What Lies Beneath: Septic Systems and Water Quality in Nags Head, North Carolina

THE UNIVERSITY OF NORTH CAROLINA AT CHAPEL HILL
UNC Institute for the Environment
Outer Banks Field Site

Fall 2020
Capstone Report

THE UNIVERSITY of NORTH CAROLINA at CHAPEL HILL

November 23, 2020

Coastal Studies Institute
A Multi-Institutional Research Partnership

AUTHORS

Janis Arrojado
Junior
B.S. Environmental Science,
B.S. Geography
Concord, North Carolina

Emma Bancroft
Junior
B.S. Environmental Science
Kitty Hawk, North Carolina

Lauren Colonair
Senior
B.A. Environmental Studies
Fayetteville, North Carolina

Harrison Davis
Senior
B.A. Environmental Studies
Jamestown, North Carolina

Meagan Gates
Junior
B.S. Environmental Science,
B.A. Economics
Harrisburg, North Carolina

Heidi Hannoush
Sophomore
B.S. Environmental Science
Wyckoff, New Jersey

Natalie Ollis
Junior
B.A. Environmental Studies,
B.A. Biology
Connelly Springs, North Carolina

Gabriella Paone
Sophomore
B.A. Political Science
Rockingham, North Carolina

Caroline Pharr
Senior
B.A. Environmental Studies
Kill Devil Hills, North Carolina

Brianna Thompson
Junior
B.A. Environmental Studies,
B.A. Public Policy
Kingston, Jamaica

ACKNOWLEDGEMENTS

Special thanks to the Faculty and staff of the Outer Banks Field Site (OBXFS) for ensuring a healthy, safe, and fun semester, despite extenuating circumstances: Andy Keeler, Linda D'Anna, Lindsay Dubbs, Corey Adams, Kimberly Armstrong

Thanks to the Community Advisory Board for their perspectives and guidance: Christin Brown, Nellie Dixon, Fay Davis Edwards, Erin Fleckenstein, Jaye Massecar, Aaron McCall, Rhana Paris, Matt Price, Kip Tabb, Heidi Wadman

Internship Mentors:
Jennifer Bland – Dare County District Attorney's Office
George Bonner – Coastal Studies Institute
Jason Brown – North Carolina Estuarine Research Reserve and National Estuarine Research Reserve
Donna Creef – Dare County Planning Department
Ann Daisey – Outer Banks Conservationists
Parker Kellam – Coastal Studies Institute
John McCord – Coastal Studies Institute
Jessica Taylor _ Outer Banks Center for Dolphin Research
Leslie Vegas – NC Coastal Federation
Holly White – The Town of Nags Head

Labs, field trips, and experiences:
Justin Barnes (Jockey's Ridge State Park); Sharon Meade (Outer Banks Center for Wildlife Education); Holly White, David Ryan, Kate Murray Jones, Kylie Shepard, Andy Garmin, Kelly Wyatt, and Michael Zehner (Town of Nags Head); Drs. Mike O'Driscoll, Charles Humphries, and Alex Manda (East Carolina University); Hadley Twiddy and Nate (Coastal Explorations); Matt Price (Duck Waterfront Shops); Fay Davis Edwards and Dare County Arts Council; Christin Brown and Rachel Potts (Jennette's Pier); Aaron McCall (The Nature Conservancy Nags Head Woods Preserve); Heidi Wadman (Army Corps of Engineers Field Research Facility)

Coastal Studies Institute support:
Corey Adams, Kim Armstrong, Reide Corbett, Mike Hosey, Parker Kellam, Claire Johnson, Jeff Lewis, Marie Magee, Robert McClendon, John McCord, Kirsten Morse, Dave Sybert, and Blake Williams

UNC–Chapel Hill support:
Violet Anderson, Susan Cohen, Morgan Douglas, Chrissie Greenberg, Jing Lui, Mike Piehler, Daniel Rauscher, Tony Rodriguez, Derek Shepard, Charu Vengavayal, and Emily Williams

Housing:
Friends of Elizabeth II Guest House; Jaye Massecar; Michelle Revels; Emily Mohler

Special thanks to Coleman Cheeley for contributions to our initial literature reviews and creation of Figure 1.

Thank you to all the community members and participants that volunteered their time and thoughts to our Capstone project!

ABSTRACT

Our study is the culmination of the Outer Banks Field Site's (OBXFS) three-year project investigating human and ecological dimensions of water quality in Nags Head, North Carolina. In conjunction with the two previous studies, our research aims to understand risks of septic wastewater contamination of surface- and groundwater as well as public awareness of these risks. This study was conducted in 2020 over four months from August to November.

One goal of our study was examining the effects of groundwater lowering on the presence of wastewater indicators in groundwater. These indicators included bacterial concentrations and the presence of optical brighteners. The next was to understand levels of awareness, risk perception and practices regarding septic system maintenance and groundwater contamination. Our research questions required a two-pronged study design. The first component involved collecting and analyzing water samples to test for indicators of septic wastewater contamination. The other centered around collecting information from Nags Head homeowners on awareness, risk perceptions, and practices regarding septic systems.

For water quality analysis, we collected water samples on four sampling occasions in September and October, 2020. Our data suggests that there is widespread septic contamination in Nags Head's groundwater. However, due to a small dataset and high variability between sampling sites, we could not definitively explain patterns of septic wastewater indicator concentrations. Additional sampling sites and a routine sampling schedule over a longer time period are needed to fully explore septic wastewater interaction with surface- and groundwater.

For human dimensions analysis, a survey was used to gauge the knowledge, awareness, and risk perception of water quality, in relation to septic systems, held by Nags Head homeowners. Our analysis found that there were varying levels of knowledge and awareness amongst homeowners. Additionally, risk perceptions were not held in common and were impacted in part by whether a homeowner owned a septic system. The data provided information on respondent's beliefs concerning the future of septic systems in Nags Head. The Town may find this information useful when implementing new policy and outreach initiatives about wastewater treatment.

TABLE OF CONTENTS

INTRODUCTION

As the human population grows, coastal ecosystems experience greater stress on their resources and coastal communities suffer the burden of a changing environment. As of 2017, approximately 40% of the world's population lives within 100 km (60 miles) of the coast (UN 2017). In the United States, 10% of land—omitting Alaska—is regarded as a coastal area. While the land area occupied by coasts is small in comparison to the entire United States, coastal counties disproportionately account for 40% of the U.S. population (U.S. Census Bureau 2015). Additionally, population density is growing as is demonstrated by the approximately 40% increase in coastal county populations between 1970 and 2010 (NOAA 2013). Coastal shoreline counties have a population density of 446 people per square mile; that is four times greater than the population density of the entire United States (NOAA 2013). Greater population densities along the coast are due, in large part, to the economic opportunities offered by these areas. Coastal counties contribute $9 trillion annually to the U.S. GDP (NOAA 2014). However, the economic benefits of a thriving coastal economy are being tempered by the recognition of human impacts and environmental changes threatening life along the coasts.

Coastal communities are already experiencing the effects of anthropogenic climate change. Greater concentrations of greenhouse gases in the atmosphere are associated with intensifying storm and precipitation events as well as sea level rise (IPCC 2012). The impact of sea level rise is compounded by human development of coastal areas. Development increases the amount of impermeable surface coverage, thereby preventing groundwater infiltration and heightening flooding susceptibility (Hart et al. 2020).

These changes have significant implications for coastal communities, which often rely on septic systems for wastewater treatment (O'Driscoll et al. 2019). When flooding occurs, the likelihood of contamination of surface- and groundwater by wastewater increases (EPA 2018b). This contamination threatens human health (EPA 2001) and environmental well-being (Dodds et al. 2009), thus disrupting connections between people and place.

Barrier Island Hydrology: An Overview

Hydrological processes on island chains like North Carolina's Outer Banks involve fluxes between water stores known as reservoirs. These include groundwater, surrounding water bodies, and the atmosphere. *Figure 1* diagrams the fluxes and reservoirs that constitute the hydrology of barrier islands. Water movement within the barrier island hydrological system occurs across various time-scales. Subterrestrial exchanges between underground water stores, known as aquifers, and the adjacent water bodies occur on a longer timescale than surface evaporation from reservoirs like the ocean and sound. An aquifer is a body of sediment that is saturated with groundwater. Groundwater enters aquifers through precipitation that infiltrates through layers of soil. There are two types of aquifers—confined and unconfined. The unconfined aquifer is located below a layer of permeable soil and above the confined aquifer (Fig. 1). These aquifers are separated by a layer of impermeable rock (National Geographic 2019), which lengthens the time-scale of water movement from the unconfined aquifer to the confined aquifer. On a much shorter time scale, surface water from precipitation and wastewater from septic systems percolate through soil and eventually reach the unconfined aquifer. These inputs alter the height of the water table, which is the upper limit of the unconfined aquifer (Fig. 1). The distance between the land surface and the water table is called the "unsaturated zone."

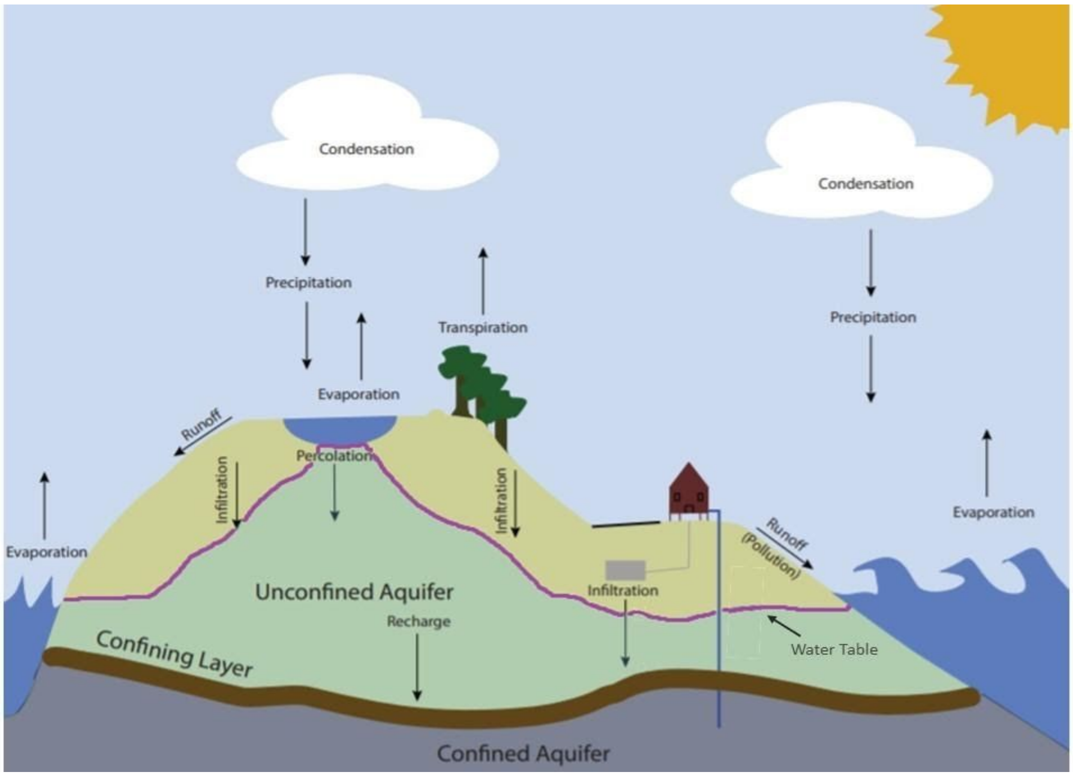

Figure 1. Barrier island socio-hydrological cycle. Fluxes are shown by arrows. Note the locations of the unconfined and confined aquifers.

Socio-Hydrological Cycle

Socio-hydrology involves examining human interactions with the hydrologic cycle. Socio-hydrological research and models can play an important role in coastal community governance through assessment of the feedback loops between human behavior and natural processes (Blair and Buytaert 2016), including sea level rise and human development

Sea level rise is a gradual change that is constantly reshaping the coastlines of barrier islands. Small increases in water level can have significant impacts on the narrow and flat topography of barrier islands and their associated hydrological reservoirs. Sea level rise has already increased water table heights on the coast of North Carolina (O'Driscoll et al. 2019) as well as fluxes between surface water and the unconfined aquifer (Masterson et al. 2014). Acknowledging these changes is important to understanding the exchanges of water between hydrological reservoirs.

Coastal environments and processes are influenced by the high density of people within them (Halpern et al. 2019). Populations on the coast are growing (NOAA 2013), bringing rising rates of development and decreasing the ability of coastal ecosystems to adapt to sea level rise. For example, within the last few decades, the coast of Louisiana has experienced a reduction of approximately 2,000 square miles of their wetland area (EPA 2016). Development blocks wetlands from migrating further inland, and inhibits the influx of sediment, and increases erosion rates. Coastal ecosystems, like the Outer Banks, are experiencing increased vulnerability as sediment input cannot keep up with sea level rise. Similarly, these effects have impeded the ecosystem's ability to act as natural barriers against flooding (EPA 2016). In addition, impervious surfaces created to meet the demand of growing populations prevent precipitation from infiltrating into the ground, creating runoff that ultimately discharges into the ocean and sounds surrounding the island (Fig. 1). Human settlement of dynamic coastal environments stresses local water supplies and inhibits natural adaptations to a changing environment.

Wastewater Treatment on Barrier Islands

Humans use and interact with water in a wide variety of ways in everyday life. Many of these interactions take place in homes; on average, each U.S. household produces over 300 gallons of wastewater per day (EPA 2018a). Wastewater is all the water that flows through a drain—from bathing, flushing toilets, cleaning, and other activities (University of Nebraska-Lincoln [date unknown]).

Wastewater treatment varies by location and includes on-site septic systems, package plants, and central sewer. About 21% of households in the U.S. treat their wastewater with on-site septic systems (CDC and HUD 2006). Traditional septic systems treat wastewater with a tank, where waste flows in as influent and is separated into three layers: solids and wastewater/effluent (Fig. 2). The solid waste settles at the bottom of the septic tank, where microorganisms break it down (EPA 2018b). Effluent exits the tank and flows through underground perforated pipes into a drainfield. A septic drainfield consists of the unsaturated zone, or the layer of "dry" soil above the water table. Wastewater percolates through the unsaturated zone and is further filtered by processes occurring within the soil. For proper treatment, there must be a sufficient distance (≥1 m) between the unsaturated zone and the water table for wastewater to percolate. Eventually, the wastewater reaches the water table and mixes with the unconfined aquifer. If the drainfield is overloaded by water influxes, the unsaturated zone may become waterlogged and flood, causing untreated waste to rise to the surface and toilets and sinks to back up (EPA 2018b).

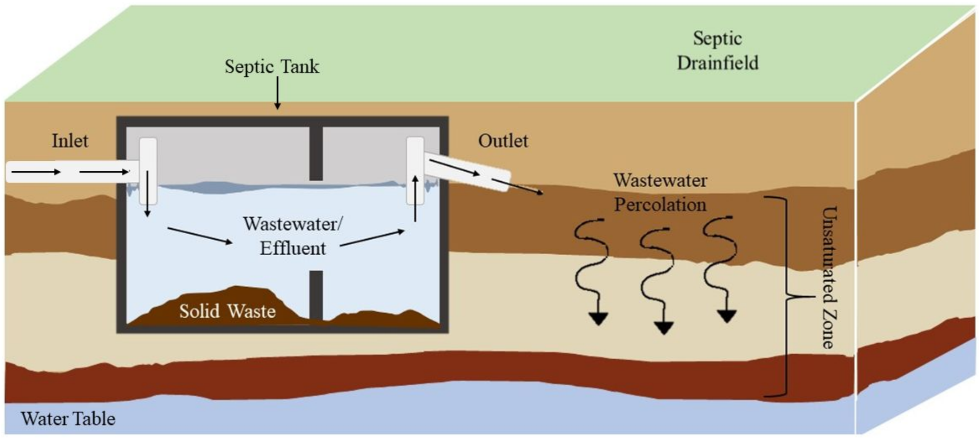

Figure 2. Septic system operation. Wastewater flows from the inlet pipe into the septic tank where solids and liquids separate. Solids sink to the bottom and wastewater, also known as effluent, flows through the outlet pipe into a drainfield. The wastewater gets further treatment as it percolates through the unsaturated zone until it reaches the water table and mixes with the unconfined aquifer.

Without proper maintenance of septic systems or an insufficient unsaturated zone, there is risk of surface and groundwater contamination by undertreated septic wastewater. Wastewater contains bacteria, viruses, and nutrients that can have harmful impacts on human health and ecosystems. Potential viral and bacterial diseases include typhoid, hepatitis A, and other gastrointestinal illnesses (EPA 2001). Nutrients from un- or under-treated wastewater, such as nitrogen and phosphorus, can also cause contamination. In marine ecosystems, excess nitrogen causes eutrophication and algal blooms, which can lead to hypoxia or deficient oxygen levels. The death of marine organisms resulting from hypoxia negatively affects fisheries and local economies which are dependent on them (Dodds et al. 2009).

Correct maintenance of septic systems is vital to avoiding these consequences. According to the U.S. Environmental Protection Agency (EPA), inspections should occur every three years and pumping every three to five years (EPA 2020), as overloading a septic system can lead to failure. It is also important to maintain the on-site septic drainfield. There should be no development or deep-rooted plants over the drainfield and vehicles should never be parked over it. Water drainage systems should be kept away from septic drainfields to avoid oversaturating the soil (EPA 2020). Following these guidelines can help reduce wastewater interactions with the surface and groundwater.

Rising water tables increase the importance of proper maintenance. As sea level rises and flooding becomes more frequent, the water table rises, thereby shrinking the unsaturated zone. Risk of contamination by wastewater is greater because septic effluent has less time to be treated (Cooper et al. 2016). Light rain events and flooding that saturate the soil exacerbate this problem and can cause untreated septic leachate to rise and mix with surface water, posing public and environmental health risks (Hart et al. 2020).

In this case study, *E. coli* concentrations were measured to determine levels of groundwater contamination. Total coliforms are a group of bacteria found naturally in the environment and in animals' digestive tracts and waste (New York State Department of Health 2017). When found specifically in warm blooded animal digestive tracts and waste, they are called fecal coliforms. *E. coli* is a type of fecal coliform (New York State Department of Health 2017). Both of these bacteria can indicate contamination by untreated septic leachate (Hart et al. 2020).

In addition to *E. coli*, an indicator unique to wastewater contamination was measured. Unique indicators are generated primarily by humans and should only appear in large concentrations if wastewater contamination has occurred. Artificial sweeteners, detergent chemicals, caffeine, and other non-native/natural compounds are commonly used indicators to measure wastewater contamination (Richards et al. 2017). For the 2018 Capstone research study, caffeine was used as an indicator, but the data was inconclusive due to the presence of caffeine in the local plant species *Ilex vomitoria*, or yaupon holly, which could have been a confounding variable (Allen et al. 2018). In this study, we examined optical brighteners, an agent in laundry detergent added to maintain the brightness of clothes. We chose optical brighteners for their ease and low cost of measurement (Cao 2009). By comparing our bacterial data to our optical brightener data, we were able to more accurately posit where wastewater contamination by septic systems was occurring.

Wastewater treatment in the Town of Nags Head

Nags Head is a town located on the Outer Banks of NC, where approximately 80% of properties are reliant upon septic systems as a means of wastewater treatment (Town of Nags Head [date unknown]). As a result, the town is susceptible to the consequences of improperly maintained systems and untreated wastewater. In order to address these problems, the Town of Nags Head developed the Todd D. Krafft Septic Health Initiative Program (SHI).

Nags Head Septic Health Initiative

The SHI is intended to encourage proper maintenance of septic systems through "free services and financial assistance." Financial incentives to pump and repair septic systems include credit for pumping a system and low-interest loans on repairs. All property owners have the opportunity to benefit from the SHI, however, participation is not required. Property owners are helped through each step of the process: inspection, contacting a contractor, and pumping or repair. While the town encourages all residents to participate in the SHI, an emphasis is placed on rental property owners because of the greater strain placed on the system when there are numerous users (Town of Nags Head [date unknown]).

Alternative wastewater treatment systems

In spite of Town efforts to ensure proper functioning of septic systems, sea level rise and increased flooding still pose threats and provide a reason to consider alternative wastewater treatment options. Centralized sewage involves the construction of a central location that receives the waste from an area through pipes. While centralized systems may reduce the potential frequency of surface water contamination from wastewater, there are concerns that a storm may break the pipes, leading to contamination of surface waters and requiring a great expense to restore (Wells et al. 2016). In contrast, package treatment plants are useful in areas devoid of centralized sewage and are similar to septic systems in that they rely on percolation through soil to treat wastewater. Package treatment plants can treat the wastewater from neighborhoods, commercial developments, and other properties (EPA 2000). While package treatment plants may be useful in coastal communities, they experience many of the same problems as septic systems. For instance, their proper functioning is also inhibited by spikes in wastewater quantity and reduced unsaturated zones that are insufficient for treatment (O'Driscoll et al. 2019). Instead of relying on septic systems for wastewater treatment, Nags Head could look to newer technologies to improve current wastewater treatment systems.

Hypotheses

As previously mentioned, our study investigates the human and ecological dimensions of water quality in Nags Head, North Carolina. We developed hypotheses, in regards to our research questions, based on previous research from the 2018 and 2019 Capstone reports (Allen et al. 2018; Anderson et al. 2019).

We predicted that we would find less frequent and abundant indicators of septic wastewater contamination—*E. coli* and optical brighteners—in areas where groundwater lowering occurred. Groundwater lowering increased the depth of the unsaturated zone, thereby enabling the water to percolate further through the soil before mixing with groundwater. Similarly, we hypothesized that bacterial and chemical septic wastewater indicator concentrations and presence, respectively, would be lower in surface- and groundwater locations where there is a sufficiently deep unsaturated zone (≥ 1 m) to allow for their removal by processes within the unsaturated soil.

With regards to the survey, we hypothesized, similarly to the 2019 Capstone, that Nags Head homeowners would have low awareness and risk perceptions of groundwater contamination by septic systems (Anderson et al. 2019). We predicted that behaviors and perceptions would vary between permanent and non-permanent residents.

METHODS

Study Site

Our study was carried out within the boundaries of the town of Nags Head in the Outer Banks of North Carolina. The town is bordered by Cape Hatteras National Seashore to the south and Kill Devil Hills to the north. It is also bordered on two sides by bodies of water: Roanoke Sound to the west and the Atlantic Ocean to the east (Fig. 3). Nags Head sits at an average elevation of 7-ft above sea level (Worldwide Elevation Map Finder [date unknown]) and spans a 6.6 square mile area (Outer Banks Guide 2020). Currently, the year-round population of Nags Head is 2,998 individuals. The average growth rate of the area is 0.98% annually. 95% of the population is categorized as urban and 5% as rural (World Population Review 2020). During the summer, at peak tourist season, the population of the area increases to approximately 40,000 people (Outer Banks Guide 2020).

