a to understand whether COVID-19 had any impact on recovery from the impact of flood events and how the pandemic itself affected households. Respondents were first asked if COVID-19 impacted their hurricane repairs or the household's recovery from the hurricanes. Then they were asked if any household members had their jobs affected by COVID-19, how those jobs were affected (e.g., closure, reduced status, childcare issues, health issues, etc.), how long their work was affected, and if there was a change in the household's income due to COVID-19.

2.3.6. Household Socio-demographic Characteristics

Most of the questions on household socio-demographic characteristics have been duplicated in household surveys since Wave 2. These include questions that obtain information to categorize the highest education level of any member in the household, racial makeup, ethnicity, and combined household annual income. This survey also asked if there were any individuals with special electricity-dependent medical needs and if the household considered itself a female-headed household. As in previous surveys, these types of questions serve to document whether the sample matches the distribution of socio-demographics indicated in Census estimates. The information is also used to examine disparities in dislocation, relocation, repair, and recovery processes due to household socio-demographics, as is expected due to social vulnerability theory and findings from previous waves.

2.4. Data Collection Methods

The household surveys were conducted face-to-face. Two interviewers were assigned to each household. An information sheet about the field study and Center project were handed to households upon answering the door; a consent script was used to obtain verbal consent prior to surveying (see Appendices B and C for the consent script and information sheet). If the household was busy, surveys and consent forms were dropped off and the research team returned later to pick the completed surveys up. The surveys took place during June 18- 26, 2022, including both weekends. In addition to required institutional human subjects training, all surveyors received team training on ethics, survey use, field coordination, and best practices for in-field safety prior to entering the field. Additional guidance and training when in the field was also provided. The following subsections provide a detailed description of training, daily operations, and data management.

2.4.1. Daily Operations

2.4.1.1. Daily Process

Following protocols established in Waves 1, 2, and 3, each morning, the team convened to review logistics for the day, including arranging survey pairs and vehicles, assigning geographic clusters for each survey pair, creating a check-in schedule, retrieving packets of data collection materials (e.g., surveys, interview guides, personal protective gear), and preparing for data collection. As needed, training sessions were folded into this schedule to accommodate new team member arrivals or shifts in team composition. Survey preparation included review of the survey instrument, review of how the sample was clustered into smaller areas for team assignments, preparation of packets for each sample cluster, and clarification of issues with survey questions, answer options, data recording in the field, and data entry. Teams entered the field around 10 AM for household surveys and returned from the field between 7 and 8 PM, including a mid-day lunch break to regroup. Summer's longer daylight allowed for surveying later into the evening.

Although resources (e.g., staff, time, and funds) were limiting factors in data collection, several actions were taken to improve the outcomes of the field study. To ensure a higher response rate to the household survey, the team:

- Trained surveyors for maximum efficiency in the field;
- Concentrated surveying on afternoons, evenings and weekends;
- Arranged scheduled follow-up times for households not available for surveying during initial visit (if willing to participate);
- Provided paper surveys for residents to complete and leave for pick up; and
- Adjusted the field work plan and team composition based upon daily evaluation of results.

Each day, the geographic assignments of teams were prioritized based on several pieces of information. This first aim was to visit all sampled units (n=567). Unfortunately, three sample units were not visited: they were accidentally skipped during data collection as team members transitioned out of the field and teams were reshuffled. Thus, 564 housing units were visited at

least once during Wave 5. Next, priority was given to housing units that had participated in two previous waves or were still classified as damaged in Wave 3a. As data collection progressed throughout the field visit, neighborhoods with smaller response rates to this current Wave were prioritized for second visits to ensure completed survey responses were captured from across the geographic sample area. Finally, areas with greater damage from the hurricanes were also prioritized for second visits compared to areas that had limited damage or were fully recovered prior to Wave 3a.

2.4.1.2. Times of Day

Emphasis was placed on concentrating survey or capacity on days and times when response rates were expected to be highest. Weekend days, weekday afternoons and weekday early evenings were the focus of the effort. Early mornings (before 10 am), and Sunday mornings (before noon) were avoided. Teams completed their surveys before dusk for safety considerations and out of respect to household private responsibilities and activities.

2.4.1.3. Team Composition

Representation of multiple disciplines was a primary focus of Wave 1 team composition. In Wave 2, the focus was on experience with surveying, knowledge of the area, and gender composition of teams. A similar experience-based approach was used in Wave 5. Other team composition factors were driven by an awareness of the importance of safety and matching best practices for field research in any location. Teams of two would travel in a single vehicle and work through assigned clusters together. A vehicle would be moved when the team would complete a small geographic area (e.g., half of a block). The rule of thumb was to keep the vehicle where the surveyors could still see it and easily access it. Team composition was maintained as much as possible, and team assignment to cluster areas was maintained as the team became aware of the neighborhood and could return to housing units as needed to pick-up surveys. Gender diversity within teams was prioritized when possible. Housing units that required a Spanish speaker were noted by team members and then revisited on the last day of fieldwork by native Spanish speaker and Wave 5 co-lead, Leonardo Duenas-Osorio.

2.4.2. Data Management

Data management was different in Wave 5 than in previous waves with the goal to reduce data entry time and increase data accuracy. The two-person survey teams used both paper and electronic versions of the survey available through the ESRI application Survey123 on their smartphones, whereas previous waves either used only paper surveys or only electronic surveys (see Appendix D). The paper and electronic surveys were identical. The team member who would conduct the interview with the respondent carried all paper survey materials on clip boards including the survey instrument, answer cards for select items (e.g., see Appendix A), and project information sheets (see Appendix C). Surveyor guidance was included on the survey form to support the proper elicitation and recording of responses when in the field. During the surveying process, the second team member used their smartphone and recorded the responses into the online version of the survey as the first team member recorded the answers onto the paper survey. Additional notes and review of the survey responses was completed between the

two surveyors after the survey was completed, but before beginning the next survey. Survey team members also discussed and verified answers with one another before moving to the next unit in the sample to verify that the data was accurate. This data collection method produced both a virtual copy of the responses stored in Survey123 and a paper copy of the survey with hand-written responses, which was important to the data cleaning process detailed below.

2.4.2.1. Data Cleaning

A number of steps were completed each day in order to ensure that all data were managed appropriately and in accordance with IRB protocol [CSU protocol # 1924]. Following day 1, team co-lead Michelle Meyer began each day with quality checks of the surveyors' work from the previous day. She selected 10 % of the sample units visited by each two-person team, regardless of response. Michelle Meyer, Shane Crawford, and other members of the social science team then cross-checked what was recorded on the paper surveys with the data entered into the Survey123 online database. Any discrepancies were returned to the two-person team for review and correction. Michelle Meyer or Shane Crawford then corrected data live in the online version, as needed, and documented any agreed upon changes on the paper version of a given survey. If a survey team had made a mistake in data entry within the 10 % sample, all their surveys from the previous day were reviewed for data entry accuracy. For example, a team that visited 20 houses the previous day had two of those surveys randomly selected for data entry review. If there was a mistake on any question between the paper and online version, the entire set of 20 surveys was reviewed. These quality checks took approximately two to three hours each morning for a team of three to five reviewers.

When cleaning the data, sampling weights were applied to each survey to account for the sampling strategy employed. As discussed above, a two-stage non-proportional random cluster sampling strategy was designed to capture a scientifically valid representative sample of the target area and areas inundated by flooding as well as areas not directly impacted by the flooding. Within this design the penultimate sampling units were Census Blocks and the primary sampling units were housing units and households residing in those units. The penultimate sampling units (Census Blocks) were selected utilizing a probability proportion to size (PPS) random sampling procedure, with blocks within a high probability of flooding selected 3 to 1 over areas with a low probability of flooding. In other words, the Census Blocks were divided into two groups by high and low probability of flooding and non-proportional random samples were drawn from each area. Housing units within randomly drawn blocks were then selected on a fixed rate of 10 random units per Census Block. The combination of PPS and fix rate random sampling ensured an overall representative sample after weighting. Completed surveys received a weight of 1 if in areas of high probability of flooding and a weight of 3 for areas with a low probability of flooding. This value provides an appropriate frequency weight (i.e., how many observations the sampled observation theoretically stands for in the target population, either 1 or 3) that should be assigned to an observation when the desire is to obtain statistics representative of the full target area in the analyses. It is vital to address sampling weights to get the descriptive statistics correct for the target areas. If the sampling groups and weights were ignored, biased results would be produced when making inferences to the target population, given the non-proportionate sampling strategy utilized. On the other hand, it is not necessary to weight, for example, when just discussing the characteristics of housing within areas with high probability of flooding.

2.4.2.2. Data Storage and Access

All paper copies of the survey data are stored in a locked storage closet at Texas A&M University and all electronic media is saved in locked offices on the password protected computers of the research team. A linked list has been created where all identifiable information was replaced with code numbers. No names are attached to this documentation.

Original data access is limited to project investigators who have completed the IRB training and whose universities have signed the IAA or have separately approved IRB protocols for the field study. The data will be maintained for a three-year archive period following the conclusion of the study and will be shared with NIST.

2.5. Household Survey Results

As discussed in Section 2.3 above, the household survey was designed to gather representative information on recovery from the hurricanes, COVID-19 impacts, mitigation and preparedness for future events, and demographic questions. This section presents descriptive results with respect to these data.

2.5.1. Survey Response Rates

Table 2-1. Household survey response rates.

Survey Result Completion Code	Occupancy Status Yes				Occupancy Status No				Tot.
	1. Yes: present, interview attempt	2. Yes: not present, occupied	3. Yes: not present, evidence of habitation	4. Yes: not present, occupied confirmed by management	5. No: not occupied, under repair	6. No: not occupied, appears abandoned	7. No: damage and not habitable	8. Don't know	Tot.
1. Completed interview	151								151
2. Ineligible, no eligible person to answer questions	35		11	1	5			5	58
3. Bad address, could not locate								6	6
4. Incomplete / partial	5		1						6
5. Not occupied residence, abandoned; destroyed		0	1		7	94	43	1	146
7. No answer, but evidence or confirmed occupied	29	12	115	3		1		9	169

	1. Yes: present, interview attempt	2. Yes: not present, occupied	3. Yes: not present, evidence of habitation	4. Yes: not present, occupied confirmed by management	5. No: not occupied, under repair	6. No: not occupied, appears abandoned	7. No: damage and not habitable	8. Don't know	Tot.
8. No access (gated, fenced, etc.)			9	2					11
9. Dropped off survey	11	2	4						17
Missing data									4
Total	231	16	141	6	12	94	43	21	568

Response rates were similar to previous waves. There were 568 housing units in the original sample. One of those was a hard refusal in Wave 1, leaving 567 in the sample. During the Wave 5 fieldwork, three housing units were accidentally missed by the survey teams and were not visited. These four sample units are marked as missing in Table 2-1. In Wave 5, 151 households completed the survey for a response rate of 26.7 %. An additional 169 houses showed evidence of or were confirmed to be occupied (30 %).

These 151 completed survey responses result in 217 weighted observations. The following results, including statistics, figures, and tables, are weighted. As discussed in Section 2.2, a two-stage non-proportional stratified cluster sampling strategy was employed, so weighting is used to adjust to this sampling strategy. If the sampling groups and associated weights are ignored, the results would be biased when making inferences to the target population, as discussed in Section 2.4.1.2. As such, any analysis needs to weigh observations accordingly.

2.5.2. Findings: State of repair and recovery following Hurricanes Matthew and Florence

2.5.2.1. Damage

The survey asked households if the home they lived in was damaged by Hurricanes Matthew in 2016 or Florence in 2018 (Table 2-2). As shown in Figure 2-2, 38 % of respondents indicated that their house was damaged by both Matthew and Florence, while 18 % reported damage from Matthew only and 5 % from Florence only. For the 7 % of respondents reporting that they do not know whether the housing unit sustained damage from either hurricane, most of these (specifically 14 of 16) moved into the home after Hurricane Florence's landfall date of September 14, 2018.

Several respondents reported damage from either Hurricane Matthew or Florence even though they personally moved into the housing unit after those events. These respondents may be reporting on their previous home (which was not in the study sample) or what they knew about the current house based on information from the previous resident or others. For accuracy in reporting, Figure 2-3 reports damage from only those respondents who reported moving into the housing unit before Hurricane Matthew. Of these, 40 % reported damage from both hurricanes, 23 % reported damage from Matthew only, and 5 % reported damage from Florence only. Table 2-2 compares damage by move-in date in reference to the two hurricanes. For respondents

moving in between Hurricane Matthew and Florence, one reported that damage was sustained from Hurricane Matthew only and four reported damage sustained from both Hurricane Matthew and Florence. For respondents moving in after Florence, five reported that damage was sustained from Hurricane Matthew only, four from Hurricane Florence only, and 20 from both.

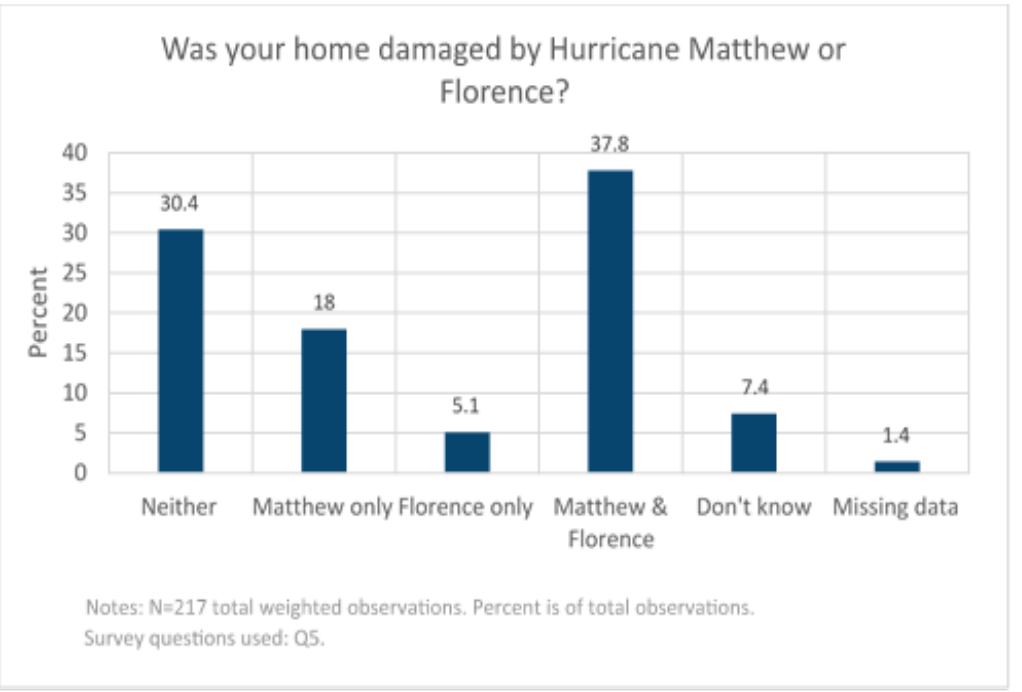

Figure 2-2. Reported housing unit damage from Hurricanes Matthew and Florence, all respondents.

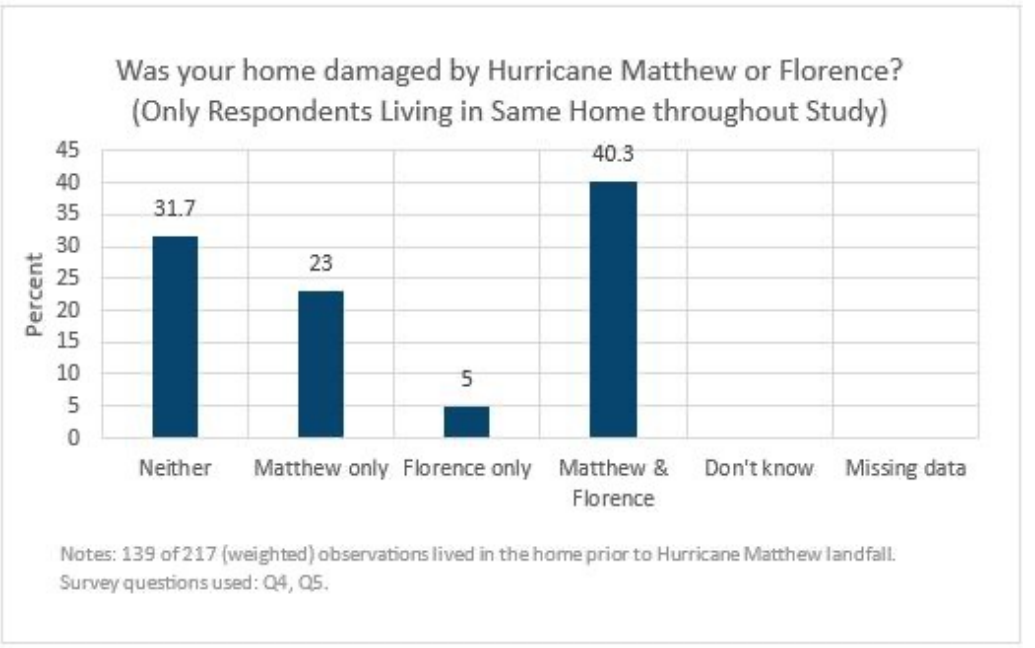

Figure 2-3. Reported housing unit damage from Hurricanes Matthew and Florence for households only those living in the same housing unit prior to Matthew.

Table 2-2. Reported housing unit damage from Hurricane Matthew or Florence by move-in date.

Damage	Move-in Date				
	Before Matthew	Between Matthew & Florence	After Florence	Missing data	Total
Neither	44	11	10	1	66
Hurricane Matthew, only	32	1	5	1	39
Hurricane Florence, only	7		4		11
Both	56	4	20	2	82
Don't know		1	14	1	16
Missing data			1	2	3
Total	139	17	54	7	217

Notes: N=217 total weighted observations. Hurricane Matthew made landfall on October 7, 2016, and Florence on September 14, 2018. Survey questions used: Q4, Q5

2.5.2.2. Dislocation

Residents were asked to recall their dislocation during the hurricanes and to estimate when they returned to permanent housing. Table 2-3 provides these results in total and compared by housing type (i.e., single family home, multi-family unit, mobile home, other) and housing tenure (i.e., own, rent, other). Out of 217 weighted respondents, 103 reported to not have been displaced, 106 were displaced, four do not know if they were displaced, and four have missing values. These numbers are slightly higher for owners (50 % displaced) than renters (46 %). Across all respondents, 49 % reported they were displaced during at least one of the hurricanes. Those living in mobile homes were most likely to report displacement (66 %), but the response rate was small and should be used with caution (n=3). There is an inverse relationship for housing tenure when assessing housing tenure by housing type. Renters of single-family homes reported displacement more frequently than owners of single-family houses but were less likely to report displacement if they were renting within a multifamily unit.

Table 2-3. Household dislocation by housing type and housing tenure following Hurricanes Matthew and Florence.

Building type by tenure	Yes, displaced	No, not displaced	Don't know	Missing data	Total
All building types	106 (48.8 %)	103 (47.5 %)	4 (1.8 %)	4 (1.8 %)	217
Own	76 (50.3 %)	68 (45.0 %)	4 (2.6 %)	3 (2.0 %)	151
Rent	29 (46.0 %)	34 (54.0 %)	0	0	63
Other	1 (50.0 %)	1 (50.0 %)	0	0	2
Missing data				1 (100%)	1
Single family	91 (49.7 %)	85 (46.4 %)	4 (2.2 %)	3 (1.6 %)	183
Own	71 (48.6 %)	68 (46.6%)	4 (2.7 %)	3 (2.1 %)	146
Rent	20 (55.6 %)	16 (44.4 %)			36
Other		1 (100 %)			1
Missing data					
Multifamily	13 (46.4 %)	14 (50.0 %)		1	28
Own	3 (100 %)				3
Rent	9 (39.1 %)	14 (60.9 %)			23
Other	1 (100 %)				1
Missing data				1 (100 %)	1
Mobile home	2 (66.7 %)	1 (33.3 %)			3
Own	2 (100 %)				2
Rent		1 (100 %)			1
Other					
Missing data					
Other building type		3 (100 %)			3
Own					
Rent		3 (100 %)			3
Other					
Missing data					

Notes: N=217 total weighted observations. Survey questions used: Q9, Q12

Out of the 106 displaced households, all had moved into permanent residency (see Figure 2-4), as would be expected with the data collection strategy (in-person surveys at residences). Considering only those respondents who reported they were displaced, 33 % were back in permanent housing in 2016 following displacement from Matthew, with an additional 19 % back in 2017. Twenty-four percent reported returning to permanent housing in 2018, and an additional 13 % in 2019. Respondents were not asked to specify displacement or return separately for each hurricane. Return to permanent housing shows the common pattern for disaster displacement, with most residents returning within 1-2 years post-disaster, but a long tail of slow return for a small portion of the population. For those displaced, 55 % reported living in only one place while displaced, 30 % reported living in two places, 11 % reported living in three places, and 5 % reported having lived in four or five places while displaced.

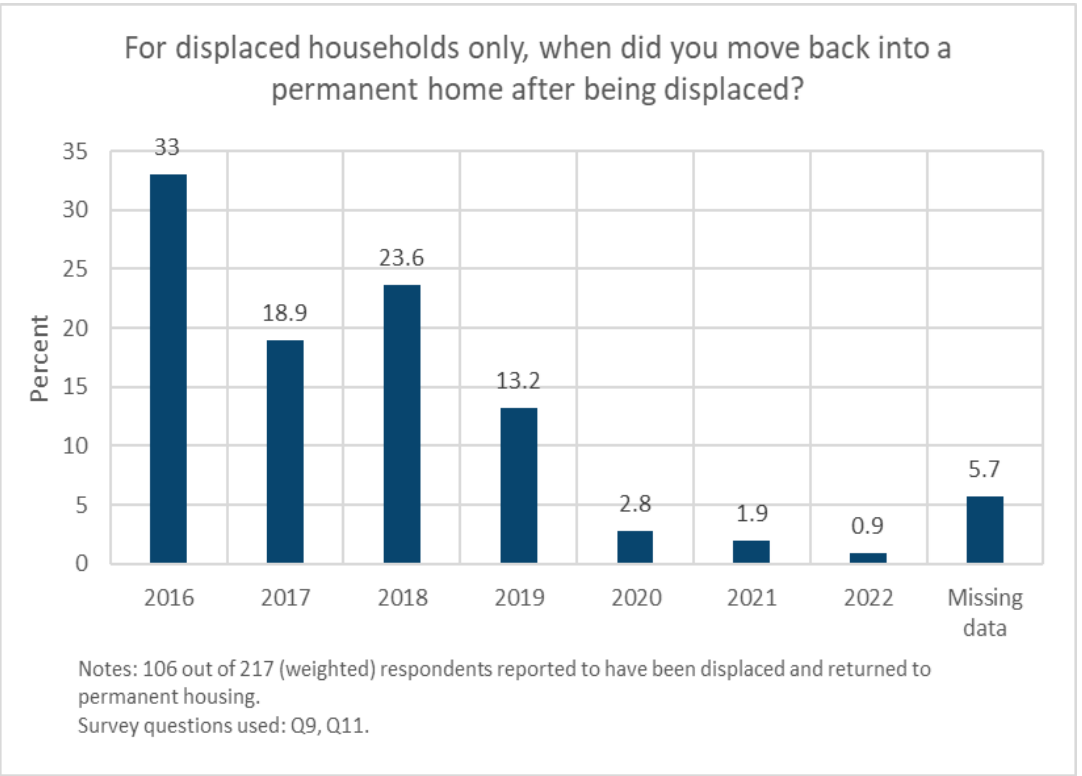

Figure 2-4. Dislocation time after Hurricane Matthew and/or Florence.

Despite the positive results of this question, the cross-sectional data should be interpreted with some caution. For this study the unit of observation is the housing unit, not the household itself. Households living in the housing unit at the time of the survey would presumably identify as having moved into permanent residency after being displaced. If households were the surveyed units of observation, it might be found that some did not yet feel they were in a permanent residency status. More obviously, there are only responses for occupied housing units. Households who lived in now abandoned or under repair units and have not returned were not surveyed. Those households may still be in temporary status (i.e., waiting for repairs to be completed to the surveyed unit) or may have found different permanent housing elsewhere. Since the survey does not track households, the results cannot be used to determine how many of the people who lived in these housing units prior to the hurricanes have found permanent housing following the events. Responses to this question will be most useful for later longitudinal analysis across waves.

2.5.2.3. Housing Recovery Progress

For respondents who reported damage from one or both hurricanes, the survey assessed recovery status by asking respondents whether the repairs were complete (Table 2-4). House repair was complete for 58 % of respondents who reported damage. Repair was more likely to be completed for those who had damage from only one hurricane (64 % of those damaged by Matthew only or by Florence only) compared to those who reported damage from both hurricanes (53 %).

Table 2-4. Reported recovery progress by hurricane that caused the damage.

Damage from Hurricanes Matthew or Florence	Repairs complete (%)	Repairs not complete (%)	Don't know (%)	Missing data (%)	Total
Hurricane Matthew, only	25 (64.1 %)	4 (10.3 %)	7 (18 %)	3 (7.7 %)	39
Hurricane Florence, only	7 (63.6 %)	4 (36.4 %)	0 (0 %)	0 (0 %)	11
Hurricane Matthew and Florence	44 (53.7 %)	25 (30.5 %)	12 (14.6 %)	1 (1.2 %)	82
Total	76 (57.6 %)	33 (25 %)	19 (14.4 %)	4 (3.0 %)	132

Notes: 132 out of 217 weighted respondents reported to have damage from Hurricane Matthew and/or Hurricane Florence. Survey questions used: Q5, Q6.

Beyond housing repair, adequate access to essential needs such as grocery stores, school, and work are important aspects of disaster recovery. Changed access to these places will affect both the household and the business or institution. Table 2-5 shows change in access by reported hurricane damage. The majority of respondents did not report change in access (74 %). None of those who reported damage from only Hurricane Florence indicated that their access to essential needs changed (0 %). Otherwise, 20-25 % of those with and without damage from Matthew or from both hurricanes reported change in access. During fieldwork, several respondents commented that a Walmart in the southern part of the city closed permanently affecting their access to groceries. According to the news media, this store closed in 2020 due to financial reasons (Brown 2023).

Table 2-5. Change in household access to essential needs after Hurricanes Matthew and Florence.

Damage from Hurricanes Matthew or Florence	Yes: Same access to essential needs	No: Not same access to essential needs	Don't know	Missing data	Total
Neither	53 (80.3 %)	8 (12.1 %)	4 (6.1 %)	1 (1.5 %)	66
Hurricane Matthew, only	29 (74.4 %)	10 (25.6 %)	0 (0 %)	0 (0 %)	39
Hurricane Florence, only	11 (100 %)	0 (0 %)	0 (0 %)	0 (0 %)	11
Hurricane Matthew and Florence	59 (72.0 %)	20 (24.4 %)	2 (2.4 %)	1 (1.2 %)	82
Don't know	8 (6.3 %)	1 (6.3 %)	3 (18.8 %)	4 (25 %)	16
Missing data	0 (0 %)	0 (0 %)	0 (0 %)	3 (100 %)	3
Total	160 (73.7 %)	39 (18.0 %)	9 (4.1 %)	9 (4.1 %)	217

Notes: N=217 weighted responses. Survey questions used: Q5, Q24.

Access to and connection with community organizations and with family and friends also affect disaster recovery. Often called “social capital” these networks are important to both individual and community functioning (Coleman 1988). The survey asked respondents if their involvement with either neighborhood or community groups or with neighbors or extended family changed since the hurricanes (Table 2-6). The majority of respondents indicated that these social connections were about the same as before the hurricanes (61 % for each question). Less than 19 % reported decreased involvement or contact with others. Less than 15 % indicated increased involvement or contact since the hurricanes. It is important to note that COVID-19 has a confounding impact on responses to these questions. Based on informal discussions with

respondents during the survey process, many respondents mentioned the COVID-19 pandemic as the reason for less involvement and connection. Thus, it is unclear if these changes are due to the hurricanes, COVID-19, or both.

Table 2-6. Change in community involvement and contact with neighbors and extended family after Hurricanes Matthew and Florence.

Social Capital Change	Increased	Same	Decreased	Don't know	Missing data	Total
Change in neighborhood/ community group participation	26 (12 %)	133 (61.3 %)	41 (18.9 %)	8 (3.7 %)	9 (4.1 %)	217
Change in neighbor/ extended family contact	32 (14.7 %)	132 (60.8 %)	37 (17.1 %)	7 (3.2 %)	9 (4.1 %)	217

Notes: N=217 weighted responses. Survey questions used: Q26, Q27.

Recovery Resources and Unmet Needs

Respondents were asked to indicate if they received funding for hurricane repairs, and if so, were asked details about the person(s) or organizations that provided the assistance. The majority of all respondents with damages reported receiving funding for repairs (62 %). Table 2-7 breaks down funding by hurricane. Twenty-seven percent of those damaged by Florence only reported receiving no funding, while 18 % of those with only Matthew damage and 15 % of those with damage from both hurricanes received no funding.

Table 2-7. Recovery funding received from any source.

Damage from Hurricanes Matthew or Florence	Yes	No	Don't know	Missing data	Total
Hurricane Matthew, only	21 (53.8 %)	7 (17.9 %)	3 (7.7 %)	8 (20.5 %)	39
Hurricane Florence, only	7 (63. 6 %)	3 (27.3 %)	0 (0 %)	1 (9.1 %)	11
Hurricane Matthew and Florence	54 (65.9 %)	12 (14.6 %)	11 (13.4 %)	5 (6.1 %)	82
Total	82 (62. 1%)	22 (16.7 %)	14 (10.6 %)	14 (10.6 %)	132

Notes: 132 out of 217 (weighted) respondents reported to have damage from Hurricane Matthew and/or Florence. Survey questions used: Q5, Q7.

Looking only at those that received funding, respondents could select multiple sources of funding including FEMA, the Small Business Administration (SBA), insurance, nonprofits, family or friends, and the Rebuild North Carolina program. Rebuild North Carolina is the state-run program funded by a HUD CDBG-DR grant. This program supported recovery for both hurricanes, with $ 492.2 million committed to all projects, including direct support to property owners to repair their homes or be bought out (Rebuild NC 2023).[3]

[3] The Hurricane Matthew Rebuild NC program began in late 2018, and the Hurricane Florence Rebuild NC program began in 2020. This funding included three programs that affect our respondents. The Homeowner Recovery Program offered repair, complete reconstruction, and elevation for eligible homeowners (i.e., for damages to primary residences of households at or below 150% the Area Median Income). All property owners (homeowners and landlords) in selected areas determined by HUD and the State of North Carolina could also be eligible for a

FEMA funding was the most common funding source reported by respondents (Table 2-8). The majority of respondents indicated that they received FEMA funding (65 % of all those who received funding), with all those damaged by Florence reporting FEMA support. The least commonly reported funding source was SBA (6 %). Insurance was used by 50 % of respondents damaged by both hurricanes, only 33 % of those damaged by Matthew only, and 0 % of those damaged by Florence only (likely due to the small response size for this subgroup). Twenty-three percent of those damaged reported receiving support from nonprofit organizations. Nine percent received funding from friends or family. Funding from the Rebuild NC Program was reported by just 5 % of those damaged from Matthew and 9 % of those damaged by both hurricanes. Respondents reporting funding from Rebuild North Carolina were likely part of the Homeowner Recovery Program. Those who accepted a buy-out themselves or who were in rental property in which the owner accepted a buy-out would not be included in the survey because those housing units would now be vacant or already demolished. During fieldwork, team members noted that some respondents reported that they had applied to Rebuild NC but were either denied or still waiting for a decision. This wave did not systematically capture those details and future research should include more detailed questions about this program.

Table 2-8. Source of recovery funding received.

Damage from Hurricanes Matthew or Florence	Any funding received	FEMA	SBA	Insurance	Nonprofit or NGO	Friends/ family	Rebuild NC (CDBG-DR)
Hurricane Matthew, only	21	13 (61.9 %)	1 (4.8 %)	7 (33.3 %)	3 (14.3 %)	1 (4.8 %)	1 (4.8 %)
Hurricane Florence, only	7	7 (100 %)	0 (0 %)	0 (0 %)	0 (0 %)	1 (14.3 %)	0 (0 %)
Hurricane Matthew and Florence	54	33 (61.1 %)	4 (7.4 %)	27 (50.0 %)	16 (29.6 %)	5 (9.3 %)	5 (9.3 %)
Total	82	53 (64.6 %)	5 (6.1 %)	34 (41.5 %)	19 (23.2 %)	7 (8.5 %)	6 (7.3 %)

Notes: 82 out of 217 weighted respondents reported damage from Hurricane Matthew and/ or Florence and that they received funding for recovery. Percentages will not sum to 100 % across because multiple sources of funding could be obtained by each household. Survey questions used: Q5, Q7.

Finally, respondents were asked about their general perceptions of recovery for their homes (i.e., the physical structure), their household (i.e., the people in their household), their neighborhood, and Lumberton as a whole. Responses included: Fully Recovered, Partially Recovered, Still in Survival Mode, Not Applicable for those houses and neighborhoods not damaged, or missing (which was recorded for those who didn't know or refused this question). Figure 2-5 shows the variation in responses across this set of questions.

property buy-out. The third program was the Public Housing Restoration Fund that provided for the repair and reconstruction of public housing.

