People, Water, and Septic: A Coastal Case Study

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Abstract

In the Outer Banks community of Nags Head, North Carolina, the risks of flood damage and degraded surface water quality are becoming more severe as the region continues to be impacted by sea level rise and high intensity storm events. The Outer Banks is a chain of barrier islands located off the east coast of North Carolina, and its hydrologic features can lead to problems with infrastructure viability due to the interconnection between the unconfined aquifer and the surrounding water bodies (the Albemarle-Pamlico estuarine system and the Atlantic Ocean). In recent years, the population of the Outer Banks has been increasing by almost double the average rate in North Carolina (Carter 2006), which in turn, is increasing the development density of the region.

The Town of Nags Head treats the majority of its wastewater from this development with septic systems. These systems are vulnerable to the effects of sea level rise and an increased volume of surface water due to high intensity storms and impermeable structures on the land surface. Poorly maintained or inundated septic systems can have harmful effects on the quality of groundwater reservoirs, which interact with nearby surface water bodies, by discharging bacteria and nutrients into the unconfined aquifer.

Our study is the second year in a three year study conducted by the Outer Banks Field Site Program through the UNC Institute for the Environment. This study uses quantitative and qualitative research methods to increase evidence regarding which areas of the Gallery Row subwatershed in Nags Head are susceptible to interactions between groundwater and wastewater, how nutrient and bacterial concentrations in the unconfined aquifer have changed since the October 2019 groundwater lowering in Nags Head, and how different groups within the Nags Head community perceive the risks associated with groundwater-wastewater-surface water interactions.

Our findings show that more than half of the subwatershed is susceptible to interactions with septic system effluent. Bacterial analysis showed that there was a decrease in *E. coli* and *Enterococcus* between 2018 and 2019. This suggests that the groundwater table lowering initiative in Nags Head may have been successful. Qualitative data showed that interviewees had a strong sense of place and noted many environmental changes in their area including an increase in flooding, which they attributed to increasing impermeable surfaces through development, a higher water table, and increased frequency of intense storms. Interviews also helped to understand that property owners do not perceive a high risk of surface-groundwater contamination with septic while researchers, public officials and septic professionals are concerned about this contamination.

We suggest that improvements to data collection be made in next year’s study. Also, more outreach and education for the general public and seasonal residents of the town is

warranted in order to increase the general knowledge level of the public's perception on wastewater risk.

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Introduction

Humans have relied on coastal land and resources throughout recorded history; human uses of the coast have gradually expanded over time from food collection to other interests, such as resource extraction, recreation, and commercial development (Nel et al. 2014). Coastal land use patterns, community structures, and economic interests have continued to change in recent decades. In 2010, NOAA reported that coastline counties (those bordering the Atlantic and Pacific oceans, the Gulf of Mexico, and the Great Lakes) contained about 39% of the total US population, or 123.3 million people, while constituting only 10% of the landmass of the contiguous United States. The overall populations of coastline counties increased by nearly 40% from 1970 to 2010 (NOAA). Population growth and the associated land use changes and increases in pollution and wastewater generation can have harmful impacts on coastal ecosystems and the critical ecosystem services they provide.

The hydrologic and climatic conditions of the coast are also changing. Theoretical projections and models have indicated that as concentrations of greenhouse gases in the atmosphere continue to rise, the average intensity of tropical cyclones and storms is likely to increase, which will amplify the risk of costly and damaging floods in developed coastal areas (Knutson et al. 2010). Sea level rise is also anticipated to lead to rising water tables, increased rates of shoreline erosion, and saltwater intrusion into groundwater (IPCC 2014).

The combined risks associated with changing environmental conditions and higher development density in coastal areas have detrimental impacts on the efficacy of coastal infrastructure, such as wastewater treatment systems and roads. Malfunctioning infrastructure can pose additional planning and management challenges, including water quality degradation and human health risks. Because of these risks, coastal communities will have to find ways to mitigate potential impacts to environmental quality and human health. In this study, we examine the environmental and sociological impacts of changes in coastal hydrology, development, and wastewater treatment efficacy in the barrier island community of Nags Head, North Carolina.

This is the second year of a three year study to better understand the complexities of hydrosocial changes in coastal communities and provide information that will help Nags Head and other coastal communities make sound decisions regarding wastewater management. We focused on three main research questions:

1. What areas of the Gallery Row subwatershed are susceptible to interactions between under-treated septic wastewater and groundwater?
2. Have nutrient, bacterial, and chemical wastewater indicator concentrations in surface and groundwater reservoirs decreased since the lowering of the groundwater in the subwatershed?
3. How do different groups and individuals perceive and understand the risk of surface and groundwater contamination from wastewater in Nags Head, NC?

Coastal Hydrology

We can assess risks that coastal communities face as development continues and environmental conditions shift in the context of barrier island hydrology (Figure 1).

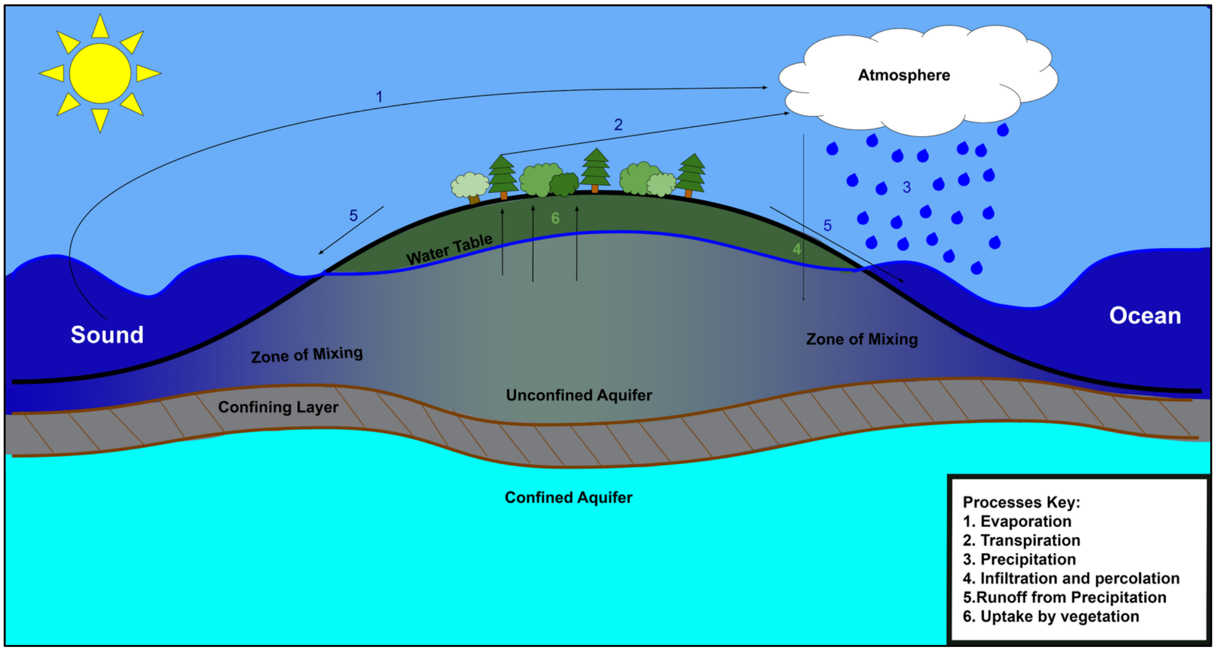

Figure 1. Hydrologic Cycle of a Barrier Island. The hydrologic cycle of a barrier island without human influence involves fluxes between different water reservoirs, including the confined and unconfined groundwater aquifers, the atmosphere, and surface waters, including the ocean and sound. Processes are indicated by numbers and are listed in the processes key. The water table, or surface of the water contained in the unconfined groundwater aquifer, slopes up with the land surface and is influenced by infiltration and percolation, uptake by vegetation, and the sound and ocean.

Barrier island hydrology (Figure 1) is driven by the same factors that influence the global hydrologic cycle. Energy from the Sun drives exchanges directly by evaporating water from Earth's water bodies like lakes, rivers, and oceans into the atmosphere, and indirectly through transpiration, where plants release water vapor through their leaves. Atmospheric water vapor returns to Earth as precipitation, and can either infiltrate and percolate into groundwater, or runoff the ground surface into surface water bodies. Nearly all the water that falls back to Earth as precipitation returns to the oceans or other water bodies where the hydrologic cycle can begin again (Graham et al. 2010). When water is transported in its liquid form through riverine transport, ocean currents, and groundwater flow (among others), it can carry suspended particles and dissolved ions.

There are several reservoirs involved in North Carolina barrier island hydrology. The deep aquifer, known as the Yorktown aquifer, from which humans draw water for residential use in the northern Outer Banks (NC Division of Water Resources [NCDWR] 2010) is confined, meaning there is a layer of impermeable material through which groundwater cannot percolate, and is thus closed to inputs from the unconfined aquifer. The upper groundwater aquifer is unconfined, meaning it is subject to inputs from infiltrated rainwater, the ocean, the sound, or anthropogenic sources. The top of the unconfined aquifer, which is known as the water table, rises and falls in response to inputs or outputs such as water pumped out by humans (Baldwin and McGuinness 1963). Locations of surface waters are determined by where the water table is in relation to the ground surface; if the water table is above the ground surface at any location, there will be a body of water. Where the water table is near to the surface, groundwater can interact with anything in the subsurface, including soil particles and septic systems. The interactions between different reservoirs of water are dynamic based on the many hydrologic factors at play (precipitation, infiltration, runoff, groundwater flow, anthropogenic inputs, etc.).

Coastal hydrology is acutely affected by extreme precipitation. Extreme precipitation events associated with storms can result in increased runoff of stormwater into local water bodies or can add a large quantity of water to the unconfined aquifer. These inputs of water to the system can result in flooding, or the submergence of normally dry land including private properties and public transportation infrastructure. This has many effects on natural and anthropogenic processes. Flooding caused by extreme precipitation events is relevant to this study because it can hinder the ability of septic systems to treat wastewater, a topic covered in greater detail in the following *Wastewater* section. High-intensity precipitation events and flooding associated with storms are expected to increase along the Atlantic coast in the coming century (Knutson et al. 2010), and will become an increasingly important topic for coastal barrier island communities to address.

It is also important to understand how human activity on the coast, such as development, interacts with and changes the hydrology of barrier islands (Figure 2). These interactions are known as the socio-hydrologic cycle, or hydrosocial cycle (Linton and Budds 2014). Development is the most substantial way that humans affect the hydrologic cycle. When areas of the land surface are developed, surface water runoff increases due to the impermeability of hard structures such as roads and houses, while the amount of water that is able to infiltrate into the soil decreases due to the loss of natural infiltration mechanisms and increased impermeable surfaces. In undeveloped coastal areas, wetland vegetation helps to filter suspended particulates and decrease the speed of water as it infiltrates into the soil, which helps to mitigate peak flows and overall stormwater volume from precipitation events (Vermont DEC 2019). In developed areas, which lack the infiltration capacity of undeveloped, vegetated areas, peak flows from storm events arrive earlier and have greater volumes of water, leading to more substantial flooding in developed areas (UNR Cooperative Extension 2005).

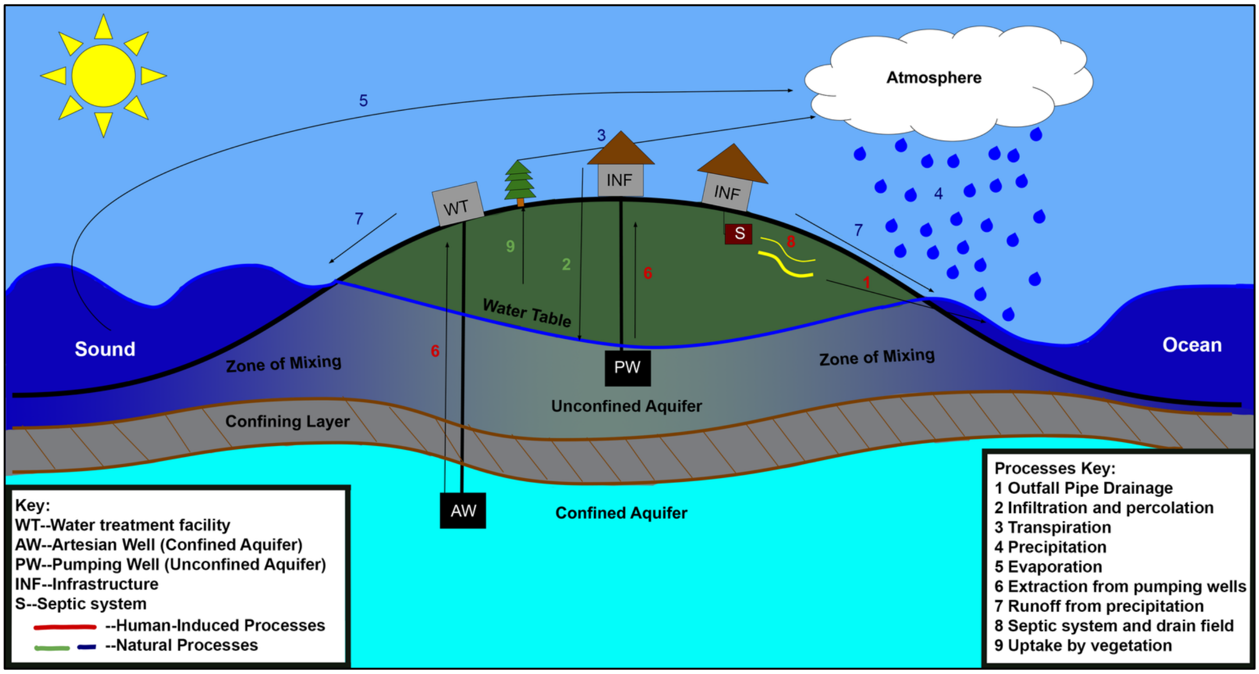

Figure 2. Hydrosocial Cycle of a Barrier Island. This figure illustrates the hydrosocial cycle, or the interactions between humans and the hydrologic cycle. Processes are indicated by numbers and are listed in the processes key. Human-induced processes are red and natural processes are in green and black. Human infrastructure is abbreviated and listed in the key on the left. This figure highlights that pumping water from the unconfined aquifer lowers the water table and can reduce interactions between groundwater and septic effluent.

Human impacts on the hydrologic cycle can be mitigated through various engineering initiatives and low-impact development. One way that the Town of Nags Head has aimed to control flooding associated with excess surface water from storm events was by lowering the groundwater table. In October of 2019, the Town completed implementation of seven pumping wells, which are used to remove water from the unconfined aquifer (Town of Nags Head 2019). The goal of lowering the water table was to increase the storage and infiltration capacity of the unconfined aquifer, while displacing the pumped groundwater to a higher-capacity drop inlet storage reservoir located near the Nags Head Acres subdivision (D. Ryan, personal communication with author, December 4, 2019). During Hurricane Dorian, which made landfall in North Carolina in early September, the partially-completed water table lowering initiative successfully lowered flood risk in the Vista Colony and Nags Head Acres subdivisions.

The increased amount of surface water associated with developed coastal areas has detrimental implications for water quality since water collects and transports contaminants, such as nutrients from fertilizer runoff and heavy metal byproducts of fossil fuel combustion, from the land surface to estuaries and the ocean (DCDOEE). Water that is contaminated, either by pollutants on the land surface or as a consequence of human use, is known as wastewater. If wastewater is not properly treated and managed, then it degrades the quality of reservoirs that it interacts with. Healthy, high-quality water is essential for the continued viability of economic and cultural interests on the coast, both now and in the future.

By studying the hydrosocial cycle of a barrier island, we can better address our first research question: what areas of the Gallery Row subwatershed are susceptible to interactions between under-treated septic wastewater and groundwater? We hypothesized that areas with lower elevation and higher groundwater elevation levels would be more susceptible to interactions between groundwater and wastewater and that areas with higher elevation and lower groundwater elevation levels would be less susceptible.

Wastewater

Wastewater generation is another way that development on the coast influences the hydrosocial cycle. Any water that is used in a house (in sinks, showers, toilets, etc.) leaves as wastewater or sewage, which is treated by either an on-site wastewater treatment system or centralized system. Many rural and coastal areas, especially barrier islands, are largely reliant on on-site wastewater treatment systems, also known as septic systems. Centralized sewage systems, which are used primarily in populous areas, have a system of connected sewer pipes, tunnels, and pumps to collect wastewater and transport it to a central treatment plant (EPA 2018). The use of centralized systems in barrier island communities is constrained by spatial requirements and expense. Typically small, rural communities do not have the financial means to support a centralized system (Mallin 2013). Just like other communities in the Outer Banks, where the majority of residents use septic systems, 80% of residents of the Town of Nags Head treat their wastewater with septic systems (Town of Nags Head 2019).

To understand the benefits and limitations of wastewater treatment by septic systems, we must first explore how they operate. There are two main components of a septic system: the septic tank and the septic drainfield (Figure 3). First, wastewater enters the septic tank where floatable matter and solids are separated from the liquid component. Heavy solids sink to the bottom of the tank, forming sludge. Grease and lighter solids float to the top, forming a layer of scum. Bacteria in the tank partially break down the sludge and scum. However, the sludge and scum are not broken down completely by the bacteria, which is why tanks need to be pumped regularly to function correctly. The liquid component of the wastewater then moves from the tank to the drainfield for additional treatment. The liquid from the tank, also known as effluent, trickles out of a series of perforated pipes, through gravel, and then through the soil (EPA 2019).

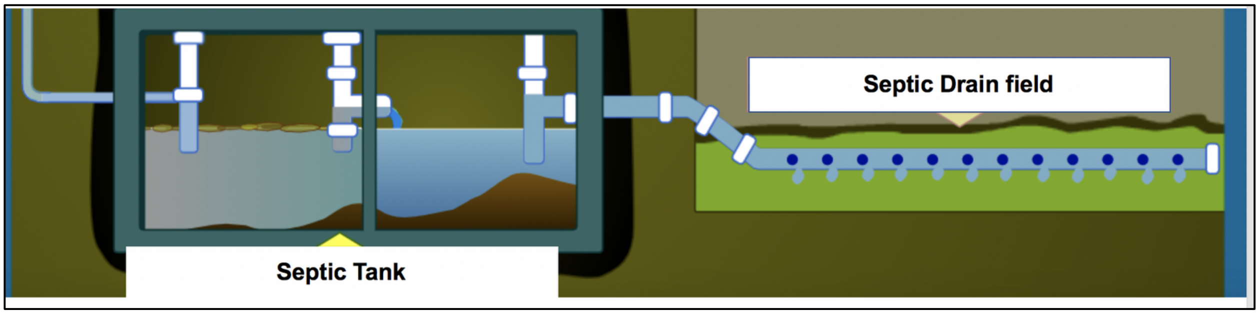

Figure 3. Septic System Layout. This is a diagram of a septic tank and drainfield connected to a house, filtering wastewater.

Interaction between liquid wastewater and soil in drainfields is integral to the wastewater treatment process and is also a major influence on how septic systems interact with the environment. The low-moisture and highly-oxygenated conditions of unsaturated soil help it to filter pathogens and fecal bacteria, such as *E. coli* and *Enterococcus*, from the wastewater as the water seeps through the soil. These unsaturated conditions encourage microbial attachment to soil particles, whereas wetter conditions reduce the opportunity for bacteria to attach to soil particles. When there is not a sufficient separation distance between the septic drainfield and the water table, under-treated septic wastewater with high fecal bacteria concentrations can mix into the groundwater. Higher and rising water tables result in wetter conditions that can support the survival and transport of bacteria, including pathogenic species (Cooper et al. 2016).

Two bacterial groups, coliform and fecal streptococci (Figure 4), which are found in the feces of mammals, are indicators of water contamination by untreated sewage. Coliforms are a group of bacteria that occur naturally in the environment. Coliforms can be present in human and animal feces, but can also be found in soil. Fecal coliform is a subgroup of coliform that is more specific to fecal matter, but is still found in other sources of anthropogenic waste. *E. coli* is a species of fecal coliform bacteria that is specific to humans and warm-blooded animals; thus, *E. coli* is the best indicator of water quality for this study. Fecal streptococci occur in the digestive systems of humans and warm-blooded animals. Enterococci is a subgroup within fecal streptococci that can survive in saltwater. This type of bacteria is also more specific to humans, so it is a good indicator of water quality in saltwater (EPA 2003).

