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FLOODED NC POULTRY

ANALYSIS OF EXTREME FLOOD IMPACTS ON ROBESON, WAYNE & LENOIR COUNTIES' POULTRY FARMS

SOURCE: Emily Sutton / Haw Riverkeeper

CONTENTS

COMMON TERMS

FLOODING

FLOODPLAIN: Generally defined as low-lying areas of land that are susceptible to flooding. For analysis purposes, this project defines the term as the FEMA-designated 100 and 500-year flood zones combined.

100 - YEAR FLOOD ZONE: Area with 1% or more chance of flooding in any given year.

500 - YEAR FLOOD ZONE: Area with 0.2%-1.0% chance of flooding in any given year.

FLOOD EXTENT: The measure of how much flooding occurs in an area or over a distance.

STORM SURGE: "The abnormal rise in seawater level during a storm (National Oceanic and Atmospheric Administration)."

FLOOD ZONES: Nationally recognized flood hazard categories used by FEMA to classify area-wide flood risk.

AGRICULTURE

POULTRY: For this study, the term includes egg-laying chickens ("layers"), chickens sold for meat ("broilers"), and turkeys.

CAFOs (CONCENTRATED ANIMAL FEEDING OPERATIONS): Industrial-scale factory farms typically used in the dairy, hog, and poultry industries. CAFOs are sometimes referred to as "mega-farms." This study uses the term to generally refer to an operation with a large number of poultry in confinement and not the Clean Water Act's definition[1]. On average poultry CAFOs have 2-6 barns where animals are kept.

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[1] To see the Clean Water Act's definition, see the following regulations: 40 C.F.R § 122.23(b)(1); 40 C.F.R § 122.23(b)(4); 40 C.F.R § 122.23(c).

DRY LITTER/WASTE: Waste management system where waste falls from animal cages to the floor and is then scraped out of the building periodically or collected (Sierra Club, 2015). The result is a waste mixture made from soiled bedding, spilled pellets, feathers, etc. The waste is then stored, typically in large, uncovered piles on site to be used or sold later as fertilizer.

WET LITTER/WASTE: Like dry litter, waste is stored in on-site ponds to be later spread on crop fields as liquid fertilizer.

NUTRIENT POLLUTION: Excessive amounts of nutrients like nitrogen and phosphorus enter our water sources resulting in public health and environmental consequences.

LITTER: Poultry bedding is normally comprised of sawdust or wood shavings.

SOCIAL

ENVIRONMENTAL RACISM: "The disproportionate impact of environmental hazards on people of color (Greenaction)." Example: When a local city council votes to build a landfill next to a historically Black neighborhood rather than a historically white neighborhood despite both neighborhoods being viable options.

ENVIRONMENTAL EQUITY: "The government's response to the demands of the environmental justice movement (Greenaction)."

MARGINILIZED/DISENFRANCHISED COMMUNITIES: Historically resilient communities that have been systematically denied political power and are disproportionately excluded from decision-making spaces.

PEOPLE OF COLOR: The following subgroups are included African Americans, American Indians and Alaska Natives, Native Hawaiians and other Pacific Islanders, and Hispanics.

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I. INTRODUCTION

EXTREME EVENTS ARE COMMON + WILL INTENSIFY

We now live in a world where wildfires, hurricanes, and other extreme climate events are routine news. Due to climate change, it is no longer surprising to hear that California is literally on fire or that another catastrophically slow storm is ravaging North Carolina's (NC) coast.

Since 1980, weather-related disasters have cost NC eighty-one billion dollars, placing the state second to Texas in climate catastrophe costs (NCEI, 2021). NC saw three of its major disasters in just three years: Hurricanes Matthew (2016), Florence (2018), and Dorian (2019). Each hurricane is now infamous for its unprecedented conditions—prolific rainfalls, record-breaking flooding, or slow and erratic storm paths—while scientists warn that storms will become stronger and wetter still (Bhatia et al., 2019).

CASH CROP POULTRY INDUSTRY

VULNERABLE TO INCREASED ENVIRONMENTAL DISASTERS

As extreme weather events exacerbated by climate change ravage NC's lands, the State's poultry industry quietly booms. This industry involves the raising, slaughtering, and selling of chickens, eggs, and turkeys. According to the NC Poultry Federation, the State's poultry industry—the top producer in the country—includes about 4,700 farms[2], provides 148,350 jobs to North Carolinians, and brings in $39.76 billion in state revenue (NC Poultry Federation, 2020).

According to the Environmental Working Group (EWG) and Waterkeeper Alliance (WKA)[3], the number of chickens in NC swelled from 147 million in 1997 to 516 million in 2018—a 250% increase in just eleven years (See Appendix A for details). In addition, between 2008 and 2016, the State saw more than sixty new poultry operations each year; during 2016–2018, the rate doubled to 122 new operations annually (Rudnquist and Carr, 2019).

As of 2021, state and local agencies in NC did not track poultry farm locations. How do we hold these facilities accountable to a higher standard or conduct proper hazard planning if we can't find them? We don't. However, farms need it, as seen by the 1.8 million heads of poultry lost to Hurricane Matthew. Those losses impact state revenue, farmer livelihood, and food accessibility. And because the industry is highly unregulated, weather disasters can quickly bring about environmental catastrophe.

Waste storage is a particular concern: typically, industrial and small-scale farms store waste without any protection, making it easy for severe storms to spread the toxic material in groundwater. Across NC, waste is stored in open pits, uncovered mounds, or near major bodies of water, resulting in environmental and public health concerns, especially for marginalized communities. Recently, NC has experienced some of the most severe hurricanes in its history, but the extent to which poultry farms are vulnerable to these storms is unknown.

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[2] There are varying reports on this number, likely due to the lack of policy requiring farms to register or acquire permits.

[3] Waterkeeper Alliance (WKA) is a sub-organization of The Environmental Working Group (EWG), a non-profit with about 30 million employees consisting of scientists, attorneys, analysts, data, and communications specialists. Both organizations are known to produce insightful research.

"The poultry are getting hit harder than the swine in this hurricane. What I'm seeing is a lot of poultry barns that are completely submerged, which means all the chickens inside are dead. The number of dead chickens is going to be in the many millions. Additionally, the floodwaters are washing piled poultry waste downstream."

–Rick Dove,
Waterkeeper Alliance founder,
discussing Hurricane Matthew aftermath

NASA, 2018 – NC COAST POST

INDUSTRY RISKS

North Carolina has much at stake as severe flooding threatens the poultry industry. Because poultry farming requires stable environmental conditions, a single disastrous flood can destroy the livelihoods of both local farmers and low-wage production and processing workers. Destroyed poultry also has downstream effects on the rest of North Carolina: Families and businesses face supply shortages and higher prices at the market. And when flooding occurs, chicken excrement can be transported into the local water and soil systems, threatening residents' health, especially NC's most vulnerable residents. In addition, a growing body of environmental justice work proves that CAFOs are often located in areas where most residents are poor, Black, or Native populations (Wing et al., 2002).

TABLE 1: Describes the toxic emissions CAFOs commonly produce and their threat to human life.

CAFO Emissions	Source	Traits	Health Risks
Ammonia	Formed when microbes decompose undigested organic nitrogen compounds in manure	Colorless, sharp pungent odor	Respiratory irritant, chemical burns to the respiratory tract, skin, and eyes, severe cough, chronic lung disease
Hydrogen Sulfide	Anaerobic bacterial decomposition of protein and other sulfur containing organic matter	Odor of rotten eggs	Inflammation of the moist membranes of eye and respiratory tract, olfactory neuron loss, death
Methane	Microbial degradation of organic matter under anaerobic conditions	Colorless, odorless, highly flammable	No health risks. Is a greenhouse gas and contributes to climate change.
Particulate Matter	Feed, bedding materials, dry manure, unpaved soil surfaces, animal dander, poultry feathers	Comprised of fecal matter, feed materials, pollen, bacteria, fungi, skin cells, silicates	Chronic bronchitis, chronic respiratory symptoms, declines in lung function, organic dust toxic syndrome

Centers for Disease Control, 2010

Disturbingly, increases in a county's number of CAFOs are also linked to increased infant mortality (Sneeringer, 2009). But despite poultry's economic, environmental, and public health risks, this industry is vital to the surrounding communities: it provides wages to many rural residents, is an important economic engine in the State, and serves as an indispensable national food source. Even so, poultry CAFOs contribute to climate change through greenhouse gas emissions. These farms are resource-intensive, rely heavily on fossil fuels (coal, oil, or gas), mass-produce greenhouse gasses, and often discharge pollutants into the air and water (Sierra Club, 2022). A typical CAFO design is an enclosed or partially enclosed "airplane hangar-like metal structure," often the size of a football field (Pelton, Lamm, and Russ, 2020). These structures run on large amounts of electricity to provide proper conditions for poultry. Egg-laying facilities require temperature-controlled environments year-round. In broiler houses, chicks must have constant heat supplied during their first few weeks of life until they are old enough to maintain their body temperatures. Then there are lighting, cooling, and water and feed systems consuming electricity and producing extensive amounts of carbon dioxide.

A HOTTER EARTH MEANS

Aside from burning fossil fuels and using substantial energy to run, NC's poultry industry also creates other, agriculture-specific pollutants. Indeed, the State's poultry industry creates more nitrogen and phosphorus than its eight million hogs (Patt, 2007). This happens in several ways. As chicks mature, they are moved to open-

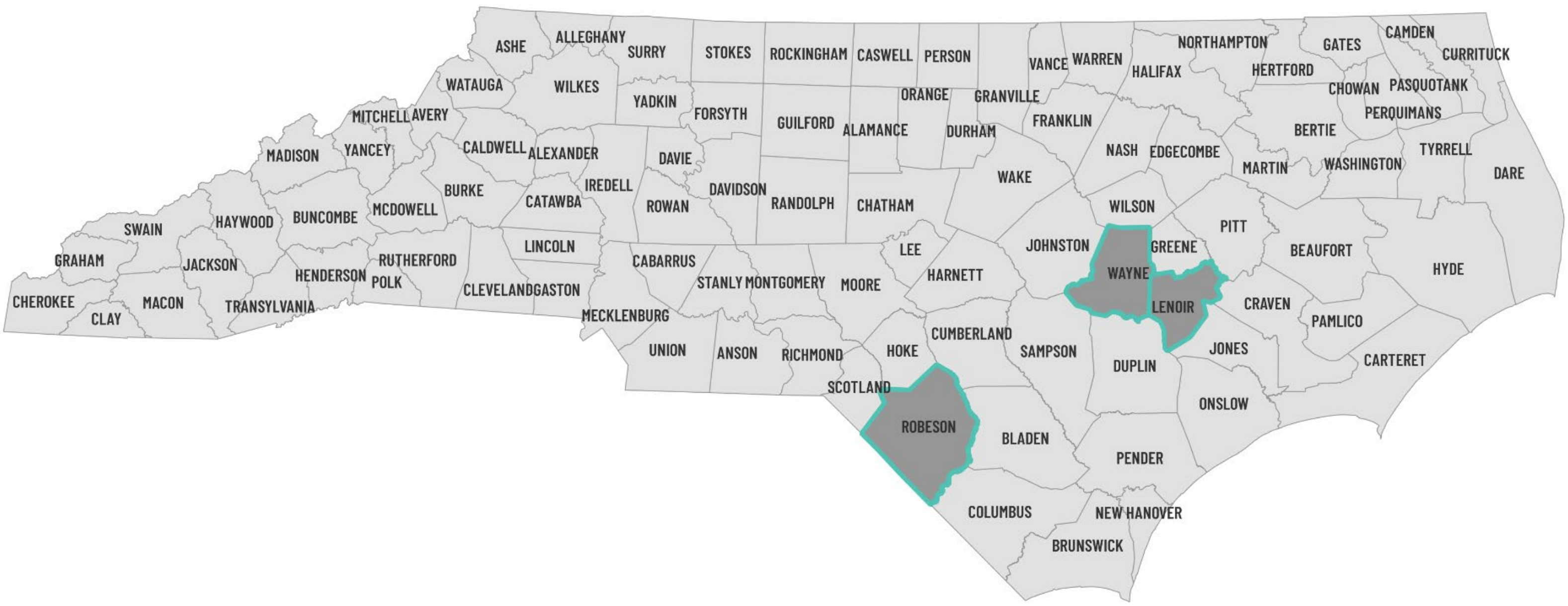
air or semi-open-air, unconfined sections of the CAFO and raised on litter. Throughout the growth process, the birds produce vast amounts of waste, soiling the litter. A major component of this waste is ammonia—the top air pollutant found near CAFOs (Centers for Disease Control, 2010). Inside the building, exhaust fans cycle air, simultaneously blowing ammonia gas out into the community (see image on previous page). Ammonia production also occurs when chicken excrement or wet/dry litter are spread on fields as fertilizer. These fans can also reduce nearby air quality by dispersing fecal matter, bacteria, and other pathogens outside (Pelton, Lamm, and Russ, 2020). Other general CAFO air pollutants include hydrogen sulfide, methane, and particulate matter (See Table 1 for health risks). When poultry waste is improperly applied as fertilizer, it can leach unsafe pathogens (i.e., bacteria, viruses, parasites) or toxic amounts of nitrates into drinking water (see image above). Meanwhile, although ammonia naturally occurs in the environment, high exposure in humans causes coughing, asthma attacks, watery eyes, and burns throat and nasal passages. It has been linked to increased rates of Blue Baby Syndrome, cancer (Knobeloch, 2000), and deadly algae blooms (Sierra Club, 2015).

