

Enhancing Community Capacity: Understanding and Mapping Community Environmental Health Impacts of Hurricane Matthew

PRELIMINARY REPORT

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Executive Summary

In October 2016, Hurricane Matthew caused record flooding in North Carolina, driving thousands of residents from their homes and causing an estimated \$1.5 billion in damage. Although the water has receded, it will take time for the affected communities to recover from the immensity of damage and disruption caused by this disaster. One aspect of the disaster that has received inadequate attention is the potential public health impact of environmental health hazards in and around the affected counties. For instance, mold in buildings, a significant and widespread environmental health hazard that can cause adverse respiratory and other health effects in occupants, may be created or exacerbated by flooding of buildings and inadequate post-flood treatment to remove the moisture and ensuing mold. Flood waters also can transport chemical and biological contaminants from one location to another. Such redistribution of contaminants may go undetected unless specifically evaluated. Similarly, some non-acute or non-specific health effects resulting from exposure to these contaminants may not be recognized as being linked to them.

These problems are likely to become more common in the future (see Hurricanes Sandy, Matthew, and, most recently, Harvey), as climate change continues to increase both the frequency and severity of extreme weather events. As our climate and environment become increasingly unstable, unprecedented flooding in highly developed areas, especially low-lying coastal areas, is likely to become more common. The frequency and severity predictions of “100-year storm events” will become increasingly inadequate, as seen recently in Houston, TX. Failure to anticipate—and prepare for—these changes, which are already underway, will simply compound future disasters, increasing the human, environmental, and monetary costs. Addressing important potential environmental health hazards before they become actual hazards, even in the absence of certainty, is imperative.

This report describes the design and conduct of a preliminary assessment of potential and known environmental health hazards resulting from Hurricane Matthew in two of the most severely impacted counties in North Carolina: Cumberland and Robeson Counties. Due to time constraints associated with study funding, this report represents a *preliminary* analysis of potential environmental health hazards and concerns in the targeted counties. More detailed analyses and presentation of findings are planned for the future, pending additional resources.

The goal of this study was to create resources that public health professionals, state decision makers, and others could use to prioritize and target community-level environmental health interventions in response to Hurricane Matthew and to help improve public health response to future floods and other disasters in the state. We assessed a wide range of known and potential environmental health hazards to allow a more comprehensive understanding of potential impacts. We focused on communities at large as well as on vulnerable populations, including children, senior citizens, and the disabled, within these communities. For logistical reasons, we restricted our assessment to Robeson and Cumberland counties, two of the hardest hit areas in the state.

The study consisted of three components: (1) structured interviews with a sample of key informants in each county, (2) an online survey, available to all adult residents of the targeted counties, and (3) maps and geospatial analyses of flooded areas overlaid with locations of vulnerable populations and sources of potential environmental health hazards.

Interviews. In interviews with 23 key informants in both counties, participants noted that **the poor were disproportionately affected by the hurricane and the resultant flooding**, with a number of African American and American Indian communities particularly hard hit. At the same time, **contamination of municipal drinking water supplies due to flooding of, or damage to, drinking water and wastewater infrastructure posed risks to residents throughout these counties**. However, the issuance of boil water advisories and the provision of bottled water by various organizations mitigated the impact of this contamination. Apart from the temporary contamination of municipal drinking water, **mold infestation of homes and public buildings, along with the potential health effects from this exposure, was, by far, the most commonly expressed environmental health concern** among participants. Receiving less attention was the potential transport of chemical and biological contaminants in the flood waters that inundated many buildings and public spaces. While most key informants had little direct knowledge of specific potential contaminants/sources, some expressed concerns about flooded gas stations, automobile repair shops, farm land, and, to a lesser extent, confined animal feeding operations, coal ash storage sites, hazardous waste sites, underground fuel storage tanks, and factories in the area. Many perceived **increases in the prevalence of respiratory illnesses and skin rashes** since the hurricane, additionally emphasizing the need to address **mental health issues** resulting from the storm among residents as well as responders.

Online survey. A total of 215 residents completed an online survey, including 143 in Cumberland County and 72 in Robeson County. **A large proportion of respondents in each county reported hurricane damage to their homes.** Most respondents who reported such damage continued to live in these homes after the hurricane, whether by choice or necessity. A substantial number of respondents reported flood water damage specifically to their homes, with concomitant mold growth in their homes since the hurricane. Slightly more than half of respondents reported getting their drinking water from municipal sources before the hurricane; despite the loss or contamination of this water source during and in the immediate aftermath of the hurricane, a large majority of them continued to use this as their primary water source. **Most respondents stated that their health was about the same as one year prior (i.e., before the hurricane).** However, almost one-tenth reported that they had experienced skin conditions most of the time or all of the time in the past thirty days, and over one-fifth indicated that these skin conditions were worse than one year before. About one in eight respondents rated their current mental health as “fair” or “poor”, which is substantially higher than the approximately one in thirteen observed in the U.S. general adult population. Respondents also reported an overall increase in the number of household members being treated by a health care professional compared to one year prior. Too few respondents reported specific diagnoses for us to investigate these health effects further. Lastly, the Hurricane Matthew-related environmental health concerns most commonly identified by respondents related to the following: flooded wastewater treatment facilities; poultry, hog, and cattle farms; hazardous waste sites; municipal waste disposal sites; and gas stations. It is important to note, however, that the demographic profile of survey respondents differs from that of the county populations, with individuals having higher socioeconomic status and greater access to computers overrepresented among these survey respondents; nonetheless, while these results may not be fully generalizable to all county residents, they do identify a number of hurricane-related concerns that warrant further investigation and response, as appropriate.

Mapping. To better understand the risk from potential environmental health hazards, we considered proximity of “vulnerable” populations to potential environmental health hazards. We defined vulnerable population locations as locations where substantial numbers of children, elderly, or disabled persons lived or congregated on a regular basis, including daycares, public and private schools, nursing homes, and churches. Potential sources of environmental contamination that we considered included gas stations, automobile repair shops, brownfields, coal ash storage sites, Dry-Cleaning Solvent Cleanup Act sites, hazardous waste sites (active, and inactive), landfills (pre- and post-regulatory), manufactured gas plants, confined animal feeding operations (CAFOs), and wastewater treatment plants. A substantial number of the vulnerable population locations that we identified in each county (Cumberland: 28.0% of 756 locations, Robeson: 21.1% of 437 locations) are within 0.25 mile of a potential environmental hazard. These locations include at least one quarter of daycares, nursing homes, public schools, and private schools in one or both counties. The number of vulnerable population locations within the Hurricane Matthew inundation extent was relatively small in Cumberland County (N=5; 0.7% of locations), and included churches, daycares, and public water sources. There were more such locations in Robeson County (N=33; 7.6% of locations), comprised primarily of churches, daycares, public schools, and public water sources. Importantly, we identified over 100 vulnerable population locations or public drinking water sources in each county within the 100-year floodplain. Both counties had a number of potential sources of environmental contamination within the Hurricane Matthew inundation extent, including 25 in Cumberland County and 60 in Robeson County. These consisted primarily of automobile repair shops, gas stations, active and inactive hazardous waste sites, pre-regulatory landfills, and wastewater treatment plants. A substantially larger number of potential sources of environmental contamination lie within the 100-year floodplain in each county, ranging between 123 and 133.

Due to the timing of project funding and overall resource constraints, it was beyond the scope of this exploratory project to test homes and public buildings and spaces that had flooded for flood-related contaminants. Therefore, it is important to emphasize that our findings primarily address *potential* environmental health hazards. However, reports both in the media and anecdotally indicate that certain gas stations released petrochemicals during the flooding. Moreover, mold problems in homes and other buildings arising subsequent to hurricane-related flooding were reported by a substantial proportion of key informants and survey participants.

Recommendations

Input from research participants and our analysis suggests the following recommendations, described in greater detail at the end of this report, related to reducing potential exposures to environmental health hazards following flooding or other natural disasters:

1. Improve coordination among agencies/organizations and strengthen connections among partner agencies/organizations prior to a disaster.
 - a. Share information on resources that each agency/organization can provide in an emergency response.
 - b. Reduce redundancy among agencies/organizations by developing protocols to efficiently allocate resources in an emergency response.
2. Establish/improve and maintain two-way communication with community organizations/leaders prior to disasters to prepare the community to assist with disaster

- response both during and after the event. While such efforts can be challenging and time-consuming, they provide a more effective and sustainable approach in the long-term.
- a. Develop alternative communication strategies for use during power outages.
 - b. Develop alternative communication strategies for reaching diverse populations, with a range of languages, literacy, internet access, and computer skills.
3. Make better use of professionals, paraprofessionals, and volunteers.
 - a. Use a “train the trainer” approach to efficiently disseminate information to agencies/organizations and to the public.
 - b. Increase the number of trained people.
 - c. Develop or revise, as needed, and disseminate educational materials that inform residents about potential environmental health hazards that they can address, such as mold in homes.
 4. Conduct additional research to assess the likelihood and likely extent of redistribution of environmental health hazards during disasters to areas where human exposure opportunity, especially of vulnerable populations, is increased.
 5. Expand the network of UNC researchers and research institutions involved in disaster response in North Carolina to facilitate assessment of disaster-related environmental health risks via timely collection of environmental samples and data, as well as interaction with disaster victims and responders.

Introduction

As described above, the goal of this study was to create resources that public health professionals, state decision makers, and others could use to prioritize and target community-level environmental health interventions to improve public health response to Hurricane Matthew and future floods and disasters in North Carolina. The study consisted of three components:

1. Structured interviews with a sample of key informants in each county, including representatives from federal, state, and local emergency response agencies and health departments; community organizations and environmental justice groups; local Native American tribes; and local faith-based organizations.
2. An online survey available to all adult residents of the targeted counties eliciting information on residents' knowledge of, and concerns about, known or potential environmental health hazards related to the hurricane and health status pre- and post-hurricane.
3. Maps and geospatial analyses of flooded areas overlaid with locations of vulnerable populations and sources of potential environmental health hazards in order to assess the opportunity for redistribution of these health hazards and the populations likely affected in such an event.

Preliminary results from each component are described below, followed by recommendations for improving disaster response to address the environmental health concerns identified in this report. These recommendations will be disseminated to the agencies and organizations with which we engaged and will be made available to the public online.

Study Context

Demographics of targeted counties

Cumberland and Robeson Counties are substantially more racially diverse than the rest of North Carolina (Table 1). Whites comprise less than half of the population in both counties, with the largest minority groups being African Americans (38.7%) and Hispanics (11.3%) in Cumberland County and American Indians (41.0%), African Americans (24.2%), and Hispanics (8.6%) in Robeson County. Socioeconomic status is appreciably lower in these counties, particularly in Robeson County, than in the state overall. This difference can be seen in the lower proportion of adults with college degrees and the lower per capita and household incomes in these counties. The disparity is most pronounced in Robeson County, where the median household income is only 65% of the statewide median. These differences result in 18.8% of Cumberland County residents and 30.6% of Robeson County residents living in poverty (vs. 16.4% statewide). Measures of health and access to care in 2015, the year before Hurricane Matthew, also indicate deficiencies. Among persons under 65 years of age, 17% in Cumberland County and 26% in Robeson County had no health insurance (although this measure is 19% statewide). Ranking of these counties by health outcomes and health factors are particularly revealing: with 100 counties in the state, Cumberland County ranked 73rd for health outcomes and 45th for health factors, while Robeson County ranked 95th for health outcomes and 100th (i.e., last) for health factors.

