Coastal Beach Watershed Bacteria Source Investigation

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Beach Program
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1.0 Introduction

The Department of Environmental Services Beach Program focuses on protecting health by detecting bacteria sources to New Hampshire's coastal beaches. The Beach Program monitors coastal beaches for bacteria that indicate the potential presence of other disease-causing, or pathogenic, organisms responsible for diseases such as cholera and Hepatitis. Sources of pathogens to beach areas include developed area runoff, failing septic systems, domestic animals, livestock, and wildlife. The Beach Program receives funding from the Beaches Environmental Assessment and Coastal Health (BEACH) Act to monitor and assess coastal public beaches for pathogens, notify the public of the potential presence of pathogens, and identify and remediate pathogen sources to coastal beaches.

Over the past year and a half, the Beach Program has conducted an investigation of eight coastal beach watersheds designed to identify and assess bacteria sources in the watersheds. The goal of the project is to sufficiently characterize watershed bacteria sources; to support development of a watershed based plan and to remediate bacteria sources. The project seeks to enhance understanding of bacteria sources and conditions that result in elevated bacteria events. Achieving this goal will lead to decreased bacteria sources and provide assistance to restore beach watersheds.

This report describes a set of tasks conducted to expand our understanding of the nature and extent of bacteria source in beach watersheds. Project tasks may be represented as three primary components:

- Watershed bacteria source investigation - A watershed bacteria source investigation was conducted to evaluate potential bacteria source pathways and watershed bacteria sources. Our approach in conducting the watershed bacteria investigation was to; (1) obtain and review available bacteria data and related reports, (2) collaborate with seacoast bacteria investigators, (3) create GIS-based land use maps, and (4) conduct watershed reconnaissance surveys. The bacteria source investigation resulted in an inventory of potential bacteria sources in each watershed and is presented in Section 2.
- Bacteria Load Estimation - Bacteria load estimates were developed for each type of source identified in the watershed investigation, including developed area runoff, failing septic systems, livestock, and wildlife. A literature review was conducted to obtain the best available methods and estimates of bacteria loads for each source type. Bacteria load estimates are useful to support prioritization of bacteria sources for removal and are a required component of watershed based planning. Estimation methods and bacteria load estimates for each watershed are presented in Section 3.
- Statistical Analysis of Beach Bacteria Data - Statistical analysis of beach bacteria data was conducted to enhance understanding of conditions that result in elevated bacteria levels at coastal beaches and to improve public notification. Statistical analyses can also support bacteria source characterization by specifying conditions (e.g., wet weather) when bacteria levels increase. The statistical analysis was conducted using the Receiver Operator Characteristic (ROC) curve analysis method and was applied to evaluate several variables, including antecedent rainfall and air temperature, as potential predictors of elevated bacteria events. The ROC statistical analyses are described and presented in Section 4.

Each project component supports the overall project goal of characterizing watershed bacteria sources and remediating bacteria sources. Section 5 provides a summary and recommendations for next steps towards watershed restoration.

2.0 Watershed Bacteria Source Summaries

This section provides a description of the study area beaches and their associated watersheds. Potential bacteria routes reaching the beaches include watershed sources, direct on-beach sources, and coastal transport sources. The report focuses on watershed sources, but each bacteria transport route is potentially important and is discussed in Section 2.1. The approach to obtain and integrate bacteria source data is provided in Section 2.2 and features reviewing of available reports, collaborating with investigators, and conducting reconnaissance surveys. A summary of known bacteria source information is provided by watershed in Sections 2.3 through 2.10.

2.1 Introduction to Beach Watersheds and Bacteria Sources

The New Hampshire beaches investigated in this project are shown in Figure 1 and are listed in Table 1. The figure also shows the contributing watersheds to each beach and the seacoast towns. The table compiles beach watershed information, such as town, watershed size, and adjacent creeks. The summary is organized by watershed, starting at the northernmost beach watershed, New Castle Town Beach, proceeding south, as follows:

- New Castle Town Beach
- Wallis Sands, Pirates Cove, and Foss Beaches
- Jenness and Cable Beaches
- Sawyer Beach
- Bass Beach
- State Beach and Northside Park
- North Beach
- Seabrook Harbor, Hampton Harbor, Sun Valley, Seabrook Beach, and Hampton Beach.

A section is provided below for each beach watershed and includes GIS-based maps and brief summaries of bacteria source information.

2.1.1 Watershed Bacteria Sources

This investigation is focused on bacteria originating in watersheds draining to beaches. These sources include the following:

- **Point sources** – pipe outfall or NPDES-permitted discharges
- **Developed area runoff** – developed areas are the build environment including residential and commercial areas. Stormwater runoff from developed areas includes runoff from roads, lawns, parking lots, and roofs. Developed area runoff includes a wide range of bacteria sources including materials accumulated on land, illicit discharges, pets, and other neighborhood sources.
- **Failing septic systems** – failing septic systems are sources due to presence of partially treated or untreated waste.

- **Wildlife** – a wide range of animals that are not domesticated and may be present throughout the watersheds
- **Livestock** – horses, sheep, and other domesticated animals are potential bacteria sources

Several of the beach watersheds are located adjacent to the mouth of a tidal creek (e.g., Parsons Creek near Pirates Cover Beach in Rye). Tidal creeks have been observed to transport bacteria to beaches as discussed below. A discussion of each type of bacteria sources is provided as part of each watershed summary.

Table 1: New Hampshire Coastal Beach Watersheds with towns, sizes, and adjacent creeks.

#	Beach Name(s)	Beach Watershed Town(s)	Area (sq. miles)	Adjacent Creeks or Outfalls
1	New Castle Town Beach	New Castle	0.08	pipe outfall
2	Wallis Sands, Pirates Cove & Foss Beaches	Rye	2.3	Parsons Creek
3	Jenness and Cable Beach	Rye	0.2	
4	Sawyer Beach	Rye, North Hampton	2.5	Eel Pond
5	Bass Beach	North Hampton, Rye	1.3	Bass Brook & Chapel Brook
6	State Beach and Northside Park	N. Hampton, Hampton, Rye	7.7	Little River
7	North Beach	Hampton	2.5	
8	Seabrook Harbor, Seabrook Beach, Hampton Harbor Beach & Sun Valley Beach	Hampton, Seabrook	46	Numerous

2.1.2 On-Beach Bacteria Sources

It is possible for bacteria to originate at the beach and adversely impact water quality. On-beach bacteria sources are not the focus of this investigation, but are worthy of consideration.

People at the beach – Microbial source tracking (MST) surveys conducted in study area beaches have found humans to be a source of bacteria at beaches (Jones 2008; Appendix B) and many people visit the beach each year.

Pets at the beach – MST surveys have also identified pets as bacteria sources to beaches (Appendix B).

Sand and Beach Wrack – Wet sand and seaweed have been sampled as part of MST investigations at several New Hampshire coastal beaches (Appendix B). Beach wrack and underlying sand were consistently observed to have very high bacteria counts and appear to be significant sources of bacteria.

Summary

Several study area beaches are raked to reduce on-beach bacteria sources. Also, several beaches have pet walking ordinances designed to reduce pet bacteria sources. In general, direct beach bacteria sources are identified as potentially significant and we recommend additional investigation of direct beach sources in the future.

2.1.3 Coastal Bacteria Sources

Bacteria originating at remote locations and traveling with ambient coastal currents to the beaches are another potential bacteria source to beaches. This source of bacteria is not a focus of this investigation, but is worthy of consideration.

The Shellfish Program collects samples for analysis of fecal coliform bacteria at coastal locations throughout the seacoast and provides summary reports annually and triennially (e.g., Nash and Chapman 2000). Samples are collected at several types of sampling locations, including offshore samples that are collected from a boat situated 300 to 500 feet from shore. These boat based samples are representative of bacteria levels present in near-shore coastal currents.

There appears to be little evidence that bacteria originating at large scale distances (e.g., miles away) from beaches are reaching beaches in significant quantities. This observation is based on review of available bacteria data (summarized below) and discussions with seacoast bacteria experts. One factor supporting this de minimus large scale impact assessment is that the large volume of water and the strong hydrodynamic forces in the Gulf of Maine currents likely result in sufficient dilution and mixing to reduce distant bacteria sources to undetectable levels over relatively small temporal and spatial scales.

Summary of Shellfish Program Coastal Bacteria Data

A recent report (Wood and Nash 2008) summarized offshore (i.e., boat based) fecal coliform (FC) bacteria data collected at 10 locations throughout the seacoast, over a 5 year period, from 2003 through 2007. At each location, 24 to 35 samples were collected for a total of 315 samples. The following observations are based on review of the offshore bacteria data:

- The vast majority of the analyses results were non-detect at FC < 2 MPN/100ml;
- Less than 1% of samples (3 of 315) exceeded the FC standard of 43 MPN/100 ml,
- 2 exceedences were situated at station ACB1A, in Hampton Beach, selected because it is near “potential WWTF impacts”, a local source; and
- The 3rd exceedence was situated at station ACB4, in North Hampton, selected because it is near “possible Little River impacts”, another local source.

Offshore bacteria data reveal generally very low bacteria levels with rare observations of elevated bacteria only near locations of known land-based sources.

Discussion with Seacoast Bacteria Investigators

The topics of offshore bacteria sources and the potential for conducting numerical coastal bacteria modeling have been discussed at several meetings over the past year. Since the Shellfish Program has

conducted the most extensive offshore evaluations, we were particularly interested in their analysis of offshore sources. Mr. Chris Nash of the Shellfish Program provided the following insights:

> *"Our data suggest that elevated bacteria levels along the Atlantic shore most likely originate from land-based sources such as tidal creeks and rivers. The open ocean is not a likely source of the elevated bacteria concentrations seen at Beach Program and Shellfish Program sites."*

Mr. Nash went on to add that the New Castle Town Beach area may be impacted by the Piscataqua River nearby and that this is an example of a nearby source, but not directly from the adjacent watershed. A dye study is being scheduled to evaluate potential connectivity between the Piscataqua River and New Castle Town Beach.

Summary

Coastal bacteria sources do not appear to be significant in most of the study area beaches. This potential source is worthy of consideration and testing will be conducted as deemed appropriate (e.g., at New Castle Town Beach).

Figure 1: New Hampshire Coastal Beaches with Contributing Watersheds and Towns Indicated.

2.2 Approach to Compiling Watershed Bacteria Summaries

The New Hampshire Beach Program has conducted a bacteria source characterization project in eight coastal beach watersheds. Bacteria source information was collected via several tasks including:

1. Obtaining available bacteria-related reports;
2. Collaborating with seacoast bacteria investigators;
3. Creating GIS-based maps of the watersheds illustrating physical/land cover characteristics; and
4. Conducting watershed reconnaissance surveys.