Suppose we do nothing to better regulate the 4,700 (Graddy, 2020) or so farms operating in North Carolina, and they, along with other fossil fuel-dependent entities, continue to release the Green House Gases (GHGs) responsible for warming our atmosphere. As our atmosphere becomes hotter, it holds more water vapor. Meaning, the chances for heavier rainfall go up. For inland places like Robeson, Wayne, and Lenoir Counties, which are centered around the Lumber and Neuse rivers, this translates into increased flood risk. Addressing the industry's growing vulnerability to extreme flooding events and creating more sustainable growth methods are crucial to mitigating flood risk in eastern North Carolina. As this paper will show, the increase in extreme flooding events coupled with NC's poultry growth directly threatens public health, the environment, and North Carolina's equitable future.

STUDY AREA

ROBESON, WAYNE, LENOIR

NORTH CAROLINA



Despite the industry's critical role in NC's economy, there is a lack of research on the flood-related needs of the State's poultry farming communities. This project aims to address that gap. Through spatial analysis, I examine risk and explore the impacts of two extreme flood events—hurricanes Matthew and Florence—in Robeson, Wayne, and Lenoir counties. These counties contained a high concentration of poultry farms and were directly affected by both Hurricanes Matthew and Florence.

By narrowing in on these three counties, this study raises awareness about flooding's impact on poultry, introduces research into industry-specific flooding mitigation techniques, and aims to amplify the disenfranchised voices of those most harmed by the impact of climate change. I invite planners, policymakers, emergency entities, researchers, community organizers, directly affected communities, and others to engage with this research and to support the work led by directly affected communities as they develop the solutions needed to protect all of us from the worst of the climate catastrophe.

RESEARCH SCOPE + LAYOUT

This research paper contains these sections: Industry Background, Literature Review, Project Design, County Profiles, Results + Discussion, and Recommendations + Conclusion. Under Industry Background, I provide information on the NC poultry industry's growth, including the increase in farms and revenue over the last several years. I also introduce the primary bodies involved in regulating the industry and the steps they are taking, or not, to keep us all safe. The Literature Review informs the project's basis and identifies the hole this research seeks to close. Additionally, it examines current poultry regulations and their connection to climate change, extreme flooding, public health, economic instability, and environmental injustice. The methods section gives a detailed synopsis of the project's design, including analysis techniques and data. I then walk through the project's findings. Lastly, I discuss the implications for this work, followed by recommendations to improve flood mitigation for NC poultry farms.

INDUSTRY BACKGROUND

NC POULTRY BOOM

Although North Carolina is commonly known for its hog production, poultry farmers comprise about 42% of the State's total agricultural income, making the industry the State's top-grossing agricultural commodity. This income comes mostly from the sale of chicken meat, followed by turkeys, and egg production. The North Carolina Department of Agriculture (NCDA) counts approximately ninety million poultry heads among the State's livestock (NCAGR, 2021). Poultry trumps the State's hog industry in size and annual profits. This is no small feat, considering NC hog production ranks second nationally (NCGAR, 2021). From 2012 to 2019, the number of poultry in Robeson County, for instance, nearly doubled, with an eighty percent increase, compared to a seventeen percent increase across the rest of the State. The number of birds farmed in NC ballooned to more than 538 million, enough poultry to produce up to 5 million tons of waste. Research connects NC's poultry industry growth to the State's 1997 moratorium on hog farms. The new regulation required all the permit-less industrial farm industries—except poultry—to obtain permits (WKA, 2018). APPENDIX B contains WKA's maps showing poultry and hog growth over time in NC.

II. LITERATURE REVIEW

AS EXTREME FLOOD RISK RISES, RESILIENCY MUST

Current literature on extreme flooding and emergency planning and mitigation is vast and dynamic. Many past researchers have done substantial work to identify the effects of climate change on rural and marginalized (yet resilient) communities and make important contributions to the study of environmental racism. That research informs this work. But past studies rarely link these topics to specific agriculture sectors or geographic regions and literature examining the impacts of extreme flooding events on the poultry industry is meager.

UNREGULATED WASTE

The Clean Water Act, overseen by the EPA, does regulate CAFOs and Animal Feeding Operations that meet specific criteria around size and pollution potential as "point sources" of pollution. The CWA prohibits the discharge of pollutants into US waters unless authorized by a National Pollutant Discharge Elimination System permit. However, agricultural storm water discharge, such as the kind that occurs after a heavy rainfall event like a hurricane, is not considered a point source of pollution as defined by the Clean Water Act. Therefore, this regulation has little to no effect on the hazards of runoff pollution from storms. (LPELC Admin, 2019). This is even though agricultural runoff is the main culprit for water quality impacts to rivers and streams and plays a key role in impairments to lakes and wetlands.

As described in the previous section, the poultry industry poses severe health and environmental hazards to surrounding communities as toxic waste seeps into the air and waterways. These dangers are made all the worse by severe flooding. But despite these risks, North Carolina's poultry regulations are relatively lax. The State classifies all poultry operations producing dry litter waste as "deemed permitted" ("Dry Litter" 2022), meaning the operations are not required to seek a permit before building, nor are they inspected regularly by state agencies (Patt, 2017). Indeed, regulators often don't even know where dry poultry waste is stored, making it nearly impossible for the State to limit its toxic impact.

Compare that approach to the State's regulation of hog farms. Statutes require that any new or expanding hog farm take steps to reduce soil and groundwater pollution, ammonia emissions, and other dangerous chemicals. These hog farms are inspected annually by the NC Department of Agriculture and Consumer Services (NCDA&CS) 's Division of Soil and Water Conservation. Meanwhile, poultry farmers are free to store dry poultry waste however they choose, with almost no regulation. They are not required to submit waste management plans or report to regulators how, where, or how much waste they apply to fields.

But this casual approach to poultry farms does not accurately reflect the relative impact of poultry farms on the health or environment of the surrounding community. These commercial poultry farms produce more nitrogen and phosphorus than commercial hog farms. And it is no surprise why—most NC poultry is raised in massive operations, packing tens of thousands of chickens into dozens of barns (Fields of Filth, 2018). These CAFOs generate 10 billion pounds of wet litter and 2 million tons of dry litter annually (WKA). Much of this waste is stored in open, unlined pits dug into the porous North Carolina soil (see picture on next page). This, in turn, allows toxins to leach into surrounding soil and water, exposing neighboring homes and communities to dangerous chemicals.

These toxins have tangible effects on communities' health. For example, a 2000 study conducted in three rural North Carolina communities found that those who lived near hog operations experienced increased rates of several ailments, including burning eyes, excessive coughing, diarrhea, and sore throat (Wing and Wolf, 2000). A 2018 study by Duke University found that living near an industrial swine operation increases

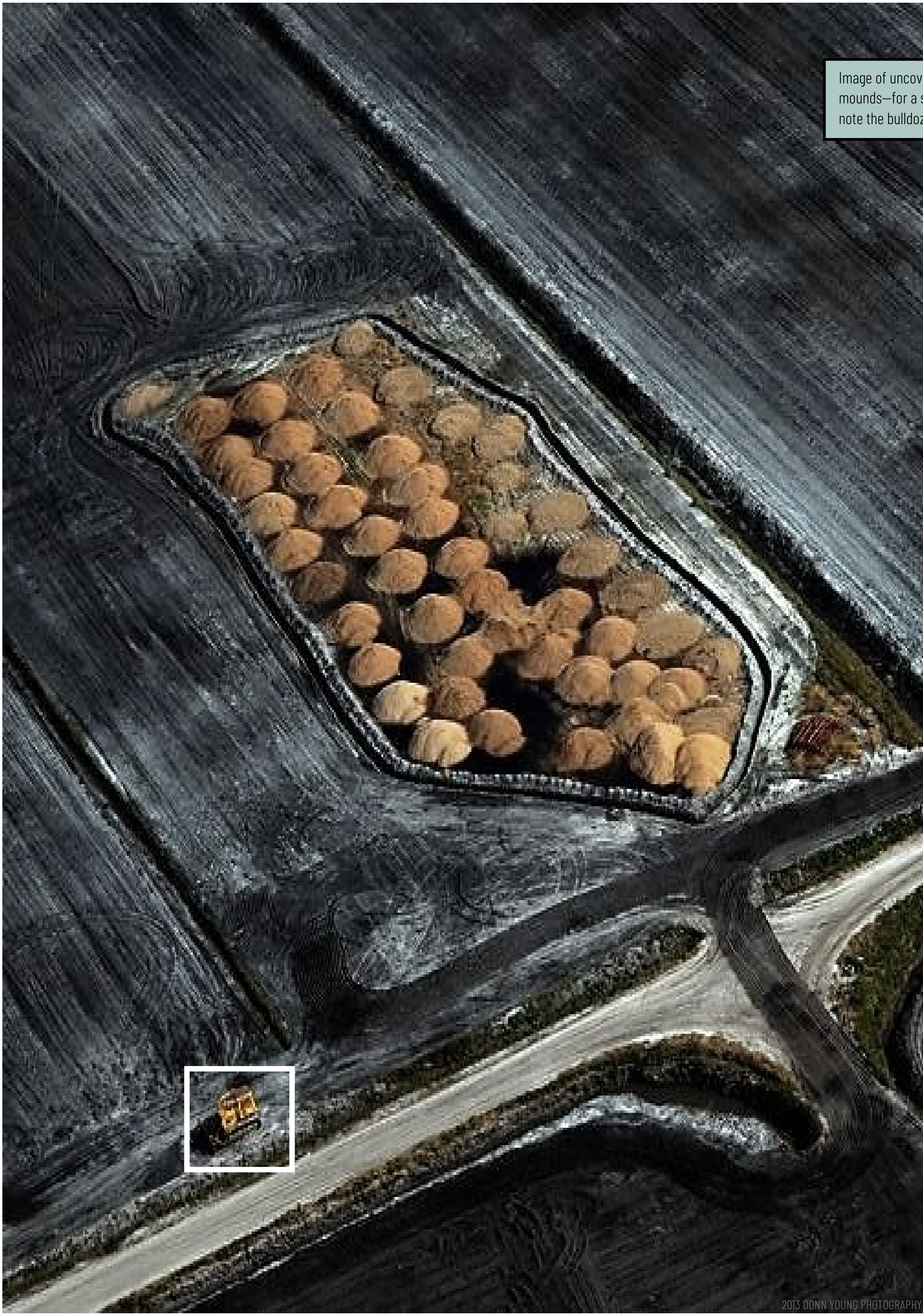


Image of uncovered poultry waste mounds—for a size comparison—note the bulldozer.

AFRICAN AMERICANS MORE LIKELY THAN WHITES TO LIVE NEAR FLOODED CAFOS ACCORDING TO SATELLITE ESTIMATES, BUT NOT ACCORDING TO DIVISION OF WATER QUALITY REPORTS.

WING ET AL. (2002)

ENVIRONMENTAL RACISM + INJUSTICE

Black, Hispanic, and Native American rural communities suffer the direst consequences from the State's regulatory policy. An environmental racism framework helps explain these phenomena: overwhelming research shows that polluters (and their resulting pollution) are disproportionately located in communities of color, meaning that marginalized populations bear the brunt of the health hazards associated with these facilities. (Newkirk, 2018). Recent history in both Flint, Michigan and Jackson, Mississippi further shows that state and local governments are often catastrophically slow to respond when environmental disaster strikes.

Racial disparities may be even worse in rural communities, which often suffer more severe damage from natural disasters and take longer to recover after the disaster ends than urban areas (Ash et al., 2013). For example, in 2014, EarthJustice filed a complaint with the EPA based on an extensive study of NC hog operations' disproportionate effect on communities of color (EPA, 2017).

It concluded that Black, Hispanic, and Native American populations were more likely than whites to live within three miles of an industrial hog operation, opening these communities up to extreme health consequences. In response to the complaint, the EPA opened an investigation into North Carolina DEQ the following year and found that the State's swine waste general permitting program may "run afoul" of federal anti-discrimination laws. The same can be said of North Carolina's poultry operations, which are largely located in poor, rural communities of color. Indeed, rural Black families are 1.5 times more likely to live near a CAFO than their white counterparts (Wing et al., 2002). Moreover, Black communities in rural areas face risks of living in flooded areas and state agencies underreporting lagoon breaches.[4] This risk is compounded by a failed public education campaign that has left many Black residents uninformed about potential flood risks or mitigation measures.

Duplin and Sampson counties—the highest poultry and hog producers in the State—have recently drawn national attention for their livestock production. Meanwhile, nearby counties have been overlooked. This project, therefore, focuses on poultry farms in Robeson, Wayne, and Lenoir counties. Like their poultry mecca counterparts, these counties have high percentages of non-white residents, especially Robeson, at almost double NC's average (WKA, 2018), which places the cumulative burden of industrial agriculture

[4] A lagoon breach describes when matter overflows from lagoons-large pits often used at livestock farms to hold excess fecal matter and urine from the animals- and into local runoff.

predominantly on communities of color. Robeson county—ranked 2nd out of 100 counties as economically distressed by the State— is also home to the largest non-federally recognized tribal community east of the Mississippi River, the Lumbee Tribe (Lumbee Tribe, 2021). This study seeks to shed light on how these communities fared during two recent mass-flooding events.

BIGGER, WETTER STORMS

Research documenting NC storms for the past 120 years shows that hurricanes are getting stronger[5] and wetter than their predecessors (Paerl et al., 2019). The three storms discussed below highlight the dangers posed by these natural disasters of unparalleled strength.