Table 1. Demographic characteristics of Cumberland and Robeson Counties for 2016, except where noted

Characteristic	North Carolina N=10,146,788	Cumberland County N=327,127	Robeson County N=133,235
Race/ethnicity			
White, non-Hispanic	63.5%	43.7%	25.5%
Black or African American	22.2%	38.7%	24.2%
Hispanic or Latino	9.2%	11.3%	8.6%
American Indian and Alaska Native	1.6%	1.8%	41.0%
Asian	2.9%	2.7%	0.7%
Educational attainment (2011-2015)			
High school graduate or higher	57.4%	66.7%	62.3%
Bachelor's degree or higher	28.4%	23.3%	12.8%
Median income			
Household income	\$46,868	\$44,171	\$30,608
Per capita income	\$25,920	\$22,931	\$15,559
Percent of population in poverty	16.4%	18.8%	30.6%
Median household size	2.5	2.6	2.9
Percent of female-headed households with children under 18 years of age	7.7%	11.0%	11.8%
Percent of home ownership	65.1%	52.6%	63.1%
Median value of owner-occupied home (2011-2015)	\$154,900	\$129,300	\$70,200
Percent under 65 years of age without health insurance ^a	19%	17%	26%
Health outcomes ranking (out of 100) ^a	-	73	95
Health factors ranking (out of 100) ^a	-	45	100

Source: US Census Bureau Quick Facts, <https://www.census.gov/quickfacts/fact/table/US/PST045216>, except where noted

^a Robert Wood Johnson Foundation, 2015 County Health Rankings: North Carolina; <http://www.countyhealthrankings.org/app/north-carolina/2015/overview>.

These demographics tend to increase vulnerability of individuals and populations to the impacts of natural disasters such as hurricanes. This vulnerability is determined by factors such as the nature and location of housing as well as by the ability to respond—financially, logistically, physically, and emotionally—to the impacts of a disaster.

Key Informant Interviews

Methods

We conducted a total of 21 interviews with 23 key informants (including two interviews with two people each), who were selected to capture a range of roles and activities, both immediate and long-term, in response to Hurricane Matthew. These individuals represented local, state, and federal government agencies (e.g., county health departments, cooperative extension services, housing authorities, emergency management, public works, social services), as well as community groups, Native American organizations, and faith-based organizations (e.g., disaster response/recovery groups, including the Red Cross, social/environmental justice groups, and food banks) (Table 2). Where appropriate, we attempted to identify individuals filling similar roles in each county. To this end, six participants worked in Cumberland County, 12 worked in Robeson County, and five worked in both counties. Most had a minimum of 5-10 years of experience in their current position or in the field, and most were in leadership positions.

Table 2. Types of stakeholders and organizations represented in interviews

County	Organization type	Expertise
Cumberland	Government	Environmental health
Cumberland	Government	Public works
Cumberland	Government	Social services
Cumberland ^a	Government	Emergency management
Cumberland	Managed Care Organization	Mental health counseling
Robeson	Educational institution	Higher education
Robeson	Government	Environmental health
Robeson ^a	Government	Emergency management
Robeson	Government	Cooperative Extension
Robeson	Government	Public works
Robeson	Government	Social services
Robeson	Government	Housing
Robeson	Government	Public services
Robeson	NGO	
Robeson	Private sector	
Robeson	Religious	
Cumberland/Robeson	NGO	
Cumberland/Robeson	NGO	
Cumberland/Robeson	NGO	
Cumberland/Robeson	Religious	
Cumberland/Robeson	Religious	

NGO: non-governmental organization

^a Two stakeholders were interviewed together.

The interviews were structured and almost all were in-person. We elicited detailed information on a number of topics, including *i*) the individual's role(s) in the hurricane response, *ii*) the organization's role in the hurricane response, *iii*) the areas and populations within each county that were most impacted by the hurricane, *iv*) the types of facilities and public services most

impacted by the hurricane, v) specific environmental health hazards that the individual/organization addressed and the extent to which they were addressed, vi) environmental health hazards in adjacent counties that *might* have affected the target counties, vii) specific environmental health hazards that were not addressed in the hurricane response and the reasons for this, viii) *potential* environmental health hazards resulting from the hurricane, ix) prevalence of mold in homes and public buildings since the hurricane, x) testing of homes and other buildings/public spaces for potential hurricane-related contaminants, xi) any known or perceived health effects that might be attributed to the hurricane, xii) community concerns about environmental health hazards and health effects perceived to be related to the hurricane, xiii) sources of information about environmental health hazards, xiv) availability of data or documents on the location, extent, nature, and duration of the hurricane's impacts on populations and potential sources of environmental health hazards, and xv) how the individual/organization could improve their response to future hurricanes. All but one of the participants agreed to recording the interview (i.e., N=20 recorded interviews). We transcribed and coded these 20 interviews, documenting key phrases and concepts related to environmental health outcomes, as articulated by the participants.

In addition to the structured interviews and at the suggestion of interviewees from Cooperative Extension, we also conducted five informal, 15-minute phone conversations with Cooperative Extension agents who specialized in field crops, livestock, and other horticulture in Cumberland (n=1) and Robeson (n=4) Counties. We asked questions about the following farming-related impacts of Hurricane Matthew: i) extent of Hurricane Matthew flood damage to farms in the county; ii) whether there was any testing of soil following the flooding of the farms; iii) whether there was any testing of crops following the flooding of the farms; iv) affected irrigation sources and testing of those sources; v) evidence of agricultural chemicals carried off by flooding; vi) known breaches of lagoons at confined animal feeding operations; and vii) knowledge of any of the aforementioned impacts on neighboring counties. Two of the agents who participated also served Hoke and Bladen Counties (in addition to Robeson or Cumberland County).

Results

Impacted vulnerable populations

Some interview participants were specific about the most impacted populations in Cumberland and Robeson Counties, with about half acknowledging that African Americans (particularly in South Lumberton) and American Indians (in and near West Lumberton) were disproportionately affected. Despite the pre-hurricane presence of ~10% Hispanic residents in both counties, there was little mention during the interviews of the impact of the hurricane on the Hispanic population specifically. Nevertheless, among the three interview participants who discussed the impact on Hispanics, one nonprofit organization representative in Robeson County mentioned that, in the aftermath of Hurricane Matthew, a record number of Hispanic individuals and families came to their offices for assistance with basic living needs. A Robeson County emergency management employee stressed the difficulty in evacuating Hispanic residents from flooded areas, attributing this difficulty to a lack of trust in the government and to communication barriers.

Nearly all of the interview subjects emphasized the burden of this hurricane upon low-income residents. Communities like South and West Lumberton in Robeson County were identified by participants as populated mostly by low-income and minority groups. One local pastor emphasized the effect upon low-income communities living in low-lying areas prior to the hurricane, saying:

But in Lumberton and in these low-lying areas – poor people live in low places... That's where we live. Robeson County – there are a lot of spots in Robeson County of just low, muddy, swampy areas. Poor people live there. I grew up there. That's where we live. And so the least able people – their burden was greatest.

The executive director of a Robeson County nonprofit stressed the inability of low-income residents to address hazards in homes:

They literally don't have anything, or they were staying in the hotel, or they had no flood insurance. And their house has been overcome with mold. And they don't know who to turn to.

More than half of the participants expressed concern about how the needs of the elderly were addressed during and after the hurricane, with one Robeson County official worrying that there was very little attention paid to their specific medical and communications needs. Additionally, two participants noted that the temporary or permanent shutdown of a number of businesses resulted in additional stress on low- and moderate-income residents who were employed in those businesses.

Impacted communities

While downtown Fayetteville (Cumberland County) and south and west Lumberton (Robeson County) were the largest and most populated cities impacted in the counties that were included in this project, interview participants identified several additional impacted towns and neighborhoods. In Robeson County, these included Red Springs, Maxton, Broad Ridge, Long Branch, Fairmont, Roland, Mayfair community, and Pembroke. In Cumberland County, these included Hope Mills, communities in the western and southwestern parts of the county, and Hollywood Heights.

Environmental health hazards

Mold

Mold in homes, businesses, and other public buildings that flooded during the hurricane was, by far, the most commonly expressed environmental health concern, noted by every participant. As a disaster response coordinator for a faith-based service organization operating in both counties put it:

The main thing that we are seeing and experiencing and even when it gets corrected, it comes back, is the most evil damaging thing ever as far as we're concerned, and that is mold, mildew.

Mold was reported to be widespread across a range of types of homes, including multi-unit, single family, and mobile homes. A frequently expressed concern was that many homeowners had returned to their homes and repaired (or hired contractors to repair) them after the flooding

had subsided, but before all flood water or wet building materials had been thoroughly dried or removed. Other residents were believed to be living in homes that had not been renovated after being flooded, but that had, or would soon have, mold infestation due to the flooding. Several participants noted that *some* homes suffered from damp conditions and mold prior to the hurricane, but that hurricane-related flooding had substantially worsened it.

One challenge noted by interviewees was that homeowners, in the immediate aftermath of the hurricane, often viewed mold or the potential for mold as a lower priority than other post-hurricane needs and, thus, devoted insufficient attention and resources to preventing or eliminating it early on. We were told that this problem was exacerbated by many residents feeling overwhelmed by the complexity of the insurance and other claims paperwork and procedures needed for storm-related repairs/remediation. It was also noted that many affected residents lived in rental properties that were not adequately maintained or repaired by the landlords after the flooding. In some cases, renters were unable to move back into their rental homes or were subsequently forced to move out. Additionally, interviewees reported community complaints about the smells emanating from abandoned homes infested with mold since the hurricane.

Several interviewees noted that mold was also a known or potential problem in a number of public buildings that had flooded. These included the Robeson County School System's headquarters (which had not been re-opened at the time of these interviews) and a number of public schools, fire stations, church and community centers, and restaurants in both Cumberland and Robeson Counties.

The county health departments that we spoke with were aware of, but had not actively addressed, the issue of mold at the time we conducted our interviews (in late spring/early summer 2017). The Cumberland County environmental health division had not yet received community complaints, but expected that mold would become a problem in the near future. The Robeson County environmental health staff did not feel sufficiently trained in mold mitigation/control methods to provide assistance in this area. One indication of the challenges of addressing mold problems was the small number of units remediated at the time of the interviews: of 270 public housing units in Lumberton damaged during the hurricane (out of a total of 729), only 9 had been repaired after 8 months. According to interviewees, this situation may have been exacerbated by the presence of asbestos in some units.

The extent of mold infestation in renovated homes in both counties remains unclear. The American Red Cross and the Federal Emergency Management Agency (FEMA) provided initial assessments of damage to homes, businesses and other structures, which served as a basis for networks of organizations to address family housing, building repairs, and other needs. The nonprofit disaster response organizations United Methodist Committee on Relief and North Carolina Baptist Men, which are playing major roles in the renovation of flooded homes in these counties, require testing of moisture levels and remediation of excessive levels before renovating damaged homes. All of the interviewees recognized the work of federal, state, and faith- and community-based relief agencies as a major force in addressing these and other physical needs. Additionally, the long-term recovery committees in both counties (Cumberland Disaster Recovery Coalition and Robeson County Disaster Recovery Committee) have begun discussing strategies for addressing mold problems in flooded buildings, according to interview participants, many of whom represent their agencies in these networks committed to long-term recovery.