Figure 3. Nags Head water sampling sites 2020. Groundwater and surface water sample sites across Nags Head, North Carolina. The center image displays a wide-scale view of the study area with boxes indicating the more specific places in which samples were collected. These boxes are connected to corresponding frames which display close-up views of the sample sites. Groundwater sites are depicted by blue markers and surface water sites are marked with orange markers. The map was created using ArcMap, a GIS software program.

The groundwater and surface water sampling sites are located within three sub-watersheds within the Town of Nags Head: the Gallery Row, Curlew, and Old Oregon Inlet sub-watersheds (Table 1). The Gallery Row sub-watershed is located farthest to the north and the Curlew sub-watershed lies in between as the Old Oregon Inlet sub-watershed is furthest to the south (Fig. 4). The percentage of impervious surface—ground cover which prevents water from infiltrating the ground—affects the amount of runoff and impacts water quality. Gallery Row has the highest percentage of impervious surfaces at 31.9%, followed by Curlew at 21.3%, and Old Oregon Inlet at 20.8% (NCDENR 2015).

Table 1. Nags Head water quality sampling sites 2020. Name and type of sampling site (surface water or groundwater well), whether or not the site is subject to groundwater lowering, dates sampled at this location, and GPS coordinates.

Site Name	Site Type	Sub-Watershed	Groundwater Lowering	Dates Sampled	Latitude	Longitude
B14	Ground water	Gallery Row	Lowered Outfall Pipe	09/16/20, 09/18/20, 10/12/20, 10/14/20	35.9848	-75.663
Curlew	Ground water	Curlew	None	09/16/20, 09/18/20, 10/12/20, 10/14/20	35.985	-75.65
Wrightsville 2	Surface Water	Gallery Row	Lowered Outfall Pipe	09/18/20	35.9885	-75.6419
Wrightsville 1	Surface Water	Curlew	None	09/16/20, 09/18/20, 10/12/20, 10/14/20	35.9794	-75.6479
B12	Ground water	Gallery Row	None	09/16/20, 09/18/20, 10/12/20, 10/14/20	35.98783	-75.6429
Blackman	Ground water	Gallery Row	None	09/16/20, 09/18/20, 10/12/20, 10/14/20	35.98	-75.6384
Vista Colony	Ground water	Gallery Row	Pumping	09/16/20, 09/18/20, 10/12/20, 10/14/20	35.97038	-75.63247
Nags Head (NH) Woods Control	Ground water	N/A	None	09/16/20, 09/18/20, 10/12/20, 10/14/20	35.97015	-75.63297
Juncos Ditch	Surface Water	Old Oregon Inlet	None	09/16/20, 09/18/20, 10/12/20, 10/14/20	35.86939	-75.57555
Juncos 1	Ground water	Old Oregon Inlet	None	09/16/20, 09/18/20, 10/12/20, 10/14/20	35.86933	-75.5757
Juncos 2	Ground water	Old Oregon Inlet	None	09/16/20, 09/18/20, 10/12/20, 10/14/20	35.86909	-75.576

Figure 4. Study area sub-watersheds 2020. Spatial relationships between Nags Head sampling sites and the sub-watersheds which contain them.

Water Quality Methods

Sampling methods

In order to evaluate the quality of groundwater in Nags Head and the interaction of groundwater with un- or undertreated septic wastewater, we collected environmental data and water samples from 11 sites within the study area during four sampling occasions between Sept. 16 and Oct. 14, 2020 (Table 1). Sites included groundwater wells and surface water ditches, each of which was sampled using a distinct protocol. The sampling sites where groundwater lowering was implemented in 2019 included B14, Wrightsville 2, and Vista Colony. A lowered outfall pipe project impacted B14 and Wrightsville 2; Vista Colony was affected by a vertical well installation project (Table 1).

For both types of sampling sites, the date, time, weather conditions, times of high/low tides for the day, and observations about the site were recorded. It was also noted whether the sampling event occurred after recent precipitation. For two of the sampling events (Oct. 12 and Oct. 14) samples from the Wrightsville 1 location were not collected due to a low water level.

For groundwater well sites, we measured the distance from the ground to the top of the water table using a Solinst water level meter. Using aseptic techniques to minimize contamination of water samples, an initial water sample was collected from the well using a bailer and placed into a sample-rinsed bucket to collect environmental data. A YSI 85 or YSI Professional Plus was calibrated for dissolved oxygen (DO) then used to measure water temperature (°C), salinity (ppt), DO (mg/L), and conductivity (µs) of the water sample in the bucket. Water samples for microbial analysis were then collected in autoclaved 250-500 mL HDPE Nalgene bottles using the bailer and aseptic technique. The bacterial samples were immediately placed on ice in a dark cooler until analysis. Samples for optical brightener analysis were then collected in acid-cleaned amber 125 mL HDPE Nalgene bottles. The bottles were immediately closed and placed on ice in a dark cooler to avoid degradation of optical brighteners by light exposure.

At surface water sites, the YSI was lowered into the water and the same environmental measurements were recorded (temperature, salinity, DO, conductivity). Water samples for both microbial analysis and optical brightener analysis were collected using a Pikstik to carefully lower the bottles into the water and collect the sample without resuspending sediments in the ditch. The bottles were immediately closed and placed in the dark on ice.

Once collected from all sampling sites, the water samples were promptly taken back to the lab to be analyzed (analysis took place within 4 hours of sample collection).

Optical brightener analysis methods

Optical brighteners are a class of chemicals often found in laundry detergents, in order to combat the yellowing of whites and to brighten other colors (Thompson and Miskewitz 2010). Their prevalence in human wastewater, makes them useful as an indicator of wastewater interactions with groundwater.

Fluorometric analysis of optical brightener samples was conducted using a Trilogy Fluorometer with an optical brightener module (PN 7200-047). Optical brightener samples were allowed to come to room temperature before analysis to maintain the accuracy of measurements. Allowing samples to return to room temperature removed condensation on cuvettes as a potential confounding variable on the fluorometer. A fluorometric standard curve was made with dilutions of various concentrations of Tide laundry detergent and deionized water (DI) water. This curve acts as a qualitative scale to compare with the unknown optical brightener concentrations in the groundwater samples. Sample water was transferred into small cuvettes and fluorescence was measured in reflective fluorescence units (RFUs) and recorded in triplicates for each sample.

High RFUs do not necessarily indicate optical brightener presence because they measure total reflectance, which includes optical brightener and organic matter values. Samples were exposed to UV to account for the potential interference of organic matter values because optical brighteners degrade more rapidly in light than organic matter. A rapid and sharp decrease in RFUs may indicate optical brightener presence. We therefore adapted a method proposed by Cao et al. (2009) to utilize the rapid photo-decay of optical brighteners as an indication of their presence (Fig. 5). Approximately 30 mL of each sample that was previously analyzed by fluorometry was poured into a beaker and exposed to UV light for 5 minutes. After 5 minutes, the fluorometric reading process was repeated. The samples were then exposed to UV for 10 minutes, and measured in triplicate a third time. The RFU measurements were converted to concentration (ppm) using the calibration curve and average percentage of fluorescence reduction after 5 and 10 minutes of UV exposure was calculated for each sample. As outlined in *Figure 6*, if initial fluorescence before UV exposure was below 5 ppm, optical brighteners were considered absent from the sample. After 5 minutes of UV exposure, if the concentration was reduced by less than 8%, optical brighteners were considered absent; if reduced by greater than or equal to 30%, optical brighteners were considered present. If the reduction after 5 minutes was between 8% and 30%, we looked at the ratio of percent reduction between 5 and 10 minutes. If this ratio was above or equal to 1.5, optical brighteners were considered absent; if it was below 1.5, they were considered present.

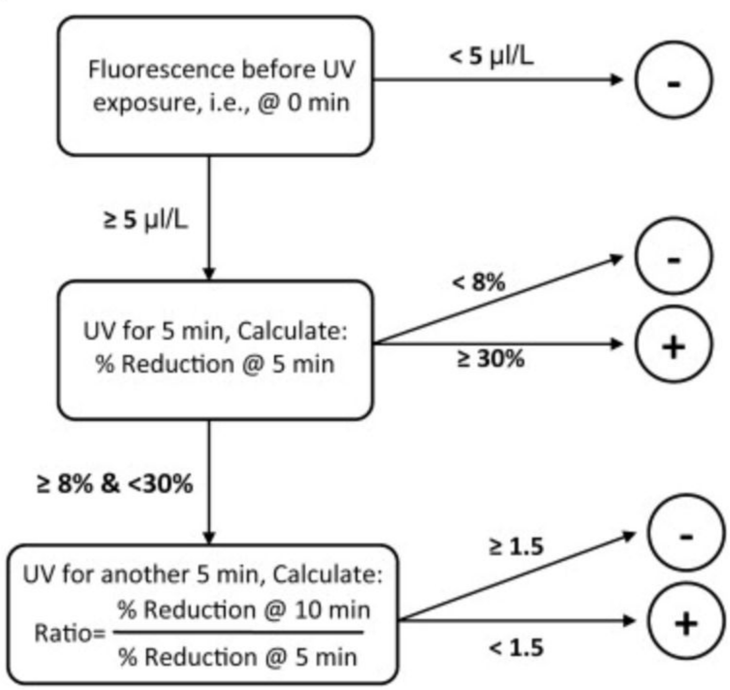

Figure 5. Optical brightener presence calculation. A modified Cao et al. (2009) method for utilizing the rapid photo-decay characteristics of optical brighteners for detection of human waste contamination.

Bacterial analysis methods

The surface- and groundwater samples from each sampling occasion and location were analyzed for total coliform and *E. coli* bacteria to assess the interaction between septic wastewater and surface and groundwater in Nags Head. Two replicates from each sampling site were processed using the Colilert™ protocols and materials, both available from IDEXX Laboratories (Westbrook, ME, USA). Using a micropipette, 10 mL of each water sample was added to a sterile 100 mL vessel with a Colilert™ media packet, and filled to the top with 90 mL of autoclaved DI water. Each bottle was shaken and inverted to dissolve the Colilert™ packet and mix the contents. The contents of the bottle were then poured into a QuantiTray 2000 and sealed with a Quanti sealer. Once all samples were sealed, the trays were placed in an incubator at 35℃ for 24 hours.

Afterwards, the trays were removed from the incubator to count and record the QuantiTray wells. Yellow wells were counted for coliforms and those that glowed blue under UV light were recorded for *E. coli*. Using the counted numbers of wells, the IDEXX most probable number (MPN) table was used to find the MPN of colony forming units (CFU) and 95% confidence intervals of bacteria per 100 mL of sample. Since our samples were only 10 mL, we multiplied each MPN by a factor of 10.

Summary statistics and analysis

For optical brightener data, we found the average initial RFU, average RFU after 5 minutes of UV exposure, average RFU after 10 minutes of UV exposure, and the respective standard deviations and variances of the replicates for each location on each sampling date. To assess presence/absence, we applied these summary statistics to the Cao et al. (2009) method.

To address the research question regarding sites with similar susceptibility of groundwater and wastewater interactions, we averaged the distance between the ground and water table across all dates for each sampling location, excluding surface water sites. If the average distance between the ground and the water table was below 1 m, we considered these sites to have high susceptibility.

In our bacterial data analysis, we decided not to report the total coliform data due to the various additional sources other than human wastewater. Our analysis focused on the *E. coli* measurements, a coliform found only in warm-blooded mammals. We averaged the MPN of CFU of *E. coli* and the 95% confidence intervals for the replicates of each location on each sampling date. We compared *E. coli* bacteria concentrations of sites with <1 m deep unsaturated zones to those with ≥ 1 m deep unsaturated zones. In addition, distributions of sites with <1 m deep unsaturated zones were statistically compared to those with ≥ 1 m deep unsaturated zones using the Mann Whitney U-test.

Survey Methods

We conducted an online survey (Appendices C, D, and E) in order to characterize the knowledge, risk perceptions, and behaviors of Nags Head homeowners regarding septic tank systems and water quality. The survey collected data on the type of homeowner, the use of their home, the type of septic systems connected to their home, and the respondents general knowledge about septic systems. There were also questions to gauge the respondents' level of concern surrounding wastewater and groundwater interactions. The OBXFS Community Advisory Board, composed of members of the local Outer Banks Community, reviewed and provided feedback on an early draft of the survey. All survey procedures were approved by the Institutional Review Board at UNC-Chapel Hill.

Through a modified version of the Dillman tailored design method (Dillman 2011), we recruited a random sample of homeowners that included both permanent and non-permanent residents of Nags Head. A list of these homeowners and their addresses were obtained through water bill records provided by the Town government. To ensure that the sample group only consisted of named individuals who own a residential property in the town, we excluded properties associated with local businesses, property management companies, and unnamed owners. Additionally, individuals that were associated with the OBXFS, Coastal Studies Institute, and the research project were excluded. This reduced the survey population to 4,787 identifiable property owners. Choosing a confidence interval of 5% and a confidence level of 95%, our target sample size was 356 respondents. Assuming a response rate of 20%, we randomly selected 1,780 property owners for recruitment.

Those selected for our sample were sent two postcards through the US Mail, two weeks apart. Both postcards had links to the survey and a QR code that could be scanned to obtain the survey in Qualtrics. The first postcard included an invitation to take the survey, explained the purpose of the research study, and detailed why individuals were specifically targeted to take the survey. The second postcard had a message thanking respondents who took the survey and encouraging those who had not to participate. The survey remained open for 27 days beginning on September 30, 2020 with the mailing of the first round of postcards. After the second round of postcards was mailed, the survey closed on October 26, 2020.

Across the two mailings, a total of 3,560 postcards were sent, 31 postcards were returned. In cases where only one of the cards were returned, we assume the addressee did not receive either card, reducing our sample size to 1,749. We received 125 responses. Of those responses, 121 individuals completed the entire survey, resulting in a response rate of 6.9%. Response rates for non-solicited mail surveys are typically low. Factors that may have impacted the low response rate are technological barriers, property owners being absent from their residence, and people thinking our survey was spam or junk mail, possibly due to the 2020 elections.

Survey analyses

Responses to the set of questions asking for information about respondents, their homes, and their septic systems served as predictor variables. These predictor variables were used in our analyses of the variability in respondents' reported knowledge, behaviors, and perceptions. Chi-Square and Fisher's Exact Test were used to see if predictor variables had a significant relationship with SHI awareness, responsibility for dissemination of septic system information, pumping frequency, and preferences of information sources. The Kruskal-Wallis Test was utilized to see if there were significant differences in septic system knowledge and perceptions about septic systems, flooding, and change between groups of respondents by predictor variables.

WATER QUALITY RESULTS AND DISCUSSION

Bacteria Results

While total coliforms generally indicate the sanitary condition of a water supply, they are widely found in soil and are not an indicator specific to human wastewater interactions. Therefore, total coliforms are not reported here. *E. coli* concentrations ranged from a minimum of zero MPN CFU at multiple locations to a maximum of 945.5 MPN CFU at Wrightsville 2 on Oct. 12. The Blackman site on Sept. 16 had the highest *E. coli* concentration, but it was not used in analyses as a bailer, that may have introduced surfaces where bacteria could proliferate, was found in the well. The mean *E. coli* concentration across all dates and sampling sites was 281 MPN CFU, although variance was high on spatial and temporal scales. The Wrightsville 2 surface water site had the highest mean *E. coli* concentration, and Sept. 18 was the sampling date with the highest mean *E. coli* concentration. B12, B14, NH Control, and Vista Colony consistently had *E. coli* concentrations equal to or below 10 MPN CFU across all sampling dates.

The EPA recreational water quality standard for *E. coli* concentrations is 126 MPN CFU (Fig. 6) (EPA 2012). All study site locations with a depth of the unsaturated zone < 1 m had MPN CFU's that exceeded the EPA standard on at least one date. High concentrations of *E. coli* can be hazardous to human health because they drain into recreational waters from the nearest outfall (Fig. 7).

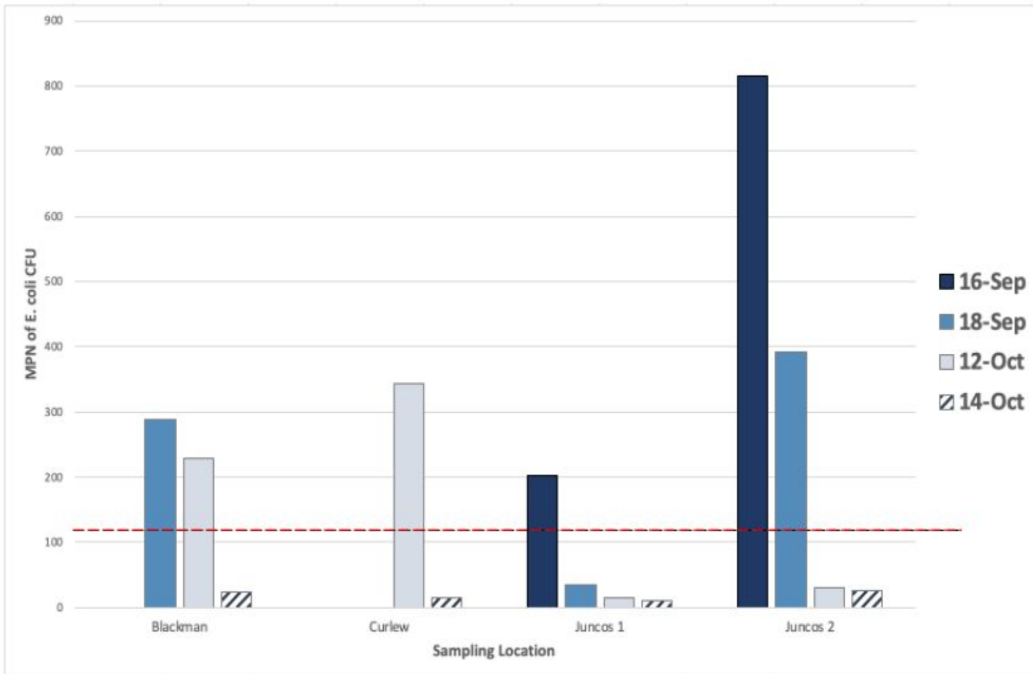

Figure 6. ***E coli.*** **MPN of CFU of sampling sites (< 1 m)by date.** *E. coli* concentrations (MPN of CFU; most probable number of colony forming units) shown for each date and groundwater sampling site in Nags Head, where the depth of the unsaturated zone was < 1 m. The EPA recreational water quality standard for *E. coli* concentrations (126 MPN CFU) is shown with the dashed red line. All sampling sites with an unsaturated zone ≥ 1 m deep (B12, B14, NH Woods Control, and Vista Colony) had E. coli concentrations < 10 CFUs and are not depicted.

Figure 7. Outfalls in relation to sampling sites. The spatial relationship between sampling sites and outfall locations within sub-watersheds in the town of Nags Head. The outfalls drain to recreational waters in the Atlantic Ocean. Recreational water quality standards are a point of reference for our analysis.

One of our hypotheses was that bacteria concentrations would be lower at sites with an unsaturated zone depth ≥ 1 m as compared to sites without 1 m of separation between the ground surface and the water table. We found that Blackman, Curlew, Juncos 1, and Juncos 2 all had a mean unsaturated zone depth of < 1 m across all sampling dates (Fig. 8). All samples from sites with ≥ 1 m unsaturated zone depth consistently had *E. coli* concentrations of 0 MPN CFUs, with the exception of B12 on Oct. 12 which had 10 MPN CFU of *E. coli* per 100 mL. These sites with a ≥ 1 m depth of unsaturated zone included B14 and Vista Colony, which are sites where groundwater lowering projects have been implemented. All the sites with a mean unsaturated zone depth < 1 m consistently had *E. coli* concentrations > 10 MPN CFU (Fig. 6). These results suggest contamination by un- or undertreated septic wastewater due to insufficient space between the septic drainfield and water table.

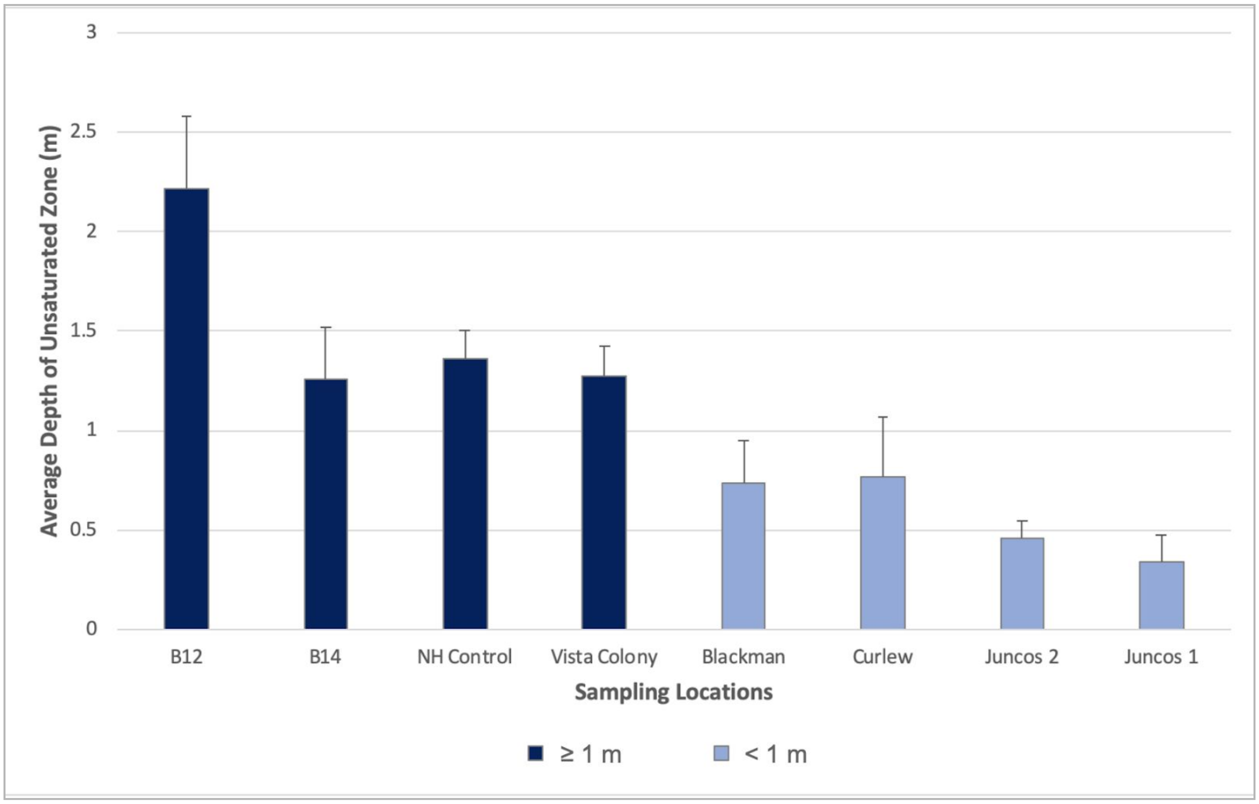

Figure 8. Average depth of unsaturated zone by sampling location and date. Average depth of unsaturated zone measured for all sampling dates (Sept. 16, Sept. 18, Oct. 12, Oct. 14), in meters, at each groundwater well sampling location in Nags Head, NC. This data was collected by measuring distance from the ground surface to the top of the water table.