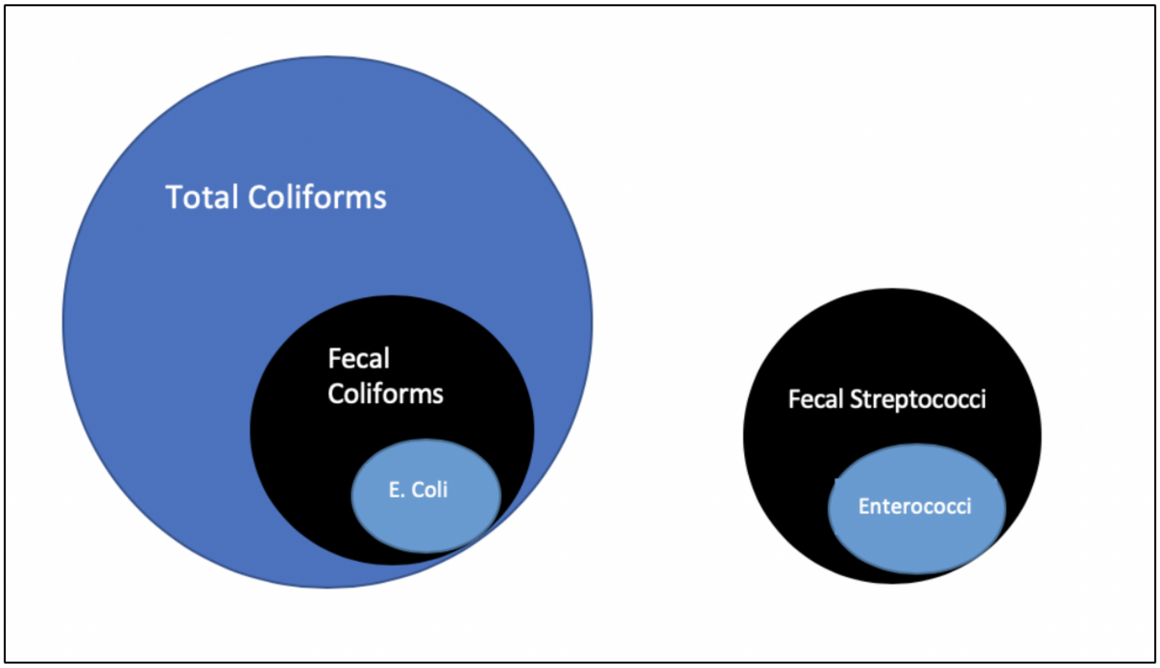

Figure 4. Bacterial Group Representation. The relationship between different types of fecal indicator bacteria that are used in our study of the water quality within the Gallery Row Subwatershed, Nags Head, NC in fall 2019.

Household wastewater also has high concentrations of nutrients, such as nitrogen and phosphorous. Septic systems are a common nonpoint source of nitrogen (N) that originates from feces and urine. Forms of N include dissolved inorganic N, ammonia, and nitrate. Given that nitrate is an anion, it does not absorb well to soil particles and is easily leached. Nitrates are naturally occurring in the environment and can exist at safe levels. However, when excessive concentrations are leached into the groundwater and surface water, it can cause harmful algal blooms, hypoxia, and fish kills in estuaries. Septic systems are also a source of phosphorus (P), which is found in feces and household chemicals. P is measured as phosphate in its ionic and dissolved form. These nutrients are typically added to wastewater via garbage disposals, toilets, and sink, but also exist in the environment at safe levels (Lusk et al. 2014). Increased storm frequency and rainfall events have been found to reduce the rate of nitrogen removal in soils. The rate of wastewater flow increases with flooding events, slowing the rate at which nutrients are removed from the soil (Cooper et al. 2016).

For a septic system to effectively remove contaminants from wastewater, the capacity of the system should not be overloaded and maintenance should be conducted regularly. Responsible septic system operation and maintenance includes conserving water, avoiding harmful additions to the system such as bleach (which kills the system's bacteria), annual inspections, and regular pumping. To encourage property owners to take care of their septic systems, the Todd D. Krafft Septic Health Initiative offered by the Town of Nags Head provides free services and financial assistance to those who pump, repair, and inspect their systems. The Town even provides a 30 dollar credit to the water bills of customers that pump their septic systems (Town of Nags Head 2019).

There has been increasing concern about the efficacy of wastewater treatment by septic systems in a coastal setting. The water table is already close to the land surface in low elevation areas, and increasing storm intensities and impermeable surfaces cause increasingly frequent flooding of aboveground infrastructure. The groundwater lowering approach employed by Nags Head presented an opportunity to explore how coastal systems could be engineered to reduce surface flooding as well as improve water quality. In this study, we explored if the nutrient, bacterial, and chemical wastewater indicator concentrations in surface and groundwater reservoirs decreased since the lowering of the groundwater in a portion of the subwatershed. We predicted that the groundwater lowering in Nags Head would decrease concentrations of wastewater indicators in the neighboring surface and groundwater reservoirs since the groundwater table would be further separated from septic drainfields.

Risk and Place Perceptions

People's perceptions of detrimental changes in environmental quality are critical antecedents of their behavior and decision-making (Masterson et al. 2017). Where people do not perceive problems or risks, they are not likely to take action or adapt to ameliorate those risks. There is limited information and research on people's perceptions of wastewater and associated risks, especially septic-generated wastewater. One study suggests that wastewater risk perceptions are dependent on wastewater education and communication: people who knew more about septic wastewater voiced stronger concern about risk, whereas those who did not know as much about the topic had less concern (Devitt et al. 2016). Therefore, people's perception of risk became altered based on the communication of how much septic wastewater treatment was an actual threat towards them. Risk perception was lowest in those who did not have a meaningful understanding of the threats septic wastewater poses (Devitt et al. 2016).

Perceptions of risk and change are also tied to people's connection to the area around them, or their sense of place. People are more likely to be attuned to changes in the places that are important to them and to want to protect the places that they care about (Kearns and Collins 2012). One study suggests that by viewing risk perception through a "sense of place lens", people's perceptions and attachments to the area in which they reside can be analyzed. Risk perception is commonly based on a subjective experience in a place. (Quinn et al. 2016). Place change can negatively impact sense of place, which is connected to well-being (Poe et al. 2016). Preserving place and maintaining connection to place is important for maintaining individual and community well-being.

This aspect of the study helps answer our third research question: how do different groups and individuals perceive and understand the risk of surface and groundwater contamination from wastewater in Nags Head, NC? We are interested in understanding people's perceptions of wastewater treatment, people's connections to the hydrosocial cycle, and knowledge gaps among people. We hypothesized that property owners would not know as much as other groups, such as public officials, septic professionals or researchers, about the wastewater interactions in Nags Head and would perceive lower risk of contamination.

Methods

Nags Head is a town located in the central Outer Banks, and is approximately 6.6 square miles long. Cape Hatteras National Seashore is to the south, and Kill Devil Hills is located to the north. Nags Head's year-round population of 2,800 increases to 40,000 in the summer.

Study Site

Our study took place in the Gallery Row subwatershed of Nags Head (Figure 5). The Gallery Row subwatershed regularly experiences flooding, and engineering modifications to lower the groundwater table were completed by the local government in October 2019. To lower the groundwater table, the government of Nags Head installed seven pumping wells in the subwatershed. We sampled seven locations across Nags Head for the field-based water quality and water table aspects of the study (Figure 1 and Table 1). Two wells located in Nags Head Woods (referred to as NHW and NNHW) served as control wells for water quality and water table measurements since human influences on the hydrologic cycle are minimal in The Nature Conservancy Nags Head Woods Preserve. The second control well was added on October 4, 2019 (the second sampling occasion) into the research process to help better understand the water table since the lowering modifications. We used both Nags Head Woods control wells for water table measurements, but only used the original NHW well water table data for GIS analysis.

The first water quality control sample was taken on September 21 in the original NHW control well, but the other water quality control samples were taken in the additional New NHW control well. We calculated a standard error for water quality measurements to make sure our data was accurate after switching wells. Figures made from these data average the two Nags Head Wood wells as one well. Two more wells were also used for both water quality and water table sampling; one well was located off a major highway (B14) and the other well was located in the Nags Head Pond subdivision (B12). Two more wells, a pumping well in the Vista Colony subdivision (VC), and the other located across from the Blackman Street public beach access (BM), were used for water table measurements only. Lastly, we sampled surface water quality in a ditch near the Red Drum Taphouse restaurant (SW), which is located directly across from the B14 well.

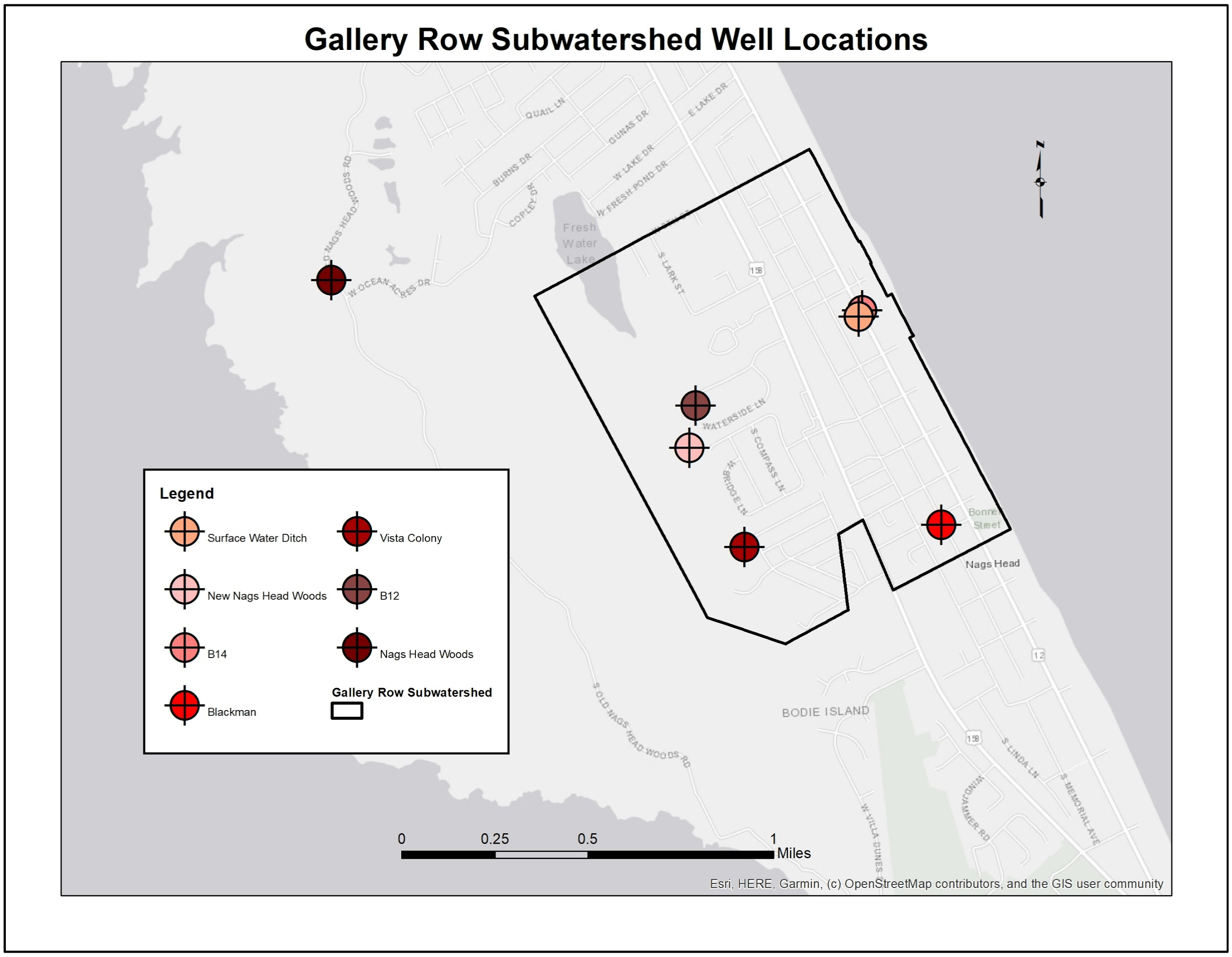

Figure 5. Well Locations. Location of wells used for the Fall 2019 water level and quality study in the Gallery Row subwatershed, Nags Head, NC.

Table 1. Names, abbreviations, and geographic coordinates of the sampling locations for the field-based water quality and water level research-based component of the 2019 OBXFS Capstone Research Project.

Sampling Site Name	Abbreviation	Geographic Coordinates
Nags Head Woods (Original control well)	NHW	35.98481°N, -75.66299°W
New Nags Head Woods (Additional control well)	NNHW	35.98333°N, -75.65037°W
Sampling site 1 (Used for both water level and water quality measurements)	B12	35.98497°N, -75.65°W
Sampling site 2 (Used for both water level and water quality measurements)	B14	35.98846°N, -75.64186°W
Vista Colony Well (Used for water level measurements only)	VC	35.98°N, -75.6479°W
Blackman Well (Used for water level measurements only)	BM	35.9794°N, -75.6384°W
Surface Water Ditch (Used for water quality measurements only)	SW	35.98823°N, -75.64204°W

Water Table and GIS Susceptibility Analysis

To analyze and visualize the susceptibility of land parcels in Nags Head to wastewater-groundwater interactions, we compared surface elevation to the elevation of the water table. For this comparison, we collected data to determine the water table elevation across Nags Head. From September 21 to October 29, we took depth to groundwater (DTGW) measurements weekly at all of the wells marked in Figure 5. The goal of this was to measure the DTGW at low, high, and neap tides to correct for uncertainty based on tide-dependent patterns in the water table elevation. DTGW is the distance between the ground surface and the top of the water table. On each measurement day, measurements for all wells were taken at the same, predetermined times (Table 2). To take these measurements, we used *Solinst* water level meters. Since the openings of wells B12, VC, NHW, and NNHW were not flush with the ground, we measured the distance from the well opening to the ground and subtracted this from the overall measurement. Protocols for measuring DTGW can be found in Appendix A.

Table 2. Dates and times for water level sampling during a 2019 study in the Gallery Row Subwatershed, Nags Head, NC.

Date	Time
9/21/19	12:03 PM
9/24/19	5:20 PM
10/1/19	4:20 PM
10/9/19	1:50 PM
10/15/19	4:10 PM
10/22/19	2:35 PM
10/29/19	3:50 PM

Data Analysis and Calculations

We geospatially analyzed water table elevation data from seven sampling occasions to create seven different maps, each representing a day on which the DTGW was measured. These maps show the potential susceptibility of different areas of Nags Head to groundwater-wastewater-surface water interactions based on relative water table and ground surface elevations. The elevation of the ground surface at each of the wells was found using the U.S. Geological Survey's The National Map (USGS 2017). Ground elevation data were used to find the elevation of the water table at each well by subtracting the DTGW from the ground elevation. Water table elevations were interpolated for each of the 7 days of measurements using ArcMap 10.4 and the Spline Interpolation tool. To make sure this interpolation sloped down to sea level at the coasts, we added 18 "dummy wells" with 0 ft elevations along the sound and ocean shorelines. These analyses yielded approximate surfaces of the water table elevation through a portion of Nags Head, which are most accurate for the Gallery Row subwatershed since all wells (except the original NHW well) are located within this subwatershed.

We used a 2014 digital elevation model (DEM) from the US Army Corps of Engineers to create susceptibility maps for each of the seven days by taking the interpolated surface from that date and subtracting it from the DEM. The resultant maps show the difference between the water table and the ground surface, where positive values indicate the water table is below the ground surface and negative values indicate the water table is above the ground surface. Because we had limited spatial data for well locations, there is some degree of uncertainty in the interpolations and thus the susceptibility maps. As such, we binned the susceptibility maps to represent areas where the water table is likely to be close to the ground surface. A high likelihood of groundwater interactions with septic effluent is binned as a -7 to 3 feet difference between the water table and the ground surface. We chose this bin because septic tanks require at least 3 feet of separation between the septic drain field infrastructure and saturated soil (the water table) for proper treatment of septic effluent (North Carolina Administrative Code [NCAC] 1990). A moderate likelihood is binned as a 3.1 to 6 ft difference. This bin was chosen because septic tanks require 3 feet of separation and are typically buried beneath the soil surface, therefore a septic tank is moderately susceptible here. We binned low likelihood as a 6.1 to 89 ft difference. The resultant products are seven water table surfaces and seven susceptibility maps for each of the days measurements were taken (see Appendix F). The analysis used here was supervised by Dr. Alex Manda and uses a method similar to his study of Bogue Banks, NC (Manda et al. 2014).

We then calculated the areal extent of each category of susceptibility. This required converting float raster layers to integer raster layers using the Int tool in ArcMap 10.4. The integer raster layer classes were reclassified using the Reclassify tool so the areal extent of each category could be calculated. We clipped the resultant layers to the Gallery Row subwatershed and then merged the polygons for each category using the Editor toolbar. The geometry of each category was then calculated in square feet using the Calculate Geometry tool.

Water Quality Field Sampling

On each of the sampling occasions (Table 3), we collected one surface water and one groundwater sample from three wells (NNHW, B12, B14). We used slightly different approaches to collect surface and groundwater samples. We used sampling protocols from the 2018 Capstone and employed them when appropriate. For surface water samples, we first took physicochemical environmental measurements using a Yellow Stone Instrument (YSI) multi-parameter probe, paying close attention to ensure that the YSI was immersed in the water. For groundwater sampling, we started by collecting well water with a bailer wrapped in plastic and treated using a sterile method. Water for environmental measurements was bailed from the wells into a 5-gallon bucket. We recorded dissolved oxygen (mg/l), salinity (ppt), temperature (°C), and conductivity (µs). Samples for bacterial analysis were collected in clear, autoclaved, high-density polyethylene (HDPE) bottles, while nutrient and optical brightener samples were collected in amber, acid-washed, high-density polyethylene (HDPE) bottles. Surface water samples were collected directly in sample bottles using a Pikstik, while groundwater samples were transferred to sample bottles from bailers. Samples were transported in a cooler filled with ice to the Coastal Studies Institute (Wanchese, NC) and were processed or stored in the laboratory within 4 hours of collection. We processed bacteria samples in which a full hydrology sampling protocol is provided in Appendix B.

Table 3. Sampling events and dates during a 2019 study in the Gallery Row Subwatershed, Nags Head, NC.

Event	Date
Dry #1	9/21/19
Dry #2	10/4/19
Dry #3	10/22/19
Wet #1	10/9/19
Wet #2	10/10/19

Nutrient Analysis

Within 30 days, we thawed and analyzed the frozen filtrate (Whatman GF/F) samples with a Lachat Quickchem with automated flow injection colorimetry. The Lachat Quickchem utilized the Cu-Cd reduction method for nitrate-nitrogen (NO_{3-}-N) analysis; phenol hypochlorite for ammonium-nitrogen (NH_{4+}-N) analysis, and antimony-phosphomolybdate complexation for orthophosphate, (PO_4 –P) analysis (according to Parsons et al. 1984). The nutrient analysis was done by the E2H2 lab at the Coastal Studies Institute. The process for this can be found in Appendix C. The nutrient analysis calculations were not used throughout the rest of the study.

Bacterial Analysis

We processed and analyzed water samples from each sampling location and occasion for total coliforms and *E. coli* bacteria using IDEXX Laboratories Colilert protocols and materials, and for concentrations of *Enterococcus* using IDEXX Laboratories Enterolert protocols and materials (refer to Appendix B). We used sterile techniques to reduce contamination and prepared two sample bottles for each water sample: one for the Colilert test and one for the Enterolert test. For each sample, 10 mL of sample was diluted with 90 mL of autoclaved water to which a IDEXX reagent packet was added. Each sample was then poured into a Quanti-Tray 2000, containing 49 individual wells, and sealed using an IDEXX Quanti-Tray Sealer. We incubated the trays for 24 hours and read the results using the IDEXX Result Interpretation table to obtain a Most Probable Number (MPN) of colonies for each bacterial group. Given that only 10 mL of the sample were used, each value was adjusted to a magnitude of 10.

The IDEXX Colilert Test uses a proprietary technology called Defined Substrate Technology (DST) to indicate the presence of total coliforms and *E. coli* bacteria. There are two nutrient indicators in the test that are metabolized by enzymes in coliform and *E. coli*. When these coliforms are present in the test, the solution turns from colorless to yellow. Cells that appeared yellow were counted as positive for total coliforms, while cells that were fluorescent were positive for *E. coli* (IDEXX US).

The IDEXX Enterolert Test also uses proprietary DST nutrient indicator technology to detect *Enterococci*; when metabolized, the indicator fluoresces. A lack of fluorescence indicated a negative result for *Enterococci*, while cells that exhibited blue fluorescence indicated a positive result for *Enterococci* (IDEXX US). We determined fluorescence for both tests using an ultraviolet light, which we held approximately five inches away from the sample tray. We then counted and interpreted positive cells by obtaining an MPN from the IDEXX Quanti-Tray/2000 MPN table. The MPN determined the bacteria colony count, which we then compared to environmental standards. A full bacteria sample processing and analysis protocol are provided in Appendix B.