Participants identified several resources they used to address mold remediation questions. For instance, one of the local housing agencies consulted with a mold expert in the North Carolina Department of Health and Human Services (NC DHHS). A local nonprofit found online information from the EPA on best practices for safely cleaning mold from homes and disseminated this booklet to residents: *A Brief Guide to Mold, Moisture and Your Home* (<https://www.epa.gov/sites/production/files/2016-10/documents/moldguide12.pdf>). Another local nonprofit used the knowledge and training of its housing director to address mold in their flooded building before it worsened, specifically removing water-damaged materials and quickly cleaning it “to make sure that we didn't have any endangerment toward the community, the families or homeless. Especially the homeless people that come in...”

When discussing mold and other potential environmental health hazards in homes and businesses due primarily to the flooding, interviewees noted that some residents abandoned their homes and businesses while others remained in them. Participants highlighted that residents often left their homes primarily because they could not afford to make the repairs or saw the damage as being too great. Similarly, they noted that most residents who remained in their homes did so because they had few options, regardless of the potential health hazards to which they would be exposed. A director of a government agency in Robeson County noted:

I know we have people who are living in condemned places that just – they had nowhere else to go, and they just moved back in and are living with whatever conditions are there.

Contaminated drinking water

Most participants expressed concern about contaminated drinking water resulting from the hurricane, which, concurrent with extensive power outages, prevented both residents and food establishments from preparing food for days. They appreciated that both counties had issued boil water advisories and that bottled water was provided by a number of nonprofit, faith-based, and business entities in the days following the hurricane. Nonetheless, they cited the flooding or breakdown of drinking water/wastewater infrastructure as major reasons for the contamination of drinking water. Moreover, a subset of the Robeson County participants cited lack of adequate communication and some confusion about the end date for the boil water advisories and the broader community’s concern about the quality of the water after the advisory ended. One participant noted that a few of the wells used to provide drinking water in one of the counties were underwater during the flooding and required surveillance because it was unknown how the floodwaters would impact them. Cumberland County emergency services credited the local health department with educating residents about testing and sanitizing their wells with the following materials:

- *How Safe Is Your Well Water?*
https://www.co.cumberland.nc.us/safe_water/SafeWater_4Color_Brochure.pdf;
- *Environmental Health Tests Well Water Affected by Floods*
http://www.co.cumberland.nc.us/public_info/news_releases/2016/October/Environmental_Health_Tests_Well_Water_Affected_by_Floods_10182016.pdf;

However, it is unclear how many private wells may have been contaminated by the hurricane flood waters and how many subsequently have been tested for contamination, underscoring the importance of alerting well owners to the potential for well contamination from flooding.

Sources of water contamination

Many participants noted that a number of gas/fueling stations had flooded, potentially releasing petrochemicals into the water. These comments were supported by reports and photographs in the news media taken during the storm of flooded gas stations. One participant noted how strong the smell of gasoline was in West Lumberton when she went outdoors during the flooding, saying:

I recall... big gas tanks, and there's gas stations. It's right here when you go across the bridge. But the smell, almost like if someone was to light a cigarette you would think the whole town would blow... I can still smell it, when you think about, right especially that area... the fumes just were, I mean truly, they were unreal.

Many participants also reported flooding of automobile repair and body shops, which may have also resulted in the contamination of the flood waters with gasoline, oil, and other organic and inorganic chemicals. Based on past work experience, one interviewee raised concerns about residents with permitted repair shops on their home properties, suggesting that many of them stored hazardous chemicals and equipment with less oversight than that required of typical commercial repair shops. Many of the participants also expressed concern about other sources of flood water contamination, including flooding of, or runoff from the following sources: agricultural lands (e.g., pesticides, fertilizers); waste disposal sites, such as municipal landfills; and wastewater treatment facilities. Participants noted that runoff from agricultural land likely occurred because so much of the county land in these geographically large counties is used for farming. A smaller number of participants mentioned concerns about confined animal feeding operations, coal ash storage sites, hazardous waste sites, underground fuel storage tanks, and dyes or other chemicals from flooded factories in the area. It should be noted, however, that few participants indicated direct knowledge of contamination by these sources.

Related to water contamination, three participants expressed concerns about consuming fish from nearby waters, with one noting:

So for example, the other day we were talking with some friends about going fishing and one of them said, 'I wouldn't feel comfortable eating fish out of the river right now.' So I think that's kind of been the perception is that our rivers, we don't know what's in them anymore because they all kind of ran together, so we don't know where they are at this point.

Despite this potential contamination of flood water, participants were not aware of testing for any of these potential contaminants in buildings or spaces that were flooded. The most commonly suggested reason for the lack of testing was the cost, which may have been a barrier for both residents and agencies/organizations. Also, in the aftermath of the hurricane, priority was placed on meeting immediate needs such as getting people back into homes, providing critical social services, and repairing damaged infrastructure. Nonetheless, participants noted a number of public buildings, child care centers, and other facilities in low-lying areas that they believed warranted testing for contamination in the aftermath of the hurricane. Because these facilities had not been tested, the extent and magnitude of any contamination of buildings and spaces that flooded during the hurricane remain largely unknown. Interestingly, and perhaps not surprisingly, participants generally seemed more comfortable discussing the visible and tangible problem of mold rather than these invisible contaminants.

Health impacts and responses

Many of the participants perceived ongoing hurricane-related adverse health effects among community residents, but their knowledge of the extent and nature of these effects was limited. Six of the participants identified respiratory illnesses, including asthma, COPD, and sinus and respiratory infections, as primary concerns and noted reports by some residents that going back into their damaged homes created “breathing problems.” According to one participant, such effects were reported by some residents living in a low-income Cumberland County community. Two participants reported seeing residents with skin rashes that they attributed to the hurricane.

In addition to the recognition that impacted populations had physical health needs following the storm, most of the professionals interviewed acknowledged the need also to address the mental health of residents, including children. Most participants mentioned mental health as a primary concern, recognizing that many residents were overwhelmed about losing their homes and possessions. Others recognized the stress that children, in particular, may have been experiencing as a result of being displaced from their homes *and* schools. Several participants noted that some residents’ stress was compounded by their poor pre-hurricane financial or living conditions, loss of family members, loss of homes, and/or exacerbation of existing health conditions. One participant, who emphasized the stigma associated with seeking mental healthcare, highlighted how low-income residents cope with the stress, saying: “...[P]oor people don't go to counseling. They talk to their neighbors; they talk to their family. And sometimes their preacher.”

Participants also recognized the mental health needs of first responders, and even clergy, many of whom spent months responding to residents’ needs following the storm. As a result of this concern for their mental well-being, one faith-based organization sought to establish resources and events for church pastors feeling overwhelmed. When discussing mental health referrals, most participants reported Eastpointe and Alliance Behavioral Health as the primary mental health care providers in Cumberland and Robeson Counties.

Sources of information on environmental health and hurricane impacts

Participants reported seeking environmental health information from a range of agencies and organizations, including the following: local, state, and federal agencies, particularly local and state health and environmental departments (e.g., NC Department of Environmental Quality); local social services departments; city and county government; state and local emergency management; FEMA; Red Cross’ Coordinated Assistance Network (CAN) system; television and newspaper media, as well as a number of other community- and faith-based organizations that are members of the long-term recovery coalitions in the targeted counties.

Farming impacts

As noted above, during the structured interviews, participants representing local NC Cooperative Extension services in both counties acknowledged their incomplete knowledge of the hurricane’s impacts related to agriculture and suggested follow-up conversations with extension agents who specialized in field crops, livestock, and other horticulture. We conducted five 15-minute phone conversations with agents in Cumberland (n=1) and Robeson (n=4) Counties. Two of the agents also served Hoke and Bladen Counties.

Among livestock farms, there was reported to be excessive standing water, but little known loss of livestock in Robeson or Cumberland. One farm in neighboring Hoke County experienced

flooding in poultry houses, forcing the owner to destroy all of the birds in those houses. None of the agents were aware of breaches of any of the lagoons at confined animal feeding operations in the counties that they served. Participants reported flooding at crop farms, including a large nursery and some farms with row crops. Agents stated that some farms were forced to destroy flooded crops, including those grown for animal feed. Despite the agents' encouragement of farmers to perform testing for soil contamination after the hurricane and before planting fall or winter crops, the agents were aware of little testing having been done. One agent explained that cost likely deterred many farmers from testing. Agents reported flooding of some irrigation systems, although it was noted that some farmers might not inform Cooperative Extension agents of such flooding, so the agents' knowledge of flooding events may be incomplete.

Online Survey

Methods

We conducted an anonymous, online survey to gain a better understanding of the Hurricane Matthew-related experiences, concerns, and impacts of the residents of Robeson and Cumberland Counties. The survey was designed to take 10-15 minutes to complete and could be done on a computer or a mobile device. It was restricted to individuals at least 18 years of age who lived in either Robeson or Cumberland County *at the time of the hurricane*. It consisted primarily of closed-ended questions on the following topics: *i*) basic demographic characteristics, *ii*) where the individual lived at the time of the hurricane and where they lived at the time of the survey, *iii*) the number of individuals in the household at the time of the hurricane and at the time of the survey, *iv*) hurricane-related damage to the individual's home, *v*) whether the individual left his/her home as a result of the hurricane and whether they later returned, *vi*) sources of drinking water before and after the hurricane and the reasons for any changes, *vii*) growth of mold in the home since the hurricane and the nature of any efforts to remove it, *viii*) presence of selected respiratory, cardiovascular, dermal, and mental health conditions, and any changes from one year before, *ix*) number of household members being treated by a health professional at the time of the survey and one year before, *x*) health concerns related to the hurricane, *xi*) concerns about specific environmental health hazards related to the hurricane, and *xii*) environmental concerns related to the hurricane.

We solicited survey respondents by sending a link to the survey together with a brief description of the survey's rationale and content to a range of governmental, community, cultural, and faith-based organizations/agencies in the two counties, with a particular emphasis on those involved in some capacity in disaster response. These organizations/agencies were asked to share this information with their constituents/members via their usual modes of communication, including listservs, websites, Facebook pages, and direct contact. A reminder email was sent to these organizations/agencies several weeks after the initial solicitation to increase the response rate. Individuals who were unable or unwilling to complete the survey online were encouraged to call a study staff member who administered the survey verbally, by telephone. All surveys completed between June 27, 2017 and August 28, 2017 were included in the present analyses, although the survey is still available online (<http://bit.ly/matthewimpact>) and we continue to collect these survey data for future analysis. A total of 215 surveys, two of which were conducted by telephone, are included in the present report. Of these 215 surveys, 143 were completed by individuals residing in Cumberland County at the time of the hurricane and 72 were completed by individuals residing in Robeson County at that time.

Results

A majority of survey respondents in both counties were female (Table 3). Respondents were more likely to be white and to have higher educational attainment and household income than the general populations of these counties.

A substantial number of respondents in each county (38.7% in Cumberland County and 54.2% in Robeson County) reported hurricane damage to their homes (Table 4). Among persons reporting damage to their homes, a majority (83.6% in Cumberland County and 66.7% in Robeson County) continued living in these homes after the hurricane, whether by choice or necessity. There was little reported change in the number of persons, or of children specifically, living in the household after the hurricane in either county. There were too few respondents who moved from their homes as a result of the hurricane to further analyze their subsequent patterns of residence.