There were variations across dates for sites with higher susceptibility based on water level (< 1 m unsaturated zone depth). However, because of the small sample size, we could not conclude any trends specific to date or sampling location. When attempting to understand the inconsistencies in bacterial data, we looked at various environmental variables across sites. These variables included temperature, salinity, DO, and conductivity. When comparing sampling sites, environmental conditions did not show any significant correlations to the patterns we observed, introducing several confounding variables, which complicated data analysis and interpretation.

The rain occurrences—both preceding and during sampling events—could have skewed bacteria concentrations in the samples. In the previous Capstone studies, days with rainfall recorded higher *E. coli* concentrations than dry days (Allen et al. 2018; Anderson et al. 2019). Our results do not show this trend, indicating there may be several variables besides precipitation that affect *E. coli* concentrations in groundwater. For example, *E. coli* bacteria prefer anaerobic conditions, warm water temperatures, and low salinity levels (Williams et al. 2015). The Juncos 1 and 2 sites had low dissolved oxygen levels, meaning they were anaerobic; they were also considered susceptible as their water table depth was < 1 m. For these reasons, we assumed *E. coli* concentrations would be consistently high at both sites. However, there was considerable variability across days. While the Sept. 16 and Sept. 18 sampling dates had high *E. coli* concentrations, Oct. 12 and Oct. 14 did not. The same variability was found at other susceptible sites. Again, this variability limited our ability to draw conclusions. The only clear result is that bacteria concentrations are regularly higher at sites with a depth of the unsaturated zone < 1 m

Due to the unequal variance within our data set and our limited sample size, we were unable to perform a T-test to compare sites with a ≥ 1 m unsaturated zone depth to those with < 1 m depth. The Mann-Whitney U test is more appropriate for analyzing non-parametric data as it allows for comparisons of distributions between sample populations. *Figure 9* shows the distribution of *E. coli* concentrations (MPN CFU) for the groundwater sampling sites at all dates that had an unsaturated zone depth of < 1 m. There was little variation in *E. coli* concentrations for groundwater sampling sites that had a depth of unsaturated zone ≥ 1 m. This statistical test suggests that sites with a sufficient (≥ 1 m) unsaturated zone depth are less likely to have measurable *E.coli* concentrations, indicating that they are less likely to be contaminated by un- or undertreated septic wastewater.

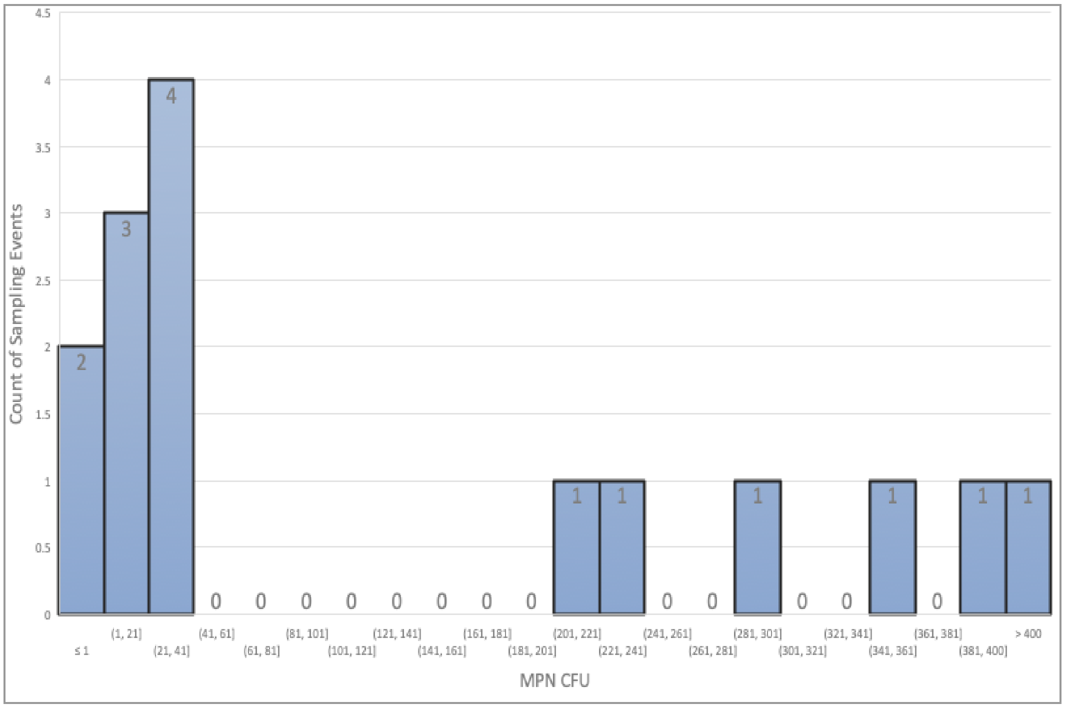

Figure 9. *E. coli* concentration distribution by sampling sites (< 1 m depth). Distribution of *E. coli* concentrations shown for groundwater sampling sites in Nags Head with < 1 m depth of the unsaturated zone (Curlew, Juncos 1, Juncos 2, and Blackman) on all sampling dates (Sept. 16, Sept. 18, Oct. 12, Oct. 14). Each bar represents the number of sampling events that had a measured *E. coli* concentration within the given MPN CFU interval.

Optical Brightener Results

Optical brighteners act as a qualitative measure and are reported as presence/absence. Groundwater sites B12, B14, and Juncos 2, had optical brighteners present on at least one sampling occasion (Table 2). B14 is a site impacted by groundwater lowering while B12 and Juncos 2 are not. Therefore, these results do not support the claim that groundwater lowering efforts are reducing chemical indicators of septic contamination. The presence of optical brighteners in B12 and B14 that have an unsaturated zone depth of ≥ 1 m could also be attributed to improper septic maintenance by nearby property owners. These three sites also varied in environmental conditions such as soil composition, salinity, DO, and unsaturated zone depth. Due to the variability across sites, the presence of optical brighteners cannot be attributed to a single factor such as water level. It is unclear how interactions between environmental variables may cause a site to be positive one day and absent the next. Therefore, groundwater contamination by wastewater likely happens more often than our data suggests. Optical brighteners are a clear indication of wastewater and groundwater interactions. Our data provides evidence that there is contamination across the study area.

Table 2. Optical brightener presence and absence at all sampling locations on all sampling dates. This was based on the modified Cao et al. (2009) method.

Site Name	September 16, 2020	September 18, 2020	October 12, 2020	October 14, 2020
NH Control	absent	absent	absent	absent
B12	present	present	present	absent
B14	present	present	absent	absent
Wrightsville 2	absent	absent	absent	absent
Curlew	absent	absent	absent	absent
Wrightsville 1	absent	absent	absent	absent
Vista Colony	absent	absent	absent	absent
Blackman	absent	absent	absent	absent
Juncos 1	absent	absent	absent	absent
Juncos 2	absent	absent	present	absent
Juncos Ditch	absent	absent	absent	absent

Limitations

There are several factors that influence the efficacy of *E.coli* concentrations and optical brightener presence as useful proxies for studying the contamination of groundwater by un- and undertreated septic wastewater. With regards to our methods and research design, the few sampling events produced a small sample size, making most forms of statistical analysis incompatible with our dataset. Though the Mann-Whitney U test allowed us to test statistical differences between bacteria concentration distributions, our sample size was still too small for extensive analysis. Additionally, our historical analysis was limited by inconsistencies in sampling sites across the three-year study, which hindered our ability to make direct comparisons between data sets (Allen et al. 2018; Anderson et al. 2019).

E. coli concentrations are not the ideal indicator of septic wastewater contamination because there are many variables affecting the presence of bacteria in the environment, complicating the identification of contamination by septic wastewater (Glickstein 2006). These variables include feces from warm-blooded animals such as pets and wildlife point sources and nonpoint source run-off (Glickstein 2006).

Environmental factors also pose limitations to our research. The presence of organic matter in soils is known to remove optical brighteners from water (Turner Designs [date unknown]). Outer Banks soil is low in organic matter as it is primarily sandy. Therefore, optical brighteners are potentially overrepresented in our sample (Natural Resources Conservation Service 2019). On the other hand, optical brighteners are diluted by water and degraded by light; while we took precautions (collection and storage in amber bottles), excessive UV exposure during sampling could have removed the brighteners from the samples before they were tested in the lab, potentially underrepresenting our sample.

Summary of Findings

Our results from bacteria and optical brightener analyses suggest that there was septic contamination across Nags Head. Due to high variability in environmental factors between sites and a small data set, we were unable to explain the trends in septic indicators in Nags Head groundwater. We found that bacteria levels were consistently higher in sampling sites that had a lower unsaturated zone depth, suggesting wastewater and groundwater interactions (Fig. 6). These findings support our hypothesis that a deeper unsaturated zone would result in lower indicator concentrations and incidence. In order to explain these trends of bacteria and optical brighteners in the future, a larger data set is required. Sampling more wells in the study area on a regular schedule throughout the year, and controlling for environmental variables, will allow for more accurate analyses and provide more information regarding septic contamination.

SURVEY RESULTS AND DISCUSSION

Respondents and Households Description

Our survey garnered 121 completed responses. 57% of respondents identified as male and 41% identified as female (Table 3). The majority of respondents were between the ages of 40 and 80, most falling between the ages of 60-69 years old. Respondents' income levels were mostly at the higher end of the range provided; 44% of respondents reported annual income over $100,000 (Table 3). For 77% of respondents, their Nags Head home was not their primary residence (Table 4).

If a respondent indicated they were a non-permanent resident, the survey inquired about the occupancy of their home when they were absent. Occupancy determines the strain placed on a septic system. Almost half (41%) of respondents rent out their homes on a weekly basis. Consistent home occupancy by visitors may result in signs of failure going unnoticed as visitors are likely to be less aware of these indicators. If the occupants are not familiar with septic systems, their actions could damage the systems. Further, signs of failure such as bubbling or smell could be ignored by renters, especially if they were unsure who to contact.

Table 3. Demographic data for respondents to our survey of Nags Head homeowners. (n = 116) Out of 121 completed surveys, only 116 respondents answered demographic questions.

Demographic Information	Responses	Percentage of Respondents (%)
Age (n = 116)	Under 20 years	0%
	20-29 years	0%
	30-39 years	0.86%
	40-49 years	8.6%
	50-59 years	20%
	60-69 years	34%
	70-79 years	29%
	80 or above	6.9%
	Prefer not to say	0.86%
Gender (n = 116)	Female	41%
	Male	57%
	Other - please specify	0%
	Prefer not to say	1.7%
Household Income (n = 116)	$20,000 - $34,999	3.4%
	$35,000 - $49,999	0.86%
	$50,000 - $74,999	11%
	$75,000 - $99,999	9.5%
	$100,000 - $149,999	21%
	$150,000 or more	23%
	Prefer not to say	31%

As expected, based on information from the Town, the majority (81%) of respondents had a septic system. Of these, most (83%) had a conventional septic system. The reported age of septic systems varied, but a third (33%) were 25 or more years old (Table 4). The prevalence of older systems is concerning, as the average lifespan of a septic system is 20-30 years and older systems have a higher risk of failure (Richards et al. 2017).

Table 4. Households data for respondents to our survey of Nags Head homeowners. Respondents provided information regarding individual property and septic system characteristics.

Households	Responses	Percentage of Respondents (%)
Septic Presence (n = 121)	Has a septic system	81%
	Does not have a septic system	16%
Septic Age (n = 99)	Less than 1-4 years	7%
	5-9 years	12%
	10-14 years	11%
	15-19 years	11%
	20-24 years	10%
	25 or more years	33%
	Unsure	15%
Septic Type (n = 99)	Conventional	83%
	Non-conventional	9%
	Unsure	7%
Home occupation (n = 119)	Rented out on an annual basis	3%
	Unoccupied when I am not there	26%
	Friends & family occasionally stay	29%
	Rented out on a weekly basis	41%
Residence (n = 121)	Full time Nags Head resident	22%
	Not a full time Nags Head resident	77%
Weeks of non-permanent residents in Nags Head property (n = 91)	Mean	10.5 weeks
	Median	8 weeks
	Standard Deviation	8.02 weeks
Years of property ownership (n = 120)	Mean	15.4 years
	Median	13 years
	Standard Deviation	11.9 years

Septic System Knowledge and Awareness

Prior research alluded to the existence of varying knowledge regarding septic systems in Nags Head (Anderson et al. 2019). In order to further investigate this trend, respondents self-evaluated their knowledge level concerning septic systems within the survey. More than half (57%) of respondents considered themselves either very or moderately knowledgeable about septic systems, while only 7% said they were not at all knowledgeable (Fig. 10).

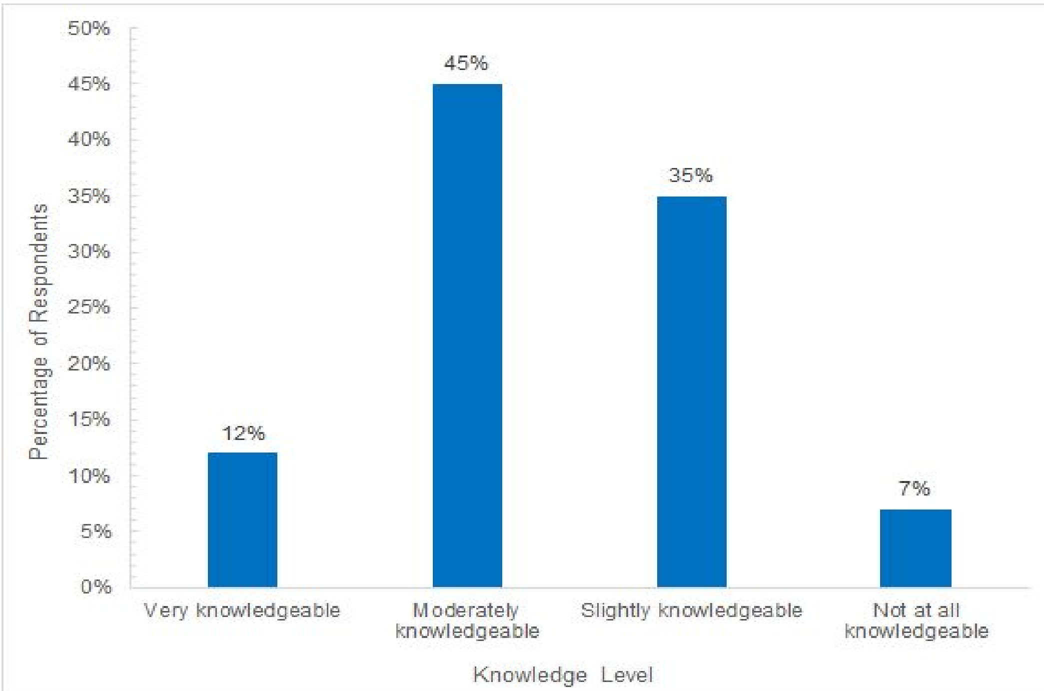

Figure 10. Septic system knowledge self-evaluation by respondents to our survey of Nags Head homeowners. (n = 99) The survey asked respondents to self-evaluate their knowledge levels concerning septic systems in order to investigate varying understandings.

Septic system owners may rely on a variety of indicators to alert them to a septic system issue. Respondents were asked which indicators would alert them to a problem with their septic system. All possible answer choices were indicators of a problem: drains backing up, toilet clogging, a smell being present on the drainfield, the ground surface of the drainfield being wet, and an alert from the septic system alert system. There were seven respondents who selected all five indicators (Fig. 11). This demonstrates varying knowledge amongst respondents regarding signs of septic system issues. However, some systems may not have an alert system; a possible explanation as to why this option was not chosen by some. This could be addressed through diversifying information dispersal methods to raise awareness of the signs associated with septic system issues.

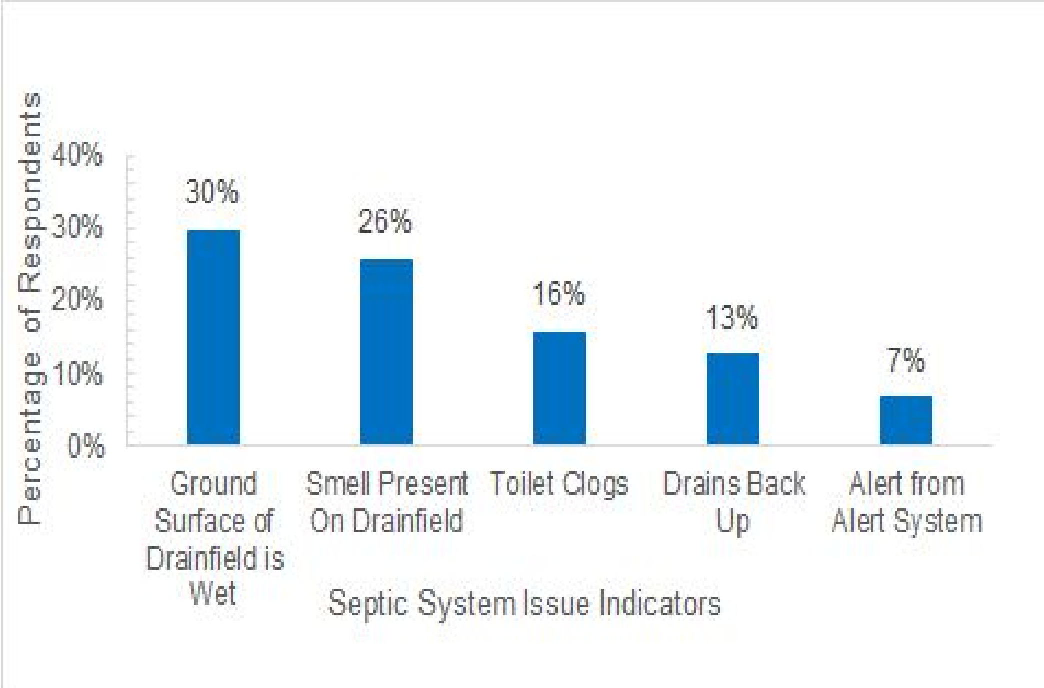

Figure 11. Septic system issue indicators used by respondents to our survey of Nags Head homeowners. (n = 92) Indicators which would alert respondents to septic system issues. Multiple options could be chosen. (Of the 92 respondents, 3% were "unsure.")

Contrary to our hypothesis, awareness of septic system issue indicators did not broadly vary with residency. The only statistically significant difference including respondent residency was regarding toilet clogging (Chi-Square, $p = 0.02$). Non-permanent resident respondents more commonly considered toilet clogging to warn of an issue. Out of 92 responses, half (50%) of non-permanent resident respondents saw clogging as a septic issue, however, few permanent resident respondents (23%) agreed. This provides Nags Head with evidence of inconsistent knowledge surrounding signs of septic system failure amongst respondents based on their residency.

Many (73%) respondents indicated awareness of the SHI within the survey. The perceived effectiveness of the SHI varied amongst respondents. Nearly half (43%) of respondents found the SHI very helpful, while a small portion (4%) found it not helpful. This suggests that the SHI is generally perceived to be helpful, with the majority (80%) of respondents indicating it is moderately to very helpful.

The survey investigated the sources of information regarding septic systems which respondents relied on (Fig. 12) and prefered (Fig. 13). Many respondents (75%) reported currently relying on septic system professionals for information (Fig. 12). Respondents would prefer to get information about septic systems from additional sources such as: Town Officials of Nags Head and officials from the Dare County Health Department. These data suggest some alternative ways to disseminate information and educate property owners about septic system health, including electronic newsletters and government websites, to mitigate variations in information and knowledge.

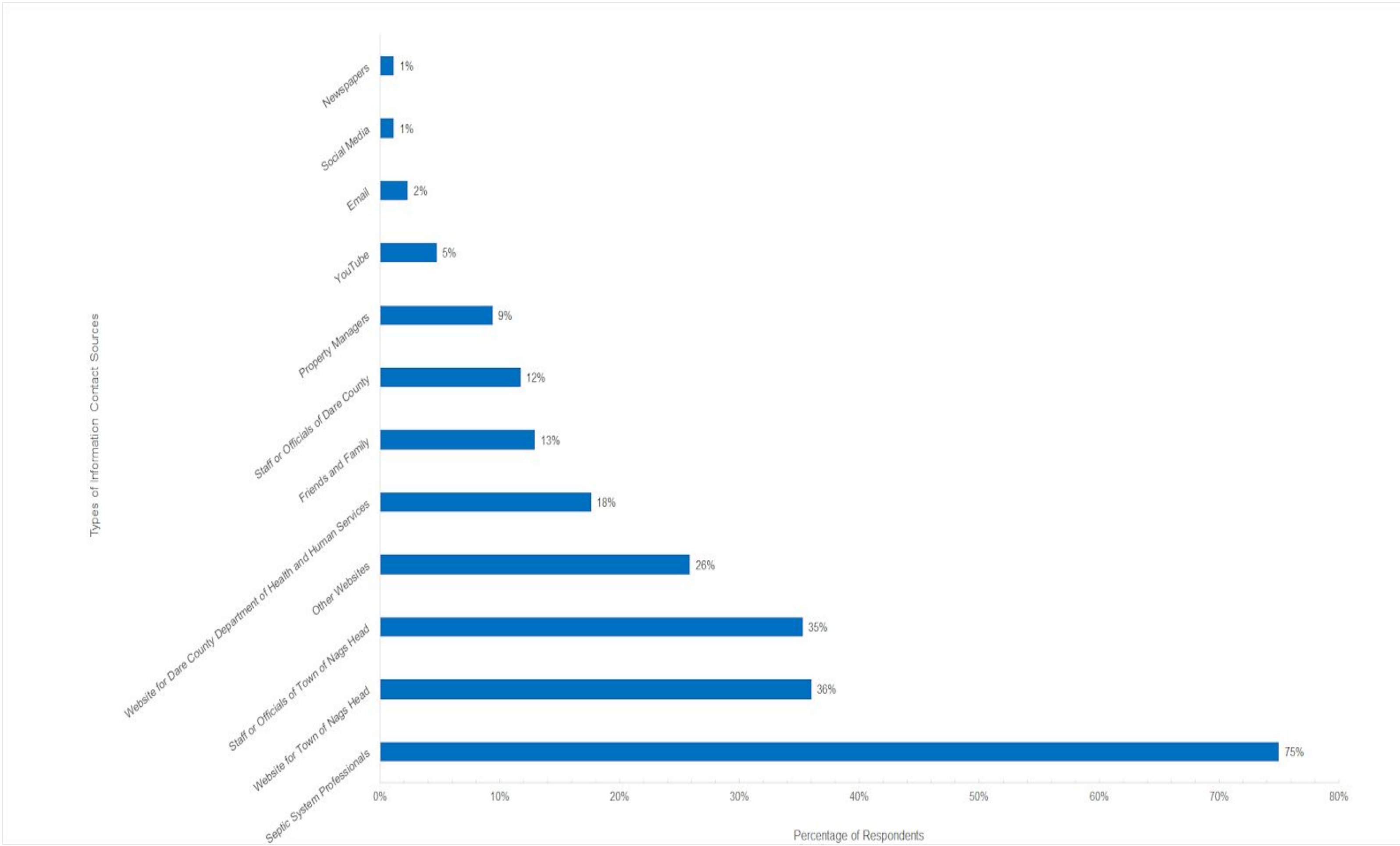

Figure 12. Current septic system information contacts. Nags Head homeowners (n = 79) indicated sources they contact for information about septic systems. Multiple options could be chosen, which is why the responses are greater than 100% when summed together.

