Water Quality & Statistics-Based Precautionary Advisory Tool for York, Maine Beaches

Final report submitted to:
The Town of York, Maine

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FORWARD

The goal of this study was to provide a management tool for the Town of York that allows for posting precautionary advisories to warn beach goers about possible public health risks for swimming at York beaches under risk conditions. The study provided a solid scientific basis for this tool focused on rainfall but also including other factors that could be significant in predicting bacterial pollution levels.

The final simplified tool is a framework for precautionary rainfall advisories. The format and content are the result of discussions and comments received from several Town of York officials and townspeople. The "*Site-Specific Precautionary Rainfall Advisory Framework for York, Maine Beaches"* is presented first in this report. The full scientific report follows, first with an Executive Summary then the details of the data collected, its analysis and interpretation, and the basis for distilling this information into a useful management tool to enable the Town to protect beach-goers from pollution.

Site-Specific
Precautionary Rainfall Advisory Framework for York, Maine Beaches
April, 2015

We have defined 5 Beach Management Areas for York, Maine coastal beaches, based on analysis of bacterial pollution data and rainfall information. These 5 areas allow for differential management to reflect findings related to public health risks from the UNH 2014 "*Water Quality & Statistics-Based Precautionary Advisory Tool for York, Maine Beaches*" report. These are the same areas designated by the Maine Healthy Beaches Program, with a slight difference for Long Sands Beach (see below).

The Beach Management Areas are the four separate beaches of York Harbor, Long Sands, Short Sands and Cape Neddick beaches, although Long Sands Beach is separated into Long Sands North and Long Sands South to enable separate and appropriate management strategies for the two ends of that beach (Figure 1).

Figure 1. Beach Management Areas for beaches in York, Maine.

The boundaries for the Cape Neddick, Short Sands, York Harbor and Long Sands beach management areas should be based on how the Town already manages these areas. We suggest that the boundary between Long Sands Beach North and Long Sands Beach South management areas should be across from where Juniper Road intersects Long Beach Avenue (Figure 2), just north of the Site #13 line.

Figure 2. Locations for the boundary line between the Long Sands Beach North and the Long Sands Beach South management areas and sampling Site #13.

We suggest any advisory signs be posted just north of this boundary line to enable postings that reflect differential public health risks for the two management areas. The Maine Healthy Beaches Program includes Site #13 in the Long Sands Beach North management area, however the data collected in 2014 supports moving it into the Long Sands Beach South management area.

Rainfall-based criteria for posting an advisory

(3 other different advisory conditions are on the next page)

Beach Management Area	Precedent Rainfall Amount (in/48 h)*	Duration of Advisory (days)†
Short Sands Beach	**1.5**	**2**
Long Sands Beach-North	**1.5**	**2**
Long Sands Beach-South	**1.5**	**1**
York Harbor Beach	**1.5**	**1**
Cape Neddick Beach	**1.5 or 1 inch in 24 h**	**2**

* *Even though the rainfall trigger in the table is based on amount of rainfall in 48 h, an advisory should be posted when the amount of rainfall (1.5 in) has been exceeded anytime prior to 48 hours elapsing.*

† *The designated duration of the advisory starts from when the rainfall ends to allow flushing of the system*.

HOW CAN I AVOID GETTING SICK AT THE BEACH?

Do not swim when an advisory has been posted or after heavy rains.
Do not swim with diarrhea or an open wound.
Avoid swallowing water or swimming near stormwater pipes.

WHO IS MOST SUSCEPTIBLE TO GETTING SICK AT THE BEACH?

Children, the elderly and people with compromised immune systems.

HOW CAN BEACH WATER POLLUTION BE PREVENTED?

Change diapers away from the water and properly dispose of the dirty ones.
Scoop up and dispose of pet waste, and do not feed birds and animals.

There are several other public health-related precautionary conditions:

1.) ***Extreme rainfall/runoff events***: There is a high likelihood of more widespread beach pollution following extreme rainfall events because of the possibilities of sewage pipe breakage or leaking, flooding of pollution sources, and greater loading of pollutants associated with runoff. For York, Maine, there were no extreme rainfall events during 2014, aside from the big storm (<3in/24 h) that occurred on August 13th, which did cause greater amounts of pollution at most sampling sites (determined the next morning).

   →*Under rainfall conditions exceeding 3 inches within 24 h, increased water quality monitoring should occur to document when conditions return to safe (enterococci levels drop below State standard) levels.*

2.) ***Identifiable sewage discharge:*** Occasionally sewage infrastructure can fail and sewage can be discharged to the environment, with the potential for polluting beach water. This includes when sewage pipes break, septic systems fail, and when a sewage treatment facility fails to adequately treat/disinfect the sewage and inadequately treated wastewater is discharged to beaches. For York, the latter example would be most important for Cape Neddick Beach.

   →*When there is an identifiable sewage discharge that is adversely impacting beach water quality, advisories should be posted for all affected areas until the problem is fixed, and thereafter until conditions return to safe (enterococci levels drop below State standard) levels.*

3.) ***Extreme accumulations of seaweed***: Unfortunately, there is consistent evidence that when seaweeds accumulate on York's beaches to the point where there are large, tightly packed 'islands' of debris, enterococci bacterial levels can become very high. The public health significance of this is unknown, but because the State beach bacterial standard is typically exceeded under these conditions, the public should be notified.

   →*When extreme accumulations of seaweed occur, advisories should be posted for affected areas. Also, because this is an unpredictable set of circumstances, water samples should be collected and analyzed to determine when bacterial levels drop below the State standard, and so allow the advisory to be lifted.*

Water Quality & Statistics-Based Precautionary Advisory Tool for York, Maine Beaches

Final report

EXECUTIVE SUMMARY

The "*Site-Specific Precautionary Rainfall Advisory Framework for York, Maine Beaches*" management tool is based on an extensive field sampling effort, followed by in-depth analysis and interpretation of the results. Enterococci bacterial are the targets of State of Maine standards for beach water quality, as they are the indicators of fecal-borne pollution that may contain pathogenic microorganisms that can cause beach-goers to become ill. There are many different factors that may affect the levels to which these bacteria occur in beach water, and management of pollution to minimize public health impacts depends on local knowledge of these factors.

The State of Maine has set standard enterococci level criteria for posting advisories at marine beaches that are in compliance with the U.S. Environmental Protection Agency.

Criterion	Enterococci concentration
Single sample exceedance	104 enterococci/100 ml
Geometric mean ($\geq$5 samples)	35 enterococci/100 ml

Table ES-1. Bacterial Water Quality Standards for State of Maine Marine Beaches.

There are two values used: one is 104 enterococci/100 ml that is the single sample exceedance criterion, and the other is 35 enterococci/100 ml that is the geometric mean of at least 5 samples collected over a 30-day period. For this study, none of the beaches had sampling sites that exceeded the geometric mean criterion and thus none of the sites were chronically contaminated. For the rest of the report, except where the details of the geometric mean analyses are presented, references to the State standard will infer use of the single sample criterion, or those that exceed 104 enterococci/100 ml. This level captures pollution event contamination and has been used since York began collaborating with the Maine Healthy Beaches Program.

This study involved intensive water sampling at 42 sites that included beach water, beach storm drains, catch basins, marsh drains, tidal and freshwater rivers, tributaries and seaweed accumulation areas. Samples were collected and analyzed for bacterial pollution levels on 51 sampling days from July 3 to September 17. Enterococci concentration averages and frequency of concentrations above the State of Maine enterococci standard for marine beaches (104/100 ml) were determined to assess relative pollution levels at the different beaches and sites. Study results were also compared with the Maine Healthy Beaches (MHB) Program data (2003-14) as it is a long-term baseline of data for York

beach water quality and as such covers conditions at beaches that expand what occurred during 2014. Enterococci, other environmental and climatic parameters, and potential pollution sources (gulls, bathers) were measured and quantified. These data, along with supplementary data from other sources (rainfall, tidal stage and height, wave height), were used to determine statistically significant relationships between enterococci and key parameters to determine their effects on enterococci levels.

To determine if any beach areas were chronically contaminated, we calculated geometric mean enterococci levels at every beach sampling site.

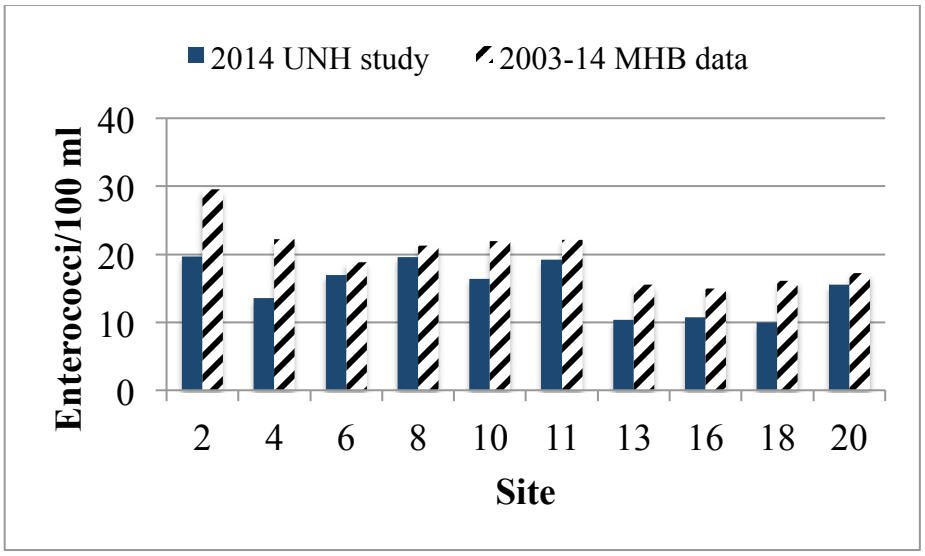


Figure ES-1. Geometric mean enterococci concentrations at York beach sites.

Enterococci concentrations were generally low at all beaches in York, with an overall geometric mean of 14.8 enterococci/100 ml, well under the standard of 35/100 ml. The highest geometric mean (19.7/100 ml) was at Site 2 (Cape Neddick Beach) and the lowest (10.0/100 ml) at Site 18 at Long Sands Beach. Considering that the detection limit for the enterococci assay is 10/100 ml, these are both relatively low values. For all ten sites, the geometric mean enterococci levels were lower than for the 2003-14 Maine Healthy Beaches (MHB) data. Both results show that none of the beach sites are chronically contaminated although both suggest Cape Neddick Beach has the highest overall levels of enterococci compared to other York beaches, and that Sites 13, 16 and 18 have lower enterococci levels compared to Sites 8, 10 and 11 on Long Sands Beach and warrant separate management strategies.

Five Beach Management Areas	
Beach	**Sites**
Cape Neddick	**2**
Short Sands	**4**
Long Sands North	**6, 8, 10, 11**
Long Sands South	**13,16, 18**
York Harbor	**20**

Table ES-2. Beach Management Areas for the 5 York Beaches, York, Maine.

As previously stated, the bacterial water quality standard that is used day-to-day and for posting advisories is the single sample standard of 104 enterococci/100 ml. To compare sites with regard to this criterion, the frequencies that samples exceeded this standard were determined for each sampling site.

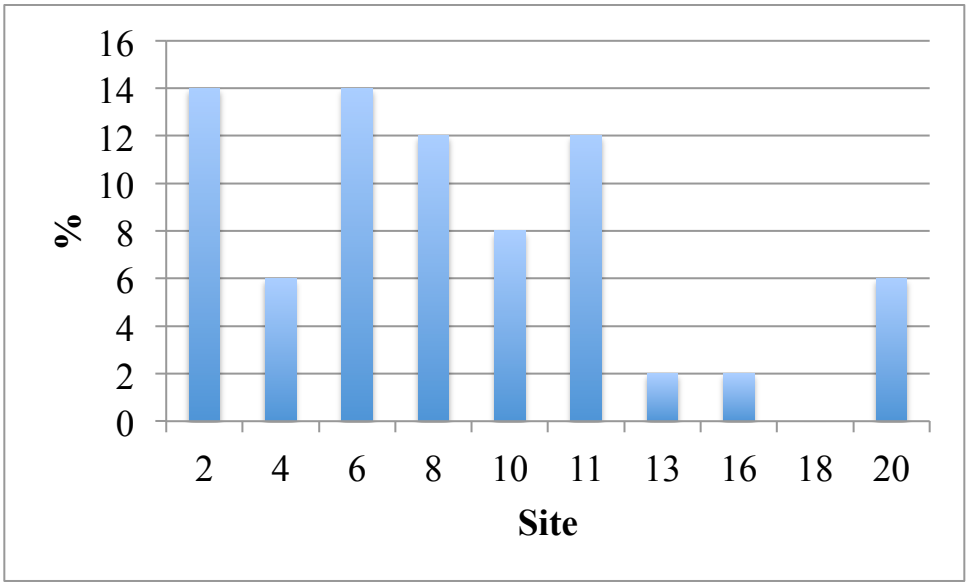


Figure ES-2. Frequency (%) of beach samples that exceeded 104 enterococci/100 ml.

The different beaches varied in this regard in a similar way to their geometric mean values. The same four sites, Sites 2, 6, 8 and 11 were the only ones where enterococci levels exceeded the State standard in >10% of the samples. Sites 2 and 6 had the highest (13.7%) rate of exceedance. Yet another gauge of contamination is the 90th percentile, which to some extent reflects the magnitude of episodic contamination events. Again, Sites 2, 6, 8 and 11 had the highest 90th percentile values and Sites 13, 16 and 18 the lowest. Thus, some sites, in particular Site 2 (Cape Neddick Beach) appear to have more bacterial pollution issues than others. In contrast, Sites 13, 16 and 18 showed rare problem conditions.

This study conducted in 2014 can be put into context by comparison of results to previous years using the MHB Program data from 2003-14. The greatest differences between this study and the full MHB study for York beach sites were observed for Sites 2 and 4 (Fig. ES-1). The lower enterococci levels detected in 2014 for Cape Neddick and Short Sands beaches may reflect recent mitigation measures taken by the Town of York to eliminate sewage sources in these areas. In addition, the geometric mean levels from this study were lower at every site compared to the MHB data. This may be a function of several differences in the two programs. The MHB program only involves sampling on Tuesdays, except when enterococci levels exceed 104/100 ml, when next-day sampling occurs until the enterococci levels are below this standard level. The MHB database also covers a 12-year time span and a wider array of environmental and weather conditions.

Further analysis of the differences between the MHB and this study show that the results of this study are not anomalous. In this study we found that enterococci concentrations

did vary by day of sampling but this finding probably reflects the timing of storm events rather than a consistent specific-day effect. This study began July 3 while the MHB program began sampling May 26, 2014. Analysis of the MHB data for May-early July compared to early July-September, and in comparison to this study showed pollution events and conditions present at York beaches are generally not different during May-June compared to July-September. The 5-day per week (plus a few weekend samples) sampling for this study may be the main factor explaining lower overall enterococci levels from this study compared to the MHB program data. For 2014, this strategy apparently provided more low enterococci level data compared to the 1-day per week sampling by the MHB program.

A variety of possible bacterial pollution sources exist along the four York beaches, and storm drains are the most obvious sources. Consistently high enterococci concentrations and other chemical and canine indicator data in storm drains from previous studies on York beaches suggest that human sources/illicit discharges probably contribute to contamination. This study suggests that enterococci from storm drains at the northern end of Long Sands Beach (LS03) and the drain at Short Sands Beach (SS01) significantly influence beach water quality. Other storm drains located on Long Sands Beach are also probably sources of beach contamination, as all 4 sampled storm drain samples exceeded the state standard >69% of the time. It is difficult, however, to definitively confirm that beach water contamination is from a given source without analyses that allow for source identification. Ongoing microbial source tracking studies should provide this information.

The Cape Neddick River and tributaries consistently contain elevated levels of enterococci that could affect water quality at Cape Neddick Beach, as has been surmised from several previous studies.