Among these respondents, race, income, and educational attainment were not strong predictors of damage to residences from the hurricane, although the small sample size limited our ability to assess these differences. Damage to homes was reported by 16 of 39 black participants (41.0%), 55 of 122 white participants (45.1%), and 7 of 11 American Indian/Alaska Native participants. Damage was reported by 21 of 46 respondents (45.7%) with less than \$40,000 total household income, 35 of 79 respondents (44.3%) with \$40,000-\$79,999 total household income, and 26 of

Table 3. Demographic characteristics of survey respondents (N=215)

Characteristic	Cumberland County	Robeson County
	% N=143	% N=72
Gender		
Female	82.5	77.8
Male	16.7	20.6
Race		
White, non-Hispanic	61.8	66.7
Black or African American	23.6	15.9
Hispanic or Latino	3.3	0.0
American Indian or Alaska Native	0.8	15.9
Asian	1.6	0.0
Other/Mixed	8.9	1.6
Marital status		
Married or living as married	61.0	68.3
Separated	4.1	4.8
Divorced	15.4	7.9
Widowed	4.1	3.2
Single	15.4	15.9
Educational attainment		
High school graduate (or equivalent)	34.9	42.9
Bachelor's degree or higher	64.3	55.6
Total household income in 2016, before taxes		
Less than \$20,000	3.4	10.3
\$20,000-\$39,999	20.2	20.7
\$40,000-\$59,999	19.3	25.9
\$60,000-\$79,999	24.4	20.7
\$80,000-\$99,999	17.6	5.2
\$100,000 or more	15.1	17.2
Median household income in 2016, before taxes	\$70,000	\$50,000

52 respondents (50.0%) with \$80,000 or more total household income. Damage to homes also was reported by 22 of 54 respondents (40.7%) without a college degree and 65 of 135 (48.1%) of those with a college degree. These results are inconsistent with information provided by a number of key informants, who reported that flooding of homes occurred disproportionately among poor and black residents of these counties. This discrepancy—combined with racial and income profiles of survey respondents that differ from those of the county populations and the recognition that persons completing an online survey may over-represent individuals with higher income and greater access to computers—suggests that these results may not be fully generalizable to all county residents.

As expected, water damage was a major cause of hurricane damage to homes, with water damage reported by 27.7% of Cumberland County respondents and 47.1% of Robeson County respondents (Table 5). Among those reporting water damage to their home, mold growth since the hurricane was reported by 12.7% in Cumberland County and 29.0% in Robeson County. Although the number of persons in this survey reporting mold problems since the hurricane was too small to reliably analyze, it should be noted that the majority reported that the mold had been cleaned from their homes by them, a family member, or a professional, using bleach and/or soap and water. A small number of participants reporting removing damaged walls or wood, or

Table 4. Impact of Hurricane Matthew on residential/household characteristics among survey respondents (N=215)

Characteristic	Cumberland County	Robeson County
	% N=143	% N=72
Home damaged by hurricane	38.7	54.2
Continued living in damaged home after hurricane ^a	83.6	66.7
Number of persons in household at time of hurricane		
1	12.8	12.5
2-4	74.5	69.4
5-9	12.8	18.1
Change in number of persons in household after hurricane		
1 or less	97.2	90.3
2 or more	2.8	9.7
Number of children in household at time of hurricane		
0	62.4	62.0
1-2	31.2	25.4
3-6	6.4	12.7
Change in number of children in household after hurricane		
1 or less	98.6	97.2
2 or more	1.4	2.8

^a Restricted to respondents who reported damage to their homes from the hurricane

Table 5. Mold growth in homes following Hurricane Matthew among survey respondents (N=215)

Characteristic	Cumberland County	Robeson County
	% N=143	% N=72
Hurricane-related water damage to home		
Yes	27.7	47.1
No	67.4	52.9
Don't know	5.0	0.0
Mold growth in home since hurricane		
Yes	12.7	29.0
No	75.4	63.8
Don't know	11.9	7.2

treating with fungicide to eliminate the mold. Some respondents also indicated that the mold kept returning despite attempts to remove it.

A majority of respondents whose usual source of drinking water before the hurricane was a public water supply or a private well reported that this water had been contaminated, damaged, or otherwise made unavailable because of Hurricane Matthew (Table 6). This finding was reported primarily by public water supply users, as expected, given the temporary boil water advisories issued by the water districts at the time of the hurricane. Most users of the public water supply reported that they were still getting their drinking water from this source, although a small proportion had switched to bottled water. There were too few private well water users to reliably interpret patterns of water use; however, it should be noted that among those whose well water was contaminated or made unavailable during the hurricane, not all had subsequently tested it and determined it to have contaminants at or below acceptable levels before resuming its use. All respondents who reported that their pre-hurricane drinking water source had been found to exceed legal limits for one or more contaminants had been using the public water supply, for which boil advisories had been issued until the hurricane-related damage to the water treatment systems was repaired.

As can be seen in Table 7, while most participants in each county report being in good to excellent physical health, an appreciable proportion (12.8% in each of the counties) report being in fair to poor health. It is important to note that the number of individuals in many of the strata in these analyses is small and, therefore, these results should be interpreted with caution. Indeed, although the survey elicited information about recent diagnoses of, or changes in, a range of respiratory, cardiovascular, and mental health conditions, there were too few reports of these conditions to be interpretable and, therefore, they are not presented here. There were no clear patterns of chronic adverse health associated with the hurricane. Most respondents stated that their health was about the same as one year ago (i.e., prior to the hurricane). More respondents reported worse physical health than better physical health compared to one year before in each county, although this difference was relatively small in Cumberland County. Similar proportions in each county (30.7-30.9%) reported experiencing dermatitis, eczema, skin rashes, sores, or blisters at least sometimes in the past thirty days, although much smaller proportions reported experiencing it most to all of the time (8.6-10.3%). However, substantial proportions reported

that these dermal conditions had worsened in severity compared to one year ago (21.9-22.6%). Similar proportions of respondents in each county (12.4-14.9%) also reported their current mental health as being fair to poor (compared to 7.7% in the U.S. general adult population), but we were unable to explore this further because of small numbers. More respondents reported an increase, rather than no change or a decrease, in the number of household members being treated by a health care professional compared to one year prior (11.2% in Cumberland County and 15.2% in Robeson County reporting 1-2 additional household members being treated).

Table 6. Impact of Hurricane Matthew on drinking water among survey respondents (N=215)

Characteristic	Cumberland County	Robeson County
	% N=143	% N=72
Pre-hurricane source of drinking water		
Public water supply	56.3	52.8
Private well	14.8	8.3
Bottled water	28.9	37.5
Drinking water contaminated/unavailable due to hurricane ^a		
Yes	50.5	81.8
No	38.6	15.9
Don't know	10.9	2.3
Current source of drinking water same as pre-hurricane source		
Yes	96.6	96.9
No	1.1	3.1
Don't know	2.2	0.0
Current drinking water tested for safety since hurricane ^b		
Yes	40.9	43.8
No	20.0	16.7
Don't know	39.1	39.6
Current drinking water exceeded legal limits for one or more contaminants ^c		
Yes	13.5	14.0
No	25.7	18.6
Don't know	60.8	67.4

^a Restricted to respondents reporting public water supply or private well as their pre-hurricane source of drinking water

^b Restricted to respondents reporting public water supply or private well as their current source of drinking water

^c Restricted to respondents who reported that their current drinking water was tested for safety since the hurricane

Table 7. Impact of Hurricane Matthew on selected health conditions among survey respondents (N=215)

Characteristic	Cumberland	Robeson
	County % N=143	County % N=72
Current physical health		
Excellent	7.8	5.7
Very good	40.4	41.4
Good	39.0	40.0
Fair	12.1	11.4
Poor	0.7	1.4
Physical health compared to one year ago		
Much better	3.5	1.4
A little better	10.6	10.1
About the same	67.4	68.1
A little worse	17.0	20.3
Much worse	1.4	0.0
Frequency of dermatitis, eczema, skin rashes, sores, or blisters in past thirty days		
All the time	2.9	5.9
Most of the time	5.7	4.4
Sometimes	22.1	20.6
Rarely	17.1	20.6
Never	50.7	47.1
Severity of dermatitis, eczema, skin rashes, sores, or blisters compared to one year ago		
Better	3.5	0.0
About the same	60.0	59.4
Worse	22.6	21.9
I don't know	13.9	18.8
Current mental health		
Excellent	25.5	22.4
Very good	39.4	28.4
Good	22.6	34.3
Fair	10.2	11.9
Poor	2.2	3.0
Number of household members being treated by health care professional for one or more medical conditions currently		
0	23.1	30.3
1-2	64.2	60.6
3 or more	12.7	9.1
Change in number of household members being treated by health care professional for one or more medical conditions after hurricane		
Decreased by 1-2	3.7	6.1
None	85.1	78.8
Increased by 1-2	11.2	15.2

The concern about Hurricane Matthew-related environmental health hazards most commonly identified by respondents was flooding of, or damage to, wastewater treatment facilities, reported by 30.1% of Cumberland County respondents and 40.3% of Robeson County respondents (Table 8). Other common concerns, identified by at least 10% of respondents in either county, were runoff from *i*) poultry, hog, and cattle farms, *ii*) hazardous waste sites, *iii*) municipal waste disposal sites, *iv*) gas stations, *v*) automobile repair shops, and *vi*) agricultural land.

Most respondents in both counties sought information on Hurricane Matthew-related environmental health hazards from the internet generally (Table 8). A large proportion in each county also obtained information from local health departments, newspapers, television or radio, social media, local social service offices, health professionals, family members, and friends. A smaller number turned for information to religious institutions, health fairs, libraries, and local tribal council offices.

Table 8. Concerns and sources of information about environmental health hazards among survey respondents (N=215)

Characteristic	Cumberland County	Robeson County
	% N=143	% N=72
Concerns about these potential sources of environmental health hazards related to Hurricane Matthew		
Flooding of or damage to wastewater treatment facilities	30.1	40.3
Poultry, hog, cattle farms	13.3	20.8
Hazardous waste sites	12.6	13.9
Municipal waste disposal sites	11.9	16.7
Gas stations	11.9	18.1
Automobile repair shops	9.1	11.1
Agricultural land	7.7	16.7
Coal ash storage sites	4.2	5.6
Information sources on environmental health hazards related to Hurricane Matthew		
Websites/Internet	65.0	59.7
Local health department	57.3	48.6
Newspapers	51.0	37.5
Television/Radio	46.2	37.5
Social media (such as Twitter or Facebook)	37.8	36.1
Doctor, nurse, or other health professional	25.2	29.2
Local social services office	23.8	20.8
Friends and family	19.6	27.8
Church or faith-based institution	10.5	20.8
Health fairs	9.1	13.9
Library	6.4	3.3
Local tribal council office	2.8	4.2

Mapping

Methods

Flood waters can transport chemical and biological contaminants from one location to another. Such redistribution of contaminants may go undetected unless specifically assessed. At the same time, certain non-acute or non-specific health effects attributable to these contaminants may not be recognized as being linked to them. Therefore, one of the aims of this project was to map sources of potential environmental contamination resulting from hurricane flooding in relation to locations where populations that are potentially more vulnerable to such contaminants live or otherwise congregate. These maps are intended to enable more targeted allocation of public health resources in Cumberland and Robeson counties in response to Matthew and to help improve public health response to future floods and other disasters in this state. It is important to emphasize that this study assessed only the *potential* for environmental contamination and did not measure *actual* environmental contamination due to insufficient resources and lateness of getting into the field.