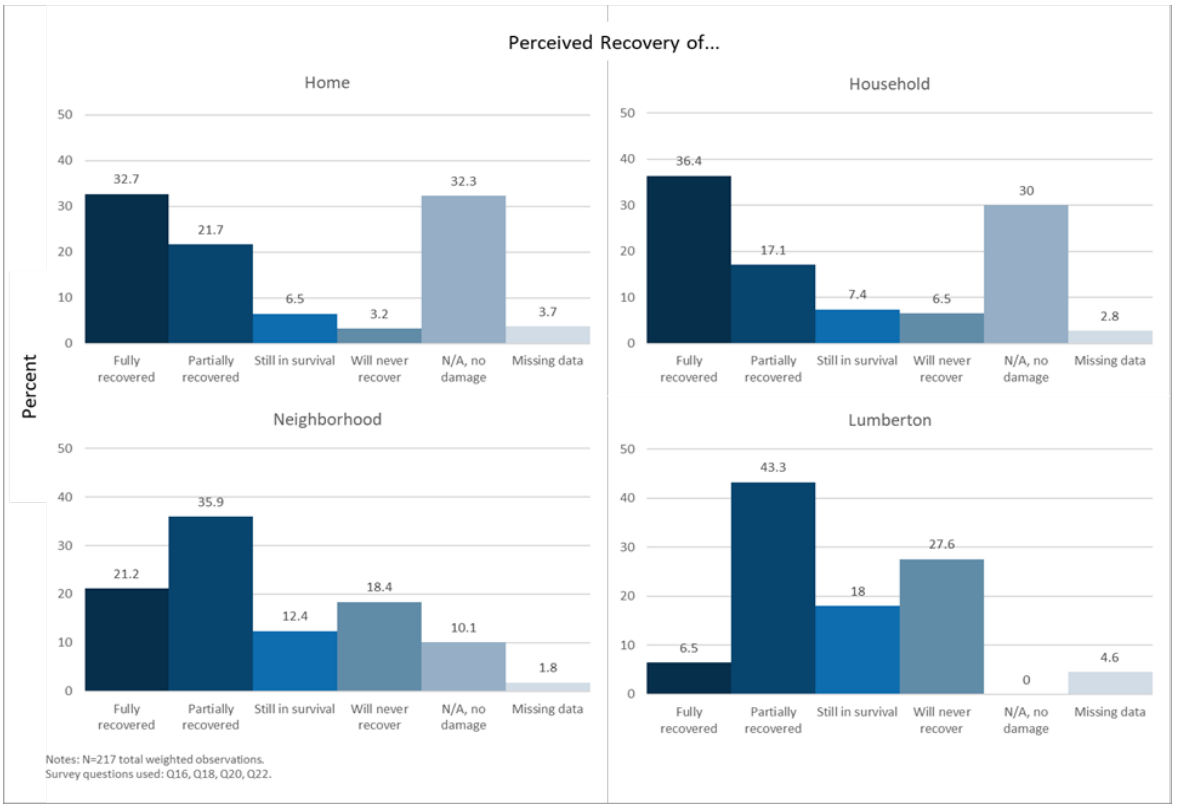

Figure 2-5. Perceived recovery of home, household, neighborhood, and Lumberton.

Respondents were more likely to say their household and homes were fully recovered (36 % and 33 % respectively) compared to Lumberton or their neighborhood. Only 3 % of respondents felt that their home (the physical structure) would never recover and 7 % felt that their household would never recover. These subjective measures of perceived recovery contrast the more objective measures reported above such as when the respondent returned to permanent housing or when repairs were completed, with fewer households perceiving their house structure or household as recovered compared to the reporting of repair completion or permanent housing attainment. Respondents were much less positive in their evaluation of their neighborhoods and Lumberton's overall recovery. Thirty-six percent of respondents perceived their neighborhood as partially recovered and over 18 % felt that it would never recover. Even more respondents, 28 %, felt that Lumberton would never recover, with 43 % reporting that it was partially recovered. Less than 7 % of respondents perceived Lumberton as fully recovered to pre-Hurricane Matthew conditions.

2.5.2.5. Impact of COVID-19 on Recovery

The impacts of COVID-19 and its associated economic repercussions on households, businesses, and the economy likely affected those who were recovering from damages due to natural hazards, like the residents of Lumberton. The protocols used to reduce the spread of COVID-19 were expected to have slowed the construction industry, for example. Supply chains for many products, including building materials, caused delays and higher costs, and labor shortages slowed contractor scheduling (Srivastava 2021). For households, their employment and income may have reduced their financial capacity to undertake repairs. Some households may have lost

family members or experienced long-term illness, again delaying repairs from the hurricanes. Finally, government and nonprofit programs slowed or changed their application procedures to incorporate social distancing and other health protocols, which may have reduced the aid received and timeliness of that aid for some affected by Hurricane Matthew and/or Hurricane Florence.

The survey asked residents the extent that the pandemic impacted their ability to complete repairs to their housing unit, to feel recovered, and their households' jobs or income. COVID-19 impact was measured as no impact, minor impact, moderate impact, or major impact on repairs to the house or on recovery of the household. The question about impact on repairs was only asked for those respondents who indicated that their repairs were not completed by 2020 (the start of the pandemic protocols in the U.S.). Only a third of respondents had not completed repairs as of the start of the pandemic (Figure 2-6). The results for these respondents were bifurcated (Figure 2-6). Half (n=36, 50 %) of those respondents reported "no impact" of COVID-19 on completing repairs from the hurricanes. A substantial minority of respondents said that COVID-19 had a "major impact" on completing repairs (n=17, 24 %).

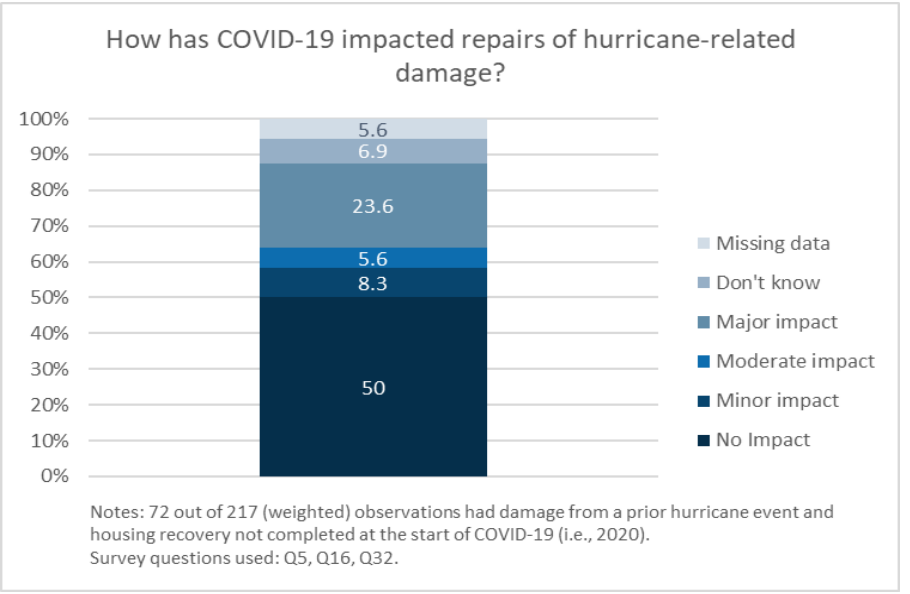

Figure 2-6. COVID-19's impact on hurricane-related housing recovery.

Figure 2-7 shows the reported impact of COVID-19 and its safety measures for household recovery for only those who reported that their household was not recovered by 2020 (the beginning of the pandemic impacts in the U.S.). Similar to housing repairs, a large portion (n=81, 56 %) of respondents indicated that COVID-19 had no impact on their household's recovery from the hurricanes. Ten percent (n=15) of respondents said that the pandemic had major impacts on their household's recovery from the hurricanes. Nearly 27 % (n=39/145) of respondents either didn't know (n=10) or did not answer (n=29) this question.

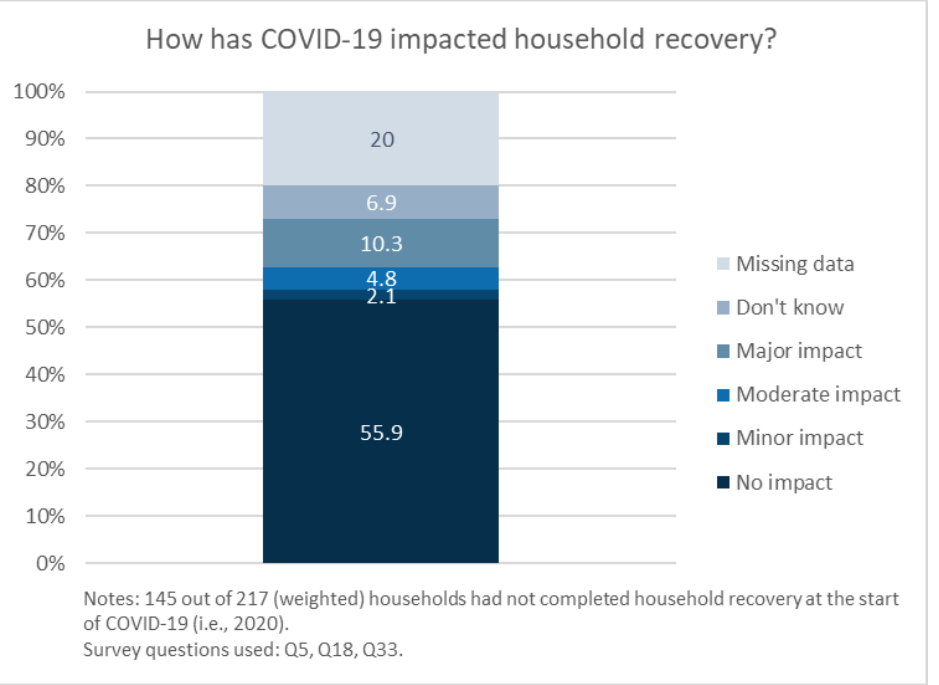

Figure 2-7. COVID-19's impact on hurricane-related household recovery.

Respondents described whether COVID-19 impacted their or household members' jobs and, if so, how the jobs were impacted (such as health issues, reduction to part-time, childcare issues, or temporary or permanent employer closure). About 37 % of respondents indicated that jobs were affected by the pandemic (Table 2-9). The most common reason was temporary closure of their employer (about 47 % of those whose jobs were affected), followed by health issues (22 % of those whose jobs were affected).

Table 2-9. COVID-19 related job impacts.

	Yes	No	Missing data	Total
COVID-19 impacted job?	81 (37.3 %)	132 (60.8 %)	4 (1.8 %)	217
If yes, how? Childcare issues	15 (18.5 %)	66 (81.5 %)	0 (0 %)	81
Health issues	19 (23. 5 %)	62 (76.5 %)	0 (0 %)	81
Reduction to part-time status	16 (19.8 %)	65 (80.2 %)	0 (0 %)	81
Permanent closure of place of employment	7 (8.6 %)	74 (91.4 %)	0 (0 %)	81
Temporary closure of place of employment	38 (46.9 %)	43 (53.1 %)	0 (0 %)	81
Other reasons	33 (40.7 %)	48 (59.3 %)	0 (0 %)	81

Notes: 81 out of 217 total weighted observations identify as having COVID-19-related job impacts. Survey questions used: Q34, Q35.

Survey respondents could specify other ways that COVID-19 affected household members' jobs. The raw responses were grouped into conceptually similar categories, as shown in Table 2-10. These *other* categories were not reintroduced into the survey and asked of all respondents; therefore, the frequencies shouldn't be interpreted as magnitude of occurrence. Rather these should be interpreted as other types of job-related impact that have occurred. Interestingly, *more*

work could be interpreted as a positive impact, albeit, in a challenging environment for the overall community. Still, additional negative impacts were captured related to employer decisions (termination, decreased physical contact, change in responsibilities, furlough), worker decisions (forced job change, quit job), and broader market conditions (supply-chain issues, reduced demand for services).

Table 2-10. COVID-19 related job impacts: other categories.

Other stated impacts	Number
More work	7
Termination	7
Decreased physical contact	6
Change in responsibilities	3
Furlough	3
Forced job change	3
Supply-chain issues	3
Quit job	2
Reduced demand for services	1

Notes: 33 of 217 weighted observations identify as having COVID-19-related job impacts and stated impacts not captured by the list of available responses on the survey instrument (e.g., "other"). Three weighted observations stated more than one impact; thus, the number does not sum to 33. Survey questions used: Q34, Q35.

To see how these employment impacts might have impeded hurricane-related repair progress, Table 2-11 shows responses for observations with damage from a hurricane event but not yet completed at the start of the pandemic. COVID-19's impact on hurricane repairs to the home are cross-tabulated with COVID-19's impact to any household member's job. The most common response for both households who had employment impacts due to COVID-19 and those that did not was "no impact" when asked how the pandemic affected their ability to complete hurricane repairs. Yet, those households with employment impacts were much more likely to say that COVID-19 had a "major impact" on their ability to complete hurricane repairs. This result shows the compounded impact of another disaster reducing recovery speed for households.

Table 2-11. Joint occurrence of COVID-19 related impacts on hurricane repairs and COVID-19 related impacts on a household member's job.

COVID-19 impact on hurricane repairs to home	Yes, COVID-19 impacted job	No, COVID-19 did not impact job	Total
No impact	12 (42.9 %)	24 (54.5 %)	36 (50 %)
Minor impact	2 (7.1 %)	4 (9.1 %)	6 (8.3 %)
Moderate impact	2 (7.1 %)	2 (4.5 %)	4 (5.6 %)
Major impact	10 (35.7 %)	7 (15.9 %)	17 (23.6 %)
Don't know	0 (0 %)	5 (11.4 %)	5 (6.9 %)
Missing data	2 (7.1 %)	2 (4.5 %)	4 (5.6 %)
Total	28 (100 %)	44 (100 %)	72 (100 %)

Notes: 72 out of 217 (weighted) observations had damage from a prior hurricane event and housing recovery was not completed at the start of COVID-19 (i.e., 2020). Survey questions used: Q5, Q16, Q32, Q34.

Similarly, when comparing the impact of COVID-19 on household recovery in general between those households that experienced employment impacts and those who did not, the most common response for both groups was “no impact” (Table 2-12). Again, those who had employment changes were much more likely to report “major impact” than those without employment impacts.

Table 2-12. Joint occurrence of COVID-19 related impacts on household recovery and COVID-19 related impacts on a household member's job.

COVID-19 impact on hurricane repairs to home	Yes, COVID-19 impacted job	No, COVID-19 did not impact job	Missing data	Total
No impact	20 (37.7 %)	58 (65.9 %)	3 (75.0 %)	81 (51.9 %)
Minor impact	1 (1.9 %)	2 (2.3 %)	0 (0 %)	3 (2.1 %)
Moderate impact	2 (3.8 %)	5 (5.7 %)	0 (0 %)	7 (4.8 %)
Major impact	12 (22.6 %)	3 (3.4 %)	0 (0 %)	15 (10.3 %)
Don't know	3 (5.7 %)	7 (8.0 %)	0 (0 %)	10 (6.9 %)
Missing data	15 (29.0 %)	13 (14.8 %)	1 (25.0 %)	29 (20.0 %)
Total	53 (100 %)	88 (100 %)	4 (100 %)	145 (100 %)

Notes: 145 out of 217 (weighted) households had not completed household recovery at the start of COVID-19 (i.e., 2020). Survey questions used: Q18, Q33, Q34.

2.5.2.6. Preparedness and Mitigation among Households

Owner-occupied households were asked about several mitigation and preparedness measures they had undertaken or planned to undertake in the next six months. These measures include having insurance (homeowners and flood), elevating hot water heaters, HVAC units, and/or ductwork, having an emergency plan and supplies for at least 3 days, seeking out additional mitigation or preparedness information, and setting aside money for future recovery needs. Respondents were also asked a few subjective questions about how adequate they felt their insurance coverage was, how likely a storm would damage their property, and how likely they would be to evacuate.

The results below are assessed by housing type and ownership status. Table 2-13 shows insurance coverage status by housing type (single-family, multi-family, and mobile home). Sample sizes are small for multi-family and mobile home residents, so these results should be interpreted with caution. A large majority (82 %) of those living in single-family homes reported having homeowners’ insurance. None of those living in multifamily housing had homeowners’ insurance, which is expected since most are renters, and only 50 % of those in mobile homes had homeowners’ insurance. Flood insurance is important coverage to address damages from floods or coastal storms since regular homeowners’ insurance does not cover flood damages. Houses with mortgages inside of 100-year floodplains are required to have flood insurance per federal law. Flood insurance was less common among respondents than homeowners’ insurance. Only 41 % of respondents in single-family homes reported having flood insurance. Again, no respondents in multifamily housing reported having flood insurance and only half of those living in mobile homes had flood insurance. Respondents did not feel that confident in the adequacy of their insurance coverage for future disasters. Only 42 % of those in single-family homes felt

adequately covered, 32 % said they were not adequately insured, and 21 % didn't know if they were or not. Again, no households in multifamily housing and half of those in mobile homes felt they were adequately insured.

Table 2-13. Insurance coverage for owner-occupied households.

Building type	Yes, homeowners' insurance	No homeowner's insurance	Don't know	Missing data	Total
Single-family	120 (82.2 %)	19 (13.0 %)	7 (4.8 %)	0 (0 %)	146
Multifamily	0 (0 %)	3 (100 %)	0 (0 %)	0 (0 %)	3
Mobile home	1 (50.0 %)	1 (50.0 %)	0 (0 %)	0 (0 %)	2
Total	121 (80.1 %)	23 (15.2 %)	7 (4.6 %)	0 (0 %)	151
Building type	**Yes, flood insurance**	**No flood insurance**	**Don't know**	**Missing data**	**Total**
Single-family	60 (41.1 %)	78 (53.4 %)	8 (5.5 %)	0 (0 %)	146
Multifamily	0 (0 %)	3 (100 %)	0 (0 %)	0 (0 %)	3
Mobile home	1 (50.0 %)	1 (50.0 %)	0 (0 %)	0 (0 %)	2
Total	61 (40.4 %)	82 (54.3 %)	8 (5.3 %)	0 (0 %)	151
Building type	**Yes, adequate insurance coverage for future**	**No, not adequate insurance for future**	**Don't know**	**Missing data**	**Total**
Single-family	62 (42.5 %)	46 (31.5 %)	31 (21.2 %)	7 (4.8 %)	146
Multifamily	0 (0 %)	3 (100 %)	0 (0 %)	0 (0 %)	3
Mobile home	1 (50.0 %)	1 (50.0 %)	0 (0 %)	0 (0 %)	2
Total	63 (41.7 %)	50 (33.1 %)	31 (20.5 %)	7 (4.6 %)	151

Notes: 151 out of 217 (weighted) observations are owner-occupied households. Survey questions used: building type, Q12.

Most respondents reported several experiences with flooding over their lifetimes. Only 3 % reported no flood experience and 9 % reported experiencing one flood. Forty-nine percent had experienced two floods in their lives, 14 % reported three floods, and 25 % reported experience with four or more floods. Respondents generally expected that their homes would flood (Figure 2-8). Twenty-four percent said it was "extremely likely" that their home would flood in a major disaster and an additional 26 % said it was "likely". Together, half of respondents felt their homes were likely or extremely likely to flood in a future major event like Hurricanes Matthew and Florence.

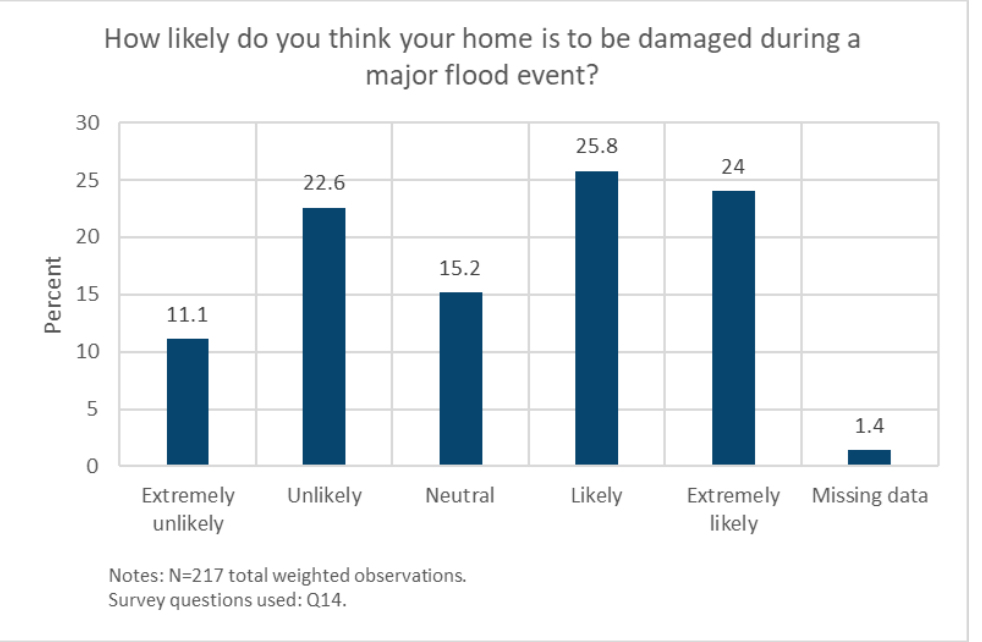

Figure 2-8. Likelihood of future flood damage.

Perceived flood likelihood is compared to perception of insurance coverage in Figure 2-9. Residents who perceived extreme likelihood of flooding in a future major disaster were less likely than others to think they had adequate insurance coverage. For example, only 33 % of these residents felt they had adequate insurance, whereas 59 % of those who thought flooding was extremely unlikely felt they were adequately insured.

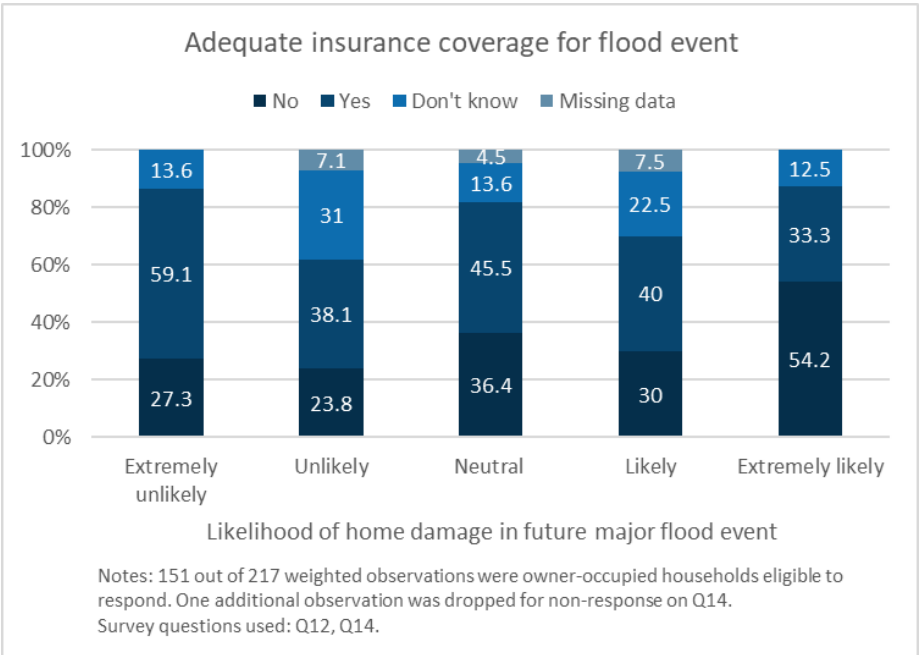

Figure 2-9. Perceived adequacy of insurance by expected likelihood of damage.

Respondents were also asked how likely they would be to evacuate during a major disaster and 52 % were extremely likely to evacuate and an additional 12 % were likely to evacuate (Figure 2-10). Approximately a quarter of respondents were unlikely or extremely unlikely to evacuate during a major event.

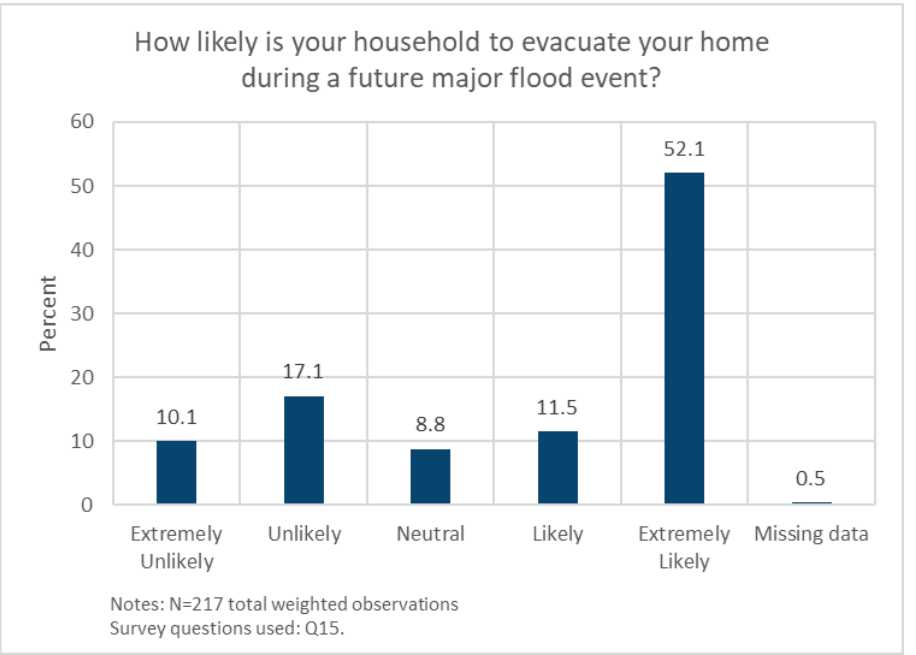

Figure 2-10. Likelihood to evacuate.

Respondents were asked about several mitigation and preparedness measures in the survey. Table 2-14 shows whether the respondents had already completed these measures while comparing respondents by housing tenure (i.e., owner, renter, or other). Table 2-15 shows whether the respondent plans to complete the measure in the next six months if they have not done so already.

Table 2-14. Mitigation and preparedness strategies currently taken.

Tenure	Yes, elevated hot water heater and/or HVAC	No	Don't know	Missing data	Total
Own	67 (44.4 %)	84 (55.6 %)	0 (0 %)	0 (0 %)	151
Rent	10 (15.9 %)	28 (44.4 %)	16 (25.4 %)	9 (14.3 %)	63
Other	0 (0 %)	1 (50 %)	0 (0 %)	1 (50 %)	2
Missing data	0 (0%)	0 (0%)	0 (0%)	1	1
Total	77 (35.5 %)	113 (52.1 %)	16 (7.4 %)	11 (5.1 %)	217
Tenure	**Yes, re-routed ductwork**	**No**	**Don't know**	**Missing data**	**Total**
Own	31 (20.5 %)	112 (74.2 %)	2 (1.3 %)	6 (4.0 %)	151
Rent	14 (22.2 %)	24 (38.1 %)	13 (20.6 %)	12 (19.0 %)	63
Other	0 (0 %)	2 (100 %)	0 (0 %)	0 (0 %)	2
Missing data	0 (0%)	0 (0%)	0 (0%)	1 (100 %)	1
Total	45 (20.7 %)	138 (63.6 %)	15 (6.9 %)	19 (8.8 %)	217
Tenure	**Yes, emergency plan developed**	**No**	**Don't know**	**Missing data**	**Total**
Own	70 (46.4 %)	78 (51.7 %)	3 (2.0 %)	0 (0 %)	151
Rent	35 (55.6 %)	25 (39.7 %)	3 (39.7 %)	0 (0%)	63
Other	0 (0 %)	2 (100 %)	0 (0 %)	0 (0 %)	2
Missing data	0 (0%)	0 (0%)	1 (100 %)	0 (0%)	1
Total	105 (48.4 %)	105 (48.4 %)	3 (1.4 %)	4 (1.8 %)	217
Tenure	**Yes, supplies to last 3+ days**	**No**	**Don't know**	**Missing data**	**Total**
Own	126 (83.4 %)	24 (15.9 %)	0 (0 %)	1 (0.7 %)	151
Rent	54 (85.7 %)	9 (14.3 %)	0 (0%)	0 (0%)	63
Other	2 (100 %)	0 (0 %)	0 (0 %)	0 (0 %)	2
Missing data	0 (0%)	1	0 (0%)	0 (0%)	1
Total	182 (83.9 %)	33 (15.2 %)	0 (0 %)	2 (0.9 %)	217
Tenure	**Yes, sought info on mitigation and preparedness**	**No**	**Don't know**	**Missing data**	**Total**
Own	63 (41.7 %)	87 (57.6 %)	0 (0 %)	1 (0.7 %)	151
Rent	19 (30.2 %)	38 (60.3 %)	3 (4.8 %)	3 (4.8 %)	63
Other	0 (0 %)	1 (50 %)	0 (0 %)	1 (50 %)	2
Missing data	0 (0%)	0 (0%)	0 (0%)	1 (100 %)	1
Total	82 (37.8 %)	126 (58.1 %)	3 (1.4 %)	6 (2.8 %)	217
Tenure	**Yes, money set aside for recovery/repairs**	**No**	**Don't know**	**Missing data**	**Total**
Own	88 (58.3 %)	61 (40.4 %)	1 (0.7 %)	1 (0.7 %)	151
Rent	22 (34.9 %)	41 (65.1 %)	0 (0%)	0 (0%)	63
Other	1 (50 %)	1 (50 %)	0 (0 %)	0 (0 %)	2
Missing data	0 (0%)	0 (0%)	0 (0%)	1 (100 %)	1
Total	111 (51.2 %)	103 (47.5 %)	1 (0.5 %)	2 (0.9 %)	217

Notes: N=217 weighted observations. Survey questions used: Q12, Q28.

Table 2-15. Mitigation and preparedness strategies planned to take in the next 6 months.

Tenure	Yes, elevated hot water heater and/or HVAC	No	Don't know	Missing data	Total
Own	6 (7.1 %)	71 (84.5 %)	7 (8.3 %)	0 (0 %)	84
Rent	0 (0 %)	15 (28.3 %)	22 (41.5 %)	16 (30.2 %)	53
Other	0 (0 %)	1 (50 %)	0 (0 %)	1 (50 %)	2
Missing data	0 (0 %)	0 (0 %)	0 (0 %)	1 (100 %)	1
Total	6 (4.3 %)	87 (62.1 %)	29 (20.7 %)	18 (12.9 %)	140
Tenure	**Yes, re-routed ductwork**	**No**	**Don't know**	**Missing data**	**Total**
Own	10 (8.3 %)	95 (79.2 %)	8 (6.7 %)	7 (5.8 %)	120
Rent	1 (2.0 %)	12 (24.5 %)	18 (36.7 %)	18 (36.7 %)	49
Other	0 (0 %)	1 (50 %)	0 (0 %)	1 (50 %)	2
Missing data	0 (0 %)	0 (0 %)	0 (0 %)	1 (100 %)	1
Total	11 (6.4 %)	108 (62.8 %)	26 (15.1 %)	27 (15.7 %)	172
Tenure	**Yes, emergency plan developed**	**No**	**Don't know**	**Missing data**	**Total**
Own	9 (11.1 %)	57 (70.4 %)	10 (12.3 %)	5 (6.2 %)	81
Rent	12 (42.9 %)	8 (28.6 %)	5 (17.9 %)	3 (10.7 %)	28
Other	1 (50 %)	1 (50 %)	0 (0 %)	0 (0 %)	2
Missing data	0 (0 %)	0 (0 %)	1 (100 %)	0 (0 %)	1
Total	22 (19.6 %)	66 (58.9 %)	15 (13.4 %)	9 (8.0 %)	112
Tenure	**Yes, supplies to last 3+ days**	**No**	**Don't know**	**Missing data**	**Total**
Own	9 (36.0 %)	12 (48.0 %)	3 (12.0 %)	1 (4.0 %)	25
Rent	5 (55.6 %)	4 (44.4 %)	0 (0 %)	0 (0 %)	9
Other	0 (0 %)	0 (0 %)	0 (0 %)	0 (0 %)	
Missing data	0 (0 %)	0 (0 %)	1 (100 %)	0 (0 %)	1
Total	14 (40.0 %)	16 (45.7 %)	3 (8.6 %)	2 (5.7 %)	35
Tenure	**Yes, sought info on mitigation and preparedness**	**No**	**Don't know**	**Missing data**	**Total**
Own	14 (15.9 %)	64 (72.7 %)	8 (9.1 %)	2 (2.3 %)	88
Rent	16 (36.4 %)	19 (43.2 %)	3 (6.8 %)	6 (13.6 %)	44
Other	1 (50 %)	0 (0 %)	0 (0 %)	1 (50 %)	2
Missing data	0 (0 %)	0 (0 %)	0 (0 %)	1 (100 %)	1
Total	31 (23.0 %)	83 (61.5 %)	11 (8.1 %)	10 (7.4 %)	135
Tenure	**Yes, money set aside for recovery/repairs**	**No**	**Don't know**	**Missing data**	**Total**
Own	8 (12.7 %)	50 (79.4 %)	3 (4.8 %)	2 (3.2 %)	63
Rent	16 (39.0 %)	25 (61.0 %)	0 (0 %)	0 (0 %)	41
Other	1 (100 %)	0 (0 %)	0 (0 %)	0 (0 %)	1
Missing data	0 (0 %)	0 (0 %)	0 (0 %)	1 (100 %)	1
Total	25 (23.6 %)	75 (70.8 %)	3 (2.8 %)	3 (2.8 %)	106

Notes: N=217 total weighted observations. Observations filtered out if mitigation action has already been taken. Survey questions used: Q12, Q28, Q29.

Across all items, having supplies to last three or more days was the most common mitigation or preparedness measure with 83 % of owners and 86 % of renters saying they had these. For homeowners, the next most common preparedness item already completed was to set aside money for repairs and recovery (58 %), followed by making an emergency plan (46 %), elevating the hot water heater or HVAC system (44 %), and seeking out information on mitigation and preparedness (42 %). The least common measure completed by homeowners was

rerouting ductwork (21 %). More renters than owners (56 % compared to 46 %) had prepared an emergency plan. Beyond having a plan, renters were less likely to have completed these mitigation or preparedness measures. Only 35 % had set aside money for recovery or repairs and 30 % had sought out information on mitigation or preparedness. Renters reported whether the place they lived had an elevated hot water heater or HVAC or rerouted ductwork, rather than if they themselves had done that. Only 16 % said their rental home had an elevated hot water heater or HVAC, while 25 % didn't know. Only 22 % noted that the ductwork was rerouted or in the ceiling already, while 21 % didn't know.