This information was compiled into narrative bacteria source summaries with GIS-based maps for each watershed. A brief description of each task is provided below followed by watershed summaries.

1. Available bacteria related reports

Obtaining and carefully reviewing available bacteria source information from a variety of sources is an important step in the source characterization process. Reports were obtained from a variety of sources including:

- NHDES Beach Program Annual Beach Monitoring Reports
- NHDES Shellfish Program Sanitary Surveys and other Investigations
- NHDES and UNH Microbial Source Tracking Investigations
- NHDES TMDL Reports
- NHDES Land Cover Maps

A bibliography of bacteria-related reports compiled as part of this investigation is attached in Appendix A. Bacteria-related data has been reviewed and the information integrated into the watershed summaries provided below.

2. Collaboration among investigators

Throughout the project, FB Environmental collaborated with seacoast bacteria investigators. A series of meetings were conducted to share knowledge and information about bacteria sources. Numerous investigators contributed to this investigation including:

- Jody Connor, Sonya Carlson, Jessica Devoid, Teresa Ptak and others, DES Beach Program
- Chris Nash and Matt Wood, DES Shellfish Program
- Steve Jones, UNH Microbial Source Tracking
- Andrew Chapman, Sally Soule, and Rob Livingston, DES Watershed Assistance
- Ken Hickey and Cayce Dalton, FB Environmental
- Pete Shanahan, HydroAnalysis

Specific information regarding bacteria sources along with general insights from these investigators have been integrated into the watershed summaries provided below.

3. Watershed Maps with Various Features Illustrated

Watershed maps of existing land cover information were created and printed for each watershed. Each watershed map included:

- A recent aerial photographic layer from the National Agricultural Imagery Program (2003), provided by UNH-GRANIT;
- A recent land cover data layer from the New Hampshire Land Cover Assessment (2001), provided by UNH-GRANIT; and
- A watershed boundary delineation layer provided by NH DES.

In order to make best practical use of this dataset, the 23 land cover categories were aggregated into the following 5 groups (note that some individual categories in the original data span widely divergent categories):

- Developed - "Res., comm., indust."; "Transportation, active ag"; "Sand dunes";
- Disturbed - "Cleared/other open tundra"; "Disturbed";
- Agricultural - "Row crops"; "Hay/rotation/perm. Pasture"; "Fruit orchards";
- Forest - all forested types; and
- Wetlands - all wetland types.

This simplified set of land cover groups was designed to support assessment of potential bacteria source areas. Watershed maps are provided by watershed below.

4. Watershed Bacteria Source Reconnaissance Surveys

- Field reconnaissance surveys were conducted in the study area watersheds. The primary goal of the surveys included documenting conditions on the ground in terms of land cover characterization and potential bacteria hot spots. Our approach to conducting the surveys was based on the Center for Watershed Protection (CWP)'s Unified Subwatershed and Site Reconnaissance method (CWP. 2005). The CWP method features four components:
- Neighborhood Source Assessment;
- Hotspot Investigation;
- Pervious Area Assessment; and
- Streets and Storm Drains.

We applied an abbreviated version of the method focused on creating a narrative characterization of neighborhoods and a search for bacterial-source hotspots. Our approach was designed to support identification of potential bacteria sources (e.g., hot spots) and to provide ground-truthing of land cover and aerial photographic layers (in GIS). Observations obtained during the reconnaissance surveys are summarized in a technical memorandum and have been integrated into the watershed summaries provided below.

2.3 New Castle Town Beach Watershed

New Castle Town Beach, New Castle, NH, and its contributing watershed are shown in Figure 2. The figure also shows the locations of bacteria sampling locations, including three beach locations and two pipe outfall locations. There are several types of sampling conducted in this area including beach program monitoring (denoted in purple circles) and special project sampling locations (in red). The contributing watershed for New Castle Town Beach is small, 48 acres (0.08 square miles) in area.

This small watershed includes medium density residential development, a large park adjacent to the beach, some wooded areas around the park, and one livestock area in the form of small pen housing several sheep. No streams were found draining to the beach in the watershed. Two wetland areas were observed in the watershed. One surrounded by homes is located behind the northern end of beach berm and a partly buried discharge pipe draining the wetland was observed. A second wetland was observed west of the main beach area. This wetland is known to drain to the beach seasonally and in extreme rain or tide events. A park, consisting of a large, mowed open space dotted with playgrounds, covers the southern portion of the watershed.

A bibliography of relevant reports for each watershed is provided in Appendix A. A summary of relevant microbial source tracking information for this watershed is provided in Appendix B. Potential bacteria sources to New Castle Town Beach include:

Point Sources – A discharge pipe is situated at the northern end of the beach and identified as "BCHNWCHWCPIPE" in Figure 2. The pipe is roughly 6" in diameter and appears to connect a wet retention pond to the beach. The pond is situated in a residential area adjacent to the beach. Water from the retention pond discharges along the beach slope via the pipe. Water from the pipe has been sampled on several occasions since 2004 and has been observed to frequently exceed the bacteria standard of Enterococci 104 counts/100 ml.

A second pipe was historically situated to the south of sampling location "New Castle TB – Right" (Figure 2). We are not aware of the current condition of this pipe.

Developed area runoff – Approximately 75% of the New Castle Town Beach watershed is characterized as developed area (0.06 of 0.08 square miles). This area includes parking lots, residential areas, and mowed open space. Stormwater runoff from developed areas is likely a source of bacteria to the beach.

An MST study was conducted in 2006 and found that the highest bacteria levels were recorded during a wet weather event (Jones 2008). Unfortunately, the 2006 MST investigation did not obtain high enough bacteria counts to support strong observations regarding bacteria sources (meeting notes Dr. Steve Jones, July 28, 2008). The 2006 MST study found both human and wildlife sources of bacteria.

Pets – The 2006 MST study identified dogs as a bacteria source. Dogs are allowed and have been observed on the town beach. To minimize adverse impacts, the beach is reportedly cleaned and raked every morning during the summer.

Septic systems – There are an estimated 43 septic systems in the New Castle Town Beach watershed (see Section 3.2). The New Castle Town Beach watershed represents a relatively small and less developed part of the island. The 2006 MST study found wastewater to be a source at the beach. The

Town Beach has its own septic system for waste disposal. Available literature suggests that typically 5 to 10% of septic systems in use are failing (Dix and Hoxie, 2001; Noss and Billa, 1988). Thus, of the 43 septic systems within the watershed, it is likely that several are failing or not properly functioning. Failing septic systems are likely a source of bacteria in the New Castle Town Beach watershed.

Wildlife – The 2006 MST investigation found gulls, deer, and other wild animals as bacteria sources. The study's overall source species identification rate was relatively low (48%) indicating that some significant source species may not have been identified. Gulls, cormorants, and ducks have been frequently observed on and near the town beach.

Livestock – There is relatively little agricultural activity in the watershed. A small farm with several sheep was observed during reconnaissance activities.

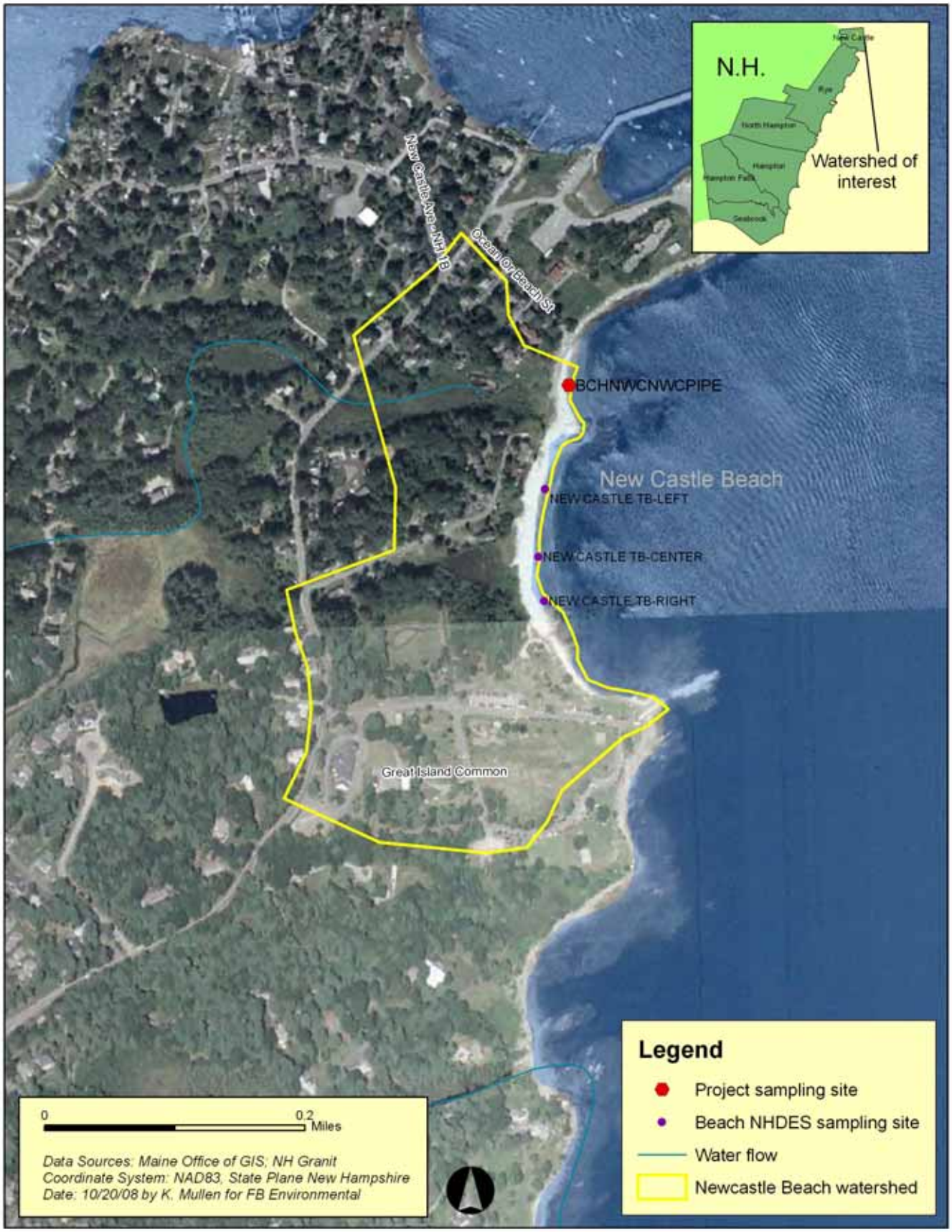

Figure 2: New Castle Town Beach Watershed with Bacteria Sampling Locations Indicated.