Potential sources of environmental contamination (due to redistribution by hurricane flood waters) included gas stations, automobile repair shops, brownfields, coal ash storage sites, Dry-Cleaning Solvent Cleanup Act sites, hazardous waste sites (active, and inactive), landfills (pre- and post-regulatory), manufactured gas plants, confined animal feeding operations (CAFOs), and wastewater treatment plants. Because flood-borne contaminants may cross county lines, we included potential exposure sources not only in Cumberland and Robeson counties, but also in adjacent counties. Sources of these geospatial data included the following:

- NC One Map (<http://www.nconemap.net/>)
- NC Department of Environmental Quality (<https://deq.nc.gov/>)
- Environmental Justice Screening and Mapping Tool (EJSCREEN) (<https://www.epa.gov/ejscreen>)
- Southern Alliance for Clean Energy (<http://www.southeastcoalash.org/>)
- National Pollutant Discharge Elimination System (<https://www.epa.gov/npdes>)
- InfoUSA (<https://www.infousa.com/>)
- Dry-Cleaning Solvent Cleanup Act sites are sites listed under the Dry-cleaning Solvent Cleanup Act of 1997 (DSCA), which provides funds to clean up dry-cleaning solvent contamination at dry-cleaning and wholesale distribution facilities (<https://deq.nc.gov/about/divisions/waste-management/dry-cleaning-solvent-cleanup-act-program>).

We focused on the following locations that may contain more vulnerable populations: daycares, schools (public and private), assisted living facilities/nursing homes, and churches (which are often frequented by children and the elderly). These sites, especially schools and churches, may also serve as shelters during or after a major storm. Because contaminated drinking water can affect entire communities, we also included public drinking water sources in this category of “population” locations. The geospatial data for these locations came from NC One Map (<http://www.nconemap.net/>) and NC Department of Health and Human Services (<https://www.ncdhhs.gov/>).

We assessed flood extent with three measures: *i*) the 100-year floodplain hydromodel, *ii*) the Hurricane Matthew inundation extent, and *iii*) a quarter-mile buffer around each building reported by NC Emergency Management to be damaged by Hurricane Matthew (“damage buffer”). Each of these measures has strengths and limitations in understanding the risk to community resources and of potential environmental exposures. The 100-year floodplain is broader than the extent of flooding during Hurricane Matthew, but represents a plausible “worst case scenario”. The inundation extent represents this hurricane well, but does not distinguish between high damage and no damage areas. The damage buffers attempt to capture the areas that were inhabited and were flooded enough in this hurricane to cause damage, but they are subject to certain reporting biases and may underreport who may be at risk in future flooding events. However, broadly, the 100-year floodplain is the most conservative and largest area, the inundation extent the next largest, and the damage buffers the most specific for the present analyses. Flood data sources include NC Department of Public Safety (<https://www.ncdps.gov/>) and NC Flood Risk Information System (<http://fris.nc.gov/fris/>).

For the present analyses, we determined whether locations of potential environmental hazards and of vulnerable populations were in or out of the boundaries of the three measures of flooding described above. We also calculated the distances between potential sources of environmental contamination and vulnerable populations.

For readability, this report contains maps of only Cumberland and Robeson Counties. Mapping and Geographic Information System (GIS) analysis were performed using QGIS v2.18 (<http://www.qgis.org/en/site/>).

Results

Locations of vulnerable populations

Five types of vulnerable population location data (N=974 locations) were collected for comparison with locations of potential hurricane-related environmental hazards in Cumberland and Robeson Counties: public schools (N=142), private schools (N=59), assisted living facilities/nursing homes (N=40), daycares (N=433), and churches (N=300). We also identified and included 219 public water supply sources in these analyses. As can be seen in Figure 1, these sites are located throughout the two counties. As expected, the greatest density of sites occurs around the largest population centers in each county – Fayetteville and Lumberton.

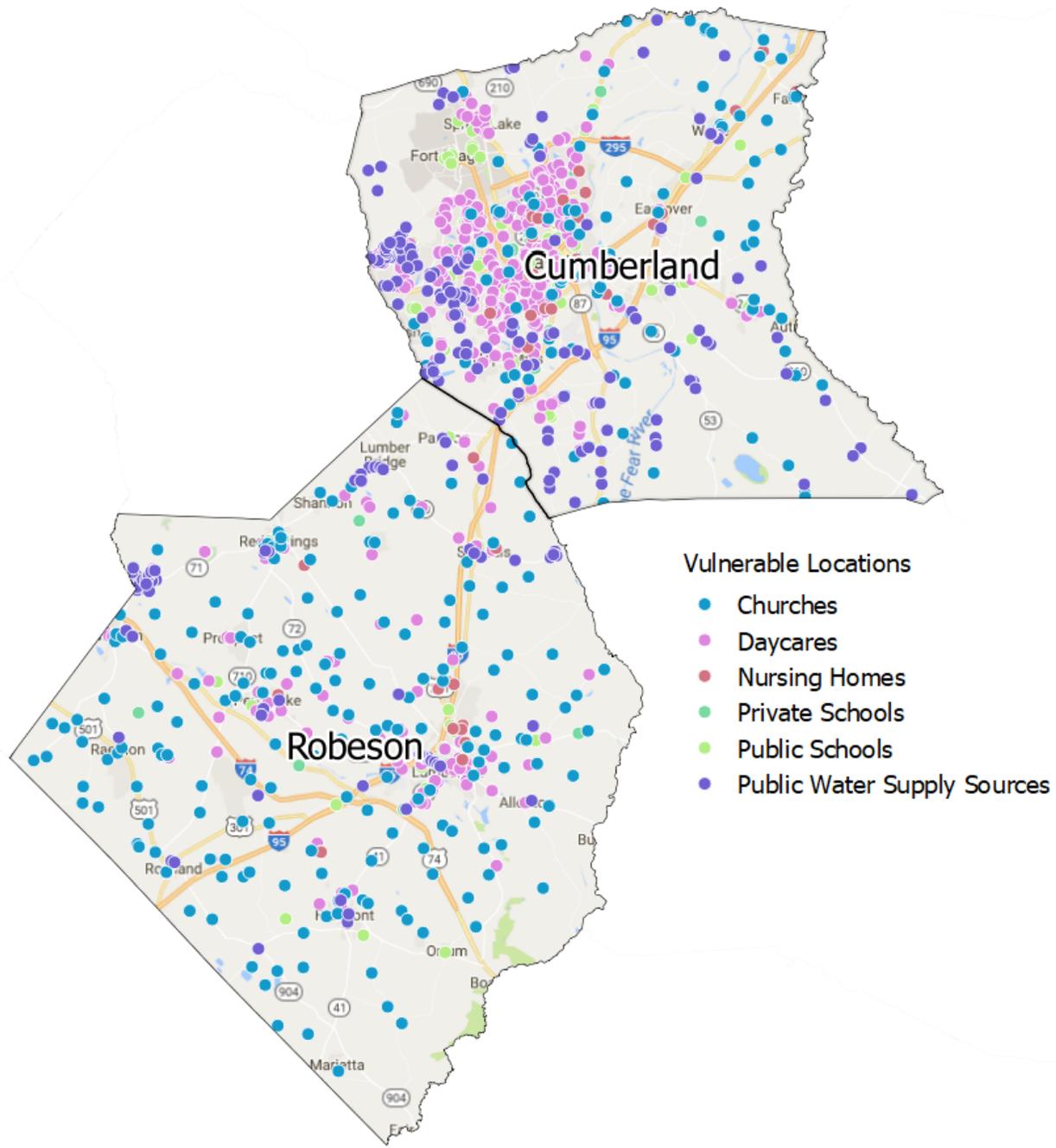


Figure 1. Vulnerable population locations in Cumberland and Robeson Counties

Locations of potential environmental exposures

The thirteen types of potential environmental hazard that were investigated in this study are shown in Table 9. As expected, services such as gas stations, automobile repair shops, and dry cleaners are found most frequently around Fayetteville and Lumberton (Figure 2). Other sites are located further from population centers, although many are located in relative proximity to large populations, as described below.

Table 9. Locations of potential environmental exposures

Potential environmental hazard	N n=910
Automobile repair shops	381
Gas stations	134
Active hazardous waste sites	96
Poultry CAFOs	93
Swine CAFOs	76
Inactive hazardous waste sites	44
Pre-regulatory landfills	29
Wastewater treatment plants	24
Post-regulatory landfills	13
Manufactured gas plants	1

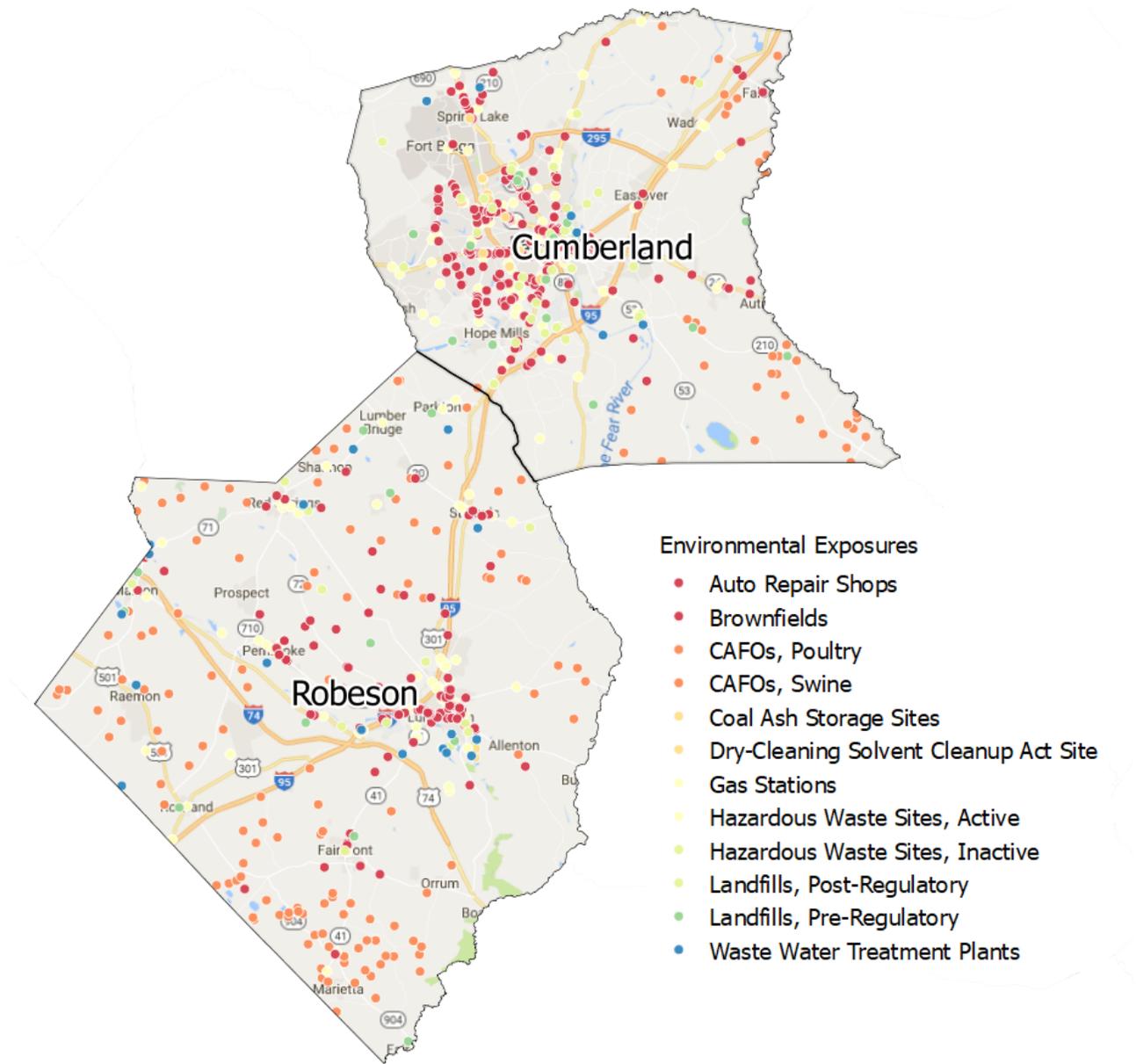


Figure 2. Potential sources of environmental contamination in Cumberland and Robeson Counties

As can be seen more clearly in Figures 3 and 4, distributions of specific potential environmental hazards differ between the two counties. Cumberland has relatively more automobile repair shops and active and inactive hazardous waste sites, while Robeson has relatively more swine and poultry CAFOs and wastewater treatment plants.