If respondents had not yet completed the mitigation or preparedness measure, they were asked whether they planned to do so in the next six months. Overall, few respondents planned to complete these measures in the next six months. For example, around 80 % of homeowners who had not elevated the hot water heater or HVAC, or rerouted ductwork did not plan to do so in the next six months. Similarly, a large majority of homeowners who had not sought out additional information or set aside money were not planning to do so in the near future. Renters were more likely than homeowners to say they planned to gather supplies (56 %), make an emergency plan (43 %), save money for recovery or repairs (39 %), and seek out mitigation or preparedness information (36 %).

To delve into mitigation and preparedness measures related to utility provision, the survey included several questions about respondents' ability to provide alternatives when utility service is disrupted during a disaster. Table 2-16 shows that 59 % of respondents reported access to a community information hub or weather radio for information4, 55 % reported having a gas tank, and 51 % reported having a power generator. Less common alternative options were water storage tanks (20 %) and solar panels (5 %). Community wi-fi was not well understood by respondents in the field with many assuming this question meant access to any internet service. Thus, responses to community wi-fi should be interpreted with caution.

Table 2-16. Respondents reported access to alternative utilities provision.

Optional utility services	Yes	No	Don't know	Missing data	Total
Can provide any utility services for households	152 (70.0 %)	61 (28.1 %)	2 (0.9 %)	2 (0.9 %)	217
If yes, what utility service?					
Power generator	77 (50.7 %)	75 (49.3 %)	0 (0 %)	0 (0 %)	152
Gas tank	83 (54.6 %)	69 (45.4 %)	0 (0 %)	0 (0 %)	152
Solar panels	7 (4.6 %)	145 (95.4 %)	0 (0 %)	0 (0 %)	152
Community wi-fi	48 (31.6 %)	104 (68.4 %)	0 (0 %)	0 (0 %)	152
Community information hub	89 (58.6 %)	63 (41.4 %)	0 (0 %)	0 (0 %)	152
Water storage tank	31 (20.4 %)	121 (79.6 %)	0 (0 %)	0 (0 %)	152
Other	31 (20.4 %)	121 (79.6 %)	0 (0 %)	0 (0 %)	152

Notes N=217 total weighted observations. Survey questions used: Q30. Other responses not recategorized. "Other" included radios, cell phones, oil tanks, propane tanks, water bottles.

[4] Respondents seemed not to know what a "community information hub" was. During fieldwork, instructions were added for surveyors to probe this question with weather radio or other way to get information if the power is out.

Respondents were asked how long they felt they could stay at their home without various utilities including water, wastewater, electricity, natural gas, internet, and phone (Figure 2-11). Wastewater was most needed by respondents with 25 % of people saying they would not stay even a day without it. Natural gas and the internet had the opposite response, with only 5 % and 6 %, respectively, saying they would need to leave immediately without those services. The majority of respondents would not stay at home longer than 10 days without electricity, water, or wastewater. In contrast, the majority of respondents could stay in their home over 30 days without natural gas or the internet. Telephone service was bifurcated, with about 60 % of respondents needing it back within 10 days and 35 % who would stay for 30 or more days without phone service.

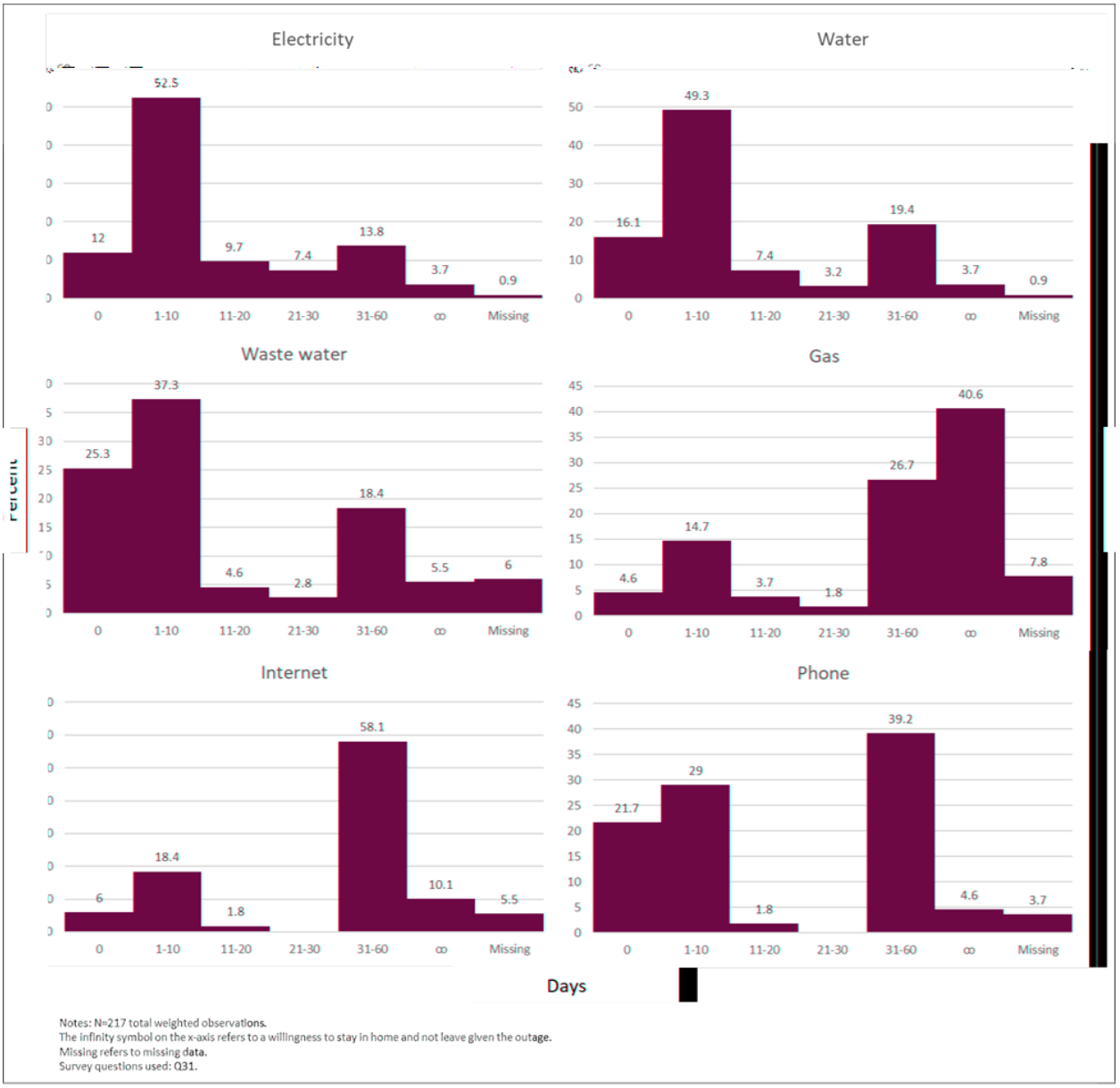

Figure 2-11. Days before leaving home due to outage or disruption.

2.5.2.7. Tracking Longitudinal Recovery

Wave 5 represents the fourth time that researchers attempted in-person surveys. The waves with in-person surveys included Wave 1 (2016), Wave 2 (2018), Wave 3c (2019), and this Wave 5 (2022). Wave 4 (2021) was conducted online because of COVID-19 travel limitations. Wave 4 had a small response rate, so it is not used in this report for longitudinal analyses.

These four time periods show changes in survey completion and perceived or confirmed occupancy which are used by the Center to understand longitudinal housing unit recovery over time. Figure 2-12 provides a Sankey diagram noting the unweighted numbers of housing units in the following categories: had a completed survey; had perceived or confirmed occupancy or was marked as under repair; was perceived or confirmed abandoned; or was inaccessible or missing.

The most notable aspect of Figure 2-12 is the limited change in perceived or confirmed abandonment since 2019. The same number of housing units were perceived or confirmed abandoned in 2022 as in 2019. A few housing units did move out of this category, and a few moved in during the last three years, but most that were abandoned in 2019 remain abandoned in 2022.

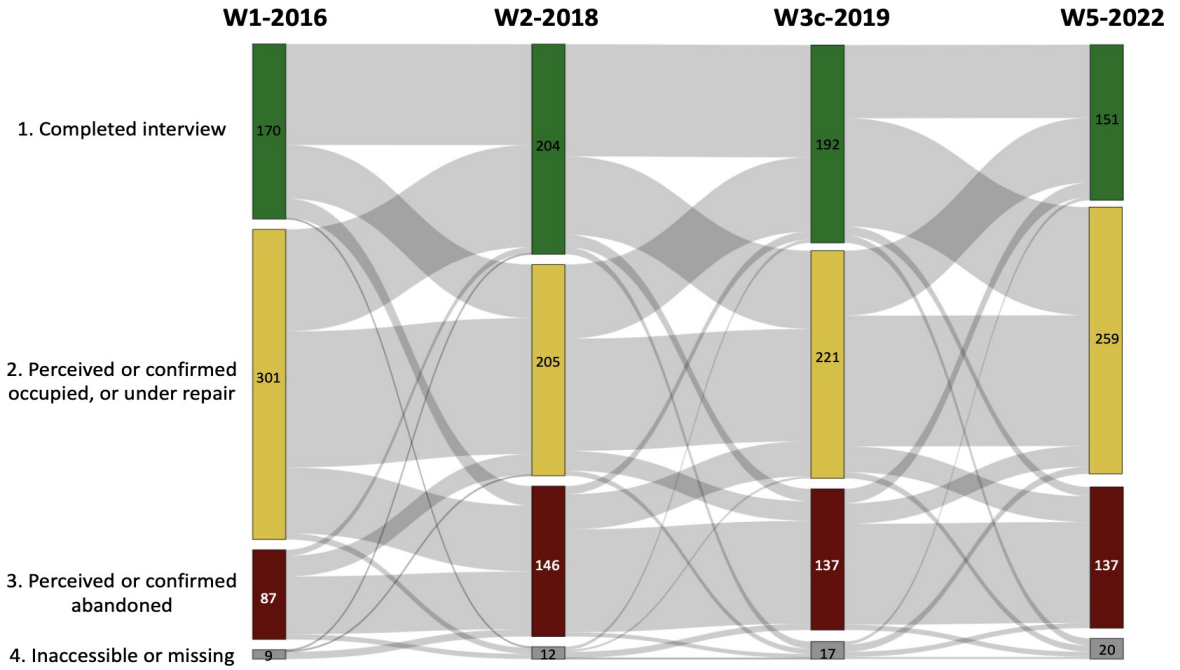

Figure 2-12. Sankey diagram depicting perceived or confirmed occupancy and abandonment of housing units across Wave 1 (2016), Wave 2 (2018), Wave 3c (2019) and Wave 5 (2022).

The Sankey diagram provides the status changes over time. To understand the longitudinal data available at the household level from the survey itself, Table 2-17 provides a different view of longitudinal information. Table 2-19 shows the number of surveys completed by a resident at each housing unit over time. A housing unit may have at most four surveys completed, one each per wave (e.g., one each in 2016, 2018, 2019, and 2022). A housing unit may also have no surveys completed - these would include abandoned units but also units where the residents were never home during surveying or refused to answer the survey. Having at least three completed

surveys is useful for longitudinal analyses of responses to survey questions that have been consistently asked over time.

Table 2-17. Number of surveys completed by each housing unit.

Number of completed surveys	Number	Percent (%)
0 (abandoned)	35	6.17
0 (others)	161	28.4
1 survey	150	26.46
2 surveys	125	22.05
3 surveys	64	11.29
4 surveys	32	5.64
Total	567	100

Thirty-five (6 %) of the 567 housing units sampled were marked as abandoned at every time period (2016, 2018, 2019 and 2022). An additional 161 (28 %) had no completed surveys, which means they may have been abandoned for some of the years or the residents were not home to complete the survey. Twenty-six percent (n = 150) housing units have one survey completed and 22 % have two surveys completed. About 11 % of housing units have three surveys completed and 6 % have a resident who completed all four waves of the survey.

2.5.2.8. Household Socio-Demographics

The unweighted survey respondent socio-demographic information is in Table 2-18. Just over half of respondents lived in households with two adults (52 %), 65 % of all households surveyed had no children under 18 in the household, and almost 40 % were female-headed households. Twenty-two percent of households reported a household member with electricity dependent medical needs. About 35 % percent of households reported the highest educational level completed by a household member to be high school diploma or less and about 27 % reported annual household incomes less than $25 000. Table 2.20 shows respondents' self-reported race and ethnicity. About 46 % of respondents were Black, 37 % White, 17 % Native American, and 5 % Hispanic of any race (Table 2-19).

Sixty-four percent of households had moved into their current home before Hurricane Matthew (pre-2016), while 8 % moved in between Matthew and Florence (2016-2018) and 25 % moved in after Hurricane Florence. The majority of respondents own their housing unit (70 %), and of those only 35% have a mortgage currently. Of homeowners, 80 % reported having homeowners' insurance and 40 % reported having flood insurance.

Table 2-18. Survey respondents' socio-demographics.

Number of adults in household	Frequency	Percent
1	50	23
2	113	52.1
3	40	18.4
4	7	3.2
5	5	2.3
6	1	0.5
Missing data	1	0.5
Number of children in household	**Frequency**	**Percent**
0	143	65.9
1	33	15.2
2	25	11.5
3	8	3.7
4	8	3.7
Missing data	0	0
Electricity-dependent medical needs	**Frequency**	**Percent**
No	168	77.4
Yes	48	22.1
Don't know	0	0
Missing data	1	0.5
Highest level of education in household	**Frequency**	**Percent**
Less than high school	12	5.5
High school diploma	64	29.5
Associate degree	54	24.9
Bachelor's degree	52	24
Master's degree or higher	34	15.7
Missing data	1	0.5
Female-headed household	**Frequency**	**Percent**
No	121	55.8
Yes	84	38.7
Don't know	1	0.5
Missing data	11	5.1

Move-in period	Frequency	Percent
Before Matthew	139	64.1
Between Matthew & Florence	17	7.8
After Florence	54	24.9
Missing data	7	3.2
Tenure	**Frequency**	**Percent**
Own	151	69.6
Rent	63	29
Other	2	0.9
Missing data	1	0.5
Has flood insurance (owner-occupied only)	**Frequency**	**Percent**
No	82	54.3
Yes	61	40.4
Don't know	8	5.3
Missing data	0	0
Has homeowners' insurance (owner-occupied only)	**Frequency**	**Percent**
No	23	15.2
Yes	121	80.1
Don't know	7	4.6
Missing data	0	0
Has adequate insurance coverage for a future flood event (owner-occupied only)	**Frequency**	**Percent**
No	50	33.1
Yes	63	41.7
Don't know	31	20.5
Missing data	7	4.6
Has mortgage (owner-occupied only)	**Frequency**	**Percent**
No	84	55.6
Yes	54	35.8
Don't know	10	6.6
Missing data	3	2

Table 2-18. Survey respondents' socio-demographics (continued).

Annual household income ($)	Frequency	Percent	Number of major flood events experienced	Frequency	Percent
1 to 3,999	7	3.2	**0**	7	3.2
4,000 to 5,999	2	0.9	**1**	19	8.8
8,000 to 9,999	6	2.8	**2**	104	47.9
10,000 to 11,999	4	1.8	**3**	31	14.3
12,000 to 14,999	14	6.5	**4**	20	9.2
15,000 to 19,999	13	6	**5**	6	2.8
20,000 to 24,999	12	5.5	**6**	7	3.2
25,000 to 29,999	15	6.9	**7**	3	1.4
30,000 to 39,999	18	8.3	**8**	5	2.3
40,000 to 49,999	11	5.1	**10**	2	0.9
50,000 to 74,999	24	11.1	**12**	3	1.4
75,000 to 99,999	19	8.8	**15**	1	0.5
100,000 to 149,999	13	6	**40**	3	1.4
150,000 +	19	8.8	**219**	3	1.4
Missing data	40	18.4	**Missing data**	3	1.4

Notes: N=217 total weighted observations. Survey questions used: Q2, Q3, Q4, Q12, Q13, Q38, Q42, Q43.

Table 2-19. Respondent reported race and ethnicity.

Race and ethnicity	Yes	Yes (%)	No	No (%)	Missing data	Missing data (%)	Total
Hispanic or Latino	10	4.6	203	93.5	4	1.8	217
American Indian or Native American	37	17.1	179	82.5	1	0.5	217
Asian or Asian American	6	2.8	210	96.8	1	0.5	217
Black or African American	99	45.6	117	53.9	1	0.5	217
Native Hawaiian or Pacific Islander	2	0.9	214	98.6	1	0.5	217
White or Caucasian	80	36.9	136	62.7	1	0.5	217
Other race	12	5.5	204	94	1	0.5	217

Notes: N=217 total weighted observations. Race and ethnicity categories are not mutually exclusive. Survey questions used: Q40, Q41.

3. Chapter 3: Business Interruption and Recovery

3.1. Goals and Objectives

The business component of the Wave 5 field study supports firm-level interruption and recovery modeling efforts in the Center and quantifies linkages and interdependencies across business, infrastructure and housing recovery. A number of key business recovery metrics have been collected through all waves of the Lumberton field study, including levels of profitability, staffing, and capacity through time. The field study continues to be a valuable source of information about types of mitigation adopted and adaptation behaviors. In addition, the study provides insight on the types of resources available to businesses affected by a disaster, particularly given changes to the resource landscape following COVID-19. Business data collection efforts for Wave 5 were critical given the low response rates and challenges to in-person data collection throughout the pandemic and in Wave 4. Therefore, the goals of the business data collection for Wave 5 included:

- Establishing the status of recovery from Hurricanes Matthew and Florence based on key longitudinal business recovery metrics;
- Continuing to understand the impact that COVID-19 had on the business recovery processes following Hurricanes Matthew and Florence;
- Understanding decision-making with respect to financial and non-financial resources used by individual businesses; and
- Validating occupancy status information collected in Wave 4b and understanding business entries and exits during the pandemic.

3.2. Business Sampling Procedure

Wave 5 data collection utilized the same longitudinal business sample as in previous waves, as well as the refreshment sample created for Wave 4. The unit of analysis is the location of each business, and the survey respondent is a representative of the business that operates at that location at the time Wave 5 data were collected. The refreshment sample was created for four reasons. First, some attrition in longitudinal surveys is to be expected. Secondly, the move to virtual data collection in Wave 4 (2021) due to COVID-19 risks were expected to have a detrimental effect on response rates given the low response rate of the sample to previous phone recruitment efforts (please see Chapter 3 in Sutley, Dillard, and van de Lindt et al. 2021). Third, low response rates and overall survey burden would be compounded by other efforts to understand the impact of COVID-19 business operations. Although Wave 5 resumed in-person data collection and the second justification was less relevant, attrition and survey fatigue were anticipated to still be a factor in Wave 5. Last, collecting data on the refreshment sample in Wave 5 will help validate the virtual data collection effort of Wave 4a and the observational information collected in Wave 4b.

The original longitudinal sample was created based on the predicted flood inundation area and the FEMA 100-year floodplain to capture businesses that were either likely to have flooded due to Hurricane Matthew or were at risk of future flooding. Business point data from *ReferenceUSA* (now *Data Axle*) were geocoded and businesses sampled based on their location, specifically all

businesses were sampled from the inundation area and a random sample was taken from the remaining businesses in the northern floodplain. This procedure resulted in an initial sample of 350 businesses. After exclusions based on ineligibility, substitutions, and data collection in Wave 2, the final sample included 164 surveyed businesses and an additional 65 businesses with observational data on operational status (please see Chapter 3 in Sutley, Dillard, and van de Lindt et al. 2021)). Data collection from Wave 3c and information gleaned from updates to online records resulted in the exclusion of 11 businesses that were identified to be nonprofits, and the inclusion of seven new businesses that began to occupy commercial structures in the sample after Hurricane Matthew (see Chapter 4 in Helgeson, Hamideh, and Sutley 2021). Wave 4a and Wave 4b continued to update information on businesses that had closed or new businesses that began operating between waves. The longitudinal sample for Wave 5 consisted of 218 businesses.

The refreshment sample was created using the remaining businesses in the floodplain not yet selected for the longitudinal sample and a random sample of businesses outside the inundation and floodplain areas. Businesses that did not experience physical impacts from flooding are also important to study given the direct and indirect impacts to businesses due to utility outages, demand changes, and supply chain disruption. A total of 270 businesses were sampled as part of the refreshment sample for Wave 4, 90 within the floodplain and 180 from outside. The 180 businesses outside of the floodplain and inundation areas, although not necessarily at risk for future flooding, serve as important controls for the effect of COVID-19. Healthcare businesses were excluded from the refreshment sample to match the previous sampling strategy and to prevent survey burden on healthcare workers during the COVID-19 pandemic. Repeat businesses and ineligible businesses were removed from the sample during Wave 4 as in all previous waves.

Between the longitudinal and refreshment samples, the overall business sample for Wave 5 totaled 461 businesses.

3.3. Survey Development

Like the household survey, the business survey was developed through the collaboration of NIST and Center researchers with diverse disciplinary backgrounds. There were seven main sections of the Wave 5 business survey, specifically:

- Business operational status,
- Impact and recovery from recent events,
- Financial resources used in recovery,
- Mitigation and preparedness,
- Businesses characteristics,
- Respondent characteristics, and
- A choice exercise on loan structure and timing.

3.3.1. Business Operational Status

The section on business operational status asked how well the business was performing. The survey asked respondents whether the business was open or closed and whether the business had changed its products and services since the beginning of the COVID-19 pandemic. In accordance with the longitudinal metrics of previous surveys, businesses were also asked about their current capacity and profitability.

3.3.2. Impact and Recovery from Recent Events

The next section on impact and recovery from recent events walked businesses through Hurricane Matthew, Hurricane Florence, COVID-19 and any other major disruptions affecting the business in the last five years. For each event, businesses were asked whether they were adversely impacted, how the business was affected, and the level of the business' recovery. If identifying as fully recovered, the business was asked to report the year it was fully recovered. If not fully recovered at the time of the survey, the business was asked why not in an open-ended format. Businesses were asked how the COVID-19 pandemic affected business recovery from previous hurricane impacts. They were additionally asked to identify factors that go into their assessments of recovery. Lastly, from a pre-populated list, businesses were asked to select the top three concerns for their business and indicate whether the business has the resources and information needed to reduce the impacts of those concerns.

3.3.3. Financial Resources Used in Recovery

As in previous waves, the section on financial resources used for recovery asked businesses to identify the Federal, state, and local resources they applied for and received after the hurricanes and the top two sources used in financing their recovery. New to the Wave 5 survey, however, was a question that asked businesses to estimate how much money in total was spent on the business' recovery from hurricane damage, to date. Businesses were given a range of values to choose from.

3.3.4. Mitigation and Preparedness

In the mitigation and preparedness survey section, businesses were asked about their previous, current, and planned future insurance coverage. Businesses were also given a list of preparedness and mitigation strategies and asked whether they had adopted each strategy. For each strategy, respondents were asked to indicate the year of adoption, whether they planned to adopt that strategy in the future, or whether they had no plans to adopt that strategy. Businesses were asked to indicate their certainty that various utilities will be available 2-3 days after an event and whether the business has an alternate source or provider for that utility. Businesses were also asked whether they had considered relocating, how well-mitigated and prepared the business perceived itself to be with respect to future hurricanes, and the reasons why businesses perceived themselves as poorly or very poorly prepared (as applicable).

3.3.5. Business and Respondent Characteristics

The survey included questions on business characteristics and respondent characteristics. These questions were repeated from previous waves. For business characteristics, these questions included size, tenure, and age of the business. For respondent characteristics, the survey included respondent experience, education race, ethnicity and role within the business. These questions provide important context to the recovery of the businesses.

3.3.6. Choice Exercise on Loans

The final section of the survey was a choice exercise to understand preferences for various types of loans to support recovery. Respondents were asked to consider a hypothetical situation: a hurricane reduced the capacity of their business by 50 % for about a year, bank loans are not an option, and a local Chamber of Commerce decided to provide loans to all businesses in the community to help mitigate the impacts. Three months after the hurricane, the business would be automatically pre-approved for the loan, and the loan would be interest free for up to 5 years. Businesses were then given a choice of two loan options that varied in their timing and value to test their preferences.

On a few occasions, the decision was made to have businesses select a maximum of only two or three options when a question had multiple possible answers to help reduce the burden of the survey. This included questions on major concerns of the business, financial resources primarily used in recovery, and others. Wherever possible, an "other" write-in category was provided.

Appendices E, F, and G include the full Wave 5 business survey, consent script, and information sheet, respectively.

3.4. Data Collection Methods

Ahead of Wave 5, the business sample was subdivided and each business unit was assigned a priority for visits by researchers to optimize time in the field. These priority designations were as follows:

> Priority 1: Open businesses in the longitudinal sample based on Wave 4 data collection as well as businesses in the refreshment sample that responded in Wave 4 (n=142);
>
> Priority 2: Open businesses in refreshment sample (n=143);
>
> Priority 3: Vacant from mailing, vacant from 4b, vacant from 4a web search, residential, or in an isolated location (i.e., beyond Lumberton's city limits) (n=176).

In the field, data collection methods for the business survey were similar to the household survey. The daily process and team composition decisions were the same across both surveys, as well as data management practices. The survey timing was different to accommodate business hours of operation and surveys were typically conducted between 9am and 5pm throughout the work week. Because surveys were conducted during business hours, sometimes businesses would be busy with customers or other operational needs. In other cases, the owner or manager with the knowledge of the hurricanes or financial details of the business would not be present. Therefore, surveyors had the option to leave a paper version of the survey with the business. Team members would then return in-person to check on the completion status of the paper survey or offer again to administer the survey verbally.

At the end of the field study, a remote team member called businesses who still had incomplete paper surveys. However, very few had been completed. As in previous waves, sometimes the option to leave a survey was used by businesses as a form of soft refusal.

3.4.1. Data Cleaning

The data cleaning process is summarized in Figure 3-1. Data collection resulted in 795 observations. Of those observations, 334 were duplicates resulting from tracking the location and recording the survey answers from the participants in separate systems. Although 121 observations were categorized as completed, a further dive into the completion status determined that a misclassification occurred during the data entry of this step. Consequently, to obtain the completed observations, the count of the completed questions of the survey answers are summarized, and all surveys in which more than 40 questions were answered are considered completed. Thus, the descriptive statistics presented in this chapter include 115 surveys.

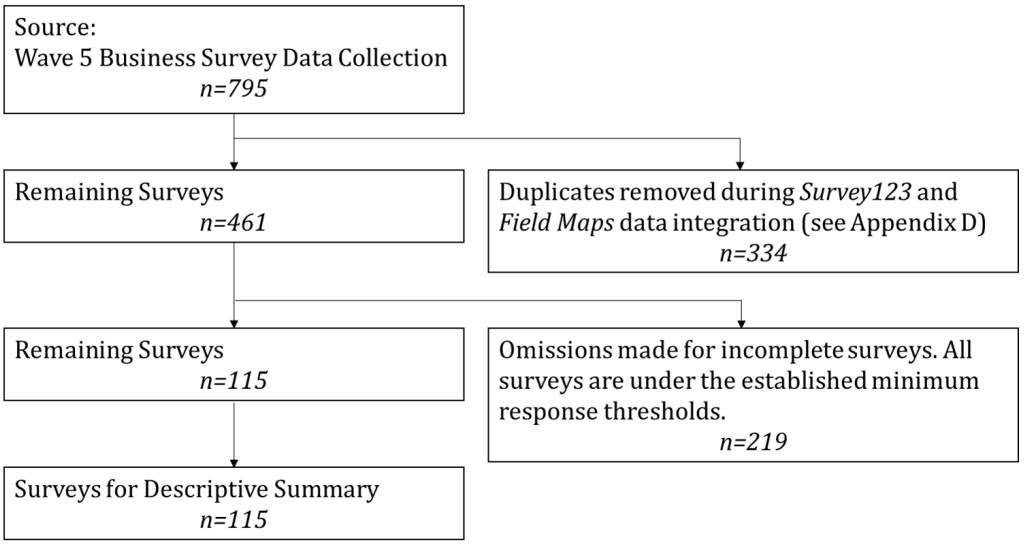

Figure 3-1. Data Processing Flow Chart.

3.4.2. Data Storage and Access

All data storage and access procedures are in accordance with the IRB protocols for the field study. All paper copies of the survey data are stored in a locked storage closet at Texas A&M University and all electronic media is saved in locked offices on the password protected computers of the research team.

Original data access is limited to project investigators who have completed the IRB training and whose universities have signed the IAA or have separately approved IRB protocols for the field study. The data will be maintained for a three-year archive period following the conclusion of the study and will be shared with NIST.

3.5. Survey Results

3.5.1. Response Rates

Response rates for the business survey were similar to those of the household survey. Of the 461 businesses in the Wave 5 sample, 115 returned or participated in a complete survey. This translates to an overall response rate of 25 %.

Many of the businesses that responded in Wave 5 had responded in previous waves of the Lumberton field study. Of the 115 complete surveys, 80 were from the original (longitudinal) sample compared to the refreshment sample that was added in Wave 4. Ninety percent of those 80 (n=72) responded in Wave 2 and 60 % (n=48) responded in Wave 3c. Almost all of those 48 businesses that responded in Wave 3c also responded in Wave 2; 45 businesses that responded in Wave 5 also responded in both Wave 2 and Wave 3c. Almost all of the businesses in Wave 5 (96) had their occupancy status assessed in Wave 4b. Nine businesses responded in Wave 4a, though this data was not reported on and provides minimal utility to the longitudinal statistical analysis due to the low response rate; however, these data may provide some useful context for the experience during COVID-19.

In terms of geographic distribution and sample, there was a good amount of variation. Of the 80 longitudinal respondents, 48 (60 %) were in the inundation area and 32 (40 %) were in the floodplain portion. Of the 35 responses from the refreshment sample, 16 (46 %) were in the floodplain and 19 (54 %) were outside the floodplain.

3.5.2. Business Survey Responses

This section provides descriptive statistics of how businesses responded to survey questions in Wave 5. The findings are organized based on survey themes; question summaries are provided under sections for business operational status, impact and recovery from recent events, financial resources used in recovery, mitigation and preparedness, and businesses and respondent characteristics.

3.5.2.1. Business Operational Status

Table 3-1 shows the operating status of the businesses that responded to the survey. Almost all of the businesses that responded were open and operating (98 %) compared to permanently closed (1 %). None had moved since Wave 4. In general, the names of businesses collected during Wave 4b matched, with three exceptions. One of those businesses was not assessed in Wave 4b, but newly opened in 2021. Two of the businesses opened after the conclusion of Wave 4b. Table 3-2 summarizes the establishment year of all businesses that responded in Wave 5. Most businesses had opened between 1999 and 2010 (30 %) or between 2011 & 2020 (31 %). Of those surveyed, 30 % of businesses were established earlier than 1999, with 15 % opening between 1985 and 1998 and 16 % opening prior to 1985.

Table 3-1. What is the operational status of this business?

Operational Status	Count (No.)	Percent (%)
Open	113	98 %
Moved	0	0 %
Permanently closed	1	1 %
Missing	1	1 %
Total	115	100 %

Table 3-2. In what year was this business established at this location?

Establishment Year	Count (No.)	Percent (%)
Before 1985	18	16 %
Between 1985 and 1998	17	15 %
Between 1999 & 2010	34	30 %
Between 2011 & 2020	36	31 %
Missing	10	9 %
Total	115	100 %

In terms of the status of the business, Tables 3-3, 3-4, and 3-5 ask different questions to understand the level of operations at which the business is currently operating. Table 3-3 reports the operating status of the Wave 5 respondents at the time of the survey, Table 3-4 reports the percent capacity at which the business was operating, and Table 3-5 reports the level of profitability of the business at the time of the survey.

Table 3-3. What is the status of this business?

Current Business Status	Count (No.)	Percent (%)
Fully open with the same products and services as pre-COVID-19	76	66 %
Open, but with fewer or different products or services as pre-COVID-19	36	31 %
Temporarily closed, but plan to reopen	0	0 %
Permanently closed	1	1 %
Missing	2	2 %
Total	115	100 %

Table 3-4. What is the percent capacity at which your business is currently operating?

Percent Capacity	Count (No.)	Percent (%)
Over 75 %	85	74 %
Between 50 % and 75 %	16	14 %
Between 25 % and 50 %	5	4 %
Less than 25 %	3	3 %
Missing	6	5 %
Total	115	100 %

Table 3-5. How profitable is your business currently?

Classification by Profitability Perception	Count (No.)	Percent (%)
Highly profitable	20	17 %
Profitable	54	47 %
Breaking even	27	23 %
Unprofitable	8	7 %
Highly unprofitable	0	0 %
Closed	1	1 %
Missing	5	4 %
Total	115	100 %

Most businesses that responded in Wave 5 were fully open with the same products and services as during the period before COVID-19 (76 or 66 % of the sample). However, 36 businesses (or 31 % of the sample), were open but with fewer or different products or services. Only 1 business was permanently closed that responded to the survey; however, most information about permanently closed businesses comes from observational data rather than survey data.

Of the responding businesses, 85 (74 %) were currently operating at above 75 % capacity. Most of the remaining businesses (14 %) were operating at 50 % -75 % capacity, though five (4 %) were operating at 25 % - 50 % capacity and three (3 %) were operating below 25 % capacity. Most businesses reported being profitable (47 %); however, the second most common profitability category was breaking even (23 %). Fewer businesses reported being highly profitable (17 %) and even fewer reported being unprofitable (7 %). None reported being highly unprofitable.

3.5.2.2. Impact and Recovery from Recent Events

When asked about recent disaster events, most of the respondents felt that their business was impacted by either Hurricane Matthew, Hurricane Florence, or COVID-19, as outlined in Table 3-6. Among 115 cases, Hurricane Matthew impacted 86 respondents (77 %), Hurricane Florence impacted 65 respondents (58 %), and COVID-19 impacted 87 respondents (77 %). A few respondents (9 or 8 %) were unsure if a hazard impacted their business while in some cases the data were missing. Businesses were also given the option of reporting other hazards that

impacted them; eight businesses responded that they were affected by another hazard (8 %). However, all but one business was referring to current events (gas prices, inflation, and politics). Given that current concerns were asked in a later survey question, the "Other hazard" category is excluded in Table 3-6 and subsequent tables reporting on recovery.