2.4 Wallis Sands, Pirates Cove, and Foss Beach (Parsons Creek) Watersheds

Wallis Sands, Pirates Cove, and Foss Beach and their contributing watersheds are situated in Rye, NH, are shown in Figure 3. This watershed is referred to as the Parsons Creek watershed because most of the land area is drained via the Creek. The figure also shows the locations of bacteria sampling locations. There are several types of sampling conducted in this area including beach program monitoring (denoted in purple circles), shellfish program sampling (in black triangles), and special project sampling (in red). The contributing watershed (Figure 4) covers 2.3 square miles and is primarily developed, forested, and wetland. The most developed areas are along the seashore and along the major roadways in the watershed.

This watershed consists primarily of low to medium density residential development, and some livestock agriculture. Residential development is generally limited to the main roads, with sizable wooded interior sections. Parsons Creek is within this watershed and its outlet is situated south of Pirate Cove Beach (Figure 3). Houses were noted all around the salt marsh and outlet, with little vegetative buffer. The Foss Beach watershed area consists of the beach only. Along Foss Beach is a single row of houses. A coastal dune divides the beach from the wetland behind it. The wetland drains to Rye Harbor to the south, outside of the study area.

A bibliography of relevant reports for each watershed is provided in Appendix A. A summary of relevant microbial source tracking information for this watershed is provided in Appendix B. Potential bacteria sources to Wallis Sands, Pirates Cove, and Foss Beach Watersheds include:

Parsons Creek – The mouth of Parsons Creek is situated just south of Pirates Cove (Figure 3) and has been observed to be a source of bacteria during many surveys. Parsons Creek flows south on the landward side of the heavily developed Route 1A (Ocean Rd) corridor. Historically, bacteria loads were believed to have entered Parsons Creek from developed areas and been transported by the Creek to the nearby coastal beaches. Parsons Creek also drains a marsh area to the west of its mouth.

A sanitary survey conducted by the Shellfish Program in 2000 (Nash and Wood 2000) found several active straight pipes and failing septic systems providing major bacteria loads to Parsons Creek. Parsons Creek is believed to be the primary source of bacteria to Pirates Cove Beach and may also be a significant source to the other beaches. Based on high bacteria counts, the Shellfish Program established a prohibited zone at the mouth of Parsons Creek in 2000.

Microbial source tracking surveys conducted in 2002 and 2003 found human sources were the most significant sources in Parsons Creek (Jones 2008; Appendix B).

Point Sources – Wallis Sands Beach has a small package plant treating wastewater and grey water from its onsite facility. The plant's design flow is 0.006 MGD and it discharges directly to the Atlantic Ocean just north of Wallis Sands Beach. Secondary treatment is achieved using a large sand filter, underlain by a collection box, which is then followed by UV disinfection. In recent years, bacteria levels from the Wallis Sands WWTF have been very low. In 2008, Chris Nash and the Shellfish Program team conducted a dye study to evaluate transport of wastewater leaving the package plant.

Developed Area Runoff – The Parsons Creek watershed has approximately 0.72 square miles of developed area representing approximately 32% of the watershed. High wet weather bacteria levels have been measured as part of beach program sampling. Storm event runoff has been observed to carry large bacteria loads directly to the beaches and also to the seacoast via Parsons Creek. Developed area runoff is likely a major source of bacteria to Pirates Cove and Wallis Sands Beaches.

Pets – The MST surveys (2001-2003) identified dogs as a bacteria source. Dogs are not allowed at Wallis Sands Beach at any time and are forbidden from Pirates Cove and Foss Beaches during beach hours (9-5).

Septic systems – There are an estimated 700 septic systems in the Parsons Creek watershed (Section 3.2). The MST surveys (2001-2003) conducted in Parsons Creek, which drains much of the contributing area; found that human waste was the primary source of bacteria. Rob Livingston (DES) reports that some failed septic systems have been observed and mitigated along Parsons Creek in the past (meeting notes July 28, 2008). Available literature suggests that typically 5 to 10% of septic systems in use are failing (Dix and Hoxie, 2001; Noss and Billa, 1988). Thus, of the 700 septic systems in use in the watershed, it is likely that approximately 35 to 70 systems are failing to function properly. Based on this information, septic systems may be a significant source of bacteria in this watershed.

Wildlife – MST surveys were conducted in Parsons Creek during 2001, 2002, and 2003. The primary bacteria source was human, but otters, deer, fox, and seagulls were also detected (Jones 2008; Appendix B). Gulls, tern and other birds have been observed at the beaches.

Livestock - The watershed contains a bison farm (an estimated 10 animals observed in the pasture) and at least one small horse farm. None of the farms presented signs of bacterial-source hotspots.

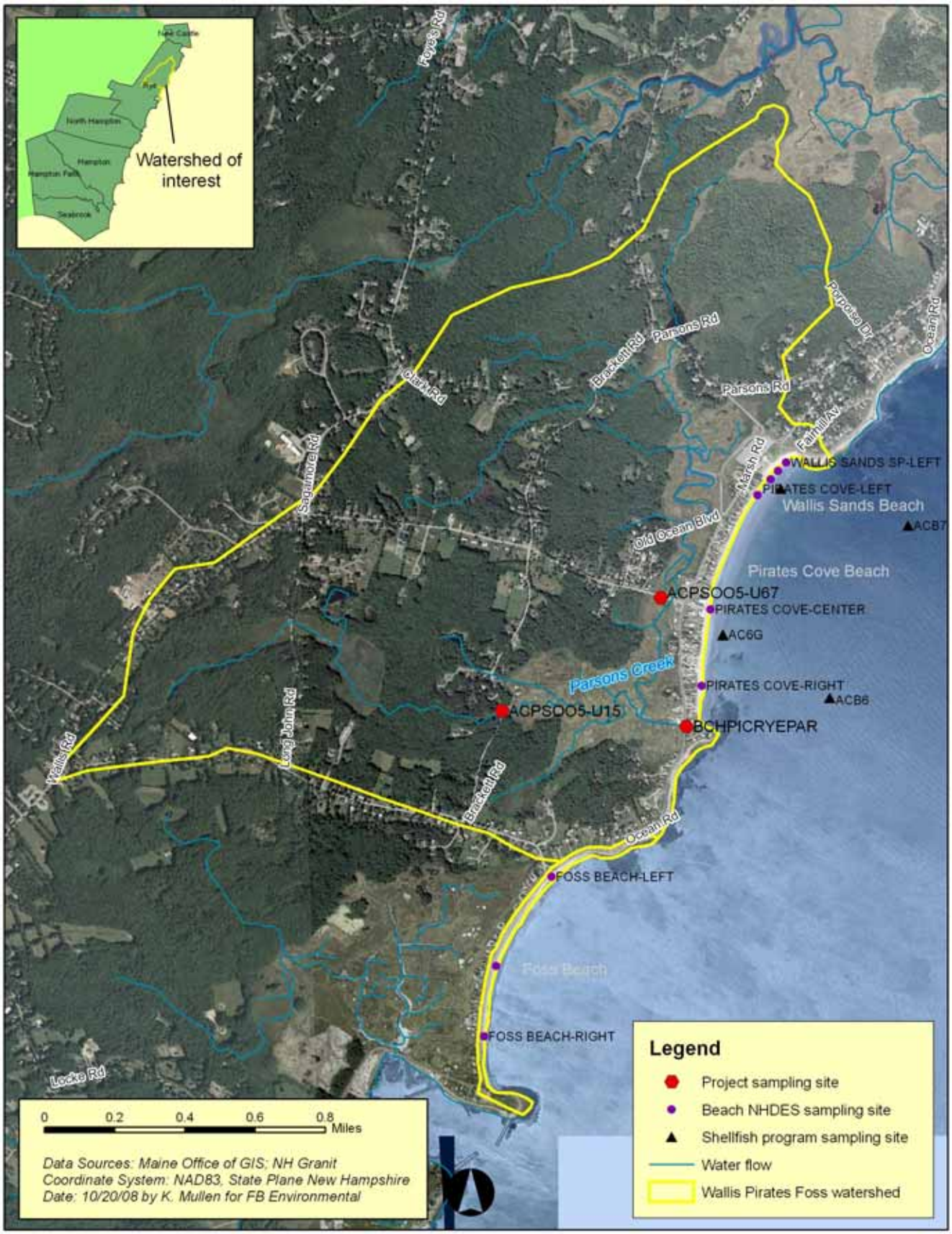

Figure 3: Wallis Sands, Pirates Cove, and Foss Beach Watersheds with Bacteria Sampling Locations Indicated.