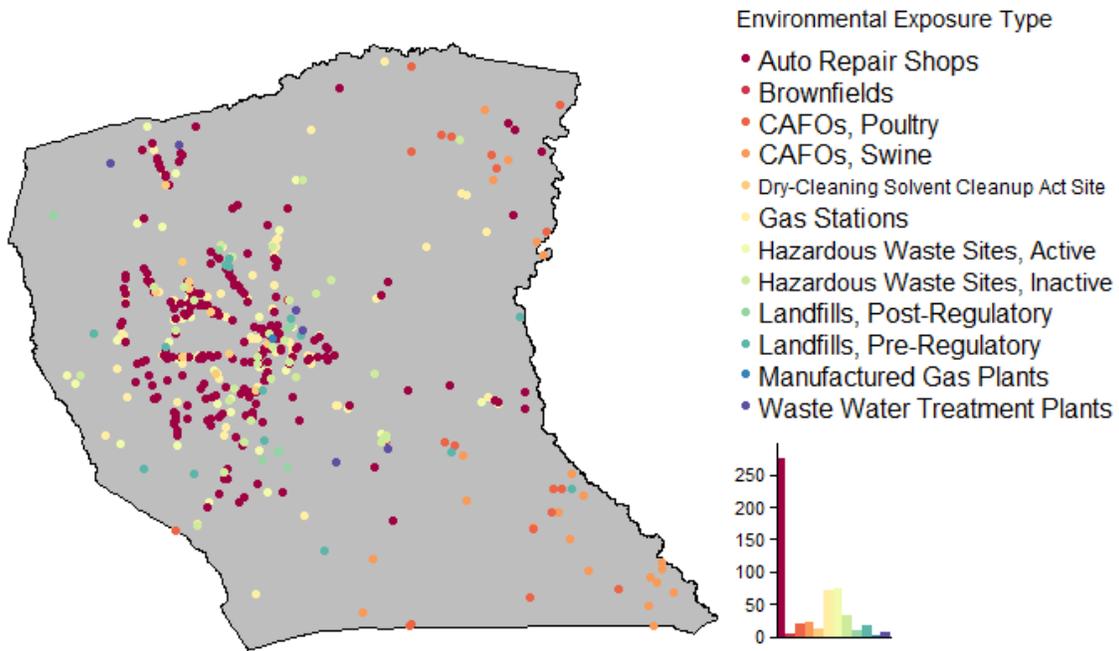


Figure 3. Counts of potential sources of environmental contamination in Cumberland County

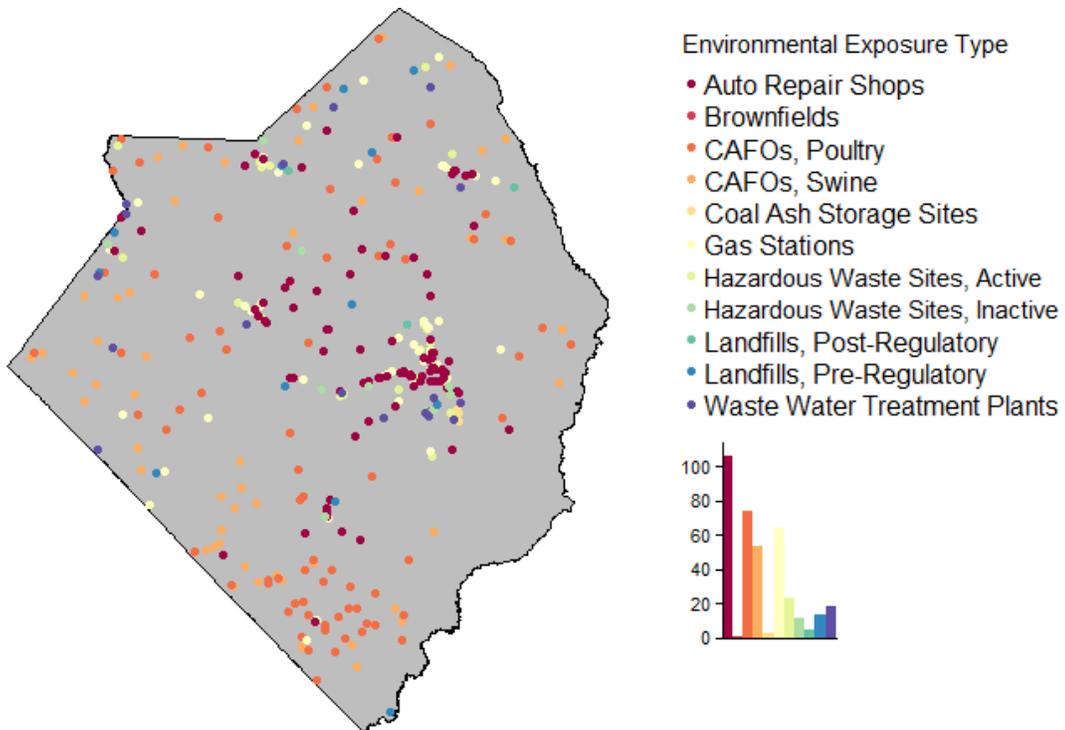


Figure 4. Counts of potential sources of environmental contamination in Robeson County

Extent of hurricane flooding

Figure 5 shows the three flood-related measures described above: (1) the modeled 100-year floodplain, (2) the Hurricane Matthew inundation extent, and (3) a quarter-mile buffer around each building reported damaged by Hurricane Matthew. The 100-year floodplain represents the largest area, although the Hurricane Matthew inundation extent includes most of the 100-year floodplain in Robeson County. This floodplain includes areas with different degrees of development and population density. The Hurricane Matthew inundation extent is, by definition, more specific to this flood event, but the degree of impact on homes and other buildings varies across this area, as suggested by the damage buffers. These points can be seen more clearly in Figure 6, which shows a close-up of the Hurricane Matthew inundation extent overlaid on the 100-year floodplain in part of Cumberland County, and in Figure 7, which provides a further close-up of the three measures of flood extent overlaid in the same area of Robeson County (but with clearer presentation of the extent of building damage from Hurricane Matthew in this area).