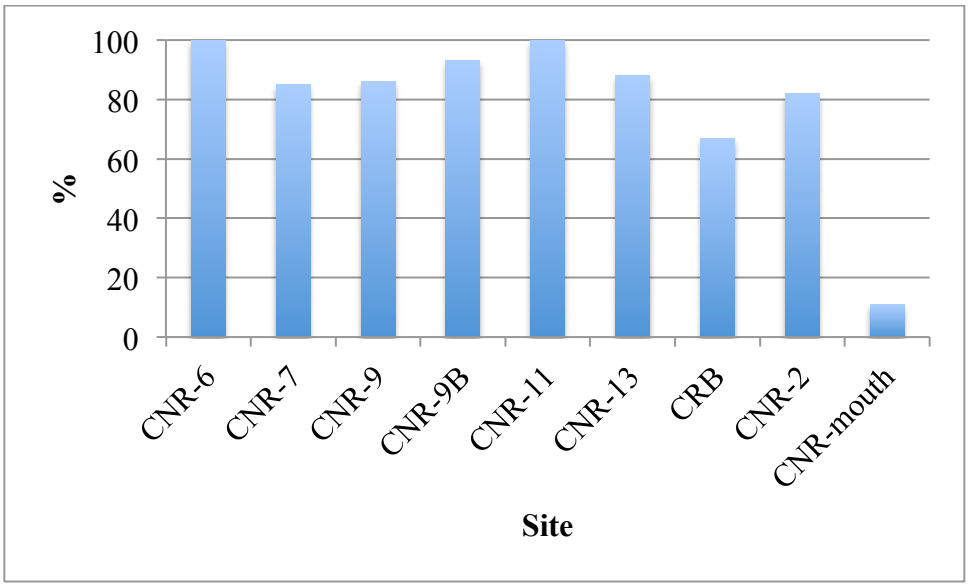


Figure ES-3. Frequency (%) of Cape Neddick River and tributary samples that exceeded 104 enterococci/100 ml.

Overall, the State standard was exceeded in 125 out of 149 (84%) samples collected from the 9 Cape Neddick River watershed. Some of these sites were in the tidal portion and others were freshwater tributaries, all of which had varying volumes of flow and thus varying potential for contaminating beach water. This study showed enterococci concentrations at several sites in the watershed, specifically CNR-mouth, 2, 11 and 13, exhibited significant relationships with Cape Neddick Beach (Site 2) water enterococci concentrations. Conversely, enterococci concentrations at some sites close to the beach, including CNR-6, 7 and 9, and other upstream sites showed no significant relation to beach water enterococci concentrations. The elevated enterococci concentrations at all upstream sites are an ongoing concern and should continue to be targeted for efforts to reduce bacterial pollution sources.

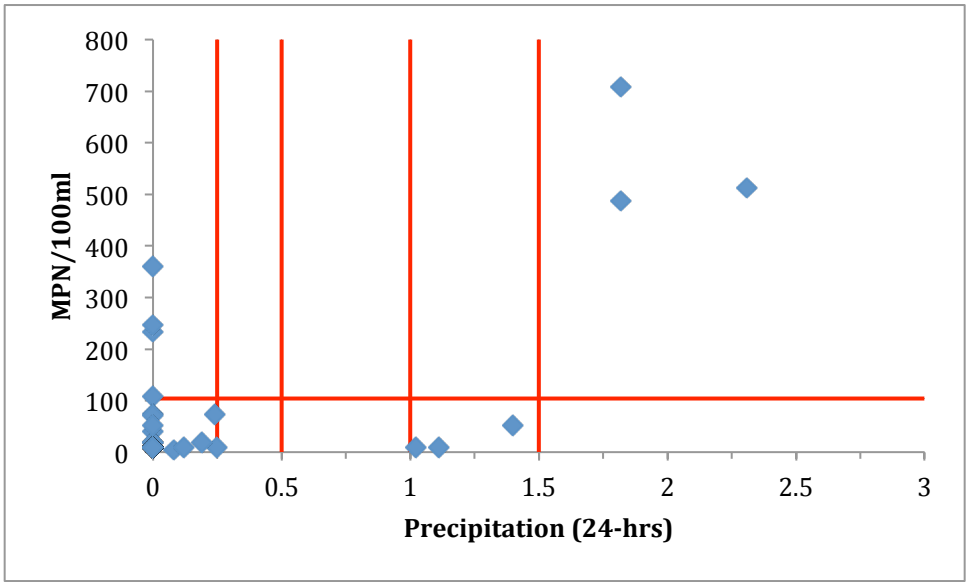
Significant accumulations of invasive and native seaweeds have been an annual nuisance on York's beaches for years, and many studies in the US have shown seaweeds can be significant sources of bacterial pollution at ocean beaches. In 2014, seaweeds were a significant and well-documented localized source of enterococci during mid to late August 2014 on Long Sands Beach. The public health significance of this is not known, yet this non-fecal borne source of bacteria causes problems for beach managers in posting advisories to protect bathers' health, and is a noted additional advisory condition in the "*Site-Specific Precautionary Rainfall Advisory Framework for York, Maine Beaches"*.

> ***Extreme accumulations of seaweed***: Unfortunately, there is consistent evidence that when seaweeds accumulate on York's beaches to the point where there are large, tightly packed 'islands' of debris, enterococci bacterial levels can become very high. The public health significance of this is unknown, but because the State beach bacterial standard is typically exceeded under these conditions, the public should be notified.
>
> →*When extreme accumulations of seaweed occur, advisories should be posted for affected areas. Also, because this is an unpredictable set of circumstances, water samples should be collected and analyzed to determine when bacterial levels drop below the State standard, and so allow the advisory to be lifted.*

Seagulls can also contribute to elevated enterococci concentrations via direct feces deposition to the beach and water, especially when they congregate, which they do along storm drainage at York beaches.

A rainfall threshold of 1.5" rainfall in 24h or 48h, based on data analysis results for all sites and beach management areas, is a useful basis for posting precautionary advisories at York beaches. The advisory would be in effect for at least 24 h, or two tidal cycles to allow for bacterial levels to be reduced due to physical mixing, dilution and transport from beaches. It appears that most pollution events last less than 2 days, although seaweeds can be a problem with longer duration than storm events. Where storm events did cause enterococci levels to remain above 104/100 ml for more than one day (Sites 2, 4, 6 and 8), advisories should continue to be in effect until bacterial testing of water

quality confirms that levels have dropped below this standard level, as is practiced now at York and through the MHB Program. This approach would be used at the Cape Neddick, Short Sands and Long Sands North beach management areas. An example of how the advisory criteria were determined can be shown for Cape Neddick Beach.



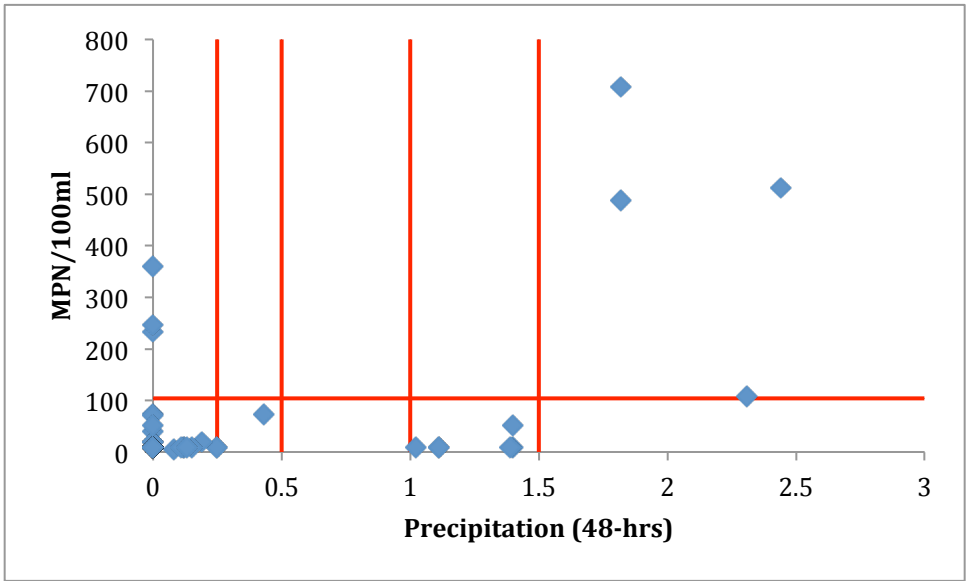


Figure ES-4. Relationship between enterococci (MPN/100ml) and precipitation (inches) for Cape Neddick Beach.

Sample condition	24 h	48 h
High bacteria, low rain	10%	6%
High bacteria, high rain	4%	8%
low bacteria, high rain	0%	0%
low bacteria, low rain	86%	86%

Table ES-3. Sample condition changes between 24 and 48 h rainfall amounts.

These results show how there are only a few samples that exceeded the State of Maine standard of 104 enterococci/100 ml at Cape Neddick Beach. These 'high bacteria' samples either occurred during dry weather when no rain had fallen in the previous 48 hours or after greater than 1.5 inches of rain had fallen in the previous 24 or 48 hours. The reason for showing both is that 3 samples exceeded the State standard following rainfall greater than 1.5 inches in 24 hours, while one more, for a total of 4 samples exceeded the State standard following rainfall greater than 1.5 inches in 48 hours. This suggests that bacterial pollution may persist at Cape Neddick Beach for longer than one day, and that is consistent with the 12-year MHB data. Thus, by setting the advisory criteria based on rainfall amounts in 48 hours, the conditions under which bacterial pollution at the beach is a concern are more comprehensively captured.

Different climatic and environmental factors were significantly related to enterococci concentrations at different sites and areas. Rainfall amounts within 24 and 48 hours prior to sampling, salinity, low and high tidal height, and the number of seagulls are the most useful factors related to bacterial contamination levels at the beaches. Rainfall and tidal stage were the most common significant factors in relation to enterococci levels in storm drains, whereas rainfall and other factors were significant at sites in the Cape Neddick River watershed, including several key sites where enterococci concentrations are also directly related to enterococci concentrations at Cape Neddick Beach (Site 2). Seaweed can also be a significant source of enterococci in beach water under special climatic and tidal conditions. Many of the high bacteria samples that occurred during dry weather were associated with times when seaweed debris was prevalent.

In-depth computer modeling, based on integration of climatic and environmental data from this study and external sources, was used to estimate enterococci concentrations above and below the State standard of 104 enterococci/100 ml. These analyses confirmed other analytical results that rainfall amount, salinity and tidal height may be significant factors affecting enterococci concentrations. Because rainfall amount and salinity are linked, as salinity at the beaches is affected only by freshwater inflows, rainfall can act as a surrogate for both parameters.

The final beach management tool that emerges from this study is the 1.5" rainfall threshold, with specific details and a few additional considerations for each Beach Management Area. Adjustments to this may be required in the future if ongoing considerations on dropping the single sample standard from 104 enterococci/100 ml drop to 60 or 70/100 ml, as the US EPA is recommending.

The Town of York will continue to use the Maine Healthy Beaches program approach for monitoring bacterial concentrations at the ten beach sampling sites. This is critical to help inform the new advisory tool, especially for when it's safe to lift advisories and to address the additional concerns mentioned in that document. The Town is also continuing to address the management of contamination from storm drains in collaboration with US EPA and UNH.

ACKNOWLEDGEMENTS

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1. INTRODUCTION

Citizens of the Town of York, Maine are interested in improving water quality at their ocean beaches, clam flats and other tidal water recreational areas. On the basis of findings from several recent studies, the Town is taking action to identify and eliminate actual and potential sources of bacterial pollution that are the causes for the public health risk-based beach advisories and limitations on shellfish harvesting.

Although existing data and monitoring efforts are in concert with standard practices, the Town has been keen to develop a comprehensive and intensive monitoring program to document water quality conditions that would lead to both investigations into the causes of detected pollution and development of a management tool for delineating public health risk conditions for bathers at the Town's four beaches. This tool would be used by the Town to post precautionary advisories at the beaches during conditions known to cause concentrations of bacterial indicators of fecal pollution (enterococci) to exceed state public health standards.

Currently, the Town of York, along with most other towns with coastal beaches in Maine, relies on weekly monitoring of beach water as part of the Maine Healthy Beaches (MHB) Program. The results of sample analyses for enterococci are compared to the State of Maine standard level of 104 enterococci/100 ml for marine recreational waters. If the level exceeds this standard level, an advisory is posted at the beach the next day, and another sample is then collected and analyzed. The advisory is lifted the next day if the results of the second day sampling show enterococci levels are below the standard. The issue with this approach is that advisories do not reflect real-time beach water quality that may be of public health concern. The presence of enterococci confirms the presence of *Enterococcus faecalis (E.faecalis), E. faecium, E. avium* and *E. gallinarium*, and the concentration measured is directly related to the risk of gastrointestinal illness (Dufour 1984). Implementation of precautionary advisories after heavy rainfall events is recommended by the MHB Program, but that has not yet happened for many towns, including York; York has waited for the results of this study to inform what, if any, rainfall conditions consistently trigger poor water quality.

This report summarizes the findings from a study conducted during the summer of 2014 at York's beaches. There have been several previous related studies that informed the design of this study. This study involved temporally and spatially intensive beach, storm drain and tributary water sample collection and analysis for enterococci concentrations and other measures to enable determining statistically significant relationships between the intensive bacterial, water quality, tidal and weather data in an integrated fashion for use by the Town to post advisories. The ultimate product is a tool useful to the Town of York and the MHB Program for predicting public health risk conditions that justify precautionary and documented beach advisories. The study findings will also help to direct intensive sanitary surveys in priority (polluted) sub-watersheds and along the

beaches. As pollution mitigation actions are taken, it is critical to show improvements in water quality. Thus, the data from the comprehensive water quality monitoring also provide a baseline for future assessments of these desired changes.

2. STUDY SITE DESCRIPTIONS AND LOCATIONS

This study took place at the four beaches in York and Cape Neddick, Maine between July and September 2014 (Figure 1). Monitoring sites included existing sites used by the Maine Healthy Beaches (MHB), Maine Department of Marine Resources (ME DMR) Shellfish Program and the Town of York Parks and Recreation Dept. and Community Development Dept., with particular emphasis on sites used during 2012-13, as presented in the Cape Neddick River Watershed-Based Management Plan (Frick et al. 2013) and as found on the MHB and DMR websites. Ten beach sites, nine Cape Neddick River sites, storm drains and five York River sites (Figures 2-5) were analyzed for bacteria concentrations, as well as in-situ salinity, dissolved oxygen, and water temperature measurements. The southern-most beach site, Site 20, is at York Harbor Beach. Sites (going south to north) 18, 16, 13, 11, 10, 8, and 6 are on Long Sands Beach. Site 4 is at Short Sands Beach, and Site 2 is located at Cape Neddick Beach (Table 1).

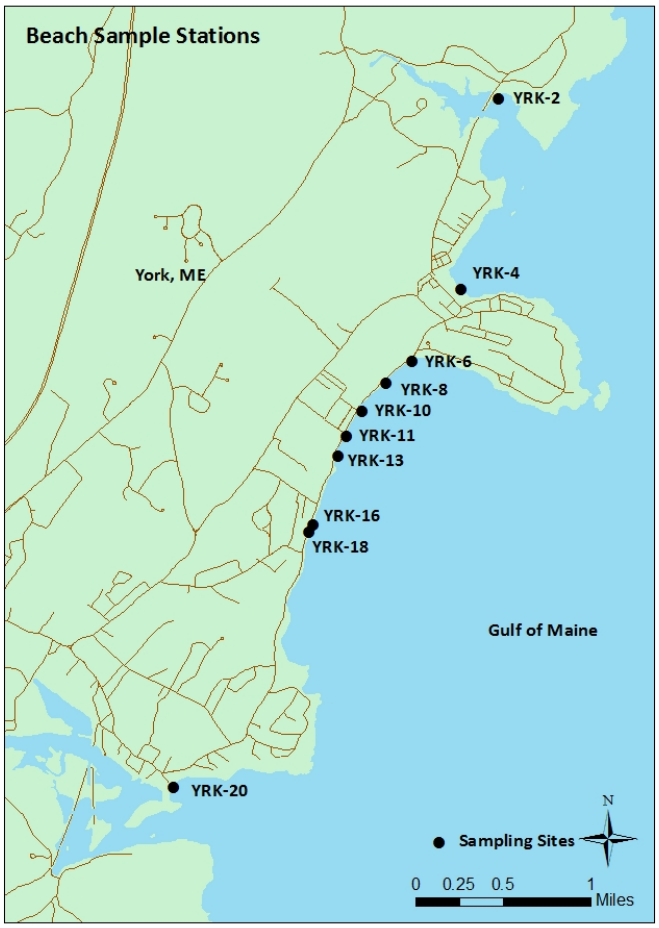

Figure 1. Beach monitoring sites at the four beaches in York, Maine

Table 1: The location and description of beach sample sites. The latitude and longitude (coordinates from Google Earth) are approximate and will change due to tide stage at time of sample.