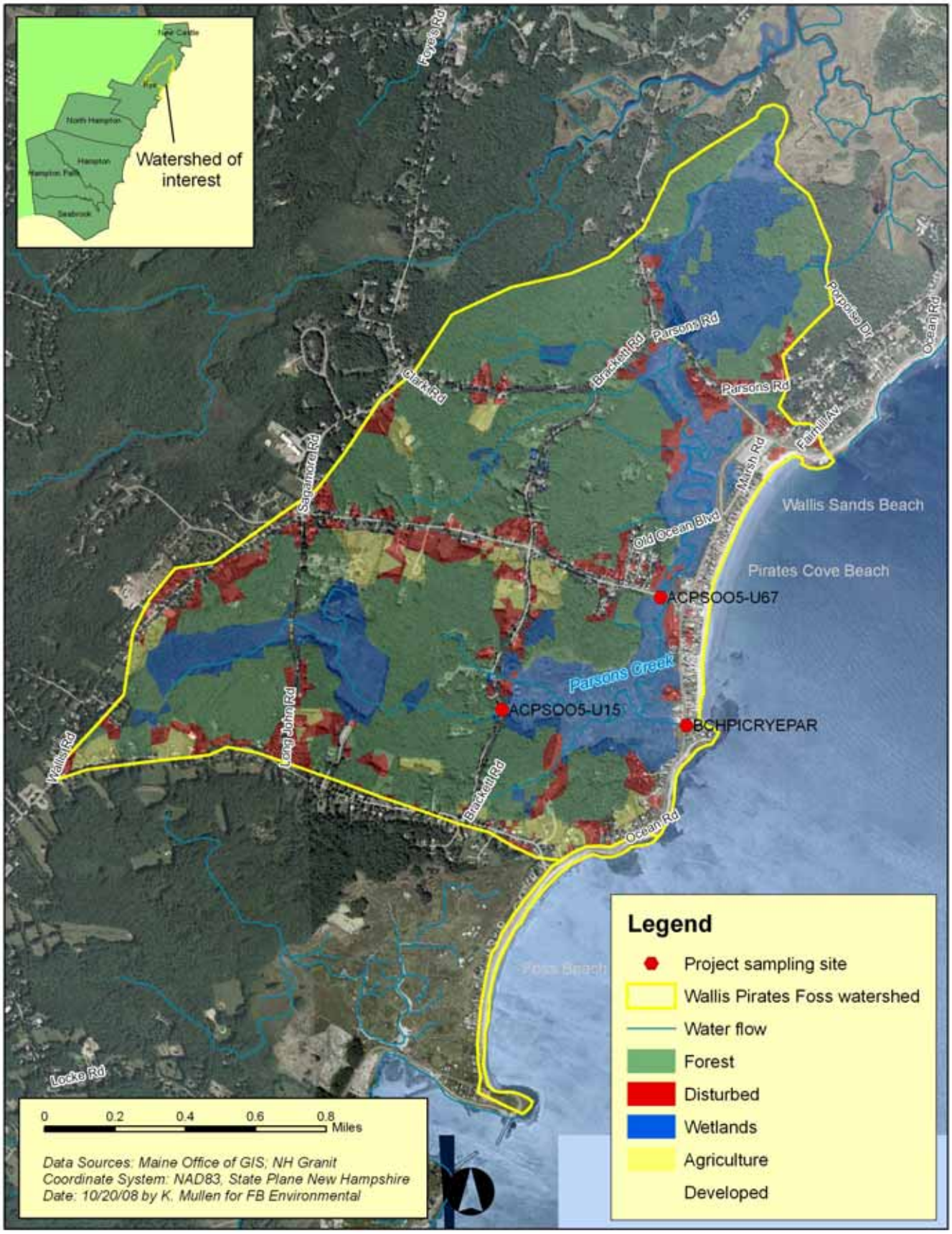

Figure 4: Wallis Sands, Pirates Cove, and Foss Beach Watersheds with Land Cover Indicated.

2.5 Cable and Jenness Beach Watersheds

Cable and Jenness Beaches and their contributing watersheds are situated in Rye, NH, as shown in Figure 5. The figure also shows bacteria sampling locations. The watershed is almost entirely residential in character, with one large mowed open space facing the beach at the intersection of Straws Point Road and Route 1A. The neighborhood grid transitions from medium to high density moving toward the ocean.

A bibliography of relevant reports for each watershed is provided in Appendix A. A summary of relevant microbial source tracking information for this watershed is provided in Appendix B. Potential bacteria sources to Cable and Jenness Beach Watersheds include:

Eel Pond Outlet – The Eel Pond outlet is situated at Sawyer Beach, to the south of Cable and Jenness Beaches (Figure 5). High bacteria concentrations have been measured in Eel Pond that could potentially be transported to Cable and Jenness Beaches. A description of Eel Pond outlet as a potential bacteria source is provided under the Sawyer Beach watershed description below.

Developed Area Runoff – The Cable and Jenness Beach watersheds have approximately 0.17 square miles of developed area representing approximately 85% of the watershed. The majority of the watershed is residentially developed. High wet weather bacteria levels have been measured as part of beach program sampling. Developed area runoff is likely a major source of bacteria to Cable and Jenness Beaches.

Pets – Dog are not allowed at Jenness Beach at any time and are forbidden from Cable Beach during beach hours (9-5).

Septic Systems – There are an estimated 290 septic systems in the Cable and Jenness Beach watershed. Available literature suggests that typically 5 to 10% of septic systems in use are failing (Dix and Hoxie, 2001; Noss and Billa, 1988). Thus, of the 290 septic systems in use in the watershed, it is likely that approximately 14 to 29 systems are failing to function properly. Based on this information, septic systems may be a significant bacteria source in this watershed.

Wildlife – Wildlife sources are a concern at these beaches. Gulls, plovers, and terns are frequently observed.

Figure 5: Cable and Jenness Beach Watersheds with Land Cover Indicated.

2.5 Sawyer Beach Watershed

Sawyer Beach and its contributing watershed are primarily situated in Rye with a westerly portion of the watershed in North Hampton. Figure 6 shows the Sawyer Beach watershed and the locations of bacteria sampling stations. The contributing watershed (Figure 7) covers 2.5 square miles and includes Eel Pond and associated tributaries.

The Sawyer Beach watershed has the lowest proportion of developed land of any of the seacoast watersheds in the study area. Residential development flanks roads that border and cross the watershed, but large interior blocks of land appear wooded and undeveloped. A single row of homes extends along about half of the beach. Several small agricultural areas that contained horses and sheep were noted in the upper portions of the watershed, all of which were adequately fenced and bordered by woods. Several greenhouses, nursery activities, and one cornfield were also observed. The very westernmost tip of the watershed drains a commercially-developed stretch of the Route 1 corridor.

Eel Pond and its surrounding wetland are located just behind the beach and drain to the beach through a culvert under Route 1A. The culvert drains onto the beach, eroding beach sand and creating deep rills.

A bibliography of relevant reports for each watershed is provided in Appendix A. A summary of relevant microbial source tracking information for this watershed is provided in Appendix B. Bacteria sources to Sawyer Beach Watershed include:

Eel Pond Outlet – The Eel Pond outlet is situated at the southern end of Sawyer Beach (Figure 6). Monitoring results have demonstrated that Eel Pond is a bacteria source. The Sanitary Survey of 2000 (Nash and Wood 2000) reported that the Eel Pond outlet travels under Route 1A through a double culvert and discharges directly on Sawyer Beach to the south. The sanitary survey also stated;" Eel Pond itself does not appear to be a source of concern; however, large flocks of seagulls tend to congregate on the beach between the culvert discharge and the Atlantic Ocean." The Shellfish Program established a prohibited zone at the mouth of Eel Pond based on high bacteria counts at this location.

Developed Area Runoff – The Sawyer Beach watershed has approximately 0.6 square miles of developed area representing approximately 24% of the watershed. Wet weather bacteria levels have been measured as part of beach program sampling. Developed area runoff is likely a major source of bacteria to Sawyer Beach.

Pets – Dogs are not allowed at Sawyer Beach during beach hours (9-5), but are allowed during other hours. Dogs have been observed on the beach and are likely a source of bacteria.

Septic Systems – There are an estimated 400 septic systems in the Sawyer Beach watershed. Available literature suggests that typically 5 to 10% of septic systems in use are failing (Dix and Hoxie, 2001; Noss and Billa, 1988). Thus, of the 400 septic systems in use in the watershed, it is likely that approximately 20 to 40 systems are failing to function properly. Based on this information, septic systems may be a significant bacteria source in this watershed.

Wildlife – Wildlife sources are a concern at these beaches. Gulls and plovers are frequently observed. As noted above, large populations of gulls have been observed in the Eel Pond outlet area.

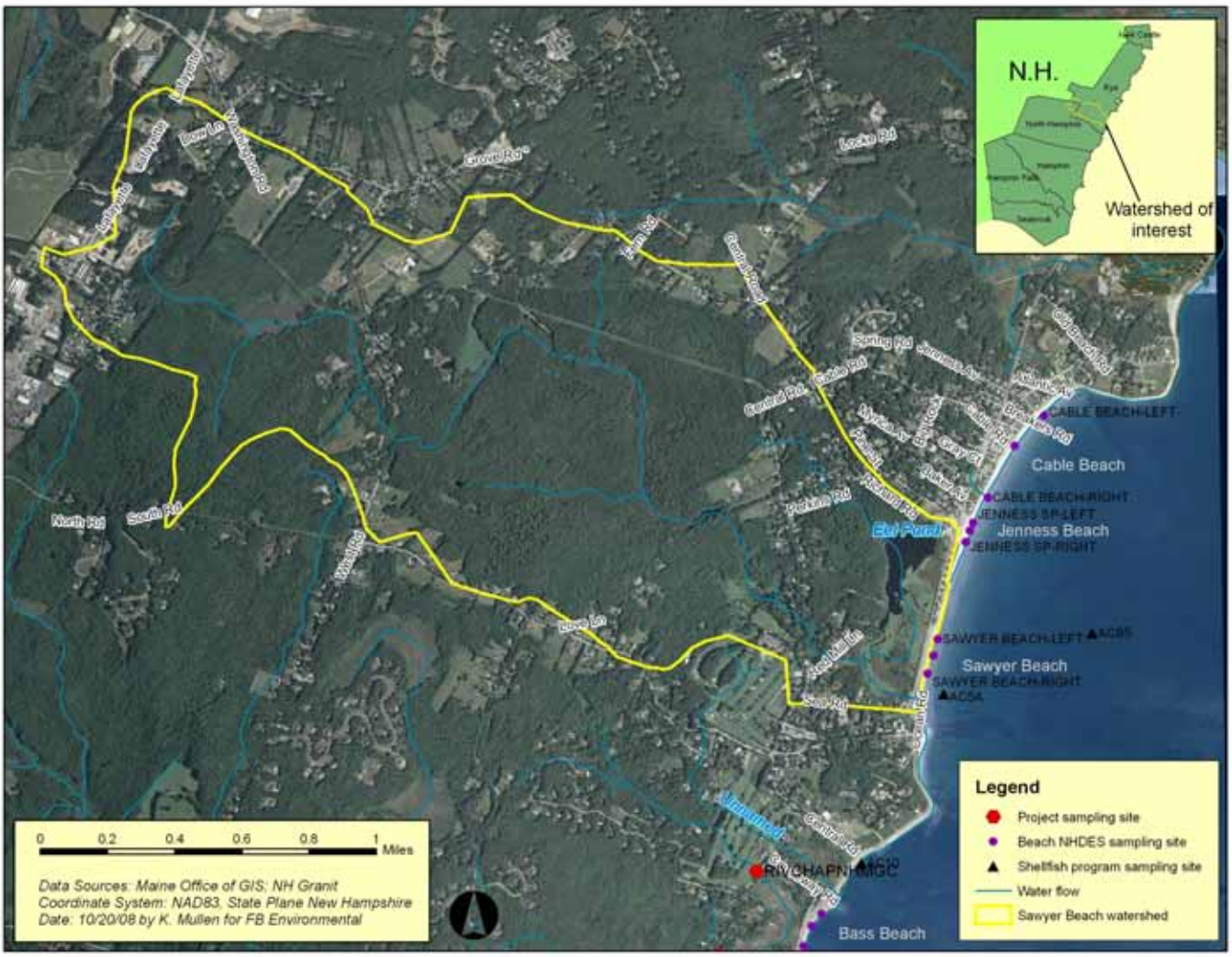

Figure 6: Sawyer Beach Watershed with Bacteria Sampling Locations Indicated.