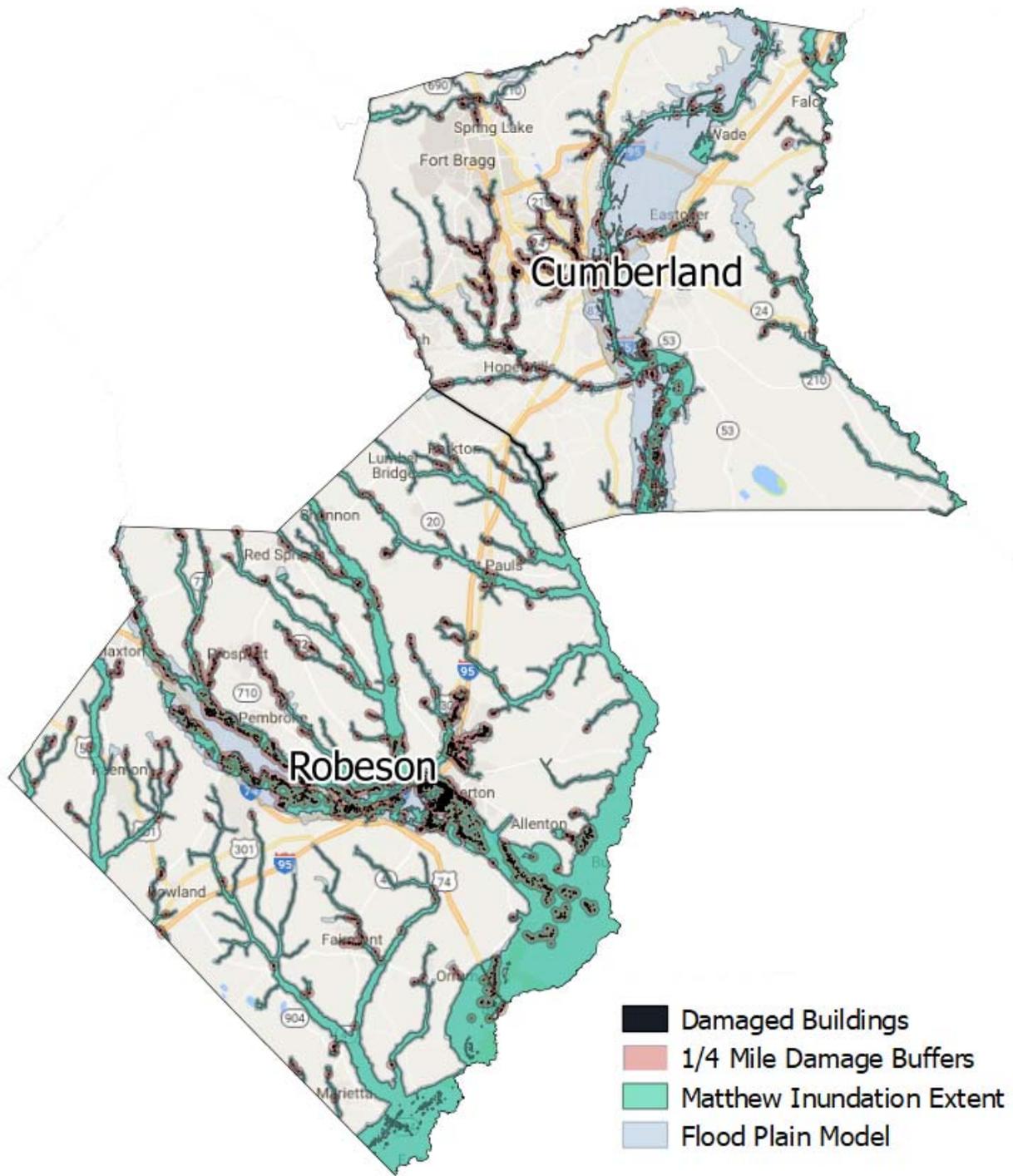


Figure 5. Three measures of the flood extent in Cumberland and Robeson Counties

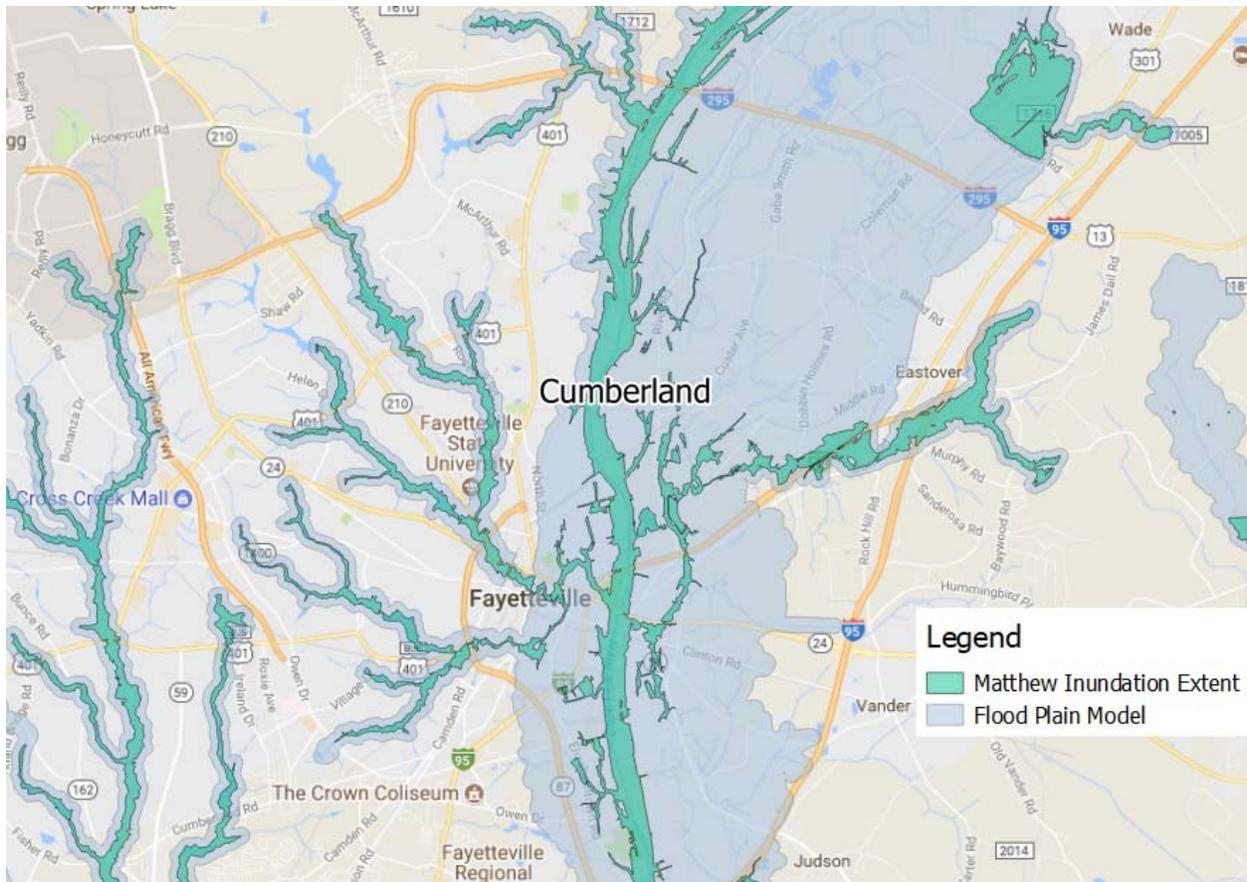


Figure 6. Close-up illustrating relationship of Hurricane Matthew inundation extent and modeled 100-year floodplain, Cumberland County

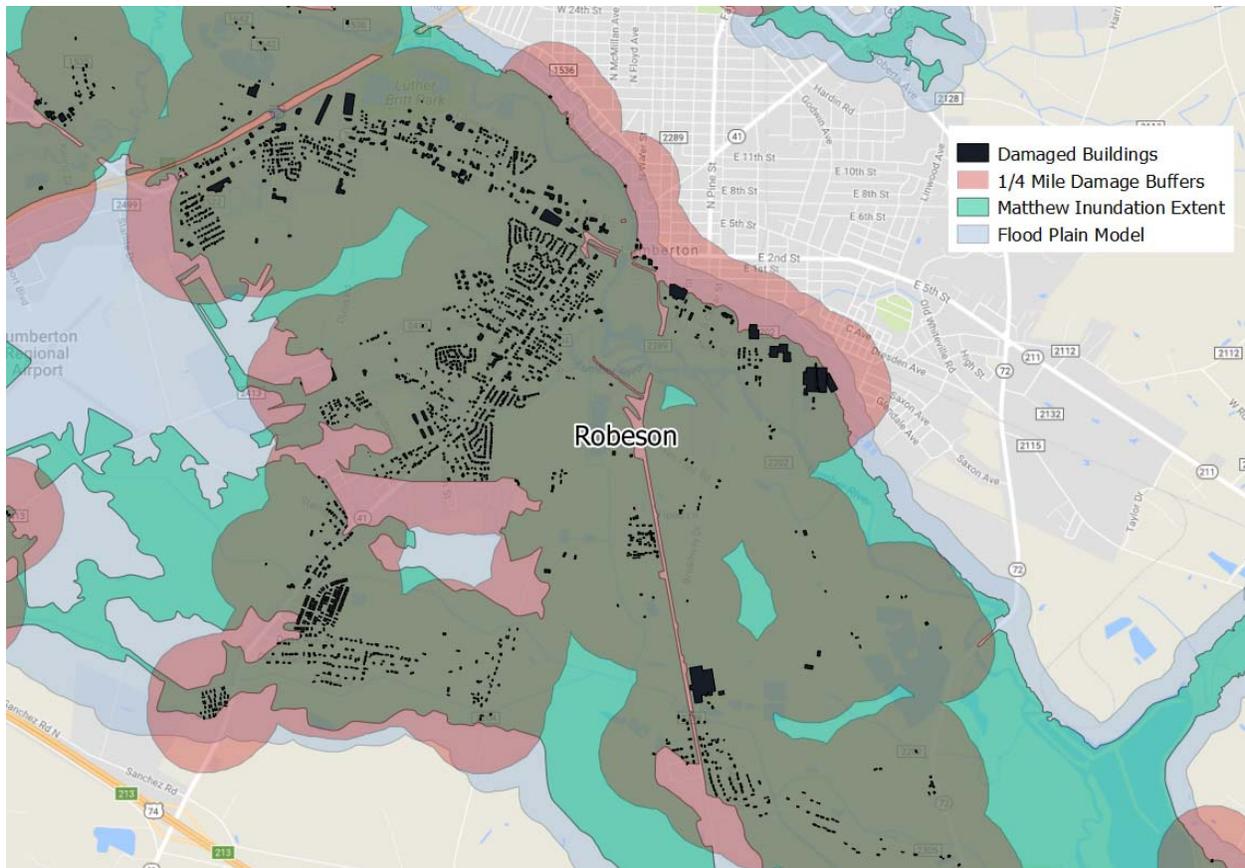


Figure 7. Close-up illustrating the relationship of the three measures of flood extent, Robeson County

Vulnerable population locations in relation to potential environmental hazards and flooding

A total of 606 (80.2%) identified vulnerable population locations in Cumberland and 311 (71.2%) in Robeson County were within 1 mile of a potential environmental hazard in each county (Table 10). A majority of each of the vulnerable population types, including daycares, schools, nursing homes, and churches, as well as public drinking water sources, fell into this category. Although some environmental contaminants may travel appreciable distances via waterways, we also considered shorter distances between potential contaminant sources and vulnerable populations, which increases the opportunity for contamination (Table 10). A substantial number of vulnerable population locations in each county, ranging from 21.1% in Robeson to 28.0% in Cumberland, are within 0.25 mile of a potential environmental hazard. These include at least one quarter of daycares, nursing homes, public schools, and private schools in one or both counties.

Table 10. Number of vulnerable population locations within varying distances of potential sources of environmental contamination

Population location	N (%) of locations within given distance of potential sources of environmental contamination						Total
	≤ 1mi		≤ 0.5mi		≤ 0.25mi		
	N	%	N	%	N	%	
Cumberland							
Churches	81	67.5	55	45.8	27	22.5	120
Daycares	292	91.0	210	65.4	114	35.5	321
Nursing homes	20	87.0	17	73.9	8	34.8	23
Public schools	83	83.8	56	56.6	23	23.2	99
Private schools	37	90.2	31	75.6	20	48.8	41
Public water supply sources	93	61.2	53	34.9	20	13.2	152
<i>Total</i>	606	80.2	422	55.8	212	28.0	756
Robeson							
Churches	108	60.0	49	27.2	22	12.2	180
Daycares	84	75.0	60	53.6	26	23.2	112
Nursing homes	15	88.2	9	52.9	5	29.4	17
Public schools	31	72.1	28	65.1	15	34.9	43
Private schools	14	77.8	13	72.2	9	50.0	18
Public water supply sources	59	88.1	39	58.2	15	22.4	67
<i>Total</i>	311	71.2	198	45.3	92	21.1	437

The number of vulnerable population locations within the Hurricane Matthew inundation extent was relatively small in Cumberland County (N=5; 0.7%), but was appreciably larger in Robeson County (N=33; 7.6%) (Table 11). In Cumberland, 1-2 churches, daycares, and public water sources were within the inundation extent. In Robeson, all of the location types were affected, with the greatest impact on churches (N=7), daycares (N=7), public schools (N=4), and public water sources (N=13).

Table 11. Number of vulnerable population locations within the Hurricane Matthew inundation extent

Population location	N (%) of locations within inundation extent					
	Cumberland			Robeson		
	N	%	Total	N	%	Total
Churches	1	0.8	120	7	3.9	180
Daycares	2	0.6	321	7	6.3	112
Nursing homes	0	0.0	23	1	5.9	17
Public schools	0	0.0	99	4	9.3	43
Private schools	0	0.0	41	1	5.6	18
Public water supply sources	2	1.3	152	13	19.4	67
<i>Total</i>	5	0.7	756	33	7.6	437

A larger proportion of vulnerable population locations were within the 0.25-mile damage buffers (Table 12). In Cumberland, more than 10% of churches, daycares, nursing homes, public schools, and private schools were located within these damage buffers. In Robeson, this proportion was over 10% for each location type, with the greatest proportions estimated for public schools (20.9%) and public water sources (28.4%).

Table 12. Number of vulnerable population locations within the 0.25-mile damage buffers

Population location	N (%) of locations within 0.25-mile damage buffers					
	Cumberland			Robeson		
	N	%	Total	N	%	Total
Churches	13	10.8	120	31	17.2	180
Daycares	40	12.5	321	19	17.0	112
Nursing homes	4	17.4	23	3	17.6	17
Public schools	10	10.1	99	9	20.9	43
Private schools	5	12.2	41	2	11.1	18
Public water supply sources	11	7.2	152	19	28.4	67
<i>Total</i>	<i>83</i>	<i>11.0</i>	<i>756</i>	<i>83</i>	<i>19.0</i>	<i>437</i>

Over 100 vulnerable population locations in each county are within the 100-year floodplain (Table 13). Churches, daycares, and public drinking water sources account for the largest number of these, although an appreciable proportion of each of these locations is within the floodplain in one or both counties.

Table 13. Number of vulnerable population locations within the 100-year floodplain

Population location	N (%) of locations within floodplain					
	Cumberland			Robeson		
	N	%	Total	N	%	Total
Churches	29	24.2	120	47	26.1	180
Daycares	40	12.5	321	25	22.3	112
Nursing homes	6	26.1	23	2	11.8	17
Public schools	6	6.1	99	8	18.6	43
Private schools	5	12.2	41	5	27.8	18
Public water supply sources	18	11.8	152	22	32.8	67
<i>Total</i>	<i>104</i>	<i>13.8</i>	<i>756</i>	<i>109</i>	<i>24.9</i>	<i>437</i>

Flooding of potential sources of environmental contamination

A substantially larger proportion of potential sources of environmental contamination were within the Hurricane Matthew inundation extent in Robeson County (16.2%) than in Cumberland County (4.6%) (Table 14). In fact, Robeson County had a larger proportion of automobile repair shops, gas stations, active and inactive hazardous waste sites, and pre-regulatory landfills within the inundation extent than did Cumberland County. Other sites were either similar in proportion or had numbers too small to interpret.