SITE	BEACH	Latitude*	Longitude*	DESCRIPTION
2	Cape Neddick	43°11'24.09"N	70°36'11.62"W	Straight out from center of sand bar on south side
4	Short Sands	43°10'27.09"N	70°36'25.07"W	Straight out from gazebo on south side
6	Long Sands	43°10'5.07"N	70°36'44.47"W	North end of beach out from house #65 just S of Cutty Sark Motel
8	Long Sands	43° 9'58.81"N	70°36'54.95"W	out from stone stairs, Long Sands General Store
10	Long Sands	43° 9'50.06"N	70°37'4.66"W	Out from cement public bathroom, House #175/Oceanside Store&St
11	Long Sands	43° 9'42.34"N	70°37'10.91"W	Just south of Beacon St, outflow from wetland
13	Long Sands	43° 9'36.81"N	70°37'14.28"W	Just across from Juniper Rd, house #247/251
16	Long Sands	43° 9'15.96"N	70°37'23.99"W	Straight out from house #325, storm drain outfall, Sea Rose
18	Long Sands	43° 9'13.84"N	70°37'25.17"W	Out from stairway in front of house #353
20	York Harbor	43° 7'56.88"N	70°38'18.72"W	Straight out from center of beach

The MHB program groups York beach sites according their location, where Cape Neddick, Short Sands, Long Sands and York Harbor beaches are separate beach management areas. Long Sands Beach is further separated into the North area, including Sites 6, 8, 10, 11 and 13, and the South area, which includes Sites 16 and 18. The temporal intensity of this study offers an opportunity to assess this delineation as it pertains to beach management relative to bacterial pollution advisories.

An additional four sites at storm drains discharging directly to beaches were added for routine sampling based on elevated enterococci levels detected by EPA in 2012 and 2013 (EPA-Reg1 2014), and by EPA and this study on July 16, 2014. Drain sampling sites at Long Sands Beach were located between Sites 11 and 13 (marsh drain), between 10 and 8 (LS04) and near station 6 (LS03), and at Short Sands Beach (SS01) on the extreme north end of the beach. Additional catch basin and other potential storm drain-related sites were also sampled on July 16th (Figures 2 & 3).

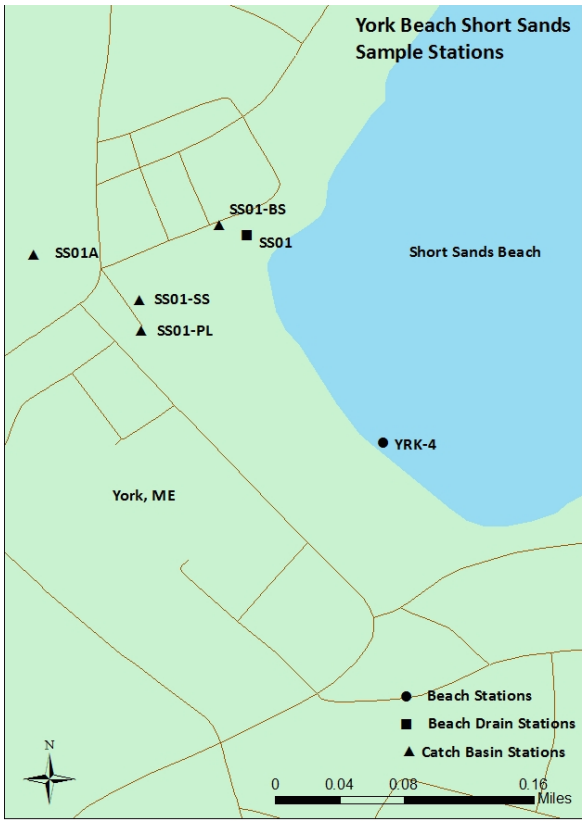

Figure 2. Drain, catch basin and beach sample sites at Short Sands Beach.

Figure 3. Drain, catch basin and beach sample sites at Long Sands Beach.

Cape Neddick River stations were located between the Route 1 Bridge and Cape Neddick Beach, with three (CNR-9, CRB & mouth) sites in tidal water, one (CRB) near the head of tide and the other six further upstream or on tributaries to the Cape Neddick River and Beach (Figure 4).

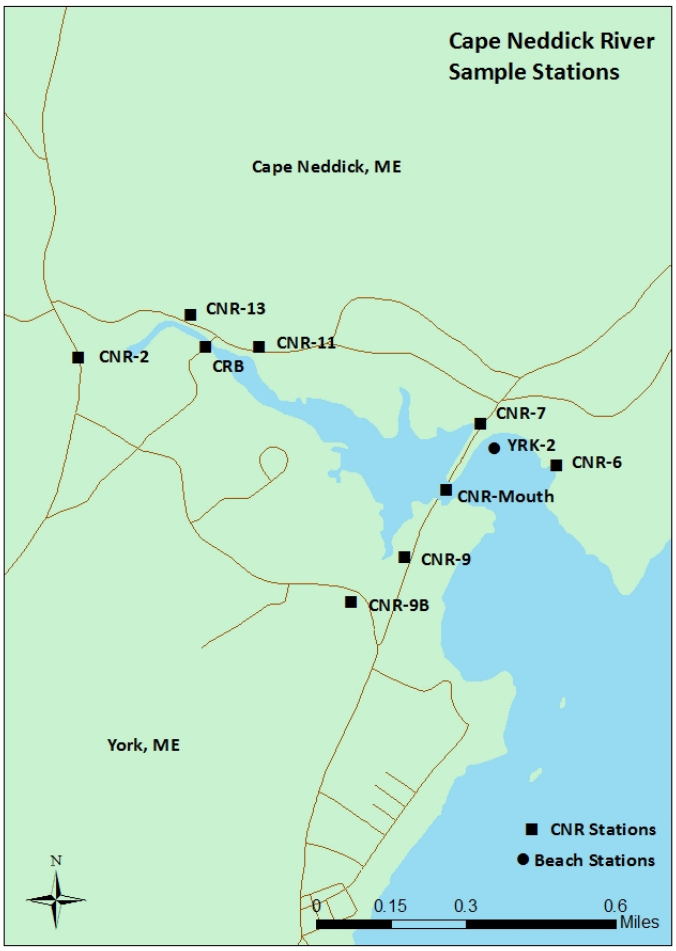

Figure 4. Cape Neddick River and Beach station locations.

3. MATERIALS AND METHODS

3.1 Sample Collection

The different types of sites were sampled at varying frequencies. The ten main beach sites at Cape Neddick, Short Sands, Long Sands and York Harbor beaches (Figures 1) were sampled 5 days per week Monday through Friday, between July 3, 2014 and September 17, 2014, with two (post-July 5-6) weekend samples. The frequency of sampling of beach sites at different tidal stages was addressed by the 5-day per week sampling, and additional sampling captured some weekend conditions. Sampling also occurred in August at the York River ME DMR sites (Figure 5).

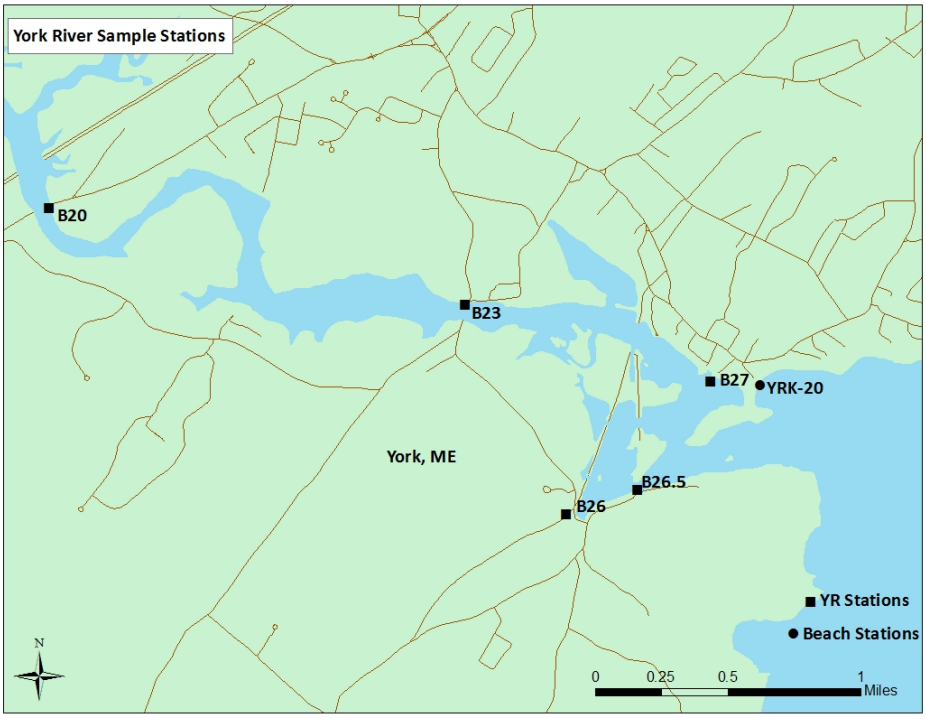

Figure 5. York River ME DMR site locations.

The main deviation from the proposed sampling design was to include more frequent sampling at some of the Cape Neddick River sites and 5-day per week sampling at a set of storm drains at Long Sands and Short Sands beaches. All sampling efforts started before 12:00 and were completed before 14:30, typically requiring ~3h of sampling and travel time. With the ~1.5h travel time to and from York and the UNH Jackson Estuarine Laboratory (JEL), sample analyses were always conducted within the holding time of 6 h. Sampling depended on safe weather conditions and the presence of water; the latter was only an issue for storm drains and some tributary sites.

At each sampling site, water temperature, dissolved oxygen concentration (mg/l) and saturation (%), and salinity were determined using a YSI Pro2030 hand-held meter. The meter was calibrated according to manufacturer instructions before and midway through sampling each day. There were occasional instrument failures, and a refractometer was used to measure salinity for two weeks (August 22-September 2). Air temperature was measured on the beach from the high tide mark to just above the water line and also over the sampling site using a Fisher immersion non-mercury thermometer. The number of bathers, including surfers, present in the water and gulls/ducks on the beach and in the water, all within ~100 feet either side of a line from the sample site to the shore, were also recorded. During periods of heavy seaweed presence on the beach, percent beach coverage (in the intertidal area near sampling sites) of seaweed was recorded. Heavy presence of suspended seaweed in the beach water was also noted.

One water sample was collected at each site in a 250-mL WhirlPak bag. One duplicate sample per day was collected at one site that changed every sample day. Samples were

stored in a cooler with adequate ice packs to keep samples cool and transported to JEL for bacterial analysis within the 6-hour holding time limit.

3.2 Laboratory methods

Water samples were analyzed for enterococci concentrations, the State of Maine water quality standard for fecal pollution in marine recreational waters. Enterococci concentrations on July 3 were determined using the US EPA-approved Method 1600 membrane filtration method (EPA 2009). Sample volumes were filtered through 0.45 µm membrane filters and incubated on mEI agar at 41±0.5 °C for 24 h. Enterococci colonies are colonies that are ≥ 0.5 mm diameter colonies surrounded with a blue halo, which results from the bacteria using β-D-glucosidase to cleave an indoxyl-based chromogen into the surrounding agar media. Positive colonies were counted as colony-forming units (cfu)/100 ml, and the results of positive and negative controls were noted. The sample volume was 50 ml for all samples, thus the limit of detection was 2 cfu/100 ml.

Fecal coliform and *Escherichia coli* concentrations were measured in York River samples collected on August 26, 2014 using a National Shellfish Sanitation Program approved (NSSP 2013) method. Sample volumes were filtered through 0.45 µm membrane filters and incubated on mTEC agar at 44.5±0.2 °C for 24 h. Fecal coliform positive colonies are yellow. Filters with yellow colonies were transferred to urea substrate-soaked cellulose pads and incubated for 5-15 min. *E. coli* positive colonies remained yellow. All concentrations were expressed as colony-forming units (cfu)/100 ml, and the results of blanks and positive and negative controls were as expected. The sample volume was 50 ml for all samples, thus the limit of detection was 2 cfu/100 ml.

For all samples after July 3, the IDEXX Enterolert® method for enumerating enterococci was used (ASTM D6503-14). This method is accurate, rapid (24 h) and economical, and can be transferred to Town personnel with minimal training. Sterile sample bottles were filled with 90 ml of clean deionized water and 10 ml of water samples was then added. The contents of a packet containing reactants (nutrients, fluorescent β-d-glucoside metabolism indicator) needed to detect enterococci were thoroughly dissolved, and the full contents of the sample bottle were then transferred to a plastic Quanti-tray®, sealed, labeled and incubated at 41±0.5 °C for 24 h. Enterococci concentrations were determined by counting the blue, UV-fluorescing wells from the 49 large and 48 small wells in the tray, and consulting the most probable number (MPN) table provided by the manufacturer. The lower detection limit concentration (LDC) for this method is 10 MPN/100 ml and the upper detection limit concentration (UDC) is 24,196 MPN/100 ml. A blank sample was analyzed each sample day, using 10 ml deionized water in place of field samples that were all diluted with 90 ml of the same deionized water. All (51) blank analyses showed no detectable enterococci. Positive and negative controls were analyzed each month and all gave positive and negative results, as expected.

One field duplicate sample was collected and analyzed on each sample date. MHB protocols (Stancioff and Lindberg 2008) were used to use field duplicate data to calculate acceptable precision for field sampling. Field duplicate sampling involved collecting two samples from one site in close succession using the sampling method. The sample site for

field duplication changed each day to provide for duplicates at each site. All duplicate data greater than or equal to the limit of detection (10 enterococci/100 ml) were used to calculate the Relative Percent Difference (RPD).

3.3 Data Analysis

Initial data calculations include the calculation of geometric means, ninetieth percentiles, and percent occurrence of enterococci concentrations over standard levels. For some calculations, data for samples with enterococci concentrations below the detection limit was expressed as 9 /100 ml (LDC – 10%) and those with concentration exceeding the detection limit were expressed as 26,620 /100 ml (UDC + 10%). The geometric mean, indicating the central tendency of a dataset, was calculated at all beach stations for each sampling date and for all dates at each sample station. The 90th percentile, a number in which 90% of the samples at the station are below the value and 9% are above, was also calculated for each station. All calculations were conducted using MS Excel software.

The RPD for each duplicate pair of data was determined using the following calculation:

$$RPD = (|X1-X2|/(X1+X2)/2) \times 100$$

|X1-X2| is an absolute value, with X1 the enterococci concentration for the first sample and X2 is the second sample concentration. The Average of RPD (AvgRPD) and the Standard Deviation of RPD (StdDevRPD) were calculated from all of the acceptable individual duplicate pair RPD values. These values were used to determine the Warning Limits (WL) and Control Limits (CL). The WL = AvgRPD + (2 x StdDevRPD), and the CL = AvgRPD + (3 x StdDevRPD), The Confidence Limits are 95% for the WL and 99% for the CL.

The percent of samples exceeding standard levels, and the number of samples out of the total number of samples exceeding the standard, for beach samples were assessed based on the US EPA standard level of 104 enterococci/100 ml. The EPA's new Beach Action Value (BAV) of 60 Enterococci bacteria per 100 milliliters was not used in data analyses.

Bacteria data from this study were compared with the MHB data for York beaches (http://www.mainecoastdata.org/public/CurrentBeachStatus.aspx). MHB samples differed somewhat as they were collected on Tuesdays earlier (starting at 7:30) in the morning than for this study, and samples were analyzed at a private lab. Bacterial concentrations were also compared with a range of climatic and environmental factors (Table 2), including rainfall amount, wind direction, wind speed and air temperature data from the "Weather Underground" York Cliffs and Short Sands sites (http://www.wunderground.com/weather-forecast/zmw:03909.1.99999). Air temperatures were also recorded at the beaches but the temperature varied from the high tide mark to the water's edge so the more consistent Weather Underground values were used in data analyses. York Harbor tide information is from the "US Harbors" webpage (http://me.usharbors.com/monthly-tides/Maine-Southern%20Coast/York%20Harbor/2014-12) and the NERACOOS Data Portal webpage (http://www.neracoos.org/datatools/historical/graphing_download). Minutes

since low tide and minutes since high tide were calculated by subtracting the closest low or high tide time from each sample time. The resulting time, in HH:MM, was then multiplied by 1400 in order to covert the HH:MM time to minutes since low or high tide.

Table 2: Climatic and environmental parameters analyzed in this study.