MATTHEW + FLORENCE

In 2016 Hurricane Matthew pummeled the East Coast with more than twenty inches of rainfall. Matthew's slow-moving path obliterated homes and left counties under substantial, record-breaking flooding for weeks (CDC, 2019). Unlike previous Atlantic hurricanes, Matthew did not make landfall at NC's southeastern beaches and track upward to the Outer Banks. Instead, the storm traveled through South Carolina and hit inland, southeastern NC counties with little experience protecting against or preparing for hurricanes (CDC, 2019). Up to five million poultry birds were lost to storm flooding (Polansek, 2016)

Two years later, Florence's thirty inches of rain exceeded the highest single storm rainfall in southeastern NC (Bates et al., 2000). The storm turned farms across southeastern NC into their own isolated islands. In Florence's wake, 3.4 million poultry were dead. That number remains the highest poultry mortality to date, doubling what the State would see with Dorian. The NCDA reports fifty percent of those birds died from drowning.

DORIAN

Most recently, 2019 brought Hurricane Dorian.[6] It was and continues to be described as one of the strongest hurricanes in NC history, with sustained winds nearing 90 mph, which spawned seventeen tornados, fourteen of which touched down in southeast NC (NWS, 2019) (Armstrong, 2020).

Hurricane Dorian highlights how current predictive models may fail to accurately reflect where the most harm will occur and therefore leaves residents ill-prepared to mitigate environmental catastrophe. Three days before Hurricane Dorian made landfall, the NCDA published forecasts of expected precipitation across the State based on the agency's predictive hurricane and inundation model's outputs. NCDA forecasted eighteen inches of rain would fall, causing substantial flood risk for farms in the 100 and 500-

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[5] Research suggests that hurricanes are becoming bigger, lasting longer, and more intense.

[6] Project does not analyze Hurricane Dorian but discusses the storm to show the area's history of 500-year storm events over a short period of time.

year floodplains. The NCDA then used that data to identify at-risk farms. Farmers were contacted, and contingency plans were made. Through FEMA funding, the agency organized the processing and hatchery placement of 1.5 million birds within those floodplains. Farms were advised to stock feed bins, fill generators, purchase reserve gas, shutter windows, and arrange for sandbags to prevent water damage.

Shortly after, Dorian made landfall. But contrary to what NCDA's models anticipated, substantial portions of rain fell in unexpected areas (Martin, 2019). Because Dorian's predictive model failed to identify and prepare at-risk communities, countless farmers were left unprepared and forced to disentangle the storm's aftermath largely on their own.

LOOKING AHEAD

As this literature review shows, insufficient regulation, and failed predictive modeling leaves rural and marginalized communities especially vulnerable to the hazards wrought by severe storms. Climate change will only worsen these storms and their environmental and public health consequences. But there are solutions that can help communities prepare for worsening storms and implement systems to mitigate climate risks. Pant et al. (2019) note a lack of researchers taking thorough assessments of hurricane risks and impacts across different locations. This lack is especially pertinent to hazard mitigation in NC. Without designing regional and local approaches, especially considering climate change, poultry farm flood risk will only increase.

III. DESIGN + METHODS

As the literature review points out, the growth of poultry has occurred under the radar despite the industry's losses after major storms like Matthew and Florence. As the industry grows and accounts for a larger portion of the state's economy, the need for adequate regulations become increasingly urgent. This is a particularly pressing issue in the face of anthropogenic (human-driven) climate change and the resulting extreme flooding events. With that in mind, this project sets out to better understand the flood risk to farms and the marginalized communities where they operate through spatial analyses. I look at the data at both a regional and county level.

Images of Lenoir County show farms buffered according to their barn count.

MAPPING FARMS

LOCATIONS

Poultry farm location data was unfortunately not available for this project. Therefore, it had to be created. To do this, I used three tools: Google Earth, WKA's Fields of Filth [7] interactive map, and Microsoft Office PowerPoint.

I used Google Earth to create three project maps: one for Robeson, Wayne, and Lenoir counties. Afterward, I took zoomed-in screenshots of small sections of WKA's farm location maps and pasted them into a PowerPoint slide. Then, one by one, I located and mapped each poultry farm's location as a point geometry on Google Earth, counted the number of barns, and crossed it off on the slide before moving to the next farm. Before crossing a farm off, I re-verified the farm's street address and its number of barns (referenced as "barn count" in this project) against WKAs reports for accuracy. In total, I mapped 353 of 353 farms.

SIZE

County and state boundaries were obtained from NC One Map and imported into QGIS. I then imported the farm location data into QGIS as point data. However, each farm is a different size depending on their number of barns. To represent farm size variation, farm points were buffered according to their barn count using QGIS' Field Calculator (see Appendix C for details). This process converted farms to a circle with a radius ranging from about 1931 to 4,448,171 square meters, depending on each farm's number of barns. The average size for farms generally was 66,180 square meters. These buffered farms were used for all analyses to improve the accuracy of overlays of flood hazard and exposure with farm locations.

[7] Exposing Fields of Filth is an interactive map detailing the locations of poultry, hog, and cattle operations in NC

FARM FLOOD RISK ASSESSMENT

IDENTIFY FEMA FLOOD ZONES

FEMA's flood risk maps[8] provide nuanced and detailed information about the geography of farming communities. For example, they show both elevation and local flood zones—which then tell communities how likely they are to experience flooding. FEMA's National Flood Insurance Program (NFIP) uses this information to help calculate insurance costs for property owners.

Given the wealth of information in these maps, I used them to help inform flood risk for poultry farms by creating maps that overlay FEMA's flood zones with poultry farms in the study area. I then noticed that a significant number of poultry farms, while located in FEMA's area of minimal flood risk, appear close to floodplains and major bodies of water, suggesting that they, too, may be vulnerable to extreme flooding. To better understand the risk these farms experience, I calculated the distance of each poultry farm from the floodplain. I also added an elevation[9] layer on these maps to get a general sense of how water could move across the study area.

PROXIMITY TO FEMA'S FLOOD ZONES

To calculate farm distance from the flood zones, I grouped farms into five fixed distances: floodplain, half a mile, one mile, one mile and a half, and two miles. Traditionally, FEMA floodplains are divided into 100 and 500-year floodplains. However, for my analyses, I combined the 100- and 500-year flood zones, which I refer to as the floodplain. This decision was made because the 500-year zone is not a continuous area (see flood severity maps in the Results section). The other distances were used because they are commonly used in day-to-day life and would therefore be accessible to more readers. This analysis began like the others with mapped farms. A FEMA shapefile of the floodplain was then overlaid on the map. Next, I merged the 100 and 500-year zones and used that as the floodplain layer. To create the first ring, I created a half-mile buffer around the floodplain. Next, I made a half-mile buffer around that first group. The result was another ring (the one-mile group). This process was repeated for the two remaining groups. Afterward, these groups needed to be turned into rings so that the group's areas did not overlap. This was accomplished with the erase tool in ArcMap. This tool subtracts one area from another.

I began by subtracting the floodplain from the half-mile buffer, then the one-mile buffer from the half-mile, followed by the one-mile buffer from the one-and-half-mile buffer, and lastly the one-and-a-half-mile buffer from the two-mile. As a result, I had autonomous rings. I then combined those rings into one layer for analysis. I used the area intersect feature to determine what percentage of a poultry farm fell into what distance group. Those results were then exported into Excel as a .csv file for further analysis.

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[8] Explore FEMA's Flood Map Service Center

[9] Elevation Data (30 Meters) for counties downloaded from USDA's Geospatial Data Gateway

FLOOD RISK BASED ON FLOODPLAIN DISTANCE

In Excel, I sorted the farms based on how close they were to the floodplain. The figure below shows the sorted farms. Column A contains each farm's unique identifier, columns B-F are the five distance groups farms were categorized into, column G pulls the highest percentage from the distance groups, columns H and I name which group the percentage came from, and column J assigns farms to a flood risk category based on their distance to the floodplain. Farms that fall mostly in the floodplain are at *Very High* flood risk, farms half a mile away are deemed *High*, those a mile away are *Moderate*, one mile and a half are *Low* risk, and those two or more miles are at *Very Low* (see Results section for analyses). This data tells us how far each farm is from a floodplain. And groups them into concentric circles based on distance from the floodplain. Each concentric circle gets one-half mile further from the floodplain.

FLOOD EXPOSURE + SEVERITY

This research focuses on Hurricanes Matthew and Florence because of their impacts on the study area, its agriculture sector especially. Though limited— for my analysis, I used The Nature Conservancy[10] remotely sensed satellite data because it showed both storm flood extents for all three counties and was straightforward. However, these flood extent data are not without limitations. They only show whether flooding was present at the exact time the image was captured by satellite once per day. In the future, additional research and more robust data collection methods may fill in the gaps left by the satellite data.

To better understand how individual farms were affected by Matthew and Florence's flooding, I ran zonal statistics to determine farm-level flood severity. First, I laid farms and storm flooding onto a map. I then measured each farm's total area and how much that area overlapped with flooding. This process provided the total area and total flooded area for every farm. With those numbers, I determined the percentage that each farm flooded during Matthew and Florence. Farms were then grouped by those severity percentages as follows: *High Severity* is when 49% or more of a farm's area flooded; *Moderate* is between 49%-20% flooding, and *Low* is flooding under 20%. Here percentages were used as they allow severity to be scaled regardless of farm size or barn count. After this data was created, it was used to make a matrix showing farm flood severity for both storms, which was then added to the maps in the results section (see each county's Legend). Each matrix has two values per category. The first value signifies Matthew's flooding, and the second is Florence. For example, if 10% of a farm flooded during Hurricane Matthew but did not flood during Florence, the farm would be in the matrix category "Low_0" (for QGIS coding, see Appendix C).

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[10] The data was originally created by the 2020 study: *Repeated Hurricanes Reveal Risks and Opportunities for Socioecological Resilience to Flooding and Water Quality Problems*

AVERAGING DATA

CAFO CLUSTERING

In Stata, I looked at number of farms and census blocks to see how farms were distributed in the study area. A table was created with the total number of farms on the Y axis and how many census blocks on the X axis. I noticed that there were several blocks with a high number of farms. Therefore, I examined the socioeconomic census variables of those blocks in R to see if there were any greater trends that might compound the ill-effects of poultry farming or be indicative of additional systemic issues. I also wanted to investigate these blocks more closely to see if this pattern was indicative of a greater risk of harm, as it can be easy to lose sight of the individual communities impacted when solely using large amounts of data.

FEMA FLOOD ZONE EVALUATION

Again, in Stata, I examined storm flood severity and FEMA's flood zones. Matthew and Florence's flood percentages at the census block level were the dependent/outcome variables. The three FEMA zones were the independent variables: the 100-year (AE), 500-year (X-0.2 PCT AREA), and Area of Minimal Flood Risk (X-AREAMINFLOODRISK). Storm flood percentages were grouped by flood zone to determine where flooding occurred.

RISK OF MARGINILIZATION INDEX

In R, I created a marginalization index to quantify the level of risk for the study area. To do this, I used data organized at the census block level, focusing on three variables: race, female-headed households, and median household income. For each variable, a census block was assigned a value of one or zero depending on whether or not they met the following criteria: for race, the blocks either predominantly made up of people of color or a diverse group, meaning no race made up a majority of the population, were assigned a one; for female-headed households, blocks within the top quartile, or the highest number of female-headed households, were assigned a one; and for median household income, blocks in the bottom quartile, or the lowest median household incomes, were also assigned a one. Blocks were then sorted on a scale of zero to three, with three being the highest risk of marginalization. With this, I was able to combine three incomparable variables into a single index that could be used for analyses, which are discussed below.

INDEX + FARM EXPOSURE

I examined farm proximity to marginalized communities. The analysis was performed for the study area as a whole and then for each county. The percentage of census block land area with a poultry farm was the dependent/outcome variable, and the Risk of Marginalization Index was the independent variable.

FLOOD SEVERITY

I then examined how flood severity for each storm affected marginalized communities. The analysis was performed for the study area and each county. The dependent/outcome variable was the average percentage of land area flooded during Matthew and Florence for each index group. While the Risk of Marginalization Index acted as the independent variable. Lastly, in R I graphed flood severity by the Marginalization Index to compare county and study area data for each storm.

IV. COUNTY PROFILES

This section provides a glimpse into the three counties. Good hazard planning rests on a sincere and transparent approach to getting to know a place and the people who live there, especially any communities traditionally left out of decision-making. That process includes learning about local points of pride, history, culture, ecology, and unique geographies. Census data, though important, tells only a small part of the communities’ story.

SOURCE: THE ROBESONIAN 2022, LUMBEETRIBE 2022, GOOGLE MAPS

ROBESON

88

CENSUS BLOCKS

132,596

POPULATION

$39, 139

MEDIAN INCOME

28%

POVERTY RATE

40%

NATIVE

27%

WHITE

24%

BLACK

9%

HISPANIC

SOURCE: ARCHLEAGU, EDNC, FAMILY DESTINATIONS, LENOIR TOWN WEBSITE, GOOGLE

WAYNE

75
CENSUS BLOCKS

123,603
POPULATION

$54,585
MEDIAN INCOME

20%
POVERTY RATE

62%
WHITE

30%
BLACK

12%
HISPANIC

.3%
NATIVE

SOURCE: ARCHLEAGU, EDNC, FAMILY DESTINATIONS, LENOIR TOWN

LENOIR

47
CENSUS BLOCKS

56, 756
POPULATION

$40,586
MEDIAN INCOME

23%
POVERTY RATE

53%
WHITE

39%
BLACK

8%
HISPANIC

.2%
NATIVE

V. RESULTS + DISCUSSION

To better understand the impacts of flooding on the three counties in eastern NC, I examined data that combined flooding, poultry farms, and local communities. These are the results.

FARM FLOOD RISK ASSESSMENT

STUDY AREA

CAFO CLUSTERING

The chart on the left helps explains where and how farms are distributed in the study area's census blocks.