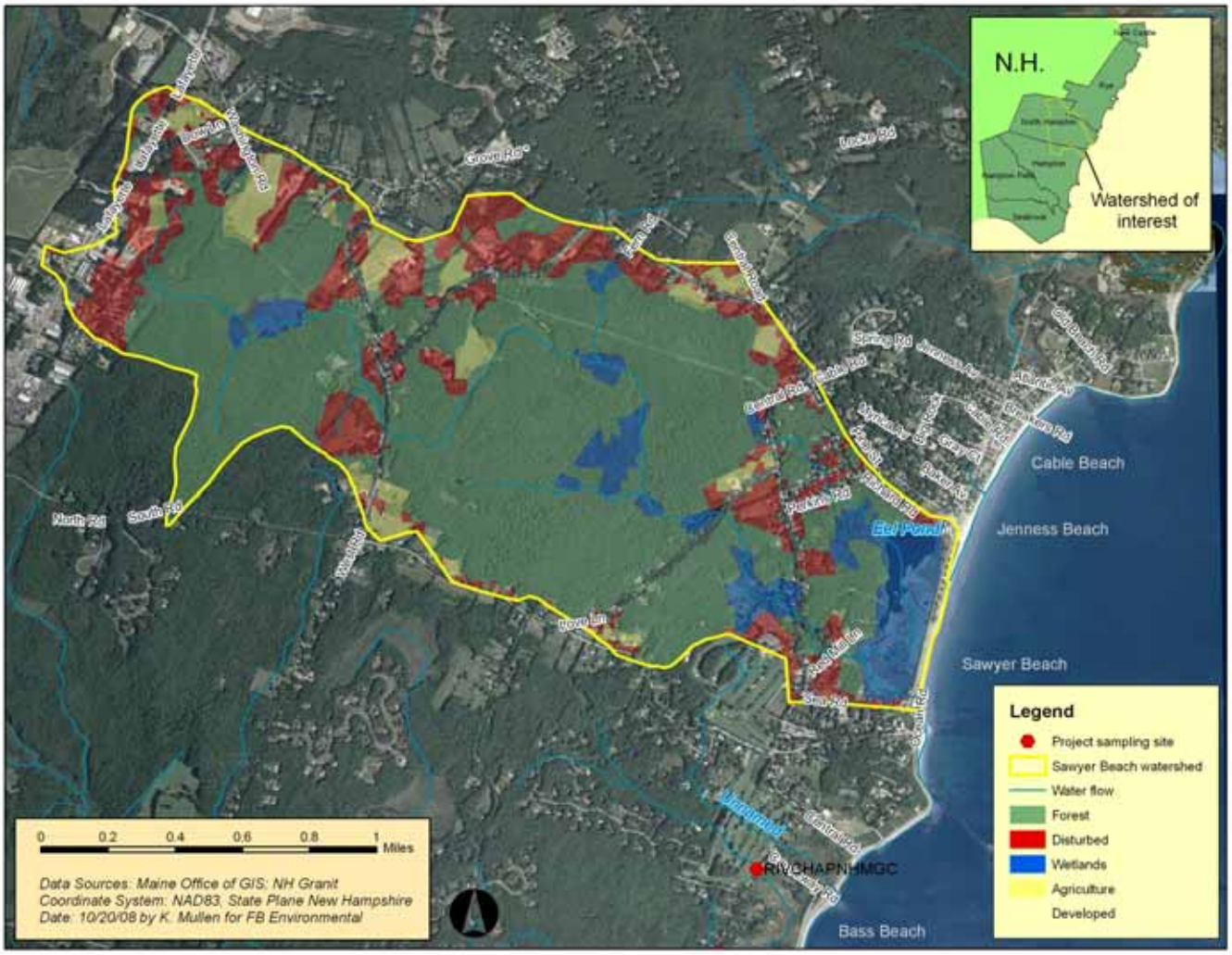

Figure 7: Sawyer Beach Watershed with Land Cover Indicated.

2.6 Bass Beach Watershed

Bass Beach and its contributing watershed are situated in Rye and North Hampton and are shown in Figure 8. The contributing watershed (Figure 9) covers 1.3 square miles and includes Chapel Brook and Bass Beach Brook.

Bass Beach watershed is largely low-density residential in character. The eastern half of the watershed consists of a large golf course about 0.2 miles from the beach, surrounded by medium density residential properties. The eastern portion of the watershed is much more heavily landscaped with expansive lawns.

Chapel Brook flows north to south beginning on Washington Street, continuing through the golf course and into a tidal wetland. The wetland was ponded at low tide and contained debris (lobster traps and tires). Bass Beach Brook and its tidal wetland lie just north of Chapel Brook with an outlet to the beach.

A bibliography of relevant reports for each watershed is provided in Appendix A. A summary of relevant microbial source tracking information for this watershed is provided in Appendix B. Potential Bacteria sources to the Bass Beach Watershed include:

Bass Beach Brook and Chapel Brook – Bass Beach Brook, previously referred to as "Unnamed Brook" (Nash and Wood 2000), drains the Bass Beach Marsh and its contributing area. The Bass Beach Brook outlet is situated in the northern part of Bass Beach and has been observed to carry high bacteria counts. As a result, the Shellfish Program established a prohibited zone at the mouth of Bass Beach Brook in 2000.

Chapel Brook drains Philbrick Pond, Chapel Pond and their contributing area. Chapel Brook's outlet is situated just south of Bass Beach. Chapel Brook's outlet is unusual in that it flows through two culverts near the mouth of the stream, the first one going through a berm in a lawn (which appears to be an old road bed), and the second through a stone wall and under Route 1A. The area between the two culverts consists of a mowed lawn to the water's edge. The Chapel Brook outlet monitoring results reflect high bacteria concentrations. As a result, the Shellfish Program established a prohibited zone at the mouth of Bass Beach Brook in 2000.

Bass Brook and Chapel Brook are believed to be the main sources of bacterial contamination for Bass Beach. Microbial source tracking (MST) investigations have been conducted in each of these brooks. In 2001 and 2002, MST surveys of Bass Beach Brook found a wide range of sources including wild animals, livestock, dogs, and humans. In 2003, wet weather MST surveys were conducted in Chapel Brook and found wild animals and humans to be the most common bacteria source.

Developed Area Runoff – The Bass Beach watershed has approximately 0.56 square miles of developed area representing approximately 43% of the watershed. Wet weather bacteria levels have been measured as part of beach program sampling and special surveys of Chapel Brook and Bass Beach Brook. In 2003, storm event runoff has been measured to carry high bacteria concentrations (e.g., E.coli 784/100 ml), while dry weather samples were relatively low (e.g., E.coli 18/100 ml). Thus, stormwater runoff, particularly via tidal brooks, is believed to be a significant source at Bass Beach.

Pets – Dogs are not allowed at Bass Beach from May 30th through October 1st each year. MST surveys have observed dogs as a source of bacteria in the watershed.

Septic Systems – There are an estimated 300 septic systems in the Bass Beach watershed (Section 3.2). MST surveys have identified septic systems as a bacteria source in this watershed. Available literature suggests that typically 5 to 10% of septic systems in use are failing (Dix and Hoxie, 2001; Noss and Billa, 1988). Thus, of the 300 septic systems in use in the watershed, it is likely that approximately 15 to 30 systems are failing to function properly. Based on this information, septic systems may be a significant bacteria source in this watershed.

Wildlife – Wildlife sources are a concern at these beaches. MST surveys have identified gulls, plovers, otter, and other wild animals. Wildlife was observed to be the largest source in MST surveys conducted in 2001 and 2002.

Livestock - Two horse farms were observed in the watershed. The first was in the very upper portion of the watershed along Washington Street (aka, South Road). The second was on Chapel Road to the south. Each farm had riding areas which were fenced and surrounded by wooded buffer.

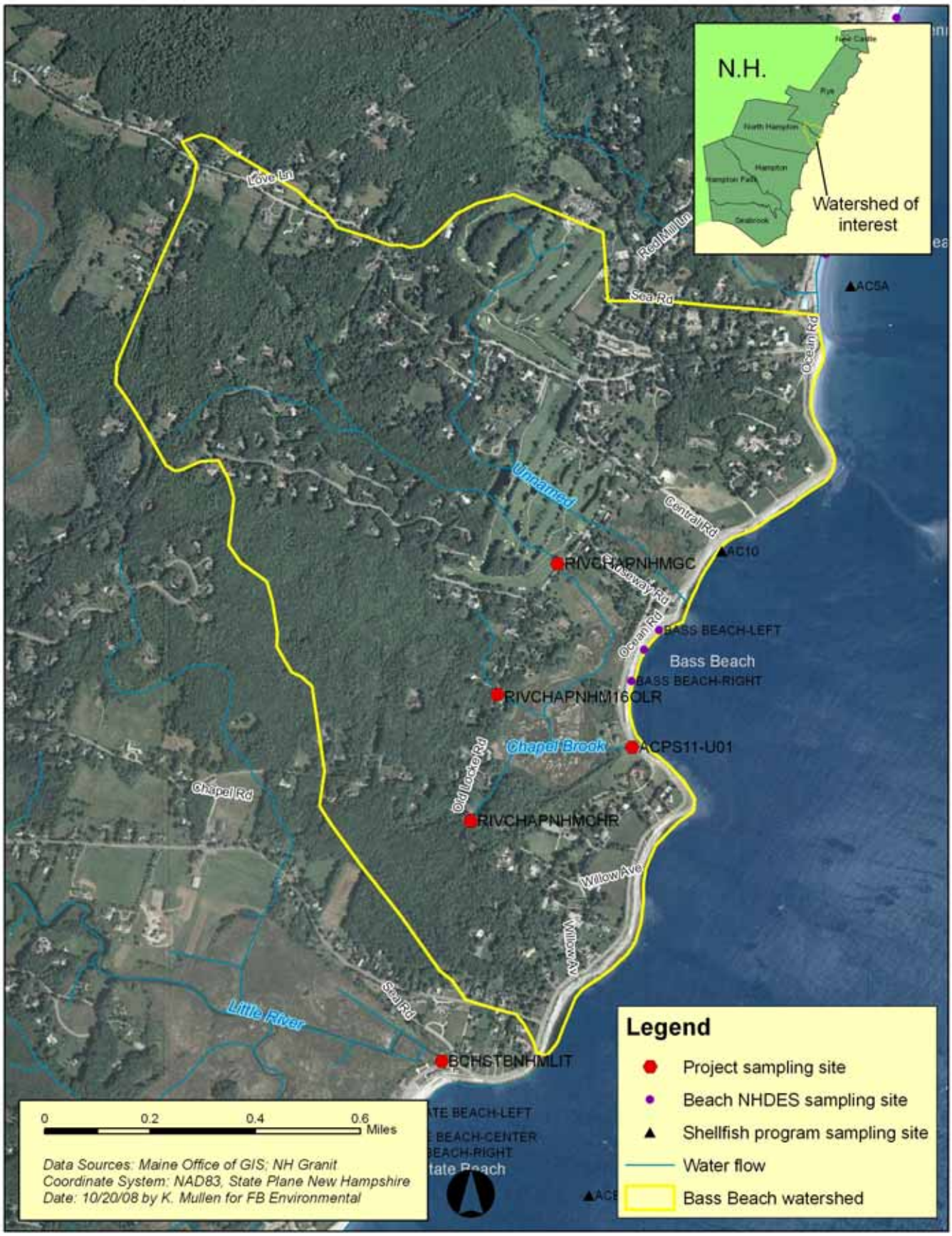

Figure 8: Bass Beach Watershed with Bacteria Sampling Locations Indicated.