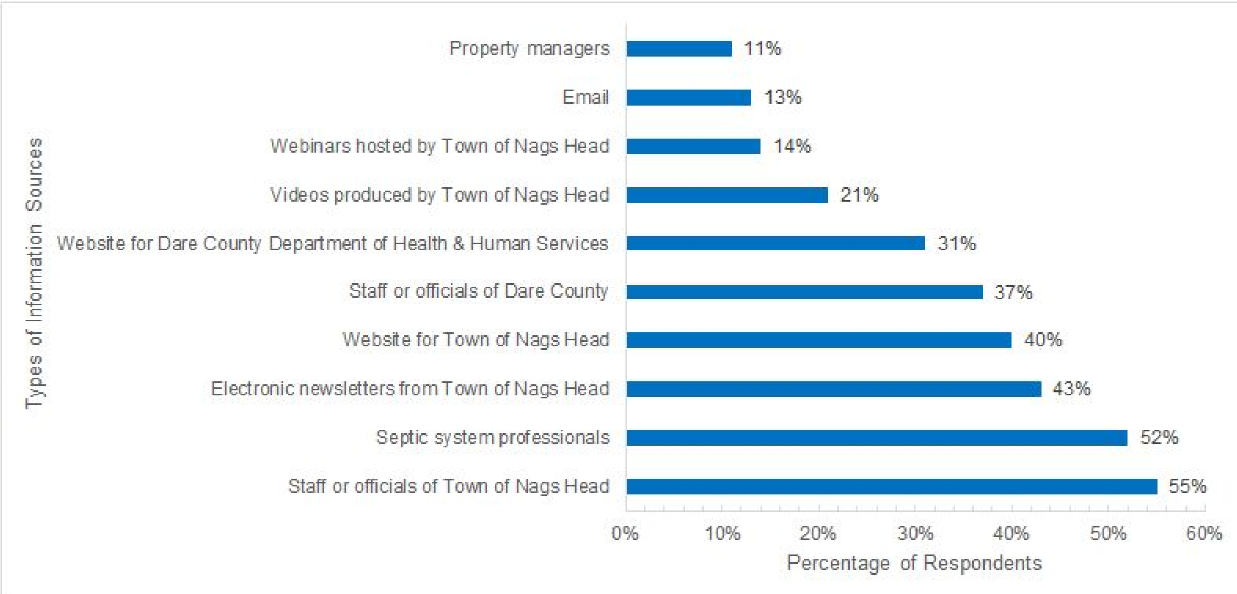

Figure 13. Preferred septic system information sources. Nags Head homeowners (n = 97) who responded to our survey indicated their preferences for information sources about septic systems. Multiple options could be chosen, which is why the responses are greater than 100% when summed together.

Respondents were asked to choose who they believed should provide information about septic systems to visitors and new homeowners; they were allowed to pick multiple options. Local government authorities, in this case the Town of Nags Head, were most commonly selected (Fig 14). Septic system professionals were considered the least responsible for providing septic information (Fig. 14), but were a significant preference for information (Fig. 13). Septic professionals were sought out as needed for repairs (Fig. 15), thus shifting responsibility for preventative measures, such as information dissemination, to government entities including the Town of Nags Head. Outreach and education efforts were supported by respondents, therefore further development of current programs and the creation of new programs by the Town of Nags Head or Dare County may be beneficial.

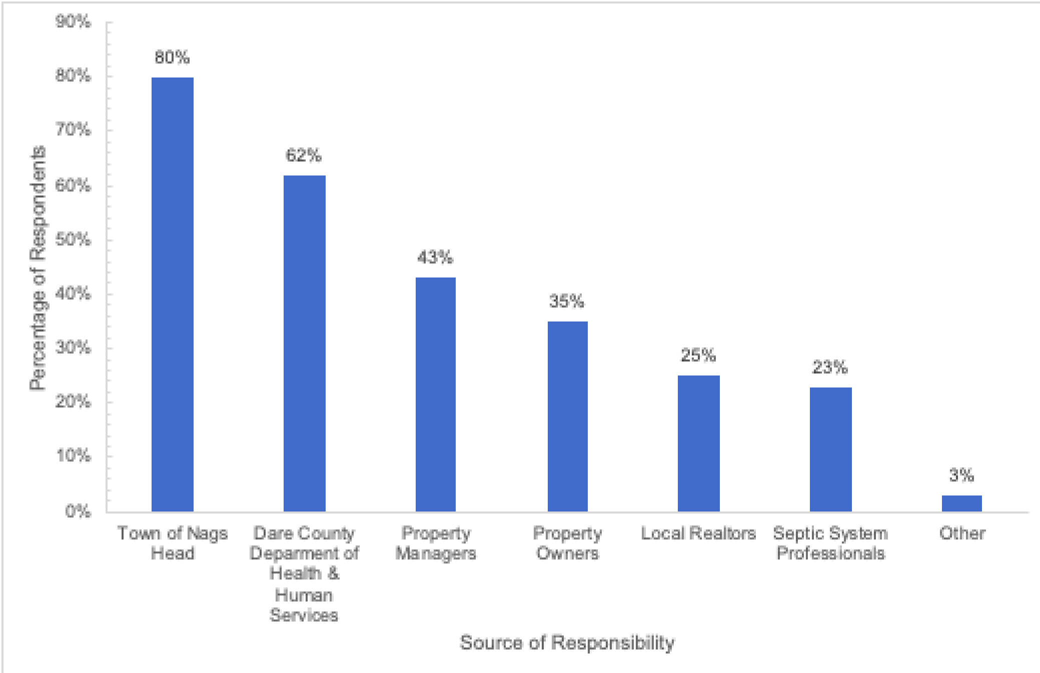

Figure 14. Responsibility for septic system information. Nags Head homeowners (n = 99) indicated who they perceived to be responsible for septic system information distribution. Multiple options could be chosen, which is why the responses are greater than 100% when summed together.

Behavior

Our survey asked respondents whom they have contacted for guidance and assistance when they experienced issues with their septic system. Nearly half (46%) of respondents indicated they have never experienced a problem with their septic system, thus they have never contacted anyone (Fig. 15). Over half (60%) of respondents turned to septic system professionals when they had a problem.

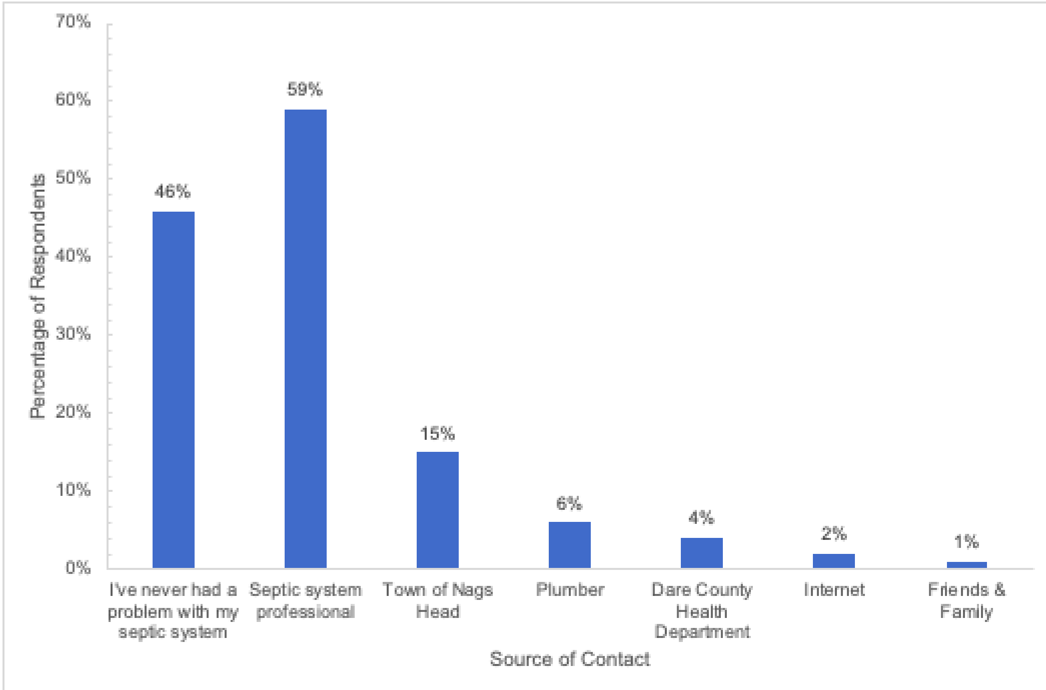

Figure 15. Reported contacts regarding septic system issues. Nags Head homeowners (n = 98) indicated who they have contacted when they had septic system issues. Multiple options could be chosen, which is why the responses are greater than 100% when summed together.

Septic tank pumping was used as an indicator of respondents' preemptive actions that allude to respondents' septic system knowledge. Nearly half (48%) of our respondents said they pump their septic tanks on the recommended schedule of every 3-5 years. The survey inquired as to when each respondents septic system had last been pumped. The majority (63%) had pumped their septic tanks within the last 5 years (Fig. 16). Septic system maintenance is crucial to the life of the system and for decreasing the chances of groundwater contamination by wastewater (Richards et al. 2017). However, many (38%) of our respondents have not pumped their systems within the recommended time frame, including nearly a fifth (18%) who said that they have never had their septic system pumped (Fig. 16). We wanted to investigate potential barriers to maintenance through the survey, however, only 16 respondents answered. Respondents could indicate if any of the following were a barrier to them receiving maintenance: not knowing enough about septic systems, cost, or not knowing who to contact. We anticipated these to be the most likely barriers for respondents, as they are barriers addressed in the SHI. The low number of responses may indicate that respondents never experienced these barriers.

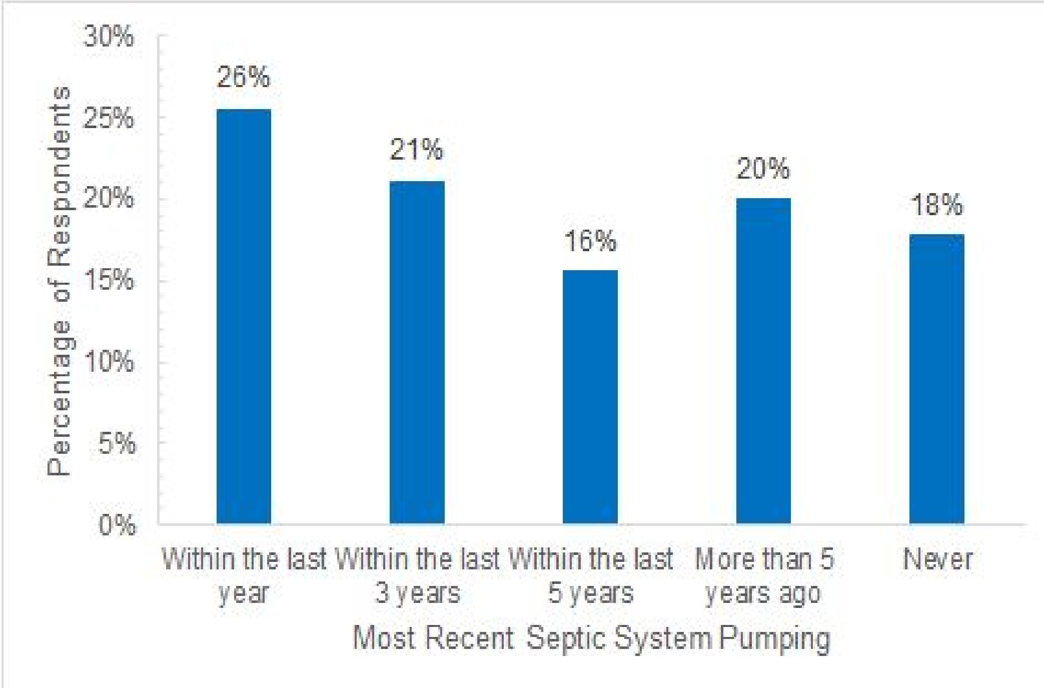

Figure 16. Most recent septic system pumping. Homeowners (n = 99) indicated the last time they pumped the septic system on their Nags Head property. The recommended frequency is 3-5 years. (Of the 99 respondents, 9 were unsure when they had last pumped their system.)

Following the recommended schedule of septic tank pumping varies with home occupation among non-permanent resident respondents as determined by the Fisher's Exact Test. There was a statistically significant relationship between respondents following a regular pumping schedule and how their home was occupied ($p_A = 0.000255$, $p_B = 0.000251$, df = 3, n = 74). Respondents who rent their homes out on a weekly basis reported following the 3-5 year regular pumping schedule more than statistically expected (Fig. 17). Respondents who rented their Nags Head homes weekly may have conducted more regular maintenance to prevent problems and keep visitors happy. Visitors may not care for the home like an owner would and might put items down drains that do not belong, leading to a need for more regular maintenance. In addition, high occupancy on a regular basis could lead to septic overload. These and other circumstances may have led respondents with weekly rental homes to conduct septic maintenance on a regular basis.

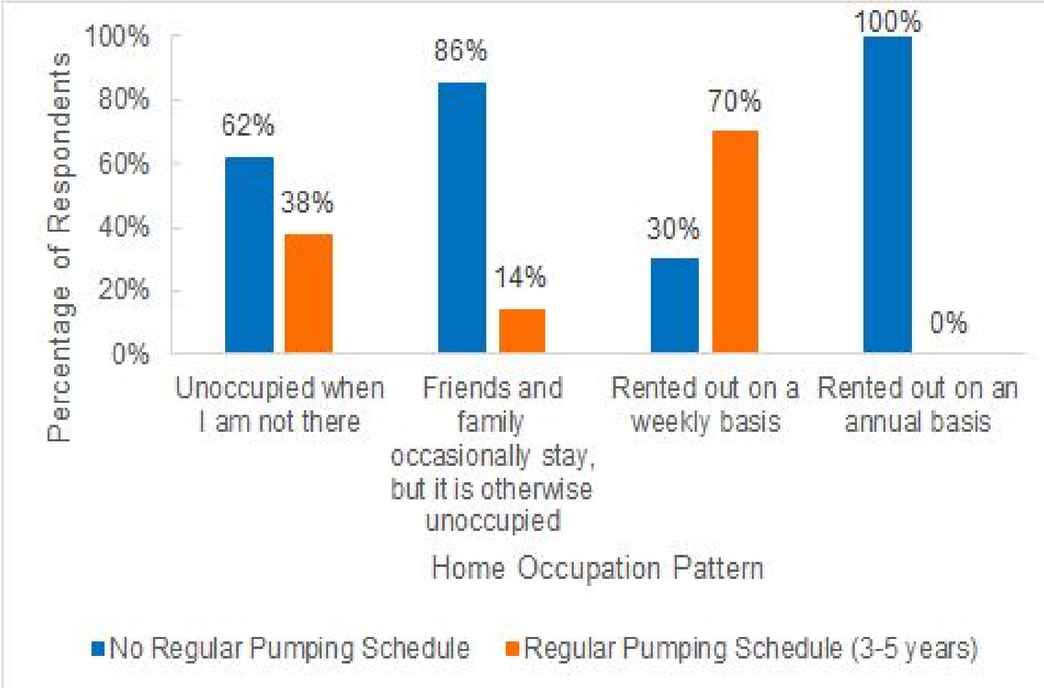

Figure 17. Pumping schedule based on home occupation. Homeowners (n = 74) stated the occupation pattern of their Nags Head homes and adherence to the recommended septic pumping schedule of every 3-5 years. The Fisher's Exact Test was used to calculate the relationship between these variables. The relationship was found to be statistically significant (p_A = 0.000255, p_B = 0.000251, df = 3, n = 74).

To explore the relationship between septic knowledge and proper septic system maintenance, *Figure 18* shows a comparison between pumping frequency as connected to respondents' knowledge level. Though not statistically significant, the data indicates that respondents who felt they were very knowledgeable about septic systems were more likely to maintain a regular pumping schedule (Fig. 18). These findings, again, suggest that dispersal of information and greater outreach, which can increase public knowledge, are important factors in water quality management. We also found that, while routine maintenance of septic systems should increase as systems age, this was not the case (Fig. 19). The responses of septic system owners with systems 25 years or older showed few (28%) were pumping regularly. With older systems, more respondents should be pumping on the regular 3-5 year schedule.

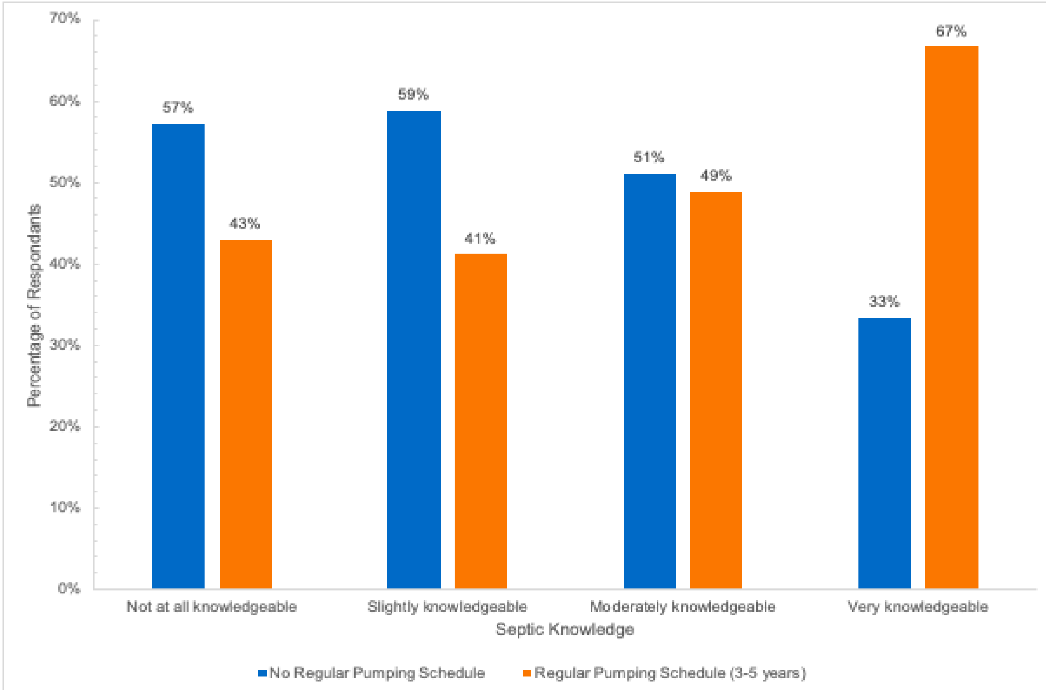

Figure 18. Pumping frequency and septic knowledge. Nags Head homeowners (n = 98) stated if they regularly pump their septic tanks, and their knowledgeability on septic systems.

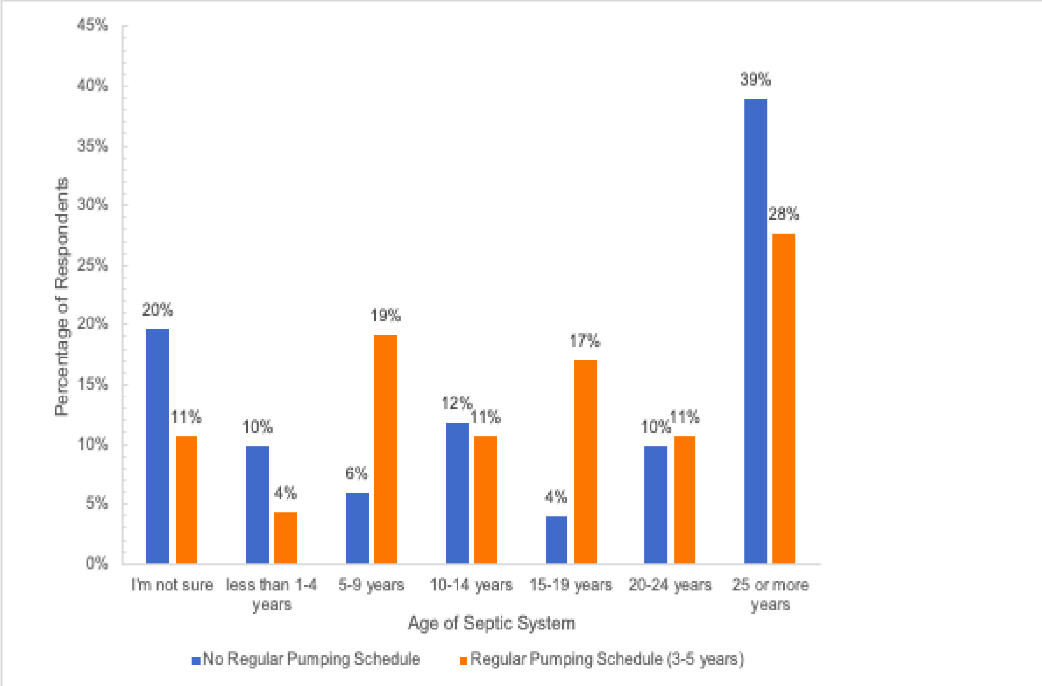

Figure 19. Pumping frequency and septic system age. Nags Head homeowners (n = 98) stated their septic system age and indicated how often they pumped their septic system. The differences in routine and maintenance for different septic age groups are displayed.