CAFO DISTRIBUTION
ACROSS ENTIRE STUDY AREA

Number of Farms per Block	Number of Census Blocks
0	123
1	26
2	16
3	7
4	11
5	5
6	5
7	2
8	3
9	3
10	3
12	1
13	4
16	1
Total	210

Specifically, it shows that the bulk of farms are in just a few census blocks. While most census blocks (123 out of 210) have zero farms. However, there are a few blocks with an astounding number of farms toward the bottom. For example, the four blocks with thirteen CAFOs and the single census block with sixteen.

Study area blocks with ten or more farms were examined. Of these blocks, most of them were in Wayne County. Within these, there was little variation in the socioeconomic variables: they all had a majority white population, were in the lower half of female-headed households, and were mostly higher-income households, with some earning in the top quartile of median household incomes—almost twenty- thousand dollars over Wayne's and NC's median income.

In comparison, Robeson had the only block with a "diverse" population in terms of race in this data subset. That block earned the lowest income in Robeson and had about a third of households headed by women. Poultry farm exposure should be examined in any context, but it is especially important in communities who already face higher risks of marginalization.

COUNTY-SPECIFIC

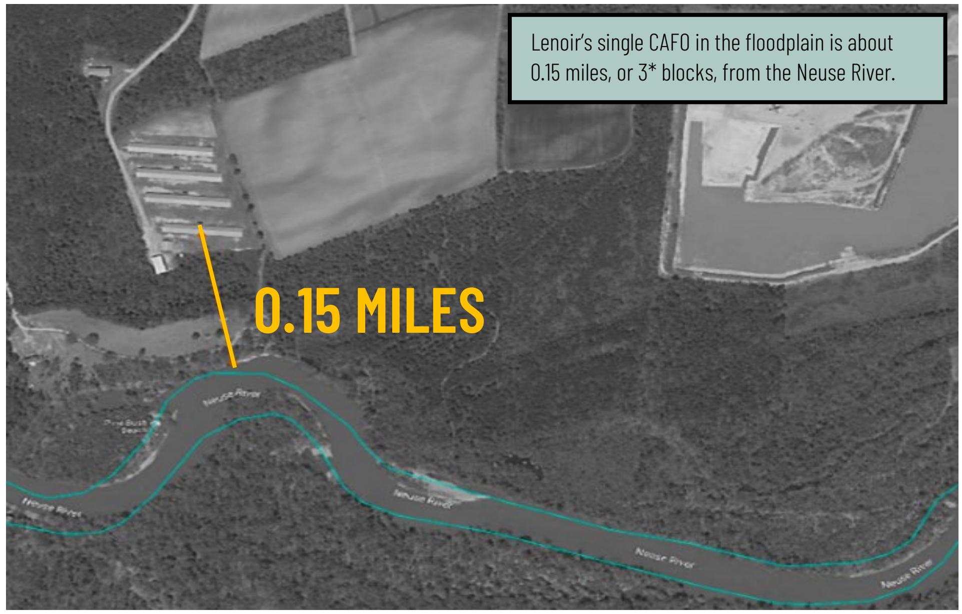
RISK OF MARGINALIZATION INDEX + FARM EXPOSURE

A look at farm locations compared to socioeconomic status and marginalization risk index indicates some surprising results. For example, 40% of Robeson blocks in index group 0—the most privileged group—lived near a farm. Meanwhile, Wayne and Lenoir's most privileged groups had 68% and 61% of census blocks with a farm.

Wayne County blocks in group 0 had a 68% chance of living near a farm, whereas the most marginalized in Wayne had a 0% chance. Again, this is a surprising finding because previous literature has indicated that historically underrepresented communities –especially people of color—are much more likely to live near industrial farms than privileged communities.

Farm exposure for Lenoir's most marginalized blocks (index group 3) was 14%, which is almost double that of the other counties and the study area. Meaning Lenoir's blocks in the lowest income quartile, with the highest number of female-headed households, and are of color are twice as likely to live near a farm when compared to the study area's 7%, Robeson's 8%, and Wayne's 0%.

HOW FAR ARE CAFOs FROM THE FLOODPLAIN?



* 1 MILE = 20 BLOCKS

Most farms in the study area were designated by FEMA as falling within an Area of Minimal Flood Risk (MFR). But even farms within an MRF might face varying degrees of flood risk; for example, a farm located two miles away from the floodplain might face a lower risk of severe flooding than would a farm located half a miles from the floodplain. As a result, I grouped farms based on distance from the floodplain and separated them into one of five risk categories (seen in the tables below). Because farms that are located closer to a floodplain face a higher risk of flooding than do farms located further from a floodplain, I labeled these categories accordingly. The charts below show that a high number of farms have been built within a mile of the floodplain. A 2013 study published by FEMA states that inland floodplains— like those in the study area—could expand by 45% within the next 75 years (AECOM).

ROBESON
TOTAL FARMS
102

FLOOD RISK BY DISTANCE	VERY HIGH	HIGH	MODERATE	LOW	VERY LOW
	FLOODPLAIN	*0.5 MILE*	*1 MILE*	*1.5 MILES*	*2 MILES*
FARMS	4	46	28	9	3
% FARMS IN BUFFER*	4%	45%	27%	9%	3%

WAYNE
TOTAL FARMS
182

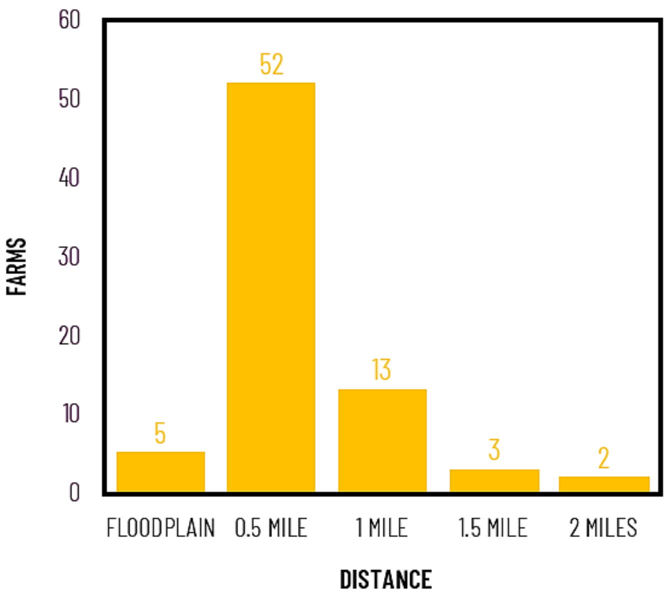
FLOOD RISK BY DISTANCE	VERY HIGH	HIGH	MODERATE	LOW	VERY LOW
	FLOODPLAIN	*0.5 MILE*	*1 MILE*	*1.5 MILES*	*2 MILES*
FARMS	4	106	54	19	3
% FARMS IN BUFFER*	4%	58%	30%	10%	2%

LENOIR
TOTAL FARMS
67

FLOOD RISK BY DISTANCE	VERY HIGH	HIGH	MODERATE	LOW	VERY LOW
	FLOODPLAIN	*0.5 MILE*	*1 MILE*	*1.5 MILES*	*2 MILES*
FARMS	1	26	15	10	3
% FARMS IN BUFFER*	1%	38%	22%	15%	4%

* PERCENTAGES HAVE BEEN ROUNDED UP FOR READABILITY

FLOODED FARM PROXIMITY TO FLOODPLAIN



FLOODING BASED ON FLOODPLAIN DISTANCE

This graph shows how farms were affected by both storms. We see that most flooded farms were located half a mile away from the floodplain, which aligns with the high-risk category in the previous section. Farms one mile out also experienced quite a bit of flooding. And looking at Appendix G, we see that 25% of farms within half a mile of the floodplain experienced flooding, while farms located just a mile out from the floodplain had only a 14% rate of flooding—nearly a decrease of 100%.

FEMA FLOOD ZONE EVALUATION

Data shows that FEMA's flood zone models are highly accurate. Farms in the 100-Year flood zone averaged 35% of their area flooded. In contrast, farms in the Area of Minimal Flood Risk (MFR) zone averaged 82% of their area flooded.

But zooming in on the data tells us that, though FEMA's predictions are statistically accurate, they do not provide 100% certainty to farmers. Some farms, even those in the FEMA-labeled MFR zones experienced extreme flooding.

Most farms without flooding, predictably, fell within that zone. But that does not mean that farms in those presumably less flood-prone zones are free from risk: Indeed, five of the farms that were 100% flooded during Florence within the study area were in zones that FEMA models indicate to be Minimal Flood Risk (MFR) zone. That was nearly half (5 out of 11) of the farms that experienced 100% flooding (See Appendix F for Florence and Matthew tables). The wide variation in the severity of flooding experienced on different farms during the storm within the MFR zone shows the need for more research to pinpoint targeted interventions.

Both Matthew and Florence both exceeded the 500-year storm expected flooding threshold. Therefore, it makes sense that even farms located in MFR zones experienced severe flooding. However, these results do indicate that FEMA's models may provide less certainty as storm severity increases. As storms become wetter and more frequent due to climate change, they may continue to exceed expected thresholds causing at-risk areas to expand. Farms that may be near a flood zone today are likely to be smack in the middle of a flood zone in years or decades to come. And even farms that may be "low risk" relative to their neighbors will still experience damage as catastrophic storms hit North Carolina year after year.

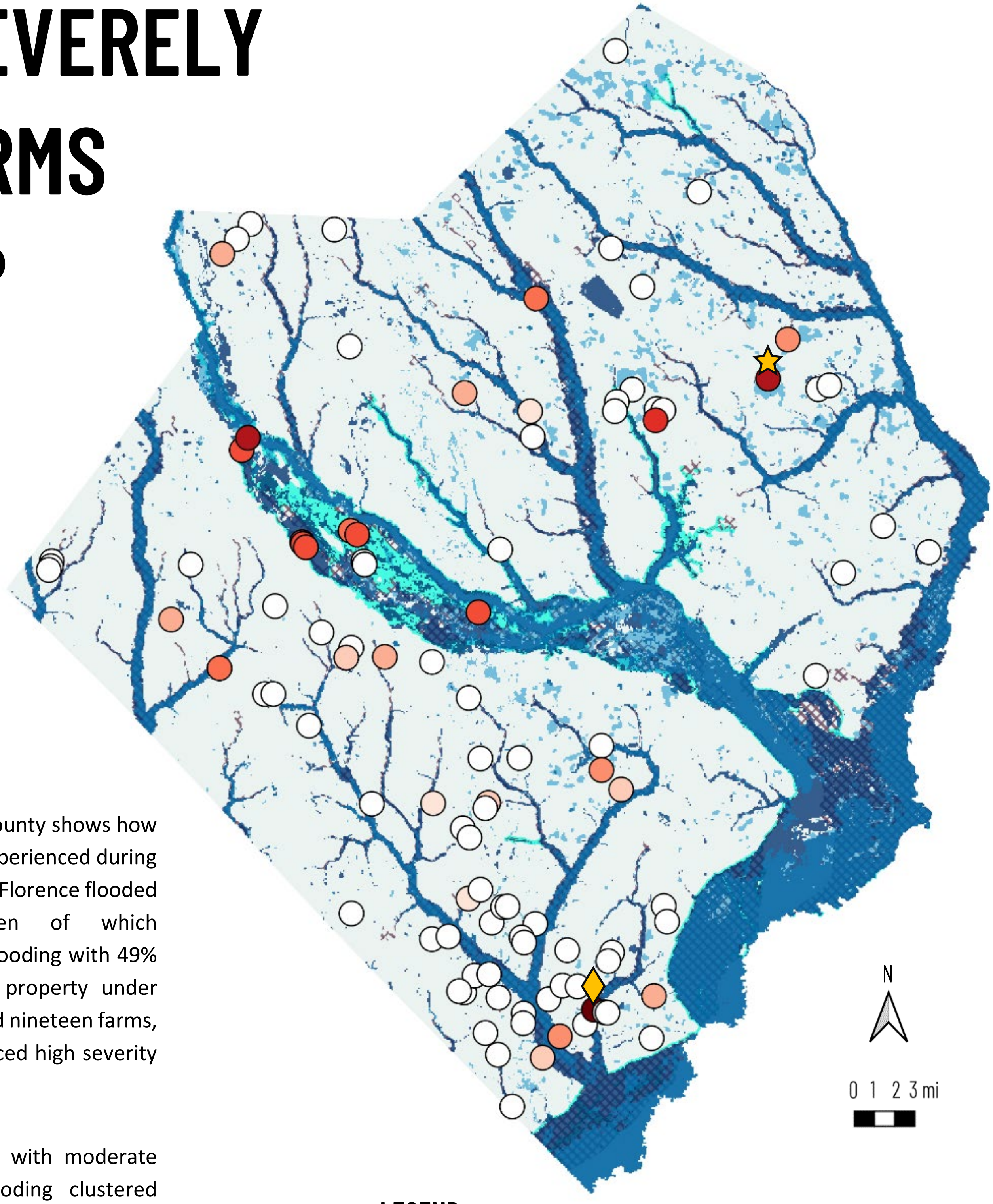
Farms in the 100 and 500-Year zones averaged a difference of 11% of their area flooded. Farms in the MFR zone averaged 15% lower area flooded than farms in the 100-Year zone

MFR FLOOD RISK

Zooming in to look at a sample county, the map of Robeson County on the next page further shows that FEMA's flood zones are largely accurate—most of the farms that experienced flooding during either of the storms (demonstrated by pink or red dots) were in FEMA flood zones while most of the farms that experienced no flooding (demonstrated by white dots) were in FEMA's MFR zone. But some farms within the FEMA MFR zone experienced severe flooding (49% or more) during both Matthew and Florence, such as the farm highlighted with an orange diamond below. It is important to note that the dots on the map do not represent actual farm area but are approximate representations of their location.