For each parameter of nutrient and bacterial data, we calculated the mean concentrations and standard deviations for each well across all sampling occasions and for those designated as wet and dry sample occasions. We denoted a wet sample as any day that directly followed or occurred during a rainfall event. A dry sample was considered a day when there was no evidence of rainfall in the recent days. We used these calculations to compare aggregate concentrations between sites, as well as to compare the differences in wet and dry sample days.

Optical Brightener Analysis

Since fecal coliform values found from our enterolert and colilert samples cannot distinguish between human and nonhuman sources of bacteria, we sampled for the presence of optical brighteners as an indicator of human bacterial origin. Optical brighteners are compounds added to some modern laundry detergents, which adhere to fabric and absorb and emit light, countering the yellowing appearance of whites and making other colors appear brighter (Thompson and Miskowitz 2010). Laundry wastewater is the largest contributor of optical brighteners to wastewater treatment systems, and can be used as an indicator of anthropogenic wastewater contributions to the groundwater reservoir. The optical brighteners are excited by light in the UV range, 360-365 nm and emit light in the blue range (400-440 nm). After light absorption, fluorescence is given off that can be measured by a fluorometer (Tavares et al. 2008).

Fluorometry was conducted with a Trilogy Fluorometer with an optical brightener module (PN 7200-047). We checked the instrument for known concentrations of Fluorescent Brightener 28, the optical brightener we used to test for the presence of detergent. A fluorometric value of approximately 120,000 (RFU) was equal to 100 mg L^{-1} of Fluorescent Brightener 28. Haegdorn et al. (2003) suggested a site with an optical density of >100 was positive for optical brighteners, which we have applied here.

Water samples were removed from the refrigerator or cooler at least one hour before sample analysis to allow temperatures to equilibrate. We analyzed the standards of each sample in a cuvette that was placed in the Trilogy Fluorometer and measured for raw fluorescence values. This process was repeated three times for each standard. A calibration curve was created for this data. We repeated the same process for the four water samples. The full protocol is attached in Appendix D.

Stakeholder Interview Process

To better understand the perceived risks of living in a coastal community, particularly awareness of septic system function and vulnerability, we collected data from a wide range of stakeholders in the community: from citizens whose wastewater is treated by septic systems, to professionals that work with septic systems, as well as public officials and researchers on the subject. Once the categories were established, we conducted 18 interviews across the four stakeholder groups: four researchers, six public officials, three septic professionals, and four property owners in or near the Gallery Row subwatershed in Nags Head. We sampled purposively, meaning that we directly targeted individuals who we expected could best engage with the interview topics. We also relied on snowball sampling, asking each interviewee to recommend other potential interviewees. CSI's faculty, internship mentors, and advisory board members also provided recommendations. Due to the short timeframe available to conduct this research, we did not sample to saturation or completion. Saturation would have been reached upon completing an interview that provided no new information. The intention of the interview process was to include many varying local perceptions to begin to characterize stakeholder views on septic wastewater treatment.

Interviews followed question guides tailored to each stakeholder group. Each guide contained questions about perceptions or general knowledge of septic systems, wastewater, and changing environmental conditions. We tailored certain questions to better suit the interviewee (interview questions and guides are included in Appendix E). For property owners, we focused on questions related to personal opinions of the area, sense of place, and perceptions of risks associated with septic systems. For public officials and septic professionals, we asked questions regarding information gaps about wastewater treatment they noticed amongst property owners and the general public. For researchers, we focused the questions on their individual research and findings related to groundwater-wastewater-surface water interactions, septic systems, and stormwater management. The interviews were done in a semi-structured format where the interviewees were asked open-ended questions, allowing them to answer and elaborate on the questions how they saw fit. The interviews were recorded with the interviewee's consent. Interviews were conducted from October 17 to November 5, 2019 and ranged in length from 10-60 minutes. The recordings were transcribed verbatim.

We used *NVivo* 12, a qualitative data analysis software, to aid in our qualitative analysis of the interviews. *NVivo* allowed us to create codes or labels that can be used to divide the interview transcripts into portions by subject matter, and group these portions together for analysis based on more detailed topics. We created a standardized list of codes and each interview transcript was coded or reviewed by three different research team members (Figure

6). Once all transcripts had been reviewed and coded, the individual codes were analyzed for content and overarching themes. This involved reading through all the tagged quotes in the codes and organizing and grouping them based on their meanings.

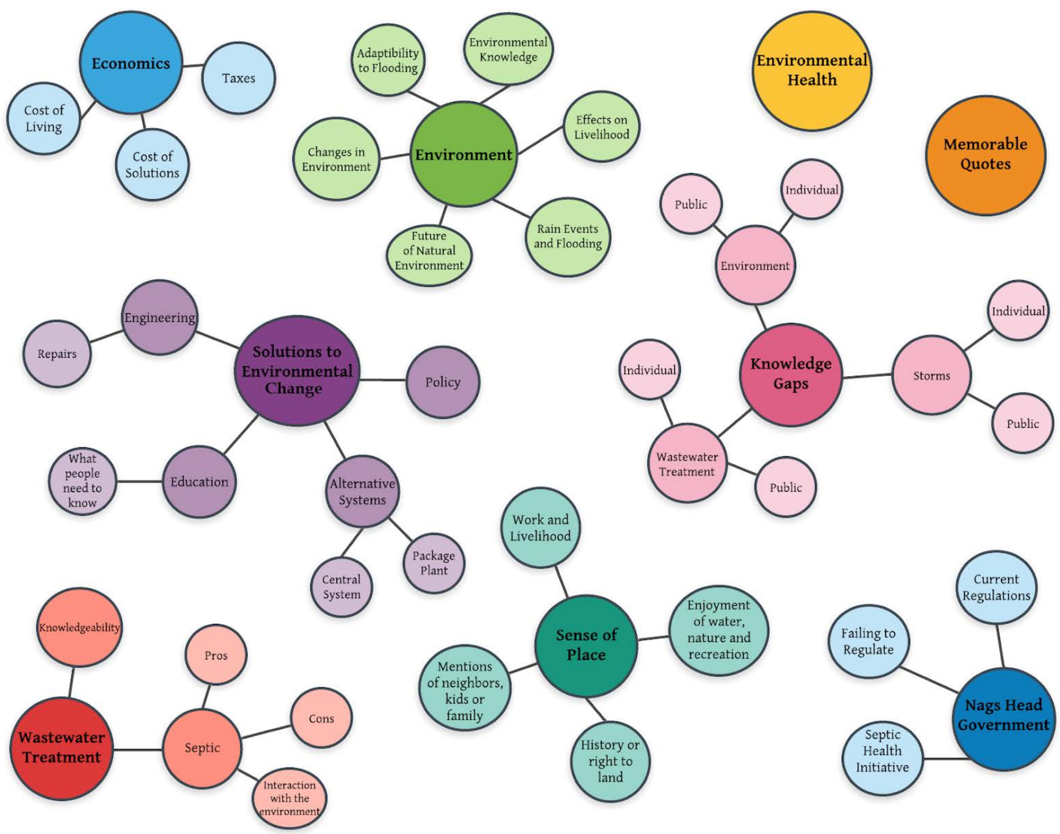

Figure 6. Model of Nodes. A conceptual representation of the nodes used to analyze participants' responses of septic wastewater and groundwater interactions. Large, bolded circles represent "main nodes", and all smaller circles were classified as "sub nodes".

Results and Discussion

Water Table Measurements and GIS Analysis

We initially visualized the hydrologic profile of Nags Head's groundwater using a time series of the water table elevation at each of the wells in the Gallery Row Subwatershed over the course of the data collection period for the study (Figure 7). The water table elevation decreased significantly in the VC well on October 22, which indicates that the well was pumped. This pumping event helps to visualize the groundwater lowering initiative taken by the Town of Nags Head.

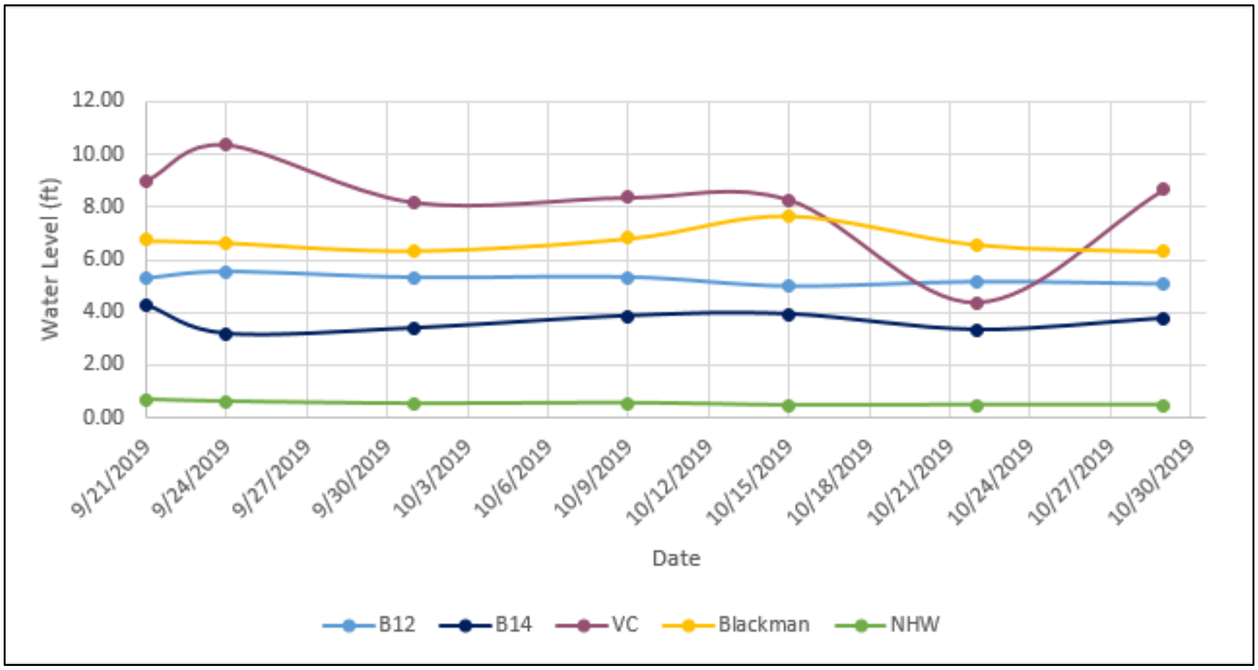

Figure 7. Water Table Elevation Time Series. Water table elevation (ft) for each groundwater sampling well in the Gallery Row subwatershed over the course of the study period from September 21, 2019 to October 29, 2019. Each well is represented by a different colored line.

We used this water table elevation data to create the susceptibility map. Many of the highly susceptible areas surround private residences and major roads where septic interactions would be more detrimental to humans (Figure 8). There are many drainage ditches along the roads and private residences here, meaning the water table is near or above the ground surface in these areas. This meets the criteria of our study and means the model has some accuracy in predicting susceptible areas. Much of Gallery Row Subwatershed appears to be susceptible to under-treated septic wastewater interactions with groundwater based on the elevation difference between the water table and ground surface (Figure 8).

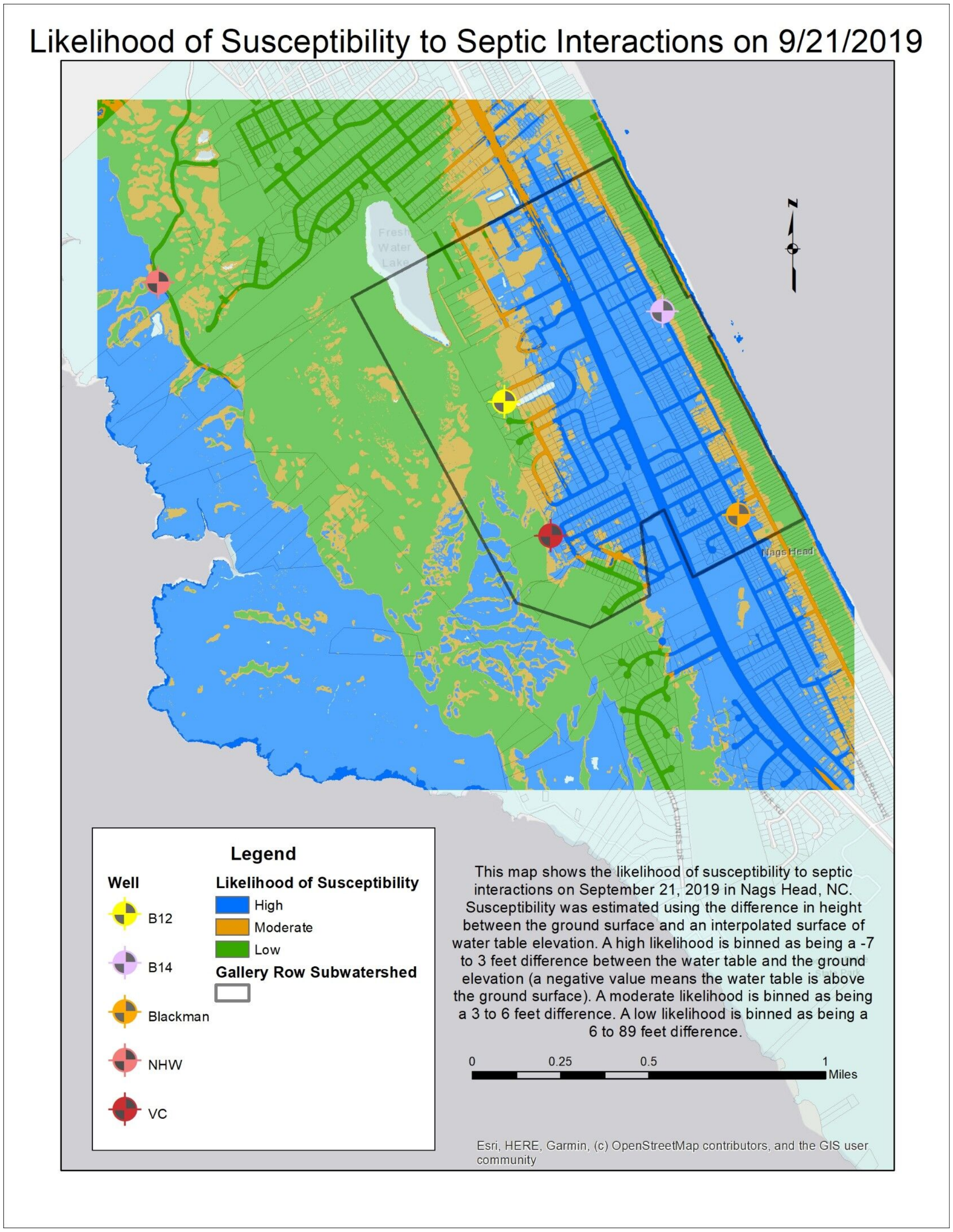

Figure 8. Susceptibility on September 21, 2019. Susceptibility of a portion of Nags Head in and around the Gallery Row subwatershed, outlined in black, to under-treated wastewater interactions with groundwater on September 21, 2019. The areal extent of high susceptibility in the Gallery Row subwatershed was determined to be the highest on this sampling day at 14,074,985 square feet or 54% of the area of the subwatershed. The areal extent of the moderate susceptibility was 17% and the low susceptibility was 27%. These values do not add up to 100% because the DEM ignored some surface water reservoirs, mainly the Fresh Water Lake.

Table 4 shows the areal extent of areas with high, moderate, and low susceptibility for under-treated septic wastewater interactions with groundwater in square feet. It also shows the percentage of the area of Gallery Row subwatershed by date. Areas classified as highly susceptible showed the largest areal extent for each date, and were followed by those with low and finally, moderate susceptibility. The area that was highly susceptible to under-treated septic wastewater interactions with groundwater in the subwatershed was nearly double the area with low or moderate susceptibility across the sampling dates. This is highlighted by standard deviation of less than five percent from the mean for each category (Table 5).

Table 4. The areal extent of susceptibility categories by sampling date for a water table study conducted in the Gallery Row subwatershed, Nags Head, NC. Susceptibility to under-treated septic wastewater interactions with groundwater were based on distances between the water table and ground surface and categorized as highly susceptible (-7 to 3 ft) moderately susceptible (3.1 to 6 ft) and low susceptibility (6.1 to 89).

Date	Susceptibility Category	Area (sq ft)	% of total area
9/21/2019	High	14074986	54
	Moderate	4319477	17
	Low	6891813	27
9/24/2019	High	12704450	49
	Moderate	5602025	22
	Low	6979897	27
10/1/2019	High	12267592	47
	Moderate	5955614	23
	Low	7063166	27
10/9/2019	High	13319200	51
	Moderate	5021605	19
	Low	6945567	27
10/15/2019	High	13217346	51
	Moderate	4777598	18
	Low	7291427	28
10/22/2019	High	10092452	39
	Moderate	7538326	29
	Low	7655594	30
10/29/2019	High	13068298	50
	Moderate	5019814	19
	Low	7198259	28

Table 5. Average percent of total area by susceptibility category across seven sampling occasions in fall 2019 for a water level study conducted in the Gallery Row subwatershed, Nags Head, NC. Susceptibility to under-treated septic wastewater interactions with groundwater were based on distances between the water table and ground surface and categorized as highly susceptible (-7 to 3 ft) moderately susceptible (3.1 to 6 ft) and low susceptibility (6.1 to 89 ft).

Susceptibility Category	Average % of total area	Standard Deviation (%)
High	49	5
Moderate	21	4
Low	28	1

Approximately half of the subwatershed was highly susceptible to wastewater-groundwater interactions between September 21 and October 29, with little deviation from the mean (Table 3 and Table 4). We compared the susceptibility maps to topographic maps and to the water table interpolations to understand their respective influences on susceptibility (Figure 9). It appears topography has a greater influence on susceptibility than the water table elevation, though both influence susceptibility (Figure 9). Topography seems to be the main determinant of susceptibility, as the contour lines often follow susceptible areas. Low-lying, flat areas appear to be most susceptible to wastewater interactions.

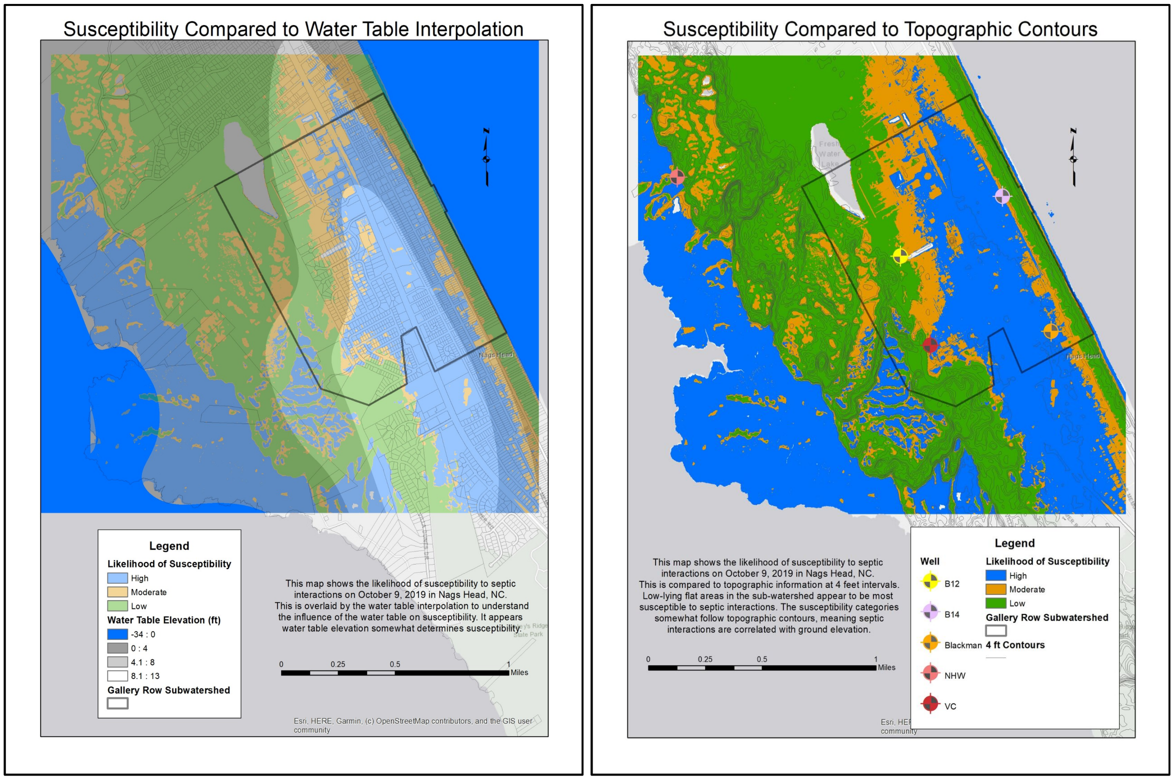

Figure 9. Water Table and Ground Elevation. Respective influences of the water table surface and ground elevation on susceptibility on October 9, 2019 in the Gallery Row subwatershed and surrounding areas of Nags Head, NC. The map on the left shows the influence of the water table and map on the right shows the influence of ground elevation.