Respondents reported numerous issues or various ways in which their business was impacted due to Hurricane Matthew (which generated 222 or 36 % of the total issues reported), Hurricane Florence (generating 173 or 28 % of the total issues reported), and COVID-19 (generating 217 or 35 % of the total issues reported). These included reports of reduced capacity (84 or 14 % of reports across all events); gross revenue impact (158 or 26 % of reports across all events); keeping customers (118 or 19 % of reports across all events); keeping employees (86 or 14 % of reports across all events); physical damage (80 or 13 % of reports across all events); or any other issues (86 or 14 % of reports across all events), as shown in Table 3-7. To better visualize these reports across events, the distribution of the different issues is presented in Figure 3-2. In general, gross revenue was the most frequently reported issue that impacted businesses after Hurricane Matthew, Hurricane Florence, and COVID-19. However, there were some differences across events. Whereas Hurricane Matthew had a high number of reports of physical damage (45 or 20 %), COVID-19 had a high number of reports for keeping employees (44 or 20 %).

Table 3-6. Impact of Hurricane Matthew, Hurricane Florence, and COVID-19.

Whether the business was impacted	Hurricane Matthew	Hurricane Florence	COVID-19
Yes	86 (77 %)	65 (58 %)	87 (77 %)
No	16 (15 %)	37 (35 %)	26 (23 %)
Don't know	9 (8 %)	8 (7 %)	-
Total	111	110	113

Table 3-7. Reports of Issues after Hurricane Matthew, Hurricane Florence, and COVID-19.

Impact felt	Hurricane Matthew	Hurricane Florence	COVID-19	Total times cited
Capacity decrease	25 (11 %)	23 (13 %)	36 (17 %)	84
Gross Revenue	56 (25 %)	43 (25 %)	59 (27 %)	158
Keeping customers	38 (17 %)	37 (21 %)	43 (20 %)	118
Keeping employees	25 (11 %)	17 (10 %)	44 (20 %)	86
Physical damage	45 (20 %)	29 (17 %)	6 (3 %)	80
Other	33 (15 %)	24 (14 %)	29 (13 %)	86
Total reported issues	222	173	217	612

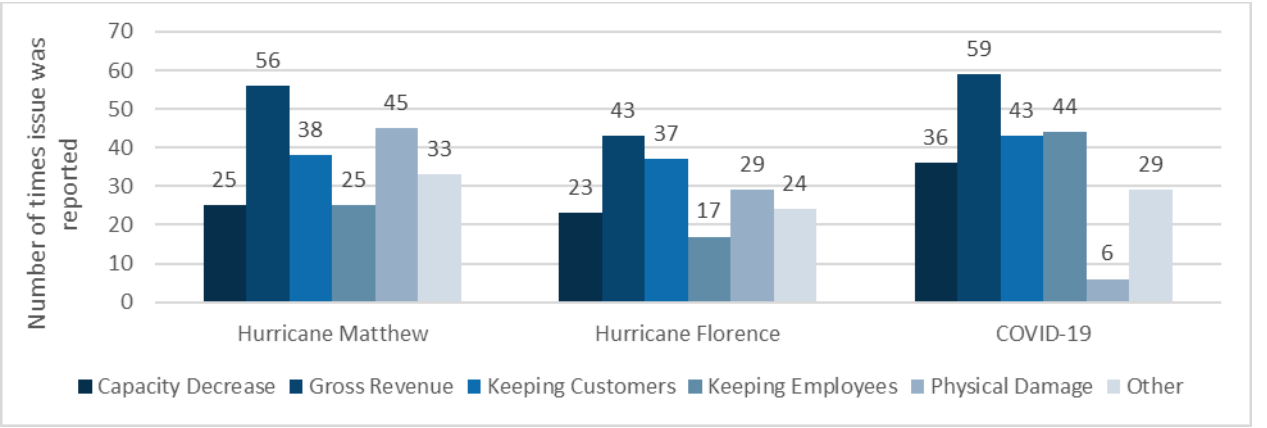

Figure 3-2. Distribution of Issues Across Hurricane Matthew, Hurricane Florence, and COVID-19.

Perceptions of where the businesses are in their recovery from Hurricane Matthew, Hurricane Florence, and COVID-19 are shown in Table 3-8. This question was only answered by businesses that responded that they were impacted by the event(s), so totals are less than the 115 overall survey respondents. Broadly, most (69 or 80 %) of the businesses report being fully recovered from Hurricane Matthew. Only 15 (18 %) respondents reported being partially recovered and two (2 %) reported being either not recovered or still in operation but will never recover. Hurricane Florence had similar responses, with 48 (75 %) businesses being fully recovered, 15 (23 %) being partially recovered, and 1 (2 %) still in operation but will never recover. COVID-19, being the most recent event, only had 39 (44 %) businesses reporting being fully recovered, 44 (51 %) reporting being partially recovered, and two (2 %) each reporting being either not recovered or still in operation but will never recover.

Table 3-8. Self-reported recovery status from Hurricane Matthew, Hurricane Florence, and COVID-19.

Recovery Status	Hurricane Matthew	Hurricane Florence	COVID-19
Fully recovered	69 (80 %)	48 (75 %)	39 (44 %)
Partially recovered	15 (18 %)	15 (23 %)	44 (51 %)
Not recovered	1 (1 %)	-	2 (2 %)
Still in operation but will never recover	1 (1 %)	1 (2 %)	2 (2 %)
Total	86	64	88

Table 3-9 provides the year in which businesses reported having recovered, if applicable. Businesses impacted by Hurricane Matthew mostly felt that they achieved full recovery by 2017 (35 or 57 %), while few others felt the business recovered by either 2016 (21 or 34 %), 2018 (4 or 7 %), and 2019 (1 or 2 %). When asked about Hurricane Matthew, the respondents attributed the lack of recovery to the loss of customers. They highly emphasized the effect of many residents' temporary and permanent relocation on independent businesses' ability to remain profitable. For Hurricane Florence respondents were distributed equally, as they felt their business recovered by either 2018 (22 or 51 %) or 2019 (21 or 49 %). When asked about Hurricane Florence, the respondents attributed the lack of recovery to the compounded effect of Matthew and Florence occurring in such brief succession. Since many businesses were still recovering from Matthew, Florence exacerbated the loss of customers and staff they were

already experiencing. COVID-19 recovery was mostly partial, with only few respondents reporting full recovery to their business by 2020 (7 or 25 %), 2021 (15 or 54 %), and 2022 (6 or 21 %). When asked about COVID-19, the respondents attributed the lack of recovery to a broader range of reasons than the hurricanes. This difference is likely attributed to the temporal and uncertain distinctions between the effects of natural disasters and the global pandemic.

Table 3-9. Year of self-reported recovery from Hurricane Matthew, Hurricane Florence, and COVID-19.

Self-reported Year of Recovery	Hurricane Matthew	Hurricane Florence	COVID-19
2016	21 (34 %)	-	-
2017	35 (57 %)	-	-
2018	4 (7 %)	22 (51 %)	-
2019	1 (2 %)	21 (49 %)	-
2020	-	-	7 (25 %)
2021	-	-	15 (54 %)
2022	-	-	6 (21 %)
Total	61	43	28

Table 3-10 shows respondent perceptions of whether business recovery from previous hurricanes was affected by COVID-19. Most businesses responded that the COVID-19 impact was not applicable to their hurricane recovery (64 or 56 %) or had no effect (20 or 17 %). However, a few businesses responded that COVID-19 hurt their recovery (21 or 18 %). Only two businesses responded that COVID-19 helped their recovery (2 %).

Table 3-10. Impacts of the COVID-19 pandemic on business recovery from previous hurricanes.

COVID-19 Impact on Recovery	Count (No.)	Percent (%)
Recovery was helped	2	2 %
Recovery was hurt	21	18 %
No effect	20	17 %
Not applicable	64	56 %
Missing	8	7 %
Total	115	100 %

Because businesses were asked to self-report the status of their recoveries, Table 3-11 shows the factors respondents considered when assessing whether their business is fully recovered after an interruption. Whether the business was producing/selling at the same level as before the disruption was the most commonly reported consideration (26 % of all factors). However, having expected gross revenues achieved, an adequate number of employees, full building functionality, and full repair of property damages, were also commonly reported factors. These made up 21 %, 18 %, 15 %, and 12 % of all reported factors, respectively. However, 7 % of the factors businesses considered were not captured by these categories (i.e., “other” in the survey response options).

Table 3-11. Factors businesses considered when assessing whether their business is fully recovered after an interruption.

Factor Considered	Count (No.)	Percent (%)
Producing/selling at the same level as before the disruption	60	26 %
Expected gross revenues achieved	49	21 %
Adequate number of employees achieved	41	18 %
Full building functionality achieved	35	15 %
Full repair of property damages	27	12 %
Other	17	7 %
Missing	5	2 %
Total factors reported	234	100 %

Lastly, businesses were asked about their current concerns. Businesses were asked to select the top three concerns for their business from a list, the results of which are displayed in Table 3-12. Next, businesses were asked whether they had the resources and information needed to reduce the impacts of these concerns; these results are shown in Figure 3-3. The most frequently cited concern was the price of fuel (16 % of all concerns cited). However, this was followed closely by inflation (14 %), the ongoing pandemic (13 %), supply side issues (12 %), workforce issues (11 %), business, financial, and market volatility (10 %), and natural hazards (8 %). Consumer-side issues, other public health issues, and utility service dependability made up few of the businesses' concerns. Looking across all business concerns, most businesses said they had the resources and information needed to reduce their impacts. However, as shown in Figure 3-3, inflation, workforce issues, and business, financial, and market volatility were issues that had a comparatively high number of "no" responses compared to "yes" responses.

Table 3-12. Please select the top three concerns for your business today from the list below. Then indicate whether you have the resources and information needed to reduce potential impacts.

Concern	No. (%)
Price of fuel	54 (16 %)
Inflation	48 (14 %)
Pandemic (subsequent wave of COVID-19)	45 (13 %)
Supply side issues	40 (12 %)
Workforce issues (e.g., safety, workforce reduction, absenteeism, retaining/ rehiring staff)	38 (11 %)
Business, financial, and market volatility (e.g., supply chain disruption, operational issues)	36 (10 %)
Natural hazards	27 (8 %)
Consumer-side issues (e.g., preferences for online shopping, reductions in foot traffic, low holiday seasonal sales)	8 (2 %)
Other	4 (1 %)
Other public health issues	3 (1 %)
Utility service dependability	2 (1 %)
Missing	40 (12 %)
Total	345

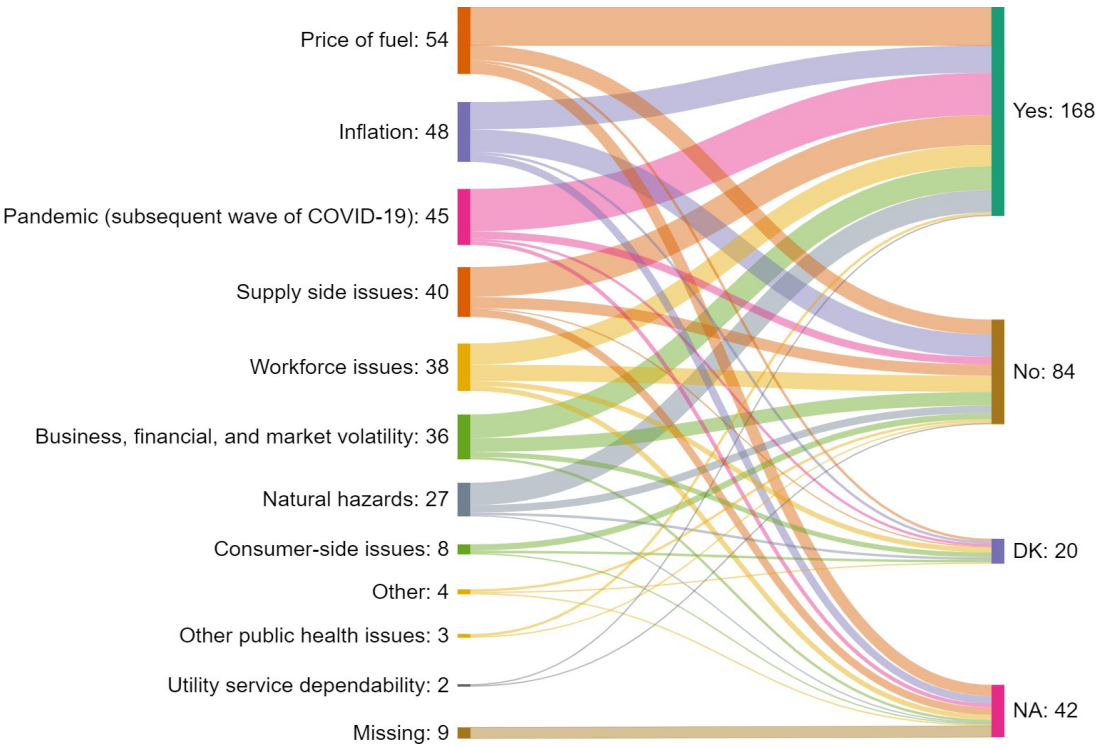

Figure 3-3. Existence of resources and information needed to reduce named concerns.

3.5.2.3. Financial Resources Used in Recovery

This section discusses the financial resources used during business recovery after Hurricane Matthew, Hurricane Florence, and COVID-19. As shown in Table 3-13, fewer businesses applied for assistance during the pandemic (45 or 39 %) than did not apply (50 or 43 %). These applications were distributed across Federal (73 %), State (15 %), Local (4 %), and Other (8 %) sources. Most Federal assistance applications were to the PPP; however, a few applied for Small Business Administration loans and state funding sources such as the Carolina Small Business Development fund and the North Carolina Business Recovery Grant Program (Table 3-14). By contrast, 50 businesses (43 %) did not apply for financial assistance.

Table 3-13. Number of businesses that applied for financial assistance during the pandemic.

Categorical Response	Count (No.)	Percent (%)
Yes	45	39 %
No	50	43 %
Don't know	17	15 %
Total	111	

Table 3-14. Types of financial support that businesses applied for and received during the pandemic.

Funding source	Count (No.)	Percent (%)
Federal	35	73 %
State	7	15 %
Local	2	4 %
Other	4	8 %
Total sources reported	48	

Table 3-15 shows businesses how they financed their recovery from the recent hurricanes. Businesses were asked to choose the top two resources they used. Given that many businesses did not apply for external assistance, it is not surprising that personal savings were the most commonly reported financial resource used (28 % of the total reported). “Other” was the second most reported option (16 %), and businesses wrote that they used their rainy-day fund, refinanced their mortgage, had “buy now, pay later” deals with suppliers, used business savings, and changed their budgeting and management strategies. Insurance accounted for 14 % of total resources listed. Corporate assistance, assistance from friends and family, private loans, government programs, and donations each had fewer than 5 % of the total responses.

Table 3-15. Sources used to finance business recovery from Hurricanes Matthew and Florence.

Recovery resources	Count (No.)	Percent (%)
Corporate Assistance	2	1 %
Federal Programs	5	4 %
Friends and family	3	2 %
Insurance	19	14 %
Personal Savings	39	28 %
Private loans	7	5 %
State Programs	4	3 %
Other	23	16 %
Donations	2	1 %
Missing	36	26 %
Total options reported	140	100 %

Table 3-16 shows the approximate total amount of money spent on the businesses' recovery from hurricane damage. Most respondents (21, or 18 %) shared that they did not spend any money on recovery from physical damage and other losses and many respondents (20, or 17 %) didn’t know. Of those that spent money on recovery, the most frequent amount was $20,000 (19, or 17 % of businesses), followed by $1,000 (13, or 11 %), $100,000 (10, or 9 %), and $50,000 (8, or 7 %).

Table 3-16. The approximate amount of money in total spent on the business' recovery from Hurricane damage.

Amount ($)	Count (No.)	Percent (%)
None	21	18 %
1,000	13	11 %
10,000	3	3 %
20,000	19	17 %
50,000	8	7 %
100,000	10	9 %
250,000	3	3 %
More than 500,000	4	3 %
NA	10	9 %
Don't know	20	17 %
Missing	4	3 %
Total	115	100 %

3.5.2.4. Mitigation and Preparedness

In terms of type of insurance, Table 3-17 shows the types of insurance businesses currently carry, previously carried, or plan to carry in the future. Many businesses currently carry (68 %, 64 %), previously carried (64 %, 60 %), and plan to carry (55 %, 52 %) business property insurance on contents and liability insurance, respectively. Fewer currently carry (27 %, 34 %), previously carried (34 %, 30 %), and plan to carry (33 %, 29 %) flood insurance on contents and income interruption insurance, respectively. Most businesses were able to respond about their property insurance on contents and liability insurance, but 49 % of businesses did not know the status of their flood insurance and 59 % did not know the status of their interruption insurance. Businesses were also less likely to respond to those two questions than others in the survey. Other questions that were likely to be skipped (i.e., had the greatest frequency of missing values) included questions on respondent race and the loan choice exercise.

Table 3-17. Insurance coverage.

Insurance Coverage Status	Business property insurance on contents	Flood insurance on contents	Business income interruption insurance	Business liability insurance
Currently carry	71 (68 %)	19 (27 %)	26 (34 %)	60 (64 %)
Plan to carry	58 (55 %)	23 (33 %)	22(29 %)	49 (52 %)
Previously carried	67 (64 %)	24 (34 %)	23 (30 %)	56 (60 %)
Don't know	22 (21 %)	34 (49 %)	45 (59 %)	27 (29 %)
Total respondents	105	70	76	94

Table 3-18 shows the types of mitigation strategies businesses either have adopted or plan to adopt for a future event. The most common mitigation strategy for businesses was backing up

important documents (70 % of respondents) followed by staying informed of weather watches and warnings (64 %). A little under half of businesses developed or plan to develop a formal emergency action plan or checklist and a little over 40 % plan to or have established or increased remote/online sales capacity, stored inventory and other supplies in higher locations, and kept an emergency fund ("rainy day" money) on-hand. Of those surveyed, 38 % of businesses plan to or have provided curbside pick-up, and approximately a third plan to or have assigned disaster responsibilities to specific employees, secured a secondary storage location, and/or had the building structurally assessed by an engineer. Fewer than 30 % plan to or have performed emergency management drills regularly, floodproofed the building, performed risk assessment to identify business vulnerability, and/or developed/updated their telework plans.

Table 3-18. Has this business adopted or have plans to adopt any of the following preparedness or mitigation strategies?

Mitigation Strategy	Count (No.)	Percent (%)
Backed up all important documents	68	70 %
Adopted strategies to stay informed of weather watches and warnings	62	64 %
Developed a formal emergency action plan or checklist	47	48 %
Assigned disaster responsibilities to specific employees	30	31 %
Establish or increase remote/online sales capacity	42	43 %
Secured a secondary storage location	32	33 %
Provide curbside pick-up	37	38 %
Stored inventory and other supplies in higher locations	40	41 %
Had the building structurally assessed by an engineer	32	33 %
Performed emergency management drills regularly	22	23 %
Keeping an emergency fund ("rainy day" money on-hand)	39	40 %
Floodproofed of the building	24	25 %
Performed risk assessment to identify business vulnerability	25	26 %
Developed/updated telework plans:	15	15 %
Other	6	6 %
Missing	18	19 %
Total respondents	97	100 %

Note: Businesses were able to select more than one strategy so column totals may exceed 100 %.

Businesses may also consider moving from their location as a form of risk mitigation or adaptation. When asked, 20 % of businesses had considered moving as shown in Table 3-19. Most of those businesses considered moving within Lumberton (18 out of 23) and only a few considered moving outside of Lumberton (5 out of 23). The majority of businesses (76 %) had not considered moving.

Table 3-19. Business moving locations considerations.

Relocation considerations	Count (No.)	Percent (%)
Yes, within Lumberton	18	16 %
Yes, outside of Lumberton	5	4 %
No	87	76 %
Missing	5	4 %
Total	115	100 %

In general, however, most respondents felt that their business was at least somewhat well-mitigated and prepared to deal with hurricane events. As shown in Table 3-20, 23 % of businesses reported being very well-mitigated and prepared, 30 % reported being well-mitigated and prepared, and 35 % reported being somewhat well-mitigated and prepared for hurricanes. Only 3 % and 4 % of businesses reported being poorly mitigated and prepared or very poorly mitigated and prepared, respectively. Of those eight businesses, the most commonly cited reason was a lack of information (cited by five out of eight businesses). Lack of money, lack of time, and lack of workers were each cited by two out of eight businesses.

Table 3-20. Mitigation and preparedness perceptions.

Perception of preparedness and mitigation	Count (No.)	Percent (%)
Very well	26	23 %
Well	34	30 %
Somewhat well	40	35 %
Poorly	4	3 %
Very poorly	3	3 %
Don’t know	5	4 %
Missing	3	3 %
Total	115	100 %

One aspect of business mitigation and preparedness is securing an alternative utility source in case of outages. Businesses were asked specifically about their confidence in utility service approximately 2-3 days after an event and whether they secured an alternative source of electricity, water, natural gas, sewer, landline phone, cellphone, internet, and cable. Broadly, businesses were most confident in the availability of cell phone service, followed by sewer and natural gas. Businesses were most likely to have an alternative source of electricity compared to other utilities (30% of businesses reporting an alternative source), followed by water (20%) and landline phone service (20%). Though the broad trends are reported here, these questions are discussed in greater detail in Chapter 4, Section 4.6.

3.5.2.5. Business Characteristics

Businesses shared their distribution of full-time and part-time employees (Table 3-21). The most common range of employees was “Between 0 and 10” as selected by 91 (79 %) and 90 (or 78 %) of businesses reporting on their full-time and part-time employment, respectively. Sixteen (14 %)

businesses had between 11 and 100 full-time employees, and eight (7 %) had between 11 and 100 part-time employees. Only five businesses had more than 100 employees.

Table 3-21. Number of full-time and part-time employees.

Employee categories	Count (No.)	Percent (%)
Full-time employees		
Between 0 and 10	91	79 %
Between 11 and 100	16	14 %
Between 101 and 250	3	3 %
Over 250 employees	1	1 %
Missing	4	3 %
Part-time employees		
Between 0 and 10	90	78 %
Between 11 and 100	8	7 %
Between 101 and 250	2	2 %
Missing	15	13 %
Total	115	100 %

As Table 3-22 shows, there was a fairly even split across businesses that owned versus rented their space. Specifically, 57 (50 %) rented, 48 (42 %) owned, six (5 %) had other arrangements.

Table 3-22. Business property tenure.

Property tenure	Count (No.)	Percent (%)
Own	48	42 %
Rent	57	50 %
Other	6	5 %
Missing	4	3 %
Total	115	100 %

Table 3-23 summarizes whether the business was deemed essential during the COVID-19 pandemic. During previous public health restrictions (e.g., stay-at-home orders, movement limitations, limits on public gatherings, or requirements for social distancing), many businesses in the sample reported that their business was designated as essential (63 %). By contrast, 22 % of the respondents reported that their business was designated as non-essential and 4 % reported that their business had some essential and some non-essential segments.

Table 3-23. Essential business designations.

Designation	Count (No.)	Percent (%)
Essential	73	63 %
Non-essential	25	22 %
Some segments were essential, some were not	5	4 %
Don't know	7	6 %
Missing	5	4 %
Total	115	100 %

3.5.2.6. Respondent Characteristics

The respondents varied in their roles and experience at their respective businesses. Tables 3-24 and 3-25 present respondents' roles and length of time at the business, respectively. Most respondents (57 %) were the managers, but many were both owners and managers (22 %). Respondents who were just owners of the business made up only 15 % of respondents. Only eight respondents (or 7 %) were neither an owner or manager, but rather a family member or other senior employee. Most respondents began working for the business in the last 20 years: 35 % began working at the business between 2003 and the time of the survey, 23 % began working between 1983 and 2002, 4 % between 1963 and 1983, and 1 % prior to 1963.

Table 3-24. Respondent's role with this business.

Business Role	Count (No.)	Percent (%)
Manager	65	57 %
Owner	17	15 %
Owner and manager	25	22 %
Other	8	7 %
Total respondents	115	100 %

Table 3-25. Respondent experience working at the business.

Managerial Experience (as applicable)	Count (No.)	Percent (%)
Up to a year	1	1 %
Between 1 and 10 years	9	8 %
Between 11 and 20 years	30	26 %
Between 21 and 40 years	27	23 %
Between 41 and 60 years	5	4 %
Over 60 years	1	1 %
Missing or N/A	42	37 %
Total	115	100 %

According to Table 3-26 most respondents who were answering the survey for the business were aged 60 or above (30 %). The rest were distributed across the age groups of 20 to 29 years (8 %), 30 to 39 years (20 %), 40 to 49 years (24 %), and 50 to 59 years (14 %).

Table 3-26. Respondent age.

Age	Count (No.)	Percent (%)
20 to 29 Years	9	8 %
30 to 39	23	20 %
40 to 49	28	24 %
50 to 59	16	14 %
60 and over	35	30 %
Missing	4	3 %
Total	115	100 %

According to Table 3-27, among 115 respondents only 4 % identified as Hispanic or Latino. Furthermore, Table 3-28 illustrates that most business respondents identified as American Indians (22 %). Among other respondents who were interviewed at the businesses, 3 % identified as both American Indian and White, 3 % identified as Asian alone, 11 % identified as Black alone, 2 % identified as White Alone, and 5 % identified as another race or racial combination.

Table 3-27. Respondent identification as Hispanic or Latino.

Hispanic or Latino	Count (No.)	Percent (%)
No	107	93 %
Yes	5	4 %
Missing	3	3 %
Total	115	100 %

Table 3-28. Respondent racial identity.

Racial identity	Count (No.)	Percent (%)
American Indian	25	22 %
American Indian and White	3	3 %
Asian	4	3 %
Black	13	11 %
White	2	2 %
Other	6	5 %
Missing	62	54 %
Total	115	100 %

Tables 3-29 and 3-30 show the level of education reported by respondents. According to Table 3-29, nearly 81 % of the respondents at the businesses interviewed had between 12 and 16 years of schooling. Of those surveyed, 10 % had over 16 years of schooling and 4 % shared that they had

less than 12 years of schooling. Similarly, with respect to highest degree earned, Table 3-30 shows that respondents of the business predominantly had a high school education or GED (41 %). The next most common degree was either an associate degree (26 %) or Bachelor's degree (23 %). Finally, 5 % of respondents had a master's degree or higher.

Table 3-29. Respondent number of years of schooling.

Years of Schooling	Count (No.)	Percent (%)
Less than 12	5	4 %
Between 12 and 16	93	81 %
Over 16 years	11	10 %
Missing	6	5 %
Total	115	100 %

Table 3-30. Respondent highest earned diploma or degree.

Highest Degree Earned	Count (No.)	Percent (%)
Associate degree	30	26 %
Bachelor's degree	27	23 %
High school	47	41 %
Masters or higher	6	5 %
Missing	5	4 %
Total	115	100 %

3.5.2.7. Choice Exercise on Loans

For the last section of the survey, the team implemented a discrete choice activity centered around the preferences of small businesses for locally funded disaster assistance loans. This exercise was carried out with the purpose of better understanding small businesses' loan preferences during post-hurricane recovery periods. In particular, there was a need to understand the tradeoff (or preference) between disbursement immediacy and larger disbursed loan amounts (i.e., loan size). To attain this objective, variations in the loan size by the program (stated as multiple months of payroll) and the disbursement waiting period were included across three questions or choices. Table 3-31 shows descriptive statistics of the different loan attributes and responses; however more advanced analytical methods will be needed to tease out respondent preferences. The three choice questions are reprinted, below, for reader convenience.

Choice A:

- Loan A will have funds available at 30 days after pre-approval and the total value of the loan is worth 2 months of your typical payroll.
- Loan B will have funds available at 180 days after pre-approval and the total value of the loan is worth 6 months of your typical payroll.

Choice B:

- Loan A will have funds available at 180 days after pre-approval and the total value of the loan is worth 2 months of your typical payroll.
- Loan B will have funds available at 360 days after pre-approval and the total value of the loan is worth 6 months of your typical payroll.

Choice C:

- Loan A will have funds available at 30 days after pre-approval and the total value of the loan is worth 2 months of your typical payroll.
- Loan B will have funds available at 360 days after pre-approval and the total value of the loan is worth 6 months of your typical payroll

In general, respondents did not wish to apply for an assistance loan. However, those that would apply demonstrated a preference for smaller loan amounts with faster disbursement periods as opposed to larger loans with longer waiting periods. This finding warrants further investigation into the factors that influence the preference for the immediacy of disbursement over disaster assistance loan size from local sources.

Table 3-31. Loan choice exercise.

Alternatives	Choice A	Choice B	Choice C
Loan A: Faster loan	17 (15 %)	20 (17 %)	21 (18 %)
Loan B: Larger loan	16 (14 %)	10 (9 %)	11 (10 %)
Wouldn't apply	48 (42 %)	50 (43 %)	48 (42 %)
Missing	34 (30 %)	35 (30 %)	35 (30 %)
Total	115 (100 %)	115 (100 %)	115 (100 %)

3.5.3. Longitudinal Findings

Figure 3-4 presents the occupancy status of the commercial units in Lumberton. Occupancy status was chosen as a longitudinal metric for two reasons. The first reason is practical: Wave 4 relied predominantly on observational data, which lends itself to occupancy indicators. This allows Wave 4 to be included in the analysis. The second reason is because occupancy status can be an important indicator for the community as a whole in terms of availability of services, economic development and employment, and tax revenue. The diagram in Figure 3-4 begins with Wave 2, which was the first study wave to include a business sample. A refreshment sample was added prior to Wave 4 and can be followed separately in the Sankey diagram.

In the longitudinal sample, 162 commercial units were occupied at the start of Wave 2 out of 223, which made up 73 % of the sampled units. By Wave 3c, that share grew to 76 %. In Wave 4, the percentage of occupied units was 89 %, however this does not include missing data and includes the addition of the refreshment sample. Many of the longitudinal businesses, both previously occupied and unoccupied, had missing data. Additionally, the refreshment sample was drawn from the northern floodplain and non-floodplain areas, which were not likely to have been flooded by the hurricanes, compared to the longitudinal sample, which was sampled

entirely from the inundation area and floodplain. In Wave 5, 85 % of units with a determined occupancy status were occupied. Again, there were many missing occupancy determinations. Future work can supplement the visual determinations with secondary sources to help create a clearer picture of occupancy changes through time.

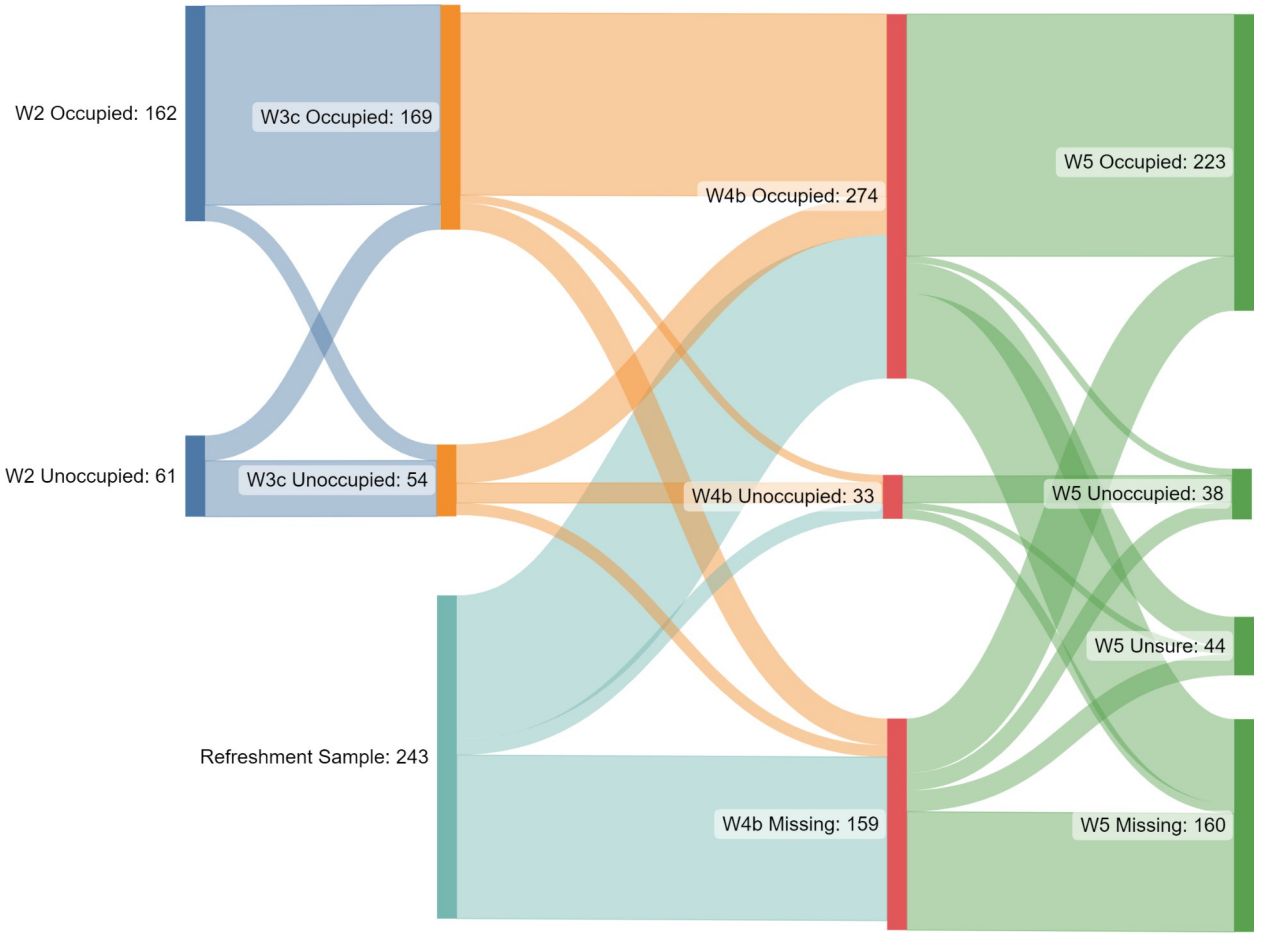

Figure 3-4. Longitudinal occupancy status of commercial buildings in Lumberton.