Perceptions of Septic Systems, Flooding, and Change

General results and trends

Perceptions of septic systems, wastewater contamination, and flooding were assessed by asking respondents to indicate their level of agreement with a series of ten statements (strongly disagree, disagree, neutral, agree, and strongly agree). The greatest amount of agreement coincided with support of centralized sewage systems if feasible for the town of Nags Head (Appendix G: Table 1). The most disagreement corresponded to water tables rising closer to the surface of the ground, on respondents property, than they used to (Appendix G: Table 1).

Several patterns were evident in the response data. The first pattern was that statements regarding flooding, water table level, and central sewage displayed skewed results towards one end or the other of the scale (Fig. 20). Based on response data, a majority of respondents disagreed that water tables were rising (45%) and there was standing water more frequently (69%) in their yards (Fig. 20a and Fig. 20b, respectively). These statements focused on risk perceptions of flooding and changing water tables regarding respondents' own properties. In contrast, respondents generally agreed with statements about flooding that were more detached from their properties and were focused on community-wide situations and burdens. These statements included the need to avoid standing water after storms (63% agreed) (Fig. 20c), the inevitability of flooding in the future in Nags Head (63% agreed) (Fig. 20d), and support for centralized sewage systems if feasible (66% agreed) (Fig. 20e). Respondents appeared more aware of the risks posed to everyone than those posed to just themselves. Perceptions of risk may be more easily managed when the burdens are distributed across a community instead of carried by a single respondent. In conjunction with this, when a potential solution's costs were distributed across the entire town, respondents supported the measure (Fig. 20e).

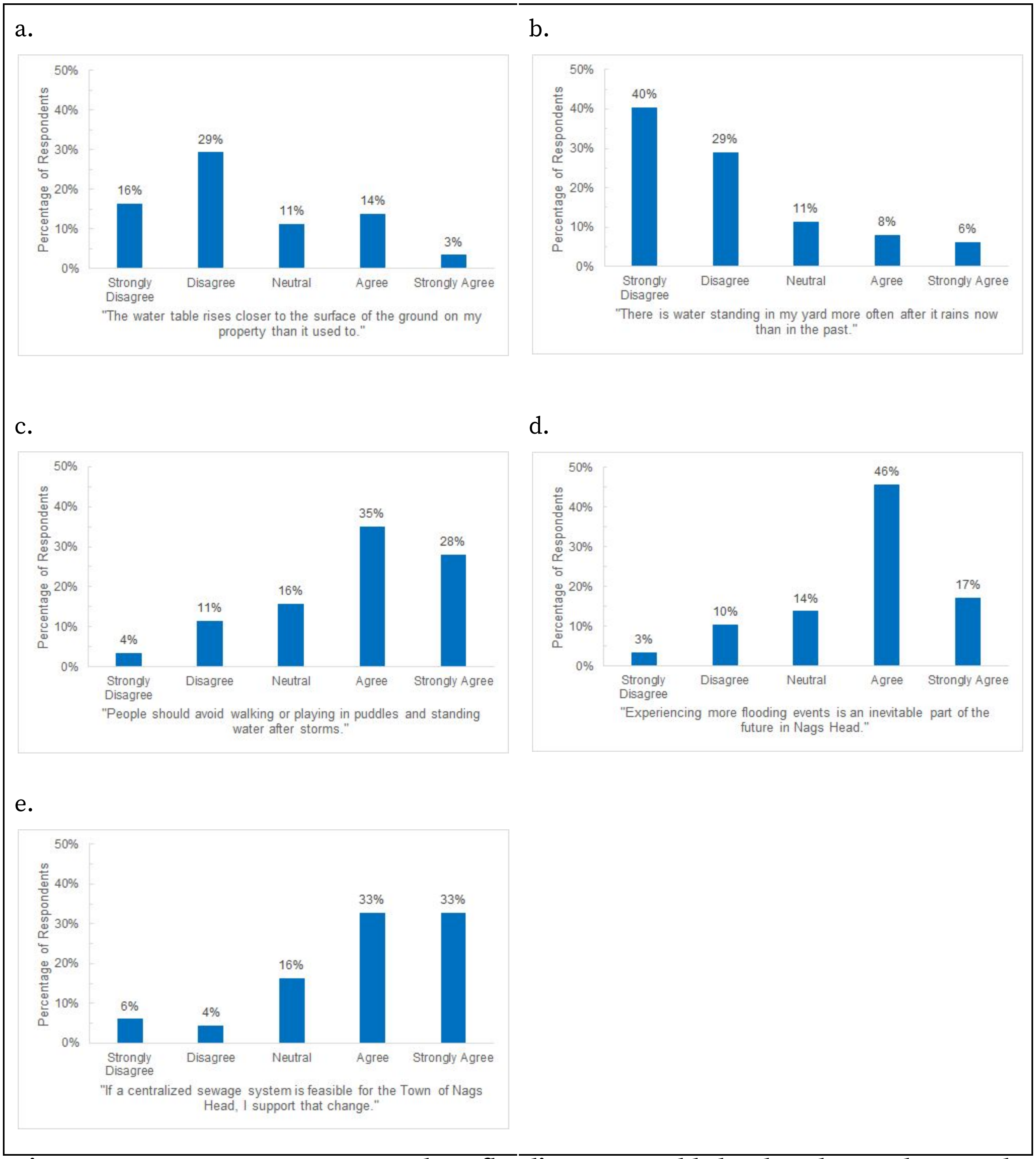

Figure 20. Responses to statements about flooding, water table level, and central sewage by respondents for a survey of Nags Head homeowners. a, n = 116, 26% responded “unsure.” **b,** n = 114, 5% responded “unsure.” **c,** n = 114, 6% responded “unsure.” **d,** n = 116, 9% responded “unsure.” **e,** n = 116, 8% responded “unsure.”

In the second pattern, statements regarding septic systems also displayed a skew towards disagreement or agreement, however, significant neutrality was also expressed by respondents (Figure 21). The statement displayed in *Figure 21a* included language that was intentionally flipped, “I am not concerned,” to reduce the potential for response bias. Respondents may have read the statement incorrectly and considered it to say, “I am concerned;” however, the statement was placed at the beginning of this section to avoid potential reading fatigue. In spite of the flipped language, over half (52%) of the respondents disagreed with the statement (Fig. 21a), which could imply that respondents were concerned about septic system wastewater contamination for both their own property and the town of Nags Head as a whole. This coincides with a third (33%) of respondents who indicated that septic systems will likely no longer be a viable wastewater treatment option in the future (Fig. 21b). Additionally, many respondents (39%) expressed a general willingness to pay fees to ensure the proper functioning of their septic systems (Fig. 21c). In contrast with our hypothesis, respondents’ concern for septic systems and the willingness to pay fees indicate a high risk perception of wastewater contamination from septic systems. However, respondents expressed significant neutrality regarding septic system statements, which indicated that respondents did not feel strongly or certain about the risks of wastewater contamination from septic systems. Additionally, respondents may have had neutral responses because of a general lack of knowledge regarding septic system operation and problems that may exist for all of Nags Head. The neutrality of responses regarding septic system fees may indicate that homeowners did not want to express a specific position for fear of receiving fees. They may have also been uncertain about their potential willingness to pay in the future, if fees were to become a reality.

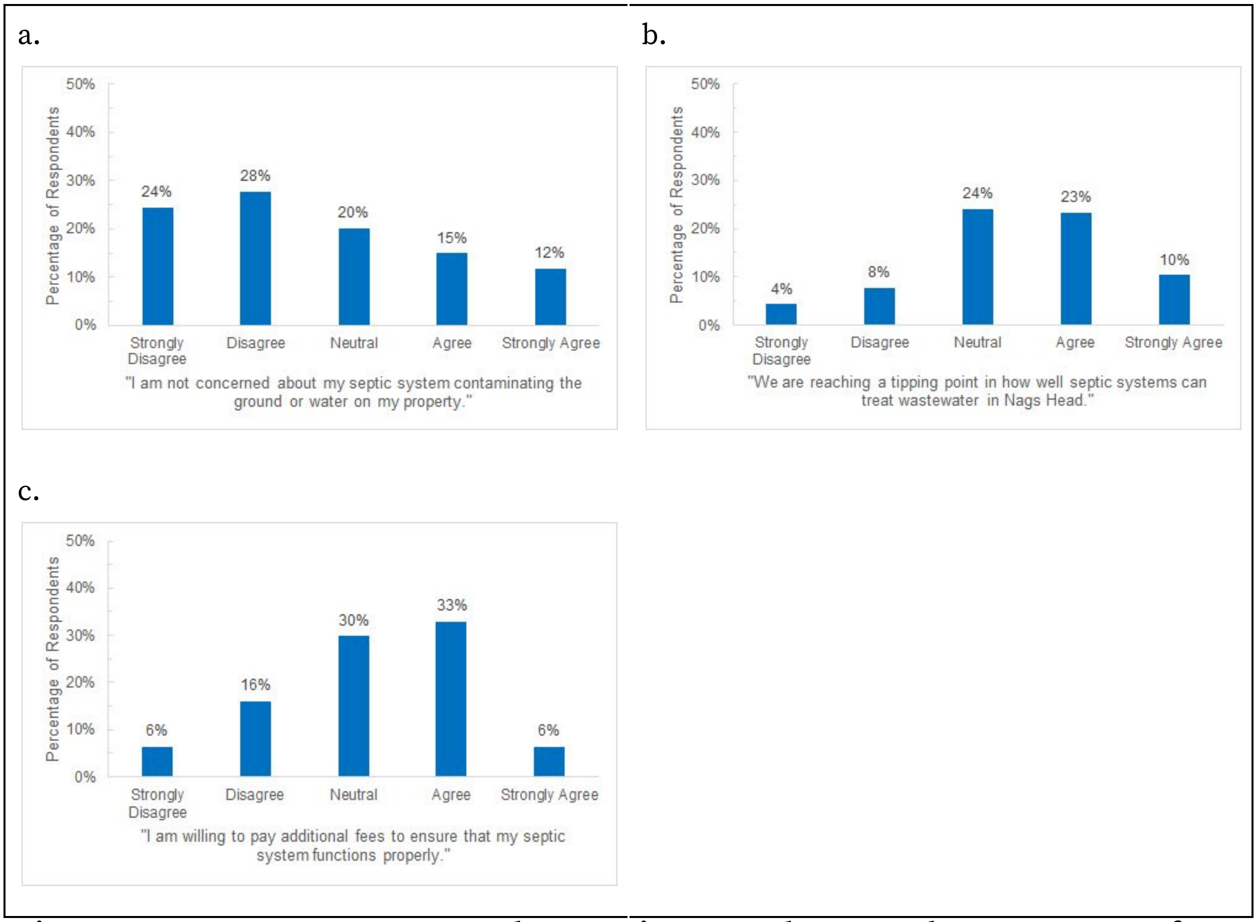

Figure 21. Responses to statements about septic systems by respondents to a survey of Nags Head homeowners. a, n = 94, 1% responded "unsure." **b,** n = 116, 30% responded "unsure." **c,** n = 94, 9% responded "unsure."

Responses to statements regarding contamination of surrounding waters demonstrated a third pattern: a lack of consensus and significant neutrality (Fig. 22). Respondents indicated conflicting perceptions of bacteria levels in the ocean near Nags Head and the ability of septic systems to prevent contamination of surrounding waters. The results showed that respondents did not share a general consensus about the bacteria levels in the ocean (Fig. 22a) or wastewater contamination of surrounding waters due to septic systems (Fig. 22b). Based on these results, respondents appeared to vary in awareness and knowledge of wastewater contamination as we posited in our hypothesis.

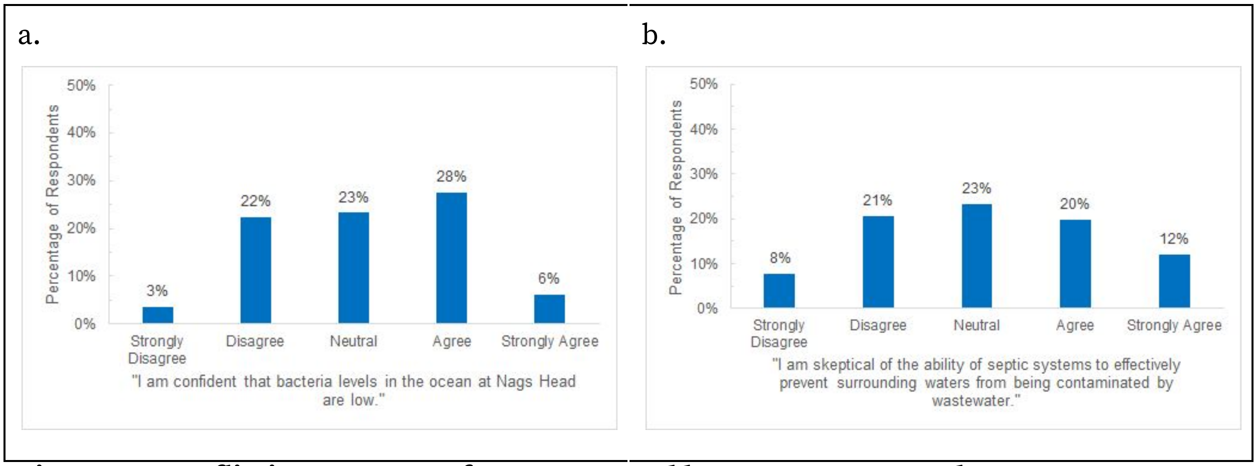

Figure 22. Conflicting responses from Nags Head homeowner respondents to survey statements with significant neutrality. a, n = 116, 17% responded "unsure." **b,** n = 116, 16% responded "unsure."

Statements with significant uncertainty

Many respondents displayed uncertainty with regards to septic systems reaching a tipping point in Nags Head (Fig. 21b), rising water tables on their property (Fig. 20a), and contamination of surrounding water bodies (Fig. 22a and Fig. 22b). Uncertainty was highest (30%) with regards to Nags Head reaching a tipping point in how well septic systems can treat wastewater. The high uncertainty leads us to believe that respondents were generally unsure about the future of wastewater treatment in Nags Head. This may stem from uncertainty about future development or environmental changes, both of which impact septic systems, or from general lack of knowledge regarding septic system operation and impacts. The uncertainty of 26% of respondents regarding a rising water table on their property is interesting to note because this statement generally lacks neutral responses. In contrast, the other statements with significant uncertainty also included many neutral responses. High uncertainty may indicate varying levels of knowledge among respondents.

Contradictions in responses

Our data indicated that respondents did not hold high risk perceptions for their own properties with regards to rising water tables (Fig. 20a) and standing water (Fig. 20b), both of which are associated with septic system problems. However, respondents indicated concern for their septic systems functioning properly and wastewater contamination of their property (Fig. 21a). The disconnect between these trends may indicate varying levels of knowledge concerning the factors influencing a septic system's ability to function properly. Standing water following storms and rising water tables are threats to the proper functioning of septic systems because the unsaturated zone is significantly reduced, thereby limiting the infiltration of the wastewater and its proper treatment (EPA 2018b). While there may not have been a change in the frequency of standing water or a rise in the water table on respondents' properties, it is also potentially true that respondents may not be aware of the connection between water levels and their septic systems. However, they may be concerned about their septic system for other reasons.

Statistical analysis

The variations in perceptions of septic systems, flooding, and change held by respondents are largely independent of potential predictor variables included in the survey. Kruskal-Wallis tests performed to assess relationships between respondent and household characteristics and respondent perceptions found that gender, income, home occupation, ownership length, and pumping frequency did not explain variation in responses. However, there was a statistically significant difference in agreement with the statement about bacteria levels in the ocean near Nags Head between permanent and non-permanent resident respondents ($H = 5.747$, $p = 0.017$). Over half (52%) of respondents who are permanent Nags Head residents disagreed with the statement regarding low bacteria levels in the ocean near Nags Head. In contrast, nearly half (46%) of respondents who are not permanent Nags Head residents agreed that bacteria levels in the ocean are low. Additionally, there were statistically significant differences in agreement regarding the effectiveness of septic systems in preventing wastewater contamination of surrounding waters based on septic type ($H = 6.503$, $p = 0.039$). While a majority (60%) of respondents with non-conventional septic systems disagreed about being skeptical of the ability of septic systems to prevent wastewater treatment, there were only three respondents who indicated this choice. In contrast, the results from the 68 respondents with a conventional septic system were more evenly dispersed with 35% indicating disagreement, 32% indicating neutrality, and 32% indicating agreement. Respondents with non-conventional septic systems exhibited lower risk perceptions of septic system wastewater contamination, which may be due to the use of septic systems that are potentially technologically different and more reliable at properly treating septic wastewater in a coastal setting compared to conventional systems.

There were statistically significant differences in agreement with statements about frequency of standing water in respondents' yards, the future of septic systems in Nags Head, the safety of standing water, rising water tables, and the ability of septic systems to effectively prevent wastewater contamination between respondents who have a septic system and those who do not (Appendix G: Table 2).

While the majority of respondents with septic systems (77%) and without septic systems (56%) disagreed that the frequency of standing water on their property had increased over time, respondents with septic systems more strongly disagreed with this statement (Fig. 23a). A majority of respondents without septic systems (61%) indicated greater agreement, while a majority of respondents with septic systems (69%) indicated greater disagreement towards the statement that water tables were rising on their property (Fig. 23b). Based on these data, respondents with septic systems perceived a lower risk of flooding and rising water tables on their property than respondents without septic systems. Standing water and rising water tables threaten the ability of septic systems to function properly, thereby posing burdens to septic system owners. The lower risk perceptions among respondents with septic systems may be due to a fear of the implications of such changes on their wastewater treatment practices and expenses.

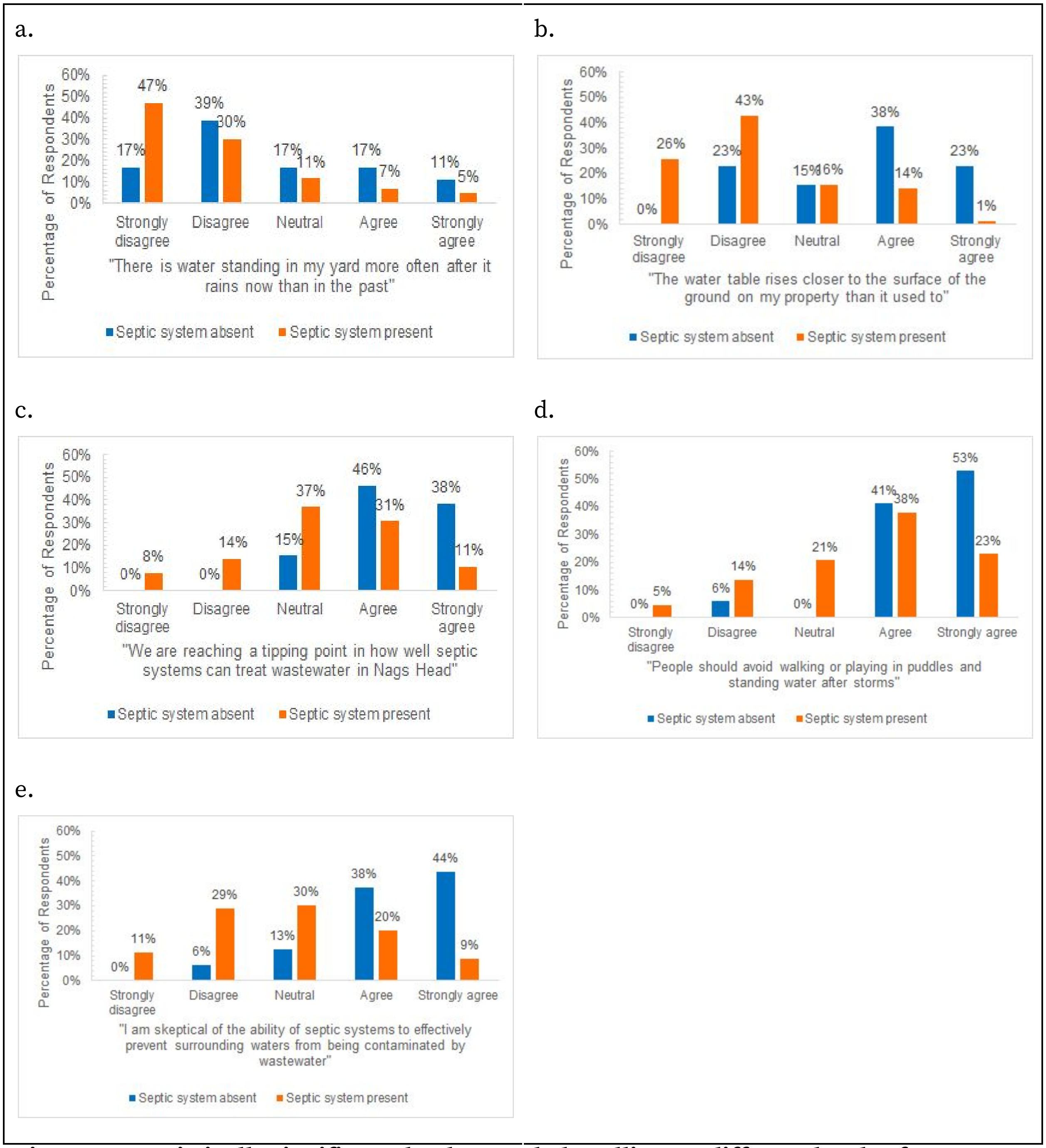

Figure 23. Statistically significant, by the Kruskal-Wallis test, different levels of agreement from Nags Head property owner respondents regarding perceptions of septic systems, flooding, and change based on septic system presence. Figures omit participants who indicated that they were unsure about whether their property had a septic system. **a,** n = 114, 5% responded "unsure." **b,** n=116, 26% responded "unsure". **c,** n=116, 30% responded "unsure". **d,** n=114, 6% responded "unsure." **e,** n = 116, 16% responded "unsure."

Additional statistically significant differences between these two groups included statements about the safety of standing water after a storm, septic system presence, and the future of septic systems in Nags Head (Appendix G: Table 2). None of the respondents without septic systems disagreed with the statement that septic systems are reaching a point of being unfeasible for Nags Head while responses from those with septic systems were more variable (Fig. 23c). This trend is paralleled with regards to septic system presence and the safety of standing water. The majority of respondents, both those without septic systems (94%) and with septic systems (61%), indicated that standing water following a storm should be avoided (Fig. 23d). However, those with septic systems more strongly disagreed than those without septic systems (Fig. 23d). Additionally, many respondents with septic systems (21%) exhibited neutrality (Fig. 23d). Respondents with septic systems may be wary of indicating agreement with these statements because of the reflection it has on the wastewater treatment system they rely on and in which they are invested. In contrast, respondents without septic systems may perceive greater risks because they have less stake in septic systems.