Abbreviation	Parameter	Units	Source
Rain24	Total precipitation 24 hours prior to sampling	inches	Weather Underground "York Cliffs"
Rain48	Total precipitation 48 hours prior to sampling	inches	Weather Underground "York Cliffs"
Atemp	Average Daily Air Temperature	degrees Celsius	Weather Underground "York Cliffs"
Wtemp	Water Temperature at time of sample	degrees Celsius	This Study- YSI Pro2030
Salin	Salinity	Parts/thousand (ppt)	This Study- YSI Pro2030
DO conc.	Concentration of Dissolved Oxygen	mg/L	This Study- YSI Pro2030
DO%	Percent of Dissolved Oxygen	%	This Study- YSI Pro2030
LTmin	Minutes since Low Tide	Minutes	US Harbors webpage and this study's sample time
HTmin	Minutes since High Tide	Minutes	US Harbors webpage and this study's sample time
LTht	Low Tide height	feet	US Harbors webpage
HTht	High Tide height	feet	US Harbors webpage
Waveht	Wave Height	feet	NERACOOS Data Portal
Gulls	Number of gulls on the beach or in the water at sample station	count	This Study
Bathers	Number of bathers in the ocean at sample station	count	This Study

3.3.1 Data Relationships/Correlation Analysis

The predictive potential and analysis of association with environmental parameters was examined using univariate correlation analysis for enterococci bacteria counts at the York beach sites. The measure of linear dependence between each enterococci sample and associated environmental parameter was calculated by Pearson's correlation, with significant relationships determined by degrees of freedom and critical value cutoffs at an alpha of 0.05. For purposes of data display and normalization, enterococci bacteria counts were log transformed and reflected in the following analysis.

To test for data independence between each of five beach management areas (according to this study), a Welch's paired t-test statistic was employed. Significant differences between distinct beach areas were determined at a two-sided alpha (p-value) of 0.05. Separation of the beach sites allowed for a more in-depth analysis of the linear associations between bacterial counts and environmental parameter for each distinct beach area. Examination of the data relationships in the form of correlation coefficients follow the previously described methods.

3.3.2 Storm Drainage/Cape Neddick River analysis

To determine the connection between the enterococci levels for each drain/Cape Neddick River sites and the corresponding beach location, Pearson's correlation was used, with significant relationships determined by degrees of freedom and critical value cutoffs set at an alpha of 0.05. Furthermore, correlation analyses within drain and river stations were implemented to determine linear relationships between stations known to be associated with elevated enterococci levels.

3.3.3 Risk model for enterococci concentrations

A Generalized Linear Model (GLM) was used to estimate the probability of presence of enterococci bacteria based on preceding precipitation levels at the York beach sites. To avoid confounding effects in binary model development, samples with significant seaweed presence were omitted from analysis. Each GLM was implemented in logistic form and trained using observational data transformed to binary presence/absence: cell count > 104 MPN/ml ≡ presence, cell count < 104 MPN/ml ≡ absence. A stepwise selection process was used to select the best-fit probability model, whereby each explanatory variable was entered sequentially into the model, and selected variables retained only if significant. For the model evaluation, significance was set at an alpha level of 0.05. For correlation analysis and model evaluation, significance was set at an alpha level of 0.05. To assess model predictive skill, the top model of the stepwise selection was tested in an out-of-sample cross validation analysis. To ensure correct binary classification, a 0.5 prediction point relative to the logistic transform of the model predictions was used. Final model selection was based on the optimization of three model assessment error indices: true positive rate (sensitivity; TPR), true negative rate (specificity; TNR), and Matthews Correlation Coefficient (MCC).

4. RESULTS

The reason for conducting this study was to provide an intensive (spatial, temporal) dataset of enterococci concentrations in beach water as the basis for developing a precautionary advisory tool for York beaches. With this comprehensive database, the precautionary advisory tool can be developed in different ways for the different beach management areas. This dataset, however, is not the only source of information that should inform the tool development, as the MHB Program dataset for York beaches covers a 12-year span from 2003 to 2014. The MHB dataset also includes data prior to July when this study began. It is important to include data and information from MHB and other prior studies to help frame the 2014 dataset and inform tool development.

4.1 How often and where were York's beaches impacted by bacterial pollution?

To address this question, data for all ten different beach sampling sites, and for all 51 sampling dates, were analyzed. Measured concentrations were compared to the State of Maine standard for marine beaches of 104 enterococci/100 ml. The MHB Program database was used to compare and expand the range of the results of this study.

Samples were collected on 51 dates between July 3rd and September 17th at the ten York beach sampling sites. Field sampling efforts were successful Monday through Friday each week, with only one sampling event (July 28th) not completed because if unsafe conditions due to severe thunderstorms.

Beach enterococci levels ranged from <9 to >24,196 enterococci/100 ml. The geometric mean of each sampling date ranged from 2 to 189 enterococci/100 ml (Figure 6), with an overall geometric mean of 14.8 enterococci/100 ml. The geometric mean of each site for the whole sampling period ranged from 10.0 to 19.7 enterococci/100 ml for Sites 18 and 2, respectively, with Sites 2, 6, 8, and 11 having the highest geometric mean concentrations (≥17 enterococci/100 ml) (Table 3). The sites with the lowest geometric mean enterococci concentrations (<11 enterococci/100 ml) were Sites 13, 16 & 18. 90th percentiles for the sites ranged from 19 to 274 enterococci/100 ml at Sites 18 and 11, respectively. The sites with the highest and lowest 90th percentiles were the same as for geometric means, i.e., Sites 2, 6, 8 and 11 highest and Sites 13, 16 and 18 lowest.

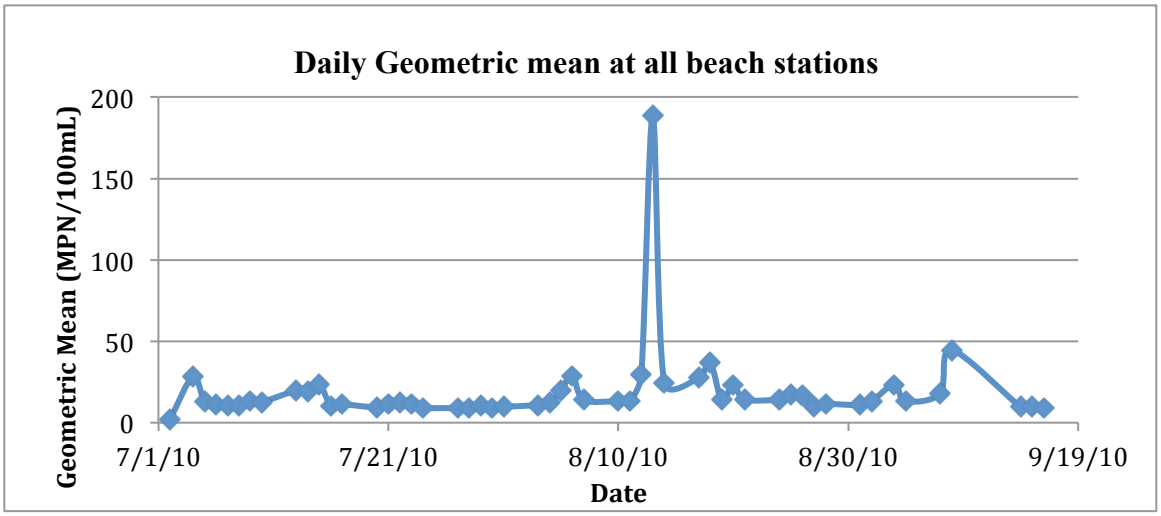

Figure 6. The geometric mean of all beach stations at each sampling date.

Table 3: The geometric mean and 90th percentile at each York beach site during this study (UNH) and geometric mean MHB Program data from 2014 and 2003-14.

	2014 UNH Study			Maine Healthy Beaches Program			
				2014		2003-14	
Site #	N	GeoMean	90th percentile	N	GeoMean	N	GeoMean
2	51	19.7	243	15	21.1	186	29.6
4	51	13.6	58	15	13.3	186	22.2
6	51	17.0	113	15	31.1	164	18.8
8	51	19.6	109	14	38.4	141	21.3
10	51	16.4	86	12	25.3	142	21.9
11	51	19.2	274	13	22.6	133	22.1
13	51	10.4	20	17	16.8	161	15.5
16	51	10.7	20	14	10.5	150	15
18	51	10.0	19	11	10.1	146	16.1
20	52	15.5	63	16	26.6	171	17.2

The geometric mean enterococci concentrations at Sites 6, 8, 10 and 11 were all higher than those for Sites 13, 16 and 18. This suggests a clear difference between these two areas (North and South) of Long Sands Beach, at least for 2014, which could have management implications where advisories may be based on different criteria. In 2014, the Town of York issued advisories for Long Sands Beach inclusive of all seven sites. The geometric mean from this study for the North Long Sands beach sites was 18.0 enterococci/100 ml, and that for the South area was 10.4 enterococci/100 ml. This is, however, different than the way that the MHB Program delineates North and South Long Sands Beach sites, where they include Site 13 in the North area, and the South area only includes Sites 16 and 18. For all York beaches, the sites are treated as five distinct areas for this study: Cape Neddick Beach (Site 2), Short Sands Beach (Site 4), Long Sands Beach North (Sites 6, 8, 10, 11), Long Sands Beach South (Sites 13, 16, 18) and York Harbor Beach (Site 20).

Comparisons of enterococci concentrations between the five beach management areas showed only one significant difference, between Cape Neddick and Long Sands South areas (Table 4). Separation of these areas back into individual sites allowed for comparisons that underpin the differences between areas. Enterococci levels at Cape Neddick Beach and Sites 8 and 10 in Long Sands North were significantly different than levels at Sites 13, 16 and 18 in Long Sands South; Site 6 in Long Sands North was also significantly different than Site 18 in Long Sands South. The significant differences in enterococci concentrations between sites at Long Sands Beach support the delineation of the two beach management areas in Long Sands Beach as described for this study.

Table 4: Comparison of enterococci concentrations between five beach areas based on a two sided T-test determining independence between stations (p-values). Significant difference in stations noted in bold.

land area #	1	2	3	4	5
1		0.48	0.4	**0.01**	0.24
2			0.31	0.25	0.83
3				0.2	0.28
4					0.11
5					

Of the 511 enterococci concentrations measured, 38, or 7.4% were greater than the State enterococci standard of 104/100 ml. Sites 2, 6, 8 and 11 showed concentrations exceeding 104 enterococci/100 ml, the State of Maine standard, in greater than 10% of samples, with Sites 2 and 8 having the most frequent (14%) high counts (Table 5). Sites 13 and 16 had only one out of fifty-one samples greater than 104 enterococci/100 ml, and Site 18 had none. These three sites are again the least problematic, consistent with the previously suggested grouping of them separate from other Long Sands Beach sites. In relation to the National Resources Defense Council's Beach Advisory Value (BAV), another 17 samples exceeded 60/100 ml, for a total of 10.8% of the samples.

Table 5: The frequency of York beach water samples exceeding the State of Maine enterococci standard.

	2	**4**	**6**	**8**	**10**	**11**	**13**	**16**	**18**	**20**
Total Number of Samples	51	51	51	51	51	51	51	51	51	52
# of samples >104/ 100 ml	7	3	7	6	4	6	1	1	0	3
Percent >104/ 100 ml	14%	6%	14%	12%	8%	12%	2%	2%	0%	6%

One consideration with precautionary advisories is how long they last. Conditions where bacterial concentrations were >104 enterococci/100 ml for more than one day did not occur at sites 10, 13, 16, 18 and 20 during this study. At the other sites, there were a total of 10 occasions where elevated enterococci levels were measured in two consecutive days. This occurred three days at Sites 2 and 11 (for Site 11, see below for explanation), on two days at Site 6, and on one day at Sites 4 and 8. Of the remaining 20 events with enterococci levels >104/100 ml, three had relatively higher (>BAV; 60 enterococci/100 ml levels the next day. One contamination event, starting on 8/18/14 at Site 11, had four consecutive days where enterococci were present at >104/100 ml, due to seaweed (see Section 4.2.3).

4.1.1 Comparisons with the Maine Healthy Beaches Program data

In 2014, the MHB program reported results for 11-17 samples at each of the 10 York beach sampling sites (Table 3). The geometric mean concentrations ranged from 10-38 enterococci/100 ml. The sites with the highest geometric means (>20 enterococci/100 ml) included Sites 2, 6, 8 and 11, similar to this study, but also Sites 10 and 20. The sites with the lowest (<10 enterococci/100 ml) included Sites 16 and 18, like for this study, but not Site 13. There were, however, three samples with enterococci concentrations >104/100 ml at Site 13 that occurred between August 20-26, the same time period where water quality at other nearby sites at Long Sands Beach was being affected by dense accumulated seaweed. Site 4 at Short Sands Beach again had a relatively low (13.3) geometric mean.

The long-term MHB database also provides a basis to determine if 2014 was unusual with regards to bacterial pollution a York's beaches. At Sites 6, 8, 10 and 20, geometric mean enterococci concentrations were higher in 2014 than for 2003-14, Sites 2, 4, 16 and 18 had lower geometric mean concentrations in 2014, and the geometric means for Sites 11 and 13 were essentially the same for both time periods (Table 3). Thus, no clear trend across all sites for 2014 relative to previous years was apparent. The lower levels at Sites 2 (Cape Neddick) and 4 (Short Sands) may reflect recent mitigation measures taken by the Town of York to eliminate sewage sources in these areas. The geometric means from this study for Sites 2 and 4 were also lower than for 2003-14 MHB data.

The Maine Healthy Beaches (MHB) database (2003-14) for the ten York Beach sample sites had 158 instances when enterococci levels exceeded 104/100 ml. MHB began consecutive day sampling after samples exceeded the standard in 2009, and in only 9 (8.7%) of 103 cases were enterococci levels still >104/100 ml on the second consecutive day. The York samples for the MHB program are collected only on Tuesdays. For this 2014 study, samples collected on Tuesdays exceeded 104 enterococci/100 ml 7.3% of the time; on Mondays, Wednesdays and Fridays the frequency of exceeding the standard was 4.4-5.0% of the time while on Thursdays it was 13% of the time. Thus, the day of sampling did vary in frequencies of high bacterial concentrations, but this probably reflects the timing of storm events rather than a consistent specific-day effect.

The MHB data for the 4 York beaches showed close (<2% difference) agreement at 8 sites for frequency of samples exceeding the standard during May-June compared to the full May-September sampling season. The exceptions, Sites 8 & 11, had no samples exceed the standard during May-June. This suggests that pollution events and conditions present at York beaches are generally not different during May-June compared to July-September.

The UDC was exceeded in this study once, on August 19th at Site 11. The MHB database also reported one sample on the same date that was >UDL concentration, but at Site 8 instead of Site 11. We detected <10 enterococci/100 ml at Site 8 while MHB analysis reported a concentration of 205/100 ml at Site 11 on that day. On August 20th we re-analyzed both of the UNH Site 8 and 11 water samples from August 19th to confirm

original results. The results confirmed the same concentration (<10/100 ml) at Site 8 and a high concentration (4352/100 ml) for Site 11. For both this study and the MHB Program, the enterococci concentrations at Site 11 continued to be above the standard for several days thereafter (see Section 4.2.3).

Overall, the geometric mean enterococci concentrations for the 2014 MHB data were either higher (Sites 6, 8, 10, 11, 13, 20) or essentially the same as (Sites 2, 4, 16, 18) the geometric means for this study (Table 3). The differences may be caused by different factors, including:

1) This study did not include sampling before July 3, whereas sampling for the MHB Program began May 27th.
2) This study had data for 5 days each week, while MHB data are mostly once weekly samples.
3) The MHB samples were collected >2 h earlier than samples for this study.
4) MHB samples were always collected on Tuesdays, and some follow-up sample results are included in MHB database when Tuesday sample results were above the State standard.

To address #1 above, the MHB site geometric mean enterococci concentrations in 2014 prior to July 3rd, when this study began, were all less than the overall 2014 MHB site geometric means except for slightly higher early geometric means at Sites 2 and 6 (Table 6). This suggests that May and June 2014 were not months in which any apparent pollution event caused problems at the beaches, and that any bias for the MHB 2014 data would be that geometric means for the same time period covered by this study would be slightly higher than the full-season 2014 MHB geometric means.

Table 6: Comparison of geometric mean concentrations for the ten York beach sites during early (pre-July) and later (July-September) summer of 2014.

Site #	Pre- July N	Pre- July GeoMean	July- Sept N	July- Sept GeoMean	Ratio early-later
2	60	31	133	29	1.05
4	57	19	129	24	0.81
6	47	19	118	19	1.02
8	14	12	127	23	0.52
10	19	14	123	23	0.61
11	12	15	122	23	0.65
13	44	14	117	16	0.88
16	35	13	115	16	0.81
18	29	13	118	17	0.76
20	50	15	121	18	0.83
All	367	16	1223	20	

To address #3 above, we did not sample at different times of the day at each site because it was more important to sample at as many beach sites as possible and still analyze samples within the 6h holding time. In addition, the constantly changing tidal stage was a significant confounding factors. Relative to #4, it may be expected that sampling the next day after bacterial levels exceeded the state standard could bias the data to having higher levels than would be expected if these samples were not included. Removing data for second-day and other non-Tuesday sampling actually resulted in higher geometric mean concentrations at eight of the ten York sites, suggesting that second day samples had relatively low enterococci levels and that, generally, beach water quality improved in less than 2 days following a pollution event.