4. Chapter 4: Critical Infrastructure Sector Interviews

In the earlier waves of the study, given the reliance of the whole community, including housing and businesses, on utility services, the research team met with key infrastructure operators to gain their perspective on resilience and recovery decision making. New to Wave 5 is the conduct of semi-structured interviews with critical infrastructure sectors. The interviews were designed to systematically learn about their resilience planning and recovery decision processes, an area which is not well-documented. This chapter reports on the findings of these interviews and is supplemented with analysis of the responses to the utility service questions asked in the housing and business surveys. The insights gained are shared, as well as their impact on the development of computational models that support infrastructure resilience decision making.

4.1. Goals and Objectives

The main goal of the infrastructure interviews was to elicit decision process trends and constraints to inform the development of decision support models for community resilience planning. Information was sought on several aspects of the decision-making process of infrastructure operators. In particular, a better understanding of the kinds of problems confronting utility service providers was sought to ensure the relevance of the decision support models being developed by the Center, NIST and other resilience researchers. The specific goals of the infrastructure interviews included:

- Characterizing infrastructure sector decision processes as they relate to resilience, including the framing of decision problems, data and models in use
- Assessing the potential for adopting higher levels of decision support requiring additional data and decision-maker engagement
- Documenting the communication between the infrastructure sectors
- Understanding issues related to obtaining and allocating resources needed for recovery
- Identifying interdependencies and collaboration across infrastructure sectors
- Gaining information on restoration plans
- Obtaining information on system operation and layout pertinent to system resilience (e.g., network redundancy, local storage to endure outages)
- Understanding the influence of stakeholders on decision processes
- Documenting the dynamics of decision making, including the evolution or resolution of challenges, the adoption of disaster mitigation policies, and the emergence of new decision problems
- Capturing where institutional culture and the pursuit of benefits not directly related to resilience ("co-benefits") can determine unique pathways for decision making that improves resilience

This information also serves the broader goal of testing the infrastructure components of computational community resilience planning models.

4.2. Interviewee Selection

Interviews were sought with officials in key infrastructure sectors (see interview consent form in Appendix H). Infrastructure sectors and their associated functions have been grouped in several ways (FEMA 2021, CISA 2024). Here, the sectors adopted are those specified by the Cybersecurity and Infrastructure Security Agency (CISA) within the U.S. Department of Homeland Security. CISA, as the national coordinator for critical infrastructure security and resilience (in addition to being the operational lead for federal cybersecurity) provides guidance to support state, local, and industry partners in identifying the critical infrastructure sectors and the essential workers needed to maintain the services and functions Americans depend on daily. CISA defines critical infrastructure as "those assets, systems, and networks that provide functions necessary for our way of life" (CISA 2024). CISA defines 16 critical infrastructure sectors[5] that are part of "a complex, interconnected ecosystem and any threat to these sectors could have potentially debilitating national security, economic, and public health or safety consequences."

Table 4.1 lists the CISA critical sectors for which interviews were targeted and secured. Among the considerations in selecting infrastructure sectors to target were alignment with the, CISA critical infrastructure sectors, the extent of damage or disruption from Hurricanes Matthew and Florence, history of contact during earlier waves, data sharing between waves, and the strength of interdependencies with the other selected sectors. Budget constraints for the study were also a consideration, limiting the number of sectors. Four CISA critical sectors were ultimately selected: Water and Wastewater Systems, Transportation Systems, Energy, and Food and Agriculture. In Table 4.1, for each critical sector, the name of the interviewed entity or entities, and the rationale for their selection are given.

The *Water and Wastewater Systems* sector provides water supply and wastewater management services, which are vital to communities. Safe drinking water is "a prerequisite for protecting public health, commerce, and other human activity", while properly treated wastewater is "vital for preventing disease and protecting the environment" (CISA 2024). In Lumberton, this sector is managed by the City of Lumberton Department of Public Works (Public Works). Members of the study team met with Public Works in each of the prior waves to learn about the impacts to and the recovery of their water systems. In contrast to Wave 5, these prior meetings were not structured, systematically conducted interviews but instead were free-ranging discussions that were helpful for interpreting the results of the household and business interviews. As described in the Wave 1 report, the water supply and water treatment system sustained significant damage from Hurricane Matthew, including to their water supply system in the form of damage to their river intake pump, and to their water treatment plant. This damage resulted in a complete lack of water service for five days followed by partial service under a conservation notice, with resumption of normal service after 15-16 days. The resumption of service was only possible with temporary measures that included bringing in four trailers carrying portable membranes to treat groundwater (van de Lindt et al. 2018). The lack of functioning of the Water and Wastewater Sector impacted government, citizens, businesses, and service providers, such as the Healthcare and Public Health Sector, which faced a lack of potable water impacting the

[5] The 16 CISA critical sectors include: Chemical; Commercial Facilities; Communications; Critical Manufacturing; Dams; Defense Industrial Base; Emergency Services; Energy; Financial Services; Food and Agriculture; Government Facilities; Healthcare and Public Health; Information Technology; Nuclear Reactors, Materials, and Waste; Transportation Systems; Water and Wastewater Systems.

functioning of a local hospital; as learned in Wave 2, these issues were addressed later with an increase in the amount of backup water at the hospital (Sutley, Dillard, and van de Lindt et al. 2021).

Table 4-1. Interviewees representing key CISA Sectors.

CISA critical infrastructure sector	CISA critical infrastructure components	CISA critical infrastructure importance	Interviewee(s)	Reason for selection
Water and Wastewater Systems	Water supply and wastewater management services	Protection of public health, and the environment; support of business operations	City of Lumberton Department of Public Works	Extensive water system damage from Hurricane Matthew resulting in a 5-day complete outage, 10-day conservation notice, 15-day boil water advisory.
Transportation Systems	Aviation, highway and motor carrier, maritime transportation system, mass transit and passenger rail, pipeline systems, freight rail, and postal and shipping	Movement of people and goods quickly, safely, and securely	North Carolina Department of Transportation (NCDOT)	Extensive flooding from Hurricanes Matthew and Florence resulting in road closures, including I-95
Energy	Electricity, oil, and natural gas	Supports community stability, as well as functionality across all critical infrastructure sectors	Duke Energy Corporation	Duke Energy manages the transmission system Substation feeding City of Lumberton flooded during Hurricane Matthew
			City of Lumberton Electric Utilities Department (Public Power)	Public Power manages Lumberton's power distribution system Perspective on power resilience and restoration following Hurricanes Matthew and Florence
Food and Agriculture	Farms, registered food manufacturing, processing, and storage facilities, restaurants	Accounts for around one-fifth of the nation's economic activity	North Carolina Cooperative Extension–Robeson County	Example of a non-traditional critical infrastructure sector Agriculture and livestock are leading industries in Robeson County

The CISA *Transportation Systems* sector consists of seven key sub-sectors including aviation, highway and motor carrier, maritime transportation system, mass transit and passenger rail, pipeline systems, freight rail, and postal and shipping subsectors. The North Carolina Department of Transportation (NCDOT) is responsible for all modes of transportation in North Carolina, including highways, rail, aviation, ferries, public transit, and bicycle and pedestrian transportation. The transportation system was profoundly impacted from the flooding associated with Hurricane Matthew, most prominently with the inundation and resulting closure of Interstate-95 (I-95) at the Lumber River (van de Lindt, Peacock, and Mitrani-Reiser et al. 2018). The flooding and I-95 closure were then repeated with Hurricane Florence. The experience with Hurricane Matthew highlights the complex interdependence between Transportation Systems, Water and Wastewater Systems and the CISA sectors Emergency Services and Healthcare and Public Health. Robeson County Emergency Services and North Carolina's Emergency Operations Center (EOC) raised in Wave 1 discussions the issue of local drownings on roads. Indeed, CDC reported for Hurricane Matthew that, in North Carolina, 18 of the 26 fatalities over a two-week period were vehicle drownings (Wang 2017). In Wave 2, the team learned that the local hospital had been inaccessible for several hours after Hurricane Matthew as a result of stormwater drainage issues leading to flooding of local roads, which was remedied later with three miles of stormwater drainage improvements (Sutley, Dillard, and van de Lindt et al. 2021). Prior to Wave 5, the team had met with NCDOT personnel with the conversation largely limited to learning of the damage to and repair of I-95.

The CISA *Energy* sector is recognized by Presidential Policy Directive 21 (White House 2013) as providing an "enabling function" across all critical infrastructure sectors. While the Energy sector consists of three interrelated segments, namely electricity, oil, and natural gas, this study focuses on electricity given its importance at the community scale. Duke Energy manages the power transmission side, while the City of Lumberton Electric Utilities Department (Public Power) handles power distribution and associated assets within Lumberton. Members of the team met with Duke Energy in Wave 1 to learn of the performance of the power transmission system during Hurricane Matthew. One of Duke Energy's substations that feeds Lumberton sustained flood damage that rendered it nonfunctional. Power was resumed only through rerouting of power via a second substation, with resumption of normal operations after a two-month repair of the substation (van de Lindt Peacock, and Mitrani-Reiser et al. 2018). Wave 5 marked the first time the team has met with Public Power and Duke Energy's electric distribution team (a follow up, remote interview), as well as the first time to ask about intervention decisions for resilience across transmission and distribution systems.

The fourth CISA sector selected for Wave 5 is *Food and Agriculture*. Unlike the other three sectors, Food and Agriculture includes a wide range of distinct entities, such as agriculture, food processing facilities, and restaurants (U.S. Department of Homeland Security 2023a). Nationally, it accounts for around one-fifth of the nation's economic activity (U.S. Department of Homeland Security 2023a). In Robeson County, agriculture is a leading industry in terms of production. Gross income from sales of crops, livestock, and livestock products in 2021 were $456M, fifth highest in North Carolina (USDA 2023), or about one-tenth that of Robeson County's GDP for that year ($4.58B GDP) (U.S. Bureau of Economic Analysis 2022). Wave 5 also marked the first time that the study team has met with the Robeson County Extension, a part of the North Carolina Cooperative Extension. The role of agriculture in community resilience and socio-economic stability offered a key broad perspective in Wave 5.

Findings from the Wave 5 interviews motivated the team to seek subsequent interviews about a month after the Wave 5 visit. Follow-on discussions were conducted to learn more about Duke Energy's power distribution assets and ties between transmission and local jurisdictions. In addition, as the infrastructure providers revealed heavy reliance on the *Communications* sector, which CISA characterizes as providing (like *Energy*) an "enabling function" across all critical infrastructure sectors (U.S. Department of Homeland Security 2023b), the team secured an interview with an expert on the telecommunications industry, particularly to learn of the industry's exploration of intervention alternatives for increasing future resilience. These follow-on Wave 5 interviews sharpened the team's understanding of asset management for handling future contingencies.

4.3. Interview Instrument Development

The infrastructure interview instrument (Appendix I), to be applied in a 90-minute interview session with the provider, was developed by researchers from the Center and NIST with experience in the modeling of infrastructure systems, and who are involved in the development of the infrastructure components of computational community resilience planning models. The team has particular expertise developing simulation and optimization models for network-structured systems such as transportation, power, and water networks. The range of experience of the team extends from the development of simulation models for the performance assessment of individual infrastructure sectors to optimization models that support planning and restoration decisions spanning multiple sectors. The team also relied on its members' experience with similar field interviews and elicitation of stakeholder decision problems. Some team members, for example, had worked with the Infrastructure Resilience Division of ASCE to assess risk across water utilities (Zhou et al. pending), and others were involved in data collection efforts following Hurricane Maria in 2017 (Main et al. 2021)

The instrument is designed to inform and enable various types of models. Table 4.2 summarizes recent modeling and algorithmic developments of the Center and NIST, and others in the field, to support infrastructure resilience decision-making. The approaches vary with respect to the scope of their analysis and data requirements.

Table 4-2. Sample of recent computational tools for infrastructure and built environment decision support falling within three categories.

(a) Criticality Assessment

Modeling Strategy	**Citations**
Stochastic resilience-based component importance measures	Baroud, Barker, and Ramirez-Marquez 2014
Probabilistic social impact criticality analysis	Beck and Cha 2022
Probabilistic Dynamic Integrated Network (DIN) Model	He and Cha 2021
Coupled probabilistic vulnerability assessment and agent-based models	Marasco et al. 2021
Probabilistic loss quantification	Nofal and van de Lindt 2020
Disaggregated multi-hazard damage analysis	Sanderson et al. 2021
Sensitivity analysis via stochastic simulation	Tababdeh, Sharma, and Gardoni 2022
Deterministic network vulnerability analysis	Zhou and Duenas-Osorio 2023

(b) Centralized Planning or Restoration Decisions

Demonstration Case	Modeling Strategy	Citations
Power and water systems, along with buildings of Lumberton, NC	Risk-averse two-stage stochastic mixed integer linear program	Harrison et al. 2023
Interdependent gas, water, and power infrastructure of Shelby County, TN	Mixed-integer programming optimization	Gonzalez et al. 2016
Building portfolio of Lumberton, NC	Mixed-integer linear programming model	Gupta et al. 2022
Telecommunication system	Multi-objective optimization	Matisziw, Murray, Grubesic 2010
Transportation system	Two-stage stochastic model	Miller-Hooks, Zhang, and Faturechi 2012
Power infrastructure in testbed community modeled after Gilroy, CA	Approximate dynamic programing with heuristics	Nozhati et al. 2019

(c) Distributed Planning or Restoration Decisions

Demonstration Case	Modeling Strategy	Citations
Interdependent Gas, Water, and Power Infrastructure of Shelby County, TN	Decentralized mixed-integer programming optimization	Talebiyan and Duenas-Osorio 2020
Interdependent power, landline and mobile telecommunications, wastewater, and water infrastructure of New Hanover County, NC	Centralized and decentralized mixed-integer programming optimization	Sharkey et al. 2015
Port of New Orleans' vertically movable bridges	Game theory	Reilly, Samuel, and Guikema 2015
Water and wastewater infrastructure of Houston, TX	Multi-objective mixed-integer programming	Zhou et al. 2023

To better understand the role that these advanced models can play in infrastructure resilience decision-making, it is important first to ascertain the existing level of input data and an understanding of the decision-making process of infrastructure providers. Certain questions in the infrastructure instrument are oriented to this goal, asking what key data is applied and what models are used to inform decisions. Table 4.3 gives an indication of the kinds of data and the levels of decision support and can be useful in situating the providers current level of data and decision strategy. Generally, each step to a higher decision support level generally requires greater data than the prior level. Network criticality indicators (Level 1) require only network topology, with more sophisticated Level 1 methods requiring other network attributes such as the capacity of arcs (e.g., the maximum flow of traffic on road segments). Level 2 extends Level 1 by considering impacts. This necessarily involves data on hazard loadings and the ability of assets to resist those loadings, and population data to link loss of assets to a measure of population wellbeing. Levels 3 and 4 extend the decision support further by addressing specific decision support challenges. Level 3 involves the application of optimization methods to address the large scale of the infrastructure systems and typically multiple decision objectives (e.g., resilience, cost, equity) that render a manual search process unlikely to yield effective solutions. Level 3 requires data on budget and other resource constraints, information on decision-maker priorities and objectives, and knowledge of available decision options and their costs. Finally, Level 4 decision support incorporates further realism with the capture of the distributed (i.e., decentralized) nature of the decision-making process and range of demonstrated decision behaviors (e.g., loss aversion). Level 4 still requires further data and engagement with decision makers.

Table 4-3. Decision support levels and associated data requirements.

Decision levels → **Data needs ↓**	**Level 1: Network Criticality Indicators**	**Level 2: Impact-Based Criticality**	**Level 3: Optimization-based interventions**	**Level 4: Strategic and distributed decisions**
Network topology (nodes, arcs): Adjacency list or adjacency matrix	X	X	X	X
Node types, locations	X	X	X	X
Arc types, layouts, capacities	X	X	X	X
Site hazard analysis, loading data		X	X	X
Asset fragility functions, hazard resistance		X	X	X
Infrastructure service areas		X	X	X
Population data, dislocation estimates		X	X	X
Available resources (crews, inventories, financial, etc.)			X	X
Prioritization of objectives (regional areas of importance, dislocation time)			X	X
Intervention alternatives, policies			X	X
Replacement and retrofit costs			X	X
Decision behaviors (competitive, cooperative)				X
Decision process and heuristics (satisficing, risk policies, loss aversion)				X
Strategies to cope with bounded rationality				X

Other questions in the interview instrument are oriented to elicit the provider's specific framing of their decision problems. To guide this set of questions, a successful strategy in the decision sciences was adopted, which breaks down decisions into parts that constitute the steps within the real-world decision process. In particular, the PrOACT approach was adopted (Hammond, Keeney, and Raiffa 1999), which focuses on the how of decision making by asking about Problems that require decisions, Objectives to achieve with such decisions, varied Alternatives to satisfy competing objectives, assessments of the Consequences from each alternative, including awareness of the Trade-offs across alternatives and objectives.

For illustration, Table 4.4 sketches a sample decision problem, with emphasis on the elements of the PrOACT decision process that allow computation of consequences from sets of alternatives and their outcomes. In the table, terminology used in the development of decision-making

models is used. For each problem, it is important to understand the range of potential actions under consideration (i.e., alternatives and decision variables), how these actions are being compared, that is, the objectives against which the actions will be assessed (i.e., objectives), and key constraints limiting the decision-making process of the infrastructure operators (i.e., constraints). Trends on decision-making revealed through the interviews in this and future waves will align the development of community resilience planning models to community decision making under uncertainty in practice.

Table 4-4. Sample decision problem with elements of the decision process and modeling potential.

Sample decision problem: Maintain maximum customer service coverage	
Elements of decision process for models	**Practical examples**
Objectives	Maintain maximum service coverage Maintain system stability Maintain safety
Alternatives and Variables	Elevate key assets by X meters Relocate assets to (Y, Z) coordinates Add redundant assets in location (Y, Z) Replace old technology with new technology increasing flood resilience to Q level
Constraints	Ensure public safety: minimize disruption days Ensure fairness of interventions Establish budget caps

The basic strategy taken for eliciting the providers' decision processes was to ask questions that re-create such decision processes. The provider, in Appendix I, is asked to think of a decision problem brought about by Hurricanes Matthew and Florence and the need to do something about it anticipating future severe weather events. The questions touch upon each of the components in Table 4.4. This information is helpful to the development and calibration of decision support models, ensuring that real-world problems are being addressed.

Then, questions in Appendix I focus on securing specific information needed for the development and validation of decision support models like those of Table 4.2, and particularly those developed by the Center and NIST. The interviewee(s) are asked questions, for example, on issues related to resource constraints. These details ensure resultant solutions are feasible, for example, with respect to budgets, or the availability of crews and equipment. Other questions inform more specific kinds of models. For instance, some questions on communications inform the development of decentralized optimization models, which recognize decision makers in different infrastructure sectors and the fact they may not communicate or cooperate in the aftermath of contingencies. Still other questions are aimed at understanding how restoration of services is approached, including any practical rules for prioritizing customers.

4.4. Data Collection Methods

Answers to the interview questions revealed how the infrastructure operators frame their decisions, specific information on their decision-making process, and how the information affects decision support models.

The first part of the instrument (Appendix I) was used to open the semi-structured interviews. This was not shared in advance, which helped to elicit the issues of concern at the time of the interview without forethought. Then, the team eased its way into the decision and constraints questions in Appendix I. Together, the questionnaires helped ensure the discussions centered around salient issues of the day, but with historical context and challenges, as intended for the longitudinal nature of the study.

The second part of the instrument (Appendix I) was made available to the infrastructure sector contacts one week prior to the interviews. This provided each sector representative a sense of its scope and, importantly, provided them the opportunity to enlist support personnel as necessary. The aim for participation in the interview was to assemble about two to three representatives per sector—a goal achieved at the time of the in-person or follow up interviews across all sectors.

An additional step to collect data was to conclude each of the interviews with explicit designated follow up contacts and actionable tasks, particularly to address clarification questions and coordinate the sharing of documents or data sets. Data sharing to complement responses to the interview questions has already occurred at various levels of detail in between waves in the past with NCDOT (e.g., flood impact reports), Duke Energy (e.g., power transmission test system after a signed MOU with Duke Energy), Lumberton's Public Power (e.g., location of distribution poles and sketches of circuits), and Public Works [e.g., details for a hydraulic model of their water distribution network in EPANET (Rossman et al. 2020).

4.5. Decision Processes and Findings for Critical Infrastructure Service Providers

The plan set at the interview guide development phase starts with the breakdown of a decision problem of high concern at the time of the interview and continues with details of decision processes that lead to action, in light of local constraints, regional context, and historical interventions.

Overall, most sectors have faced significant challenges in acquiring resources, such as disaster response crews, materials, and funds. Interviewees, particularly the local providers, reported that hiring and maintaining a qualified workforce was also challenging due to insufficient incentives, as qualified workers often accept more attractive options in more affluent neighboring jurisdictions or states. In addition, pandemic impacts on supply chains resulted in long lead times for new equipment and spare parts. These reported logistical issues combined with limited funds and inflation in the country in 2022, exacerbated the difficulty of maintaining a sufficient inventory for operation, upkeep, emergency response, and resilience.

Understanding the breakdown of decision processes is at the heart of decision support as it informs how problems lead to objectives, alternatives to satisfy such objectives, and consequences from not achieving objectives. The subsections that follow focus on this problem-to-consequences phase, with a summary in Table 4.5.

4.5.1. Decision Problems

To elicit decision problems, at the time of the interview each of the critical infrastructure sectors were asked to identify their main challenge to achieve disaster resilience. Responses ranged from limited experience managing the execution of capital investment projects, to alternatives for the shortage of supplies and labor, the identification of strategies to improve operations, limited resources for benefit/cost analyses of alternatives, and the search for better strategies to maintain overall customer satisfaction. In particular, there was significant interest in minimizing the impact of events on customers via infrastructure hardening. Also, there were challenges on how to improve emergency operation practices tailored to different constituents like elderly citizens, emergency services, businesses, etc. In addition, there was interest on how to best invest various but limited resources to achieve resilience, how to manage assets and personnel ahead of an event, and how to disseminate information to manage contingencies more effectively. Salient infrastructure sector-specific concerns are described below.

The *Energy Sector* was concerned with how to justify strategies to improve reliability, such as undergrounding segments of the transmission network and quantifying the benefits and costs of such interventions. Importantly, the undergrounding project would be for upwards of a hundred miles of transmission lines to link future offshore wind power to an inland transmission substation. As for the power distribution system, the challenge was mainly on how to secure materials and equipment like poles and transformers to ensure customer service and expeditious outage restoration. There was also interest in asset management tools, particularly for proactive upkeep and replacement.

In the *Food and Agriculture Sector*, the main decision problem expressed was how to make farmers aware of available help from Emergency Services, both from the City and the County. Also, a standing challenge is that of how to rescue stranded animals and the coordination of County and State animal response teams.

4.5.2. Decision Objectives

Shared across infrastructure sectors was the objective of service continuity, typically measured as a percentage of customers with commodity demand satisfaction. This objective naturally allows for quantitative progress tracking and serves as a stability metric of resilience. For instance, the energy sector wanted to make decisions to support their goal of restoring electricity without any safety incident to as many customers as possible. Similarly, the water sector decisions focused on having a normal level of raw water intake (supply) and fully using their capacity for potabilization. During contingencies, the water sector reasons that if supply is normalized as fast as possible, water distribution will necessarily follow–in practice this objective still offers opportunities for a smart systems future with distribution-level temporal monitoring, modeling and analysis capabilities. As for the transportation sector, it remains preoccupied with the objective of efficiently rerouting I-95 if the need arises, while managing high volumes of vehicles and a variety of weights, which pose safety and structural integrity challenges in and around local re-routing roads. These objectives across sectors were said to be limited by availability of crews, materials, equipment, and funds among others, as detailed in Constraints below.

4.5.3. Decision Alternatives

Identifying and assessing decision alternatives is a critical step of the decision process, as considered alternatives constrain future ones, and affect the use of resources and management of ongoing interventions. Alternatives revealed by all infrastructure sectors tended to fall into two broad categories: one is related to lessening the impact of flood hazards by increasing resistance (e.g., hardening or by reducing exposure), and the other one adds system redundancies so as to gracefully handle component failures. As detailed below, strategies to achieve decision objectives tended to be tried-and-true alternatives, perhaps with practical variations on standard approaches, with only a few out-of-the-box alternatives playing a role in infrastructure decisions.

The most common measure to lessen flood hazard demands on system components and operation was to elevate facilities and equipment. Examples from the energy sector included the elevation of entire substations, particularly those few close to the Atlantic coastline. Similarly, the transportation sector embraced the significant elevation of portions of I-95 through Lumberton (and possibly of I-74) for several miles north and south of the Lumber River at 4 m (13 ft.) high. Also, the water sector sought to elevate generators and its main raw water intake. Other common strategies to lessen flood hazard demands included adding external lines of defense with a higher flood protection level, such as new or taller levees and berms to protect facilities and equipment, as with the water treatment plant (WTP) or select power transmission substations. In particular for power infrastructure, flood walls were built around flood-vulnerable substations, with the option of sealing the gate to enclose the entire substation, while equipping it with pumps and access hardware. The innovation to this standard approach of reducing hazard demands was to make the sealing gates removable and lightweight for easy and expeditious maneuvering. Finally, some sectors, like transportation, also considered the less-traveled road of building a new dam upstream of Lumberton to mitigate flooding, although this alternative was discarded on the basis of preliminary costs.

An observation from the interview team is that there was limited coordination early on across infrastructure sectors regarding the level of flood protection for the design of alternatives. The most common design benchmark was that of 500-year events, but this was not a consensus goal across sectors. One example of a project with design goals for the 500-year event is the construction of a flood gate to protect Lumberton from inundation. This project, despite early limited coordination, triggered coordination as it became a reality, requiring adjustments to construction tasks and flood-level design choices across multiple agencies, from Public Works to NCDOT, to power operators, and the railroads.

Another common category of alternatives to achieve infrastructure sector resilience objectives was that of adding redundancies to constituent systems. These include redundancies or expansions in supply, as well as redundancies and backups in components at facilities or in the transport of commodities. As an example, the water sector considered new redundant sources of water, particularly groundwater wells, with old wells becoming the backup. This sector also considered adding redundancy with decentralization of water potabilization plants but ruled it out on cost grounds. The power sector is considering more sources of renewable energy, particularly 79 MW solar farms (currently in operation and more to be added), as well as potential offshore wind farms. These new sources can offset some polluting sources or add to them if they are needed together in the aftermath of contingencies. System redundancies also take the form of storage and backup mechanisms. For instance, there are opportunities to store water in a new 0.5 MG elevated tank, which will also serve as fire support for a new Industrial Park meant to

promote new economic development in the city. Additionally, there was widespread impetus to expand and manage gasoline and diesel generators across all infrastructure sectors. However, infrastructure sectors also indicated interest in natural gas generators as alternatives given their constant supply via pipelines, and the ability to minimize reliance on possibly obstructed transportation networks. In general, the sentiment was that varied alternatives to electricity and water were welcome, multiple strategies can be better at keeping essential equipment running for basic operation, including electricity for computers and telecommunications equipment. Also, storage of water to support operations and associated sanitary processes remained a desirable alternative critical to achieve the goal of system service delivery goals.

Other alternatives to satisfy objectives were in the form of pre-emptive support, including mutual aid agreements for materials and direct a priori engagement with suppliers. Similarly, there remain opportunities to link separate systems for on-demand redundancy, such as joining water pipes from the City and from the County at predefined water main locations or joining similar-voltage power junctions for sub-transmission and distribution systems across jurisdictions. In addition, vegetation management is always welcome across sectors, particularly power and water, as it is more common that sector failures initiate with tree failure events than with structural or facility failures.

4.5.4. Consequences

In the pursuit of their operational and safety objectives, infrastructure sectors aligned on avoiding negative consequences. In particular, operators want to reduce the potential for system instability because of the high negative consequences for the system and customers. Infrastructure sectors also sought minimization of service outages, as they carry obvious socio-economic consequences, particularly when extended beyond interruptions of minutes or hours. In keeping stability and system service, every interviewee stressed the need to maintain personnel safety and not let incidents happen.

Another common worry for infrastructure sectors is that of underperformance of protected areas or formerly intervened assets. Public works, power systems and transportation sectors were all concerned with flooding on the protected side of levees, temporary berms or sealed gates. The concern is that protections lead to a heightened sense of safety among operators, citizens, industrial facilities and other users of utility services, but designs for protective structures always strike a compromise between cost and level of protection. This is an area where design codes and guidelines play a role, showcasing how risk categories and flood hazard design criteria relate for the planning and execution of projects involving flood protection systems.

With the problem-to-consequences breakdown just discussed by infrastructure sectors, the following subsection focuses on contextual details constraining such decision problems. Constraints are at the core of decision making, mediating what is possible and what is not, forcing planning changes, difficult prioritization, and also novel thinking including the use of emerging science and technology.

4.5.5. Constraints

While crew availability, monetary resources, equipment and materials tend to limit the set of management possibilities to infrastructure sectors before, during, and after contingencies, there

are additional constraints that cut across sectors. One example is that of prioritization of resources, either for areas to restore service or areas for planning improved future service. To achieve decision objectives, infrastructure sectors commonly defer priority to emergency services and essential facilities, hospitals, hospices, assisted living centers, and customers (private or commercial), while also accounting for the requests from community leaders. Specific priority entities named by infrastructure operators included fire departments, police departments, assisted living facilities, and resource centers. These prioritizations typically take into account the fact that some facilities or institutions have their own power, water sources, and alternative communication systems. All sectors also coordinate with the local Emergency Control Center (ECC), which often sets and communicates priorities for intervention, particularly when considering public safety and regional stability.

An interesting example of emerging constraints among infrastructure sectors is that of *communications.* For instance, most sectors depend on cellular phones and pre-existing personal connections. The potential constraint is that cellular communication, while performing well during past events is not necessarily guaranteed to perform in future events, leaving the possibility of severed communication within and across sectors.

In addition, a great deal of communication happens through personal communication even if typical means of communication are available. This is because contacts are established through frequent pre-event discussions/coordination with other decision-makers, who know critical locations and local emergency management practices. The downside of this person-to-person crisis management network is that of a possible communication vacuum when personnel retire, get promotions, or change jobs.

Another common example of constraints among sectors is that of mutual aid among utility operators, particularly power systems, which makes additional crew and equipment supplies available in the aftermath of a hazard event, but with the caveat that as large events affect multiple utilities, the overall assistance may not meet all needs as the total number of crews may be in short supply. In addition, even when assistance arrives, the extra workforce and the management of their accommodations and safety becomes a logistical challenge when providers compete over limited resources, ranging from qualified personnel, to hotels, water and food, to the daily planning of routes and access to repair sites after an event. These latter challenges apply to most infrastructure sectors, which were also exacerbated by the post-pandemic supply-chain delays and workforce realignment.

Besides resources and internal logistics, infrastructure sectors also experience tangible constraints from their interdependence with other sectors and government (federal, state, and local). In general, the execution of large capital projects to improve resilience leads to operational and planning constraints. For example, the widening and elevating of I-95 (and possibly I-74), spearheaded by the transportation sector and government agencies, imposes restrictions on the layout of electric power and water systems, as well as the options for future community development, and alternatives for resilience-based decision-making, such as the installation of floodgates, berms, and the relocation of facilities. Interdependence constraints also require more coordination among sectors, as not only do interventions need to be agreed upon, but the very details of their designs as well. To recapitulate the main example in Lumberton, the floodgate design required significant coordination between transportation, public works, power, and the railroad company on not only the type of protection (i.e., type of floodgate), but also its

location and its elevation, with the latter pitting different design practices and demanding iterative solutions as coordination emerged slowly.

Finally, long-term resource constraints are typically managed by infrastructure sectors via grants, cost sharing agreements, or local funds. For example, the local transportation sector got significant federal support for the I-95 elevation and widening, so it only is responsible for 25 % of the cost. However, for a local sector, 25 % of a large capital project could equate to millions of dollars, which still poses a challenge for communities like Lumberton. Additional alternatives include recovery funds that are distributed through the state or its subcontractors. For example, the Golden LEAF Foundation, selected to serve as subcontractor to the state of North Carolina to manage the distribution of significant amounts of recovery assistance, has granted capital reserve funds to infrastructure sectors for projects that improve system operation and amplify future resilience. Examples include partial funds for the raw water intake elevation project, the floodgates, and various local drainage systems.

4.6. Summary of Interventions and Paths Forward for Infrastructure Resilience

The intervention alternatives and constraints reveal thus far that to improve infrastructure sector resilience, agencies have a tendency to deploy shovel-ready projects already in their intervention planning portfolios, execute opportunity projects enabled by post-disaster funding, and plan for long-term alternatives. Specific to Lumberton, infrastructure sectors aimed to reduce the impact of future floods and accelerate infrastructure service restoration for community resilience. This was commonly achieved by elevating assets, moving facilities or protecting facilities. Less common but still considered as potential interventions were adding new assets or adopting new technologies and best practices.

Regarding infrastructure-specific actions, besides barrier interventions such as the city floodgate or temporary berms around public works facilities, infrastructure sectors are building upon typical interventions and expanding their portfolio of alternatives. This latter point is significant as funding applications typically require comparisons among alternatives, incentivizing contrasts between existing and new intervention ideas. As an example, the water sector is considering exposure reduction in operations, besides addressing their issues with water intake and potabilization plant flooding. In particular, the water sector considered raising power generators and controls 0.914 meters (3 feet) above the flood line, much like the transportation sector with their goal of raising I-95 up to reduce exposure to closures. As an additional layer of redundancy, the transportation sector is also defining re-routing strategies and conditioning of such detours of I-95 throughout the city and neighboring jurisdictions. A bolder strategy for the future across sectors is to reduce exposure by relocation of assets to a no-flood zone. For example, public works considered this approach for their headquarters to ensure capability of operation and coordination during and after events.