<u>Implications</u>

According to our analysis, it appears that about 50% of the Gallery Row Subwatershed was highly susceptible to wastewater-groundwater interactions over our data collection period. These areas tend to be low-lying and flat, and are concentrated near the center of Gallery Row along roads, residences, and businesses. The water table elevation does influence susceptible areas, but the topography determines where the water table can interact with surface water and groundwater. Though our model may not accurately capture susceptibility due to limitations (see “limitations” section below), we believe that it draws attention to a water quality concern that warrants further investigation.

<u>Limitations</u>

Our geospatial analysis has several temporal and spatial limitations. This study was done over roughly one month between September 21, 2019 and October 29, 2019 and does not accurately reflect the year-round conditions in Nags Head, NC. Because of this, our analysis may not be applicable to other seasons with different precipitation patterns, temperature, and septic tank use. This study lacks some spatial accuracy because we have only five well locations to measure the water table across the approximately 1.5 mile wide island, four of which are in the study area. The interpolated surface may not accurately reflect the water table in Nags Head because of the limited number of data points used, which skews the susceptibility maps made from these interpolations. The 2014 DEM used also skews the data because newer development, including more impermeable surfaces and improved septic drainfields bolstered by fill, is not represented. This model also does not consider differing soil types, which can affect the efficacy of septic drainfields. Comparing our results to the 2005 Town of Nags Head Decentralized Wastewater Management Plan Technical Report by Stone Environmental Inc., which incorporated soil types and septic drainfields into the study, we see differences in susceptibility (Stone Environmental, Inc. 2005 [Figure 10]).

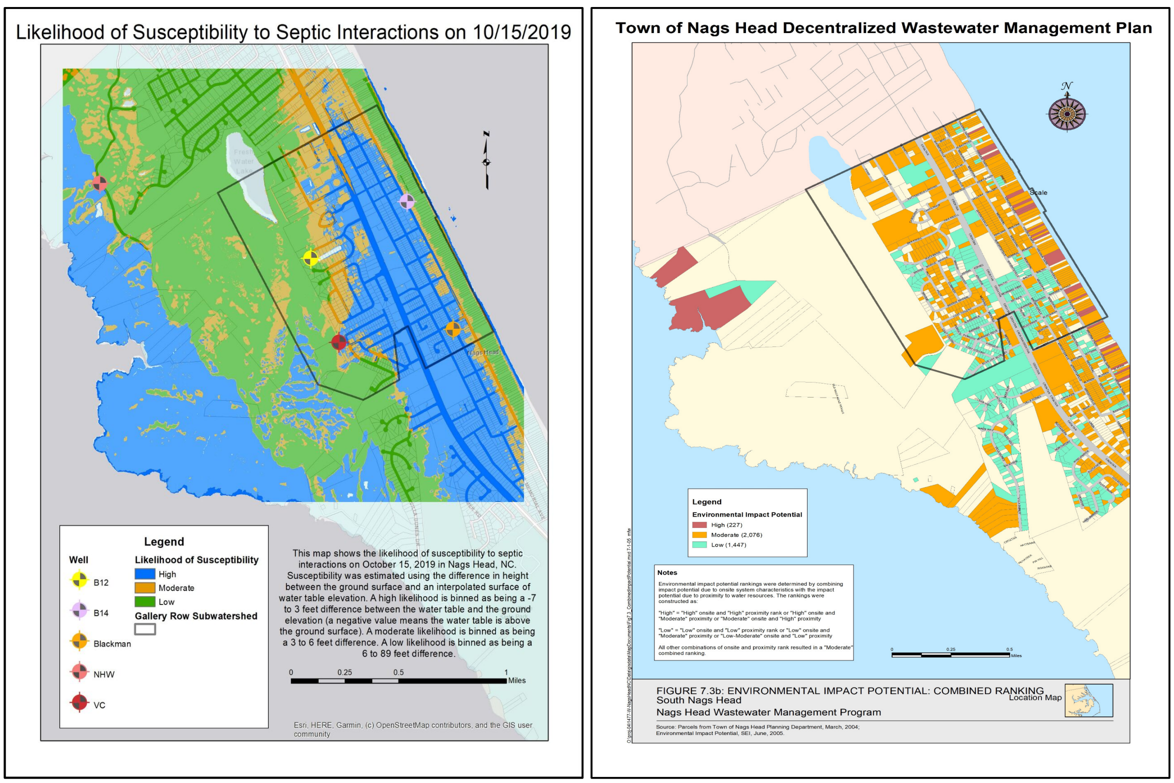

Figure 10. Comparison to Stone Report. Comparison of our susceptibility analysis in the Gallery Row subwatershed in Sept. and Oct. 2019 to that of the technical report produced by Stone Environmental Inc. for the Town of Nags Head in 2005.

Though a legitimate GIS analysis comparison between these two is not possible because of the use of different parameters, there appear to be some visual similarities between our analysis of susceptibility and that of Stone Environmental Inc. (2005, Figure 10). Some of the moderate and high susceptibility areas in our analysis line up with the moderate susceptibility listed in the Stone Environmental Inc. report. However, towards the beach, the outcomes of the analyses differ drastically. Most of the areas along the beach in our analysis show a low susceptibility where the Stone Environmental Inc. report shows moderate and high susceptibility. These differences are likely due to the artificial dune system increasing the ground elevation along the beach, the different criteria used, and the 14-year time gap between reports.

Calculating the areal extent of the different categories also had limitations. To convert from raster to vector to calculate areal extent, the raster layers had to be converted from float to integer layers. A float value can have decimal places where integers cannot, meaning data was lost in this conversion. This loss of resolution is pictured in Figure 11.

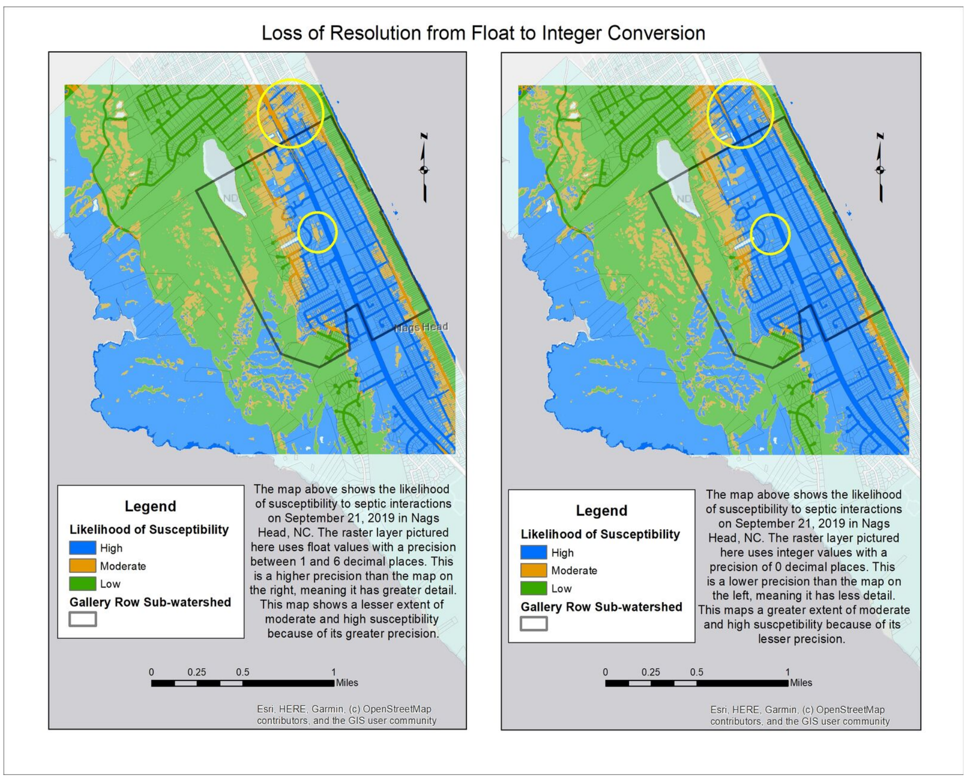

Figure 11. Loss of Resolution. The loss of resolution in our analysis as data were converted from float (left) to integer (right) values. More areas appear in the high and moderate susceptibility categories in the map on the right where values were converted to integers.

In a future study, we would recommend focusing on quantifying and reducing error and uncertainty in this conversion. We would recommend monitoring more wells over a longer period of time to increase both the spatial and temporal accuracy. This would allow for a better comparison across seasons and years, and provide greater accuracy in locating areas that may be susceptible to under-treated septic wastewater interactions with groundwater. We would also recommend using data from the Dare County Health Department to find failing septic systems or systems with insufficient separation between the drainfield and groundwater to incorporate into a future study. We collected some data from the Dare County Health Department with the intention of conducting this additional analysis, but did not have time to follow-through on our plans for analysis.

Water Quality

Environmental Variables

The SW site consistently had a salinity less than 2 parts per thousand (ppt) across all sampling dates. Salinity remained below 3 parts per thousand for each of the wells, with the exception of our control well, NHW, on October 10, 2019 (wet sample date) with a salinity of 1.3 ppt. Temperatures among all of the sites remained relatively constant (15.9 degrees C to 24 degrees C) throughout the sampling process, with an average variation of 4.03 degrees C among each sample site. The lowest temperature across sampling sites was 15.9 (NHW) and the highest was 24 (SW) (See Appendices A and B for additional environmental protocol).

Bacteria

Total coliform concentrations in groundwater and surface water samples ranged from 0 colony forming units (CFU) on October 4, 2019 at the SW site to 24196 CFU on October 4, 2019 at both B12 and SW sites. The SW and B12 sites consistently had the highest total coliform concentrations across all dates, as well as wet and dry conditions. The EPA does not recommend that total coliform be used an indicator of recreational water quality, since they do not have thresholds for contamination like *E. coli* and *Enterococcus* do (EPA 2003). These indicators will not be discussed extensively in the remainder of our report.

E. coli concentrations were between 0 and 1 CFU, or nearly absent, in groundwater samples across all sampling dates. While *E. coli* was present at considerably higher concentrations at the SW site on all sampling occasions, regardless of wet or dry conditions (ranging from 85-117 CFU), the *E. coli* concentrations still largely remained under the EPA threshold of 126 CFU (Figure 12). When comparing aggregate *E. coli* concentrations for the SW site across wet and dry sample dates, we found that concentrations for wet conditions are higher than for dry conditions, and that there is high variability in concentrations across dry sampling occasions (Figure 12).

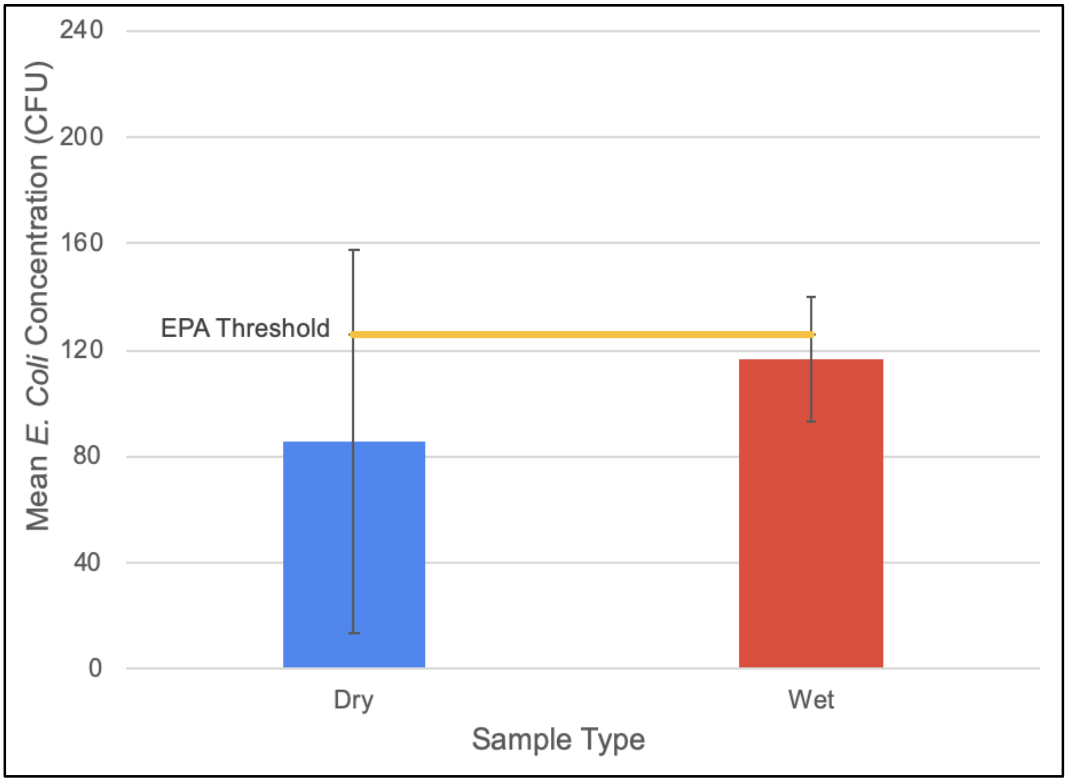

Figure 12. E. Coli Concentrations. Mean aggregate *E. coli* concentrations (colony forming units; CFU) across dry (absence of rainfall) sampling occasions (n=3) and wet (presence of a rainfall event) sampling occasions (n=2) for samples collected from study sites in Nags Head, NC in October 2019. These levels are compared to the EPA threshold for *E. coli* concentrations (CFU) in recreational waters. Error bars represent one standard deviation of the mean.

While surface water *E. coli* concentrations were below the threshold for safe recreational water conditions in 2019, averaged wet samples taken in the first year of the study in 2018 were noticeably higher than the EPA standards (Figure 13). While, on average, 2018 *E. coli* concentrations were noticeably higher than both of the 2019 averages and the federal threshold, the error bars indicate large variations between individual sample dates. The two wet sampling dates for 2019 had much lower standard deviations and variation. The 2018 data had a large CFU value for their wet samples, which was 2603 CFU, versus 315 CFU in 2019. These results suggest that groundwater lowering has reduced the interactions between untreated septic effluent and the groundwater-surface water reservoirs. Water quality was predicted to improve, and this was observed through *E. coli* concentrations in 2019. This is because of the increased depth of unsaturated soil where biological, chemical, and physical processes remove contaminants before the effluent reaches the water table. Before the groundwater lowering (in 2018), higher *E. coli* concentrations suggest a higher water table and narrower unsaturated zone, causing septic interactions with storm runoff at the surface level. In 2019, significantly lower *E. coli* concentrations indicate a beneficial outcome of the groundwater lowering, where unsaturated conditions in the soil and increased oxygen levels facilitate the removal of contaminants from septic wastewater and stormwater. In 2018, prior to groundwater lowering, the water table was closer to the ground surface, so stormwater runoff and septic wastewater may not have been sufficiently treated for fecal coliform and bacteria through aerobic processes because of the narrow unsaturated zone.

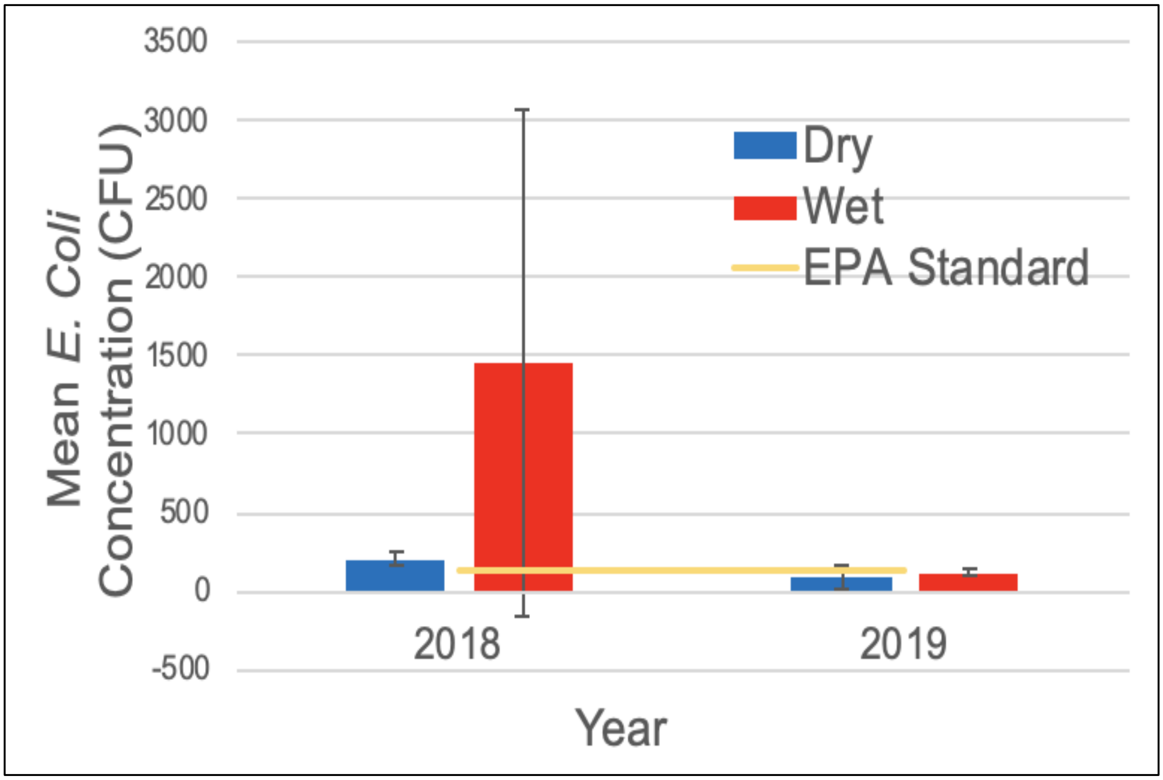

Figure 13. E. Coli Concentrations, SW Site. Mean *E. coli* concentrations (colony forming units; CFU) across dry (absence of rainfall event) and wet data (presence of a rainfall event) for SW site samples collected throughout October 2019 compared to those collected in October 2018 from the same sampling locations in Nags Head, NC. These concentrations are compared to the EPA threshold for *E. coli* in recreational waters (126 CFU). Error bars represent one standard deviation from the mean.

Since 2019 was a much drier year than 2018, the groundwater lowering may not have been the sole reason for a larger unsaturated zone. The water year (October 1 to September 30) leading up to the fall of 2018 had a sum of average monthly precipitation values of 45.03 inches, while 2019 had 34.03 inches (NC State Climate Office). This data might indicate that the separation between the water table and septic drainfields is a result of drier conditions and not solely the engineering measure employed to reduce flooding. Similar mechanisms to the groundwater lowering might drive the lower *E. coli* concentrations of 2019. Less rainwater yields less saturated soils and more room for contamination filtration.

While, on average, *E. coli* concentrations were significantly higher than both of the 2019 averages and the federal threshold, the error bars indicate large variations between individual sample dates. The two wet sampling dates for 2019 had much lower standard deviations and variation. The 2018 data had a large standard deviation value for their wet samples, 2603 CFU versus 315 CFU in 2019.

Aside from the NHW control groundwater well, where *Enterococcus* was absent, *Enterococcus* concentration largely exceeded the EPA threshold of 33 CFU (Figure 14) across groundwater and surface wells and sampling locations. While groundwater and surface water in ditches are not recreational waters, the EPA *Enterococcus* threshold is a good indicator of water quality concerns, and these reservoirs directly mix with the nearby recreational waters of the sounds and ocean. *Enterococcu*s concentrations from the wells where it was detected ranged from 41 CFU on September 21, 2019 at the B14 site to 2098 CFU on October 4, 2019 at the SW site.