Considering factors that may result in higher bacterial levels, the 5-day per week sampling (factor #2) may be significant in explaining the differences observed between the findings of this study and MHB data. Bacterial water quality at the York beach sites was generally well below the advisory level, so more (5d/week) data appear to support that condition by resulting in a lower geometric mean for most sites.

Findings:

-The enterococci concentrations are generally low at all beaches in York, but the different beaches vary in the frequency and magnitude of events where enterococci levels are high.

- Some sites, in particular Site 2 (Cape Neddick Beach) appear to have more bacterial pollution issues than others. In contrast, Sites 13, 16 and 18 at the southern end of Long Sands Beach had rare problem conditions.

-Geometric means and the frequency of high enterococci concentrations at the ten beach sites support treating the four beaches as separate beach management units. At Long Sands Beach, it might be useful for advisory management to treat Site 13 in the same was as Sites 16 and 18 because all three sites had the best water quality and were similar to each other.

-Curiously, Site 4 at Short Sands Beach exhibited low indications of bacterial pollution. This may be a function of the distant proximity of the sampling site relative to the storm drain at the beach. Future sampling nearer to the storm drain, which is in fact a place where many bathers gather, should be considered to better understand whether bacterial pollution levels truly are low relative to other York beach areas.

-It appears that most pollution events last less than 2 days. Seaweeds can be a problem, causing longer duration elevated enterococci levels than storm events.

-The day of sampling did vary in terms of high bacterial concentrations, but probably reflects the timing of storm events rather than a consistent specific-day effect.

-Pollution events and conditions present at York beaches are generally not different during May-June compared to July-September.

-No clear trend across all sites for 2014 relative to previous years was apparent. The lower levels for Cape Neddick and Short Sands beaches may reflect recent mitigation measures taken by the Town of York to eliminate sewage sources in these areas.

-The 5-day per week sampling for this study may be the factor explaining lower overall enterococci levels from this study compared to the MHB program data. For 2014,

this strategy apparently provided more data with low enterococci levels for 2014 compared to the 1-day per week sampling by the MHB program.

4.2 Are there significant identifiable sources of bacterial pollution at York's beaches?

To address this question, data collected from this study and previous EPA-Town efforts on storm drain water quality have been analyzed to determine if there is evidence that drains cause bacterial pollution in beach water. Data from this study and previous studies in the Cape Neddick watershed were also analyzed to determine the nature of contamination at Cape Neddick Beach. This study also addressed other potential bacterial pollution sources including gulls and bathers, and most notably seaweed where enterococci and other bacteria can thrive under warm, most conditions and potentially cause elevated bacterial levels to be present in beach water.

4.2.1 Storm drains: Is there evidence that drainage from storm drains impacts beach water quality?

Water samples from flowing storm drains were collected unless high tide interfered with drain discharge or seaweed/sand blocked flow. Flow rates were not determined, so data for the drains are concentrations and not loading amounts. Storm drainage at low tides flowed down gradient across the sand to the beach water, and gulls would congregate along the drainage flow. At higher tides the flowage would have less distance to flow to the water, and some spring tides caused the beach water to flow into the drains.

Storm drains were first sampled in conjunction with the Town of York and the US EPA on July 16, 2014. Samples were collected from ten sites at Long Sands and Short Sands beaches, including six catch basins/storm drains, 2 outfalls to the beaches, one stream and one culvert draining a wetland (Figures 2 & 3). Analyses of all samples by the Town of York (private lab), US EPA (private lab) and UHN (this study) showed enterococci concentrations were all well above the State standard of 104/100 ml (Table 7). The RPD for UNH analyses compared to the other two labs were within acceptable limits.

Table 7: Storm drain Town, UNH, and EPA data from July 16, 2014

			VARIOUS LAB RESULTS (MPN/100ml)			RPD	
DATE	TIME	SITE ID	(Town) NELSON	UNH LAB	EPA LAB	UNH-York	UNH-EPA
7/16/14	8:54	LSR-1	1240	2603	727	70.9	112.7
7/16/14	9:27	OSA-01	2060	3441	1585	50.2	73.9
7/16/14	9:46	LS04-A	1860	2841	1565	41.7	57.9
7/16/14	10:12	LS03	3870	4160	4106	7.2	1.3
7/16/14	10:44	LS03A	1580	3282	1223	70.0	91.4
7/16/14	11:25	SSO1	2490	3130	1376	22.8	77.9
7/16/14	11:49	SSO1-PL	2610	2187	2495	17.6	13.2
7/16/14	12:00	BS	2610	2723	2247	4.2	19.2
7/16/14	13:02	SS01-SS	3450	4786	2187	32.4	74.5
7/16/14	13:15	SS01A	1250	524	657	81.8	22.5

The EPA analyses also included ammonia, chlorine, surfactants, caffeine, cotinine, and five other pharmaceuticals and personal care products (PCPP) (EPA-Reg1 2014). Only low levels of caffeine (18 ng/l) and cotinine (2.1 ng/l) were detected in the drainage from LS03, whereas much higher levels of chemicals were detected in the drainage from SS01, including caffeine (4800 ng/l) and cotinine (70 ng/l), acetaminophen (120 ng/l) and 1,7-dimethylxanthine (44 ng/l). Previous SS01 sample analyses on May 29, 2013 by EPA showed 63 enterococci/100 ml, 3.6 ng/l acetaminophen and 380 ng/l caffeine (EPA-Reg1 2014). Other results for samples collected at LS03 and LS04 on May 29, 2013 and September 4, 2012 also showed elevated levels of caffeine and detection of PCPPs. The 2014 findings for SS01, and the earlier results for the other drains, suggest possible human sources/illicit discharges probably contribute to contamination in these drains. Follow-up microbial source tracking can confirm whether the bacteria are from humans.

Routine sampling of storm drains continued thereafter to document whether results from this single sample event reflected chronic or episodic bacterial pollution levels. The flow was relatively consistent for four drains, SS01, LS03, LS04 and a culvert draining a marsh (Figures 2&3). Another drain, LS01, was not flowing when checked except for one day in September when the enterococci concentration was 20/100 ml. There were 127 samples collected from the four storm drains on 38 sampling dates. The geometric mean of all storm drain data was 359 enterococci/100 ml, with geometric mean concentrations at SS01 (31 samples), LS03 (28 samples), LS04 (32 samples) and the marsh drain (36 samples) of 375, 614, 171 and 432 enterococci/100 ml, respectively (Table 8). The State enterococci standard was exceeded in 104 of the 127 samples (82%), and in 81% of SS01 samples, 86% for LS03, 69% for LS04 and 92% for the marsh drain.

Table 8: Geometric mean enterococci concentrations and frequency of samples greater than the enterococci standard at four storm drains at Long Sands and Short Sands beaches.

	LS04	Marsh	LS03	SSO1	All
Geomean	171	432	614	375	359
N=	32	36	28	31	127
Samples >104	22	33	24	25	104
% occur	69%	92%	86%	81%	82%

The relationship between enterococci concentrations at storm drains shows they are all highly correlated, with correlation coefficients >0.80 for each relationship (Table 9). Enterococci concentrations in storm drains were also analyzed in comparison to downstream beach sites that could be affected by drain-borne bacteria. Enterococci concentrations in LS04 drainage were not related to concentrations at Sites 8 and 10, nor were concentrations from the marsh drain related to concentrations at Sites 10 and 11 (Table 9). Enterococci from LS03 and SS01, however, did appear to influence downstream beach water quality, as there were significant correlations between drain and beach water enterococci concentrations. Follow-up microbial source tracking can confirm this finding.

Table 9: Relationships for enterococci concentrations between storm drains and between storm drains and downstream beach sites.

Site	Marsh Drain	LS03	SS01
LS04	**0.9**	**0.94**	**0.94**
Marsh Drain		**0.9**	**0.93**
LS03			**0.81**

Beach station	Drain station	Correlation	Significant?
8	LS04	0.11	no
10	LS04	-0.01	no
10	Marsh Drain	0.09	no
11	Marsh Drain	0.001	no
6	LS03	0.56	**YES**
4	SS01	0.83	**YES**

Some of the same drains were sampled in a previous study (FBE 2013) and subject to canine detection of human wastewater on July 30, 2013. Enterococci concentrations were all above the State standard, ranging from 359/100 ml at SS01 (their SS1 site) to 521/100

ml at LS04 (LS2) to 754/100 ml at the marsh drain (LS7). They also detected 275 enterococci/100 ml at the LS01 (LS8) drain. The canine detection of human wastewater gave positive results at LS01 and the marsh drain, and equivocal results (1 dog positive, 1 dog negative) at SS01. Follow-up microbial source tracking would confirm these results.

4.2.2 Are there bacterial contaminants from the Cape Neddick River and tributaries that affect Cape Neddick Beach water quality?

Cape Neddick River (CNR) sites were sampled unless the (tributary/ditch) site had no water or, in the case of CNR-Mouth, the tide was too high. All sites were accessible from the land, and included many of those deemed to be of most concern from previous studies (http://www.yorkmaine.org/Departments/CommunityDevelopment/CapeNeddickRiver/CapeNeddickRiver.aspx; Frick et al. 2013; FBE 2014).

Routine sampling of CNR sites occurred on nearly a weekly basis throughout the study, with daily sampling at CNR-6, a drainage site for a wetland that empties directly to the Cape Neddick Beach and where 33 samples were collected (Table 10). Sampling at CNR-2 (11 samples) and CNR-mouth (9 samples) began later than at other six sites, where 13 to 20 samples were collected. There were 149 samples collected from the nine CNR sites on 38 sampling dates. The geometric mean concentrations ranged from 15 enterococci/ 100 ml at CNR-mouth to 1608/100 ml at CNR-6, with all sites but CNR-mouth having geometric means greater than 104/100 ml (Table 10). The State enterococci standard was exceeded in 125 of the 149 samples (84%), including only once (11%) at CNR-mouth and up to 100% at Sites CNR-6 and CNR-11. Site CNR-9 was one of three tidal sites, and had a geometric mean of 266 enterococci/100 ml and 12 of 14 (86%) samples exceeded the state standard. Site CRB was in the main stem of the river at the upstream end of tidal influence and had a geometric mean of 208 enterococci/100 ml and 12 0f 18 (67%) samples exceeded the State standard. These results suggest that the Cape Neddick River and tributaries contain elevated levels of enterococci that could affect water quality at Cape Neddick Beach, as has been surmised from several previous studies.

Table 10. Geometric mean enterococci concentrations and frequency of samples greater than the enterococci standard at nine sites in the Cape Neddick River watershed.

	CNR 6	**CNR 7**	**CNR 9**	**CNR 9B**	**CNR 11**	**CNR 13**	**CRB**	**CNR 2**	**CNR mouth**	**All**
Geomean	1608	715	266	2718	971	1016	208	337	14	629
N=	33	20	14	15	13	16	18	11	9	149
Samples >104	33	17	12	14	13	14	12	9	1	125
% occur	100%	85%	86%	93%	100%	88%	67%	82%	11%	84%

Enterococci concentrations at CNR sites suggested some relationships exist between sites based on proximity (Table 11). Concentrations at Sites CNR-9 and 9A, Sites CNR-6 and 7, and Sites CNR-2 and CRB show relationships between sites in close proximity, although there is no relationship between Sites CNR-13 and CRB. Enterococci concentrations at CNR sites were also analyzed in comparison to Site 2 at Cape Neddick

Beach site to determine what potential source areas may be related to bacterial pollution at the beach (Table 11). Enterococci concentrations at CNR-mouth were related to the beach water quality, as expected. Other sites where enterococci concentrations related to beach water quality were CNR-2, 11 and 13, all freshwater sites well upstream of the beach. Enterococci concentrations at sites closer to the beach, including CNR-6, 7 and 9 showed no relation to beach water enterococci concentrations. Further analysis of the data (below) in relation to environmental, meteorological and other water quality parameters provide some insights into the basis for these findings.

Table 11: **Relationship between enterococci concentrations at CNR sites.**

Site	CNR-7	CNR-9	CNR-9B	CNR-11	CNR-13	CRB	CNR-2	CNR-mouth
CNR-6	**0.62**	0.6	0.11	0.46	0.42	**0.57**	0.1	NaN*
CNR-7		**0.9**	**0.9**	**0.63**	**0.6**	**0.79**	**0.88**	NaN
CNR-9			-0.1	0.28	0.34	**0.99**	**0.98**	NaN
CNR-9B				0.46	**0.51**	-0.15	0.13	NaN
CNR-11					**0.77**	0.22	0.43	NaN
CNR-13						0.31	0.35	NaN
CRB							**0.92**	NaN
CNR-2								NaN

*NaN=amount of data inadequate for analysis

Beach station	River station	Correlation	Significant?
2	CNR-6	0.33	no
2	CNR-7	0.44	no
2	CNR-9	0.06	no
2	CNR-9B	0.38	no
2	CNR-11	0.76	**YES**
2	CNR-13	0.62	**YES**
2	CRB	-0.02	no
2	CNR-2	0.82	**YES**
2	CNR-Mouth	0.82	**YES**

4.2.3. Is there evidence that seaweed causes bacterial contamination in beach water?

Seaweed presence was noted throughout the study at many sites, especially Site 6 at the north end of Long Sands Beach. After the significant storm of August 13th that was preceded by significant spring tides, however, the amount of seaweed that accumulated starting the next week on the beach and in the water was far greater than at other times. This occurred on Long Sands Beach from Site 13 northward to Site 6. This phenomenon was significant for water quality because levels of enterococci in the water at Site 11 were well above 104/100 ml starting on August 18 (a Monday, so possibly before that) through August 21 before returning to a lower level (52/100 ml) on August 22 (Figure 7-

note log scale for enterococci concentrations). The enterococci concentration at Site 11 on August 19 was above the detection limit of 24,196/100 ml. The high levels at this site were in part a reflection of the large, packed blocks of seaweed that collected at the low tide mark between Sites 10 & 11 (Figure 8). Enterococci concentrations at other sites, including Site 8 (once) and 10 (twice), and 13 based on MHB data, were also probably elevated due to seaweed during this time period.

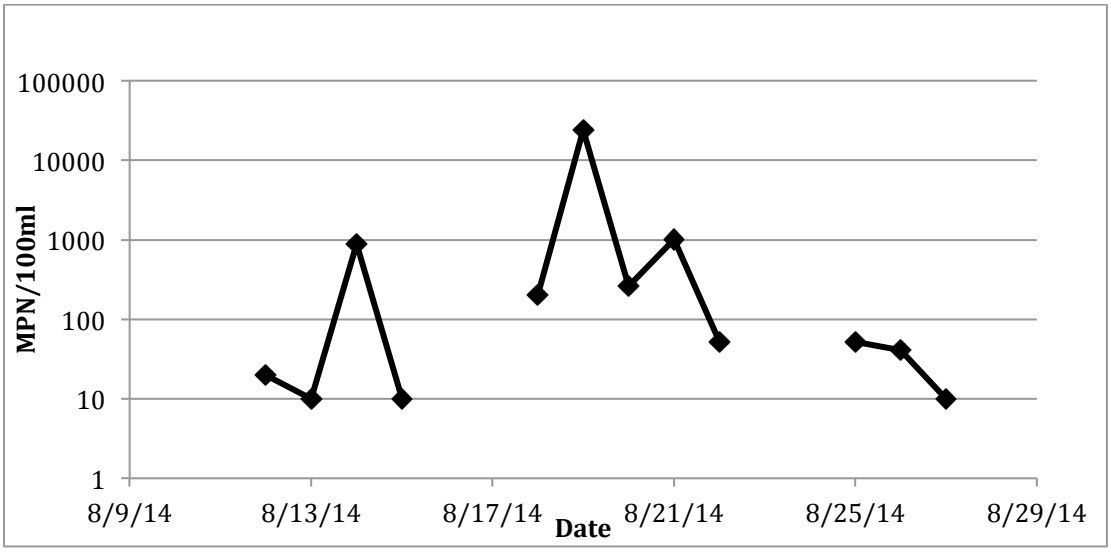

Figure 7. Enterococci concentrations at Site 11: August 12-August 27, 2014.

Figure 8. Large seaweed accumulation near Sites 10 and 11 on Long Sands Beach: August 21, 2014.