Besides hardening, redundancies, and exposure reduction, the space for new technologies or existing technologies opens up. For instance, the water sector is considering adding supervisory control and data acquisition (SCADA) systems, used in the power sector, to monitor the largest fuel tank for the refurbished backup power generator (to operate up to 6 days). The power distribution sector is in turn considering Advanced Metering Infrastructure (AMI) to acquire automatic situational awareness of outages in the field. The power transmission sector is attempting to achieve joint resilience and sustainability goals by possibly investing up to $10

Billion in transmission generation (including renewables), transmission lines, and control technologies, so as to support corporate goals of reliability, return on investment, and future carbon neutrality. This sector is also eyeing the performance of microgrids, the acquisition of MW-level tractor trailers for emergency response, the testing of batteries for storage, and the computational modeling of failure rates of equipment and components from field data.

Technology also helps with shorter-term operational goals across infrastructure systems. Examples include expanding or acquiring alternative means for communication, such as two-way radios and satellite phones. Also, infrastructure sectors desire computer-assisted generation of user-friendly day-to-day plans before, during and after events. The goal is to start with 5-day-ahead plans, updating daily down to the event day, and further integrating with up to a week of daily plans after the event. Also, as these plans are specific to an event, there is interest in future generic restoration plans, informed or adapted through time to serve as templates for training and what-if computer simulations. Infrastructure sectors reported that usually there are sporadic documents with information on the restoration process for a given event, but not necessarily an automatic and systematic extraction of best practices and lessons learned from cumulative experience (which currently resides mainly with personnel and not in playbooks). Finally, there is openness to using or examining data visualization tools as well as computational models of system performance.

Given that emerging technologies will continue to rely on telecommunication services (i.e., digitally transmitted data) and power reliability, the team discussed select portions of the interview instrument with representatives of these sectors by videoconference within three months following the Wave 5 field study. At a glance, in a discussion with representative familiar with the general operation of companies with a national footprint, such as AT&T, it was relayed that they tend to operate with a business continuity culture, including routine tabletop exercises and drills, and adequate resources for contingency response (e.g., personnel, equipment). This sector is generally self-sufficient regarding data needs, weather intelligence, and equipment for accessing facilities, including amphibious vehicles, barges, planes, and aerostats. Also, their national footprint allows them to mobilize resources to any place in the country and easily support affected areas. Because of the scale of operation of this sector, there is a great deal of coordination with federal agencies, including the Department of Homeland Security, FEMA, and the Federal Communications Commission (FCC), among others. Finally, the telecommunications sector has the opportunity to test new technologies and their role in resilience, including the use of drones, low-orbit satellites, and flyable cellphone towers, to name a few.

As for power reliability, and confirmed in discussions with representatives of the power company managing the region covering Lumberton, the power transmission sector also has a large footprint and needs to coordinate and report not only with regional and local entities, but also with federal and national agencies, including the Federal Energy Regulatory Commission (FERC) and the North American Electric Reliability Corporation (NERC). In particular, this power transmission sector and its reliability and distribution representatives are aiming at a 5–10-year timeframe to enable power distribution systems to reach above average reliability standards, as quantified by the System Average Interruption Frequency Index (SAIFI), System Average Interruption Duration Index (SAIDI) or the Customer Average Interruption Duration Index (CAIDI), among others. There are plans for a multi-year investment on automation, isolation equipment, and reconfiguration capabilities to enhance reliability and resilience. In

addition, there are plans for increased use of outage management systems and the assessment of asset criticality by hazard types in both power transmission and distribution. Finally, this reliability branch of the power sector also coordinates and strives to simplify processes for travel waivers across jurisdictions, aims to share crisis management plans with state and local government officials, and maintain updated contacts with departments of transportation.

To sum up the trends from the infrastructure sectors interviews, the following Table 4.5 synthesizes key directions across sectors as well as custom strategies with value for adoption by others. Note that several of the unique and desirable interventions by infrastructure sectors remain unaddressed due in part to the lack of decision analysis tools or benefit/cost analysis capabilities, niche areas that computational tools could fulfill in the future to support resilience.

Table 4-5. Summary of trends on decision making by interviewed infrastructure sectors, including public works and its water departments, transportation, energy with power transmission and power distribution, and the food and agriculture sector.

Component of Decision-Making Process	Common Trends across Sectors	Select Sectoral Strategies/Issues
Main Decision Problems	● Execute capital investment projects ● Identify interventions to improve resilience ● Prioritize customer satisfaction ● Coordinate projects and response with other infrastructure systems ● Re-route or add redundancies for sustained infrastructure operation	The public works sector, as an integrative institution, had to reach agreement on return periods for design of the flood gate and associated structures, given impacts on other infrastructure sectors and community services. The consensus, with significant input from the transportation sector including the railroad industry, was to design for 500-yr return periods. The power transmission sector also grapples with deciding target designs, which range from 500-yr return period events to 1,000-yr returns and ad-hoc 100-yr returns plus 0.61 m (2 ft.).
Constraints	● Limited availability of crews, materials/equipment, and funds ● Need for prioritization of resources and locations to use them (starting with essential facilities, hospitals, and assisted living facilities) ● Difficult management of logistics for mutual aid assistance on-site (limitations on hotels, food, equipment)	Public works and power distribution, with their local footprint, grapple with the prioritization of resources for system intervention and operation, while also accounting for non-technical community leaders' requests. Transportation and power transmission, with their local and regional coordination needs, have challenges with communications, both in terms of points of contact and access to equipment or hardware.
Objectives	● Achieve high levels of service continuity and stability ● Aim at no safety incident records	Particularly for power transmission, telecommunications, and transportation, there is impetus to minimize impacts that may escalate at the national level. Expand support to farmers as more than 90 % of the food and agriculture sector is composed of family farms, at the core of community and regional resilience

Table 4.5. Continued.

Component of Decision-Making Process	Common Trends across Sectors	Select Sectoral Strategies/Issues
Current Actionable Alternatives	● Reduce flood exposure via asset elevation, ranging from less than 1m (3.28 ft.) for some public works assets to up to 4 m (13.1 ft.) for transportation infrastructure ● Reduce flood exposure via relocation, as in the case of Public Works headquarters or intakes for water potabilization ● Add barriers to reduce hazard impact ● Harden assets ● Add asset redundancies ● Add storage capacity for supply side management ● Add or expand backup power and fuel, with some sectors like Public Works aiming at 6 days of self-sufficiency ● Consolidate mutual aid agreements and supplier commitments ● Improve communication means via two-way radios and satellite phones	● Construct flood gate for city protection (on going by public works) ● Consider dam upstream of the Lumber River (due to cost, ruled out by NCDOT) ● Deploy infrastructure asset management tools (ongoing across local operators like power distribution and water network) ● Add capability for temporary or on-demand deployable berms as well as sealing gates (ongoing by sectors with local facilities) ● Consider underground power transmission (pending due to lack of benefit/cost analysis) ● Expand renewable energy including solar and offshore wind (ongoing at the power transmission level) ● Expand SCADA systems to critical assets and backup equipment (ongoing at the power distribution level, pending at the water network sector)
Consequences to Avoid	● System instabilities ● Customer outages ● Flooding of protected areas	Any low probability but high consequence event, such as safety issues with nuclear reactors at the power transmission level. Misalignment with national averages of power reliability as measured by energy industry indices like SAIDI, SAIFI, and CAIDI. Sewer overflows in public works systems, given their public health impact.

Table 4.5. Continued.

Component of Decision-Making Process	Common Trends across Sectors	Select Sectoral Strategies/Issues
Future Interventions and Computer-Aided Support	• Expand public education on emergency management resources • Develop restoration playbooks from cumulative experience and consultant analyses • Continue or improve access to weather forecasting tools • Deploy denser arrays of sensors and monitors to improve situational awareness • Exploit drone technologies • Expand sets of alternatives to satisfy objectives, which will also support grant applications	• Consider new wells for potable water supply • Explore decentralized water treatment or potabilization processes • Add gas-fired backup generators with pipe-based supply infrastructure • Add infrastructure connections across jurisdictions, particularly for local sectors like power distribution and water networks • Install advanced metering infrastructure • Acquire or expand physics-based modeling capabilities, particularly to integrate water, sewer, and stormwater systems and inform public works • Improve GPS locators during re-routing operations across transportation sector stakeholders • Consider structural health monitoring and actuation technologies, including remote operation of switches for system reconfiguration in the power transmission sector • Develop computational prediction of asset failures from field failure rates, particularly among the power and water sectors • Normalize use of infrared cameras to assess the state of equipment at the power distribution level • Consider switch to electric bucket trucks to capitalize on electric vehicle grants and align with sustainability goals • Improve crop assessment methods and technologies to easily quantify yield losses or crop damage • Consider methane capture as an alternative source of energy for farmers

4.6.1. Data and Computer-Aided Tools

In light of the variety of future intervention strategies noted by interviewees and an openness to computer-aided decision support, the following material focuses on responses from infrastructure sectors on currently used and desired tools to inform decision making tasks. Respondents discussed tools in the context of both short-term response and long-term planning. We note that insights from respondents are particularly useful for the development of emerging computational tools that assess community resilience and help with infrastructure planning and its management.

In general, utility providers do support their decisions with data and models of varying degrees of sophistication. Weather data and system models are utilized by all utilities. However, the sophistication of such data and models generally increases with the size of the utility operator.

Smaller utilities rely on public weather models, such as the ones published by the National Oceanic and Atmospheric Administration (NOAA) and its National Weather Service (NWS) (NOAA 2023), while larger utilities rely on their own meteorological teams or private consultants. Regardless of the source, they all use such weather monitoring and forecast models to develop their response and recovery plans. These plans ideally evolve from tentative week-ahead plans to more precise day-ahead plans as the forecasting models become more accurate with the approaching event day. Following the hazard event, service providers usually develop and implement day-to-day plans prioritizing interventions for the most pressing community and institutional needs. Future field studies may be designed to reveal attitudes and preferences towards these categories of needs.

Most utilities also rely on data and models of their current network assets, commonly stored in GIS files and asset management databases. Beyond these common inventory tools, each utility sector has specific data and models relevant to them although with high variability in their capabilities. For instance, smaller-system sectors, like the water network, tend to be asset-centric, inferring system performance and customer satisfaction from asset or facility functionality, whereas larger-system sectors, such as the power transmission or transportation sectors, tend to embed assets into network-level analyses. These analyses can inform actions when facing contingencies or identify damage configurations that affect performance or system stability for planning. However, smaller infrastructure sectors do aspire to expand their capabilities from asset-driven to system-level models.

Also, there is an emerging trend to embed monitoring data into models, or to develop data-driven models to complement existing models or by-pass expensive model developments and serve as data-driven screening tools. An example of hybrid model goals is with the power distribution sector, which relies on SCADA and is preparing to incorporate automated meter data into their situational awareness and outage tools. Similarly, transportation relies on bridge flood level watches and placement models, while public works relies on hydrologic and hydraulic (H&H) models coupled with water gauge data, particularly as flood gates come into operation in the future. And while data availability is generally desirable, there could be downsides as experienced by the transportation sector; for example, GPS devices sent traffic from the freeway onto local roads, including closed roads, overwhelming system mobility at critical post-event times.

4.7. Infrastructure Survey Questions Trends

To complement insights from the interviews, the infrastructure team included two questions in each of the housing and business surveys. In particular, the team asked households about alternatives to utility service disruptions and amount of outage time they can cope with (Questions 30 and 31, Appendix A) or expected utility restoration times for businesses and alternatives to utility service disruptions (Question 17, Appendix E). Insights from availability of alternatives and time without services inform infrastructure restoration and planning models. Also, the gap between utility estimates for service restoration and anticipated restoration times by users informs communities on where to manage expectations and plans for closing wide gaps.

Regarding the household survey questions on infrastructure, Figure 4.1 shows households with options to utility service disruptions or alternative information sources (n = 151 corresponding to the unweighted sample; see Subsection 2.4.2.1 for data management specifications prior to

analysis and inference). At least 25 % of the sample (between 40-60 respondents), identified sources of information besides their traditional sources about hurricanes and floods, or have added alternatives to mitigate disruptions, such as propane gas options or power generators. While these responses are encouraging, at least the same proportion of respondents definitely has not taken any actions to increase their options in case of disruption. However, there is awareness of the need for protective actions and for diverse alternative options, as the "other" category reveals a few items in the mind of select respondents, such as radios, walkie-talkies, water, tanks and jugs (for water, gas and oil), and sporadic mentions of community institutions as resources, including churches, hospitals and family (Figure 4.2).

Regarding the number of days households report they are able to cope without specific utility services before considering leaving the home, Figures 4.3, 4.4 and 4.5 show a sample of responses on mobile phone, electric power, and potable water, respectively. Subsection 2.5.2.6 on "Preparedness and Mitigation among Households" contains tables and graphs with detailed responses and weighted samples. Here, at a finer time scale, a general trend is that *at least* a third of the households (between 50-60 respondents) start considering the option of leaving their homes after 3 days without utility services. It is also interesting how mobile phones, despite their more recent arrival to the utility infrastructure, have become as essential as power or water, which traditionally are considered key to recovery and wellbeing. Also, note that the right-most column indicates about 20-40 % of the sample (30-60 respondents) do not care about utility service outages in the decision to leave their homes.

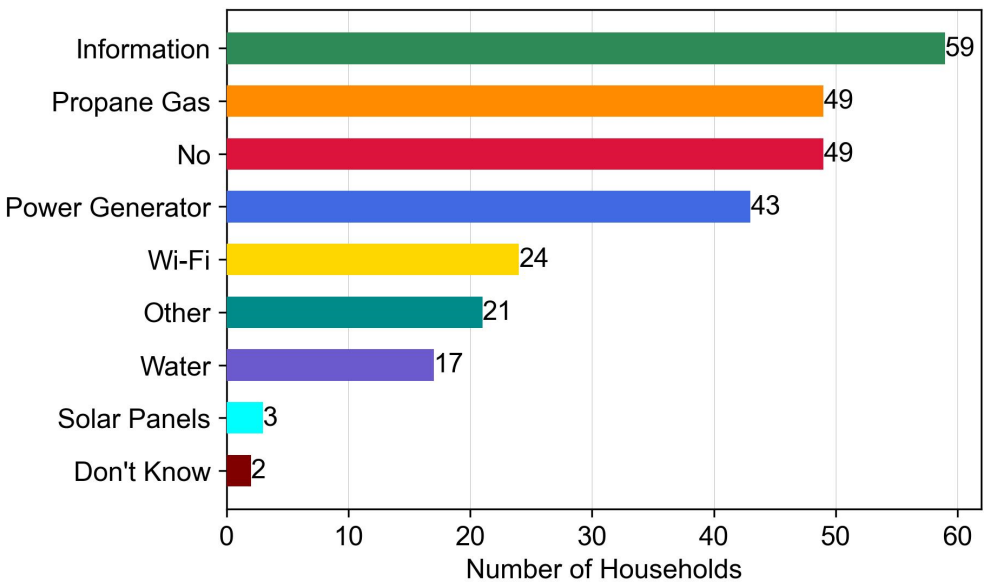

Figure 4-1. Number of respondents with backup options in the event of utility disruptions or alternatives to information sources in the event of hurricanes and floods.

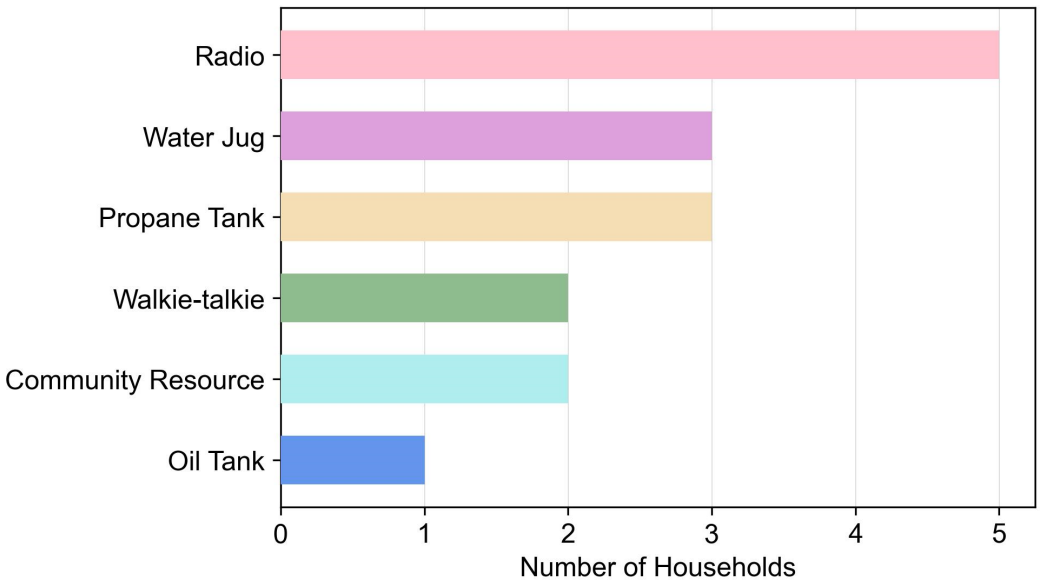

Figure 4-2. Other items select respondents consider as options to ameliorate disruptions to utility services or information sources.

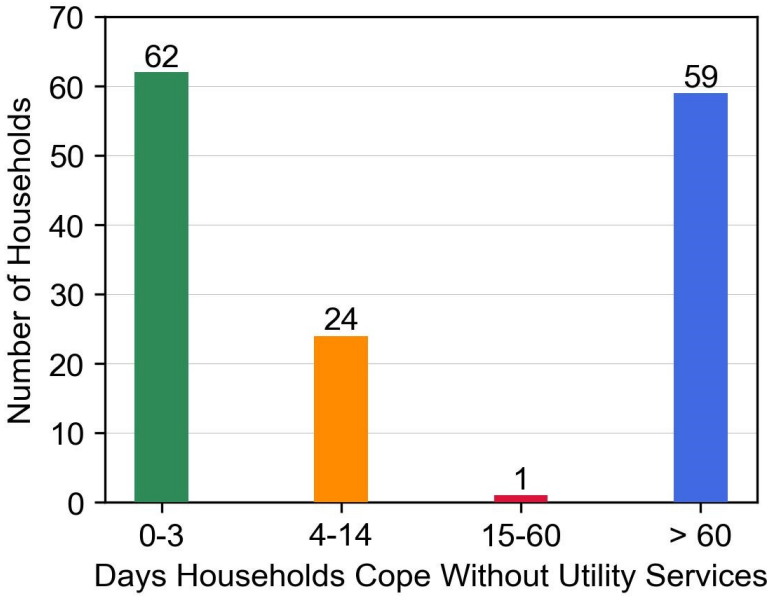

Figure 4-3. Number of days respondent report they can cope with cellular phone outages before considering leaving their home.

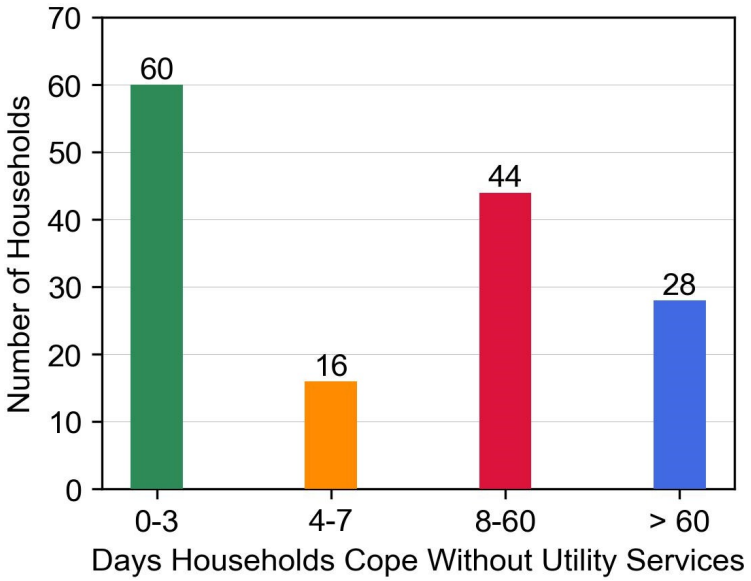

Figure 4-4.Number of days respondents report they can cope with electric power outages, before considering leaving their home.

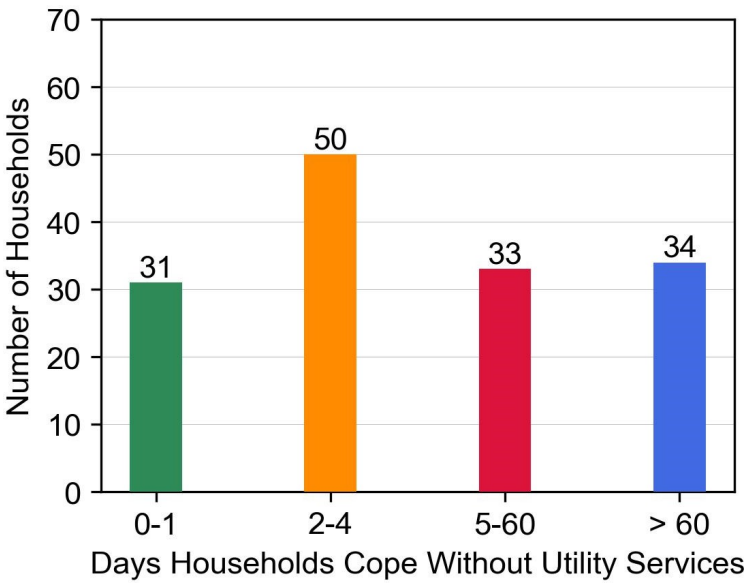

Figure 4-5. Number of days respondents report they can cope with potable water outages, before considering leaving their home.

Regarding the business survey questions, and consistent with the data management in Subsection 3.4.1, the confidence in utility service restoration 2 to 3 days post-disaster (for a generalized disaster event) was captured by having respondents rate their confidence on a 0-5 scale, with 0 being no confidence in service provision and 5 being complete confidence in service provision

after the disaster event. The businesses' responses are visualized in Figure 4.6. This question revealed that for most utility services, businesses were roughly evenly split between low confidence and high confidence. Cable and electricity services were slightly more low-confidence leaning, while sewer, natural gas, and water were slightly more high-confidence leaning. Cellular phone service was the only utility to have a high vote of confidence in service restoration and not an approximate confidence split. This confidence in mobile systems is consistent with prior experience, as no major disruptions on telecommunication services were observed in previous hurricane events.

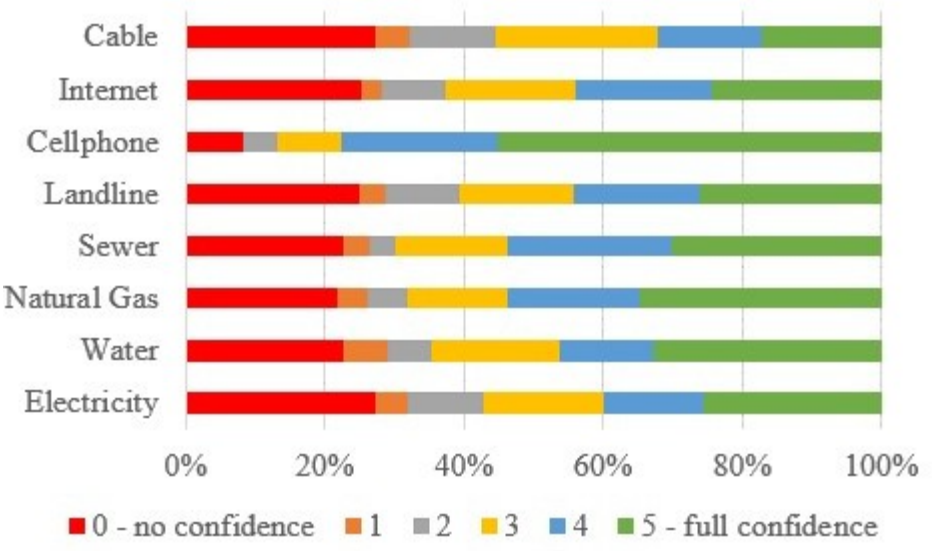

Figure 4-6. Confidence of businesses in utility service restoration 2-3 days after a hurricane/flood event.

The ability of businesses to provide utility services by themselves was captured by asking respondents if they have utility alternatives. The businesses' responses are visualized in Figure 4.7. Across all utilities the percentage of businesses that had alternatives ranged from approximately 5% to 30%. Electricity had the greatest number of businesses with alternatives, mainly through power generators. Water, also a critical service for business continuity, ranked high. Note that among the lowest percentages, including natural gas, sewer, and cable, sewer is also critical for business continuity and yet there are no easy alternatives to it.

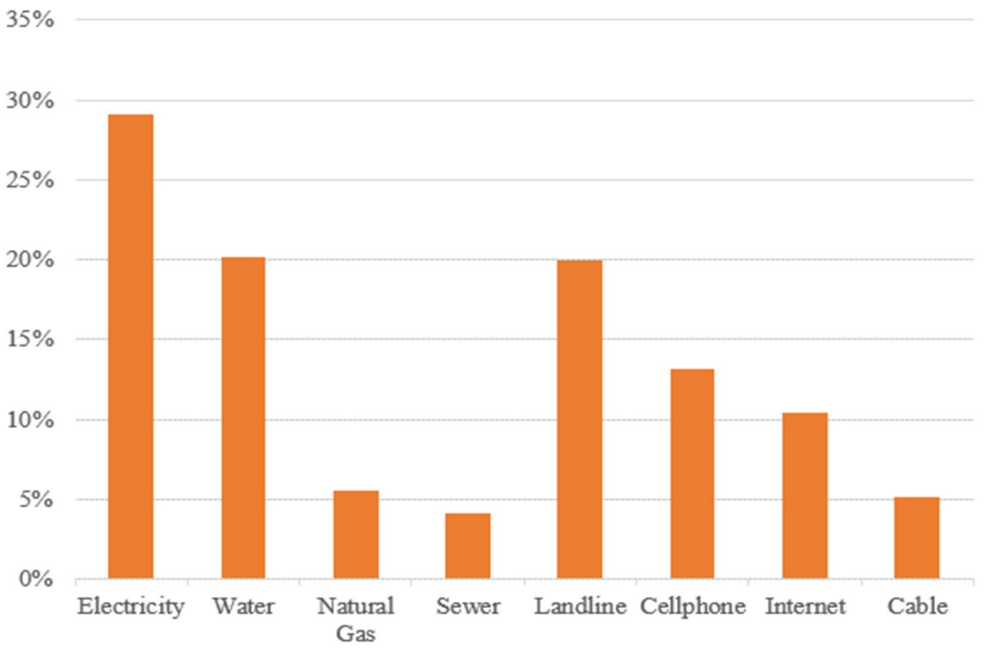

Figure 4-7. Percentage of businesses with alternative utility service sources.

In businesses' general responses to how they were impacted by both Hurricanes Matthew and Florence, many write-ins mentioned utility-driven impacts (i.e., specific utility outages or outages in general). This reaffirms the importance of utility services for businesses' post-disaster recovery to reach functionality. However, when asking about businesses' top three concerns for their business at the time of the survey, very few selected utility dependability. This is most likely because businesses were addressing more day-to-day concerns rather than those in a post-disaster setting. However, many businesses selected natural hazards as a primary concern, and with these events' utility disruption would be implied.

4.8. Informed Modeling: Implications of Findings for the Center and NIST Models

After previous waves of data collection, the team offers here a perspective on how field data start informing computational modeling, particularly decision support tools that would be available in IN-CORE and NIST models. As infrastructure team members are involved in such as computational tool development, they illustrate more specifically how interviewee response trends and parameter settings inferred from the interviews and surveys inform decision support tools. Drawing from the decision levels in Table 4.3 which rely on increasing levels of input information per level, take for instance, Level 3 decision support, which aims at optimization-based models, and also ensures enough input to solve the previous decision support Levels 2 and 1 on impact-based criticality and network element rankings. Hence, it is possible to discuss a generic optimization-based infrastructure restoration problem (González et al. 2016; Harrison 2022). A typical problem in the context of infrastructure system restoration after events is to decide what elements to repair, their location, and the best time to intervene, while minimizing the operational and repair costs.

A full objective function to minimize when deciding on a restoration plan, has multiple terms, each accounting for different cost types, such as those in Table 4.6. Each of the cost types and decision variables in the objective function, which include damaged and undamaged elements, are indexed by their location, the infrastructure system they belong to, the commodity they carry, and a time stamp for restoration.

Table 4-6. Summary of possible costs, parameters, and decision variables in a generic optimization-based interdependent infrastructure restoration model (González et al. 2016; Harrison 2022).

Example Costs in Objective Function	(Cost Parameter, Decision Variable)
Arc Repair/Mitigation	$(\boldsymbol{f}, \Delta\boldsymbol{y})$
Node Repair/Mitigation	$(\boldsymbol{q}, \Delta\boldsymbol{w})$
Geographical Repair/Mitigation Coordination	$(\boldsymbol{g}, \Delta\boldsymbol{z})$
Operational Penalties	$(\boldsymbol{M}, \boldsymbol{\delta})$
Operational Costs	$(\boldsymbol{c}, \boldsymbol{x})$

There are also operational constraints, in terms of physical supply/demand flows, element capacities, and dependencies across infrastructure sectors. In addition, there are socio-economic constraints in terms of resources available for intervention per network, and incentives or penalties for service satisfaction, among others.

Note that supply-side interview responses from utility operators can naturally inform models about priority locations for intervention of nodes or links, the penalties for undersupply of commodities at essential facilities or priority customers, the changes in demand from population dislocation, or the resources available per infrastructure sector for intervention. In addition, insights from household and business survey respondents point at utilities with the most alternatives or the ones respondents can cope with their outages the most (and hence most flexible in terms of restoration times), to better steer restoration model optimizers.

Level 3 optimization-based decision support models are flexible to account for uncertainties if a suite of hazard scenarios is available. These models can also be decentralized to mirror decision making in practice where no single decision-maker oversees all infrastructure sectors, but rather infrastructure sectors address their needs while recognizing upstream dependencies and downstream impacts (Talebiyan and Duenas-Osorio 2020; Zhang and Chow 2012). A full deployment of the infrastructure restoration model with Lumberton data is an ongoing study.

Finally, as decision support tools typically require models of the systems they study, here is an example of an infrastructure model requested by the water sector to the infrastructure team. In particular, the water distribution network model of Lumberton is now part of the IN-CORE Lumberton testbed and has the capabilities of what-if hydraulic-based queries not within reach of the local utility (Zhou and Duenas-Osorio 2023), thus complementing public works tools for decision planning under uncertainty (Figure 4.8).

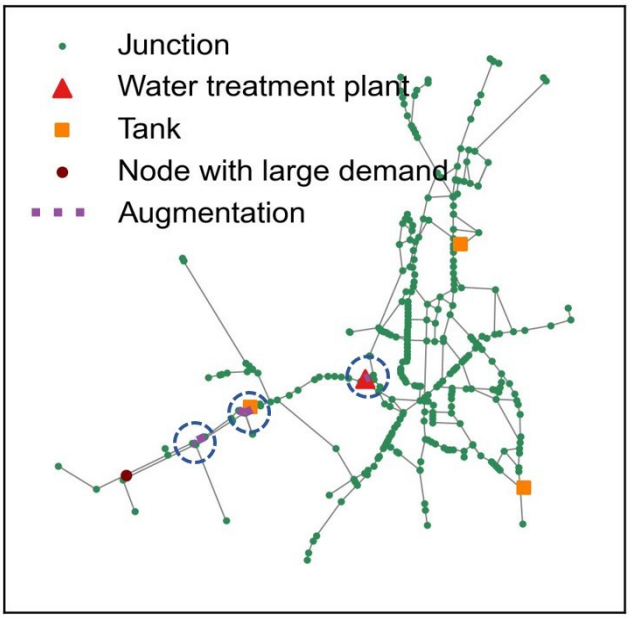

Figure 4-8. Water distribution network model of Lumberton, NC with the capability to perform what-if analyses.

Notes: The encircled areas show pipe additions (purple dash) that significantly improve system performance by creating redundant loops around tanks and water treatment areas or en route to large demand areas, as identified from hydraulic modeling and network augmentation algorithms.

4.9. Findings and Closure

Responses to utility operator interviews as well as to specific survey questions to households and businesses highlight the role of critical infrastructure services on community resilience and reveal how decision processes unfold. Together, interview and survey insights can help inform the development of computational decision support tools. These computational environments are meant to clarify how decision alternatives would satisfy decision problem objectives while facing a multitude of technical and administrative constraints.

From the supply side of the utility infrastructure, utility sectors aim to minimize consequences of service disruption, including outages to emergency services or assisted living facilities. Utility sectors also strive to keep or increase resources for contingencies, maintain safety and minimize incidents with their own personnel and critical assets, including nuclear reactors, water treatment plans, or interstate highways. In addition, at the time of the interview, a common challenge among utility sectors was that of disrupted supply chains, which delayed acquisition of materials and spare parts, and also triggered competition for specialized personnel.

Specific protective actions decided by utility sectors tended to rely on known strategies, not only readily available in the minds of decision makers, but also that had undergone preliminary or feasibility assessments before. These strategies for flood hazards include reduction of exposure by elevating assets, ranging from less than a meter (for some public works assets) to up to 4 m (13 ft.) (for transportation infrastructure), where the levels are established from a combination of return period event expectations (e.g., 100, 500, 1,000-yr events), as well as field or design

criteria such as 100-year return periods plus 0.61 m (2 ft.), or flood elevation marks from Hurricanes Mathew or Florence plus 0.61 m (2 ft.). Other exposure reduction strategies rely on relocation, as in the case of public works headquarters and the intakes for water potabilization, or rely on the addition of barriers to reduce hazard impacts. Alternative but also readily available strategies included hardening of assets, or the addition of asset redundancies or increased capacities, as in the case of water storage capacity for supply side management or the replacement of wells for redundancies. In a similar vein, utility sectors aimed at expanding backup power systems and fuel supplies, with some sectors like public works aiming at six days of self-sufficiency.