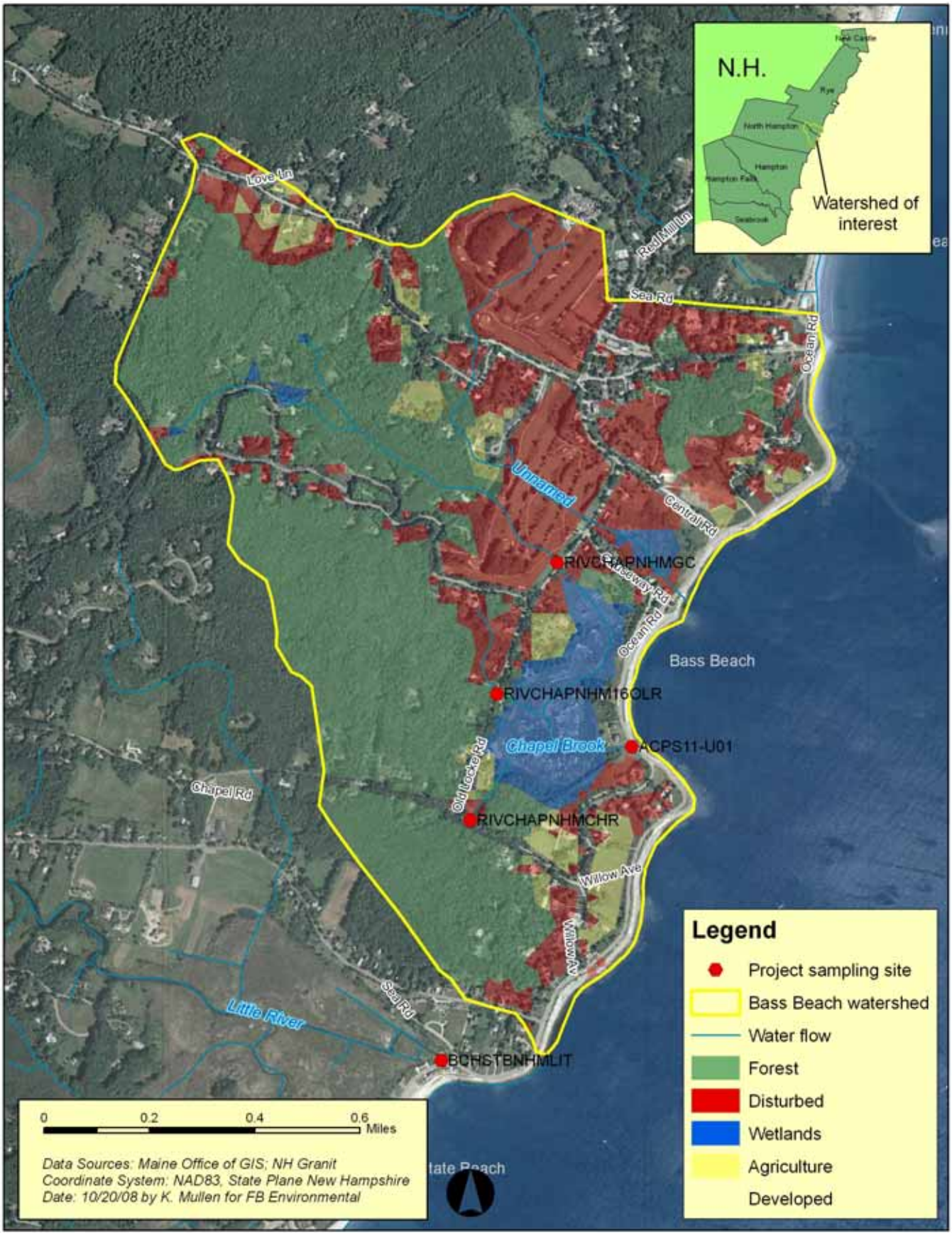

Figure 9: Bass Beach Watershed with Land Cover Indicated.

2.7 State and Northside Park Beach (Little River) Watershed

State Beach, Northside Park Beach and their contributing watershed are situated in North Hampton, Hampton and Rye, as shown in Figure 10. The contributing watershed (Figure 11) covers 7.7 square miles, primarily in North Hampton, and includes Little River and its tributaries.

The Little River watershed contains a wide variety of land uses, including residential, commercial and agricultural, with low-density residential development most common. Older development is concentrated along major roads, while new and much larger homes on larger lots line cul-de-sac tipped spurs throughout the area. Concentrated development is present on the strip of land between the marsh and beach. Much of the residential development in the watershed is wooded with nearly full canopy cover. In contrast, the homes at the beaches and the upper edges of the watershed sit on open lawns. Agricultural land including riding stables, and small hayfields were observed. The watershed also has conservation land in the westernmost region and, near Route 1, medium density commercial and light industrial land use.

A bibliography of relevant reports for each watershed is provided in Appendix A. A summary of relevant microbial source tracking information for this watershed is provided in Appendix B. Potential bacteria sources to State and Northside Park Beaches include:

Little River – Little River is the dominant hydrologic feature of the watershed. The River is formed by over 15 first order tributaries, a few of which enter the tidal marsh directly. Many of the streams are fringed by intact forested wetlands, and road crossings appeared to be stable throughout the watershed. There is a dam on Mill Pond which is being restored just north of Mill Road. The last stretch of the Little River (approximately a half mile of tidal channel through the marsh) appears to have been dredged and straightened to its outlet underneath Route 1A.

The Little River outlet is in the northern part of State Beach and drains the Little River Swamp and its contributing area (Figure 11). The Little River has been observed to carry high bacteria counts. As a result, the Shellfish Program established a prohibited zone at the mouth of the Little River in 2000. Several MST surveys were conducted in the Little River during the 2001-2003 time period. These investigations found wild animals, including otters and birds, to be the largest bacteria source. Humans were also identified as significant sources of bacteria to the Little River.

Little River is believed to be a significant source of bacterial contamination for both State Beach and Northside Park Beach. Chris Nash (meeting notes, July 28, 2008) described Little River as a long-standing bacteria problem area, which was worsened by a salt-marsh restoration effort that greatly reduced a tidal restriction. The shellfish program had to expand the closure area after they replaced a small culvert with multiple large ones.

Developed Area Runoff – The Little River watershed has approximately 2.36 square miles of developed area representing approximately 31% of the watershed. High wet weather bacteria levels have been measured as part of beach program sampling. Storm event runoff has been observed to carry large bacteria counts, while dry weather samples were typically below the water quality standard. Thus, stormwater runoff, particularly via Little River, is believed to be a significant source at these beaches.

Pets – Dogs are not allowed on State Beach. Dogs are allowed by ordinance on Northside Park Beach before 8 am and after 8 pm and fecal matter must be removed.

Septic systems – There are an estimated 1,200 septic systems in the Little River watershed (Section 3.2). Available literature suggests that typically 5 to 10% of septic systems in use are failing (Dix and Hoxie, 2001; Noss and Billa, 1988). Thus, of the 1,200 septic systems in use in the watershed, it is likely that approximately 60 to 120 systems are failing to function properly. Based on this information, septic systems appear likely to be significant sources of bacteria in this watershed.

Wildlife – Wildlife sources are a concern at these beaches. MST surveys have identified otters, gulls, and other wild animals. At some locations, otter latrines were found. Wildlife was observed to be the largest source in MST surveys conducted in 2001-2003.

Livestock - Agricultural land uses dot the landscape, including a large riding stable and range near the estuary on Route 111 (Runnymeade Stables), several donkeys on Route 111, a few goats on Mill Rd, and a few small hayfields scattered in the upper portions of the watershed. No “hot-spots” (manure mismanagement, livestock with direct access to streams, etc.) were observed in the watershed which would suggest a direct vector for bacterial pollution into waters.