Seaweed samples were collected on August 21 from the largest seaweed block (Figure 8), and analysis showed seaweed contained140 enterococci/g wet weight. Intertidal seaweed samples were also collected on August 28 from Sites 6, 10, 11 and 13. Enterococci were detected in all samples at concentrations ranging from 4 to >9500/g wet weight of seaweed (Table 12).

Table 12: Enterococci concentrations in seaweed samples collected from Long Sands Beach during August, 2014.

Date	Site	Weight (g)	MPN	MPN/g
8/21/14	10-11	1.11	156	140
8/28/14	6	2.81	>24196*	9402
8/28/14	10	2.64	10	4
8/28/14	11	1.28	141	110
8/28/14	13	2.78	>24196*	9501

*Concentration > detection limit = 26,420 /100ml (estimated)

The York Dept. of Public Works (DPW) Director, Dean Lessard, provided insight into this problem. When seaweed washed up on Long Sands Beach between Sites 6-13 after the August 13th storm, tourists and landlords began calling the Town to have the noxious seaweed removed. The DPW used large-bucket front-end loaders to pick up the drift seaweed off the beach and deposit it back into the surf, optimally on an outgoing near-low tide with an offshore wind to enable maximum ocean dispersion. This management strategy took several days to be effective as large amounts of seaweed continued to drift in on shore, (see: http://www.seacoastonline.com/article/20140827/News/408270345; Figure 9), however, it did eventually address citizen complaints as the smell, flies and slippery decomposing seaweeds were eventually diminished. The seaweed responsible for the foul odors is probably *Heterosiphonia japonica*, which has in recent years invaded and become more predominant in the Northeast (Newton et al. 2013).

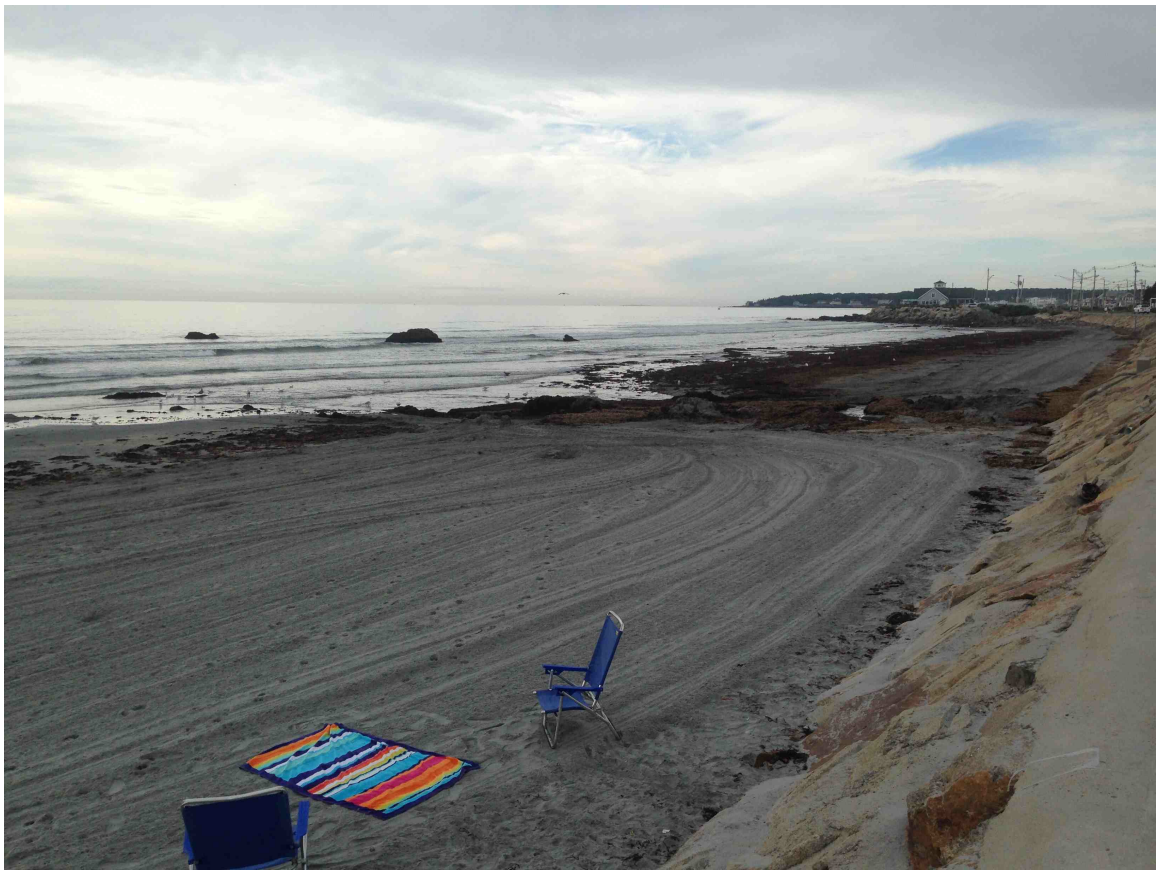

Figure 9. Beach and intertidal seaweed accumulation at Long Sands Beach on August 21, 2014.

Significant accumulations of seaweed have been a nuisance on York's beaches almost every year, and there has appeared to be recent changes in species where the types of seaweeds that wash up have changed from relatively benign brown algae (*Fucus, Ascophyllum spp.*) to species more susceptible to decomposition. This change has been characterized by greater problems with foul odors, flies and possibly regrowth of enterococci concentrations. The location of the worst conditions also changes from year

to year. Short Sands Beach had a significant problem with decomposing seaweed around July 4th, 2012.

Students in the Fall 2014 UNH Marine Ecology class, taught by Dr. Arthur Mathieson, conducted drift algal studies at nearby Seapoint Beach in Kittery on September 7.2014. Their surveys showed a majority of the seaweeds on the beach were *Chondrus crispus*, a red seaweed, and to a lesser extent *Desmarestia aculeata* and *Fucus vesiculosus*, both brown seaweeds, with some *Heterosiphonia japonica* (class report). These species are probably similar to those present at nearby Long Sands Beach when problems were occurring 3 weeks before the Seapoint Beach sampling. The dominance of red algae in 2014 was in contrast to the dominance of brown algae in a previous UNH Marine Ecology class collection in 2010, although that sample was collected in January. These findings provide more insight into what species are probably causing problems at York beaches.

4.2.4. Were other sources of bacterial pollution observed in this study?

Seagulls were the most common birds observed during sampling and the only birds to be present on beach sand. They can contribute significant numbers of enterococci to beach area via deposition of feces. The numbers of seagulls were noted each day at each site, and thus were as a factor that may affect beach water quality (see next section). Seagulls were more prevalent in areas with storm drainage and probably contribute to bacterial pollution of the beach water.

Bathers were also counted at every site on every sampling day. Bathers can contribute enterococci to beach water via fecal discharge, and were also considered a factor that may affect beach water quality.

The York River was surveyed at sampling sites used by the ME Department of Marine Resources (ME DMR) for classifying shellfish growing areas on August 26, 2014. Most samples contained low levels of both enterococci (<10/100 ml) and fecal coliforms (<2 to 6/100 ml), which is consistent with the latest (2012) ME DMR data (http://www.maine.gov/dmr/rm/public_health/G_A_reports/wbdata2007-12.pdf). The exception was at Site 26, a small tributary to the tidal river, where the enterococci concentration was 295/100 ml, yet the fecal coliform and *E. coli* concentrations were <2/100 ml. Data later than 2012 are not yet posted on the ME DMR website and coordination with their field personnel to do further sampling did not occur. Given the predominant north to south direction of near-shore currents, the York River is probably not a significant source of bacterial pollution at York beaches.

Findings:

-Consistently high enterococci concentrations and other chemical and canine indicator data suggest that possible human sources/illicit discharges probably contribute to contamination in the four storm drains.

-Enterococci from LS03 and SS01 appear to influence downstream beach water quality, as there were significant correlations between drain and beach water enterococci concentrations.

-The Cape Neddick River and tributaries contain consistently elevated levels of enterococci that could affect water quality at Cape Neddick Beach, as has been surmised from several previous studies.

-Enterococci concentrations at CNR-mouth, 2, 11 and 13 were related to the beach water quality. Enterococci concentrations at sites close to the beach, including CNR-6, 7 and 9 showed no relation to beach water enterococci concentrations.

-Significant accumulations of invasive and native seaweeds have been an annual nuisance on York's beaches and were a significant localized source of enterococci during mid to late August 2014 on Long Sands Beach.

-Seagulls can contribute to elevated enterococci concentrations, especially when they congregate, which they do along storm drainage at beaches.

4.3 What climatic and beach water factors affect bacterial pollution levels at York's beaches?

To address this question, data for factors that may affect enterococci levels are statistically compared with log-transformed enterococci concentration data are used to determine possible relationships. The analyses in this section include comparisons of other factors with enterococci data for each site, the different beach management areas and the full dataset. Significant factors identified through the initial analyses are then used to develop a generalized linear model for estimating the probability of enterococci concentrations above the State standard of 104/100 ml.

4.3.1 Do rainfall/stormwater runoff events impact beach water quality, and if so, is there a threshold above which bacterial pollution is likely?

Rainfall events are the climatic condition that is most commonly associated with elevated levels of bacterial pollution in surface waters. It is a factor recommended for marine beach advisory management by EPA and the MHB Program. Factors associated with potential impacts of rainfall on bacterial pollution are related to the amount and intensity of stormwater runoff from pollution sources and include rainfall amount over a set time period, rainfall intensity during the event and length of precedent dry period.

Between July 3, 2014 and September 17, 2014, rainfall events occurred in the York beaches area twenty six times, with precipitation amounts ranging from 0.01 to 1.82 inches per day. Two storms exceeded 2.0" during the full event. For analysis purposes, only the 18 rain events accumulating more than 0.1" were included (Table 13).

Table 13: Significant rainfall events and frequency of enterococci concentrations that exceed the State standard at all ten York beach sites.

Date	Rainfall* in/24 h	Volunteer† Rain gauge	Enterococci > 104/100 ml incidence Within 0-24 h	Within 24-48 h
7/3/14	0.13		NA	1
7/4/14	1.18		1	1
7/5/14	0.5		1	0
7/7/14	0.25		0	0
7/15/14	0.9	1.35	1	0
7/16/14	0.5	0.22	0	0
7/23/14	0.13	0	0	0
7/24/14	0.98	1.6	0	0
7/27/14	0.37	0.44	NA	0
7/28/14	1.02	0.97	0	0
8/1/14	0.4	0.33	NA	NA
8/6/14	0.19	0	2	0
8/7/14	0.24	0	0	0
8/8/14	0	0.69	0	2
8/13/14	3.07**	1.7	7	0
8/31/14	0.12	0.11	0	0
9/2/14	0.15	0.23	0	3
9/7/14	0.11	0.18	1	3
9/13/14	0.13	0.13	NA	0

*Daily 24 h rainfall amounts at York Cliffs (Weatherunderground)
**Rainfall amount ceased being recorded at York Cliffs site at 18:16 on 8/13/14, but storm continued at other nearby sites; 3.07 in is average of amounts from Cider Hill and Perkins Cove sites (Weatherunderground) for 8/13/14
†Data for on-shore site on tidal portion of Cape Neddick River, read daily at 9 AM.

The incidence of enterococci concentrations exceeding 104/100 ml at the ten beach sites relative to rainfall amount suggests a rainfall threshold may exist above which poor water quality may be predictable. This approach is used by MHB where they determine the percentages of data that fall into true and false positive and negative categories in relation to a threshold rainfall amount (MHB, 2013; unpublished reports). This then serves as the basis for determining the most accurate threshold for use as a precautionary advisory in managing beach use at several Maine marine beaches.

The MHB approach was used across spatial scales including for each of the ten York beach sites, each of the five management areas, and for the full dataset to determine the best threshold rainfall amount for each unit, based on both 24h and 48h rainfall amounts (Appendix D). Generally, the high (>104/100 ml) bacterial levels occurred under the 0.25" threshold or above the 1.5" threshold, so the percentage of data in the 'high bacteria-low rain' and 'high bacteria-high rain' categories did not change across threshold levels for all analyses. This reflects the fact that high bacterial levels occurred either under conditions where there was minimal or no rain, or under heavy rainfall conditions. As previously discussed, some of the high bacteria data are associated with the presence of highly concentrated seaweed at some sites and thus represent a non-rainfall impacted condition where bacteria levels are high. As the threshold rainfall amount was increased from 0.25" to 1.5", however, the percentage of data in the 'low bacteria-high rain' (false

positives) category decreased while the percentage in the 'lo bacteria-low rain' (true positive) category increased.

Based on data from this study, the 1.5" rainfall threshold is the most appropriate rainfall threshold across all spatial scales for both 24h and 48h rainfall events. The MHB Program, however, suggests using a more restrictive 1" in 24 h threshold for all of York beach sites and management areas (MHB 2013). That conclusion is based on use of York Beach MHB data from 2008-13, and thus covering a more expansive, though non-overlapping, time period that may have included rain events of different amounts. Using more recent data from this study may better reflect recent improvements in water quality from efforts by the Town of York to eliminate bacterial pollution sources. Using a threshold of 1.5" within the previous 24-48 h for all York beach sites is what is suggested from this study, with site-specific details described in the following sections.

4.3.2 Are rainfall amounts and other environmental factors related to enterococci concentrations at York's beaches?

A range of factors can be consider that may be useful in predicting conditions associated with elevated enterococci concentrations. Water temperature, salinity and dissolved oxygen, air temperature, sample timing relative to tide stage, tide height, seaweed presence, wave height, wind direction and speed, and potential pollution sources like seagulls, seaweed and bathers can all impact beach bacteria concentrations, and are considered in different ways in this report. Seaweed presence and wind direction and speed were not used in statistical analyses, but were used to help interpret some of the enterococci data. The following are statistical analyses that determine what relationships are significant.

Log-transformed enterococci concentrations for all sites combined were significantly related to rainfall amount after 24h and 48h (rain24, rain48), water temperature (Wtemp), high tide height (HT ht) and the number of gulls, and inversely related to air temperature (Atemp), salinity (saln), dissolved oxygen concentration (Doc) and saturation (Do%), and low tide height (LT ht) (Table 14). These same factors were also related to enterococci concentrations for each beach management area. Cape Neddick Beach (CNB; Site 2) showed enterococci concentrations that were significantly related to rainfall amounts after 24h and 48h, high and low tide height, and salinity. The significant inverse relationship with salinity makes sense given this is the York beach most affected by freshwater inflow. At Short Sands (SSB; Site 4), enterococci levels were related to rainfall amount after 48h, high and low tide heights, air temperature and salinity. The significant inverse relationship with salinity for this site also makes sense given the significant flow from the storm drain and short distance to the beach water at the north end of the beach. At York Harbor Beach (YHB; Site 20), enterococci concentrations were significantly related to high and low tide height, water temperature and gulls.

Table 14: **Statistical relationships between log-transformed enterococci concentrations and a range of environmental, climatic and source factors.**

	Rain 24	Rain 48	lt mins	lt height	ht mins	ht height	waveh	A temp	W temp	saln	DO conc	gulls
All Sites	**0.09**	**0.14**	0.07	**-0.19**	-0.01	**0.14**	0.08	**-0.11**	**0.16**	**-0.28**	**-0.14**	**0.34**
CNR (Site 2)	**0.41**	**0.47**	0.10	**-0.36**	-0.10	**0.33**	0.24	0.07	-0.08	**-0.43**	-0.16	0.15
SSB (Site 4)	0.20	**0.33**	0.25	**-0.30**	-0.13	**0.39**	0.19	**-0.30**	0.12	**-0.51**	-0.19	0.09
LSN	0.00	0.00	-0.16	-0.14	-0.05	0.24	-0.08	-0.21	0.14	-0.25	-0.07	**0.53**
LSS	0.08	0.02	0.17	**-0.34**	-0.02	**0.45**	0.17	**-0.33**	0.24	-0.05	-0.22	-0.14
YHB (Site 20)	-0.03	0.10	0.05	**-0.33**	0.04	**0.32**	0.01	-0.09	**0.30**	-0.01	-0.15	**0.29**
Site 6	-0.09	0.05	0.15	**-0.46**	0.10	**0.38**	**0.29**	0.18	-0.08	-0.09	0.21	0.23
Site 8	0.21	0.18	-0.01	-0.23	-0.05	**0.30**	0.14	0.00	-0.07	-0.08	0.11	**0.29**
Site 10	0.04	0.11	-0.10	-0.06	0.10	0.10	-0.06	**-0.31**	**0.36**	**-0.31**	-0.21	**0.46**
Site 11	0.18	0.27	0.11	-0.16	0.19	-0.02	0.12	-0.17	0.27	**-0.45**	-0.13	0.10
Site 13	-0.09	-0.02	0.00	-0.14	-0.02	0.23	-0.13	-0.27	0.27	-0.28	-0.19	-0.06
Site 16	0.06	-0.04	0.19	-0.22	0.07	0.20	0.08	-0.17	0.10	0.24	0.04	-0.02
Site 18	0.17	0.17	0.24	**-0.38**	-0.10	**0.42**	**0.51**	-0.17	0.11	**-0.30**	-0.22	0.07

Enterococci concentrations at the Long Sands Beach North (LSN) management area were significantly related to gulls (Table 14). When each beach site is analyzed separately, enterococci concentrations are significantly related to high tide height at Sites 6 and 8, low tide height and wave height (wave ht) at Site 6, salinity at Sites 10 and 11, and air and water temperatures and gulls at Site 11. Salinity may be a factor at Sites 10 and 11 because of their close proximity to LS04 and the marsh drainage, respectively. At Long Sands Beach South (LSS), enterococci concentrations were significantly related to low and high tide height, wave height and salinity at Site 18; enterococci at Sites 13 and 16 showed no significant relationships with other factors.