Decision analyses after going over decision processes and constraints with utility sectors, reveal opportunities for improved future resilience. These range from expanding public education on emergency management resources to developing restoration playbooks from cumulative experience and consultant analyses. Opportunities also include improving access to weather forecasting tools, deploying sensors and monitors to improve situational awareness, and flying drone technologies to support assessment and operations, including asset and vegetation management. Overall, utility sectors expect to expand their sets of alternatives to satisfy objectives in the future, given new funding opportunities. There is a renewed interest for benefit-costs analysis, what-if scenarios to support decisions, updated contingency response plans, and enhanced coordination and communications among utility sectors, emergency responders, and government. These last points complement emerging computational environments like IN-CORE to support risk-based resilience planning of communities as a portfolio of information available to decision makers.

Finally, infrastructure survey questions also revealed opportunities to steer the demand-side of infrastructure towards protective actions, as households and businesses recognize the need for alternative sources of critical utility services and the planning for extended outages from their primary service provider. For example, approximately 30 % of households and businesses own power generators, which is a percentage that should continue to increase, but is already useful for community resilience as it is a factor for business continuity and reduction of population dislocation. However, challenges remain with certain services for which immediate alternatives are not easily deployable given current practices, including sewer and telecommunications, but for which scalable portable options exist and may be adopted as part of community planning policies.

5. Chapter 5: Conclusions, Local Government Context, and Next Steps

The Wave 5 data collection provides housing and business data nearly six years following the major flooding damage due to Hurricane Matthew in early October 2016, almost four years following flooding damage due to Hurricane Florence in September 2018, and a little over two years since the beginning of COVID-19 pandemic disruption in the U.S. in March 2020. Importantly, Wave 5 was the first in-person data collection effort since the COVID-19 pandemic pause on travel and represented a unique opportunity to understand community resilience in relation to three hazard events. Wave 5 also expanded the longitudinal study through emphasis on utility provision and disruption by adding items to both the housing and business data collection surveys as well as incorporating interviews with various critical infrastructure sectors. The information collected in Wave 5 augment findings from previous waves and contribute to the on-going IN-CORE modeling efforts, as well as to NIST models and research on community resilience. This chapter provides conclusions related to the household survey findings, business survey findings, and utility providers interview findings, as well as local government context.

5.1. Conclusions for Housing Disruption and Recovery

The housing unit survey collected data on ongoing recovery processes from Hurricanes Matthew and Florence as well as the impact of the COVID-19 pandemic on these processes. In addition, the survey looked to the future asking residents about mitigation or preparedness strategies they have or plan to implement.

Dislocation, which has been measured throughout the longitudinal data collection effort, showed a common pattern for post-disaster return to permanent housing with most respondents returning within 1-2 years post-disaster, but a long tail of slow return for a small portion of the population. Since this study followed housing units rather than households, the survey may overestimate the number of people who had returned to permanent housing since houses needed to be occupied to complete the survey. Those housing units that were perceived abandoned in 2022 (n = 137), including those that were marked as abandoned during every data collection since Hurricane Matthew (n = 35 housing units), may represent households still searching for permanent housing or households that have permanently relocated elsewhere.

Wave 5 highlighted the compounded effects of successive disasters on households' recovery processes. As noted in previous Waves, housing repair was important for household return. While a majority of survey respondents reported that their housing repairs were complete, repair was more likely to be completed for those who had damage from only one hurricane compared to those who reported damage from both hurricanes. COVID-19 and its associated economic impacts further compounded the impacts of Hurricanes Matthew and Florence for Lumberton residents. While COVID-19 did not directly affect house repairs for most residents, those households who reported employment disruption from COVID-19 also reported greater effect of the pandemic on their ability to complete hurricane repairs.

The addition of subjective measures of perceived recovery in Wave 5 provided a different perspective than the objective measures of return to permanent housing or housing repair completion. Respondents could report completed repairs but still perceive that their house’s or household’s recovery was not “complete”. Residents described the context for some of their responses by indicating that they would never complete some repairs. These residents had

stopped repairing their home before it was completely back to where they would like. Thus, there were aspects that they felt would never be fully recovered. Furthermore, respondents evaluated their own recovery, in general, much more positively than that of their neighborhoods and Lumberton overall. A significant minority of respondents felt that their neighborhoods and Lumberton, in general, would never fully recover. Respondents often spoke about out migration from the city or neighbors who did not return as evidence of this lack of community recovery.

Less than half of the household respondents said they used insurance for addressing damages from the hurricanes. As the first line of funding for individual disaster recovery in the U.S., this result is troubling. In terms of insurance for future events, a large majority (82 %) of those living in single-family homes reported having homeowners' insurance, but less than half living in single-family homes had flood insurance. Respondents were generally aware that the insurance coverage may not be adequate for future storms similar to Matthew or Florence.

Nearly six years after Hurricane Matthew, Wave 5 captured the slow start of HUD CDBG-DR funding for households. Receipt of funding from the Rebuild NC Program was reported by just 5 % of those damaged from Matthew and 9 % of those damaged by both hurricanes. During fieldwork, team members noted that some respondents reported that they had applied to Rebuild NC but were either denied or still waiting for a decision. From the housing unit survey, it is not possible to capture use of this funding for rental units, since the owner is the applicant and recipient. A further challenge is that the program offered elevation, repairs or complete reconstruction on site, or a buy-out for some properties. Homeowners who accepted a buy-out themselves or households who were in a rental property in which the owner accepted a buy-out would not be included in the survey because those housing units would now be vacant or already demolished.

5.2. Conclusions for Business Interruption and Recovery

The Wave 5 business survey continued the collection of recovery metrics from Hurricanes Matthew and Florence as well as collected information on the impacts of COVID-19 on that process. The survey found that most businesses reported being recovered from the hurricanes, but over half were still dealing with the effects of COVID-19. For businesses that were still recovering from the hurricanes, COVID-19 exacerbated recovery challenges. Often these challenges were financial; when asked what factors businesses considered when they assessed their recovery status, the most common responses were whether the business was producing/selling at the same level as before the disruption or whether their expected gross revenues were achieved.

Given the focus on financial performance as a recovery indicator, the business survey also sought to understand decision-making with respect to resources used by individual businesses. In previous waves, few businesses in Lumberton received recovery programs. In Wave 5, a choice exercise was given to businesses to help understand the factors businesses weighed when choosing to apply for locally-funded disaster assistance loans. The survey question asked businesses to consider whether they would apply for a loan as well as tradeoffs (or preferences) between disbursement immediacy and larger disbursed loan amounts (i.e., loan size). The survey found that businesses were generally reluctant to apply for loans. However, respondents that indicated that they *would* apply demonstrated a preference for smaller loan amounts with faster disbursement periods as opposed to larger loans with longer waiting periods.

When asked how businesses financed their recovery from Hurricanes Matthew and Florence, personal savings was the most commonly used resource. Businesses also used insurance–over 50 % of businesses currently carry property insurance–or other creative sources of funding, including deals with suppliers, mortgage refinancing, and changes in budgeting. However, when it came to COVID-19, 43 % of businesses applied for financial assistance, primarily Federal programs. COVID-19 saw the introduction of the PPP, which offered forgivable rather than low-interest loans, which may have been more appealing to businesses.

Going forward, businesses cited several current concerns that they foresaw impacting their business. The most frequently cited concern was the price of fuel, followed closely by inflation, the ongoing pandemic, supply issues, workforce issues, and business, financial, and market volatility. Of these issues, businesses perceive inflation and workforce issues as the most outside of their control (i.e., do not have the resources and information needed to reduce their impacts). However, though several businesses did cite natural hazards as a concern for their business, almost all respondents to the Wave 5 survey generally felt their business was prepared for a future hurricane. Businesses have taken or plan to take a variety of mitigation and preparedness actions, most commonly backing up important documents and staying informed of weather watches and warnings. Almost half of businesses have developed or plan to develop a formal emergency action plan or checklist.

5.3. Conclusions for Critical Infrastructure Sectors

Responses to interviews with several critical infrastructure sectors, including power transmission, power distribution, water distribution and public works, transportation, and the food and agriculture cooperative extension, revealed several trends to manage contingencies by making decisions under uncertainty and constraints. In particular, interviewees independently identified the same main problem, which is to minimize impact to their customers or constituents when facing natural disasters, such as flooding in Lumberton. This overarching problem was also accompanied in general by shared objectives such as hardening assets or restoring system operation without safety incidents, augmenting capacity of systems to satisfy end-users' demands, enabling re-routing or adding redundancies to balance the supply/demand dynamics among providers and users, and stockpiling spare parts and equipment while securing personnel and assistance pre-event.

Alternatives included strengthening of structures, exposure reduction of assets and equipment, and the addition of redundancies for system components or system operation. In particular, critical infrastructure operators and institutions facing flood hazards often considered the option of elevating assets or protecting them with barriers, either with berms, gates, or a combination of walls and gates. Also, it is common to consider the addition of redundancies to supply sources, storage capabilities, and ensuring the continuity of electricity and communication means via backups or alternative devices.

As the consequences from failing to achieve infrastructure operator objectives are high, interviewees stressed their goal of managing contingencies and continuing service, for which they are willing to explore new technologies, new sources of information, and entertain alternatives different from tried-and-true best practices. For example, power and water sectors discuss future decentralized systems, either via microgrids or a combination of tanks, wells, and wastewater reuse for distributed water potabilization processes. Also, fuel alternatives to diesel

and gasoline via pipe-delivered gas may become advantageous during contingencies affecting transportation systems. In addition, expanding infrastructure interconnections across jurisdictions, particularly for local sectors like power and water, easily adds redundancy to their systems, as does the expansion of advanced metering infrastructure. Also, utility sectors were interested in acquiring or expanding physics-based modeling capabilities, complemented with structural health monitoring, actuation technologies, and sensor-based monitoring of asset failures. This includes risk-based resilience planning tools like IN-CORE. Custom models are currently under development for public works to add decision alternative assessment capabilities to their water distribution network.

Notably, while most typical interventions tried in the past were re-adopted and even new technologies are embraced for situational awareness, the aftermath of the 2016 and 2018 hurricanes also provided the opportunity to improve infrastructure safety at much higher levels than ever before. Examples include the 4 m (13.1 ft) elevation and widening of I-95 around the Lumber River in Lumberton, the 500 yr flood protection gates and associated structures, and the new industrial park with additional water storage of 0.5 M gal (1.9 M liters). These projects bring multiple co-benefits and also spark bold possible strategies, including the acquisition of electric bucket trucks, the development of data-assisted crop assessment methods and technologies to quantify yield losses or crop damage, the capture of methane as an alternative source of energy for farmers, and the construction of renewable off-shore wind energy farms, among other interesting projects.

Complementing the insights from utility sectors, households and businesses also revealed in survey questions their increasing awareness of protective actions to limit dislocation and business interruption. Local policies for improved power, water, sewer and telecommunication services soon after contingencies will support community resilience, as will the adoption of updated codes with modern flood protection risk categories and the implementation of infrastructure restoration best practices for service restoration.

5.4. Local Government Context

Given the coordination of city officials and infrastructure operators in city planning, including planning for resilience and recovery, and pursuit of funding through grant programs, the local government perspective is key to understanding the implementation of recovery projects and the pursuit of resilience actions going forward. Additionally, the local government's perspective on capital investment projects is a much needed component for the development of decision support models for community resilience planning. Lumberton's Office of the City Manager, which administers projects, coordinates city government activities, and implements policy set by city council, met with the team to provide an update of recovery from Matthew and Florence.

Even as of 2022, the City of Lumberton continues to deal with challenges associated with the aftermath of Hurricane Matthew, including the installation of flood gates at the levy opening and floodplain buyouts. The flood gates project is complex due to the involvement of many participants and levels of authority including the city government, NCDOT, Federal Highway Administration, FEMA, and CSX Transportation (which operates the railroad near the planned project). Another factor adding to the complexity of this work is the numerous sources of financing for the floodgates, including Golden Leaf Foundation, Economic Development Administration (EDA), and state government sources (n.a. 2021). Additionally, a plan to both

widen and elevate part of I-95 has created a need to update the plans for the flood gates partway into their design phase. The contracting phase, now delayed, is expected later in 2023. An upside to the protracted timeline is that the engagement across participants has improved. City officials highlighted more positive interactions with CSX Transportation and indicated the positive influence of the press and the governor in this dynamic. A more frequent and regular process for engagement has been established through regular meetings of all parties involved in the flood gates project.

Managing recovery projects remains a large area of focus for the City staff at this time. A consistent challenge for Lumberton is the ongoing nature of managing recovery projects and disaster assistance funding with largely the same level of city government staffing as before Hurricane Matthew. For some types of projects (e.g., FEMA's Hazard Mitigation Grant Program funded projects, flood gates), the City has involved external consultants.

There have been changes in the city's budget over time that also affect recovery operations. The General Fund has decreased due to the federal and state disaster assistance reimbursement timeline. This remains a significant concern because the result of dropping below 8 % is that the local government commission will begin fiscal management monitoring. Sales tax revenues have not declined, despite the impacts to businesses in Lumberton. Consumer spending remains high, likely because of the federal relief provided during the COVID-19 pandemic. The City is struggling with high rates of non-payment for the utilities.

Changes aimed at improvements in existing disaster assistance systems can cause some communities within the transition to have to move from the old system to the new due to the long tail on the recovery process. With already highly bureaucratic processes, the change can be overwhelming. FEMA's Grants Manager portal is one such example for Lumberton. The new process began with Hurricane Florence, so the City has had to navigate a new process from the one used with Hurricane Matthew. Learning the new portal has been difficult and meant additional staff hours. FEMA provides technical assistance for Public Assistance funding approximately 6-9 months post-event; after this, city staff are left to manage the process. Similarly, the FEMA Building Resilient Infrastructure and Communities (BRIC) Grant process was also cited as complex to navigate. Beyond process changes, are procedural changes. For example, debris removal now requires a monitor per federal requirements. Failure to properly monitor debris removal and document locations and quantities of debris removed by an applicant jeopardizes the applicant's reimbursement (NC DPS n.d.).

After more than five years, the Hurricane Matthew buyouts are wrapping up and the buyouts for Hurricane Florence are getting underway. With Hurricane Florence, funds have just been released for approximately 50 properties being purchased. The City is working with the same consultants as for Hurricane Matthew. City officials described the state of many homes in Lumberton including unrepaired flood damage; ductwork removed and never added back in; holes in flooring; and issues with mold. There is an awareness of the incredible gap in what has been done and what still remains as issues for their residents. Vacant housing continues to be a growing issue for the City. With approximately 400 houses vacant, the City is beginning to explore options such as federal sources of funds that might be used to condemn and clear the properties (e.g., American Rescue Plan Act) and plans for redevelopment. The State's CDBG-DR roll out of housing recovery funding has been slow and is affecting housing recovery in Lumberton.

In 2022, the City also highlighted a number of areas of growth and new opportunities. Among them, the development of an industrial park at I-74 and I-95 was viewed as an avenue for growth for the City and region, more broadly (Stiles 2021). For example, Elkay Manufacturers, the first tenant of the park, will create 20 new jobs in Robeson County (Barkin 2022; Barry 2021). Similarly, the infrastructure improvement of the I-95 corridor through Lumberton was identified as a beneficial change for the future, even though the project posed several short-term challenges. The widening and elevation of the highway has involved extensive coordination of the City and other partners in the project, meaning weekly meetings involving City staff. Also, despite cost-sharing, the City's percentage of the total cost of the project (25 %) still amounts to millions of dollars, which has not been easy to secure.

By 2022, Lumberton had changed with respect to disaster preparedness. Before Hurricane Matthew, the City did not prepare because they were told their risk was very low. With Hurricane Florence, they prepared despite the low risk. Ahead of Hurricane Florence, pumps were installed. There ended up being more rainfall with Florence than Matthew, so the forward-looking actions made a big difference in the outcomes. The power substation on Water Street that flooded during Matthew had a dam around it by the time flooding from Florence impacted the City. This substation, in partnership with Duke Energy, serves the hospital. The flood barriers that are available today allow for a hole in the levee to be closed within an hour; the future flood gates will improve the response time. This change in the City's approach to risk is viewed as a beneficial one by officials. In other spaces, advances in resilience are also evident. The Robeson County Disaster Recovery Center was created during Hurricane Matthew and has been in place in its new location near City Hall since 2021. The center provides disaster kit-related supplies, including food, and is highly preparedness-focused in its work.

5.5. Next Steps for the Lumberton Longitudinal Field Study

One of the original aims of this field study was to make recommendations about the appropriate frequency of data collection to capture community functioning over time. Over the course of five waves of data collection, this field study team has documented a number of important factors that help answer the question of "how long does it take for a community to recover from a disaster?" but the question is not resolved. Thus, a Wave 6 field study is planned. Housing and business surveys as well as interviews with infrastructure agencies and meetings with city and other public sector officials reveal unique issues worthy of continued tracking over time. For instance, HUD funding for individual buyouts or rebuilding with elevation were still taking applications through April 2023. Several of the households in the Wave 5 sample indicated that their applications were under review at the time of Wave 5. This wave did not systematically capture those details and future research should include more detailed questions about this program. By continuing longitudinal data collection, information on the implementation of this funding mechanism will be captured. This opportunity is important because HUD funding is often the largest federal funding provided for post-disaster rebuilding and few disaster recovery studies can adequately capture its impact in the way this longitudinal study can. Public housing, also, is still in flux, with new developments not completed yet and units slowly coming back online to new tenants. Both of these processes (HUD funding and public housing) capture residents who are more socially vulnerable than others who have completed recovery already. Thus, an additional wave of data collection will assess inequities in disaster recovery by capturing the continued recovery process for socially vulnerable households.

Wave 6 data collection can be directed in ways to improve efficiency in terms of topic coverage and results precision. For example, an additional wave of data collection (i.e., Wave 6) could be targeted in manners to focus energy on increasing the number of housing units with more than one completed survey and consequently improve the precision of longitudinal analysis. Having three data collection timepoints, allows for additional analysis techniques that are not available for observations with only one or two observations. Those housing units with three or more completed surveys could be skipped in Wave 6 if their hurricane recovery is fully complete. The aim of the longitudinal research was to track recovery progress over time. By visiting only housing units that have not completed recovery, have only one or two completed surveys, or those that have been awaiting particular funding types (e.g., HUD CDBG-DR) in Wave 6, time in the field can be most effectively prioritized. Such changes would mean that the Wave 6 housing unit sample may be smaller than 567 and take fewer resources to complete.

For businesses, each additional field study wave has historically provided a much richer picture on the occupancy status of businesses in the sample. Because of differences in operating hours, temporary closures during the pandemic, and hurricane-related repairs, it can take several waves to determine whether a business has permanently closed. As shown in Figure 3-4, there are still several commercial units with missing occupancy information and therefore the business operating status is undetermined. Knowing the occupancy status of commercial buildings and the types of businesses in them is an important indicator for the community as a whole in terms of availability of services, economic development and employment, and tax revenue. Furthermore, in-depth interviews of select businesses can help understand their unique circumstances and provide clarity on reports of recovery status in previous structured surveys. In some cases, these can highlight sector and geography specific lessons.

Similarly, most infrastructure system operators are in the process of building, designing, or planning significant projects to improve their resilience and support community development. In particular, Public Works is engaged with Lumberton's industrial park project with new water distribution network assets, including tanks, pumps and pipes. These assets not only address water expansion needs and fire safety standards, but also expand the overall resilience of the existing system. Wave 6 will allow the CoE and NIST to engage Lumberton Public Works with models ahead of their project completion to truly showcase the capabilities of IN-CORE-style computational aids to support decision making under uncertainty. Similarly, Wave 6 will provide another update on the priorities guiding utility sector decision processes, which evolve from tried-and-true in the aftermath of events, to bold intergenerational improvements that minimize repeats of high consequences in the community, to planning for the future with new more affordable strategies, rich in new technologies, and that address multiple community needs.

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Appendix A. Household Survey Instrument

Hurricane Matthew Community Recovery Study for Lumberton, NC
Center for Risk-Based Community Resilience Planning
A U.S. National Institute of Standards and Technology-funded Center of Excellence
OMB CONTROL NO. 0693-0078 Expiration date: 07/31/2022

Instructions to Surveyor: All instructions to surveyor are in italics in this document. Do not read italics. Questions to be read to the respondent are in **bold.**

Fill out this top portion before knocking on the door.

Date:_____

Surveyor(s):_____

Household ID:_____

Attempt (1st, 2nd, or 3rd): _____

Unit Address:_____

Circle Building Type: 1, Single family 2, Multi-family, # housing units _____ 3, Mobile home 4, Other, _____

Approach house and knock on door.
Provide them the information sheet and read Consent Script from laminated form.
Fill in following box.
Then begin the survey on the next page.

Result/ Completion Codes	1. **Completed interview** 2. **Ineligible**, no adult or eligible person to answer questions 3. **Bad address**, could not locate Housing Unit 4. **Incomplete/partial**	5. **Not occupied residence**, abandoned; home destroyed 6. **Ineligible**, structure not a residence 7. **No answer or response**, but evidence or confirmed occupied 8. **No access**, gated community, fence preventing entry 9. **Dropped off survey** (enter when should return in comments)

Housing Unit Occupancy status:	YES: household present interviewed or attempted	YES, household not present; evidence of habitation	DK: Indeterminate/ uncertain	NO: not occupied, appears abandoned
	YES, household not present; occupied confirmed by neighbor	YES, household not present but occupied, confirmed by management	NO: not occupied, under repair/ reconstruction.	NO, damaged and not habitable

Add any additional notes or comments, such as when to return, etc. Comments:

Please confirm you are a Lumberton resident above 18 years of age, and consent to participate in this survey by marking the circle. ☐ I am above 18 years of age and consent to participate in this survey.

If they are not 18, ask for an adult over 18. If none are available try to reschedule a time to return when one will be available or drop off a survey and schedule a time to pick up the survey. DO NOT SURVEY ANYONE UNDER 18.

The first set of questions is about your household in general.

1. **What is your current home address**: _____
   This can be asked as a confirmation of the address above: "Can you confirm that _____ is your home address?"

2. **How many adults (18 years or older) live in your household?**..... #_____Adults
3. **How many children (younger than 18 years) live in your household?**..... #_____Children

4. **When did you move into your current home?** Month:_____ Year:_____
   If they moved in after 2018, likely none of the hurricane questions will apply. Go ahead and ask all questions. But add some talking points like "I think I know the answer to this question, but I still need to ask it…"

5. **Was your home damaged by Hurricane Matthew or Hurricane Florence?**
   (Please mark the choice that most closely matches)
   ☐ Hurricane Matthew, only
   ☐ Hurricane Florence, only
   ☐ Yes, both Hurricanes Matthew and Florence
   ☐ No, neither hurricane damaged my home *Skip to Q9*
   ☐ Don't know *Skip to Q9*

6. *If yes to Q5, home was damaged by any storm*: **What year were your repairs completed?** _____
   Insert year or select one of the following: ☐ Still not complete ☐ Don't know

7. *If yes to Q5 your home was damaged*: **Did you receive funding for repairs?** *Pause for a yes or no, or don't know, then ask:* **From what source?** *Read all the options, wait for a yes after each one.*
   ☐ yes, from FEMA
   ☐ yes, from Rebuild NC homeowner recovery program**
   ☐ yes, from insurance
   ☐ yes, from SBA Loans
   ☐ No funding
   ☐ yes, from friends or family
   ☐ yes, from a nonprofit
   ☐ Don't know

   ***This is the name of the program that used funding from HUD CDBG-DR. It may be referred to by different names, such as NC office of recovery and resiliency NCORR, or NC department of public safety. Try to double check that it is this program, respondents often don't know exactly where recovery money comes from. This program started in 2019.*

8. *If yes to Q7, you received funds*: **Was this funding for repairs, complete rebuilding, or something else?**
   Please check all that apply:
   ☐ repairs ☐ complete rebuilding ☐ temporary housing
   ☐ something else, *please describe:* _____

9. **Were you and your household displaced from your home?** ☐ Yes ☐ No ☐ Don't know
   (If no or DK skip to Q12)

10. *If yes, you were displaced*, **How many different places did you live before returning home?** _____

11. *If yes, you were displaced*, **When did you move back into a permanent home?** Month:_____ Year:_____
    Insert month and year or select one of the following: ☐ Still displaced ☐ Don't know

The next questions are going to ask about your household's perceived preparedness now. Please select the option that most closely matches your experience or situation.

12. Do you rent or own your home? ☐ Own ☐ Rent ☐ Other, please describe:_____

If you own your home, (pause after each for a response)	**Yes**	**No**	**Don't Know**
Do you have flood insurance?	☐	☐	☐
Do you have homeowners' insurance?	☐	☐	☐
Do you believe you have adequate insurance coverage for a flood event?	☐	☐	☐
Do you have a mortgage?	☐	☐	☐

13. How many major floods or hurricanes have you experienced first-hand in your lifetime? #_____Floods

14. How likely do you think your home is to be damaged during a major flood event, similar to Hurricane Matthew or Hurricane Florence? *Read all options at once*

☐ Extremely unlikely ☐ Unlikely ☐ Neutral ☐ Likely ☐ Extremely likely

15. If given evacuation orders, how likely is your household to evacuate your home during a future major flood event, similar to Hurricane Matthew or Hurricane Florence? *Read all options at once*

☐ Extremely unlikely ☐ Unlikely ☐ Neutral ☐ Likely ☐ Extremely likely

The next set of questions asks about the recovery of your home, your household, your neighborhood and Lumberton from Hurricanes Matthew and Florence.

16. When thinking about your <u>home</u> (the physical building in which you live), would you say your home is: *Read all the options at once*

Fully recovered	Partially recovered	Still in survival/response mode	Will never recover	n/a home not damaged
☐	☐	☐	☐	☐

17. *If your home is fully recovered:* **What year do you feel your home was fully recovered?_____**

18. When thinking about your <u>household</u>, would you say your household is: *Read all the options at once*

Fully recovered	Partially recovered	Still in survival/response mode	Will never recover	n/a home not damaged
☐	☐	☐	☐	☐

19. *If your household is fully recovered:* **What year do you feel that your household was fully recovered? _____**

20. When thinking about your <u>neighborhood</u>, would you say your neighborhood is: *Read all the options at once*

Fully recovered	Partially recovered	Still in survival/response mode	Will never recover	n/a home not damaged
☐	☐	☐	☐	☐

21. *If your neighborhood is fully recovered:* **What year do you feel that your neighborhood was fully recovered?_**

22. When thinking about <u>Lumberton</u>, would you say Lumberton is: *Read all the options at once*

Fully recovered	Partially recovered	Still in survival/response mode	Will never recover	n/a home not damaged
☐	☐	☐	☐	☐

23. *If Lumberton is fully recovered:* **what year do you feel that Lumberton was fully recovered?_____**

24. **Do you and your household have the same access to school, work, grocery stores, and other essential needs as you did before Hurricane Matthew in October 2016?**

☐ Yes ☐ No ☐ Don't know

25. **Do you and your household plan to move to a different house within the next year?**

☐ Yes ☐ No ☐ Don't know

26. **How has your participation with neighborhood and/or community groups changed since before the hurricanes in October 2016?** *(Examples include: volunteering or participation in local nonprofit, church or religious group, neighborhood association, food bank)*

☐ Decreased ☐ Stayed the Same ☐ Increased ☐ Don't know

27. **How has your contact with neighbors and/or extended family and friends changed since before Hurricane Matthew in October 2016?**

☐ Decreased ☐ Stayed the Same ☐ Increased ☐ Don't know

The next set of questions ask about mitigation and preparedness strategies used by your household now or that you plan to put in place in the next six months. Please respond Yes, No, or Don't Know to each item. *It will be faster to ask 28 and 29 together by mitigation strategy. For example, ask 28 a, and if they say no or don't know, ask 29 a. Etc.*

28.	**<u>Currently</u>, has your household:** *(pause after each for a response)*	**Yes**	**No**	**Don't Know**
a.	Elevated hot water heater and/or HVAC?	☐	☐	☐
b.	Re-routed ductwork from below floor to attic space?	☐	☐	☐
c.	Developed an emergency plan with household members?	☐	☐	☐
d.	Gathered supplies to last 3 or more days?	☐	☐	☐
e.	Sought information on mitigation or preparedness?	☐	☐	☐
f.	Set money aside for recovery or repairs?	☐	☐	☐

29.	**<u>In the next 6 months</u>, does your household plan to:**	**Yes**	**No**	**Don't Know**
a.	Elevate hot water heater and/or HVAC?	☐	☐	☐
b.	Re-routed ductwork from below floor to attic space?	☐	☐	☐
c.	Develop an emergency plan with household members?	☐	☐	☐
d.	Gather supplies to last 3 or more days?	☐	☐	☐
e.	Seek information on mitigation or preparedness?	☐	☐	☐
f.	Set money aside for recovery or repairs?	☐	☐	☐

30. **Do you have the option to provide any utility services, even if temporarily, for your household?**
*Read all the options, pause between each one. Mark all that apply. *community information hub is a physical space for disaster needs, information, activities*

☐ Yes, power generator ☐ Yes, community wi-fi ☐ Don't know
☐ Yes, gas tank(s) ☐ Yes, community information hub* ☐ None
☐ Yes, solar panels ☐ Yes, water storage tank(s) ☐ Other, please explain:
_____

31. **How many days could you stay in your home with an outage or disruption in…**

a. Electricity? _____Days
b. Water? _____Days
c. Wastewater _____Days
d. Natural Gas? _____Days
e. Internet? _____Days
f. Phone or cell phone? _____Days

The next set of questions are intended to capture the impacts of COVID-19 on your household.

32. **How has COVID-19 impacted hurricane repairs to your home?** *Read all options at once*

No impact	Minor impact	Neutral	Moderate impact	Major impact	Don't know	n/a no damage
☐	☐	☐	☐	☐	☐	☐

33. **How has COVID-19 impacted your household's recovery from the hurricanes?** *Read all options at once*

No impact	Minor impact	Neutral	Moderate impact	Major impact	Don't know	n/a no damage
☐	☐	☐	☐	☐	☐	☐

34. **Was your or your household members' jobs affected because of COVID-19?** ☐ Yes ☐ No ☐ Don't know
(If no or DK skip to Q37)

35. *If your job was affected*: **How were those jobs affected, was it due to?**
(Read all options at once and mark all that apply):

☐ Temporary closure of place of employment
☐ Permanent closure of place of employment
☐ Reduced to part-time status
☐ Childcare issues
☐ Health issues
☐ Other, please explain_____

36. *If your job was affected*, **how long was your work affected?** *(please enter the number of days)* #_____Days

37. **What was the change in your household's income due to COVID-19?** *Read all options.*

☐ Significant Decrease
☐ Decrease
☐ No Change
☐ Increase
☐ Significant Increase
☐ Don't know

Finally, there are six questions about your household in general.

38. **Do you have any individuals with special electricity-dependent medical needs in your house?** ☐ Yes ☐ No
(Examples include individuals who require power wheelchairs, ventilators, oxygen concentrators, CPAP and other sleep apnea devices.)

39. **When considering all members in your household, what is the highest level of schooling completed?**

☐ Less than high school
☐ High school diploma
☐ Associate's degree
☐ Bachelor's degree
☐ Master's degree or higher

40. **When considering your household, how would you describe its ethnicity, are you Hispanic or Latino?**
☐ Yes, Hispanic or Latino ☐ Not Hispanic or Latino

41. **When considering your household, how would you characterize its racial makeup?** *(select one or more)*
☐ American Indian or Native American ☐ Asian or Asian American ☐ Black or African American
☐ Native Hawaiian or Pacific Islander ☐ White or Caucasian ☐ Other, please specify: _____

42. **Do you consider your household a female-headed household?** ☐ Yes ☐ No ☐ Don't know
Read if the respondent pauses: This is when a household is maintained by a female with no spouse present.

43. **Finally, we do not want to know the exact amount, but please estimate your household's combined annual income. Would you say it is:** *Begin reading options and select appropriate category.*

☐ Under $4,000	☐ $4,000 to $5,999	☐ $6,000 to $7,999	☐ $8,000 to $9,999
☐ $10,000 to $11,999	☐ $12,000 to $14,999	☐ $15,000 to $19,999	☐ $20,000 to $24,999
☐ $25,000 to $29,999	☐ $30,000 to $39,999	☐ $40,000 to $49,999	☐ $50,000 to $74,999
☐ $75,000 to $99,999	☐ $100,000 to $149,999	☐ $150,000 or higher	☐ decline to respond

---

That is all our questions. Is there anything else you would like to share about your households' experience since the hurricanes? _____
_____
_____
_____
_____
_____

Thank you again for completing our survey! Do you have any final questions for us?

This collection of information contains Paperwork Reduction Act (PRA) requirements approved by the Office of Management and Budget (OMB). Notwithstanding any other provisions of the law, no person is required to respond to, nor shall any person be subject to a penalty for failure to comply with, a collection of information subject to the requirements of the PRA unless that collection of information displays a currently valid OMB control number. For this collection, the OMB Control number is:0693-0078 with an expiration date: July 31, 2022. Public reporting burden for this collection is estimated to be 15 minutes per survey, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed and completing and reviewing the collection of information. Send comments regarding this burden estimate or any aspect of this collection of information, including suggestions for reducing this burden, to the National Institute of Standards and Technology, Attn: Dr. Jennifer Helgeson, NIST, 100 Bureau Drive, MS 8603, Gaithersburg, MD 20899-1710, telephone 240-672-2575, or via email:jennifer.helgeson@nist.gov

Appendix B. Verbal Household Survey Consent Script

Six-Year Post-Hurricane Matthew Field Study in Lumberton, North Carolina
Housing/Household Recovery Survey
Consent Script
OMB CONTROL NO. 0693-0078 Expiration date: 07/31/2022

Hello, my name is ***(interviewer name)*** and I am a researcher from ***(name of university or National Institute of Standards and Technology)*** in the ***(department name/Engineering Laboratory)***. We are conducting a research study on recovery following the flooding that occurred in Lumberton, N.C. from Hurricanes Matthew and Florence. In particular, we are interested in learning about the process of recovering from the flooding.

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 Jamie Kruse and is funded by the National Institute of Standards and Technology (NIST).

We would like to ask you some brief survey questions about your household's experience of recovery from these hurricanes as well as some details about your household during this time. Participation will take approximately fifteen minutes. Your participation is voluntary. If you decide to participate in the study, you may withdraw your consent and stop participation at any time without penalty.