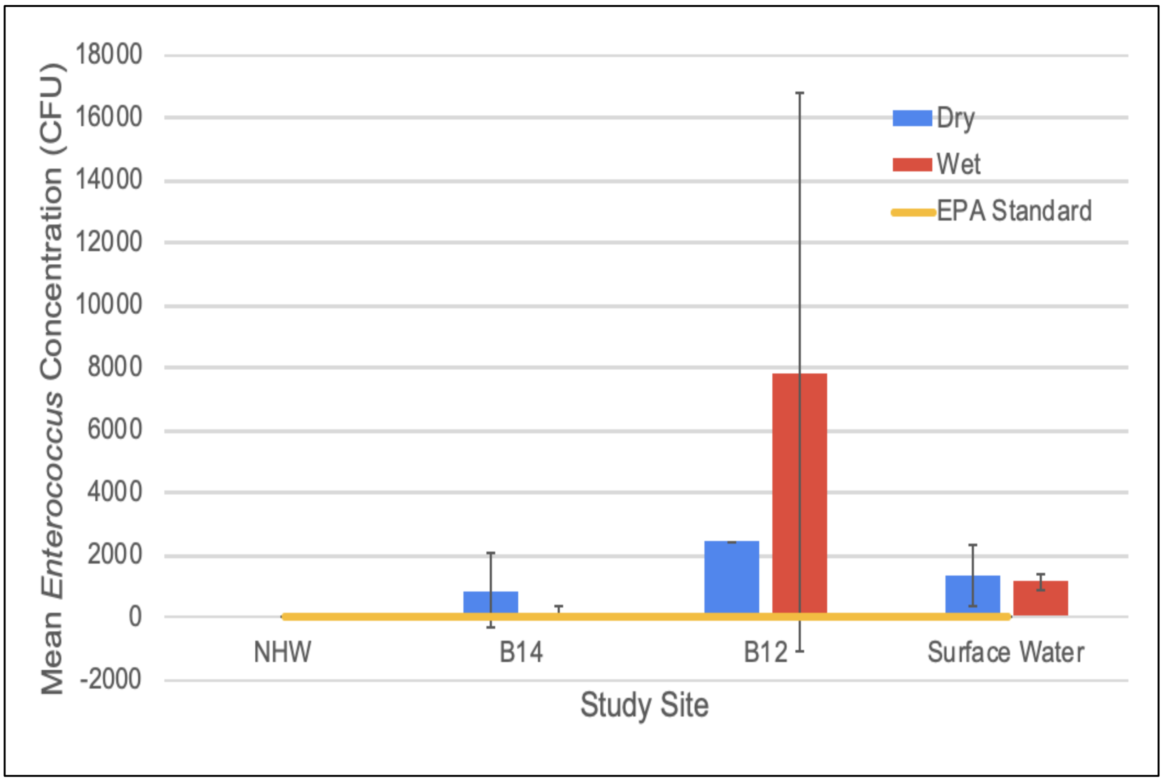

Figure 14. Enterococcus Concentrations. Mean aggregate *Enterococcus* concentrations (colony forming units; CFU) across dry (absence of rainfall) sampling occasions (n=3) and wet (presence of a rainfall event) sampling occasions (n=2) for samples collected from study sites in Nags Head, NC in October 2019. These levels are compared to the EPA threshold for *Enterococcus* concentrations (CFU) in recreational waters at 33 CFU. Error bars represent one standard deviation of the mean. B12 does not have error bars as the site was only sampled once during dry events due to sampling errors and lack of equipment.

We found a great deal of variability in *Enterococcus* concentrations between sampling locations (Figure 14), with the highest concentrations at well B12 (mean across dates of 5138 CFU +/- 4460), and SW (mean across dates of 1239 +/- 595). *Enterococcus* was also detected at B14 in wet and dry conditions, but the concentrations were notably lower (mean across dates of 534 +/- 679) than at the other non-control sampling locations. While the exposed SW site has high amounts of *Enterococcus* for both wet and dry sample days, the high levels of *Enterococcus* detected in the B12 site's wet samples are staggering. However, it should be noted that the error bars are large. This high variability in concentrations might be due to local septic sources and their times of water usage throughout the day or certain times of the week. We also see variability between sampling locations with regard to differences in *Enterococcus* concentrations during wet and dry conditions. *Enterococcus* concentrations were higher in wet conditions than dry at the B12 site, as expected. The same precipitation-associated pattern was not found at B14 and SW. The differences between *Enterococcus* concentrations in the non-control sampling locations may reflect differences in separation distances between septic drainfields and the water table. High *Enterococcus* concentrations at B12 may indicate an underlying problem with the efficacy of wastewater treatment in a nearby drainfield, and relatively higher concentrations on wet sampling occasions may be a result of an even smaller separation distance as the water table rises in response to receiving precipitation inputs or contaminated runoff that mixed with the groundwater during storm events. The results for *Enterococcus* are more concerning than those of *E. coli*.

Enterococcus concentrations were noticeably lower in 2019 than 2018 for both wet and dry conditions, and were significantly lower under wet conditions (Figure 15). Saturated ground conditions inhibit *Enterococcus* bacteria from attaching to soil particles, leading to higher contaminant concentration in surface waters. These conditions would have existed in 2018 when there was high rainfall and the groundwater had not been lowered. The smaller error bars in 2019 might also indicate a constant, non-point source of pollution, rather than the 2018 values which have larger magnitudes of error, representing increased variability in sources. Even though the 2019 values for wet and dry conditions are significantly lower than 2018, they still exceed the threshold for contamination at 33 CFU. The high levels of *Enterococcus* at the SW site still indicate a potential threat to human health.

Even with the large variability between sampling locations and relatively high *Enterococcus* concentrations at B12 (Figure 14), the mean Enterococcus concentrations aggregated across all sampling sites were noticeably lower in fall 2019 than fall 2018. This data supports the hypothesis that groundwater lowering in July 2019 nearby to B14 and SW would improve surface and ground-water quality.

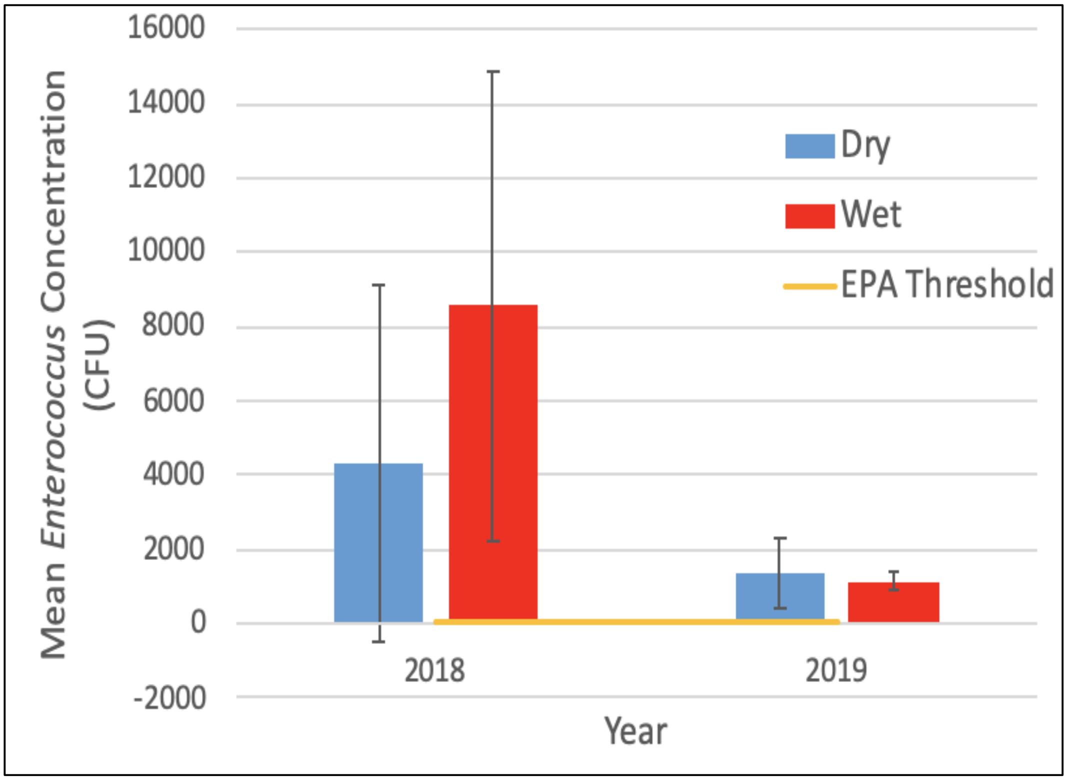

Figure 15. Enterococcus Concentrations, SW Site. Mean *Enterococcus* concentrations (colony forming units; CFU) across dry (absence of rainfall event) and wet (presence of a rainfall event) sampling occasions for SW site samples collected throughout fall 2019 in Nags Head, NC, compared to fall 2018. These levels are compared to the EPA threshold for *Enterococcus* concentrations in recreational waters at 33 CFU. Error bars represent one standard deviation from the mean.

Overall, the reduction in all fecal indicator bacteria (*Enterococcus* and *E. coli*) from fall 2018 to fall 2019 at the sampling locations neighboring one of the groundwater lowering installations (B14 and SW) suggest that the groundwater lowering reduced bacteria concentrations. The high *Enterococcus* but low *E. coli* concentrations found at B12 are a bit perplexing. The presence of only one of the types of fecal bacteria tested for could be caused by a wide array of environmental conditions. For instance, *Enterococcus* concentrations from storm runoff, irrigation, and agricultural activities can exceed concentrations of human sewage (Olivieri et al. 2007). These could be potential sources of contamination to the B12 well that do not contain the same high levels of *E. coli* concentrations that a septic system might.

<u>Nutrients</u>

All three water quality sampling wells have higher nitrate concentrations for wet samples compared to dry, with NHW and B12 having noticeably higher values. Nitrate concentrations from all the wells ranged from 2.63 µg-N/L on September 21, 2019 at NHW to

204 µg-N/L on October 9, 2019 at NHW. The nitrate concentrations in our samples are noticeably lower than the federal threshold for nitrates in recreational waters, which is 10000 µg-N/L. A study in the Cape Hatteras National Seashore (Mallin et al. 2012) found average nitrate samples on dry sampling days to range from 12 to 71 µg-N/L. Further, Mallin et al. (2012) named these values "low to moderate." Our dry samples ranged from 2.63 (NHW) to 35.6 (SW) µg-N/L in 2019 thus our samples would be considered to have "low" nitrate concentrations. While nitrates are found naturally-occurring in the environment, humans can drastically increase their concentrations due to their presence in septic effluent and overland runoff (Mallin et al. 2012). We do not observe the nitrate levels as high enough to be a concern for nutrient loading or contamination.

Phosphate average concentrations were 105 µg/L for dry conditions and 261 µg/L for wet. While mean wet phosphate concentrations in NHW and B12 were found to be exceedingly higher than respective dry samples, our observations do not necessarily indicate phosphate contamination from septic wastewater. Mallin et. al (2012) reported a mean orthophosphate concentration of 127 µg/L, while the 2018 OBXFS Capstone reported lower mean concentrations: 23.5 µg/L under dry conditions and 59.9 µg/L under wet ones. Our results are higher, on average, than those reported in the 2018 OBXFS Capstone report. Mallin et. al's mean concentrations were considered to be "generally high", and phosphate concentrations reported in the 2018 OBXFS Capstone report were noticeably greater than the Mallin et al. (2012) average. Mallin et al. (2012) mentioned that while the values might be attributed to human-sources, phosphates are present in the environment through naturally occurring processes such mineralization. It is unclear whether the levels reported here and in the previous OBXFS Capstone report (2018) are considered excessive or cause for concern. With no federal standards for phosphates, we do not have a clear reference for an acceptable level.

Optical Brighteners

Average fluorometric UV reflection values across all sampling dates range from 4800 relative fluorescence units (RFU) on October 9, 2019 at NHW to 17319 RFU on October 9, 2019 at the SW site. We followed the Haegdorn et al (2003) threshold for designating a sample as positive for optical brighteners as those with a reflectance unit (RFU) value greater than 120,000 RFU (equivalent to a zero-corrected optical density of 100). Using this presence or absence threshold criteria, none of the samples tested positive for optical brighteners (Figure 16). In addition, optical brightener levels do not appear to have a significant difference between dry and wet sampling dates. The 120,000 RFU threshold came from our calibration curve sample of 100 ppm. Hartel et al.'s 2007 paper specified an optical density greater than 100 to be positive for optical brighteners. The study looked at two sampling locations: Puerto Rico and Georgia. Puerto Rican waters had relatively low concentrations of organic matter that minimally impacted fluorescence values, while Georgia waters had higher concentrations that were likely to affect fluorometric results (Hartel et al. 2007). We determined that Georgia waters had more similar characteristics to the Outer Banks.

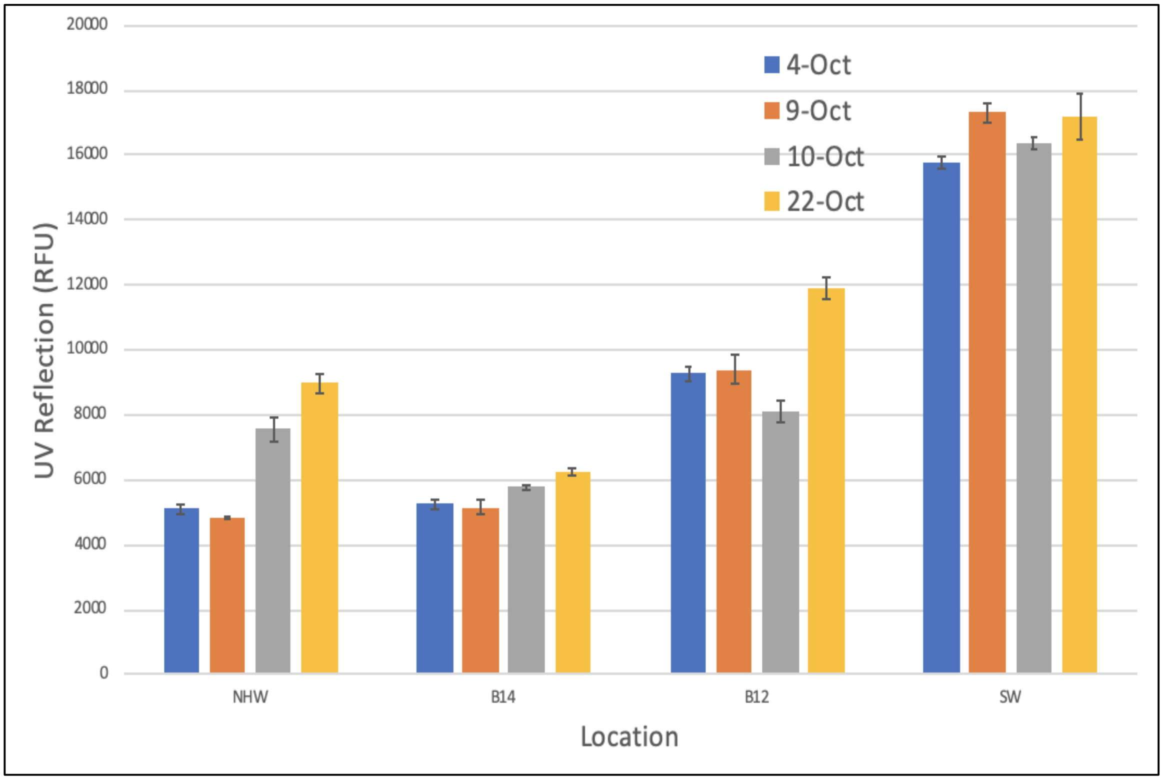

Figure 16. RFU Values. Fluorometric UV reflection (RFU) for samples collected from locations in Nags Head, NC in October 2019 on 4 out of the 5 sample dates. Blue and yellow lines indicate a dry (absence of rainfall event) and orange and grey represent wet (presence of a rainfall event) sampling occasions. Error bars represent one standard deviation of the mean. This figure does not include data from the initial dry sample date (9/21/19) because the samples were used as a trial run for students to learn the methods for OB analysis.

While reflectance at the wavelength of optical brighteners was detected across all samples, they were not measured at concentrations high enough to qualitatively call them positive for detergents. The reflectance units we measured in our samples did not change with exposure to UV light (Figure 17) by more than 15%, a threshold proposed by Hartel et al. to differentiate between reflectance from organic matter and that from detergents. Background organic matter can influence fluorescence, thereby reducing the detection limits for optical brighteners and detergents.

This might indicate that optical brighteners are not the optimal septic wastewater indicator for the Outer Banks region. However, a study conducted on Ocracoke Island, reported that, at a minimum, 50% of their water samples tested positive for optical brighteners at each surface water site (Hyde County Center of NC Cooperative Extension 2010). In addition, our sampling locations may have been too few and not optimally located to use optical brighteners as a septic wastewater indicator. For instance, some homes use optical brightener-free laundry detergents. In addition, the SW and B14 sites are near businesses and large rental houses. Businesses and restaurants are not likely to use laundry detergents and some companies that own rental houses in the OBX send laundry out to a separate location to be washed. This means that large volumes of water coming from these properties could be devoid of or low in optical brightener concentrations. Relative to the total amount of water being used by households, vacation homes, and businesses, laundry may be a small percentage, which would decrease the overall concentration of optical brighteners. Refining the optical brightener analysis and carefully selecting sampling sites may yield usable information in the future.

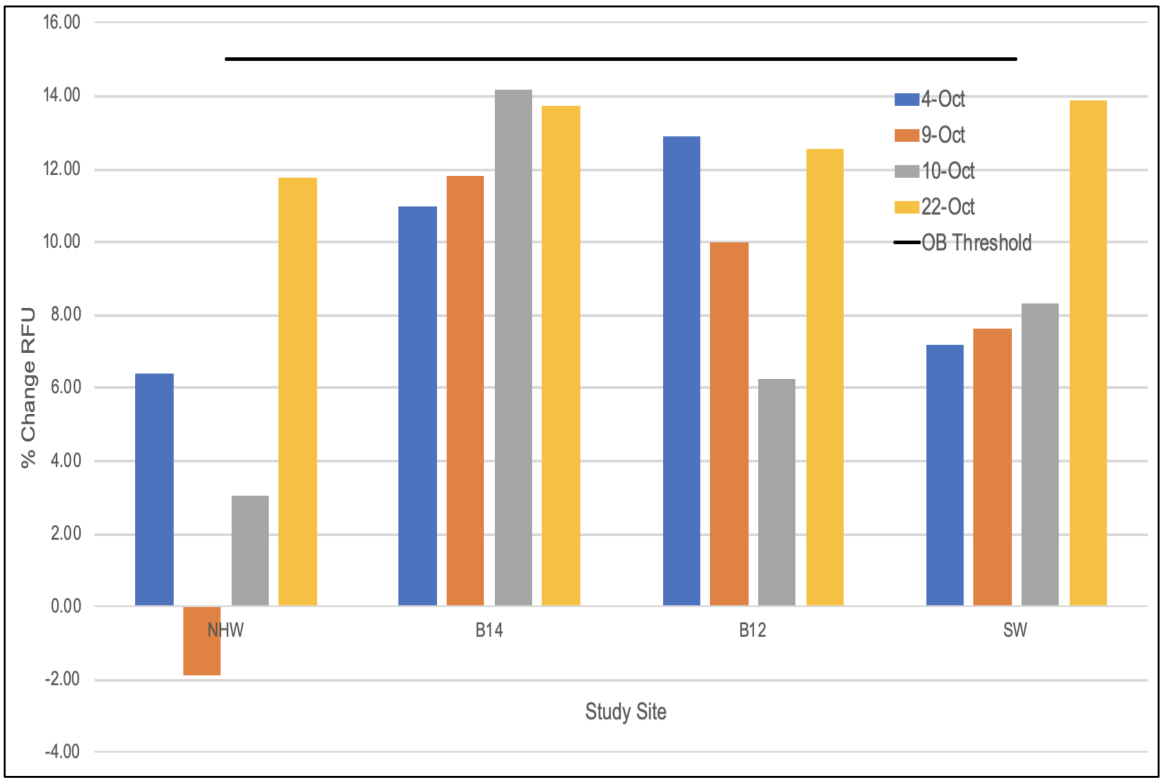

Figure 17. Percent Change in RFU Values. % Change in RFU for each well location for 4 out of the 5 sample dates. Blue and yellow lines indicate dry (absence of rainfall event) and orange and grey represent wet data (presence of a rainfall event) for samples collected from sampling locations in Nags Head, NC in October 2019. These levels are compared to a 15% threshold (OB Threshold) that indicates presence or absence of optical brighteners (Hartel et al. 2007). This figure does not include data from the initial dry sample date because the samples were used as a trial run for students to learn the methods for OB analysis.

<u>Implications</u>

Our bacterial data suggest that the groundwater lowering in October 2019 near the B14 and SW sites reduced bacterial concentrations (*Enterococcus* and *E. coli)* where surface water and groundwater reservoirs are closely connected. In 2018, before the groundwater lowering, higher *E. coli* concentrations might indicate that higher water table and narrower unsaturated zone, caused interactions between septic wastewater and surface water. Septic drainfields with more separation from the water table allow for a larger zone where aerobic processes that reduce bacteria levels can occur.

Similarly, septic drainfields that are closer to the water table typically have higher counts of bacteria (Cogger 1988). A study on the NC coast supports this observation by concluding that *E. coli* concentrations decreased with increased distance between the water table and septic drainfields (Schneeberger 2015). The groundwater lowering initiative in Nags Head had a goal of increasing the distance between the ground surface and water table to reduce flooding of above-ground infrastructure. Based on our findings, the groundwater lowering initiative may have improved water quality because of an increase in the distance between septic drainfields and the water table. Bacterial concentrations do not unequivocally indicate septic wastewater inputs to surface and groundwater reservoirs. Optical brighteners are an indicator of human bacterial origin that have successfully been used in nearby studies; however, we did not detect optical brighteners in our samples, and attribute this to methodological approaches that may be resolved with further investigation.