The majority of respondents without septic systems (82%) indicated that they questioned the ability of septic systems to prevent wastewater contamination (Fig. 23e). Few respondents without septic systems (6%) expressed disagreement (Fig. 23e). In contrast, the results from respondents with septic systems are more evenly distributed (Fig. 23e). A majority (40%) of respondents with septic systems disagreed, implying that they did not question the ability of septic systems to prevent wastewater contamination (Fig. 23e). However, there were also many neutral (30%) and agreement (29%) responses from respondents with septic systems (Fig. 23e). This indicates that respondents with septic systems do not share the same risk perceptions regarding potential wastewater contamination of surrounding waters due to septic systems. Respondents without septic systems displayed greater risk perceptions of wastewater contamination of surrounding waters in comparison to respondents with septic systems.

General Comments from Respondents

At the end of the survey, respondents were given an open-ended opportunity to share additional thoughts or comments about wastewater treatment, septic systems, and/or water quality in Nags Head. 48 respondents provided comments. We grouped responses into categories (Appendix G: Table 3). Water quality was the most prevalent subject within the comments, with 14 responses containing thoughts and opinions related to water quality in Nags Head. The data demonstrate that respondents have concerns about water quality and feel septic systems should be maintained properly (Appendix G: Table 3).

Limitations

While our survey presents interesting results, there are limitations to its application due to the low response rate (6.9%) with 121 responses. Based on a confidence interval of 5% and a confidence level of 95%, 356 respondents was a representative number of homeowners in Nags Head. This low response rate may be due to the limited amount of time, 27 days, in which the survey was open. Additionally, distributing the link to the survey on a postcard may have limited our responses because of the extra effort required to either type in the URL or use the QR code. Another potential contributor to the low response rate is assumptions by homeowners that the postcard was junk mail or related to 2020 elections. The insufficient number of responses inhibits our results ability to be widely applied to homeowners in Nags Head.

Summary of Findings

Prior to designing our survey, we hypothesized that, in general, Nags Head homeowners would perceive low risks and have low awareness of wastewater contamination by septic systems. We also believed there would be differences in knowledge and awareness about septic systems. Based on the results of our survey, there were diverse arrays of risk perceptions regarding septic systems, flooding, contamination, and change. These risk perceptions were displayed by both behaviors of respondents and responses to survey statements directly regarding these perceptions.

Our results indicate that there are high risk perceptions regarding wastewater contamination from septic systems (Fig. 21a and Fig. 22b). These results are supported by multiple studies which have shown a high risk perception of poorly managed septic systems harming the environment (Devitt et al. 2016, Naughton and Hynds 2014). Our survey results also indicate that respondents recognize and acknowledge impacts that are widely dispersed throughout Nags Head, such as flooding (Fig. 20d) and the safety of standing water after storms (Fig. 20c). However, there were low risk perceptions for respondents' own properties being impacted by changing hydrology. Prior research on individual risk perceptions supports this finding. Devitt et al. found that it is common for homeowners to acknowledge the risk of septic systems overall, but do not have proper maintenance plans in place to combat personal risks (2016). Since individuals may not hold their households responsible for education and maintenance, this may undermine beneficial septic system health behaviors because the responsibility for management of wastewater is placed elsewhere (Devitt et al. 2016). Regulatory and planning authorities are perceived by respondents to take on this role, as they placed responsibility for septic information on the local authorities and officials of Nags Head rather than property owners themselves (Fig. 14). If the Town of Nags Head wishes to encourage future positive septic behavior, further engagement and education of the public, regarding homeowners responsibility to properly maintain their septic systems, should be considered.

Previous research has shown that those who live in Nags Head chose this area to live because they have a deep connection with the natural environment and more specifically water (Allen et al. 2018; Anderson et al. 2019). The sense of place for those in Nags Head is so strong that locals may be unaware of the behaviors which are harming the place they love. The problem with property owners ignoring the effects of negligent septic behaviors to the environment is that they are less likely to support corrective policy. Educating the public is a pivotal step in homeowners' individual actions toward healthy septic systems. Norm activation theory posits that awareness of a problem is a precondition of action for responsible behavior (Confente and Scarpi 2020). Informing property owners and local residents of Nags Head about the importance of proactive septic behaviors can lead to more individuals engaging in behaviors such as maintenance and pumping to reduce adverse impacts.

As many septic systems in Nags Head are greater than 25 years old, proper maintenance is a key aspect to having good water quality. As seen in *Figure 19*, those with older septic systems are not commonly adhering to required schedules for maintenance and pumping. Nags Head should focus on outreach efforts that incorporate the deterioration of septic systems over time. Our results also indicated that respondents who assessed themselves to be more knowledgeable about septic systems were more likely to routinely pump (Fig. 18). This could be because those with knowledge about septic systems know the negative implications of not regularly pumping their system.

Variations in knowledge are prevalent based on the results of our survey and these gaps may undermine beneficial septic system maintenance behaviors. While the majority of respondents claimed to be at least slightly knowledgeable about septic systems (Fig. 10), only seven respondents chose all of the septic system issue indicators (Fig. 11). This demonstrates that there are varying knowledge levels amongst respondents which may inhibit identification of septic system issues. Having accessible and accurate information about septic systems is important to educating homeowners about proper maintenance and use, thereby mitigating environmental impacts from wastewater. For example, the SHI, which provides information and improves accessibility to septic system repairs and maintenance, was perceived by respondents who were aware of it to be at least marginally helpful. By expanding educational and outreach efforts the Town of Nags Head can improve septic system health and reduce the potential for groundwater contamination.

CONCLUSION

The overlaps between the results of our two-pronged research approach highlight the intersectional nature of studying coastal communities. Our conclusions provide insight into improving wastewater testing methods and the behaviors and beliefs that underlie actions taken by permanent and non-permanent resident homeowners of Nags Head. The Town may find our conclusions useful when developing new policies for water quality testing and resident outreach initiatives.

Though additional environmental factors and summary statistics limitations influence our ability to make definitive and specific conclusions, we feel confident in asserting the following overarching claims. Our water quality analysis of *E. coli* concentrations and presence of optical brighteners shows widespread septic contamination of groundwater in Nags Head. Groundwater lowering is effective in reducing some septic wastewater indicators (*E. coli* concentrations), though not others (optical brighteners). When comparing environmental characteristics on a spatial and temporal scale, we found high variability between sampling sites and dates. Each site differed from one another by multiple environmental factors. Therefore, we could not determine correlations between these variables to explain our bacteria and optical brightener trends.

Our results contribute to the wider body of research on septic contamination in coastal systems by revealing patterns of wastewater indicators even over a short time period. The difficulty of explaining these trends aligns with previous groundwater contamination research (Allen et al. 2018; Anderson et al. 2019), further demonstrating the need for more consistent and extensive groundwater data collection. For future research on septic health in Nags Head, we suggest an increased sample size, a regular sampling schedule, and inclusion of more environmental variables (we note that the SHI does measure several additional water quality parameters than we did in our study). Comparing wells with similar environmental characteristics would allow for better analysis across sites. Having regular sampling occasions throughout the year would provide more consistent data and could reveal clearer trends than we identified with our limited data set.

There were several takeaways from the human dimensions aspect of this study. Survey respondents indicated high risk perceptions regarding septic systems, which correlates with the findings that groundwater contamination from septic systems is a problem in Nags Head. However, there are variations in knowledge regarding septic information among survey respondents. Those who claimed to be knowledgeable were more likely to have their tanks pumped regularly, indicating that engaging and educating property owners about septic maintenance could encourage positive behavior in the future. Most respondents believe the Town of Nags Head has a responsibility to provide information on septic systems. If the town would like to increase outreach and property owners' access to information, survey respondents expressed they would prefer to receive information in the form of electronic newsletters from the Town, the Town of Nags Head website, the Dare County Health Department website, and videos/webinars produced by the Town of Nags Head.

While respondents expressed a high risk perception for widespread issues such as contamination across the town, they were less likely to recognize concerns directly affecting their individual properties. The consequences of septic contamination of groundwater are not easily excludable, meaning that there are few circumstances where only a handful of individuals would feel the impacts. More often than not, septic contamination affects entire subwatersheds rather than isolated properties. As a result, if there is to be effective protection against septic contamination, homeowners must see risks as impactful to both the broader community and their own properties.

Differences in the knowledge and awareness of stakeholder groups have implications for policy-making, such as disagreement between citizens concerning potential solutions. In order to enact policy and solve problems effectively, it is important to meet the needs of individuals from different backgrounds. The diversity of needs throughout communities makes this a difficult challenge. The information available to guide policy could be improved if hydrologists were challenged to include the causes and expand their studies to examine socio-hydrology.

BIBLIOGRAPHY

Allen J, Bell K, Byron D, Howachyn C, Kane K, Karlok E, Kellogg A, Kendrick E, Konsouh M, Kopp H, Pollard A, Szczesiul E, Tran L. 2018. Environmental Change and Septic Systems in Nags Head: Local Perspectives and Impacts on Water Quality and Quantity. Outer Banks Field Site: University of North Carolina at Chapel Hill Institute for the Environment. [accessed 2020 Nov 3]. https://ie.unc.edu/files/2019/03/Fall2018_ENEC698_OBXFSCapstone_final_report.pdf.

Anderson AG, Badgett C, Bradley C, Calhoun E, Galvin E, Kaplan H, Hardy CS, Henshaw S, Marcou P, Morea A, O'Reilly R, Williams B. 2019. People, Water, and Septic: A Coastal Case Study. Outer Banks Field Site: University of North Carolina at Chapel Hill Institute for the Environment. [accessed 2020 Nov 3]. https://ie.unc.edu/files/2019/12/Final-Capstone-Report-OBXFS-2019.pdf.

Blair P, Buytaert W. 2016. Socio-Hydrological Modelling: a Review Asking "Why, What and How?". Hydrology and Earth System Sciences. [accessed 2020 Oct 3];20:443-478. https://core.ac.uk/download/pdf/77008345.pdf. doi: 10.5194/hess-20-443-2016.

Cao Y, Griffith JF, Weisberg SB. 2009. Evaluation of optical brightener photodecay characteristics for detection of human fecal contamination. Water Research. [accessed 2020 Oct 3];43(8):2273–2279. https://www.sciencedirect.com/science/article/abs/pii/S0043135409001146. doi: https://doi.org/10.1016/j.watres.2009.02.020.

Cao Y, Griffith JF, Weisberg SB. 2009. Evaluation of optical brightener photodecay characteristics for detection of human fecal contamination. Water Research. [accessed 2020 Oct 3];43(8):2273–2279. Figure 2. contamination.https://www.sciencedirect.com/science/article/abs/pii/S0043135409001146. doi: https://doi.org/10.1016/j.watres.2009.02.020.

[CDC] Centers for Disease Control and Prevention and [HUD] U.S. Department of Housing and Urban Development. 2006. Chapter 10 - On-site Wastewater Treatment. Healthy Housing Reference Manual. Atlanta: US Department of Health and Human Services. [accessed 2020 Oct 4]. https://www.cdc.gov/nceh/publications/books/housing/cha10.htm#:~:text=use%20both%20processes.-,Septic%20Tank%20Systems,areas%2C%20in%20the%20United%20States.

Confente I, Scarpi D. 2020. Achieving Environmentally Responsible Behavior for Tourists and Residents: A Norm Activation Theory Perspective. Journal of Travel Research. [accessed 2020 Nov 16]. https://journals.sagepub.com/doi/abs/10.1177/0047287520938875. doi: doi.org/10.1177/0047287520938875.

Cooper JA, Loomis GW, Amador JA. 2016. Hell and High Water: Diminished Septic System Performance in Coastal Regions Due to Climate Change. PLOS ONE. [accessed 2020 Sept 19];11(9):e0162104. https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0162104. doi: 10.1371/journal.pone.0162104.

Dillman DA. 2011. Mail and Internet Surveys: The Tailored Design Method -- 2007 Update with New Internet, Visual, and Mixed-Mode Guide. Hoboken (NJ): John Wiley & Sons. 544 p.

Devitt C, O'Neill E, Waldron R. 2016. Drivers and barriers among householders to managing domestic wastewater treatment systems in the Republic of Ireland; implications for risk prevention behaviour. Journal of Hydrology. [accessed 2020 Nov 16]; 535: 534-546. https://www.sciencedirect.com/science/article/abs/pii/S0022169416300403. doi: doi.org/10.1016/j.jhydrol.2016.02.015.

Dodds WK, Bouska WW, Eitzmann JL, Pilger TJ, Pitts KL, Riley AJ, Schloesser JT, Thornbrugh DJ. 2009. Eutrophication of U.S. Freshwaters: Analysis of Potential Economic Damages. Environmental Science & Technology. [accessed 2020 Oct 21];43(1):12-19. https://pubs.acs.org/doi/10.1021/es801217q. doi: 10.1021/es801217q.

[EPA] Environmental Protection Agency. 2000. Wastewater Technology Fact Sheet: Package Plants. Washington, D.C. (U.S.): EPA; [accessed 2020 Oct 5]. https://www3.epa.gov/npdes/pubs/package_plant.pdf.

[EPA] Environmental Protection Agency. 2001. Source Water Protection Practices Bulletin: Managing Septic Systems to Prevent Contamination of Drinking Water. (U.S.): EPC; [accessed 2020 Oct 5]. https://www.epa.gov/sites/production/files/2015-06/documents/2006_08_28_sourcewater_pubs_septic.pdf.

[EPA] Environmental Protection Agency. 2012. Recreational Water Quality Criteria. (U.S.): EPA; [accessed 2020 Nov 16]. https://www.epa.gov/sites/production/files/2015-10/documents/rwqc2012.pdf.

[EPA] Environmental Protection Agency. 2016. Climate Impacts on Coastal Areas. (U.S.): EPA; [accessed 2020 Oct 21]. https://19january2017snapshot.epa.gov/climate-impacts/climate-impacts-coastal-areas_.html#:~:text=Sea%20level%20rise%20could%20erode,to%20respond%20to%20climate%20changes.

[EPA] Environmental Protection Agency. 2018a. How We Use Water. (U.S.): EPA; [accessed 2020 Oct 4]. https://www.epa.gov/watersense/how-we-use-water#:~:text=The%20average%20American%20family%20uses,in%20more%20water%2Dintensive%20landscapes.

[EPA] Environmental Protection Agency. 2018b. How Your Septic System Works. (U.S.): EPA; [accessed 2020 Oct 4]. https://www.epa.gov/septic/how-your-septic-system-works.

[EPA] Environmental Protection Agency. 2020. How to Care for Your Septic System. (U.S.): EPA; [accessed 2020 Oct 5]. https://www.epa.gov/septic/how-care-your-septic-system.

Glickstein N. 2006. Optical Brighteners in Laundry Detergents Help Us Determine the Source of Bacterial Contamination. The American Biology Teacher. [accessed 2020 Oct 17];68(5):296-298. https://online.ucpress.edu/abt/article/68/5/296/17552/Optical-Brighteners-in-Laundry-Detergents-Help-Us. doi: https://doi.org/10.2307/4451992.

Halpern BS, Frazier M, Afflerbach J, Lowndes JS, Micheli F, O'Hara C, Scarborough C, Selkoe KA. 2019. Recent pace of change in human impact on the world's ocean. Scientific Reports. [accessed 2020 Oct 3];9(11609). https://www.nature.com/articles/s41598-019-47201-9. doi: https://doi.org/10.1038/s41598-019-47201-9.

Hart JD, Blackwood AD, Noble RT. 2020. Examining coastal dynamics and recreational water quality by quantifying multiple sewage specific markers in a North Carolina estuary. Science of The Total Environment. [accessed 2020 Sep 15];747(141124). https://www-sciencedirect-com.libproxy.lib.unc.edu/science/article/pii/S0048969720346532?via%3Dihub. doi: https://doi-org.libproxy.lib.unc.edu/10.1016/j.scitotenv.2020.141124.

[IPCC] Intergovernmental Panel on Climate Change. 2012. Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation. A special report of working groups I and II of the Intergovernmental Panel on Climate Change [Field, C.B., V. Barros, T.F. Stocker, D. Qin, D.J. Dokken, K.L. Ebi, M.D. Mastrandrea, K.J. Mach, G.-K. Plattner, S.K. Allen, M. Tignor, and P.M. Midgley (eds.)]. New York (NY): Cambridge University Press. [accessed 2020 Nov 4]. https://www.ipcc.ch/report/managing-the-risks-of-extreme-events-and-disasters-to-advance-climate-change-adaptation/.

Masterson JP, Fienen MN, Thieler ER, Gesch DB, Gutierrez BT, Plant NG. 2014. Effects of sea-level rise on barrier island groundwater system dynamics - ecohydrological implications. Ecohydrology. [accessed 2020 Oct 20];7(3):1064-1071. https://onlinelibrary.wiley.com/doi/abs/10.1002/eco.1442. doi: https://doi.org/10.1002/eco.1442.

National Geographic. 2019. Aquifers. National Geographic Society. [accessed 2020 Oct 20]. https://www.nationalgeographic.org/encyclopedia/aquifers/.

Natural Resources Conservation Service. 2019. Web Soil Survey. United States Department of Agriculture. [accessed 2020 Nov 3]. http://websoilsurvey.sc.egov.usda.gov/.

Naughton O, Hynds PD. 2014. Public Awareness, Behaviours and Attitudes Towards Domestic Wastewater Treatment Systems in the Republic of Ireland. Journal of Hydrology. [accessed 2020 Nov 4];518(A):108-119. https://www-sciencedirect-com.libproxy.lib.unc.edu/science/article/pii/S0022169413006446?via%3Dihub. doi: https://doi.org/10.1016/j.jhydrol.2013.08.049.

New York State Department of Health. 2017. Coliform Bacteria in Drinking Water Supplies. Drinking Water Program. [accessed 2020 Oct 5]. https://www.health.ny.gov/environmental/water/drinking/coliform_bacteria.htm.

[NOAA] National Oceanic and Atmospheric Administration. 2013. National Coastal Population Report: Population Trends from 1970 to 2020. (U.S.): NOAA; [accessed 2020 Nov 4]. https://aamboceanservice.blob.core.windows.net/oceanservice-prod/facts/coastal-population-report.pdf.

[NOAA] National Oceanic and Atmospheric Administration. 2014. Socioeconomic Data Summary. (U.S.): NOAA; [accessed 2020 Nov 4]. https://coast.noaa.gov/data/digitalcoast/pdf/socioecon-pocket-guide.pdf.

[NCDENR] North Carolina Department of Environment and Natural Resources. 2015. Ocean Outfall Master Plan [Draft]. Raleigh (NC): NCDENR. p. 173.

Outer Banks Guide. 2020. Town of Nags Head. [accessed 2020 Nov 13]. https://obxguides.com/nags-head/nagshead#:~:text=Its%2011%20miles%20of%20oceanfront,enjoyment%20of%20the%20natural%20environment.

O'Driscoll M, Bean E, Mahoney RN, Humphrey Jr. CP. 2019. Coastal Tourism and Its Influence on Wastewater Nitrogen Loading: A Barrier Island Case Study. Environmental Management. [accessed 2020 Oct 5];64:436-455. https://link.springer.com/article/10.1007/s00267-019-01201-7#citeas doi: https://doi.org/10.1007/s00267-019-01201-7.

Richards S, Withers PJA, Paterson E, McRoberts CW, Stutter M. 2017. Potential tracers for tracking septic tank effluent discharges in watercourses. Environmental Pollution.[accessed 2020 Nov 3];228:245-255. https://pubmed.ncbi.nlm.nih.gov/28550797/. doi: 10.1016/j.envpol.2017.05.044.

Thompson J, Miskewitz R. 2010. Standard Operating Procedure: Optical Brightener Analysis by Fluorometry. Rutgers School of Environmental and Biological Sciences. [accessed Oct 15]. https://water.rutgers.edu/Projects/Musquapsink/Musquapsink_Restoration_Plan_AppendixB.pdf.

Town of Nags Head. [date unknown]. Todd D. Krafft Septic Health Initiative Program. [accessed 2020 Oct 4]. https://www.nagsheadnc.gov/280/Septic-Health-Initiative-Water-Quality.

Turner Designs. [Date unknown]. Application Note: Optical Brighteners. Turner Designs. [accessed 2020 Nov 3]. http://docs.turnerdesigns.com/t2/doc/appnotes/S-0080.pdf.

[UN] United Nations. 2017. Factsheet: People and Oceans. The Ocean Conference. New York (NY): UN; [accessed 2020 Nov 4]. https://www.un.org/sustainabledevelopment/wp-content/uploads/2017/05/Ocean-fact-sheet-package.pdf.

University of Nebraska-Lincoln [date unknown]. Wastewater - What Is It? UNL Water. [accessed 2020 Oct 4]. https://water.unl.edu/article/wastewater/wastewater-what-it.

U.S. Census Bureau. 2015. American Community Survey Five-Year Estimates. (U.S.): NOAA Office for Coastal Management, U.S. Census Bureau; [accessed 2020 Nov 4]. https://coast.noaa.gov/digitalcoast/data/acs.html.

Wells EC, Zarger RK, Whiteford LM, Mihelcic JR, Koenig ES, Cairns MR. 2016. The impacts of tourism development on perceptions and practices of sustainable wastewater management on the Placencia Peninsula, Belize. Journal of Cleaner Production. [accessed 2020 Oct 4]; 111(B): 430-441. https://www.sciencedirect.com/science/article/abs/pii/S0959652614008737?via%3Dihub. doi: https://doi.org/10.1016/j.jclepro.2014.08.050.

Williams ML, LeJeune JT, Gardener BM. 2015. Soil Conditions That Can Alter Natural Suppression of *Escherichia coli* O157:H7 in Ohio Specialty Crop Soils. American Society for Microbiology. [accessed 2020 Nov 16]; 81(14): 4634-4641. https://aem.asm.org/content/81/14/4634. doi: 10.1128/AEM.00125-15.

World Population Review. 2020. Nags Head, North Carolina Population 2020. World Population Review. [accessed 2020 Nov 13]. https://worldpopulationreview.com/us-cities/nags-head-nc-population.

Worldwide Elevation Map Finder. [date unknown]. Elevation of Nags Head, NC, USA. 2020 [accessed 2020 Nov 13]. https://elevation.maplogs.com/poi/nags_head_nc_usa.24269.html.