But not only the farms near flood-prone zones need to worry. For example, the farm highlighted with a star on the second image below is located solidly in what FEMA deems to be a MFR area—far from any flood plains. And yet, it experienced substantial flooding during hurricane Florence and Matthew (the two shades of blue). Flooding that was once understood to have a minimal chance of occurring (0.2%-1.0% during any year) is now becoming a more regular occurrence. That tells us something about the potential changing behavior of hurricanes. One farm may experience substantial flooding in both storms while its neighbor survives practically unscathed. As Hurricane Matthew and Florence's destruction revealed, these communities—and many others across North Carolina—are not prepared to withstand storms of that caliber.

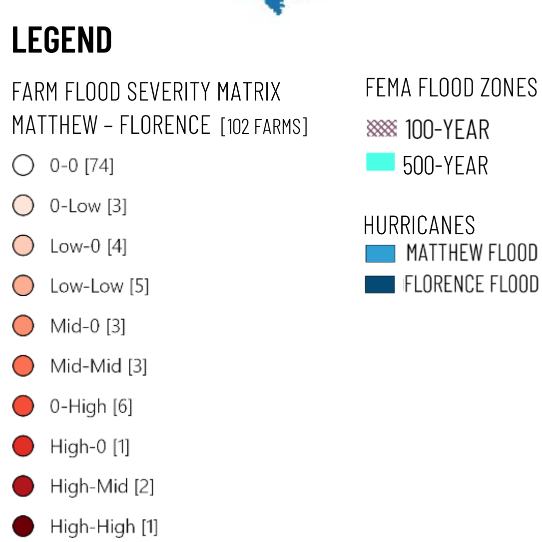
HOW SEVERELY DID FARMS FLOOD?

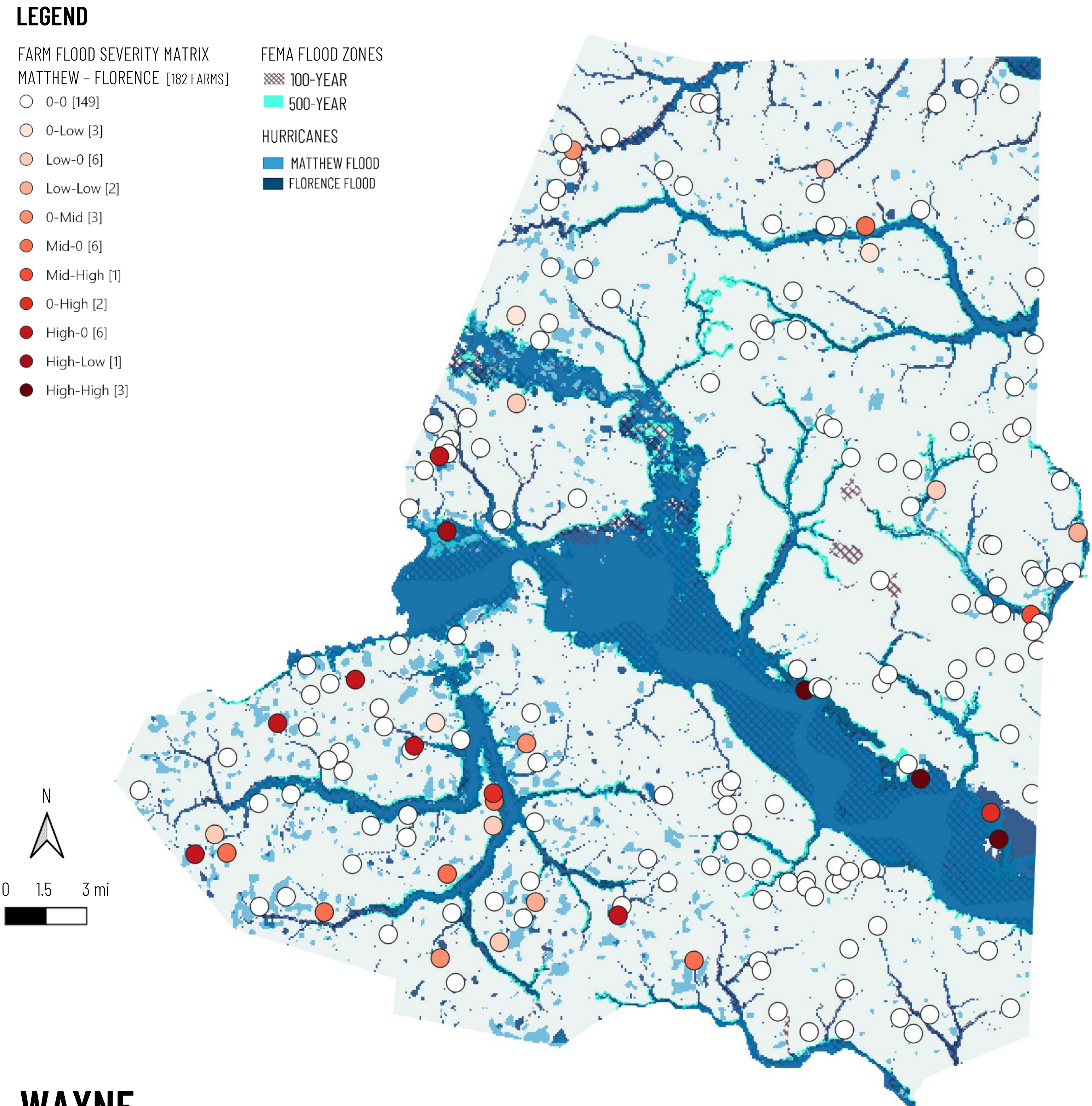


ROBESON

This map of Robeson County shows how much flooding farms experienced during Matthew and Florence. Florence flooded twenty farms, seven of which experienced extreme flooding with 49% or more of the farm property under water. Matthew flooded nineteen farms, four of which experienced high severity flooding.

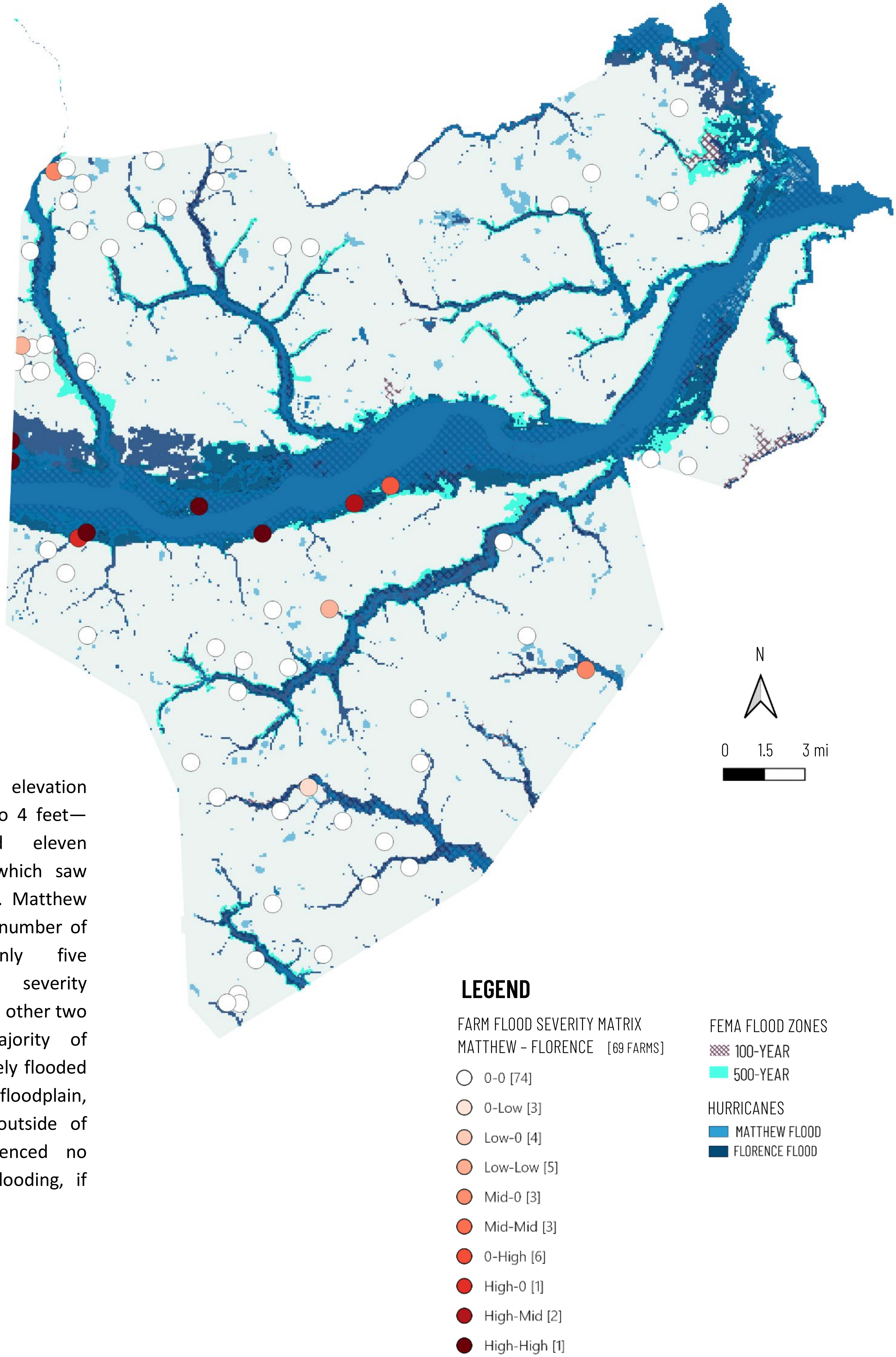
The map shows farms with moderate and high severity flooding clustered mostly in northern and western Robeson—parts of which are the highest elevated at about 243 feet above sea level. The lowest elevated area—at about 54 feet above sea level—is in South Robeson and contains another prominent cluster of farms. (See Appendix J for elevation maps for each county). Apart from one farm (represented by a dark red dot), most of the farms in South Robeson survived the storms unscathed by flooding.





WAYNE

Wayne County was hit the hardest by Matthew, as the flooding on the map shows. Matthew flooded twenty-five farms, ten of which experienced high severity flooding. While Florence flooded fifteen Wayne County farms in total, of those, six farms flooded over 49%. Wayne County sits at elevation ranging from 226 to 28 feet. The worst flooding occurred near the main channel of the Neuse River, but there was higher concentration of flooding in Wayne's southwest region. Interestingly, the region's dispersion of flooded farms versus unflooded farms varies much more than the area just to the west, which was almost uniformly un-flooded.



LENOIR

In Lenoir—where elevation ranges from 191 to 4 feet—Florence flooded eleven farms, seven of which saw flooding over 49%. Matthew flooded the same number of farms, but only five experienced high severity flooding. Unlike the other two counties, the majority of moderate to severely flooded farms fell in the floodplain, while the farms outside of floodplains experienced no more than 20% flooding, if any.

FLOOD SEVERITY BY CENSUS BLOCKS

COMMUNITY MAKEUP

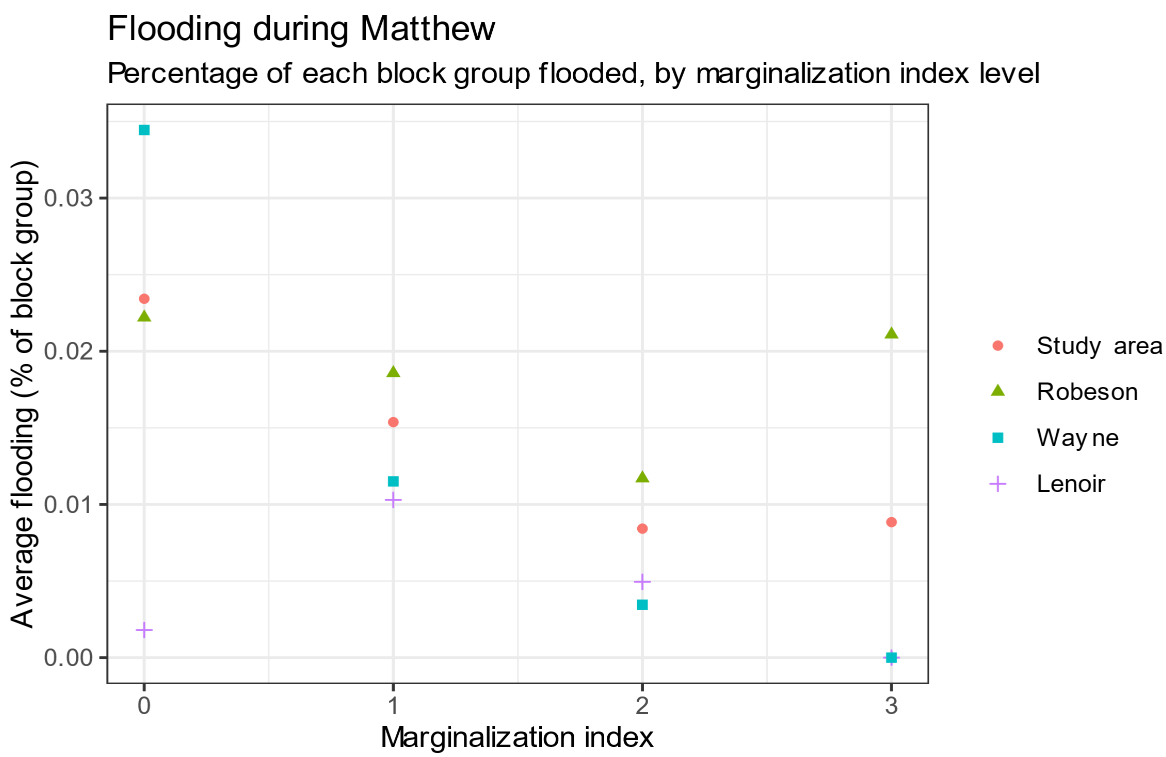
Within the land area affected by flooding during Hurricanes Matthew and Florence, the people living there were also affected. These results show the demographics of those people based on the marginalization index on a scale of 0-3, with zero being the least at risk for marginalization and three being the most at risk.