Limitations

Our data were not collected over an extensive period of time, with all sampling events falling within a five-week period in the fall of 2019. The hydrology of the Outer Banks region was also significant during this time period because rainfall was lower than average in the 2019 water year, at 34.03 inches, compared to 45.03 inches in 2018. While data about specific human decisions regarding water and septic systems is logistically difficult to collect, the lack of water usage data remained a large limitation in interpreting results. Water usage statistics could have aided in nutrient analysis, as well as in understanding *Enterococcus* bacteria trends.

Additionally, we only had two “wet” sampling occasions, which may not be enough instances to show the effects of storm events on water quality. Two “wet” events may not be enough to show the overall effects of flooding on water quality. In total, we had five sampling events over a one-month period, which does not show the temporal range of changes in water quality and water table elevation over the whole year.

In addition, our sampling was not always accurate with protocol standards, and we had to switch control wells once. While the wells are within the same watershed and water drainage area, it should be reiterated that the control wells, while included in the graphs as the same well site, were not uniform across sampling days.

Stakeholder Perceptions

We identified variable perceptions of risk related to water quality degradation by wastewater across four stakeholder groups in Nags Head: researchers, public officials, septic professionals and property owners. Four key themes emerged from our qualitative analysis of stakeholder interviews: the importance of water for identity; change in environmental parameters and events; contamination risk perception; and challenges for addressing risk into the future.

<u>Water as a Source of Identity</u>

Almost all interviewees emphasized how much the barrier-island environment matters to them. They discussed ways in which they enjoyed the beach, sound, and various ecosystem services from these water sources, such as a place to recreate, a habitat for fish that people enjoying catching and eating, and more. Interviewees are connected to place through recreational and economic activities, and express a sense of pride in where they live. Interviewees described how the waters are of paramount importance to Nags Head. One public official stated:

"I think [the Sound and Ocean] make Nags Head, Nags Head. I think if you put this town somewhere else inland, it wouldn't be Nags Head. And so I think it creates this sense of place on Nags Head, and the whole Outer Banks are a place that directly interacts with water. And I think that's why people come here, want to live here [...]" -Public Official

The beach, the sound, and the ocean define the town. Everything relies on these natural places, from individual happiness and livelihoods to community dynamics. For many stakeholders we interviewed, this place could not be what it is without water. While local sense of place and identity are derived from activities in and around the water, they also arise from family and social connections (Poe et al. 2016).

"My family is very water oriented. We're always on the sound, always on the boat. So we're just…we just love it here. I love this small town feeling. I love raising my kids here." -Resident

The recreational activities that participants enjoy would not be appreciated to the same extent without their families. These strong family ties lead to an even stronger sense of place and enjoyment of the waters in Nags Head. Many participants talked about their children and families in their interviews, and mentioned enjoying time on the water watching their kids play or surf. A few discussed about the good friends that they had made in Nags Head that kept bringing them back until they eventually stayed. A few also mentioned the importance of water quality, since their children and families play in it and enjoy it.

Interviewees work in a variety of jobs and professions, and these livelihoods shaped their sense of place in Nags Head as well.

"It's obvious […] that this town is tourist driven and so we get a big influx of money and all that kind of stuff from people coming to the ocean to fish and enjoy the ocean, and people come into the sound and fish. I mean, I don't think my restaurant could probably sustain itself without the tourist industry for sure." -Resident

The natural environment and outdoor recreation residents enjoy also supports the local economy. Tourism, among other resource-based industries supported by the environment is so important to the Outer Banks as $1.9 billion dollars were spent here in the last year (Hampton 2019). People are deeply rooted through their sense of place which is informed by their livelihoods (Amundsen 2015).

Environmental Change

Many interviewees have 20 to 40 year histories in the Outer Banks. These people know Nags Head extremely well and have seen changes in development, environment, and culture during their time here. Feeling safe in a certain location is correlated with an increase in the likelihood of perceiving environmental risk (Quinn et al. 2019), and therefore individuals with a stronger sense of place worry more about place changes (McIntyre et al., 2018). Because of this, living in an area for a long time can lead to strong attachments and informs sense of place (Brown and Raymond 2007). People are invested in their community and notice changes over time and these connections can make people more protective of their community so it remains in the same condition for generations to come. People experience more grief when they are connected to an area that is changing greatly (Marshall et al. 2019). Interviewees notice change all around them, as the following quote shows:

"Well I definitely notice the island getting smaller. […] On the sound side I see our yard […] definitely shrink and it is changing. […] We see the effects of sea level rise here […] We definitely see more flooding." -Resident

This respondent, like other interviewees, is seeing impacts very close to home on their own piece of property. Property owners can see the environment changing around them, and the perception among our interviewees is that it is typically changing for the worse. People we interviewed did not talk about their emotions in connection with the noticed changes, but seemed matter-of-fact. They did recognize the difficulty that these changes pose. They focused mostly on how the changes would impact them in the future and on the ways that they would adapt. For example, one property owner discussed a need to put up furniture in their restaurant before a predicted flood. Other stakeholder groups, such as septic professionals, observed changes directly related to their work.

"The water table has definitely been a big change in just a little bit of time that I've been [in this line of work]." -Septic Professional

Even over a short time, a large change has occurred that can have repercussions for professionals' work, as well as people in general. As much as people want this area to stay the same for future generations, they see it changing.

Across all interviews, there was discussion of perceptions of environmental and landscape change including erosion, climate change, and increased development. We also asked interviewees what they thought about flooding. Some interviewees spoke only about large storm events or how their properties did not flood because their lot was higher than the surrounding area. Most considered flooding to be the most substantial naturally occurring threat to life in general in the Outer Banks. There was broad agreement among interviewees that flooding and flood damage have increased due to a combination of development, higher water tables, and more intense storms.

One of the ways that development contributes to flooding cited by interviewees is by increasing impermeable surfaces. As the amount of permeable ground is reduced by development, there is a trend in increased "flashiness" of flooding, meaning the rate and amount of water collected spikes up (Usinowicz et al. 2017). This has increased runoff rates in the area and directly led to the collection of water in low-lying areas. One public official describes this:

"The Outer Banks is reaching a point where it's not development, it's redevelopment. We don't have that much land that's sitting that hasn't been developed. So there's an increase in stormwater because there's not much surface now that's not developed. So my concern is knowing that in many places we have not been able to develop new ways to manage that water." -Public Official

Because Nags Head is reaching maximum development density, the flooding has intensified and has become a more prevalent and destructive issue. It is a concern to interviewees that the stormwater management issue is going to get worse and will require innovative solutions.

In addition to impermeable surfaces preventing water from infiltrating into the ground, several interviewees recognized that the rising water table also prevents or reduces the ability of water (mainly from rain events) to percolate into the ground. While a relatively high water table has been a consistent issue in Nags Head because the sound and ocean both contribute to a naturally higher water table, interviewees viewed it as a persistent contributor to increased flooding. One resident stated:

"Well, I think as we have rain and […] as the water table rises, and [...] doesn't go back down, if it's gonna rain at high levels, then the effectiveness of your system depends on how much sand you have between your outflow pipe and the water table. For me, there's a concern, like I've definitely thought about that and worried about that and wished that we would slow the pace of development so we could get a handle on stuff like that before we build any more." -Resident

With more heavy rain and storm events predicted as a result of increased climate change (IPCC 2018), the community is in a sort of trap as described by this interviewee. With high water tables already, the area is even more susceptible to flooding because there is no more room for the water coming down to infiltrate. This impacts septic function and efficacy.

"We have certain setbacks from water tables because we want our effluent coming out of tanks and into the drainfield to have a filter process time through the sand before it gets introduced back into the water table. So the state actually came out with new rules. I think it was a year before last where our separation from the high water table mean to the bottom of a drainfield was 24 inches. They bumped it up to 28 inches now. And so where the fact that the water table has risen and we have an extra four inches of separation now, all of our systems are having to be really raised up." -Septic Professional

As this interviewee points out, high water tables have prompted changes in state regulated specifications for septic systems. This can mean more work and more expense for installing and repairing these systems. While septic professionals often described the consequences of the environmental changes, researchers focused more on the causes.

"*With the […] changes to sea-[level], our impacts from sea level rise [affect the] groundwater table and individuals are having to spend money […] to maintain their property much more than they used to"* -Researcher

This demonstrates the underlying cause of this higher water table: sea-level rise. This specific phenomenon is exaggerated in a barrier island system because it is surrounded by water that can infiltrate into the groundwater. A typically higher water table in tandem with sea-level rise means greater vulnerability to flooding and resulting damages (IPCC 2014).

Another major influence on flooding noted by the interviewees was an increased intensity in storms. In combination with a high water table and increased presence of impermeable surfaces, storms often act as triggers for flood events. It was noted by several interviewees that storms have been increasing in both intensity and frequency over the past few years, with one stating:

"I think we have seen an increase in the last five years in the frequency and intensity of some of these storms. And I think some of the areas that have historically flooded are maybe flooding more severely." -Public Official

This interviewee notes changes in only a five-year period. As storms and their effects are a threat to barrier islands, such a fast rate of change is worrisome for the future, even with more implementation of mitigation techniques.

In general, interviewees from all groups have noticed that the environment is changing. When asked an open-ended question about environmental change, they did not mention wastewater interaction with ground and surface water, but with prompting and subsequent discussion, they demonstrated that they understood how the interaction could occur.

Environmental change is pivotal to analyzing and solving the septic contamination problems facing Nags Head. All stakeholder groups recognized changes in the hydrosocial cycle in varying intensities, as causes of flooding. Interviewees noted changes in the social aspect of the cycle and increased surface impermeability through development. They also noticed changes in the hydrologic part of the cycle such as a higher water table and more intense storms. The interactive and cumulative nature of the impacts of social and hydrologic changes demonstrates the connections between humans and their environment. This cycle is no longer two separate parts, but the interworking of both.

Risk Perceptions

The heart of our research was to understand how risks of contamination are perceived by different stakeholders in Nags Head. Risk perceptions varied across stakeholders; some focused on septic effluent contamination of groundwater and surface water, while others focused on contamination of swimmable waters, and still others focused on public health risks in general. Interviewees in the resident and property owner groups perceived little to no risk of groundwater and surface water contamination from wastewater, while the other stakeholder groups perceived a high risk of contamination.

One of the most common risks discussed by resident and property owner interviewees was risks to the ocean or sound, the water around them that contributes to their sense of place. One stated:

"I realize that wastewater directly affects the family. And the ocean quality in the ocean can really affect our lives, and so it's very important. […] You want the water to be clean, you want some confidence it doesn't have high bacteria levels, but it's really safe." -Resident

Interviewees like this one seem unsure whether to trust recreational waters to be safe. This and other property owners' primary concern is with the recreational waters rather than the ground and surface water on the island. In some circumstances, when prompted, property owners described the potential for septic contamination; however, they followed up by discussing a need for further education on the topic. In general, property owners we interviewed perceived little risk of wastewater contamination.

Risks perceived by septic professionals differed from all other groups and were more specific to their work. One professional described:

"*When [septic systems] are conventional gravity flow systems, it changes the whole dynamic due to a need to pump up."* -Septic professional

This quote demonstrates the risk implied from needing to shift installation techniques. Septic professionals, working with the equipment and infrastructure everyday, are well aware of the risks of contamination for human health, and believe that there is a need for more education for the general public and property owners in the area. One septic professional described watching people play in flooded waters after a storm and noted the public health risk due to the high probability of septic systems being under water and leaking effluent. A public official described similar potentially risky behavior:

"And we have, over the past three years, every summer and fall, had to put out advisories reminding people to watch your children that played in the rain water. Children see this going, 'Oh! How fun! Let me go to my yard, look at all this water I don't normally have. I'm loving it.' […] For us it's like, 'No, please. I know it looks appealing, but let's not do that because of the increased risk of disease spread and health issues associated with that.'" -Public Official

In more than one circumstance, people are making potentially unsafe choices in the face of flood waters. Public officials are very concerned about the risks of ground and surface water contamination by wastewater for their constituents and visitors. Researchers seemed to be the most familiar of the groups we interviewed with the reasons for flooding and the possible implications of flooding for contamination. One researcher stated:

"The water table in eastern North Carolina is very proximal to the surface of the land and so one of the biggest issues related to septic system function in eastern North Carolina happens to be the soil type and infiltration and the water table height. […] So in many cases, the [drain] field for a septic system in eastern North Carolina can actually be residing within the water table. And that particular case the treatment that one would expect from a septic system will not

actually take place as designed and the treatment efficacy of the system will be very much decreased." -Researcher

This researcher is very knowledgeable about the water table and how it interacts with septic systems as it rises. Researchers we interviewed perceived high risk for interactions between groundwater, surface water and septic wastewater in Nags Head as well as more generally for barrier islands.

While risk perceptions varied, researchers, septic professionals, and public officials perceived greater risk of groundwater contamination than the property owners we interviewed. Higher risk perception seemed to correlate with possessing more detailed information about wastewater treatment systems and the water table. This suggests that the greatest inhibitor to developing an appropriate level of risk perception may be lack of education. In this way, lack of education or detailed awareness of the issue acts to inhibit property owners from taking appropriate action to implement solutions to mitigate risk. This poses a risk for the present generations as well as those to come.

Septic professionals attributed lack of knowledge about septic tanks to a variety of causes, but all resulted in reduced understanding of groundwater-wastewater interaction risks. One of the causes of this lack of understanding is described by a professional:

"We have a fair number of people that move here from other areas that aren't used to being on septic" because "properties change hands all the time." **-**Septic Professional

From this professional's perspective, most property owners are absentee and do not know or understand the functionality of their septic system, especially in terms of maintenance. Although there are incentives in place to get people to do annual inspections and maintain their system, many property owners are not aware of these incentives. The only time they really become aware of an issue or think about their septic system is when a problem arises. However, the potential for wastewater interaction with ground and surface water can be a perennial risk.

Addressing Risk

Our interviews suggest lack of awareness and education inhibits property owners from developing an appropriate level of risk perception about ground and surface water contamination by wastewater, and taking appropriate action to mitigate the risk. Septic system maintenance is the responsibility of each individual property owner, including absentee owners (owners using the house as a vacation home or as a place that is not one's main residence). Many people we interviewed explained the role of individual responsibility:

"Residents just need to do their part and look at their own systems, maintain their own systems and have them inspected. Have them pumped when they need to be pumped" because "people should know: their actions have a profound impact on the quality of life we have here." -Public Official

There was a strong sentiment among some interviewees such as this one, that each individual's action impacts the greater whole. Because of this, people must be informed and proactively maintain their piece of the island so that it does not become a larger issue. Individual responsibility is complicated by the summertime influx of short-term visitors who seem equally unaware of septic issues. Town officials discussed this issue:

"Obviously, the town has a Septic Health Initiative that's designed to help people to perform that maintenance and educate them on it. […] It's a little bit of a learning curve for some of the folks. And then, you know, properties change hands all the time. You're never really dealing with the same group of people, especially in a rental community where a lot of the homes are partial or a full investments designed to generate rental income." -Public Official

Town officials are struggling to address the need for better educational outreach, including increasing the efficiency and sheer volume of educational outreach materials. While this is a challenge, the fact that septic professionals and property owners both have some knowledge about the outreach initiative, as seen in the interviews, is a good sign. Septic professionals recommended maintenance measures that should be followed, but concurred that contamination problems will likely be exacerbated without a heavier emphasis on education about septic systems and potential groundwater-wastewater-surface water interactions. One septic professional suggested that realtors provide information to potential home buyers and renters.

Another reason informed property owners and residents can be critical in reducing contamination risk is that, once informed, they can prompt Town officials to take action to address their risk perceptions. The Nags Head government officials we interviewed also had a plethora of ideas on efforts the Town could take on behalf of the community. They had a lot to say about their work on a daily basis, and their efforts to participate in long-range planning. They have to plan for storms and deal with their aftermath. The National Flood Insurance Program came up multiple times in interviews with Town officials. Many expressed concerns that the revised flood maps take a large amount of Nags Head out of official flood zones. This reduction in the extent of the official flood zone could induce property owners to lower their risk perception of flooding and potential contamination from wastewater.

The public officials we interviewed all recognized the increase in intensity and frequency of flood events and storms, and discussed ways in which they have been dealing with that such as groundwater lowering and inserting culverts. This official discusses the goals of groundwater lowering:

"We've installed groundwater lowering systems in some areas to deal with flooding and some engineers have suggested that doing that on a widespread basis will artificially lower the groundwater and will effectively improve water quality, because now you're- you're increasing the separation to groundwater, not by fill, but by lowering the groundwater." -Public Official

By lowering the groundwater in key locations and undertaking additional efforts, the Town is active in mitigating this issue. These techniques may need to expand to other locations in the future to lower the risk of contamination by wastewater and flooding.

Interviewees seemed to know about the Todd D. Krafft Septic Health Initiative, but because of the aforementioned difficulty in distributing information about the program, interviewees felt that other people did not, and therefore it wasn't as effective as they thought it could be. Aside from that, non-public official interviewees mostly had glowing reviews of the job that the Town of Nags Head is doing to be proactive in their planning efforts. However, there were some criticisms such as one interviewee who stated:

"I think that if they were very concerned about the flooding and very concerned about the people walking through all this water and everything, […] they would probably move some funds towards rectifying the situation." -Resident

The biggest critiques of the Town of Nags Head's efforts were from the public officials themselves, including the need to test water quality year round, not just in the summer, and to improve the impact of the Todd D. Krafft Septic Health Initiative.

<u>Implications</u>

Stakeholder groups and individuals exhibited differences in how they perceived and understood the risk of surface and groundwater contamination from wastewater in Nags Head. Property owners and other local interviewees exhibited strong place attachments and sense of place. This sense of place arises from repeated engagement with the environment over time through recreational activities, livelihoods, and social and familial connections. Sense of place predisposes these local interviewees to recognize changes in the hydrosocial cycle that leads to increased risk of flooding. These changes include increased land cover impermeability, increased storm intensity and frequency, and a higher water table.

Recognition of hydrosocial change did not necessarily translate into perception of risk of groundwater-wastewater-surface water interactions and resultant contamination. Compared to researchers, Town officials, and septic professionals, interviewees in the property owner stakeholder group expressed lower overall risk. Their risk perceptions focused mainly on cleanliness of recreational waters (the ocean and the sounds) as opposed to groundwater and wastewater interactions. While they seemed to recognize the potential for wastewater interaction and how detrimental such interactions could be for water quality, our findings suggest there is little in-depth understanding of how or why this might occur among property owners and visitors.

Other stakeholder groups stressed the importance of individual action to address their perceived risks of contamination since each septic tank is the responsibility of the individual property owner. As a result, all stakeholder groups indicated that education and outreach efforts to raise awareness levels and improve septic maintenance efforts were needed. Additionally, there was a common view that there may need to be some sort of broader, long-lasting adaptive action that may shift life on the Outer Banks and potentially alter people's sense of place. One interviewee stated:

"We're loving this island to death and the necessity that we have some sort of visioning which says this is the kind of environment we want to live in. And therefore we've got to understand that there might need to be some limitations even though they are not currently necessary or regularly regulated." -Researcher

This attitude demonstrates that solutions beyond septic system maintenance will be necessary. Interviewees also felt so passionate about helping save the place they are connected to. A researcher shares a similar sentiment:

"But what we do have to begin to understand is that we're just not going to move away. We're just not going to give up. That's not what people do. People desire to be here for a reason. If we're wise enough and more sensitive enough to begin to realize those subtle changes, then I think we're going to see, either with our own intellect or with our own wallets, economic impacts, that we no longer are that wonderful place that we call the Outer Banks, and we'll begin to make some changes which will protect that sort of environment we want to live in." -Researcher

Nags Head is home to people that love it and all it has to offer them. People's deep place attachments can motivate them to act on the changes occurring around them. From all interviewees, no matter the perceived risk or concern, it was clear that this community wants to be resilient, and that they will continue to work towards finding sustainable solutions in the face of environmental change.

Limitations

Our study of stakeholder perceptions was limited by the number of interviews we were able to conduct during our relatively short study period. There were six more people interviewed from the researcher and public official stakeholder groups than the property owner group, which could have shifted reported perceptions of risk higher than they actually are. In addition, since we did not sample to saturation, we may have missed other relevant information and perspectives. Because of the nature of qualitative data and interviews, our conclusions and results cannot be generalized beyond our interviewees to the population of Nags Head, the Outer Banks, or other coastal locations. The interviews do offer emerging insights into how risk perception can impede mitigation action to address ground and surface water contamination by wastewater.