4.3.3 Are rainfall amounts and other environmental factors related to enterococci concentrations from storm drains, tributaries and other potential contamination sources?

Enterococci concentrations in the four **storm drains** were significantly related to a number of factors (Table 15). Enterococci concentrations in LS04 drainage water were inversely related to salinity, consistent with the drain being a source of fresh water and any bacteria that it may contain. Salinity was not a significant factor related to enterococci levels in the other three drains, where rainfall amounts after 24h and 48h and tidal height were significant factors. Air temperature and dissolved oxygen were also significant factors at LS03, and water temperature was a significant factor at LS03 and the marsh drain. Thus, rainfall and tidal stage were the most common significant factors in relation to enterococci levels in storm drains.

Table 15: **Relationship between enterococci concentrations in storm drains and rainfall amount, minutes since high tide, high tide height, air temperature, water temperature, salinity, dissolved oxygen, and gulls.**

Site	rain24	rain48	htmins	htheight	Atemp	Wtemp	saln	DO	gulls
LS04	0.34	0.31	0.20	0.04	-0.27	-0.16	**-0.49**	0.13	0.03
Marsh drain	**0.36**	**0.42**	-0.13	**0.46**	-0.15	**-0.39**	-0.11	0.04	0.41
LS03	**0.43**	**0.53**	-0.27	**0.50**	**-0.38**	**-0.40**	-0.03	**0.42**	-0.31
SSO1	**0.65**	**0.54**	-0.24	**0.52**	-0.26	-0.24	0.06	-0.29	0.06

Based on this and previous studies, areas within the **Cape Neddick River watershed** are probable sources of contamination at Cape Neddick Beach. Understanding what factors may affect them as bacterial sources is key to managing pollution source tracking and elimination efforts. Rainfall amount after 48h was significantly related to enterococci concentrations at Sites CNR 7, 11 and 2, which is of interest because Sites CNR 11 and 2 were also related to beach water quality at Site 2 at the beach (Table 16). Water temperature was a significant inversely related factor at CNR 9B, a small ditch in the open sun where bacterial levels could be subject to die off in the heat and exposure to UV light. CRB enterococci levels were inversely related to salinity and dissolved oxygen. This site is near the head of tide and lower salinity/lower DO levels reflect the greater influence of freshwater from upstream sources compared to tidal water. CNR 6 and 7 enterococci levels are also significantly related to low and high tide heights, possibly as a result of changes induced in groundwater flow.

Table 16: **Relationship between CNR site and rainfall amount, air temperature, water temperature, salinity, dissolved oxygen, minute since low tide, low tide height, minutes since high tide, and high tide height.**

	rain24	rain48	Atemp	Wtemp	saln	DO	ltmins	ltheight	htmins	htheight
CNR-6	0.29	0.28	0.08	-0.21	-0.22	0.09	0.15	**-0.47**	-0.28	**0.52**
CNR-7	0.42	**0.61**	0.11	-0.33	-0.30	-0.14	0.09	**-0.57**	-0.41	**0.57**
CNR-9	0.28	0.43	0.11	-0.06	-0.18	0.07	-0.46	-0.09	0.14	0.11
CNR-9B	0.15	0.14	-0.42	**-0.64**	0.33	-0.11				
CNR-11	**0.59**	**0.70**	-0.25	0.09	-0.45	0.15				
CNR-13	0.34	0.30	-0.10	-0.24	-0.07	-0.02				
CRB	0.30	0.39	-0.04	-0.18	**-0.48**	**-0.52**	-0.42	-0.01	0.12	-0.01
CNR-2	0.24	**0.75**	-0.11	-0.03	-0.29	0.11				
CNR-mouth	0.05	-0.16	0.15	0.08	-0.03	-0.28	0.31	-0.13	-0.26	0.55

As described above, drift **seaweed** on Long Sands Beach during 2014 was a significant cause of elevated enterococci levels during August, when seaweed presence was at its highest. The influx of seaweed from near-shore sub-tidal areas occurred soon after a significant rainstorm on August 13th. Several storm-related factors together may have caused this to occur. The most extreme spring tide of August (tidal range 12.8 ft) occurred on the 12th, followed by a shift in wind direction to an (onshore) ESE wind on August 13th with average and maximum wind speeds of 8.6 and 34 mph, respectively, in association with the storm that battered the Maine coast with up to 6 inches of rain in some areas. This is in contract to the storm of July 4th when the tidal range was 7.2 ft, and wind direction was WNW with average and maximum wind speeds of 5.2 and 24 mph. Seaweed accumulation on the beach was nowhere near as noticeable after July 4th as it was after the August 13th storm, thus, climatic and ecological conditions were factors associated with the highest enterococci levels measured in beach water in this study.

Using the full beach water quality database, there was a significant relationship between enterococci concentrations and numbers of **seagulls**. More detailed analysis showed this relationship was significant in the Long Sands North and York Harbor beach areas, and more specifically at Sites 8 and 10 at Long Sands Beach-North. Further analysis suggests gulls were in greater numbers during more extreme tides and less saline water (Appendix E). These results are in agreement with observations made during this study that gulls congregate on the beaches near storm drainage as it crossed the beach sand. There was no significant relationship between numbers of **bathers** and enterococci concentrations. Not surprisingly, however, water and air temperatures were positively correlated and wave height and gulls were negatively correlated with bather numbers (Appendix E).

A risk model for enterococci contamination at York beaches was developed using a GLM to estimate enterococci concentrations above and below the State standard of 104 enterococci/100 ml. Of the three models developed, Model 3, which includes rainfall amount in prior 48h, salinity, and low tide height, presented the best out-of-sample suitability with improved error indices over Model 1 and Model 2 (Figure 10). None of the three models, however, adequately classified enterococci presence cases (as indicated by the true positive rate of each model), as the nature of the zero-inflated (i.e., acceptable water quality) dataset dominates the binary distribution. Using just Rain48, Model 1 predicts all zeros, adding saln (Model 2), and then saln and LT ht improves prediction and binary classification but the issue remains that the models are predicting mostly zeros, or enterococci MPN<104/ml. These results underscore findings from correlation and other previously described analyses that rainfall and salinity provide some level of value for predicting high enterococci concentrations.

MODEL 1

	Predicted		
	1	0	
1	0	28	28
0	0	402	402
	0	430	430

MODEL 2

	Predicted		
	1	0	
1	4	24	28
0	1	401	402
	5	425	430

MODEL 3

	Predicted		
	1	0	
1	6	22	28
0	0	402	402
	6	424	430

	Model 1	Model 2	Model 3
TPR	NaN	0.142	0.214
TNR	NaN	0.998	1.00
MCC	NaN	0.323	0.451

Figure 10. Model predictions and model assessment errors of enterococci concentrations above 104/100). TPR= true positive rate; TNR= true negative rate; MCC= Matthews Correlation Coefficient.

Findings:

-A rainfall threshold of 1.5" rainfall in 24h or 48h could be a useful basis for a precautionary advisory at York beaches. The advisory would be in effect for 24 h, or two tidal cycles to allow for bacterial levels to be reduced due to physical mixing, dilution and transport from beaches.

-Different climatic and environmental factors were significantly related to enterococci concentrations at different sites and beach management areas. Rainfall amounts in prior 24 and 48h, salinity, low and high tidal height, and number of seagulls are the most useful factors in helping to inform management of the beaches.

-The same factors were useful in understanding conditions conducive to elevated levels of enterococci from different sources. Rainfall and tidal stage were the most common significant factors in relation to enterococci levels in storm drains, whereas rainfall and other factors were significant at sites in the Cape Neddick River watershed, including several key sites where enterococci concentrations are also directly related to enterococci concentrations at the beach (Site 2).

-Seaweed can be a significant source of enterococci in beach water under special climatic and tidal conditions, as well as stage of growth of the seaweeds.

- Computer modeling based on integration of climatic and environmental data for estimating enterococci concentrations above and below the State standard of 104 enterococci/100 ml suggest rainfall amount, salinity and tidal height may be significant factors affecting enterococci concentrations.

4.4 What are people at the beach and York residents saying?

Walking to the water's edge with water sampling and measuring equipment often drew attention to the UNH sampling crew, who would then engage in conversations with bathers and beach goers about the basic purpose of the project for the Town of York. The

most common question was about water temperature, but people were also curious about bacterial pollution and its impact on water quality. Beachgoers and shop owners who knew of our work would often offer information on what they perceived to be pollution sources and problems at the beach. These included some of the local businesses, the storm and marsh drains, and seaweed.

Sampling at storm drains drew people in who often provided anecdotes about flow, smell, seaweed clogging, and other observations about the drains. Several parents asked about their children playing in the cross-beach storm drainage, including one mother who asked whether it was safe for her immune-compromised child to play in the storm drainage. The crew responded in general terms, stating that the purpose of sampling was to determine if there might be pollution present. Overall, the citizens who engaged the crew through the project were well informed, interested in and seemed generally supportive of the project and efforts by the Town of York to take action about beach water quality.

5. SITE-SPECIFIC SUMMARY

Cape Neddick Beach

Water quality at Cape Neddick Beach was generally acceptable, however, the watershed does appear to contribute bacterial pollution to the beach. Rainfall events can cause increases in enterococci concentrations at the beach and simultaneously at some sites in the watershed that may be consistent sources of pollution to the beach. Enterococci concentrations exceeded the State enterococci standard more than 10% of the time, and there were three events where enterococci concentrations remained above the standard for more than one day. The 1.5 in/24-48h/1.0 in/24h precautionary advisory fits well for this site, and should remain in effect for 2 days or until bacterial concentrations at the beach fall back below the standard concentration based on follow-up water sample analysis.

Short Sands Beach

Water quality at Short Sands Beach was also generally acceptable and better than expected in 2014 based on previous year results. The lower levels at Site 4 may reflect recent mitigation measures taken by the Town of York to eliminate sewage sources in this area. The consistent and significant amount of flow from the storm drain at the north end of the beach is a concern. That concern is punctuated by the consistent enterococci concentrations above the State standard and findings from EPA analyses this year and in 2012 and 2013 that revealed elevated levels of chemicals associated with human sources and sewage contamination. Enterococci levels were also significantly related to rainfall amount within 48h, high and low tide heights, air temperature and salinity, all factors that suggest that the 1.5 in/24-48h precautionary advisory also fits well for this site. Again, the advisory should remain in effect for 2 days or until bacterial concentrations at the beach fall back below the standard concentration based on follow-up water sample analysis.

Long Sands Beach-North
Beach water quality in this area was generally acceptable. Because of the complexity of this area relative to potential pollution sources, there are 4 sites for which data are available to inform management decisions. Three of the sites (6, 8, 11) had relatively high rates of unacceptable water quality, where >10% of samples exceeded the State enterococci standard, and these sites also had some of the highest geometric mean and 90th percentile values of all York beach sites. At the northern end of this area (Site 6), beach water quality was significantly related to storm drain (LS03) water quality. That was not the case for other sites and the two other nearby drains, although enterococci levels in the drains were all highly correlated to each other. Levels of human pollution source-related chemicals at LS03 were not present at elevated levels in 2014, but were in previous years. Thus, the main sources of concern are the storm and marsh drains that empty directly to the beach. The drainage from these also attracts concentrations of seagulls that can also contribute bacterial pollution in high numbers from their feces. The 1.5 in/24-48h precautionary advisory should be used for this area and remain in effect for 2 days or until bacterial concentrations at the beach fall back below the standard concentration based on follow-up water sample analysis.

Long Sands Beach-South
This beach management area, including Site 13, was the least problematic based on geometric mean enterococci concentrations, which were the lowest of all York beach sites and were close to the detection limit of 10/100 ml because of frequent samples where no enterococci were detected. These sites also had only 1 or 0 instances of enterococci exceeding the State standard. The 1.5 in/24-48h precautionary advisory would certainly be a protective step for this area, but probably for no longer than 2 tide cycles within 24 h following the rainfall event.

York Harbor Beach
York Harbor Beach had no obvious sources of bacterial pollution other than bathers, sea birds and seaweeds. Enterococci concentrations were significantly related to high and low tide height, water temperature and gulls. Otherwise, this site fell between the cleanest sites (LSS area) and the more contaminated sites. Even though enterococci concentrations were not significantly related to rainfall amounts and salinity at this beach, enterococci levels were well above the State enterococci standard the day after the August 13th rainfall-runoff event and remained above 60 enterococci/100 ml on August 15th. Thus, the 1.5 in/24-48h precautionary advisory would be a protective step for this area, and should probably remain in effect for one day or until bacterial concentrations at the beach fall back below the standard concentration based on follow-up water sample analysis.

6. PRESS COVERAGE

Media coverage includes:

Seacoast Online June 29, 2014
"Intensive testing coming to York beaches"-Susan Morse
http://www.seacoastonline.com/article/20140629/News/406290351

Seacoast Online August 27, 2014
"Seaweed clogs beach, causing foul smell"-Susan Morse
http://www.seacoastonline.com/article/20140827/News/408270345

7. LIST OF ACRONYMS

AvgRPD	Average of Relative Percent Difference
BAV	Bacteria Action Value
cfu	Colony-forming units
CL	Control limit for differences between duplicate sample analyses
CNR	Cape Neddick River
DPW	Department of Public Works
EPA	Environmental Protection Agency
g	Gram
GLM	Generalized linear model
h	Hour
L	Liter
LDC	Lower detection limit concentration
JEL	Jackson Estuarine Laboratory
ME DMR	Maine Department of Marine Resources
mg	Milligrams
MHB	Maine Healthy Beaches
mL	Milliliter
MPN	Most probable number
ng	nanograms
NSSP	National Shellfish Sanitation Program
PCPP	Pharmaceutical and personal care products
RPD	Relative percent difference
StdDevRPD	Standard deviation of relative percent difference
UDC	Upper detection limit concentration
UNH	University of New Hampshire
WL	Warning limit for differences between duplicate sample analyses

8. REFERENCES

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APPENDICES

Appendix A: Enterococci concentrations for the ten beach water quality sites.