First, who makes up the communities living near these industrial poultry farms? Out of the 210-block study area, three out of five blocks with the lowest marginalization score (group 0) live near a farm. This means that predominantly white blocks earn the most and have the least number of female-headed households are the ones most likely to have a farm. Whereas blocks with the highest marginalization score (group 3) only had a 7% chance of having a farm. A general trend for the study area was as the marginalization score increased, the presence of farms decreased. This is particularly interesting because of the numerous academic studies suggesting otherwise. One reason for this may be because census blocks –relatively small areas/sample size—were used in this study rather than tracts. This project aims to lay the groundwork in an under-researched field; drawing the wrong conclusions from these results risks further harm to already-marginalized communities. Future studies would benefit from examining the discrepancy between my data and opposing trends in academic literature to ensure that at-risk individuals are not overlooked during flood preparedness and mitigation.

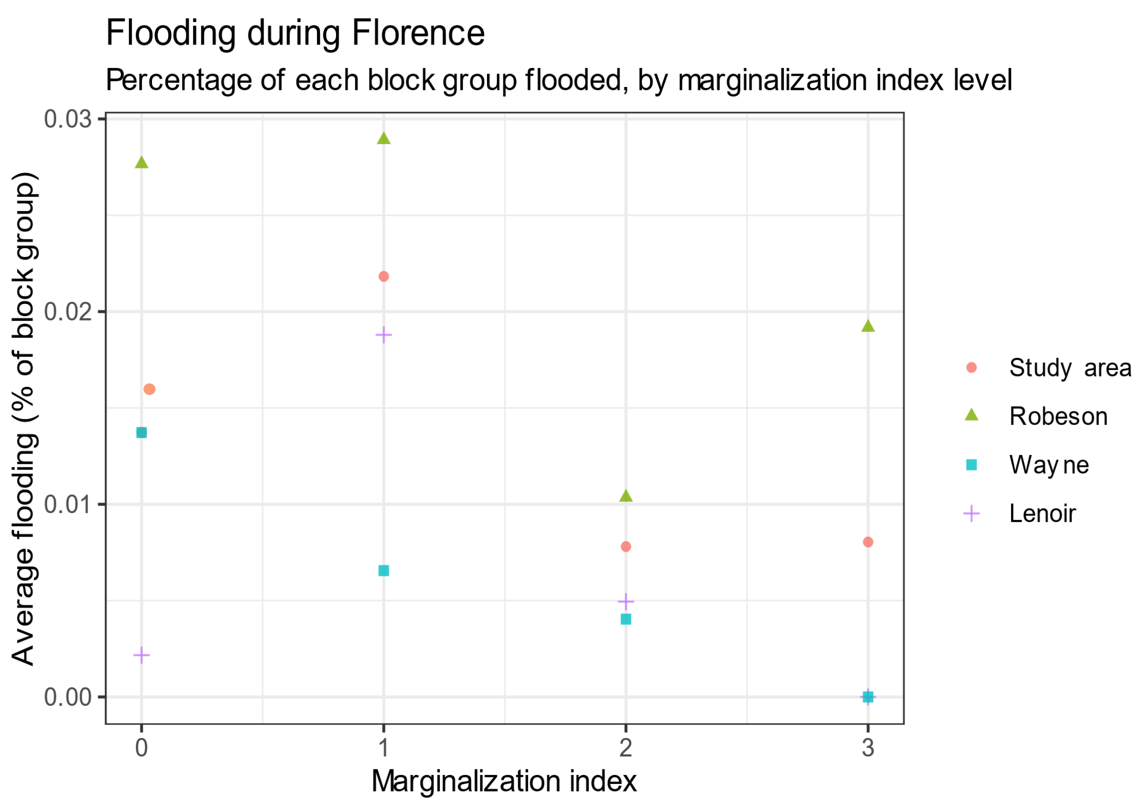
MARGINALIZATION INDEX & FLOOD SEVERITY

These are the results that I came to when examining how Florence and Matthew impacted census blocks (see graphs on following page): For Florence flooding, study area blocks in group 1 had the highest flooding percentage compared to groups 0, 2, and 3—even though group 1 had less farm exposure than group 0. In addition, of the three counties, Robeson has the highest area of land flooded in general. Meanwhile, Wayne's flooding percentage decreases steadily from group 0 to 3 compared to the other area groups.

During hurricane Matthew, the study area's average flood percentage steadily decreased as the marginalization index increased until group 3; Robeson County blocks followed a similar pattern. For Wayne, Matthew's area flooded percentage was highest across any subgroup within the marginalization index 0. In addition, the pattern for Wayne County from index 0-3 follows a similar trend to the flooding during Florence, decreasing as the index increases.



Flooding during Matthew
Percentage of each block group flooded, by marginalization index level
Average flooding (% of block group)
0.00
0.01
0.02
0.03
0
1
2
3
Marginalization index
Study area
Robeson
Wayne
Lenoir



Flooding during Florence
Percentage of each block group flooded, by marginalization index level
Average flooding (% of block group)
0.00
0.01
0.02
0.03
0
1
2
3
Marginalization index
Study area
Robeson
Wayne
Lenoir

VI. RECOMMENDATIONS + CONCLUSION

SOLUTIONS FOR + FROM COMMUNITIES

If the substantial flood risk in these communities is not addressed, there will continue to be economical, health, and environmental consequences. The poultry industry serves as a major revenue source for North Carolina, but if flood risks are not dealt with, the industry within the State may be in danger. While poultry farming has some negative impacts on local communities, there are also benefits that communities cannot afford to lose.

An increased probability of wetter storms like Hurricanes Florence and Matthew, however, pose a risk to poultry farms in the eastern part of the State that may be historically unaccustomed to wide scale flooding.

FEMA models are not geared to predict unique storm events, and, as my results have shown, they alone cannot be relied on to protect key assets and communities. New solutions must protect against and mitigate harm from future flood risk, not only to sustain the poultry industry but also to protect people within the adjacent communities, especially those who have been historically overlooked.

CURRENT FLOOD PREPAREDNESS + MITIGATION

There are current actions communities are taking as a response to extreme flood events. The following efforts likely represent a small fraction of the steps study area counties have and are taking to reduce flood exposure. Lenoir County's Princeville Community Floodprint[11] outlines strategies to reduce flood risk by preserving natural areas and turning plots of land into natural buffers to improve storm water management. Lenoir and Wayne Counties have also implemented buyout programs to invite residents to relocate away from high-risk flood areas. A detailed report of Robeson County's response to Hurricane Matthew can be found in Robeson County Resilient Redevelopment Plan.[12] Large-scale flood mitigation efforts by the US Department of Agriculture's Forest Service provide pre/post-flood measures and resources for poultry farms.[13] Another plan created by several counties in NC's Neuse River Basin demonstrates a largescale partnership to mitigate flood risk. This kind of regional collaboration and communication is necessary for effective flood responses within the total affected areas of a storm event. Looking forward, planning efforts that take the poultry industry into account should also evaluate and

[11] Princeville Community Floodprint
https://www.coastaldynamicsdesignlab.com/princeville-floodprint

[12] Robeson County 2017 Resilient Redevelopment Plan
https://files.nc.gov/rebuildnc/documents/matthew/rebuildnc_robeson_plan_combined.pdf

[13] Forest Service U.S. Department of Agriculture Poultry Producers Guide
https://doi.org/10.2737/SRS-GTR-260o

build upon previous flood mitigation efforts.

EQUITABLE SOLUTIONS

Extreme flooding events, or really any disaster, present a complexity of problems. Many factors must be simultaneously addressed by many public and private entities from the local to federal levels. In addition, every affected community has its own unique set of needs for every disaster. Therefore, no single one-size-fits-all approach will be sufficient in mitigating flood risk. The members of the community, such as residents of Lenoir, Robeson, and Wayne Counties, have the best understanding of the complexities of their situation. With that in mind, this paper is not in a position to provide broad solutions to these counties but instead offers solution-makers some components to find equitable and long-term solutions in the face of extreme flood risk.

While the study area is comprised of many stakeholders with intersecting and, at times, competing interests, flood events and other natural disasters give cause for common interests to arise: protection and recovery. Finding equitable solutions means that no single interest outweighs the greater needs of the community. Given current power structures, the entities with the most power may seek to meet their own needs while overlooking or ignoring others. For instance, the concerns of NC residents living near hog farms went largely unheard when they reported harmful pollution from animal waste lagoons in their neighborhoods. Furthermore, standardized solutions often provide relief for many, but not all. For example, relocation programs often prioritize homeowners while leaving renters to relocate without the same level of support. Narrow and inaccessible solutions are not effective.

Community members need more agency in the decision-making process. Input and engagement from all members of the community are key. During times of crisis, resources are often stretched thin as it is, especially in economically distressed rural counties, which can make it difficult to implement a robust feedback system. However, feedback networks are essential to hearing the needs of everyone. Leveraging existing communication networks and community organizations can be part of the solution. Civic groups, faith leaders, a local chamber of commerce, and communities like the Lumbee Tribe in Robeson County are examples of potential networks.

Streamlined communication is another key component to finding solutions. In the context of poultry farms, for instance, state officials alone were unable to handle an influx of calls from poultry farmers as Hurricane Florence made landfall (Martin, 2019). As a result, the NCDA took action to partner with the poultry industry regional representatives. These representatives logged and reported farmer concerns to the NCDA. By streamlining communication, the NCDA was then better able to meet farmer needs. Partnerships and efficient communication are possible when separate entities work towards a common goal. In this instance, the interests of poultry corporations aligned with those of the local farmers and NC officials. More broadly, this is not always the case but should be the goal. Rebuilding healthy communities in the aftermath of extreme flooding means supporting workers and farmers, restoring infrastructure, strengthening the local economy, and more. When all these occur, industries that rely on the community they are a part of, such as the poultry industry in eastern NC, will also be better off. But no single entity may be able to achieve this on its own, hence the need for efficient lines of communication.

In addition, another potential source of solutions is local expert knowledge. After all, the people who live through multiple extreme flood events have developed knowledge and lived experiences that can be critical to flood risk reduction. The residents of an area also have a greater sense of the local environment, specific cultural practices, and social and economic needs. Existing community institutions—academic, cultural, professional, elected representatives, etc.—can be utilized to access expert knowledge. Furthermore, specific cultural needs may be overlooked by outsiders but can be advocated for by community members. For example, often industrial, agricultural workers may not be native English speakers and, therefore, may require alternative or additional support. Without local experts who know their communities and environment the best, successful or equitable solutions could go overlooked.

CHANGING SITUATION – ADAPTABLE, CONTINGENCY PLANNING

Lastly, all solutions must recognize that extreme flooding events are often unpredictable and an evolving risk due to human-driven climate change. Increased frequency of extreme flood events may compound issues and delay recovery timelines. My research also highlights why many policy solutions discussed to help mitigate flooding and destruction to North Carolina poultry will be insufficient. For example, although FEMA's flood models label some areas at minimal risk even though they ultimately have experienced substantial flooding during both Hurricane Florence and Hurricane Matthew, improved FEMA models are unlikely to make much difference. This is because models provide statistical representations of the likelihood of flooding but are not intended to represent flooding from any specific event. Model accuracy is further strained by changes in rainfall and storm patterns fueled by human-caused climate change.

That also means that moving farms into "safer" zones will not protect all farms. Even farms labeled low risk by FEMA's modeling sometimes experience catastrophic flooding.

Therefore, solutions must focus on building up communities' adaptive capacity. A single organization like FEMA—an already under-resourced agency—is not going to create a magic solution through data analysis. To protect farms from flooding and help farms recover after floods occur, we must invest in solutions that engage and support the entire community.

FURTHER RESEARCH AREAS

There is a lack of research into the effects of flooding on NC's poultry industry, yet robust and thorough flood mitigation solutions are more necessary than ever. This study itself has limits that future research can address.

As this area of research expands, other areas that require more research are poultry farm permitting to protect communities from the spread of toxic waste during floods, Native floodplain management techniques, registering poultry farm locations to inform flood mitigation efforts, building mutual aid systems to help communities recover, and uniting community partners through coalition building.

By continuing to research the impacts of extreme flooding, we can better inform policy and community-driven flood mitigation solutions.

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Project Design Inspired by North Carolina State University's 2021 Coastal Dynamics Studio Project

APPENDICES

APPENDIX A: The data below depicts the poultry industry's growth between 1997-2002, a five-year period that saw poultry inventory numbers triple in North Carolina. Since 1997, the poultry industry has gone from one hundred forty-seven million birds to over five hundred and fifteen million.