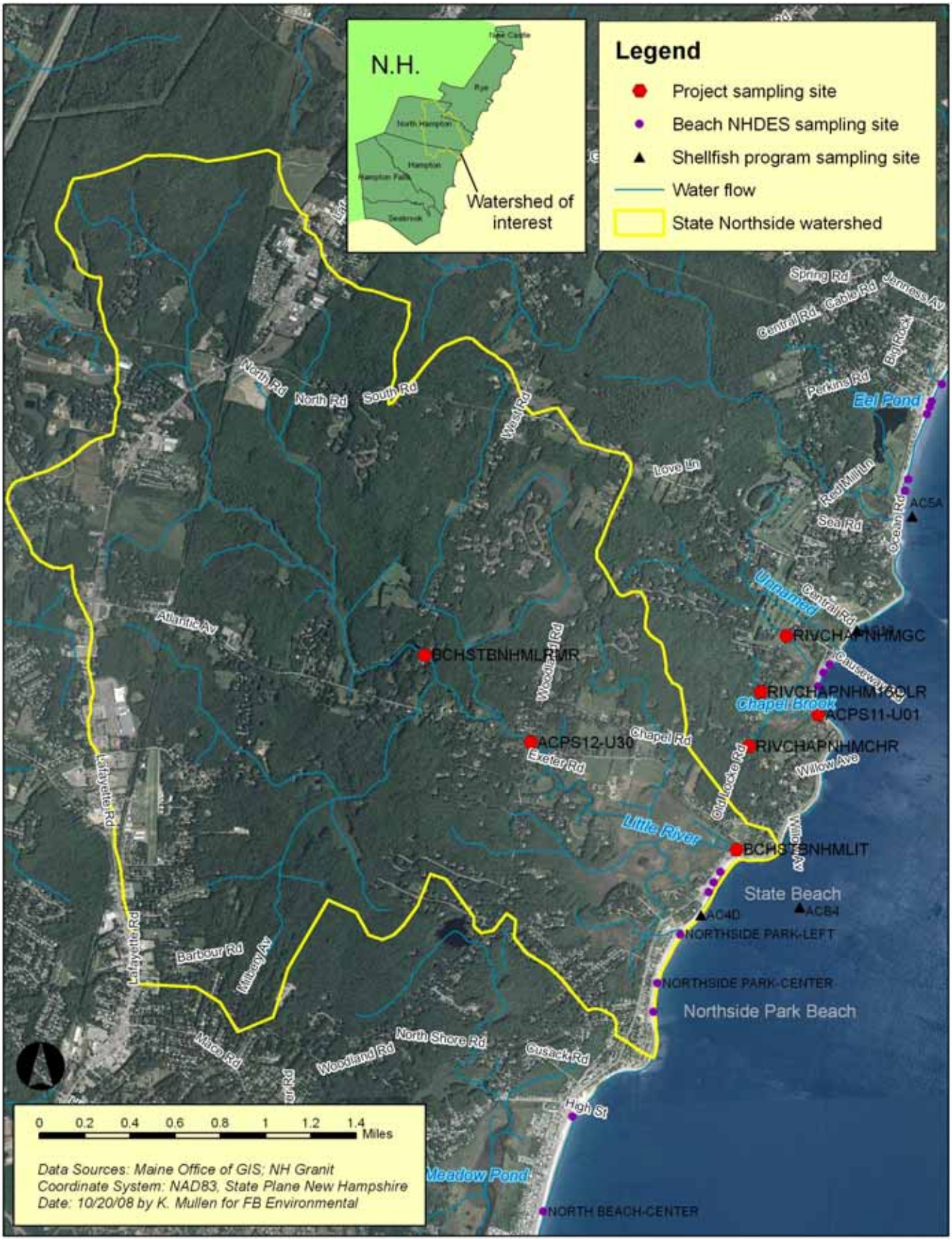

Figure 10: State and Northside Park Beach Watersheds with Bacteria Sampling Locations Indicated.

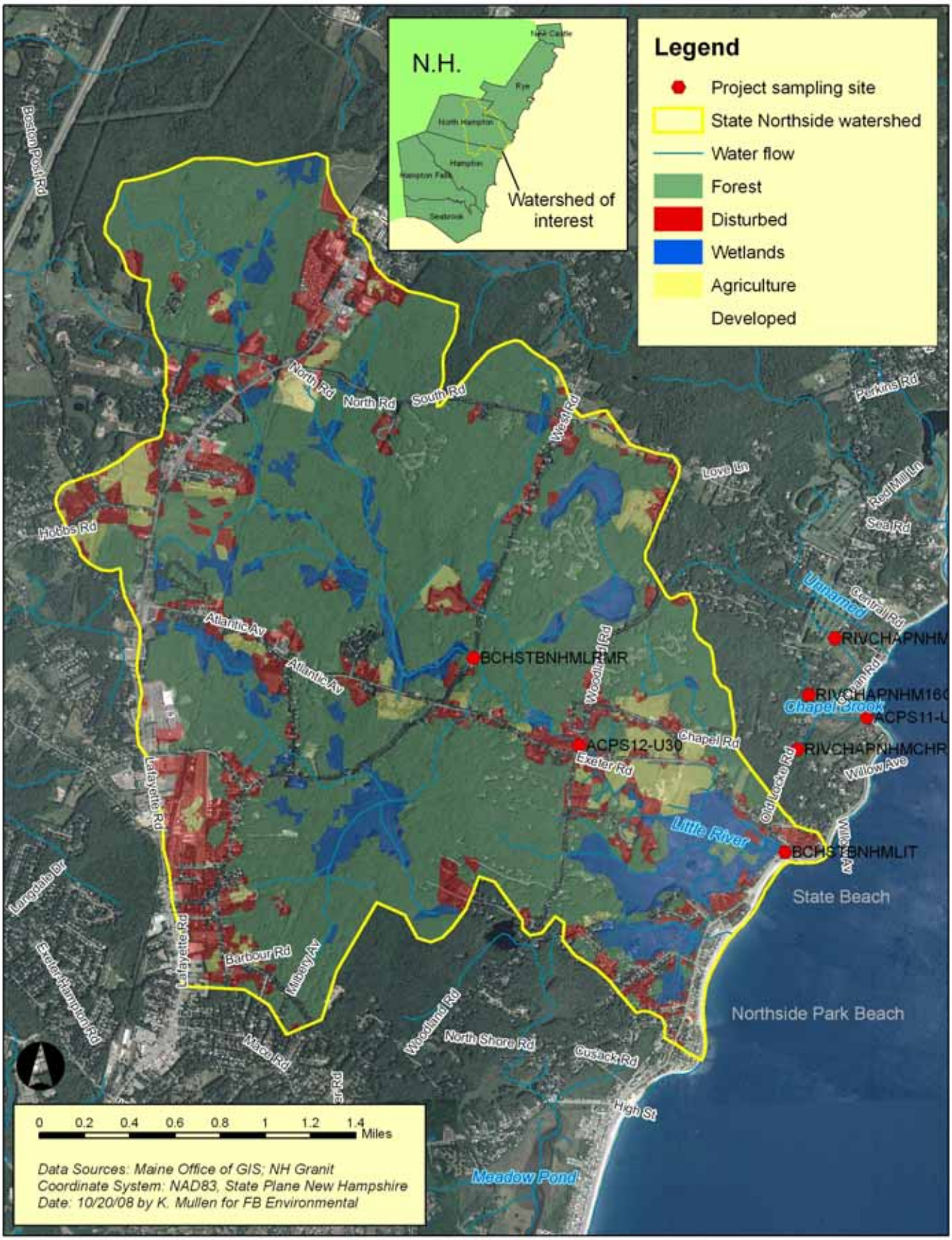

Figure 11: State and Northside Park Beach Watersheds with Land Cover Indicated.

2.8 North Beach Watershed

North Beach and its contributing watershed are situated in Hampton, as shown in Figure 12. The contributing watershed covers 2.5 square miles. The North Beach watershed is highly developed particularly along the coastline and to the south and southwest (Figure 12). Meadow Pond is a large wetland marsh area situated landward to North Beach. Meadow Pond appears to drain to Tide Mill Creek to the south, raising questions about the true watershed delineation of this low lying area.

The North Beach watershed can be divided in three general areas according to land use. The northern and central portions are primarily wooded, with medium density development flanking the roads that bisect the area, such as Woodland and North Shore roads. There were a few sites of new construction observed in this area during the summer of 2008. The southern and western portion of the watershed is dense suburban development. The area between the marsh and beach has high density development, including tiny cabins along Acorn Drive in the north, and a dense seasonal campground (RV's and campers) and houses along Witch Island Way jutting into Meadow Pond salt marsh.

There are approximately four first-order streams draining into Meadow Pond, an impounded salt marsh, which then drains southward to Tide Mill Creek in Hampton-Seabrook Estuary. As such, it appears that the North Beach watershed may technically be part of the Hampton-Seabrook watershed. Development crowds the impounded section of Meadow Pond, with only a few areas showing intact vegetated buffer. The tributary to the north of NH Route 27, however, has generally good vegetative buffer. No signs of unstable road crossings were observed.

A bibliography of relevant reports for each watershed is provided in Appendix A. A summary of relevant microbial source tracking information for this watershed is provided in Appendix B. Potential bacteria sources to North Beach include:

Developed Area Runoff – The North Beach watershed has approximately 1.3 square miles of developed area representing approximately 53% of the watershed. No bacteria samples collected at North Beach from 2004 to 2007 have exceeded the water quality standard. Developed area runoff may be a source of bacteria in the North Beach watershed, but elevated bacteria events at North Beach have not been a problem in recent years.

Pets – Dogs are not allowed on North Beach.

Septic Systems – There are an estimated 130 septic systems in the North Beach watershed (Section 3.2). Available literature suggests that typically 5 to 10% of septic systems in use are failing (Dix and Hoxie, 2001; Noss and Billa, 1988). Thus, of the 130 septic systems in use in the watershed, it is likely that approximately 7 to 13 systems are failing to function properly. Based on this information, septic systems may be a significant bacteria source in this watershed.

Wildlife – Gulls, plovers, ducks and other wildlife have been observed at North Beach.

Livestock – No livestock were observed in the North Beach watershed.

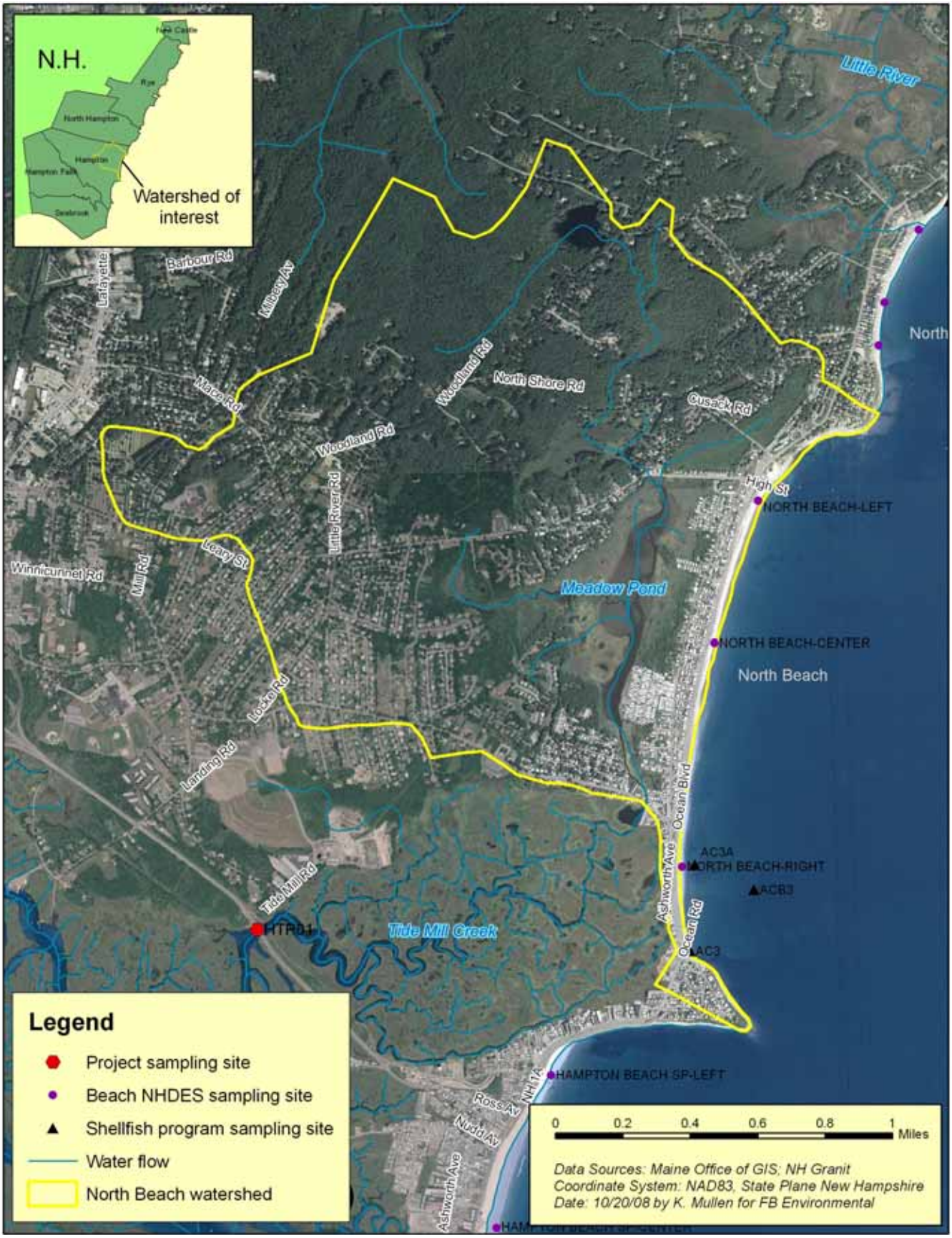

Figure 12: North Beach Watersheds with Bacteria Sampling Locations Indicated.