APPENDICES

Appendix A: Hydrology Field Sampling Protocol

Field Sampling Materials:

- 20 pre-labeled sampling bottles for
- samples and extras (10 amber 125 mL
- bottles for optical brightener samples
- and 10 autoclaved/sterile 125 or 250 mL
- bottles for bacterial samples)
- 2 extra sampling bottles (1 of each)
- Sharpie
- Lab tape
- Extra ziplocks
- Pikstik
- 8 Bailers (+1 extra)
- Twine
- Scissors
- Bucket for groundwater sample
- environmental measurements
- Large cooler with ice
- Small transport cooler
- Hand sanitizer
- First aid kit
- Deionized water rinse/squirt bottle
- Kimwipes in Ziplock
- YSI 85
- Solinst water level gauge
- Latex gloves
- Notebook
- Writing instrument
- Yard stick
- Well opening supplies – hex wrench,
- box cutter, screwdrivers, zip ties
- Trash bag for used gloves and wipes

Sample Collection Dates:

- September 16
- September 18
- October 12
- October 14

Sample collection protocol:

- It is very important to use aseptic technique for all aspects of bacterial sample collection and processing. Avoid sampling bottles and bailers coming in contact with anything—including hands, the ground, and non-sampled water—aside from the water samples. Do not let the YSI handheld screen get wet.
- Double-check that you are at the correct location via visual markers and GPS.
- Collect all samples and record observations about the study site, weather, date, time, movement of water, etc.
- Transport samples back to the lab and process as soon as possible. Microbial samples must be processed immediately. Optical brightener samples may be read after reaching room temperature or refrigerated at 4°C for up to five days.

At surface water sampling sites:

- Record environmental measurements using YSI (YSI User Manual)
    - Calibrate for DO (See pg. 14 of YSI User Manual)

- Record DO (mg/L), salinity (ppt), temperature (deg C), and conductivity (µs) – make sure that the top and bottom of the probe are immersed in the water.

- Rinse the YSI with DI water and dab with a kimwipe after each measurement.
- Collect samples for microbial and optical brightener analysis.
- Use a Pikstik to hold the bottle and collect samples from just below the water's surface
    - Try not to touch the bottom to avoid stirring up sediment.
- Recap the bottle without touching the inside of it's lid and immediately place it on ice in the dark.

At groundwater sampling sites:

- Record water level using a Solinst water level meter.
- Unwrap the bailer and do not let it come into contact with any surfaces. 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.
- Record environmental measurements using YSI and calibrate for DO as above. Measure DO (mg/L), salinity (ppt), temperature (C), and conductivity (µs) of the water sample collected in the bucket – make sure that the probe is immersed in the water.
- Rinse the YSI with DI water and wipe with a kimwipe after each measurement.
- Collect microbial and optical brightener samples using the bailer.
- Uncap the sample bottle and pour water from the bailer into the bottle until it is full. Recap the bottle immediately and place it on ice in the dark.

Appendix B: Laboratory Processing and Analysis Protocols

Lab Analysis materials:

- Fluorometer (Trilogy, Turner Designs, Sunnyvale, California).
- Optical Brightener Module (Turner Designs, part number 7200-047): UV LED excitation light to cause fluorescence signal at a 90 degree angle
- Quantitray sealer
- Sterile 100 ml bottles
- Sterile water
- Colilert
- Quantitrays
- Refrigerator
- Polystyrene Cuvettes
- Scale (1.0 mg readability)
- Powdered Tide
- Deionized water
- Micropipette (1–10 μm)
- Pipette tips (non-sterile for optical
- brightener)
- Sterile pipette tips (bacteria analysis)
- Graduated cylinders
- 250 mL opaque bottles for calibration
- curve sample preparation
- Timer
- UV light
- Beakers
- Tub to hold UV light over beaker

IDEXX Procedure for Total Coliform and E. coli Bacterial Samples:

- Use aseptic technique for all aspects of bacterial sample collection and processing.
- Plug in Quanti Tray sealer (when the light is green, it is ready to use).
- Prepare to process two Colilert Test replicates for each water sample.
  - Remove shrink wrap from the sterile 100 mL vessels—2 per sample. Label each vessel.
  - Measure 90 mL of autoclaved water into a graduated cylinder and transfer to each of the labeled and empty 100 mL vessels.
  - Pour Colilert/Enterolert media packets into the above vessels.
  - Close the cap and agitate. Let it rest. Repeat until all of the media has dissolved.
  - Add 10 mL of sample to the appropriately labeled vessel using a sterile pipette tip. The same tip can be used for replicates of the same sample. Invert samples immediately before withdrawing the 10 mL.
- Pour contents of each 100 mL vessel into a QuantiTray 2000.
- Place QuantiTray into the molded rubber mat and insert into the Quanti Sealer.
  - Keep the tray upright. If the top is not closed, the sample could spill.
- Remove sealed QuantiTrays and place into the appropriate incubator (Colilert—35°C±0.5°C) for 24 hours.
- After incubation, remove QuantiTrays. Count large and small positive wells for total coliforms. Positive wells are yellow.

- Under a blacklight, count positive wells for *E. coli*. Positive wells glow blue.
- Use the IDEXX Most Probable Number (MPN) data sheet to determine MPN of colony forming units (CFU) of bacteria per 100 mL of sample. Move the decimal 1 place to the right because the data sheet gives results for 100 mL of sample and we used 10 mL.

Fluorometric Procedure for Optical Brightener Samples:

- Install an optical brightener kit in the Trilogy fluorometer before samples are read. This kit includes a lamp (10-049) emitting near UV light at 310-390 nm, a filter (10-069R) for the 300-400 nm light range, and a 436 nm filter to decrease background fluorescence.
- Remove the samples from the cooler at least one hour before sample analysis; they must be at room temperature for analysis.
- Fluorometric Standard Curves—make a standard curve that will be a qualitative scale to compare your samples with unknown concentrations of optical brighteners.
    - Make two-fold serial dilutions from a solution of 100 mg powdered Tide in one-liter deionized water (100 ppm).
    - Mix 500 mL of the 100 ppm Tide solution with 500 mL deionized water to create the first dilution (50 ppm).
    - Mix 500 mL of the 50 ppm solution with 500 mL deionized water to create the second dilution (25 ppm).
    - Mix 500 mL of the 25 ppm solution with 500 mL deionized water to create the third dilution (12.5 ppm).
    - Using the instructions in the Sample Analysis below, create a standard curve by recording fluorometric readings of the solutions created by the serial dilution.
    - All results should be graphed (Fluorometric Reading vs. Concentration) to obtain a linear standard curve.

Sample Analysis:

- Turn on the Trilogy using the switch on the back and choose UV from the home screen. Allow the fluorometer to warm up for 30 minutes.
- Invert each sample several times before pouring it into a cuvette and analyzing.
- Fill each cuvette about 2/3 full using a pipette or by pouring. Expel any air bubbles in the sample by tapping the cuvette gently on a counter.
- Wipe the outside of the cuvette so there are no fingerprints or liquid on the plastic.
- Place the cuvette in the fluorometer and push the green button on the touchscreen that says “Measure Fluorescence Raw”. Record the displayed RFU value.
- Dispose of the sample water and rinse the cuvette three times with deionized water.
- Repeat steps C through G three times for each sample. Do not measure the same sample three times as the UV exposure during measurement degrades the samples.

UV light exposure:

- Pour 50 mL of each sample into glass beakers. Make sure to record which beaker each sample is in (1-5).
- Place the beakers in a plastic UV exposure tub and place the UV light over the top.
- Turn on the UV light and begin timing (2 consecutive 5-minute increments with measurements after each increment).
- UV Exposure 1: Expose samples directly to UV light for 5 minutes and then measure fluorescence again.
- Each water sampling location has three samples. For each location, take the average of the calculated percent reduction in fluorescence after 5 min. compared to fluorescence levels before UV exposure.
    - If % reduction ≤ 5%, conclude the sample is negative for optical brighteners.
    - If % reduction ≥ 30%, conclude the sample is positive for optical brighteners.
    - If % reduction ≤ 30% and ≥ 5%, continue to UV Exposure 2.
- UV Exposure 2: Expose samples under UV for another 5 min. (i.e. cumulatively 10 min) and measure fluorescence
- Take the average of the calculated percent reduction again.
- Calculate the ratio of % reduction in fluorescence after 10 min. UV exposure over the % reduction after the 5 min. UV exposure.
    - If the ratio is no less than ≥ 1.5, the sample is negative for optical brighteners.
    - If the ratio is < 1.5, the sample is positive for optical brighteners.

Appendix C: Survey Questions for Respondents with Septic Systems

1. You are invited to participate in a research study by the Class of 2020 students of the UNC Outer Banks Field Site in partnership with the Coastal Studies Institute. The purpose of this study is to understand views and awareness of septic systems and wastewater treatment among property owners in Nags Head, North Carolina. Your name and home address were randomly selected from a list of Nags Head property owners.You will be asked to complete a survey and answer questions about yourself, your house, septic system function and maintenance, and your views on water quality in Nags Head. It will take about 15 to 20 minutes to complete this survey. If you choose to participate, the information you provide will never be connected with your name, address, or any other identifiable information. Data may be made public or used for future research and teaching purposes, but your identity will always remain confidential. All data will be stored on a secure network. The survey results are intended to inform future planning and educational efforts regarding wastewater treatment and water quality in the Nags Head area. However, the research and research results may not benefit you personally. While it is not our intention to create any risks for you, we recognize that you may view the survey topics sensitively or experience an emotional reaction. Your participation is voluntary. Choosing not to participate will not affect any relationship you may have with UNC. Thank you for your participation! If you have any questions about our research or team, feel free to contact Linda D'Anna, our instructor, at 252-475-5457 or ldanna@email.unc.edu. If you have any questions or concerns about your rights as a research subject, please contact UNC Chapel Hill's Institutional Review Board at 919-966-3113 or IRB_subjects@unc.edu. Do you consent to take this survey?
    a. Yes
    b. No

The following questions are about your home in Nags Head.

2. Is your Nags Head home your primary residence?
    a. Yes
    b. No
3. On average over the last 5 years, about how many weeks out of the year did you spend at your home in Nags Head?
    a. Number of Weeks: ___________________________
4. Which of these statements best describes how often your house has been occupied over the last few years when you're not there?
    a. Unoccupied
    b. Family & Friends
    c. Weekly rental
    d. Annual rental
5. How long have you owned your home in Nags Head?

a. Number of Years: ________________________

The following questions are about how wastewater is treated at your home in Nags Head. Any water that is used in your home (in sinks, showers, toilets, etc.) leaves the house as wastewater.

6. Does your home have an on-site individual septic system?
    a. Yes
    b. No
    c. I'm not sure
7. In a conventional septic system, wastewater flows into an underground tank. In the tank, solids in the wastewater are separated from the liquids and partially treated. The liquid exits the tank and trickles out of a set of pipes and down through the ground in a drainfield in your yard where it is further treated. Non-conventional septic systems have added treatment steps, such as filters or sand beds, or they may be above ground. What kind of septic system does your house have?
    a. Conventional
    b. Non-conventional
    c. I'm not sure
8. How old is your septic system?
    a. Less than 1-4 years
    b. 5-9 year
    c. 10-14 years
    d. 15-19 years
    e. 20-24 years
    f. 25 or more years
    g. I'm not sure

The following questions are about your experiences with your septic system.

9. How would you rate your knowledge about septic systems?
    a. Very knowledgeable
    b. Moderately knowledgeable
    c. Slightly knowledgeable
    d. Not at all knowledgeable
10. Would any of the following events lead you to think you have an issue with your septic system? (Select all that apply)
    a. Drains back up
    b. Toilet clogs
    c. Smell present on drain field
    d. Ground surface of drain field is wet
    e. Alert from alert system
    f. Other (please specify): ______________________________
    g. I'm not sure
11. How often do you experience problems with your septic system?
    a. Every year
    b. Every 2 or 3 years
    c. Every 4 or 5 years
    d. More than every 5 years
    e. I have not experienced any problems
    f. I'm not sure
12. When was the last time your septic tank was pumped?
    a. Within the last year
    b. Within the last 3 years
    c. Within the last 5 years
    d. More than 5 years ago
    e. Never
    f. I don't remember
13. Do you get your septic tank pumped on a regular basis every 3 to 5 years?
    a. Yes
    b. No
14. Have any of the following reasons led you to delay maintenance on your septic system? (Select all that apply)
    a. Cost
    b. Not knowing who to contact
    c. Not knowing enough about septic systems
    d. None of the above
15. Who do you contact if you have a problem with your septic system? (Check all that apply)
    a. Friends and family

b. Septic system professional
c. Plumber
d. Dare County Health Department
e. Town of Nags Head
f. Wastewater regulatory agency
g. Internet
h. I've never had a problem with my septic system
i. I don't remember

The following questions are about providing and getting information about septic systems.

16. Who do you think should be responsible for providing information about proper septic system maintenance to visitors and new property owners in Nags Head? (Select all that apply)
    a. Septic system professionals
    b. Town of Nags Head
    c. Dare County Department of Health & Human Services
    d. Property managers
    e. Local realtors
    f. Property Owners
    g. Other (please specify): ______________________
17. Have you heard of the Septic Health Initiative in Nags Head?
    a. Yes
    b. No
18. How helpful do you think the Septic Health Initiative is in encouraging people to correctly maintain their septic systems?
    a. Very helpful
    b. Moderately helpful
    c. Somewhat helpful
    d. Not helpful
    e. I'm not sure
19. Where do you go to get information about septic systems and maintenance? (Select all that apply)
    a. Septic system professionals
    b. Friends and family
    c. Property managers
    d. Staff or officials of Town of Nags Head
    e. Staff or officials of Dare County
    f. Website for Town of Nags Head
    g. Website for Dare County Department of Health & Human Services
    h. YouTube
    i. Other websites
    j. Social media

k. Email
l. Television
m. Radio
n. Newspapers
o. Magazines
p. Other (please specify): ________________________
q. None of the above

20. How would you prefer to obtain information about septic systems and maintenance? (Select all that apply)
    a. Septic system professionals
    b. Friends and family
    c. Property Managers
    d. Staff or officials of Town of Nags Head
    e. Staff or officials of Dare County
    f. Electronic newsletters from Town of Nags Head
    g. Webinars hosted by Town of Nags Head
    h. Videos produced by Town of Nags Head
    i. Website for Town of Nags Head
    j. Website for Dare County Department of Health & Human Services
    k. YouTube
    l. Other websites
    m. Social media
    n. Email
    o. Television
    p. Radio
    q. Newspapers
    r. Magazines
    s. Other (please specify): ____
    t. None of the above

21. The following statements were compiled from previous interviews about wastewater with key stakeholders in Nags Head. Please indicate your level of agreement with each statement. This is question 1 of 2 questions like this.

Statement	Strongly disagree	Disagree	Neutral	Agree	Strongly agree	I'm not sure
I am not concerned about my septic system contaminating the ground or water on my property						
I am confident that bacteria levels in the ocean at Nags Head are low.						
There is water standing in my yard more often after it rains now than in the past.						
We are reaching a tipping point in how well septic systems can treat wastewater in Nags Head.						
People should avoid walking or playing in puddles and standing water after storms.						

22. The following statements were compiled from previous interviews about wastewater with key stakeholders in Nags Head. Please indicate your level of agreement with each statement. This is question 2 of 2 questions like this.

Statement	**Strongly disagree**	**Disagree**	**Neutral**	**Agree**	**Strongly agree**	**I'm not sure**
Experiencing more flooding events is an inevitable part of the future in Nags Head.						
I am willing to pay additional fees to ensure that my septic system functions properly						
The water table rises closer to the surface of the ground on my property than it used to.						
I am skeptical of the ability of septic systems to effectively prevent surrounding waters from being contaminated by wastewater.						
If a centralized sewage system is feasible for Nags Head, I support that change.						

Lastly, some questions about you.

23. Your age group is:
    a. Under 20
    b. 20-29
    c. 30-39
    d. 40-49
    e. 50-59
    f. 60-69
    g. 70-79
    h. 80 or above
    i. Prefer not to say
24. You identify as:
    a. Male
    b. Female
    c. Non-binary
    d. Other (Please specify if desired): ______________________________
    e. Prefer not to say
25. What was your total annual household income during the last year before taxes?
    a. Less than $20,000
    b. $20,000 - $34,999
    c. $35,000 - $49,999
    d. $50,000 - $74,999
    e. $75,000 - $99,999
    f. $100,000 - $150,000
    g. $150,000 or above
    h. Prefer not to say
26. Do you have any additional thoughts or comments about wastewater treatment, septic systems, and/or water quality in Nags Head?
    a. Free Response: ______________________________

Appendix D: Survey Questions for Respondents without Septic Systems

1. You are invited to participate in a research study by the Class of 2020 students of the UNC Outer Banks Field Site in partnership with the Coastal Studies Institute. The purpose of this study is to understand views and awareness of septic systems and wastewater treatment among property owners in Nags Head, North Carolina. Your name and home address were randomly selected from a list of Nags Head property owners.You will be asked to complete a survey and answer questions about yourself, your house, septic system function and maintenance, and your views on water quality in Nags Head. It will take about 15 to 20 minutes to complete this survey. If you choose to participate, the information you provide will never be connected with your name, address, or any other identifiable information. Data may be made public or used for future research and teaching purposes, but your identity will always remain confidential. All data will be stored on a secure network. The survey results are intended to inform future planning and educational efforts regarding wastewater treatment and water quality in the Nags Head area. However, the research and research results may not benefit you personally. While it is not our intention to create any risks for you, we recognize that you may view the survey topics sensitively or experience an emotional reaction. Your participation is voluntary. Choosing not to participate will not affect any relationship you may have with UNC. Thank you for your participation! If you have any questions about our research or team, feel free to contact Linda D'Anna, our instructor, at 252-475-5457 or ldanna@email.unc.edu. If you have any questions or concerns about your rights as a research subject, please contact UNC Chapel Hill's Institutional Review Board at 919-966-3113 or IRB_subjects@unc.edu. Do you consent to take this survey?
    a. Yes
    b. No

The following questions are about your home in Nags Head.

2. Is your Nags Head home your primary residence?
    a. Yes
    b. No
3. On average over the last 5 years, about how many weeks out of the year did you spend at your home in Nags Head?
    a. Number of Weeks: ___________________________
4. Which of these statements best describes how often your house has been occupied over the last few years when you're not there?
    a. Unoccupied
    b. Family & Friends
    c. Weekly rental
    d. Annual rental
5. How long have you owned your home in Nags Head?

a. Number of Years: ______________________

The following questions are about how wastewater is treated at your home in Nags Head. Any water that is used in your home (in sinks, showers, toilets, etc.) leaves the house as wastewater.

6. Does your home have an on-site individual septic system?
    a. Yes
    b. No
    c. I'm not sure
7. Since you don't have an on-site individual septic system at your home, we'd like to know what type of wastewater treatment you have. Please enter it here. If you're not sure, you can enter I'm not sure.
    a. Free Response: ________________________________

8. The following statements were compiled from previous interviews about wastewater with key stakeholders in Nags Head. Please indicate your level of agreement with each statement. This is question 1 of 2 questions like this.

Statement	Strongly disagree	Disagree	Neutral	Agree	Strongly agree	I'm not sure
I am not concerned about my septic system contaminating the ground or water on my property						
I am confident that bacteria levels in the ocean at Nags Head are low.						
There is water standing in my yard more often after it rains now than in the past.						
We are reaching a tipping point in how well septic systems can treat wastewater in Nags Head.						
People should avoid walking or playing in puddles and standing water after storms.						

9. The following statements were compiled from previous interviews about wastewater with key stakeholders in Nags Head. Please indicate your level of agreement with each statement. This is question 2 of 2 questions like this.

Statement	**Strongly disagree**	**Disagree**	**Neutral**	**Agree**	**Strongly agree**	**I'm not sure**
Experiencing more flooding events is an inevitable part of the future in Nags Head.						
I am willing to pay additional fees to ensure that my septic system functions properly						
The water table rises closer to the surface of the ground on my property than it used to.						
I am skeptical of the ability of septic systems to effectively prevent surrounding waters from being contaminated by wastewater.						
If a centralized sewage system is feasible for Nags Head, I support that change.						

Lastly, some questions about you.

10. Your age group is:
    a. Under 20
    b. 20-29
    c. 30-39
    d. 40-49
    e. 50-59
    f. 60-69
    g. 70-79
    h. 80 or above
    i. Prefer not to say
11. You identify as:
    a. Male
    b. Female
    c. Non-binary
    d. Other (Please specify if desired): **______________________________**
    e. Prefer not to say
12. What was your total annual household income during the last year before taxes?
    a. Less than $20,000
    b. $20,000 - $34,999
    c. $35,000 - $49,999
    d. $50,000 - $74,999
    e. $75,000 - $99,999
    f. $100,000 - $150,000
    g. $150,000 or above
    h. Prefer not to say
13. Do you have any additional thoughts or comments about wastewater treatment, septic systems, and/or water quality in Nags Head?

    Free Response: **______________________________**

Appendix E: Survey Questions for Respondents Who Were Unsure if They Have a Septic System

1. You are invited to participate in a research study by the Class of 2020 students of the UNC Outer Banks Field Site in partnership with the Coastal Studies Institute. The purpose of this study is to understand views and awareness of septic systems and wastewater treatment among property owners in Nags Head, North Carolina. Your name and home address were randomly selected from a list of Nags Head property owners.You will be asked to complete a survey and answer questions about yourself, your house, septic system function and maintenance, and your views on water quality in Nags Head. It will take about 15 to 20 minutes to complete this survey. If you choose to participate, the information you provide will never be connected with your name, address, or any other identifiable information. Data may be made public or used for future research and teaching purposes, but your identity will always remain confidential. All data will be stored on a secure network. The survey results are intended to inform future planning and educational efforts regarding wastewater treatment and water quality in the Nags Head area. However, the research and research results may not benefit you personally. While it is not our intention to create any risks for you, we recognize that you may view the survey topics sensitively or experience an emotional reaction. Your participation is voluntary. Choosing not to participate will not affect any relationship you may have with UNC. Thank you for your participation! If you have any questions about our research or team, feel free to contact Linda D'Anna, our instructor, at 252-475-5457 or ldanna@email.unc.edu. If you have any questions or concerns about your rights as a research subject, please contact UNC Chapel Hill's Institutional Review Board at 919-966-3113 or IRB_subjects@unc.edu. Do you consent to take this survey?
    a. Yes
    b. No

The following questions are about your home in Nags Head.