We are collecting information about the recovery process for your home and household, any COVID-19 impacts on your household's recovery, and actions taken by your household to prepare for future disruptive events. 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. We hope to gain more knowledge on how you and others were affected by Hurricanes Matthew and Florence 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**. **Would that person be you and would you be willing to participate?**

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Appendix C. Household Survey Information Sheet

Household/Housing Recovery Survey
Hurricane Matthew Community Recovery Study for Lumberton, NC
Center for Risk-Based Community Resilience Planning
A U.S. National Institute of Standards and Technology-funded Center of Excellence

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The *Center for Risk-Based Community Resilience Planning* is based at Colorado State University in Fort Collins, Colorado, and includes collaborations with researchers from universities across the United States. The National Institute of Standards and Technology's Community Resilience Program is based in Gaithersburg, Maryland and includes engineers, economists, and sociologists. Collectively, we are working to understand what makes a community "resilient" – or able to bounce back – in the face of disaster.

Our research in Lumberton focuses on community recovery following the flooding that occurred due to Hurricanes Matthew and Florence. We are returning to Lumberton for our fifth year to follow up on progress with recovery. We will be collecting information from households like yours to gain knowledge on the impacts and the recovery from Hurricanes Matthew and Florence, as well as how COVID-19 has impacted your recovery. We hope to learn from your experiences to help communities better prepare for similar events in the future.

This research is part of a ten-year project that will be carried out by experts from engineering, the social sciences, economics, and many other disciplines. This community was selected as one of our six research locations around the country that we hope to learn from. Our field team will be in Lumberton from June 17 through 26, 2022.

Because NIST is part of the federal government, this research was reviewed through a special process. This collection of information contains Paperwork Reduction Act (PRA) requirements approved by the Office of Management and Budget (OMB). Notwithstanding any other provisions of the law, no person is required to respond to, nor shall any person be subject to a penalty for failure to comply with, a collection of information subject to the requirements of the PRA unless that collection of information displays a currently valid OMB control number. For this collection, the OMB Control number is: 0693-0078 with an expiration date of July 31, 2022.

Public reporting burden for this collection is estimated to be 15 minutes per survey, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed and completing and reviewing the collection of information. Send comments regarding this burden estimate or any aspect of this collection of information, including suggestions for reducing this burden, to the National Institute of Standards and Technology, Attn: Dr. Jennifer Helgeson, NIST, 100 Bureau Drive, MS 8603, Gaithersburg, MD 20899-1710, telephone 240-672-2575, or via email:jennifer.helgeson@nist.gov

If you have more general questions about the project or the *Center for Risk-Based Community Resilience Planning*, please contact: Dr. John van de Lindt at 970-218-4076 or via email: t jwv@engr.colostate.edu.

Appendix D. Data Collection Technology

In previous survey implementations, the respondent's data were recorded on paper-based survey forms at the time of the interview and entered into *Qualtrics* survey platform at the end of every day by each survey team. The survey data were then exported from the *Qualtrics* application to review the locations of completed surveys and to assign new survey routes for the following day using *Google Maps*. The data also required several steps of cleaning and validation, making the data collection and preparations for surveying the following day a lengthy process. Due to these limitations, the research team developed an alternative survey data collection strategy focused on the ESRI *ArcGIS* suite of geographic information software applications. Two cellphone-based applications were utilized for this survey effort: *Survey123* and *Field Maps*.

The reasons for implementing the *Survey123* and *Field Maps* applications are many. First, with these cellphone-based mobile applications, an increased efficiency in data collection was realized. The survey forms used in *Survey123* provided the option of having business names and addresses auto-populated as well as the addresses of the housing units in the sample. This reduced the time required to populate those survey entries while in the field. The auto-populated fields were editable by the team in case a business changed names between survey waves. The auto-populate feature also applied to PINs assigned to the sample frame, however, this field was not alterable. Furthermore, the use of digital surveying instrument allowed for quick changes in the field. At times, the survey instrument needed to be modified in some way; this was easily accomplished, and the modified survey was pushed to the research team in a short time.

Secondly, the implementation of the two applications made the data collection effort less prone to re-coding errors. This is because of the near real-time conversion from the paper-based survey instrument to the cellphone-based application. Rather than waiting until the end of the day to enter the paper-based responses into an application, the survey team could do the transfer directly in the field and review any concerns after the conclusion of the survey.

Third, maps displaying the locations of housing units and businesses not yet surveyed were available in real-time to the research team. This allowed the team to quickly determine where they should focus their efforts. Additionally, a Dashboard provided real-time locations of completed surveys. This gave the teams a better understanding of the time required to complete the allotted surveys.

Fourth, the survey responses were time and date stamped for both the beginning and the end of the survey; this information was captured in hidden fields and will be used to calculate the average time for survey responses.

Fifth, graphs and charts displaying the results were available to the research team at the end of the surveying day. These graphs and charts were used in an at-a-glance manner to quickly identify any potential issues with the data collection.

Starting in Wave 4, the research team began to develop apps to efficiently capture data in the longitudinal survey effort. These first efforts utilized the applications during tornado damage reconnaissance for Mid-Western outbreak combined with 360-degree street view cameras. These new capabilities offer the opportunity to utilize geospatial analyses in all forms of data collection performed by the research teams.

Appendix E. Business Survey Instrument

Hurricane Matthew Community Recovery Study for Lumberton, NC
Center for Risk-Based Community Resilience Planning
A U.S. National Institute of Standards and Technology-funded Center of Excellence

OMB Control # 0693-0078
Expiration Date 7/31/2022

This collection of information contains Paperwork Reduction Act (PRA) requirements approved by the Office of Management and Budget (OMB). Notwithstanding any other provisions of the law, no person is required to respond to, nor shall any person be subject to a penalty for failure to comply with, a collection of information subject to the requirements of the PRA unless that collection of information displays a currently valid OMB control number. For this collection, the OMB Control number is: 0693-0078 with an expiration date: July 31, 2022. Public reporting burden for this collection is estimated to be 15 minutes per survey, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed and completing and reviewing the collection of information. Send comments regarding this burden estimate or any aspect of this collection of information, including suggestions for reducing this burden, to the National Institute of Standards and Technology, Attn: Dr. Jennifer Helgeson, NIST, 100 Bureau Drive, MS 8603, Gaithersburg, MD 20899-1710, telephone 240-672-2575, or via email:jennifer.helgeson@nist.gov

Date: _____ **Surveyor(s):** _____
PIN: _____ **Business Name:** _____

Address:
_____
_____

Assess the business from the outside. If a new/different business is occupying the business location, note the new name. Go into the new business (or a neighboring business) and ask an employee when the business opened in that location -- record any information you receive. You may provide the information sheet to the new business.

1. What is the operational status of this business?
- ◯ Open
- ◯ Permanently closed
- ◯ Moved to alternative location *provide address*:_____
- ◯ Not sure/don't know *take notes on anything that can help us identify the status of the business*:

_____

_____

*Enter business and ask to speak to a manager or owner. If one is not available, ask whether a senior employee is available. If not, make a note as to the **first name** of the person you will need to survey and when they will be at the business next.*

If an appropriate survey participant is available, provide the respondent with the information sheet and read Consent Script on laminated form. Start the survey with the next question.

THE FOLLOWING QUESTIONS SHOULD BE ANSWERED BY THE BUSINESS OWNER OR MANAGER

2. In what year was this business established at this location? _____

3. What is your role with this business? ◯ Owner ◯ Manager ◯ Owner and Manager

4. In which year did you start working for this business? _____

RECOVERY STATUS

5. What is the current status of this business? *Read all options at once*

◯ Fully open with the same products and services as pre-COVID-19
◯ Open, but with fewer or different products or services as pre-COVID-19
◯ Temporarily closed, but plan to reopen
◯ Permanently closed
◯ Other (Please explain):_____

6. What is the % capacity at which your business is currently operating? _____ **%**

(Provide the following prompt if needed: think of what 100% capacity means for your business. For "capacity," consider aspects of the business that are most important to you, like the quality and/or quantity of service or product offerings. For example 50% for reduced capacity, 110% for increased capacity, or 0% for businesses that have not resumed operations.)

6.a. *[if 6 is less than 100%]* **What are the reasons your business is not running at full capacity?**

(Pause and let respondent answer. If a prompt is needed: options include hiring or reduced supplies.)

_____
_____

7. How profitable is your business currently? *Read all options at once.*

◯ Highly profitable ◯ Profitable ◯ Breaking even ◯ Unprofitable ◯ Highly unprofitable ◯ Closed

8. Do you feel like your business was impacted by the following events and have you recovered?

(For this series ask the main question and only provide the specific options if the answer is "yes")

8.a. Was your business adversely impacted by Hurricane Matthew: ◯ YES ◯ NO ◯ Don't know

i. *[If Yes]* **How was it affected?** *Please select all that apply. Read all options at once.*

◯ Gross revenue decrease
◯ Physical damage
◯ Capacity decrease
◯ Keeping employees
◯ Keeping customers
◯ Other, please explain _____

ii. *[If Yes]* **Did the business recover fully?**

◯ Not Recovered ◯ Partially recovered ◯ Fully recovered ◯ Still in operation but will never recover
Please explain_____
_____

iii.

1. *[if Yes – fully recovered]* **When did it fully recover?** Month: _____ Year: _____
2. *[[if not recovered or partially recovered]* **Why not?** _____

8.b. Was your business adversely impacted by Hurricane Florence: ◯ YES ◯ NO ◯ Don't know

i. *[If Yes]* **How was it affected?** *Please select all that apply. Read all options at once.*

◯ Gross revenue decrease ◯ Keeping employees
◯ Physical damage ◯ Keeping customers
◯ Capacity decrease ◯ Other, please explain _____

ii. *[If Yes]* **Did the business recover fully?**

◯ Not Recovered ◯ Partially recovered ◯ Fully recovered ◯ Still in operation but will never recover
Please explain_____
_____

iii.

1. *[if Yes – fully recovered]* **When did it fully recover?** Month: _____ Year: _____
2. *[if not recovered or partially recovered]* **Why not?** _____

8.c. Was your business adversely impacted by COVID-19: ◯ YES ◯ NO ◯ Don't know

i. *[If Yes]* **How was it affected?** *Please select all that apply. Read all options at once.*

◯ Gross revenue decrease ◯ Keeping employees
◯ Physical damage ◯ Keeping customers
◯ Capacity decrease ◯ Other, please explain _____

ii. *[If Yes]* **Did the business recover fully?**

◯ Not Recovered ◯ Partially recovered ◯ Fully recovered ◯ Still in operation but will never recover
Please explain_____
_____

iii.

1. *[if Yes – fully recovered]* **When did it fully recover?** Month: _____ Year: _____
2. *[if not recovered or partially recovered]* **Why not?** _____

8.d. Was your business adversely impacted by another major event (in the last 5 years)? ◯ YES ◯ NO ◯ Don't know

[If Yes] **What event was it?** _____

i. *[If Yes]* **How was it affected?** *Please select all that apply.*

◯ Gross revenue decrease ◯ Keeping employees
◯ Physical damage ◯ Keeping customers
◯ Capacity decrease ◯ Other, please explain _____

ii. *[If Yes]* **Did the business recover fully?**

◯ Not Recovered ◯ Partially recovered ◯ Fully recovered ◯ Still in operation but will never recover
Please explain_____
_____

iii.

1. *[if Yes – fully recovered]* **When did it fully recover?** Month: _____ Year: _____
2. *[if not recovered or partially recovered]* **Why not?** _____

9. Please assess how the COVID pandemic affected business recovery from previous hurricane impacts: *Read all options at once.*

- ◯ No effect due to the COVID pandemic
- ◯ Recovery was hurt by the COVID pandemic
- ◯ Recovery was helped by the COVID pandemic
- ◯ N/A, no hurricane impact or was already fully recovered

10. How do/would you assess whether your business is FULLY RECOVERED after an interruption? Select all that apply. *Read all options at once. Prompt: such interruptions include things like a hurricane or pandemic*

- ◯ Expected gross revenues achieved
- ◯ Adequate number of employees achieved
- ◯ Producing/selling at the same level as before the disruption
- ◯ Full repair of property damages
- ◯ Full building functionality achieved
- ◯ Other *(Please explain)*_____

11. From the list below, please select the top three concerns for your business today. Then indicate whether you have the resources and information needed to reduce potential impacts. *(Show the respondent the laminated sheet with the response options.)*

Circle the three of greatest concern today	**Does your business have the resources and information needed to manage this risk?**
Natural hazards and extreme weather events	◯ Yes ◯ No ◯ Don't Know ◯ n/a
Pandemic (Subsequent wave of COVID-19)	◯ Yes ◯ No ◯ Don't Know ◯ n/a
Business, financial, and market volatility (e.g., operational issues, interest rates)	◯ Yes ◯ No ◯ Don't Know ◯ n/a
Other public health issues	◯ Yes ◯ No ◯ Don't Know ◯ n/a
Workforce issues (e.g., workforce safety, workforce reduction, absenteeism, retaining/rehiring staff)	◯ Yes ◯ No ◯ Don't Know ◯ n/a
Consumer-side issues (e.g., preferences for online shopping, reductions in foot traffic, low holiday seasonal sales)	◯ Yes ◯ No ◯ Don't Know ◯ n/a
Supply side issues	◯ Yes ◯ No ◯ Don't Know ◯ n/a
Inflation	◯ Yes ◯ No ◯ Don't Know ◯ n/a
Price of fuel	◯ Yes ◯ No ◯ Don't Know ◯ n/a
Utility service dependability	◯ Yes ◯ No ◯ Don't Know ◯ n/a
Other _____	◯ Yes ◯ No ◯ Don't Know ◯ n/a

12. Approximately how much money in total has been spent on this business' recovery from Hurricane damage (combined Hurricane Matthew and Florence)? Please consider physical damage to the structure and any other losses. *Pause to allow them to respond, and if they don't then begin reading the options.*

- ◯ None
- ◯ $1 – $9,999
- ◯ $10,000 - $19,999
- ◯ $20,000 – $49,999
- ◯ $50,000 - $99,999
- ◯ $100,000-$250,000
- ◯ $250,000-$500,000
- ◯ More than $500,000
- ◯ Don't Know
- ◯ Does not apply

13. Did your business apply for financial assistance during the pandemic? ◯ Yes ◯ No ◯ Don't Know

[If Yes] **What types of financial support have been applied for and received during the pandemic?** *Read each item, if they respond yes they applied then ask when.*

	Applied?	If received, When?
Federal assistance, e.g. Paycheck Protection Program (please specify): _____	◯ Yes ◯ No	Month, Year:
State assistance, e.g. North Carolina COVID-19 Rapid Recovery Lending Program (please specify): _____	◯ Yes ◯ No	Month, Year:
Local assistance (please specify): _____	◯ Yes ◯ No	Month, Year:
Other (please specify): _____	◯ Yes ◯ No	Month, Year:

14. **How did you finance your business' recovery from the Hurricanes? Please circle the <u>two</u> sources that covered the greatest percentage of the expense.** *(Show the the laminated sheet with the response options.)*

- ◯ Personal savings
- ◯ Credit card
- ◯ Corporate assistance
- ◯ Insurance
- ◯ Donations
- ◯ Private bank loans
- ◯ Crowdfunding
- ◯ Assistance from family and friends
- ◯ Federal assistance programs (e.g., SBA loans, PPP), Please list:

  _____
- ◯ State assistance programs (e.g. Resilient Recovery Loan Program), Please list:

  _____
- ◯ Local assistance programs (e.g. grant or loan from the city or local non-profit) Please list:

  _____
- ◯ Other Please list:

  _____

15. Did this business previously carry, currently carry, or plan to have any of the following insurance coverage?
Read each coverage, ask if previously carried, and wait for response. Then ask if they currently carry, and wait for response. Then ask if plan to carry in the next 6 months, and wait for response.

Insurance Coverage	Previously carried	Currently carry	Plan to in next 6 months
Business property insurance on contents	◯ Yes ◯ No ◯ Don't Know	◯ Yes ◯ No ◯ Don't Know	◯ Yes ◯ No ◯ Don't Know
Flood insurance on contents (NFIP)	◯ Yes ◯ No ◯ Don't Know	◯ Yes ◯ No ◯ Don't Know	◯ Yes ◯ No ◯ Don't Know
Business income interruption insurance	◯ Yes ◯ No ◯ Don't Know	◯ Yes ◯ No ◯ Don't Know	◯ Yes ◯ No ◯ Don't Know
Business liability insurance	◯ Yes ◯ No ◯ Don't Know	◯ Yes ◯ No ◯ Don't Know	◯ Yes ◯ No ◯ Don't Know

MITIGATION AND PREPAREDNESS

16. Has this business adopted or have plans to adopt any of the following preparedness or mitigation strategies?
(Read each option and pause for the respondent to answer the year of adoption or if they plan to adopt.)

Floodproofing of the building: ◯ Yes, Year adopted_____ ◯ Plan to in future ◯ No

Secured a secondary storage location: ◯ Yes, Year adopted_____ ◯ Plan to in future ◯ No

Had the building structurally assessed by an engineer: ◯ Yes, Year adopted_____ ◯ Plan to in future ◯ No

Performed risk assessment to identify business vulnerability to extreme weather events: ◯ Yes, Year adopted_____ ◯ Plan to in future ◯ No

Adopted strategies to stay informed of weather watches and warnings: ◯ Yes, Year adopted_____ ◯ Plan to in future ◯ No

Assigned disaster responsibilities to specific employees: ◯ Yes, Year adopted_____ ◯ Plan to in future ◯ No

Performed emergency management drills regularly: ◯ Yes, Year adopted_____ ◯ Plan to in future ◯ No

Developed a formal emergency action plan or checklist: ◯ Yes, Year adopted_____ ◯ Plan to in future ◯ No

Backed up all important documents: ◯ Yes, Year adopted_____ ◯ Plan to in future ◯ No

Store Inventory and other supplies in higher locations: ◯ Yes, Year adopted_____ ◯ Plan to in future ◯ No

Provide curbside pick-up: ◯ Yes, Year adopted_____ ◯ Plan to in future ◯ No

Develop/update telework plans: ◯ Yes, Year adopted_____ ◯ Plan to in future ◯ No

Establish or increase remote/online sales capacity: ◯ Yes, Year adopted_____ ◯ Plan to in future ◯ No

Keeping an emergency fund ("rainy day" money on-hand): ◯ Yes, Year adopted_____ ◯ Plan to in future ◯ No

Other: Please describe_____ ◯ Yes, Year adopted_____ ◯ Plan to in future ◯ No

17. The next set of items are about utility services. *For each item read the following questions, filling in the utility to the blank each time.*

On a scale of zero to five, how certain are you that _____ will be available 2-3 days after an event?

Does this business have an alternate source or provider for _____?
Prompt as needed with examples, such as: changed cell carrier, bought a generator, drilled a well, etc.

	0= Very uncertain 5= Very certain	The business has found an alternative provider or source
a. Electricity	0 1 2 3 4 5 N/A	1. yes 2. no
b. Water	0 1 2 3 4 5 N/A	1. yes 2. no
c. Natural Gas	0 1 2 3 4 5 N/A	1. yes 2. no
d. Sewer/septic	0 1 2 3 4 5 N/A	1. yes 2. no
e. Landline Phone	0 1 2 3 4 5 N/A	1. yes 2. no
f. Cell Phone	0 1 2 3 4 5 N/A	1. yes 2. no
g. IT/Internet	0 1 2 3 4 5 N/A	1. yes 2. no
h. Cable TV	0 1 2 3 4 5 N/A	1. yes 2. no

18. Has this business ever considered moving locations? *Read options.*

◯ Yes, within Lumberton ◯ Yes, outside of Lumberton ◯ No, never considered

19. In your opinion, TODAY how well-mitigated and prepared is your business to deal with hurricanes? *Read options at once.*

◯ Very well *(SKIP TO QUESTION 20)*
◯ Well *(SKIP TO QUESTION 20)*
◯ Somewhat well *(SKIP TO QUESTION 20)*
◯ Poorly
◯ Very poorly
◯ Don't know *(SKIP TO QUESTION 20)*

19b. Why do you feel your business is poorly mitigated and prepared? Was it: *Please select all that apply. (Pause after each option to have them respond yes or no)*

◯ Lack of money
◯ Lack of time
◯ Lack of workers
◯ Lack of information on how to mitigate and prepare for hurricanes
◯ Other (*Please*): _____

BUSINESS INFORMATION

The next set of questions asks about general business operations and management.

20. How many full time and part time employees does this business have? Full time _____ Part time_____

21. Does this business own or rent the space?

◯ Own (including buying the building with mortgage)
◯ Rent
◯ Other (please specify) _____

22. If there were any public health restrictions (e.g., stay-at-home orders, movement limitations, limits on public gatherings, or requirements for social distancing), is/was your organization designated as:

Read all options.

◯ Essential ◯ Non-essential ◯ Some segments were essential, some were not ◯ Don't know

OWNER/MANAGER DEMOGRAPHICS

23. How many years have you worked as a business owner/manager? _____ (years)

24. What is your age? _____

25. Do you consider yourself Hispanic or Latino/a? ◯ Yes ◯ No

26. What race do you classify yourself as (select all that apply)?

◯ White
◯ Black or African American
◯ American Indian or Native American
◯ Asian (Asian Indian, Chinese, Korean, etc.)
◯ Native Hawaiian or other Pacific Islander
◯ Other:_____

27. What is your number of years of schooling? Enter number of years _____

27.a. Indicate type of diploma or degree:

◯ High School ◯ Associate degree ◯ Bachelors ◯ Masters or higher degree ◯ Other:_____

Thank you for your time so far. We only have a few more questions. Do you have time to continue?

(If they indicate that they have time, proceed with this last question set.)

Loan Choice Activity

28. We are interested in understanding your preferences for various types of loans to support business recovery after a storm. This set of questions uses a hypothetical situation to help us understand what businesses might do in future storms.

Suppose a hurricane reduces the capacity of your business by 50% for about a year, bank loans are not an option, and a local Chamber of Commerce decides to provide loans to all businesses in your community to help mitigate the impacts. Three months after the hurricane, you are automatically pre-approved for the loan, and the loan is interest free for up to 5 years.

28.a. There are two Loan options. I'm going to describe them both. I would like to know which you apply for or if you wouldn't apply for either.

A. **Loan A will have funds available at 30 days after pre-approval and the total value of the loan is worth 2 months of your typical payroll.**
B. **Loan B will have funds available at 180 days after pre-approval and the total value of the loan is worth 6 months of your typical payroll.**

Would you apply for: ◯ Loan A ◯ Loan B ◯ I would not apply for a Loan

28.b. Next loan options are the following.

A. **Loan A will have funds available at 180 days after pre-approval and the total value of the loan is worth 2 months of your typical payroll.**
B. **Loan B will have funds available at 360 days after pre-approval and the total value of the loan is worth 6 months of your typical payroll.**

Would you apply for: ◯ Loan A ◯ Loan B ◯ I would not apply for a Loan

28.c Great, the last set of loan options are the following.

A. **Loan A will have funds available at 30 days after pre-approval and the total value of the loan is worth 2 months of your typical payroll.**
B. **Loan B will have funds available at 360 days after pre-approval and the total value of the loan is worth 6 months of your typical payroll.**

Would you apply for: ◯ Loan A ◯ Loan B ◯ I would not apply for a Loan

That is all of our questions! We are continuing this long-term study of disaster recovery here in Lumberton. We would like to get some additional information from you in order to make future surveys easier and at your convenience. Would you be willing to provide your first name and email address? YOU WILL NOT RECEIVE ANY EMAILS BEYOND OUR REQUEST FOR ADDITIONAL INFORMATION ON THIS PROJECT.

Name:_____ Business Email:_____

THANK YOU VERY MUCH FOR COMPLETING THE SURVEY!

Laminated Sheets:

11. From the list below, please select the <u>top three concerns for your business today</u>.

Potential concern
Natural hazards and extreme weather events
Pandemic (Subsequent wave of COVID-19)
Business, financial, and market volatility (e.g., supply chain disruption, operational issues)
Other public health issues
Workforce issues (e.g., workforce safety, workforce reduction, absenteeism, retaining/rehiring staff)
Consumer-side issues (e.g., preferences for online shopping, reductions in foot traffic, low holiday seasonal sales)
Supply side issues
Inflation
Price of fuel
Utility service dependability
Other _____

14. How did you finance your business' recovery from the Hurricanes? Please indicate the <u>two</u> sources that covered the greatest percentage of the expense.

Personal savings
Credit card
Corporate assistance (or assistance from another branch/location)
Insurance
Donations
Private bank loans
Crowdfunding
Assistance from friends or family
Federal assistance programs (e.g. Small Business Administration loans) List:_____
State assistance programs (e.g. Resilient Recovery Loan Program) List:_____
Local assistance programs (e.g. grant or loan from the city or local non-profit) List:_____
Other:
Other:

Appendix F. Verbal Business Survey Consent Script

Six-Year Post-Hurricane Matthew Field Study in Lumberton, North Carolina
Business Recovery Survey
Consent Script
OMB CONTROL NO. 0693-0078 Expiration date: 07/31/2022

Hello, my name is ***(interviewer name)*** and I am a researcher from ***(name of university or National Institute of Standards and Technology)*** in the ***(department name/Engineering Laboratory)***. We are conducting a research study on recovery following the flooding that occurred in Lumberton, N.C. from Hurricanes Matthew and Florence. In particular, we are interested in learning about the process of recovering from the flooding.

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 Jamie Kruse and is funded by the National Institute of Standards and Technology (NIST).

We would like to ask you some brief survey questions about your business's experience of recovery from these hurricanes as well as some details about your business during this time. Participation will take approximately fifteen minutes. Your participation is voluntary. If you decide to participate in the study, you may withdraw your consent and stop participation at any time without penalty.

We are collecting information about the repair and recovery process for your business, any COVID-19 impacts on this recovery, and actions taken by your business to prepare for future disruptive events. 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 business can be identified. There are NO KNOWN RISKS or direct benefits to you. We hope to gain more knowledge on how you and others 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 owner or manager <u>of the business</u>**. **Would that person be you and would you be willing to participate?**

This collection of information contains Paperwork Reduction Act (PRA) requirements approved by the Office of Management and Budget (OMB). Notwithstanding any other provisions of the law, no person is required to respond to, nor shall any person be subject to a penalty for failure to comply with, a collection of information subject to the requirements of the PRA unless that collection of information displays a currently valid OMB control number. For this collection, the OMB Control number is:0693-0078 with an expiration date: July 31, 2022. Public reporting burden for this collection is estimated to be 15 minutes per survey, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed and completing and reviewing the collection of information. Send comments regarding this burden estimate or any aspect of this collection of information, including suggestions for reducing this burden, to the National Institute of Standards and Technology, Attn: Dr. Jennifer Helgeson, NIST, 100 Bureau Drive, MS 8603, Gaithersburg, MD 20899-1710, telephone 240-672-2575, or via email:jennifer.helgeson@nist.gov

Appendix G. Business Survey Information Sheet

Business Recovery Survey
Hurricane Matthew Community Recovery Study for Lumberton, NC
Center for Risk-Based Community Resilience Planning
A U.S. National Institute of Standards and Technology-funded Center of Excellence

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The *Center for Risk-Based Community Resilience Planning* is based at Colorado State University in Fort Collins, Colorado, and includes collaborations with researchers from universities across the United States. The National Institute of Standards and Technology's Community Resilience Program is based in Gaithersburg, Maryland and includes engineers, economists, and sociologists. Collectively, we are working to understand what makes a community "resilient" – or able to bounce back – in the face of disaster.

Our research in Lumberton focuses on community recovery following the flooding that occurred due to Hurricanes Matthew and Florence. We are returning to Lumberton for our fifth year to follow up on progress and challenges. We will be collecting information from businesses like yours to gain knowledge on the impacts and the recovery from Hurricanes Matthew and Florence, as well as how COVID-19 has impacted your recovery. We hope to learn from your experiences to help communities better prepare for similar events in the future.

This research is part of a ten-year project that will be carried out by experts from engineering, the social sciences, economics, and many other disciplines. This community was selected as one of our six research locations around the country that we hope to learn from. Our field team will be in Lumberton from June 17 through 26, 2022.

Because NIST is part of the federal government, this research was reviewed through a special process. This collection of information contains Paperwork Reduction Act (PRA) requirements approved by the Office of Management and Budget (OMB). Notwithstanding any other provisions of the law, no person is required to respond to, nor shall any person be subject to a penalty for failure to comply with, a collection of information subject to the requirements of the PRA unless that collection of information displays a currently valid OMB control number. For this collection, the OMB Control number is:0693-0078 with an expiration date of July 31, 2022.

Public reporting burden for this collection is estimated to be 15 minutes per survey, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed and completing and reviewing the collection of information. Send comments regarding this burden estimate or any aspect of this collection of information, including suggestions for reducing this burden, to the National Institute of Standards and Technology, Attn: Dr. Jennifer Helgeson, NIST, 100 Bureau Drive, MS 8603, Gaithersburg, MD 20899-1710, telephone 240-672-2575, or via email:jennifer.helgeson@nist.gov

If you have more general questions about the project or the *Center for Risk-Based Community Resilience Planning*, please contact: Dr. John van de Lindt at 970-218-4076 or via email: jwv@engr.colostate.edu.

Appendix H. Signed Consent Form for Interviews

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 I. Semi-Structured Interview Guides for Utility Service Providers

Part 1 - Interview Questions on Decision Processes

Please think of a decision problem brought about by hurricanes Matthew and Florence and the need to do something about it anticipating future severe weather events.

1. What is your **decision problem**?
2. Who is the **decision-maker** of your decision problem?
3. What are the **alternatives/policies** for your decision problem?
4. What are the **objectives** you try to achieve? (quantifiable/non-quantifiable)
   4.1. Are there **community resilience goal(s)** used to guide decision objectives?
5. What are the main **constraints** on achieving the above objectives via desirable alternatives?
6. What **consequences** do you try to manage or avoid?

Please think of data, models and overall situational awareness.

7. What key **data** is required to help solve your decision problem?
8. For your decision problem, do you use **models** to inform decisions?
9. For your decision problem, how is the **output data** represented most successfully?

Part 2 - Interview Questions on Decisions and Constraints

	Question	Infrastructure sector of Interest (X)	Sample Range of Answers	Use of the data
	I. Resources			
1	What types of resources do you need for restoration after a disaster?	Power, Gas, Water, Cellular, Internet, Other	Money, crew, machinery	Resource constraints of optimization models
2	Do you have to share/compete over any of the above resources with other sectors or utility systems?	Power, Gas, Water, Cellular, Internet, Other	Name of the resource: Yes (name of other sectors or utility systems) or No	Resource constraints of optimization models
3	How do you prioritize available resources to different damaged components?	Power, Gas, Water, Cellular, Internet, Other	Name prioritization rules or rationale	Resource constraints of optimization models
	II. Communication			
1	Are your decisions affected by decisions made by other utilities/sectors?	Power, Gas, Water, Cellular, Internet, Other	Yes, No	Decentralized optimization models
2	How often do you communicate with decision-makers of other sectors or utility systems? (Normal condition, during disasters, recovery phase)?	Power, Gas, Water, Cellular, Internet, Other	Always, often, sometimes, never	Communication protocol for decentralized optimization models
3	If you communicate, is it an iterative process so you can adjust your decisions based on others'?	Power, Gas, Water, Cellular, Internet, Other	Yes, No	Communication protocol for decentralized optimization models
4	Quality of communication: If you communicate, how much information is revealed?	Power, Gas, Water, Cellular, Internet, Other	Complete, partial, minimal	Communication protocol for decentralized optimization models
5	Do you have other means to get information about others?	Power, Gas, Water, Cellular, Internet, Other	Yes (name it), No	Communication protocol for decentralized optimization models
6	If the communication is incomplete, How do you compensate for the lack of information?	Power, Gas, Water, Cellular, Internet, Other	Name your approach	Judgments in decentralized optimization models
7	Are you willing to extend communications for future events?	Power, Gas, Water, Cellular, Internet, Other	Yes, No	Retrofit of communication

8	Whom else do you communicate with?	Power, Gas, Water, Cellular, Internet, Other	Local government officials, state officials, other emergency providers, including hospitals, hardware stores, etc.	Communication network
	III. Restoration plans			
1	Is there a record of your executed restoration plans in the past events?	Power, Gas, Water, Cellular, Internet, Other	Type, time, increase in the capacity of the facility, cost	V&V: system-level recovery trajectories
2	Do you have a tentative restoration plan for future events?	Power, Gas, Water, Cellular, Internet, Other	Time, duration, cost, initial damage, final performance, restoration curve/total cost curve, decision approach, available resources	V&V: system-level recovery trajectories
3	Have you coordinated your plans with emergency operation authorities?	Power, Gas, Water, Cellular, Internet, Other	Yes (elaborate), No	Resource constraints of optimization models
4	Do you consider open contracts with external entities as a part of your future restoration plan?	Power, Gas, Water, Cellular, Internet, Other	Yes (elaborate), No	Resource constraints of optimization models
5	What are the critical customers for your system?	Power, Gas, Water, Cellular, Internet, Other	Name	Demand dissatisfaction penalties for the optimization model
6	How do you address the customers' criticality after contingencies?	Power, Gas, Water, Cellular, Internet, Other	strategy (isolation, repair, backup source)	Demand dissatisfaction penalties for the optimization model
	V. System operation and layout			
1	Does your system include microgrids?	Power	Yes, No	Network configuration and demand distribution
2	If yes, what is the energy source of the local systems?	Power	Solar, wind, etc.	Network configuration and demand distribution
3	Can you use mobile generation for the temporary service after contingency?	Power, Gas, Water, Cellular, Internet, Other	Yes (type, capacity), No	Demand dissatisfaction penalties
4	Do you have local storage (e.g., elevated tanks) for temporary supply after contingency?	Water	Yes (type, capacity), No	Network configuration and demand distribution
	IV. Stakeholders			
1	Is your company publicly traded on the stock market?	Power, Gas, Water, Cellular, Internet, Other	Yes, No	Decision criteria for decentralized optimization models

2	If yes, how do the shareholders' opinions influence your decisions?	Power, Gas, Water, Cellular, Internet, Other		Decision criteria for decentralized optimization models