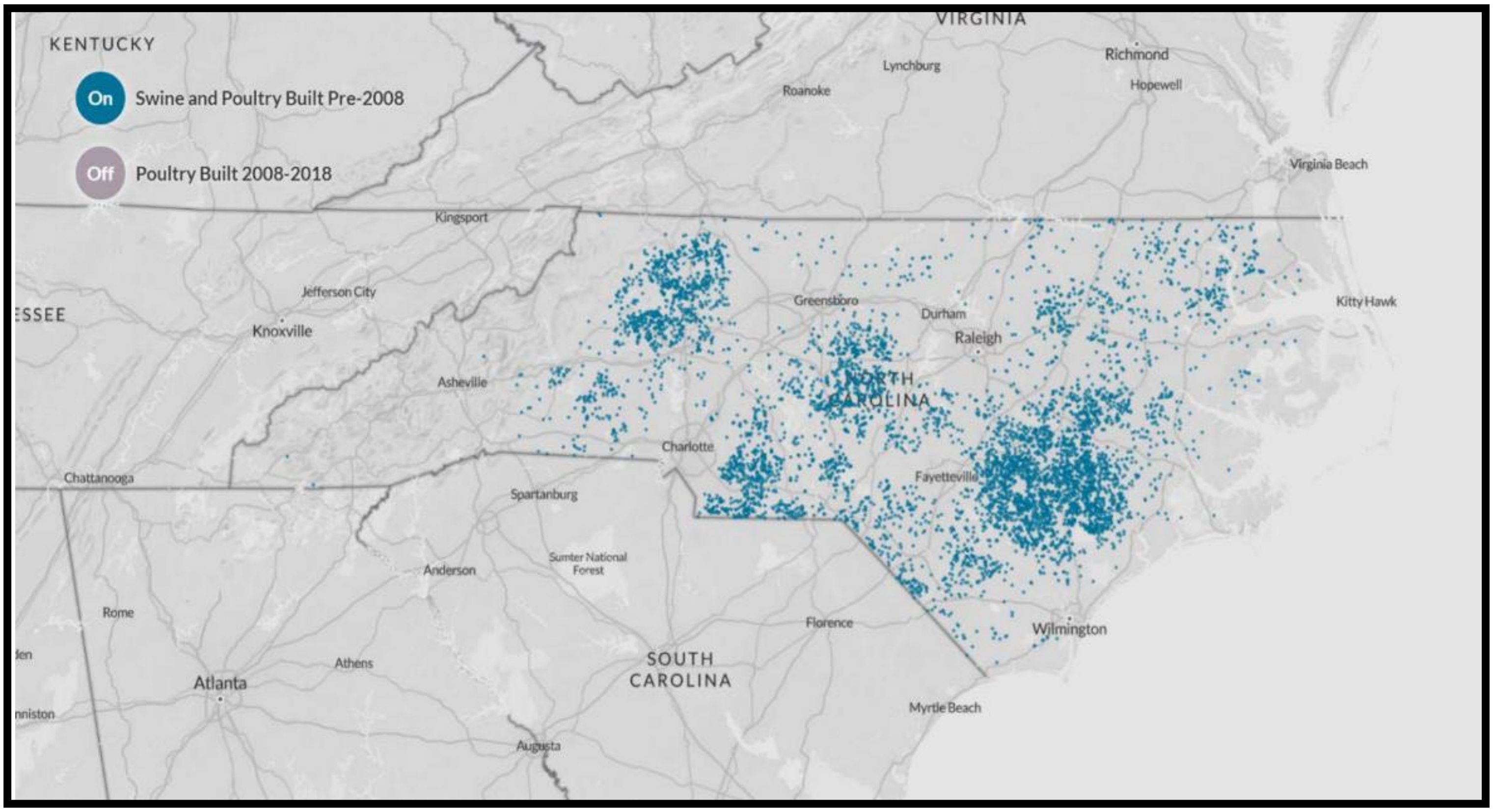
Table 27. **Poultry - Inventory and Number Sold: 2002 and 1997**

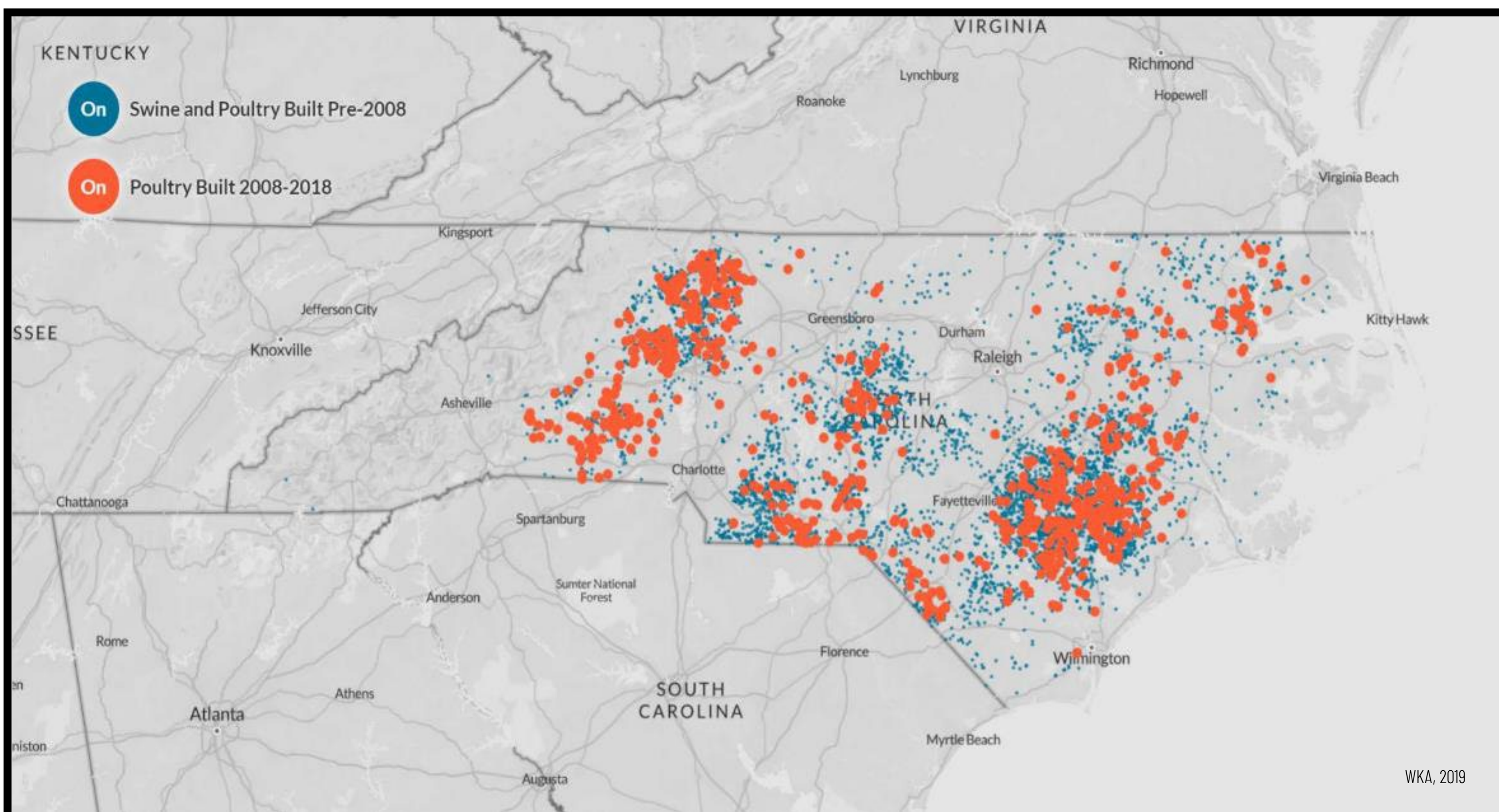
[For meaning of abbreviations and symbols, see introductory text]

Item	2002		1997	
	Farms	Number	Farms	Number
INVENTORY				
Layers 20 weeks old and older	2,571	10,150,213	1,820	12,311,155
Farms with inventory of-				
1 to 49	1,868	29,618	1,130	16,817
50 to 99	181	10,900	69	4,067
100 to 399	84	12,180	33	4,310
400 to 3,199	14	16,314	11	14,310
3,200 to 9,999	117	948,086	197	1,577,011
10,000 to 19,999	164	2,469,423	223	3,186,945
20,000 to 49,999	125	3,339,120	121	3,136,030
50,000 to 99,999	9	592,000	25	1,623,592
100,000 or more	9	2,732,572	11	2,748,073
Pullets for laying flock replacement	961	5,705,003	(NA)	(NA)
Broilers and other meat-type chickens	2,466	149,439,592	2,158	116,958,793
Turkeys	899	14,554,229	824	17,834,223
Emus	156	902	(NA)	(NA)
Ostriches	77	647	(NA)	(NA)
Ducks, geese, and other poultry [1]	1,340	(X)	662	(X)
NUMBER SOLD				
Layers 20 weeks old and older	851	8,590,685	732	12,351,823
Pullets for laying flock replacement	480	11,835,396	258	12,402,312
NUMBER SOLD - Con.				
Broilers and other meat-type chickens	2,444	739,566,977	2,414	663,439,144
Farms by number sold-				
1 to 1,999	13	259	33	6,787
2,000 to 15,999	16	157,950	13	106,850
16,000 to 29,999	30	689,588	16	369,100
30,000 to 59,999	55	2,547,387	108	4,987,705
60,000 to 99,999	158	12,651,762	193	15,613,415
100,000 to 199,999	539	82,102,113	576	83,397,795
200,000 to 299,999	625	146,305,532	690	164,082,412
300,000 to 499,999	659	252,171,299	488	186,701,132
500,000 or more	349	242,941,087	297	208,173,948
500,000 to 749,999	257	150,044,941	204	119,949,958
750,000 or more	92	92,896,146	93	88,223,990
Turkeys	667	50,896,556	775	56,471,428
Farms by number sold-				
1 to 1,999	105	2,748	(NA)	(NA)
2,000 to 7,999	3	15,000	(NA)	(NA)
8,000 to 15,999	9	115,800	(NA)	(NA)
16,000 to 29,999	52	1,192,994	(NA)	(NA)
30,000 to 59,999	179	7,687,394	(NA)	(NA)
60,000 to 99,999	171	12,833,469	(NA)	(NA)
100,000 or more	148	29,049,151	(NA)	(NA)
Emus	31	181	(NA)	(NA)
Ostriches	14	226	(NA)	(NA)
Ducks, geese, and other poultry [1]	423	(X)	219	(X)

Census of Agriculture, 2002

APPENDIX B: WKA spatial data showing both hog and poultry operation growth. The blue dots show operations built before 2008. While, the second map shows operations built pre-2008 (blue dots) and between 2008-2018 (orange dots).





APPENDIX C: Qgis coding used to create flood matrices for Hurricane Matthew and Florence.

1: CREATE TNC MATTHEW & FLORENCE FLOOD MATRIX (FARM-LEVEL)

TOOL - SAMPLE RASTER VALUES

1.1 combine farms in FEMA floodplains with TNC Matthew layer

OUTPUT: new layer with tncmatthew column

1.2 repeat the above process using TNC Florence layer

OUTPUT: new layer with tncflorence2 column

TOOL - FIELD CALCULATOR CREATES MATRIX WITH EACH STORMS FLOOD SEVERITY CATEGORY

1.3 enter following script

1.4 Concat("FLD_ZONE",'_', "tnc_matthe",'_', "tnc_floren")

OUTPUT: matrixmf column

2: CATEGORIZE FLOOD MATRIX

TOOL - FIELD CALCULATOR

2.1 Enter the following script:

```
CASE
  when "matrixmf" = 'ae_0_0' then 'high risk| neither'
  when "matrixmf" = 'ae_0_1'then 'high risk| florence'
  when "matrixmf" = 'x_0_0' then 'low risk| neither'
  when "matrixmf" = 'x_0_1' then 'low risk| florence'
  when "matrixmf" = 'x_1_0' then 'low risk| matthew'
  when "matrixmf" = 'x_1_1' then 'outside fema| both' end
```

3: COUNT BARNS PER FARM

TOOL - FIELD CALCULATOR

3.1 CREATE 3 NEW VARIABLES (COLUMNS)

NEW VARIABLE	LENGTH	DASH	BARNCOUNT
EXPRESSION	LENGTH(NAME)	STRPOS(NAME, '-')	RIGHT(NAME, LENGTH-DASH)

OUTPUT: barncount column now contains the number of barns per poultry farm

3.2 CREATE 1 NEW VARIABLE

NEW VARIABLE	NEWBUFFER
EXPRESSION	BARNCOUNT(20)

OUTPUT: creates different size buffers for each farm according to their number of barns, multiplied by 20

APPENDIX F: the Y-axis of this chart shows the percent flooding of farms for all three counties. The X-axis tells us where those farms were located within FEMA's flood zones. The first chart is Matthew, and the second is Florence.

. . tab fldpctM FemaZone_3cat

fldpctM	FemaZone_3cat 1. AE-	2. X-0.2	3. X-AREA	Total
0	4	6	287	297
1.06	0	0	1	1
1.39	0	0	1	1
2.44	0	0	2	2
2.59	0	0	1	1
2.91	0	0	1	1
3.39	0	0	1	1
4.76	0	0	1	1
5.26	0	0	1	1
5.56	0	0	1	1
8.33	0	0	1	1
8.77	0	0	1	1
9.09	0	0	1	1
10	0	0	2	2
10.34	0	0	1	1
11.11	0	0	1	1
11.76	0	0	1	1
12.5	0	0	1	1
13.61	0	0	1	1
14.29	0	0	2	2
20	0	1	5	6
22.22	0	0	1	1
28.57	0	0	1	1
30	0	0	1	1
31.36	0	0	1	1
31.58	0	0	1	1
33.33	0	0	1	1
35	0	1	0	1
37.93	0	0	1	1
50	0	0	3	3
52.63	0	0	1	1
57.14	0	0	1	1
60	0	0	1	1
60.61	0	1	0	1
66.67	0	1	0	1
72.55	0	0	1	1
80	0	0	1	1
85.71	0	0	1	1
99.96	0	0	1	1
100	1	2	3	6
Total	5	12	334	351

fldpctF	FemaZone_3cat 1. AE-	2. X-0.2	3. X-AREA	Total
0	0	3	302	305
.88	0	0	1	1
3.45	0	0	1	1
3.47	0	0	1	1
4.76	0	0	1	1
4.88	0	0	1	1
5.26	0	0	1	1
6.67	0	0	1	1
8.33	0	0	2	2
9.09	0	0	1	1
10	0	0	1	1
11.11	0	0	1	1
12.5	0	0	3	3
13.51	0	0	1	1
18.39	0	0	1	1
20	0	1	1	2
22.22	0	0	1	1
25	0	1	1	2
33.33	0	0	1	1
34.48	0	0	1	1
40	0	1	0	1
42.86	0	0	1	1
50	0	0	1	1
60	1	2	0	3
63.16	0	0	1	1
71.43	0	0	1	1
75	1	0	0	1
80	0	0	1	1
94.44	1	0	0	1
100	2	4	5	11
Total	5	12	334	351

APPENDIX G: The chart below shows the percentages of farms that flooded (% FLOODED) and did not flood. The chart also provides the total number of farms at different distances from the floodplain (# FARMS).