2. Is your Nags Head home your primary residence?
    a. Yes
    b. No
3. On average over the last 5 years, about how many weeks out of the year did you spend at your home in Nags Head?
    a. Number of Weeks: ___________________________
4. Which of these statements best describes how often your house has been occupied over the last few years when you're not there?
    a. Unoccupied
    b. Family & Friends
    c. Weekly rental
    d. Annual rental

5. How long have you owned your home in Nags Head?
    a. Number of Years: ______________________

The following questions are about how wastewater is treated at your home in Nags Head. Any water that is used in your home (in sinks, showers, toilets, etc.) leaves the house as wastewater.

6. Does your home have an on-site individual septic system?
    a. Yes
    b. No
    c. I'm not sure
7. The following statements were compiled from previous interviews about wastewater with key stakeholders in Nags Head. Please indicate your level of agreement with each statement. This is question 1 of 2 questions like this.

Statement	**Strongly disagree**	**Disagree**	**Neutral**	**Agree**	**Strongly agree**	**I'm not sure**
I am not concerned about my septic system contaminating the ground or water on my property						
I am confident that bacteria levels in the ocean at Nags Head are low.						
There is water standing in my yard more often after it rains now than in the past.						
We are reaching a tipping point in how well septic systems can treat wastewater in Nags Head.						
People should avoid walking or playing in puddles and standing water after storms.						

8. The following statements were compiled from previous interviews about wastewater with key stakeholders in Nags Head. Please indicate your level of agreement with each statement. This is question 2 of 2 questions like this.

Statement	**Strongly disagree**	**Disagree**	**Neutral**	**Agree**	**Strongly agree**	**I'm not sure**
Experiencing more flooding events is an inevitable part of the future in Nags Head.						
I am willing to pay additional fees to ensure that my septic system functions properly						
The water table rises closer to the surface of the ground on my property than it used to.						
I am skeptical of the ability of septic systems to effectively prevent surrounding waters from being contaminated by wastewater.						
If a centralized sewage system is feasible for Nags Head, I support that change.						

Lastly, some questions about you.

9. Your age group is:
   a. Under 20
   b. 20-29
   c. 30-39
   d. 40-49
   e. 50-59
   f. 60-69
   g. 70-79
   h. 80 or above
   i. Prefer not to say
10. You identify as:
    a. Male
    b. Female
    c. Non-binary
    d. Other (Please specify if desired): ______________________________
    e. Prefer not to say
11. What was your total annual household income during the last year before taxes?
    a. Less than $20,000
    b. $20,000 - $34,999
    c. $35,000 - $49,999
    d. $50,000 - $74,999
    e. $75,000 - $99,999
    f. $100,000 - $150,000
    g. $150,000 or above
    h. Prefer not to say
12. Do you have any additional thoughts or comments about wastewater treatment, septic systems, and/or water quality in Nags Head?
    a. Free Response: ______________________________

Appendix F: Water Quality Summary Statistics

Location	Date	E. Coli MPN CFU/100mL	E. Coli C.I. Lower	E. Coli C.I. Upper	TC MPN CFU/100mL	TC C.I. Lower	TC C.I. Upper
B12	9/16/2020	0	0	37	1174.5	826.5	1619
B14	9/16/2020	0	0	37	3719	2471.5	5408.5
Blackman	9/16/2020	2795.5	2100	3646	8511	6436	11050
Curlew	9/16/2020	0	0.5	46	11246	7880.5	16788.5
Junco 1	9/16/2020	203.5	125.5	318	17156	10900.5	50000
Junco 2	9/16/2020	815.5	581.5	1106	24200	14395	50000
Junco Ditch	9/16/2020	0	0	37	10133	6828	14596
NH Control	9/16/2020	0	0	46	656	\	880
Vista Colony	9/16/2020	0	0	37	126.5	68	216
Wrightsville 1	9/16/2020	4160	2756.5	6027.5	24200	14395	50000
Wrightsville 2	9/16/2020	352.5	231	513	17697	11191	28266.5
B12	9/18/2020	0	0	46	192.85	1928.5	4586.5
B14	9/18/2020	0	0	37	24200	14395	50000
Blackman	9/18/2020	289.5	186.5	431.5	24196	14395	50000
Curlew	9/18/2020	0	0	46	24200	14395	50000
Junco 1	9/18/2020	36	10.5	89.5	24200	14395	50000
Junco 2	9/18/2020	393	269	551.5	24200	14395	50000
Junco Ditch	9/18/2020	180	106.5	284	24200	14395	50000
NH Control	9/18/2020	0	0	46	30.65	306.5	631.5
Vista Colony	9/18/2020	0	0	37	57.5	24.5	119.5
Wrightsville 2	9/18/2020	460	311.5	649	24200	14395	50000
B12	10/12/2020	10	1.5	54	3174	2046.5	4834
B14	10/12/2020	0	0	37	2522.5	1173.5	2437.5
Blackman	10/12/2020	229.5	140.5	351	24200	14395	50000
Curlew	10/12/2020	343.5	228.5	500.5	16903	10715.5	50000
Junco 1	10/12/2020	15	2	63	2872	1896	4241.5
Junco 2	10/12/2020	30.5	10	83	24200	14395	50000
Junco Ditch	10/12/2020	20	3	71	16430	10362	25984
NH Control	10/12/2020	0	0	37	333.5	216	486
Vista Colony	10/12/2020	0	0	37	25.5	5	80
Wrightsville 2	10/12/2020	945.5	685.5	1271.5	1693	12220	33002
B12	10/14/2020	0	0	37	456	6577.888889	638
B14	10/14/2020	0	0	37	338.5	221.5	493
Blackman	10/14/2020	25	5	72.5	24200	14395	50000
Curlew	10/14/2020	15.5	3.5	63	7932.5	5495.5	11343
Junco 1	10/14/2020	10	1	55	4162.5	2776.5	5970
Junco 2	10/14/2020	25.5	5	80	24200	14395	50000
Junco Ditch	10/14/2020	35.5	10	82.5	6221	4070.5	9062.5
NH Control	10/14/2020	0	0	37	1042.5	755	1403
Vista Colony	10/14/2020	0	0	37	3253	2182	4737.5
Wrightsville 2	10/14/2020	147.5	80	243	24196	15349.5	47161

Location	Date	avg. inital RFU	standard dev. (initial)	variance (initial)	avg. 5 min. RFU	standard dev. (5 min)	variance (5 min)	avg. 10 min. RFU	standard dev. (10 min)	variance (10 min)	present/absent (1/0)
B12	9/16/2020	12799.46	239.52	57367.68	11420.08	355.29	126232.16	10788.45	46.25	2139.33	1
B14	9/16/2020	2182.40	33.06	1093.07	2054.03	33.97	1154.27	2030.13	66.25	4388.99	1.00
Blackman	9/16/2020	19937.28	992.51	985079.33	20332.76	844.59	713332.43	20136.98	720.16	518631.96	0.00
Curlew	9/16/2020	15466.72	492.45	242508.83	15713.10	315.36	99452.96	14865.26	418.74	175339.97	0.00
Junco 1	9/16/2020	5016.79	155.35	24135.02	4755.37	298.16	88901.84	4618.41	137.91	19018.65	0.00
Junco 2	9/16/2020	24306.76	115.35	13306.24	24789.76	234.54	55009.92	23681.66	415.00	172226.56	0.00
Junco Ditch	9/16/2020	16346.54	276.39	76389.07	16477.74	833.86	695317.03	16718.35	180.00	32400.18	0.00
NH Control	9/16/2020	22079.68	67.47	4552.49	21550.33	165.17	27281.27	21313.56	579.80	336164.01	0.00
Vista Colony	9/16/2020	10284.20	524.71	275318.46	10619.45	56.12	3149.82	9859.00	97.09	9427.03	0.00
Wrightsville 1	9/16/2020	16453.49	170.38	29027.66	15801.97	367.90	135352.38	15508.44	900.92	811649.72	0.00
Wrightsville 2	9/16/2020	15399.03	1006.59	1013214.28	14609.96	296.55	87940.21	15396.66	209.45	43869.57	0.00
B12	9/18/2020	12998.62	211.33	44659.53	11888.53	550.99	303585.11	11445.07	169.51	28733.97	1.00
B14	9/18/2020	2255.15	37.22	1385.16	2087.11	5.02	25.23	2145.44	97.52	9510.65	1.00
Blackman	9/18/2020	18201.98	483.79	234050.29	18096.13	1227.78	1507454.10	16633.60	1150.11	1322747.72	0.00
Curlew	9/18/2020	16967.58	291.78	85133.22	16358.31	804.53	647271.77	16253.81	260.62	67922.08	0.00
Junco 1	9/18/2020	4155.09	189.00	35721.00	4139.63	45.51	2071.03	4010.63	189.72	35992.78	0.00
Junco 2	9/18/2020	26959.76	833.42	694595.28	24877.19	1106.75	1224893.68	21187.86	3132.31	9811386.40	0.00
Junco Ditch	9/18/2020	16266.11	319.15	101858.49	15640.51	116.39	13547.12	16065.23	654.68	428611.00	0.00
NH Control	9/18/2020	21632.00	438.67	192427.55	21849.48	219.51	48183.48	20707.11	429.99	184887.86	0.00
Vista Colony	9/18/2020	13805.13	316.17	99963.82	13399.62	217.79	47432.12	13632.91	513.51	263688.75	0.00
Wrightsville 2	9/18/2020	15007.87	413.25	170772.39	14383.98	174.46	30435.80	15526.24	690.13	476277.98	0.00
B12	10/12/2020	13126.09	315.10	99288.52	12040.23	372.45	138720.32	11851.77	322.24	103841.10	1.00
B14	10/12/2020	2704.57	176.15	31029.68	2669.47	236.51	55935.29	2530.99	214.24	45900.80	0.00
Blackman	10/12/2020	17013.91	498.67	248671.70	15642.28	363.68	132265.39	16287.94	854.47	730114.48	1.00
Curlew	10/12/2020	13569.08	209.42	43858.20	12715.98	178.47	31850.28	11931.77	286.64	82162.14	0.00
Junco 1	10/12/2020	2497.65	34.45	1186.64	2156.72	44.61	1990.50	2146.06	124.27	15444.15	0.00
Junco 2	10/12/2020	21585.65	652.18	425342.48	20636.96	1326.87	1760585.97	19965.16	322.37	103921.00	1.00
Junco Ditch	10/12/2020	15772.81	828.33	686124.40	15615.34	289.10	83580.09	15602.83	334.34	111783.40	0.00
NH Control	10/12/2020	23257.32	1058.02	1119410.74	23425.45	421.92	178019.44	21887.10	1185.08	1404410.83	0.00
Vista Colony	10/12/2020	15557.19	330.80	109427.91	14848.51	116.26	13516.67	14498.24	251.06	63033.19	0.00
Wrightsville 2	10/12/2020	16037.13	698.50	487903.60	15695.70	427.68	182913.99	14497.68	510.79	260909.68	0.00
B12	10/14/2020	13604.62	125.7737673	15819.04053	12661.09	802.12	643399.09	11599.19	288.06	82980.96	0.00
B14	10/14/2020	3381.78	94.35653678	8903.156033	3341.96	325.93	106231.37	3037.40	141.28	19960.96	0.00
Blackman	10/14/2020	15318.41	617.0346102	380731.7102	16021.25	264.26	69832.19	14306.69	452.03	204335.09	0.00
Curlew	10/14/2020	14120.44	456.582302	208467.3985	13710.66	264.12	69757.46	13845.03	534.17	285337.40	0.00
Junco 1	10/14/2020	2402.66	76.03984022	5782.0573	2363.31	91.93	8450.53	2154.36	128.70	16564.90	0.00
Junco 2	10/14/2020	19216.04	304.3582021	92633.9152	19270.74	194.27	37739.86	19072.38	1159.36	1344108.10	0.00
Junco Ditch	10/14/2020	15527.84	488.0125666	238156.2652	15466.97	419.17	175705.35	15429.46	751.95	565425.65	0.00
NH Control	10/14/2020	22033.13	974.1192333	948908.2807	21242.83	469.45	220385.85	21047.65	1140.44	1300607.39	0.00
Vista Colony	10/14/2020	16110.74	635.8174997	404263.8929	15558.54	431.23	185959.33	15535.54	313.45	98251.94	0.00
Wrightsville 2	10/14/2020	15478.19	202.5898174	41042.6341	14649.81	419.40	175895.65	14065.09	346.76	120245.86	0.00

Location	Date	Unsaturated Zone (m)	elev(m)	DO (mg/l	salinity (ppt)	temperature (deg C)	conductivity (µs)	Avg. wind speed (mph; Cl	Avg wind direction (C	Precipitation day of and before (mm)
B12	9/16/2020	2.45	3.69	3.05	0.30	21.10	528.00	6.60	SSE	0.00
B14	9/16/2020	1.13	1.95		0.10	24.10		6.60	SSE	0.00
Blackman	9/16/2020	0.46	2.41	3.30	0.20	24.20	484.00	6.60	SSE	0.00
Curlew	9/16/2020	0.4	2.19	4.56	0.30	24.60	690.00	6.60	SSE	0.00
Junco 1	9/16/2020	0.37	1.87	0.05	0.30	24.60	661.00	6.60	SSE	0.00
Junco 2	9/16/2020	0.47	1.16	0.19	0.30	24.30	534.00	6.60	SSE	0.00
Junco Ditch	9/16/2020	NA	0.59	10.52	0.30	27.70	738.00	6.60	SSE	0.00
NH Control	9/16/2020	1.34	2.11	4.80	0.10	19.20	278.90	6.60	SSE	0.00
Vista Colony	9/16/2020	1.36	3.34		0.20	24.70	385.30	6.60	SSE	0.00
Wrightsville 1	9/16/2020	NA	1.98	3.92	0.10	23.10	235.30	6.60	SSE	0.00
Wrightsville 2	9/16/2020	NA	1.81		0.20	22.80	519.00	6.60	SSE	0.00
B12	9/18/2020	1.68	3.69	3.00	0.32	21.90	612.00	12.20	NE	39.90
B14	9/18/2020	1.22	1.95	5.24	0.09	24.70	198.00	12.20	NE	39.90
Blackman	9/18/2020	0.99	2.41	0.33	0.30	22.50	572.00	12.20	NE	39.90
Curlew	9/18/2020	0.93	2.19	1.31	0.30	23.50	702.00	12.20	NE	39.90
Junco 1	9/18/2020	0.57	1.87	0.40	0.30	23.40	661.00	12.20	NE	39.90
Junco 2	9/18/2020	0.36	1.16	0.68	0.20	23.60	455.50	12.20	NE	39.90
Junco Ditch	9/18/2020	NA	0.59	9.25	0.30	23.00	526.00	12.20	NE	39.90
NH Control	9/18/2020	1.56	2.11	3.58	0.12	20.70	227.50	12.20	NE	39.90
Vista Colony	9/18/2020	1.39	3.34	2.72	0.18	24.80	386.50	12.20	NE	39.90
Wrightsville 2	9/18/2020	NA	1.81	3.00	0.19	24.30	399.40	12.20	NE	39.90
B12	10/12/2020	2.42	3.69	2.71	0.30	18.80	564.00	3.90	S	7.60
B14	10/12/2020	1.11	1.95	2.41	0.00	21.00	223.00	3.90	S	7.60
Blackman	10/12/2020	0.75	2.41	1.95	0.21	22.90	412.90	3.90	S	7.60
Curlew	10/12/2020	1.07	2.19	1.84	0.34	23.10	673.00	3.90	S	7.60
Junco 1	10/12/2020	0.41	1.87	0.83	0.38	23.70	761.00	3.90	S	7.60
Junco 2	10/12/2020	0.37	1.16	1.56	0.33	23.50	662.00	3.90	S	7.60
Junco Ditch	10/12/2020	NA	0.59	3.13	0.31	19.50	579.00	3.90	S	7.60
NH Control	10/12/2020	1.32	2.11	3.07	0.10	16.90	211.50	3.90	S	7.60
Vista Colony	10/12/2020	1.30	3.34	2.00	0.20	20.20	450.00	3.90	S	7.60
Wrightsville 2	10/12/2020	NA	1.81	4.60	0.10	18.50	314.70	3.90	S	7.60
B12	10/14/2020	2.33	1/2/1900	3.35	0.10	22.60	618.00	5.00	NNE	0.00
B14	10/14/2020	1.64	12/31/1899	6.01	0.10	23.70	197.00	5.00	NNE	0.00
Blackman	10/14/2020	0.73	1/1/1900	0.56	0.28	23.60	560.00	5.00	NNE	0.00
Curlew	10/14/2020	0.68	1/1/1900	2.50	0.35	23.60	692.00	5.00	NNE	0.00
Junco 1	10/14/2020	0.483	12/31/1899	0.73	0.38	24.10	772.00	5.00	NNE	0.00
Junco 2	10/14/2020	0.15	12/31/1899	1.52	0.33	24.00	671.00	5.00	NNE	0.00
Junco Ditch	10/14/2020	NA	12/30/1899	12.55	0.31	24.60	627.00	5.00	NNE	0.00
NH Control	10/14/2020	1.21	1/1/1900	1.94	0.10	18.60	219.60	5.00	NNE	0.00
Vista Colony	10/14/2020	1.06	1/2/1900	2.60	0.20	22.20	384.00	5.00	NNE	0.00
Wrightsville 2	10/14/2020	NA	12/31/1899	4.98	0.20	21.80	466.00	5.00	NNE	0.00

Appendix G: Survey Results

Table 1. Response counts from Nags Head homeowner respondents and summary statistics from survey statements. Calculations were made by using numbers as proxies for statements (0: unsure, 1: strongly disagree, 2: disagree, 3: neutral, 4: agree, 5: strongly agree). Unsure results were not included in the calculation of mean, median, and standard deviation (SD). The table is ordered from highest to lowest mean. Very high mean values indicate a strong agreement, and very low mean values represent strong disagreement.

Statement	0	1	2	3	4	5	Mean	Median	SD
If a centralized sewage system is feasible for the Town of Nags Head, I support that change.	9	7	5	19	36	36	3.6	4	1.5
People should avoid walking or playing in puddles and standing water after storms.	7	4	13	18	37	30	3.5	4	1.4
Experiencing more flooding events is an inevitable part of the future in Nags Head.	11	4	12	16	51	19	3.3	4	1.5
I am willing to pay additional fees to ensure that my septic system functions properly.	8	6	15	28	31	6	2.9	3	1.3
I am not concerned about my septic system contaminating the ground or water on my property.	1	23	26	19	14	11	2.6	2	1.3
I am confident that bacteria levels in the ocean at Nags head are low.	20	4	26	27	30	7	2.6	3	1.5

I am skeptical of the ability of septic systems to effectively prevent surrounding waters from being contaminated by wastewater.	19	9	24	27	22	12	2.6	3	1.6
We are reaching a tipping point in how well septic systems can treat wastewater in Nags Head.	35	5	9	28	27	10	2.4	3	1.8
There is water standing in my yard more often after it rains now than in the past.	6	46	33	13	9	6	1.9	2	1.3
The water table rises closer to the surface of the ground on my property than it used to.	30	19	34	13	15	3	1.8	2	1.5

Table 2. Differences in agreement with statements about septic systems, flooding, contamination, and change between respondents for a survey of Nags Head homeowners who have septic systems and those who have other types of wastewater treatment systems. *Cells labeled NA (not applicable) indicate statements that were only included in the survey version for respondents who indicated that their property had a septic system. Bold indicates significant values ($p < 0.05$).

Statement	Adjusted H	p-value
I am not concerned about my septic system contaminating the ground or water on my property.	NA*	NA*
I am confident that bacteria levels in the ocean at Nags head are low.	3.132	0.209
There is water standing in my yard more often after it rains now than in the past.	6.389	0.041
We are reaching a tipping point in how well septic systems can treat wastewater in Nags Head.	10.184	0.006146
People should avoid walking or playing in puddles and standing water after storms.	13.279	0.001308
Experiencing more flooding events is an inevitable part of the future in Nags Head.	1.504	0.471
I am willing to pay additional fees to ensure that my septic system functions properly.	NA*	NA*
The water table rises closer to the surface of the ground on my property than it used to.	13.325	0.001278
I am skeptical of the ability of septic systems to effectively prevent surrounding waters from being contaminated by wastewater.	16.386	0.000277
If a centralized sewage system is feasible for the Town of Nags Head, I support that change.	2.132	0.344

Table 3. Survey responses of Nags Head property owners to the open-ended question. Comments from respondents (n = 48) were categorized according to similar topics. The frequency with which these topics were mentioned in the comments was recorded. An example comment referencing each category topic was included.

Category	Frequency	Example Comment
Water Quality	14	“Just that we have an issue with "red water" in our system here all the time. At least once a week. And it most often happens when we are washing laundry, and our whites and lights keep getting ruined. That HAS to stop!”
Septic System Maintenance	7	“I am a little concerned about the life of septic systems and what happens if they get to the end of their useful life or fail. Having an alternative for when/if that happens would be useful. My house is rented and gets heavy use by people doing who knows what and that puts a lot of additional strain on septic systems that would not be present in other areas.”
Pro-Centralized Sewage System	6	"The town of Nags Head should now seriously consider the establishment of a sewer system. The water table has been rising over the years and a sewer system should be on the town's 10 year plan. I have owned my home for over 30 years and remember when the side drain ditches did not contain any water except during a heavy storm. Now they constantly have water."
Other	6	"Hello, I responded to a previous postcard, signing up on the website for a free septic inspection. However, I never received a reply."
Anti-Centralized Sewage System	5	"Septics are great systems if maintained. A central system with city sewage would allow for denser development which would be much worse for nags head and the outer banks. "
Development	4	"1. Further development (more houses = more toilets) will lead to increased challenges for septic system operations (Example: Key West, FL). This includes the mega-mansions (!) with 10+ bedrooms and even more toilets (they are ruining Nags Head!). 2. Once the soil is unable to handle the bio-wastes, there may not be enough time then to develop a proper solution without avoiding a devastating situation. "
Flooding /Storm Events	4	"Standing water on NC1243 (South Old Oregon Inlet Road) following heavy rains and high tides are a wastewater problem

		in South Nags Head."
Climate Change/Sea Level Rise	3	"I believe global warming and sea water rise will inevitably and increasingly negatively impact the OBX."
Septic Health Initiative	3	"We've participated in the Septic Health Initiative Program in Nags Head. I do think that is a good program to offer homeowners. I would appreciate a reminder via email or mail when another inspection should be done to check our septic health. Since we are not there permanently, it is not in the forefront of our mind."
Future Research	3	"Part of the questioning for this survey should have included age of the property and whether single family, duplex or condo. This plays a key role in how one views traditional/routine septic vs town treatment plant and how much the property owner knows about what they do/do not have."