Date	2	4	6	8	10	11	13	16	18	20
7/3/14	4	1.8	1.8	4	1.8	1.8	1.8	1.8	1.8	1.8
7/5/14	512	63	9	41	52	63	10	9	9	10
7/6/14	108	10	9	10	20	10	9	9	10	10
7/7/14	10	20	9	9	10	9	9	10	9	20
7/8/14	10	9	41	9	10	9	9	10	9	9
7/9/14	10	9	31	9	9	9	9	9	10	10
7/10/14	9	9	109	41	9	9	9	9	9	9
7/11/14	10	10	9	228	9	9	9	9	9	9
7/14/14	233	9	243	10	9	9	9	9	9	31
7/15/14	359	10	411	9	9	9	9	9	9	9
7/16/14	52	41	10	63	10	52	9	31	9	31
7/17/14	9	10	9	31	9	9	9	9	9	10
7/18/14	10	9	9	63	10	9	9	9	9	10
7/21/14	9	10	9	9	10	9	9	10	9	10
7/22/14	10	9	10	75	9	10	9	9	9	9
7/23/14	9	10	30	9	20	9	9	9	20	9
7/24/14	9	10	9	20	31	10	10	10	9	9
7/25/14	9	9	9	9	10	9	9	9	9	9
7/28/14										9
7/29/14	9	10	9	9	9	9	9	9	9	9
7/30/14	9	9	20	10	20	9	9	9	9	9
7/31/14	9	9	9	9	9	9	9	9	9	10
8/1/14	9	20	9	9	9	9	9	9	9	9
8/4/14	20	9	9	9	9	10	10	9	9	20
8/5/14	10	9	9	9	9	9	10	9	9	146
8/6/14	74	41	9	31	9	10	20	9	10	63
8/7/14	20	10	9	10	74	933	9	201	9	20
8/8/14	73	9	10	31	20	9	10	9	9	10
8/11/14	10	10	9	9	20	10	9	20	9	63
8/12/14	10	9	31	10	9	20	9	20	9	20
8/13/14	488	20	41	109	10	10	10	<10	41	30
8/14/14	708	1336	958	135	120	886	30	10	20	733
8/15/14	72	108	9	9	20	10	108	9	10	61
8/18/14	41	30	9	109	63	201	20	9	10	10
8/19/14	20	10	<10	<10	86	24196	41	<10	<10	41
8/20/14	20	9	9	9	10	259	10	9	9	10
8/21/14	52	10	9	10	121	1012	9	9	9	10
8/22/14	9	9	9	10	51	52	10	10	9	20

8/25/14	9	9	9	10	51	52	10	10	9	20
8/26/14	9	9	9	95	108	41	9	10	9	9
8/27/14	246	9	51	20	10	10	9	9	9	9
8/28/14	9	9	9	9	9	10	10	20	9	9
8/29/14	9	62	10	10	10	10	10	9	9	9
9/1/14	9	10	9	52	9	9	9	9	9	9
9/2/14	9	9	40	30	9	9	9	20	9	10
9/4/14	9	9	150	337	10	9	10	9	9	163
9/5/14	9	9	113	30	10	9	9	9	9	9
9/8/14	10	9	9	10	275	9	20	10	9	97
9/9/14	10	109	109	243	86	31	10	41	98	10
9/15/14	9	9	9	9	9	9	9	9	20	9
9/16/14	9	20	10	9	9	9	9	9	9	10
9/17/14	9	9	10	9	9	9	9	9	9	9

Appendix B: Enterococci concentrations for the four storm and marsh drains.

Date	drain 8-10	marsh 10-11	LS03	SSO1
7/16/14	ND	ND	4160	3130
7/17/14	545	669	2046	505
7/18/14	199	568	1989	291
7/21/14	107	254	1913	102
7/22/14	63	285	630	62
7/23/14	134	179	383	98
7/24/14	4352	3448	9804	8164
7/25/14	243	332	984	291
7/28/14	ND	ND	ND	ND
7/29/14	235	311	359	538
7/30/14	85	160	355	231
7/31/14	97	85	393	108
8/1/14	435	158	301	169
8/4/14	107	315	238	97
8/5/14	62	260	520	52
8/6/14	135	228	752	134
8/7/14	148	201	145	108
8/8/14	72	98	96	187
8/11/14	ND	631	ND	ND
8/12/14	ND	17329	ND	ND
8/13/14	ND	7701	26600	5475
8/14/14	ND	12997	19863	15531
8/15/14	1095	1391	4884	4352
8/18/14	717	1450	1145	842
8/19/14	663	1223	1014	776
8/20/14	272	816	318	300
8/21/14	145	1334	933	497
8/22/14	52	120	452	226
8/25/14	177	790	ND	ND
8/26/14	171	439	ND	ND
8/27/14	20	189	ND	ND
8/28/14	9	105	10	291
8/29/14	41	119	ND	199
9/1/14	10	122	20	98
9/2/14	203	137	10	156
9/4/14	865	605	ND	448
9/5/14	275	216	ND	959
9/8/14	169	86	ND	ND

Appendix C: Enterococci concentrations for the nine Cape Neddick River watershed sampling sites.

	CNR-6	CNR-7	CNR-9	CNR-9B	CNR-11	CNR-13	CRB	CNR-2	CNR-mouth
7/10/14	6294		193	490	1211	9	422		
7/17/14	5794	10462							
7/18/14	1631	2167							
7/21/14	1060	746							
7/22/14	818	1320							
7/23/14	708	346							
7/24/14	26620	11199	12997	3123	3654	6867	14136		
7/25/14	1093	1093	120	466	958	1212	400		
7/28/14									
7/29/14	820	798	275	393	512	296	331		
7/30/14	262	97	246	1509	544	84	52		
7/31/14	620	333	10	794	714	569	108		
8/1/14	226	262	9	72	602	160	10	41	
8/4/14	294								
8/5/14	675								
8/6/14	563								
8/7/14	144								10
8/8/14	355								
8/11/14	8664						75		
8/12/14	14136						520		
8/13/14	17329	4611	228	26600	9804	12083	145	1036	
8/14/14	9208	8664	3654	17329	5475	7270	1720	9804	
8/15/14	2613								
8/18/14	985								108
8/19/14	2613								
8/20/14	3076	295	1008	12033	1145	4366	645	719	10
8/21/14	609	363	393	4884	428	9208	591	633	
8/22/14	253								
8/25/14	1674								
8/26/14	465								
8/27/14	26620	2755	359	498	303	1850	350	247	
8/28/14	2631	97	364	26620	169	1092	20	294	
8/29/14	26620								
9/1/14	386							115	10
9/2/14									31
9/4/14		223		14136		1767	73	199	10
9/5/14		41				1034	52	209	9
9/16/14		181	110	26600		585	121	97	9

Appendix D: Rainfall threshold tables.

Site 2											
0.25 Threshold			0.50 Threshold			1.0 Threshold			1.5 Threshold		
	24 hr.	48 hr.		24 hr.	48 hr.		24 hr.	48 hr.		24 hr.	48 hr.
	%	%		%	%		%	%		%	%
High bact, low rain	8	6	High bact, low rain	8	6	High bact, low rain	8	6	High bact, low rain	8	6
High bact, high rain	6	8	High bact, high rain	6	8	High bact, high rain	6	8	High bact, high rain	6	8
low bact, high rain	8	18	low bact, high rain	6	12	low bact, high rain	6	12	low bact, high rain	0	0
low bact, low rain	78	69	low bact, low rain	80	75	low bact, low rain	80	75	low bact, low rain	86	86
Site 4											
0.25 Threshold			0.50 Threshold			1.0 Threshold			1.5 Threshold		
	24 hr.	48 hr.		24 hr.	48 hr.		24 hr.	48 hr.		24 hr.	48 hr.
	%	%		%	%		%	%		%	%
High bact, low rain	4	4	High bact, low rain	4	4	High bact, low rain	4	4	High bact, low rain	4	4
High bact, high rain	2	2	High bact, high rain	2	2	High bact, high rain	2	2	High bact, high rain	2	2
low bact, high rain	12	24	low bact, high rain	10	18	low bact, high rain	10	18	low bact, high rain	4	6
low bact, low rain	82	71	low bact, low rain	84	76	low bact, low rain	84	76	low bact, low rain	90	88
Site 6											
0.25 Threshold			0.50 Threshold			1.0 Threshold			1.5 Threshold		
	24 hr.	48 hr.		24 hr.	48 hr.		24 hr.	48 hr.		24 hr.	48 hr.
	%	%		%	%		%	%		%	%
High bact, low rain	12	12	High bact, low rain	12	12	High bact, low rain	12	12	High bact, low rain	12	12
High bact, high rain	2	2	High bact, high rain	2	2	High bact, high rain	2	2	High bact, high rain	2	2
low bact, high rain	12	24	low bact, high rain	10	18	low bact, high rain	10	18	low bact, high rain	4	6
low bact, low rain	75	63	low bact, low rain	76	63	low bact, low rain	76	63	low bact, low rain	82	80
Site 8											
0.25 Threshold			0.50 Threshold			1.0 Threshold			1.5 Threshold		
	24 hr.	48 hr.		24 hr.	48 hr.		24 hr.	48 hr.		24 hr.	48 hr.
	%	%		%	%		%	%		%	%
High bact, low rain	8	8	High bact, low rain	8	8	High bact, low rain	8	8	High bact, low rain	8	8
High bact, high rain	4	4	High bact, high rain	4	4	High bact, high rain	4	4	High bact, high rain	4	4

low bact, high rain	10	22	low bact, high rain	8	16	low bact, high rain	8	16	low bact, high rain	2	4
low bact, low rain	78	67	low bact, low rain	80	73	low bact, low rain	80	73	low bact, low rain	86	84
Site 10											
0.25 Threshold			0.50 Threshold			1.0 Threshold			1.5 Threshold		
	24 hr.	48 hr.		24 hr.	48 hr.		24 hr.	48 hr.		24 hr.	48 hr.
	%	%		%	%		%	%		%	%
High bact, low rain	6	6	High bact, low rain	6	6	High bact, low rain	6	6	High bact, low rain	6	6
High bact, high rain	2	2	High bact, high rain	2	2	High bact, high rain	2	2	High bact, high rain	2	2
low bact, high rain	12	24	low bact, high rain	10	18	low bact, high rain	10	18	low bact, high rain	4	6
low bact, low rain	80	69	low bact, low rain	82	75	low bact, low rain	82	75	low bact, low rain	88	86
Site 11											
0.25 Threshold			0.50 Threshold			1.0 Threshold			1.5 Threshold		
	24 hr.	48 hr.		24 hr.	48 hr.		24 hr.	48 hr.		24 hr.	48 hr.
	%	%		%	%		%	%		%	%
High bact, low rain	10	10	High bact, low rain	10	10	High bact, low rain	10	10	High bact, low rain	10	10
High bact, high rain	2	2	High bact, high rain	2	2	High bact, high rain	2	2	High bact, high rain	2	2
low bact, high rain	12	24	low bact, high rain	10	18	low bact, high rain	10	18	low bact, high rain	4	6
low bact, low rain	76	65	low bact, low rain	78	71	low bact, low rain	78	71	low bact, low rain	84	82
Site 13											
0.25 Threshold			0.50 Threshold			1.0 Threshold			1.5 Threshold		
	24 hr.	48 hr.		24 hr.	48 hr.		24 hr.	48 hr.		24 hr.	48 hr.
	%	%		%	%		%	%		%	%
High bact, low rain	2	2	High bact, low rain	2	2	High bact, low rain	2	2	High bact, low rain	2	2
High bact, high rain	0	0	High bact, high rain	0	0	High bact, high rain	0	0	High bact, high rain	0	0
low bact, high rain	14	73	low bact, high rain	12	78	low bact, high rain	12	78	low bact, high rain	6	8
low bact, low rain	82	25	low bact, low rain	86	20	low bact, low rain	86	20	low bact, low rain	92	90
Site 16											
0.25 Threshold			0.50 Threshold			1.0 Threshold			1.5 Threshold		
	24 hr.	48 hr.		24 hr.	48 hr.		24 hr.	48 hr.		24 hr.	48 hr.
	%	%		%	%		%	%		%	%
High bact, low rain	2	2	High bact, low rain	2	2	High bact, low rain	2	2	High bact, low rain	2	2

High bact, high rain	0	0	High bact, high rain	0	0	High bact, high rain	0	0	High bact, high rain	0	0
low bact, high rain	14	25	low bact, high rain	12	20	low bact, high rain	12	20	low bact, high rain	6	8
low bact, low rain	84	73	low bact, low rain	86	78	low bact, low rain	86	78	low bact, low rain	92	90
Site 18											
0.25 Threshold			0.50 Threshold			1.0 Threshold			1.5 Threshold		
	24 hr.	48 hr.		24 hr.	48 hr.		24 hr.	48 hr.		24 hr.	48 hr.
	%	%		%	%		%	%		%	%
High bact, low rain	0	0	High bact, low rain	0	0	High bact, low rain	0	0	High bact, low rain	0	0
High bact, high rain	0	0	High bact, high rain	0	0	High bact, high rain	0	0	High bact, high rain	0	0
low bact, high rain	14	25	low bact, high rain	12	20	low bact, high rain	12	20	low bact, high rain	6	8
low bact, low rain	86	75	low bact, low rain	88	80	low bact, low rain	88	80	low bact, low rain	94	92
Site 20											
0.25 Threshold			0.50 Threshold			1.0 Threshold			1.5 Threshold		
	24 hr.	48 hr.		24 hr.	48 hr.		24 hr.	48 hr.		24 hr.	48 hr.
	%	%		%	%		%	%		%	%
High bact, low rain	4	4	High bact, low rain	4	4	High bact, low rain	4	4	High bact, low rain	4	4
High bact, high rain	2	2	High bact, high rain	2	2	High bact, high rain	2	2	High bact, high rain	2	2
low bact, high rain	13	25	low bact, high rain	12	19	low bact, high rain	12	19	low bact, high rain	4	6
low bact, low rain	81	69	low bact, low rain	83	75	low bact, low rain	83	75	low bact, low rain	90	88
Sites 6,8,10,11											
0.25 Threshold			0.50 Threshold			1.0 Threshold			1.5 Threshold		
	24 hr.	48 hr.		24 hr.	48 hr.		24 hr.	48 hr.		24 hr.	48 hr.
	%	%		%	%		%	%		%	%
High bact, low rain	9	9	High bact, low rain	9	9	High bact, low rain	9	9	High bact, low rain	9	9
High bact, high rain	2	2	High bact, high rain	2	2	High bact, high rain	2	2	High bact, high rain	2	2
low bact, high rain	11	23	low bact, high rain	9	17	low bact, high rain	9	17	low bact, high rain	3	5
low bact, low rain	77	66	low bact, low rain	79	72	low bact, low rain	79	72	low bact, low rain	85	84
Sites 13,16,18											
0.25 Threshold			0.50 Threshold			1.0 Threshold			1.5 Threshold		
	24 hr.	48 hr.		24 hr.	48 hr.		24 hr.	48 hr.		24 hr.	48 hr.
	%	%		%	%		%	%		%	%

High bact, low rain	1	1	High bact, low rain	1	1	High bact, low rain	1	1	High bact, low rain	1	1
High bact, high rain	0	0	High bact, high rain	0	0	High bact, high rain	0	0	High bact, high rain	0	0
low bact, high rain	14	25	low bact, high rain	12	20	low bact, high rain	12	20	low bact, high rain	6	8
low bact, low rain	85	73	low bact, low rain	87	79	low bact, low rain	87	79	low bact, low rain	93	91
All Beach sites											
0.25 Threshold			0.50 Threshold			1.0 Threshold			1.5 Threshold		
	24 hr.	48 hr.		24 hr.	48 hr.		24 hr.	48 hr.		24 hr.	48 hr.
	%	%		%	%		%	%		%	%
High bact, low rain	7	5	High bact, low rain	7	5	High bact, low rain	7	5	High bact, low rain	7	5
High bact, high rain	1	2	High bact, high rain	1	2	High bact, high rain	1	2	High bact, high rain	1	2
low bact, high rain	11	23	low bact, high rain	9	18	low bact, high rain	9	18	low bact, high rain	3	6
low bact, low rain	81	69	low bact, low rain	83	75	low bact, low rain	83	75	low bact, low rain	89	87

Appendix E: Relationship between beach stations (with seaweed presence) and all environmental parameters. Bold indicated a significant relationship at the 0.05 level.

	rain24	rain48	ltmins	ltheight	waveh	Atemp	Wtemp	saln	doc	dos	bathers	gulls	htmins	htheight
y=log(MPN)	**0.09**	**0.14**	0.07	**-0.19**	0.08	**-0.11**	**0.16**	**-0.28**	**-0.14**	**-0.11**	0.00	**0.34**	-0.01	**0.14**
rain24		**0.68**	0.03	**-0.11**	**0.3**	-0.03	**-0.19**	-0.06	-0.03	-0.02	0.06	0.01	-0.01	**0.18**
rain48			**0.11**	**-0.17**	**0.29**	0.08	**-0.23**	**-0.12**	-0.02	0.00	**0.14**	-0.03	-0.05	**0.26**
ltmins				**-0.46**	**0.35**	0.02	**0.14**	**-0.14**	-0.01	**-0.12**	0.09	**-0.14**	**0.93**	0.06
ltheight					**-0.51**	0.05	**0.18**	0.04	-0.02	0.04	0.07	0.11	**0.15**	**-0.96**
waveh						-0.01	**-0.09**	-0.07	-0.03	**-0.09**	**-0.09**	-0.08	-0.06	**0.54**
Atemp							**-0.21**	**0.33**	**0.24**	**0.19**	**0.19**	-0.1	0.02	**-0.10**
Wtemp								**-0.29**	**-0.46**	**-0.29**	**0.12**	0.03	0.01	**-0.14**
saln									**0.18**	**0.10**	-0.03	**-0.11**	0.02	0.03
doc										**0.69**	**-0.21**	0.02	-0.01	0.06
dos											**-0.19**	0	0.00	0.03
bathers												**-0.13**	0.01	-0.04
gulls													**0.12**	-0.08
htmins														**-0.18**