Conclusions

The goal of this study was to examine the interactions between surface water, wastewater, and groundwater, and the public perceptions of the risks associated with rising water tables in Nags Head, North Carolina. Using multidisciplinary qualitative and quantitative analyses, we endeavored to answer three research questions:

1. What areas of the Gallery Row subwatershed are susceptible to wastewater-groundwater interactions?

2. Have nutrient, bacterial, and chemical wastewater indicator concentrations in surface and groundwater reservoirs decreased since the October 2019 lowering of the groundwater in the subwatershed?

3. How do different groups and individuals perceive and understand the risk of surface and groundwater contamination from wastewater in Nags Head, NC?

Based on geospatial analyses of water table height and ground elevation, we found that about half the area of the Gallery Row subwatershed is consistently susceptible to interactions between under-treated septic wastewater and groundwater during the sampling period. Areas of highest susceptibility are between highways and west of highway 64. Though both ground elevation and water table elevation influence susceptibility, it appears ground elevation is a stronger determinant of susceptibility. Low-lying, flat areas are the most susceptible to flooding. Though our model has some limitations, we believe it brings attention to a possible water quality issue in Nags Head.

Bacterial indicators have shown that water quality has improved from 2018 to 2019 in the SW and B14 well sites. We cannot determine the exact source of this improvement, but the efficacy of groundwater lowering should be explored further since it is a possible explanation for this improvement in water quality. Another possible explanation is the drier conditions of this year compared to last year's study. For nutrients, we could not tell that the presence of nutrients were specifically from human sources. Optical brighteners were used as an indicator of contamination of groundwater by septic effluent. However, because of the many confounding variables associated with optical brighteners, including that significant levels of them were not detected in any of the water samples, they were not a good indicator of bacterial origin. This could be explored further in next year's study. Since there was a decrease in bacteria concentrations from last year to this year, our hypothesis that the groundwater lowering improved water quality in the Gallery Row subwatershed is supported by our findings.

When gauging risk perceptions, we found that in line with our hypothesis, three stakeholder groups (public officials, researchers, and septic professionals) perceive a high risk of contamination of groundwater from poorly maintained septic systems. Property owners, however, perceive a risk of the sound and the ocean being contaminated, and did not typically address septic interactions. More awareness of groundwater-wastewater-surface water contamination could be raised through outreach, and would likely be successful in mitigating the issue because of people’s deep connections to this area and their awareness of many environmental changes that are already occurring, making them more motivated to change personal behaviors.

Because of the limitations of this study, more research into the interactions between wastewater, groundwater, and surface water in Nags Head is warranted. There are many improvements to data collection that could be made to the study in the next year to increase the accuracy and connectivity of the study’s conclusions. For bacterial analyses, sampling the same wells for water quality, identifying additional indicators of bacterial origin in wastewater, and looking at water use records will help explore connections between localized and seasonal water use and groundwater-wastewater-surface water interactions. Mining for data on septic system age, type, and inspection history will improve our understanding of the relationship between septic systems and their effects on the hydrologic cycle. Next year’s study could further explore the hydrosocial cycle through a sociological lens by looking into how the considerably larger seasonal population of Nags Head can be educated about groundwater-wastewater-surface water interactions.

The findings of our study indicate that Nags Head would benefit from more action by both individuals and decision makers for the Town to ameliorate issues arising from groundwater-wastewater-surface water interactions. More research into these interactions is warranted so that the temporal and spatial limitations of our study can be minimized. Our study helped to demonstrate the risk of these interactions through GIS analysis to determine if the Town’s recent actions, including the Todd D. Krafft Septic Health Initiative and the recent groundwater table lowering, have been successful. Our findings indicate that the groundwater lowering may have been successful in improving water quality in the at-risk areas, but more research and connectivity is needed to strengthen these conclusions. More outreach and education for the general public and seasonal residents of the town is warranted in order to increase the general knowledge level of the public’s perception on wastewater risk. The three-episode podcast *Flushed: A Potty Talk Podcast*, which was produced concurrently with this report and uses the study’s findings, would be an effective tool to use in this outreach.

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Appendices

APPENDIX A

Hydrology Field Sampling Protocol

Field supply list

- 8 Pre-labeled sampling bottles for samples (4 acid-washed for nutrient analysis (<u>BROWN</u>) and 4 autoclaved/sterile for bacterial analysis (<u>CLEAR</u>))
- 2 extra sampling bottle (1 of each)
- Sharpie
- Lab tape
- Extra ziplocks
- Pikstik
- 2 Bailers (1 extra
- Twine
- Scissors
- Bucket for groundwater sample environmental measurements
- Large cooler with ice
- Hand sanitizer
- First aid kit
- Technu
- Sunscreen
- Bug spray
- Deionized water rinse/squirt bottle
- Kimwipes in ziplock
- YSI 85
- Solinst water level gauge
- GPS
- Latex gloves
- Notebook
- Writing instrument
- Dress appropriately for sites
- Yard stick
- Well opening supplies – hex wrench, bolt cutters, box cutter, screwdriver, zip ties
- Trash bag for used gloves and wipes

Sample collection dates and times

Baseline samples

- Sept. 21
- Oct. 11
- Oct. 25

Wet samples

- Oct. 9
- Oct. 10

Sampling locations

<u>Groundwater sampling locations (GPS, directions, and map below)</u>

- Nags Head Woods control (35.98481°N, 75.66299°W)
    - Directions: taking Ocean Acres Drive past the NH Woods visitor center, make a left on the gravel road through Nags Head Woods. After 0.4 miles, pass gate "3" and well is immediately after. You can pull out of road on the road just south of well. There are 2 wells. The one to be sampled is that which is blue (not silver).
- B12 (35.98497°N, 75.65°W)
    - Directions: Go to the end of Oa Knoll Rd. (stay to right at split with Waterside Dr.). The well appears to be in the yard of the orange house, to the right as you approach the front of the house, but is actually located on an easement. Park in the cul de sac and access via the cleared trail between houses at the western end of the cul de sac. The well is on the left as you go down the trail.
- B14 (35.98846°N, 75.64186°W)
    - Directions: The well is directly across the beach road (NC 12) from Red Drum, between a wooden fence and the road. It is flush with the ground.

<u>Surface water sampling location</u>

- SW3 Surface water ditch on the south side of Red Drum, running perpendicular to S. Virginia Trail/Hwy 12/Beach Road – be sure to fully pull off of 12 and its bike lane when sampling N 35.98823 W 075.64204 **(This is the ditch near B14)**

Sample collection protocol

- It is very important to use aseptic technique for all aspects of bacterial sample collection and processing! Avoid sample bottles and bailers coming in contact with anything (hands, ground, water other than sample water) aside from the samples!
- Do not let the GPS or YSI handheld screen get wet!

At each sampling location:

- Double-check that you are at the correct location via visual markers and GPS
- Record observations about the study site, weather, date, time, movement of water, etc.

At surface water sampling sites:

- <u>Record environmental measurements using YSI</u> (YSI User Manual)
- Calibrate for DO (See pg. 14 of YSI User Manual)
    - Use the 'Mode' button to swap to measuring DO – The units will be mg/L or % - then press both the 'up' and 'down' arrow keys at the same time. The machine will ask for elevation to the nearest 100 ft, so leave it on 0 and press 'enter'. The machine will then begin calibrating – let it stabilize until the readout on the screen stops fluctuating. Once it's stable press the 'enter' key. The device is now calibrated for DO.

- Record DO (mg/L), salinity (ppt), temperature (C), and conductivity (µs) – *make sure that the top and bottom of the probe are immersed in the water (you may have to hold it sideways away from the bottom)*
- Rinse the YSI with DI water and dab with a kimwipe after each measurement
- Collect samples
    - Uncap the sample bottle (be sure not to touch the inside of the cap or bottle)
    - Use Pikstik to hold bottle and collect sample from just below the surface of the water – *try not to touch the bottom and resuspend sediment*
    - Recap the bottle without touching the inside of the lid or mouth of the bottle
    - Immediately place on ice, in the dark

At groundwater sampling sites:

- Record water level
- Collect water from the well using a bailer
- Unwrap the bailer and be sure not to touch the ground or anything else with it. Use latex gloves to avoid contamination
- Bail 2-3 gallons of water out of the well (half a bucket) and dispose of away from the well
- Bail 4 more times into the bucket for environmental measurements
- <u>Record environmental measurements using YSI</u>
    - Calibrate YSI for DO as above
    - Measure DO (mg/L), salinity (ppt), temperature (C), and conductivity (µs) of water sample collected in bucket – *again, make sure that the probe is immersed in the water*
    - Rinse the YSI with DI water and wipe with a kimwipe after each measurement!
- <u>Collect sample using the bailer</u>
    - Uncap the sample bottle (be sure not to touch the inside of the cap or bottle) and collect sample using the bailer and recap the bottle without touching the inside of the lid or mouth of the bottle
    - *Immediately place on ice*, in the dark

Transport samples back to the lab and process samples ASAP

APPENDIX B

Bacterial Analysis Protocol

IDEXX procedure for total coliform, E. coli, and enterococcus bacterial samples

It is very important to use aseptic technique for all aspects of bacterial sample collection and processing!

1. Plug in Qunti Tray sealer (when the light is green, it is ready to use)
2. For each water sample, process 2 replicates of each the Colilert and Enterolert tests, *unless the salinity of the sample was 0 ppt, in which case, only process 2 replicates of Colilert*
    a. Remove shrink wrap from sterile 100ml vessels to be used for analysis – 2 per water sample.
    b. Label each vessel (enter vs coli, date, time, OBXFS).
    c. Measure 90ml of autoclaved water into graduated cylinder and transfer to each of the labeled empty 100ml vessels.
    d. Snap open Colilert/Enterolert media packets and pour into vessel containing 90ml of sterile water (ensure all of the media was poured out, sometimes it helps to tap them all upside down before they are opened to loosen the media inside the packet)
    e. Close cap and agitate, let rest. Repeat until all of the media has dissolved.
    f. Add 10 ml of samples to the appropriately labeled vessels using a sterile pipette tip for each water sample (the same tip can be used for replicates of the same sample. ***Be sure to invert samples immediately before withdrawing the 10 ml samples.***
    g. Close cap and invert the diluted sample with media several times to mix thoroughly.
    h. Pour contents of vessel with water, media and sample into a QuantiTray 2000.
    i. Place Quanti Tray into molded rubber mat and insert into the Quanti Sealer. Remember to keep the tray upright because if the top is not closed you could potentially spill it all over the place (Figure 1.)
    j. Remove sealed Quanti Trays and place into appropriate incubator (Colilert - 35°C±0.5°C ; Enterolert - 41°C ± 0.5°C)
    k. PLACE CLEAR BOTTLES IN THE REFRIGERATOR
3. Incubate for 24 hours
4. After incubation, remove Quanti Trays and count large and small positive wells using a blacklight (for some) and record on data sheet.
    a. Enterolert positive glow blue
    b. Colilert positive
        i. E. coli glow blue
        ii. Total Coliforms turn yellow
5. Use IDEXX Most Probable Number (MPN) data sheet to determine MPN of colony forming units (CFU) of bacteria per 100ml of sample. Remember to move the decimal over 1 place to the right because of your dilution. The data sheet gives results for 100ml of sample, you used 10ml.

APPENDIX C

Nutrient Analysis Protocol

Filtration for nutrient samples

- To avoid nutrient contamination between samples, be sure to rinse the filter box and towers and transfer vessels with deionized water (3x) after any of these things had come in contact with a sample.
- To avoid dilution of nutrient samples by rinse water, rinse the manifold components and falcon tube with sample if there is any deionized water present after rinsing.
- **Be sure to invert samples immediately before pouring them into the filtration towers to make sure that the sample is well-mixed.**

1. Set-up filtration manifold
    a. Box connected to filter via tubing; filter connected to vacuum pump via tubing
    b. Label falcon bottles with your sample names, dates, times (for storm samples) and OBXFS and place in foam of filter box to space such that the filtrate dispensers are inside of the tubes when the filtration box top is put in place. Do not touch inside of the tubes.
    c. Place top on filtration box.
    d. Place pre-combusted Whatman GF/F filters onto the filtration manifold. Place filtration towers on top of the filters, making sure that they are seated/sealed properly (they should be straight and not wobbly).
    e. Invert water samples and immediately pour the appropriate amount into the corresponding filter towers
        i. You need at least 30 mL of filtrate
        ii. For samples with a lot of sediment and/or algae, filter small volumes at a time, changing out filters in between by removing the entire box top with the filtration towers attached
2. Turn on vacuum pump (not above pressure of 15 mmHg)
3. Ensure that white knobs attached to the manifold are turned *down* for towers being used.
4. When filtration has been completed and you have at least 30 ml of sample in the falcon tubes, remove the towers and filtration box top and rinse with deionized water. Remove falcon tubes containing samples and cap.
5. Transfer samples to a Ziplock with the date, "OBXFS", time (if a storm sample), and "nutrients" and place ***IN THE FREEZER***. Be sure to add the samples to the sample log on the outside of the freezer.
6. These samples will be analyzed for dissolved nutrients using a Lachat Quickchem in November.
7. Rinse the graduated cylinders, filter towers and all parts of the filtration box with DI water.

8. PLACE THE REMAINING BROWN BOTTLES WITH UNFILTERED SAMPLE IN THE REFRIGERATOR

*some sample will finish filtering before others. When the samples finish filtering, close the prongs of the values so that the rest of the samples can retain the pressure. UP/DOWN prongs=open, sideways=closed

APPENDIX D

Optical Brightener Analysis Protocol

I. Background

Fecal coliform concentrations in aquatic water bodies are often used as a water quality indicator by federal, state, and local agencies, but their human versus non-human sources cannot be attributed. Optical brighteners offer an alternative environmental indicator that can be attributed to human-generated waste water. Optical brighteners are compounds added to nearly all modern laundry detergents, which adhere to fabric and absorb and emit light, countering the yellowing appearance of whites and making other colors appear brighter (Thompson and Miskowitz 2010). Laundry wastewater is the largest contributor of brighteners to wastewater systems, and can be used as an indicator of wastewater contributions to a water reservoir.

Optical brighteners are excited by light in the near UV range (360-365nm) and emit light in the blue range (400-440 nm). After light absorption, fluorescence is given off during the second exited state and can be measured by a fluorometer (Tavares et al. 2008).

II. Materials

A. Fluorometer (Trilogy, Turner Designs, Sunnyvale, California).
B. Optical Brightener Module (Turner Designs, part number 7200-047): UV LED excitation light to cause fluorescence signal at a 90 degree angle
C. Nalgene 250 mL opaque collection bottles
D. Refrigerator
E. Polystyerene Cuvettes
F. Cooler
G. Scale (1.0 mg readability)
H. Fluorescent Brightener 28 (M.P. Biomedicals Cat#158067)
I. Deionized water
J. Micropipetter (1-10 mm)
K. Pipette tips
L. Graduated cylinders
M. 250 mL opaque bottles for calibration curve sample preparation
N. Timer
O. UV light
P. Beakers
Q. Tub to hold UV light over beakers

III. Sample Collection and Storage

A. Collect samples from the targeted waterbody in Nalgene 250-1000 mL sampling bottles that have been acid cleaned. You will need at least 100 mL of each sample for UV analysis. Bottles should be labeled and kept on ice and in a dark cooler after collection.

B. Upon arrival to the lab, samples may be read after reaching room temperature or refrigerated at 4°C for up to five (5) days.

C. Remove the samples from the refrigerator or cooler at least one hour before sample analysis. **The samples must be at room temperature for analysis! You can also turn on the fluorometer at this time to allow it to warm up.**

IV. Fluorometric Calibration and Standard Curves

A. An optical brightener optical kit should be installed in the fluorometer before any samples are read.

B. Make ten-fold serial dilutions from a solution of 100 mg powdered Fluorescent Brightener 28 in one liter deionized water (100 ppm). The 100 ppm solution has been made for you. This concentration level is will not be measured on the Trilogy fluorometer. Please use the micropipette to measure 5 ml samples into the plastic 50 ml volumetric flasks (be sure to switch the pipette volume to 5 ml to begin with and set back to 10 ml before placing back with the bacteria analysis materials).

C. Mix 5 mL of the 100 ppm Fluorescent Brightener 28 solution with 50 mL deionized water to create the first dilution (10 ppm). This concentration level will not be measured on the Trilogy fluorometer.

D. Mix 5 mL of the 10 ppm solution with 50 mL deionized water to create the second dilution (1 ppm).

E. Mix 5 mL of the 1 ppm solution with 50 mL deionized water to create the third dilution (100 ppb/0.1 ppm).

F. Mix 5 mL of the 0.1 ppm solution with 50 mL deionized water to create the third dilution (10 ppb/0.01 ppm).

V. Sample Analysis

A. Turn on the Trilogy using the switch on the back (see quick guide) and choose UV from the home screen.

B. Allow fluorometer to warm up for 30 minutes.

C. Invert each sample several times before analysis, each time that you pour the sample into the cuvette.

D. Fill cuvette approximately 2/3 full using a disposable plastic pipette or by pouring. Make sure that there aren't any air bubbles in the sample by tapping the cuvette gently on the counter.

E. Carefully wipe the outside of the cuvette, ensuring that there isn't any liquid or fingerprints on the bottom two thirds of the plastic.

F. Place the cuvette in the fluorometer and push the green button on the touchscreen that says "Measure Fluorescence Raw". Wait for instrument to provide RFU value.

G. Record reading in sample spreadsheet.

H. Dispose of 9mL sample water and rinse cuvette with deionized water.
I. Repeat steps C through G three times for each sample.
J. Rinse the cuvette three times with deionized water before analyzing the next sample.
K. If the mean concentration calculated by the calibration curve and averaged in the spreadsheet is <5 mg/L (5 ppm), the sample can be considered to be negative for optical brighteners.
L. If the mean concentration calculated by the calibration curve and averaged in the spreadsheet is >5 mg/L (5 ppm), proceed to UV light exposure steps.

VI. UV light exposure

A. Pour approximately 50 ml of each sample into glass beakers. Make sure to record which beaker each sample is in (1-4).
B. Place beakers in the plastic UV exposure tub (labeled as such; Figure 1) and place UV light over the top.
C. Turn on the light and begin recording the time (2 consecutive 5-minute increments with measurements each 5 minutes – see below).

UV exposure 1: Expose samples directly to UV light for 5 minutes and then measure fluorescence again. Calculate the percentage of reduction in fluorescence after 5 min compared to before UV exposure (Figure 2).

- If % reduction < 8%, conclude the sample is negative for optical brighteners.
- If % reduction >30%, conclude the sample is positive for optical brighteners.
- If % reduction <30% and >8%, continue to Step UV exposure 2.

UV exposure 2: Expose samples under UV for another 5 min (i.e. accumulatively 10 min), measure fluorescence, calculate the ratio of % reduction in fluorescence after 10 min UV exposure over % reduction after 5 min UV exposure (Figure 2).

- If the ratio is no less than (equal to or greater than) 1.5, conclude that the sample is negative for optical brighteners.
- If the ratio is less than 1.5, conclude that the sample is positive for optical brighteners.
- Step 4.

Out of the 3 replicates:

- If all three are positive, conclude that the sample is positive for optical brighteners.
- If two out of three are positive, conclude that the presence of optical brighteners within the sample is undetermined.

VII. Results

Sample analysis will provide qualitative results. The magnitude of the fluorescence reading indicates the relative strength of optical brightener through multiple result and multiple site comparisons.

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APPENDIX E

Interview Guides

Septic Professionals and Public Officials

Materials:

Consent document (2 copies)
iPad (*Remember to check battery life*)
Microphone + connector
Charger
Pen/pencil
Clipboard

Introduction:

Thanks again for agreeing to be interviewed for this study. I want to remind you that there are no wrong answers to any of the questions – we're interested in your personal experiences and thoughts on these topics.

We would like to record this interview and use it to make a podcast that will be available for anyone who would like to listen to it. The recording may also be used in future academic research. There is a space on the consent form where you can give your permission to record.

Ask the interviewee to read and sign the consent document, including their indication about recording.

Do you have any questions for me before we start?

When starting the recorder, ask him/her to mark the recording by saying a few sentences, like his/her name, the date and where you are.

Outer Banks & Water:

I'd like to start by asking you to tell me a little about your history in this area.

Where around this area do you live?

- How long have you lived there?
- How did you come to live there?
- *If not living in Nags Head*: How much does your work bring you to Nags Head?

Tell me about your company and the kinds of work that you do.

- While you may not have a typical day at work, what are some of the main activities or tasks that go into your work?

Being in the Outer Banks means being surrounded by water. How often do you go out to the ocean or sound?

- What do you like to do while you're there?
- How do the ocean and sounds matter to you?
    - *If you need to clarify:* How are the ocean and sounds important to you? or What do they mean to you?
- What roles do you think these waters play in the life of the town?
- How do these waters shape the community?