Table 14. Number of potential sources of environmental contamination within the Hurricane Matthew inundation extent

Potential contamination source	N (%) of potential sources of environmental contamination within inundation extent					
	Cumberland			Robeson		
	N	%	Total	N	%	Total
Automobile repair shops	9	3.3	275	20	18.9	106
Brownfields	0	0.0	3	1	100.0	1
CAFOs, poultry	0	0.0	19	0	0.0	74
CAFOs, swine	0	0.0	23	0	0.0	53
Coal ash storage sites	0	-	0	1	33.3	3
Dry-Cleaning Solvent Cleanup Act sites	0	0.0	12	0	-	0
Gas stations	3	4.3	70	9	14.1	64
Hazardous waste sites, active	2	2.7	73	7	30.4	23
Hazardous waste sites, inactive	4	12.1	33	4	36.4	11
Landfills, post-regulatory	0	0.0	8	0	0.0	5
Landfills, pre-regulatory	1	6.3	16	4	30.8	13
Manufactured gas plants	1	100.0	1	0	-	0
Wastewater treatment plants	5	83.3	6	14	77.8	18
<i>Total</i>	<i>25</i>	<i>4.6</i>	<i>539</i>	<i>60</i>	<i>16.2</i>	<i>371</i>

Over 100 potential sources of environmental contamination in each county were located within the 0.25-mile damage buffers (Table 15). These consisted primarily of automobile repair shops, gas stations, and active hazardous waste sites. The proportion of locations within the 0.25-mile damage buffer was greater in Robeson County (28.6%) than in Cumberland County (18.9%).

Table 15. Number of potential sources of environmental contamination within the 0.25-mile damage buffers

Potential contamination source	N (%) of potential sources of environmental contamination within 0.25-mile damage buffers					
	Cumberland			Robeson		
	N	%	Total	N	%	Total
Automobile repair shops	61	22.2	275	40	37.7	106
Brownfields	1	33.3	3	1	100.0	1
CAFOs, poultry	2	10.5	19	7	9.5	74
CAFOs, swine	0	0.0	23	0	0.0	53
Coal ash storage sites	0	-	0	0	0.0	3
Dry-Cleaning Solvent Cleanup Act sites	1	8.3	12	0	-	0
Gas stations	13	18.6	70	26	40.6	64
Hazardous waste sites, active	12	16.4	73	11	47.8	23
Hazardous waste sites, inactive	7	21.2	33	6	54.5	11
Landfills, post-regulatory	0	0.0	8	1	20.0	5
Landfills, pre-regulatory	3	18.8	16	5	38.5	13
Manufactured gas plants	1	100.0	1	0	-	0
Wastewater treatment plants	1	16.7	6	9	50.0	18
<i>Total</i>	<i>102</i>	<i>18.9</i>	<i>539</i>	<i>106</i>	<i>28.6</i>	<i>371</i>

A large proportion of potential sources of environmental contamination lie within the 100-year floodplain (Table 16). Indeed, one or more of each type of site found within a county is expected to be affected in such a flood event. This includes an appreciable number of gas stations and automobile repair shops. It also includes substantial proportions of the hazardous waste sites, CAFOs, and pre-regulatory landfills in one or both counties. Some brownfields and coal ash sites, while small in number, will also be within the floodplain.

Table 16. Number of potential sources of environmental contamination within the 100-year floodplain

Potential contamination source	N (%) of potential sources of environmental contamination within the 100-year floodplain					
	Cumberland			Robeson		
	N	%	Total	N	%	Total
Automobile repair shops	58	21.1	275	35	33.0	106
Brownfields	1	33.3	3	1	100.0	1
CAFOs, poultry	5	26.3	19	20	27.0	74
CAFOs, swine	5	21.7	23	16	30.2	53
Coal ash storage sites	0	-	0	1	33.3	3
Dry-Cleaning Solvent Cleanup Act sites	1	8.3	12	0	-	0
Gas stations	15	21.4	70	20	31.3	64
Hazardous waste sites, active	10	13.7	73	12	52.2	23
Hazardous waste sites, inactive	13	39.4	33	6	54.5	11
Landfills, post-regulatory	2	25.0	8	1	20.0	5
Landfills, pre-regulatory	6	37.5	16	7	53.8	13
Manufactured gas plants	1	100.0	1	0	-	0
Wastewater treatment plants	6	100.0	6	14	77.8	18
<i>Total</i>	<i>123</i>	<i>22.8</i>	<i>539</i>	<i>133</i>	<i>35.8</i>	<i>371</i>

Recommendations

In this section, we offer two sets of recommendations. First, we share recommendations that came directly from study participants, who are community leaders in Cumberland and Robeson Counties and experienced the flooding and its aftermath firsthand. Following these recommendations, we share suggestions from the research team, based on our analysis of 26 structured and informal interviews, 215 surveys, and the mapping of potential environmental health hazards in both counties.

Key informants' recommendations for addressing environmental health hazards

Key informants recommended a number of ways that local response and service networks could be more effectively deployed to respond to community and public health needs during future disasters. A primary focus was on improving communication. **Informants suggested developing alternative methods of communication and information sharing for times when there is no electrical power and employing alternative methods of communication and information sharing to reach residents who are illiterate/semi-literate, do not have access to the internet, or do not use social media.** This improved communication should be used in part to increase awareness of the resources that various organizations can provide to other organizations and to community members; such communication could avoid situations like one experienced during Hurricane Matthew in which a food bank had bottled water to distribute, while local emergency management had no bottled water to give its first responders.

Specific recommendations from participants that relate to responding to environmental health issues included the following:

- Use the “Code Red Alert” system in Robeson County (using landline phones and cell phone texting) to share instructions on boil water advisories.
- Maximize the use of existing networks to reach vulnerable populations.
 - For instance, Robeson Church and Community Center mentioned that residents are offered an opportunity to get supplies, clothing, and food every 2 weeks, and they used this existing distribution network to disseminate flyers and information sheets in the bags and boxes of those supplies.
 - Similarly, the *Indian Country Today Media Network* (<https://indiancountrymedianetwork.com/>) is a tool for sharing information with American Indian populations.
- Develop or revise, as needed for different language groups and literacy levels, etc. and disseminate educational materials that inform residents about identifying and remediating mold in homes and testing well water. Existing materials include:
 - US EPA’s booklet *A Brief Guide to Mold, Moisture and Your Home* (<https://www.epa.gov/sites/production/files/2016-10/documents/moldguide12.pdf>)
 - NC Department of Health and Human Services’ (NC DHHS) infographic on cleaning mold (http://epi.publichealth.nc.gov/oe/mold/docs/Mold_Moisture_Cleaning_Prevention_infographic.pdf)

- Cumberland County Health Department’s brochure informing residents about well water testing
(https://www.co.cumberland.nc.us/safe_water/SafeWater_4Color_Brochure.pdf).

Additionally, in keeping with the strategies to be proactive in addressing immediate needs of communities after a flood and promoting coordination among various agencies, one public works professional recommended developing approaches for pumping flood water out earlier and faster.

Additional recommendations from the research team

- Agencies/organizations can take better advantage of knowledgeable professionals, paraprofessionals, and volunteers who are experienced in addressing some of the environmental health hazards described in this report. For example, within NC DHHS, mold expert David Lipton is available for training and consultation on mold identification and remediation. Such training could be provided to health department staff (e.g., environmental health specialists) in counties at high risk for future flooding (such as coastal counties). NC DHHS has didactic training that would benefit from the addition of hands-on activities.
- We also recommend increasing the capacity of agencies/organizations conducting door-to-door outreach for mental health and/or social services after a disaster (as was done in response to Hurricane Matthew), as well as faith-based organizations engaged in disaster response, to educate community members about mold and safe and effective ways to remove it. In addition to disseminating existing outreach materials (like the aforementioned EPA booklet), any such agencies/organizations that are part of long-term recovery committees could also collaborate with universities and other members of these committees to develop additional needed, culturally competent educational materials.
- Long-term recovery committees in each county are well positioned to foster connections among service organizations within each county, preparing them to mobilize to meet needs in future disasters. Based on the participant feedback in the interviews, these committees could address the following needs:
 - Helping residents to understand the intricacies of insurance and other paperwork and procedures required to obtain assistance with disaster-related home repairs. Long-term recovery committees in each county could host sessions/clinics with residents to assist in completing paperwork for insurance coverage and other applications for assistance. University students could be recruited to assist in this process (similar to the way that accounting students are often used to help individuals with limited resources file their income tax forms).
 - Developing county resource guides that identify supplies and services that member organizations and agencies can provide to others during an emergency response.
 - Working with water utilities and public health departments to identify best practices for communicating boil water notices and working together to implement them, when needed.
- We recommend increased collaboration with organizations specifically addressing the needs of immigrant populations (such as Centro Hispano in Cumberland County) to ensure effective communication about the urgency of evacuations and other emergency efforts during disasters and the awareness of exposures to potential environmental health hazards.

- Health departments should communicate to well owners the importance of well testing following floods (and every 2-3 years, in any case).
- We recommend that additional research be conducted to assess the likelihood and likely extent of redistribution of environmental health hazards during disasters from their current locations to areas where human exposure opportunity is increased, especially for vulnerable populations.
- We recommend expanding the network of UNC researchers and research institutions involved in disaster response in North Carolina to facilitate assessment of disaster-related environmental health risks through timely collection of environmental samples and data, as well as (IRB-approved) interaction with disaster victims and responders. This may require providing incident command system (ICS) training to these researchers to allow their participation in emergency operations centers (EOC), as needed to conduct their research in a timely, safe, and coordinated manner. Researchers could present to long-term recovery committees on their capacity to assist with environmental health research and with education of health professionals and individuals working directly with residents on issues related to mold and water contamination (contingent on availability of funding).

Plans for the coming year

As previously noted, the findings in this report are *preliminary* due to the limited time and resources available to conduct this research. We collected as much of the relevant data as possible during the 3-month funded study period, leaving limited time for analysis and write-up of these data. Thus, we will concentrate our future efforts on more thorough and systematic analysis and mapping of potential environmental health hazards in relation to the flooding and to impacted populations. One area of interest is identification of the most likely sources of potential contamination and of potential contaminants for specific areas of flooding in the two counties. It is also important to better understand the sociodemographic characteristics and resources of the communities that were most impacted by Hurricane Matthew, particularly those in the most heavily flooded areas. This information would help us to examine social and environmental justice issues introduced or exacerbated by the hurricane. To gain that understanding, provided sufficient time and resources for staff and students, we aim to collect additional community survey data in venues that provide community perspectives more representative of the ethnic and socioeconomic diversity of the target counties. Such venues would include churches, community centers, libraries, businesses like salons/barber shops, and events like Lumbee Tribe pow wows. In addition, we wish to obtain emergency room discharge data from these counties in order to look for evidence of illnesses that may have resulted from either contaminants transported by the hurricane flood waters or the mold that subsequently grew in some residents' homes after the flooding receded. Finally, we will continue to pursue and to strengthen relationships with emergency responders in these counties, as well as microbiologists and analytic chemists, to enable us to get into the field and collect appropriate samples and data in a timely manner when future disasters strike.