ALL FARMS						
NO FLOOD FARMS						
FLOODED FARMS						
	1 - 3	4	5 - 6	7 +	# FARMS	% FLOODED
FLOODPLAIN					5	100%
		4		1		
0.5 MILE	57	47	35	14	205	25%
	10	11	12	19		
1 MILE	21	36	15	11	96	14%
	3	3	4	3		
1.5 MILE	14	11	4	6	38	8%
	0	2	1	0		
2 MILES	2	4		1	9	22%
	0	1	0	1		
TOTAL FARMS	353					

APPENDIX H: Printout from R measuring Risk of Marginalization Index + farm proximity at the study area level.

```
> # Has a farm, whole study area:
> lm(has_a_farm ~ vulnerability_index, data=data_byblocks) %>%
+   print_vulnerability_group_averages() %>%
+   summary()
Averages by group(%):
group0 group1 group2 group3
0.6000 0.4200 0.3710 0.0645
% difference to group0:
group0 group1 group2 group3
   0.0  -30.0  -38.1  -89.2

Call:
lm(formula = has_a_farm ~ vulnerability_index, data = data_byblocks)

Residuals:
     Min       1Q   Median       3Q      Max
-0.60000 -0.42029 -0.06452  0.40000  0.93548

Coefficients:
                     Estimate Std. Error t value Pr(>|t|)
(Intercept)           0.60000    0.05570  10.772  < 2e-16 ***
vulnerability_index1 -0.17971    0.07906  -2.273   0.0241 *
vulnerability_index2 -0.22857    0.09648  -2.369   0.0188 *
vulnerability_index3 -0.53548    0.10054  -5.326 2.68e-07 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 0.466 on 201 degrees of freedom
  (5 observations deleted due to missingness)
Multiple R-squared:  0.1256,    Adjusted R-squared:  0.1125
F-statistic:  9.62 on 3 and 201 DF,  p-value: 5.793e-06
```

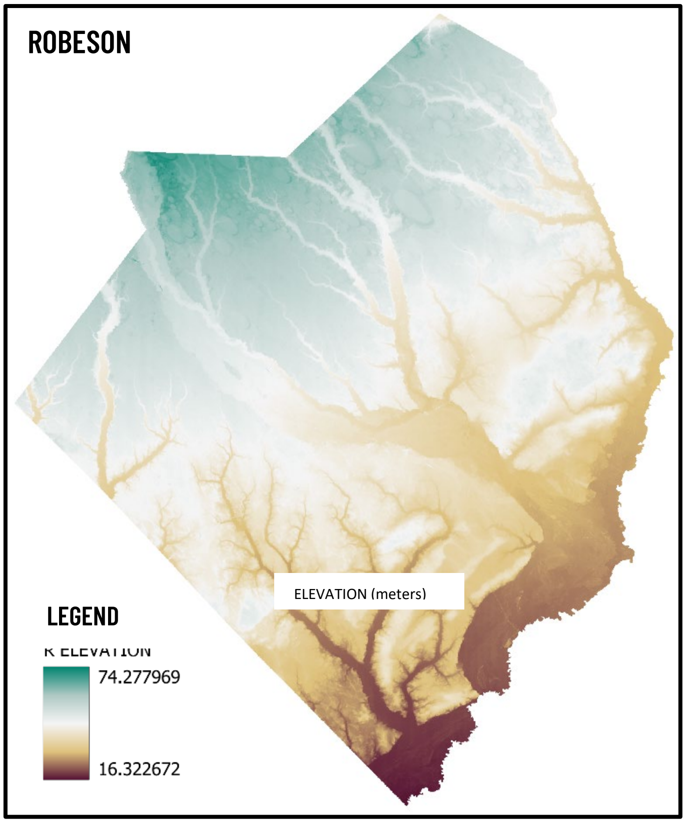
APPENDIX I: Also, an R printout measuring Risk of Marginalization Index + farm proximity, but at the county level.

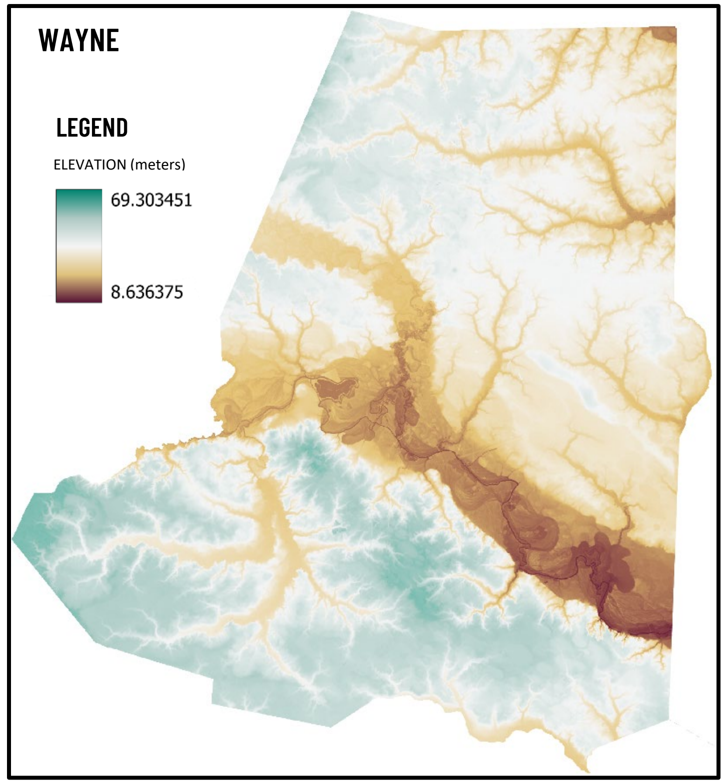
```
> lm(has_a_farm ~ vulnerability_index, data=filter(data_byblocks, county == "robeson")) %>%
+   print_vulnerability_group_averages() %>%
+   summary()
Averages by group(%):
group0 group1 group2 group3
0.4000 0.4750 0.4500 0.0769
% difference to group0:
group0 group1 group2 group3
   0.0   18.8   12.5  -80.8

Call:
lm(formula = has_a_farm ~ vulnerability_index, data = filter(data_byblocks,
    county == "robeson"))

Residuals:
     Min       1Q   Median       3Q      Max
-0.47500 -0.45000 -0.07692  0.52500  0.92308

Coefficients:
                     Estimate Std. Error t value Pr(>|t|)
(Intercept)            0.4000     0.1242   3.220  0.00183 **
vulnerability_index1   0.0750     0.1457   0.515  0.60803
vulnerability_index2   0.0500     0.1643   0.304  0.76171
vulnerability_index3  -0.3231     0.1823  -1.772  0.08003 .
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 0.4812 on 84 degrees of freedom
Multiple R-squared:  0.0774,    Adjusted R-squared:  0.04445
F-statistic: 2.349 on 3 and 84 DF,  p-value: 0.07833
```

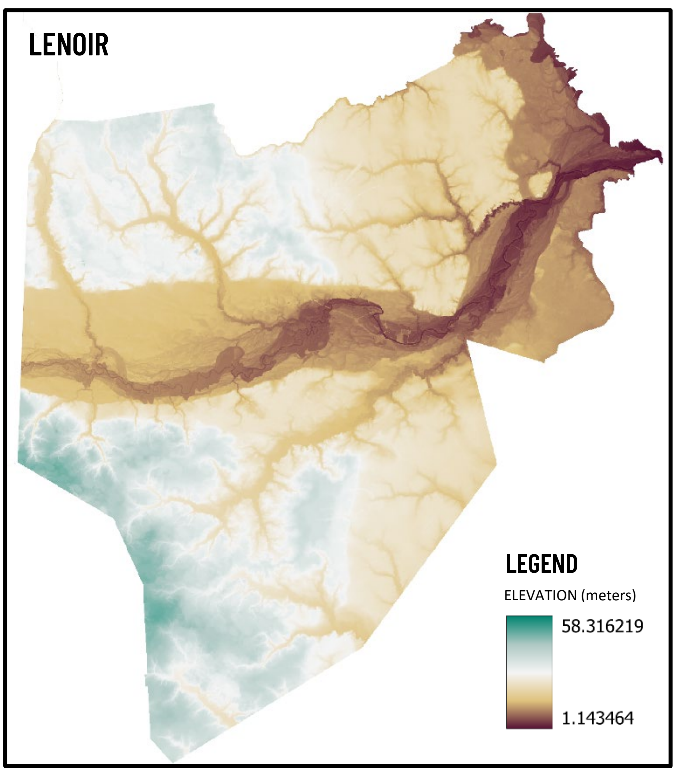
```
> lm(has_a_farm ~ vulnerability_index, data=filter(data_byblocks, county == "lenoir")) %>%
+   print_vulnerability_group_averages() %>%
+   summary()
Averages by group(%):
group0 group1 group2 group3
 0.611  0.308  0.167  0.143
% difference to group0:
group0 group1 group2 group3
   0.0  -49.7  -72.7  -76.6

Call:
lm(formula = has_a_farm ~ vulnerability_index, data = filter(data_byblocks,
    county == "lenoir"))

Residuals:
    Min      1Q  Median      3Q     Max
-0.6111 -0.3077 -0.1429  0.3889  0.8571

Coefficients:
                     Estimate Std. Error t value Pr(>|t|)
(Intercept)            0.6111     0.1102   5.547 2.04e-06 ***
vulnerability_index1  -0.3034     0.1701  -1.784   0.0821 .
vulnerability_index2  -0.4444     0.2203  -2.017   0.0504 .
vulnerability_index3  -0.4683     0.2082  -2.249   0.0301 *
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 0.4674 on 40 degrees of freedom
  (3 observations deleted due to missingness)
Multiple R-squared:  0.1624,    Adjusted R-squared:  0.0996
F-statistic: 2.586 on 3 and 40 DF,  p-value: 0.0665
```

```
> lm(has_a_farm ~ vulnerability_index, data=filter(data_byblocks, county == "wayne")) %>%
+   print_vulnerability_group_averages() %>%
+   summary()
Averages by group(%):
   group0    group1    group2    group3
 6.76e-01  3.75e-01  3.33e-01 -7.77e-16
% difference to group0:
group0 group1 group2 group3
   0.0  -44.5  -50.7 -100.0

Call:
lm(formula = has_a_farm ~ vulnerability_index, data = filter(data_byblocks,
    county == "wayne"))

Residuals:
    Min      1Q  Median      3Q     Max
-0.6757 -0.3750  0.0000  0.3243  0.6667

Coefficients:
                     Estimate Std. Error t value Pr(>|t|)
(Intercept)           0.67568    0.07368   9.171 1.46e-13 ***
vulnerability_index1 -0.30068    0.13409  -2.242   0.0282 *
vulnerability_index2 -0.34234    0.16657  -2.055   0.0436 *
vulnerability_index3 -0.67568    0.15390  -4.390 3.99e-05 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 0.4482 on 69 degrees of freedom
  (2 observations deleted due to missingness)
Multiple R-squared:  0.2371,    Adjusted R-squared:  0.2039
F-statistic: 7.147 on 3 and 69 DF,  p-value: 0.0003004
```

APPENDIX J: These maps— created in Qgis—depict each counties elevation.







APPENDIX K: Table to examine the socioeconomic makeup of Census blocks with ten or more farms.

```
> data_byblocks %>%
+   group_by(county) %>%
+   mutate(income_quartile_by_county = cut_number(MHInc, 4, label=FALSE)) %>%
+   ungroup() %>%
+   filter(farm_count >= 10) %>%
+   select(
+     county, farm_count, PredDiv, female_quartile, HHs_totalfemale, TotalHouseholds, income_quartile, income_quartile_by_county, MHInc,
+   )
# A tibble: 9 × 9
  county  farm_count PredDiv female_quartile HHs_totalfemale TotalHouseholds income_quartile income_quartile_by_county MHInc
  <chr>        <dbl> <chr>             <int>           <int>           <int>           <int>                     <int> <int>
1 robeson         13 White                 1              98             423               2                         3 35250
2 robeson         13 Diverse               2             105             349               1                         2 27455
3 wayne           16 White                 1             190             891               2                         2 35951
4 wayne           10 White                 2             632            1843               4                         4 78295
5 wayne           13 White                 1              31             392               4                         4 78438
6 wayne           12 White                 1              50             417               4                         4 72974
7 wayne           10 White                 1              91             678               4                         4 61489
8 wayne           13 White                 2             209             617               2                         2 37634
9 wayne           10 White                 2             394            1167               3                         3 45688
>
```