<u>Environmental Health & Flooding:</u>
I'd like to continue talking about the ocean and water with you, but I also want to ask you, when you think about the environment in general, what environmental conditions have you noticed that have changed in the Outer Banks?

- *Listen for or possible prompts*: precipitation patterns (storm frequency, storm intensity, rainfall amounts), air or water temperature, erosion rates, water/tide level, landscape/vegetation
- *Follow-up*: What do you think is contributing to those changes? (*go through each change the interviewee mentions as necessary*)
- Would you say the same is true specifically in Nags Head?

How would you say your work is affected by storms?

- *Follow-up*:
    - How much of a concern is flooding for you personally?
    - Has flooding in this area changed in any way over time? In what ways?
    - How do you deal with the risk of storms and flooding?

Based on your experience, what preventative measures can property owners take reduce the impacts of flooding?

<u>Wastewater:</u>
Now I'd like to ask you about wastewater.

If you were describing a septic tank system and how it works to someone who had never heard of one, what would you tell them?

What sorts of information gaps have you noticed among local property owners in terms of how their septic tank systems work?

- What about in terms of how they need to be maintained?
- Why do you think these gaps exist?
- How do you think these gaps could be addressed?

What kind of maintenance should property owners with septic tank systems be conducting?

- What would you advise people in terms of how to take care of their septic tanks and leach fields?

- How often?
- What are the approximate costs?

What challenges to the effectiveness of wastewater treatment by septic tank systems do you think people should be thinking about as the coastal environment changes?

- How concerned are you about contamination of surface waters from leaching from septic tank systems during flooding events or other times when soils stay saturated?
- How concerned are you that these events may become more frequent and widespread in the future?

Some areas of Nags Head have package plants for wastewater treatment instead of septic tank systems. What do you think about that as an alternative to septic tank systems?

What do you think residents and the town of Nags Head should be doing to manage wastewater into the future?

How do you think current regulations for wastewater treatment are working in Nags Head?

- How would you like to see those regulations changed?
- If you were in charge of making decisions about wastewater, what if anything would you do differently?
- What do you think the public thinks about the current regulations?

<u>Closing Questions:</u>
That's everything that I wanted to ask you. Is there anything you'd like to add about water, flooding, wastewater or anything else?

Do you have any questions for me?

<u>Conclusion:</u>
Thank you so much for participating in this interview. If at any time you have any questions about this interview or our project, you can feel free to contact me or our project coordinator. *Provide a copy of the consent form and any necessary additional contact info.*

You've been incredibly helpful, and I appreciate you giving us your time and insights.

Do you know of anyone else you think would be a good person for us to interview?

- *Ask for contact information to go along with names*.
- *Clarify that they should not take it upon themselves to ask people to do interviews. If they ask about contacting the person first, explain that they can reach out to the person and ask if they would be willing to hear from a student about the project and then think about participating.*

Thanks again for participating in this study. We will be creating a podcast from our findings and about our research this semester. This will be available early next year. We will be playing some clips from it as part of a public presentation about our study at the end of the semester. You are more than welcome to attend. It will be Thursday, December 12 from 2:00-4:00pm at the Coastal Studies Institute.

Property Owners

Materials:

Consent document (2 copies)
iPad (Remember to check battery life)
Microphone + connector
Charger
Pen/pencil
Clipboard

Introduction:

Thanks again for agreeing to be interviewed for this study. I want to remind you that there are no wrong answers to any of the questions – we're interested in your personal experiences and thoughts on these topics.

We would like to record this interview and use it to make a podcast that will be available for anyone who would like to listen to it. The recording may also be used in future academic research. There is a space on the consent form where you can give your permission to record.

Ask the interviewee to read and sign the consent document, including their indication about recording.

Do you have any questions for me before we start?

When starting the recorder, ask him/her to mark the recording by saying a few sentences, like his/her name, the date and where you are.

Nags Head & Water:

I'd like to start by asking you to tell me a little about your history in Nags Head.
How did you come to live in Nags Head?

- How long have you lived here?

Can you tell me some of the main reasons that you've stayed here?

- What are your favorite things about it?
- What are your least favorite things about it?

Being in Nags Head means being surrounded by water. How often do you go out to the ocean or sound?

- What do you like to do while you're there?

How do the ocean and sounds matter to you?

- If you need to clarify: How are the ocean and sounds important to you? or What do they mean to you?
- What roles do you think these waters play in the life of the town?
- How do these waters shape the community?

Environmental Health & Flooding:

I'd like to continue talking about the ocean and water with you, but I also want to ask you, when you think about the environment in general, what environmental conditions have you noticed that have changed around Nags Head?

- Listen for or possible prompts: precipitation patterns (storm frequency, storm intensity, rainfall amounts), air or water temperature, erosion rates, water/tide level, landscape/vegetation
- Follow-up: What do you think is contributing to those changes? (go through each change the interviewee mentions as necessary)

How have you and your property been affected by storms?

Follow-up:

- How much of a concern is flooding for you personally?
- If livelihood depends on water: How have storms impacted your [business/ livelihood]?
    - As a result, how have you had to change your practices or the way you do business?
- Could you describe the worst flooding event that you have experienced here in Nags Head?
- Has flooding changed in any way over time? In what ways?
- How do you deal with the risk of storms and flooding?

What sorts of preventative measures do you take, if any, to reduce the impacts of flooding on your [property/home/business]?

- Have they been effective?

What sorts of preventative measures have you noticed other community members taking to reduce the impacts of flooding?

Wastewater:

I'd like to ask you about wastewater, and when I say wastewater I'm talking about water that has been used in homes and businesses and then released down different kinds of drains.

How familiar would you say you are with the ways wastewater is treated in Nags Head?

How is your [choose one: home's or business's] wastewater treated?

If septic tank system:

Have you ever had any issues with your septic tank system? What happened?

What kind of maintenance have you had to do?

- Where did you get your information about what to do to maintain it?

How do you feel about septic tanks systems for wastewater treatment?

- Some areas of Nags Head have package plants for wastewater treatment instead of septic tank systems which is basically a sewage treatment plant for a small group of properties. What do you think about that as an alternative to septic tank systems?

There are some concerns that leaching from septic tanks and drainfields contaminates surface waters during flooding events or other times when soils stay saturated and that these events may become more frequent and widespread in the future. At the same time, switching to other methods of wastewater treatment could be costly and logistically difficult. What do you think about wastewater treatment in the future?

If package plant:
How do you feel about the package plant for wastewater treatment?

- What benefits do you think there are for treating wastewater in this way?
- What about any downsides?

Have you had any issues with the package plant? What happened?

The majority of properties in Nags Head treat wastewater with septic tank systems. How do you feel the package plant system where you are compares to these?

There are some concerns that leaching from septic tanks and drainfields contaminates surface waters during flooding events or other times when soils stay saturated and that these events may become more frequent and widespread in the future. At the same time, switching to other methods of wastewater treatment could be costly and logistically difficult. What do you think about wastewater treatment in the future?

All: What do you think residents and the town of Nags Head should be doing to manage wastewater into the future?

<u>Future Change:</u>
So we've talked about storms and flooding, and we've talked about surface waters and wastewater

How do you think flooding and its impacts might change in the future?

- What makes you think so or what do you attribute that to?

How open to adapting to changing conditions would you say the Nags Head community is?

- If s/he says Not that open: How could local adaptability be increased?
- If s/he says Open: In what ways do you think they are?
- What factors might prevent adaptations from being implemented?

Closing Questions:
That's everything that I wanted to ask you. Is there anything you'd like to add about water, flooding, wastewater or anything else?

Do you have any questions for me?

Conclusion:
Thank you so much for participating in this interview. If at any time you have any questions about this interview or our project, you can feel free to contact me or our project coordinator. Provide a copy of the consent form and any necessary additional contact info.

You've been incredibly helpful, and I appreciate you giving us your time and insights.

Do you know of anyone else you think would be a good person for us to interview?

- Ask for contact information to go along with names.
- Clarify that they should not take it upon themselves to ask people to do interviews. If they ask about contacting the person first, explain that they can reach out to the person and ask if they would be willing to hear from a student about the project and then think about participating.

Thanks again for participating in this study. We will be creating a podcast from our findings and about our research this semester. This will be available early next year. We will be playing some clips from it as part of a public presentation about our study at the end of the semester. You are more than welcome to attend. It will be Thursday, December 12 from 2:00-4:00pm at the Coastal Studies Institute.

Researchers
Materials:
Consent document (2 copies)
iPad (Remember to check battery life)
Microphone + connector
Charger
Pen/pencil
Clipboard

Introduction:
Thanks again for agreeing to be interviewed for this study.

We would like to record this interview and use it to make a podcast that will be available for anyone who would like to listen to it. The recording may also be used in future academic research. There is a space on the consent form where you can give your permission to record.

Ask the interviewee to read and sign the consent document, including their indication about recording.

Do you have any questions for me before we start?

When starting the recorder, ask him/her to mark the recording by saying a few sentences, like his/her name, the date and where you are.

Research & History:
For someone listening who isn't familiar with your work, could you describe your research interests?

What current projects you're working on?

How did you become interested in these research topics?

What have been some of the key findings of your research?

Wastewater Treatment & Environmental Change:
If you were describing how a septic tank system works to someone who had never heard of one, what would you tell them?

In low elevation coastal locations, what kinds of environmental changes can affect the functionality of septic tank systems? **Wells and well water**

- Listen for or possible prompts: precipitation patterns (storm frequency, storm intensity, rainfall amounts), air or water temperature, erosion rates, water/tide level, landscape/vegetation
- Follow-up: What do you think is contributing to those changes? (go through each change the interviewee mentions as necessary)

What about where you live and work - how have you personally experienced these kinds of changes?
Follow-up:

- How much of a concern is flooding for you personally?
- Could you describe the worst flooding event that you have experienced?
- Has flooding changed in any way over time? In what ways?
- How do you deal with the risk of storms and flooding?

What happens when a septic tank and leach field aren't functioning properly?

- What kinds of hazards or risks can that present?
- How concerned are you about contamination of surface waters from leaching from septic tank systems during flooding events or other times when soils stay saturated?
- How concerned are you that these events may become more frequent and widespread in the future?

What can communities do to address inefficiencies of septic tank systems?

Some areas of Nags Head, the town where we are working, have package plants for wastewater treatment instead of septic tank systems. What do you think about that as an alternative to septic tank systems?

Future Change:

What do you think are the critical information gaps among property owners in terms of how their septic tank systems work and how they need to be maintained?

- What concerns do you think people should have about the effectiveness of wastewater treatment by septic tank systems as coastal environments continue to change?

What do you think residents and the town of Nags Head should be doing to manage wastewater in the future?

What do you think wastewater treatment in low elevation coastal places will look like in the future?

Closing Questions:

That's everything that I wanted to ask you. Is there anything you'd like to add about water, flooding, wastewater or anything else?

Do you have any questions for me?

Conclusion:

Thank you so much for participating in this interview. If at any time you have any questions about this interview or our project, you can feel free to contact me or our project coordinator. Provide a copy of the consent form and any necessary additional contact info.

You've been incredibly helpful, and I appreciate you giving us your time and insights.

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APPENDIX F

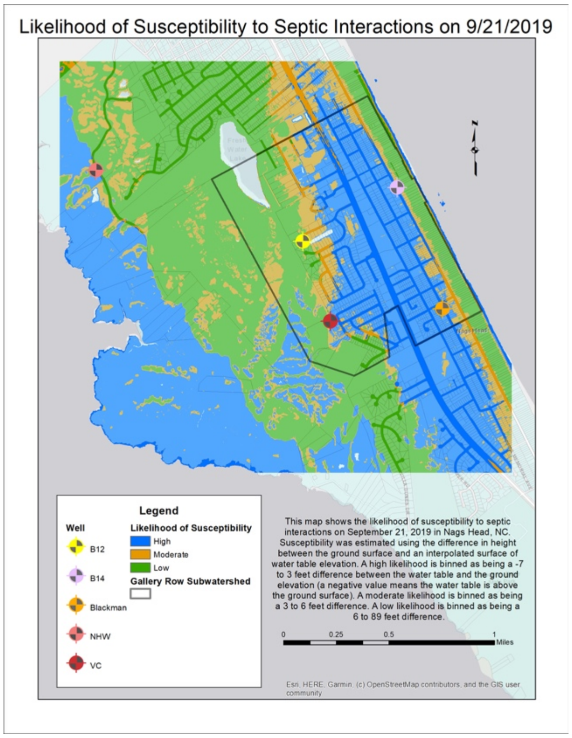
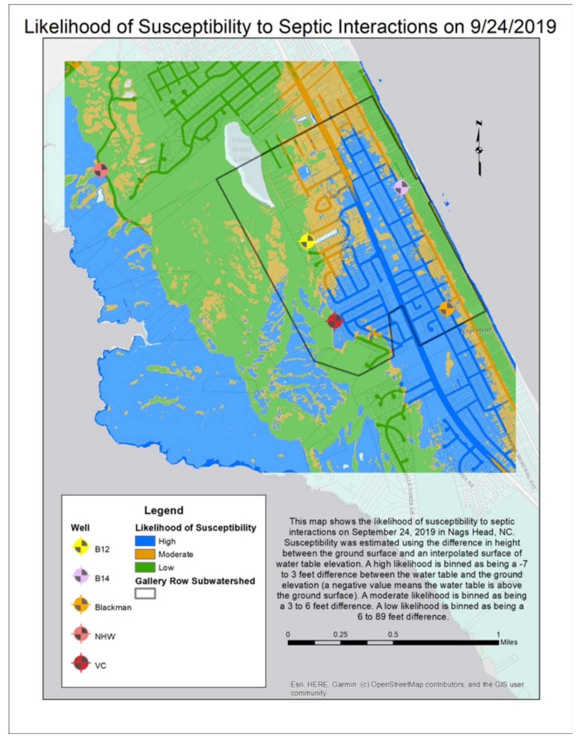


Figure 8.



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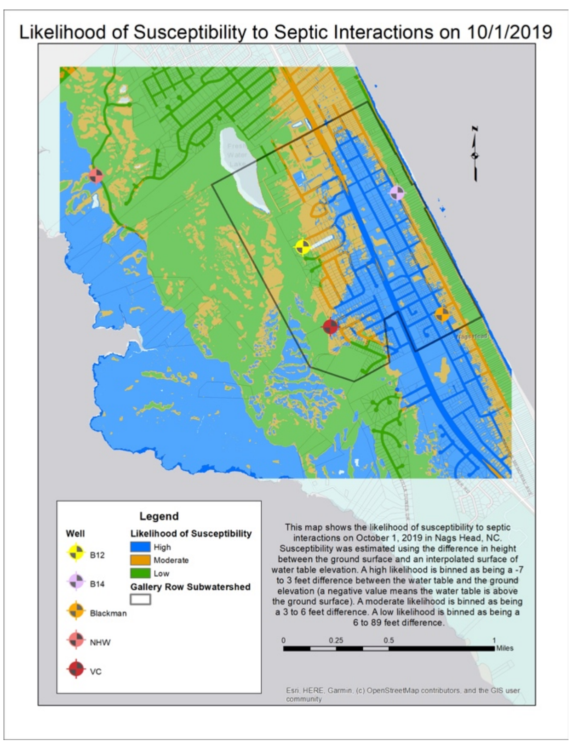
Susceptibility on 10/9/2019.



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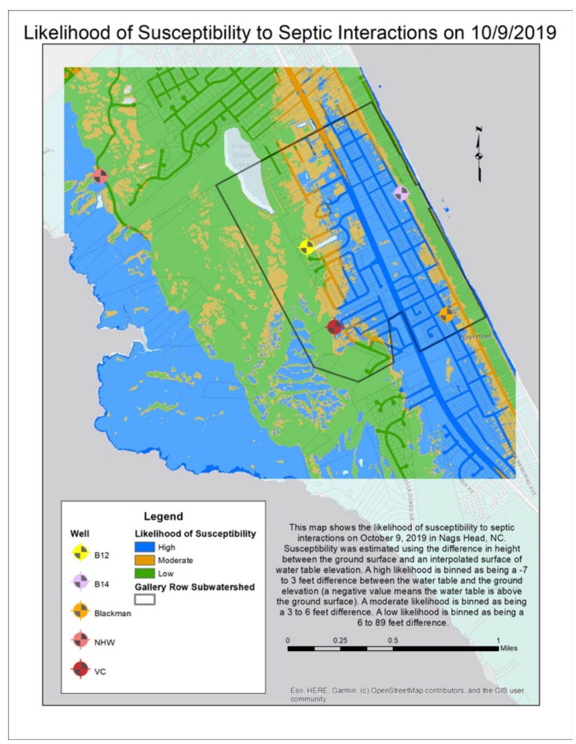

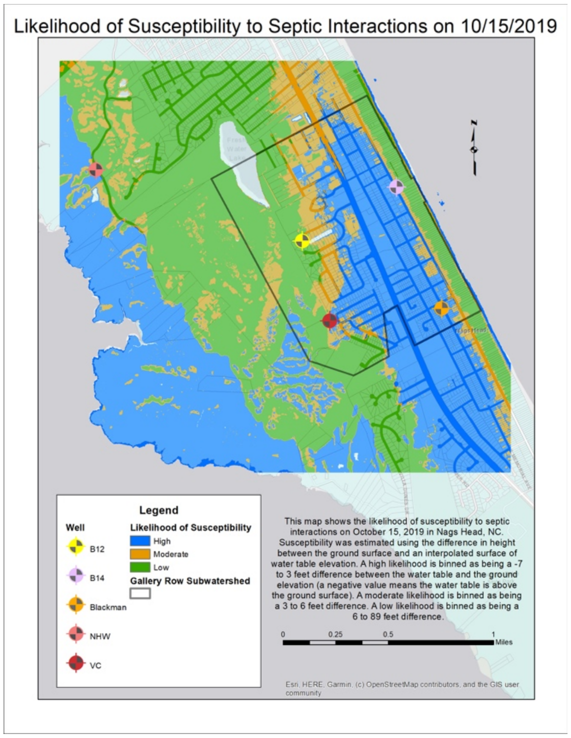

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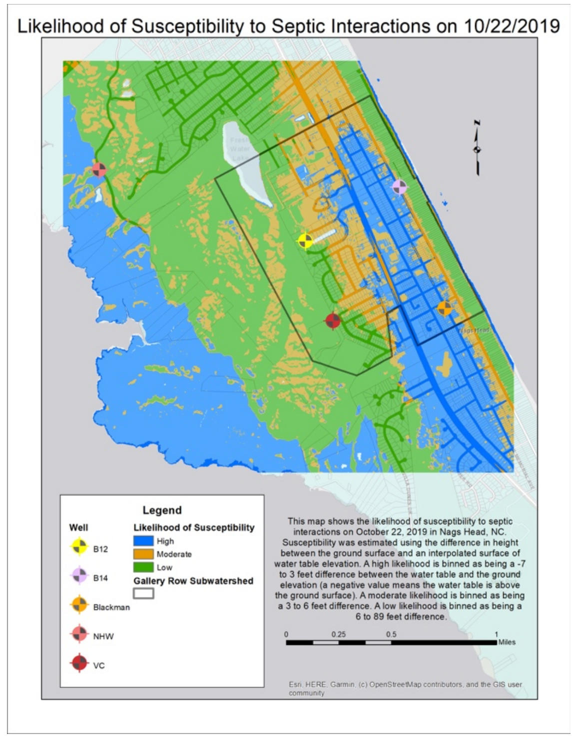

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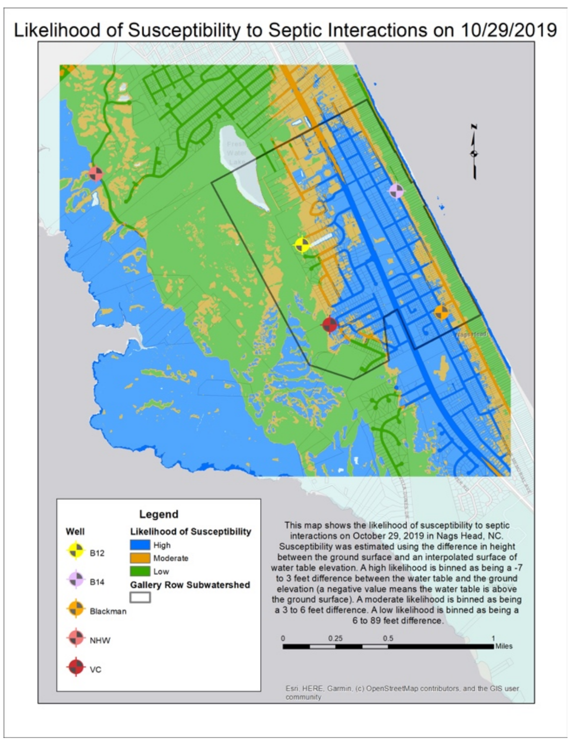

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