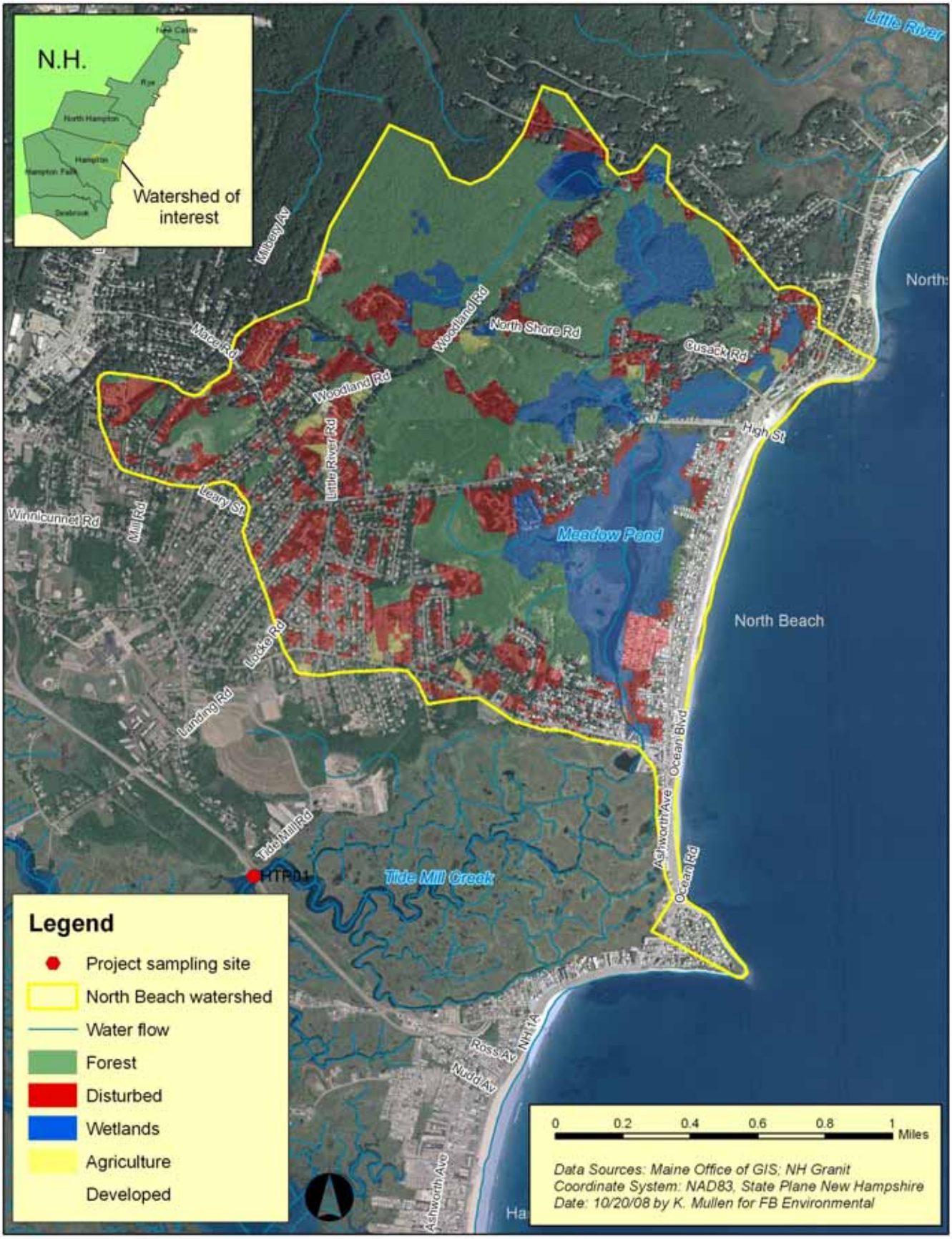

Figure 13: North Beach Watersheds with Land Cover Indicated.

2.9 Seabrook Harbor, Hampton Harbor, Sun Valley Beach, Seabrook Beach, and Hampton Beach Watersheds

Seabrook Harbor, Seabrook Beach, Hampton Beach and their contributing watershed are situated primarily in Hampton and Seabrook, as shown in Figure 14. The watershed also extends into parts of Hampton Falls, Kensington, Exeter, and Stratham. Figure 14 also shows bacteria sampling locations. The contributing watershed (Figure 15) covers 46 square miles and is very large compared to the other study area watersheds.

The Hampton/Seabrook area is highly developed with very dense residential and commercial development along the seashore. The watershed has a diverse mix of land uses. Residential land uses range from low to high density. While several areas upland around the estuary, such as the one just north of Browns River, appear to have ample forested buffer surrounding development (in this case, medium density residential, hayfields, and horses), many areas along streams and the estuary show high-intensity uses with no buffer whatsoever, and in some cases appear to encroach into the salt marsh.

The risk of bacterial contamination to the beaches in the event of any wastewater system malfunction (whether public sewer or private system) in these areas is evident. Particularly notable in this regard are Walton Road and River Street in Seabrook, and Mooring Drive, Hobson Avenue, and Battcock Avenue in Hampton. An extreme risk of septic system contamination was observed between Brown Avenue and Island Path in Hampton, where a two-acre rectangle of marsh is bordered on all sides by structures and pavement, and visible on the ground only from within the adjacent parking lots and buildings. Unlike most of the New Hampshire coast, there is a wide range of housing from large, new homes to aging trailers

Industrial uses are prominent in the watershed, with the Seabrook power plant immediately adjacent to and visible from every angle of the salt marsh. In the northern portion of the watershed, a capped landfill, a wastewater treatment plant, and a light industrial complex abuts Tide Mill Creek. Heavy commercial development exists along most of the US Route 1 corridor, with shopping plazas and large retail stores crowding many riparian corridors, such as Cains Brook, Hunts Island Creek, and Browns River.

Seabrook and Hampton harbors, situated just inside the mouth of the estuary, provide for high intensity maritime activities in close proximity to the public beaches, indicating an additional potential source of bacterial loading. Seabrook Harbor lies landward of the seashore and drains a network of tidal creeks. Several of these creeks historically carry high bacteria counts and have been investigated.

This summary provides an overview of this large and complex watershed. Several major investigations have been conducted in this watershed including the following:

- Nash, C., M. Wood. 2006. Sanitary Report for Hampton/Seabrook Harbor, Shellfish Program, New Hampshire. NH Department of Environmental Services. Concord, NH. Document R-WD-07-27. December 2006

- Jones. S.H. and C. Edwards. 2007. Management of Non-Human Sources of Bacterial Pollution in Hampton/Seabrook Harbor. Final report. New Hampshire Department of Environmental Services, Concord, NH.
- Jones. S.H., N. Landry and C. Edwards. 2005. Tracking Bacterial Pollution Sources in the Mill Creek Watershed, Seabrook, NH. A Final Report to the U.S. Environmental Protection Agency. New Hampshire Department of Environmental Services, Concord, NH.
- Trowbridge, P. 2004. Total Maximum Daily Load (TMDL) Study for bacteria in Hampton/Seabrook Harbor. NHDES-R-WD-03-32. New Hampshire Department of Environmental Services, Concord, NH.

The reader is encouraged to review the referenced documents to obtain additional information regarding known and potential bacteria sources in this watershed.

Mill Creek and other Tidal Creeks - Mill Creek, situated adjacent to Cains Brook in the southern portion of the harbor (Figure 14), is considered a chronic source of fecal-borne bacteria. Trowbridge (2004) and other investigations have identified elevated bacteria levels in Mill Creek. Other tidal creeks in the Hampton/Seabrook watershed have been measured to have elevated bacteria levels. The documents referenced above and the bacteria summary report provided in Appendix B provide descriptions of these sources.

Point Sources – Hampton/Seabrook Harbor has three NPDES permitted discharges, the main one is the Hampton municipal wastewater treatment facility (WWTF). The other two permitted sources for bacteria discharges, EnviroSystems, Inc. (NPDES # NH0022055) and Aquatic Research Organisms, Inc. (NPDES # NH0022985), are considered negligible sources (Trowbridge 2004). Estimated fecal coliform (FC) loads from the Hampton WWTF were based on Discharge Monitoring Reports from 1989 to 2001 and data conversion for effluent total coliform concentrations. The geometric mean loading rate from the WWTF decreased from ~0.8 billion FC/d in 1989 TO 0.3 billion FC/d in 2001.

Developed area runoff – The Hampton/Seabrook watershed has approximately 9.2 square miles of developed area representing approximately 20% of the watershed. As described above, development near the harbor and the beaches is intensive. Previous investigators have observed elevated bacteria levels at beaches following rainfall events and greater increases in bacteria counts with increasingly larger storms (Trowbridge 2004). Stormwater runoff from developed areas is certainly a source of bacteria to the harbor and the beaches.

For example, MS4 stormdrains discharged an estimated average of ~3500-6100 FC/100 ml in July and October 2002, with a range of 50 to 14,200 FC/100 ml. This translated to a loading of 120 to 630 billion FC/d during the July and October storm events, respectively. This is much higher than the calculated loading from the Hampton WWTF, though it only occurs during storm events (Jones 2008; Appendix B).

MST surveys conducted in the watershed identified human sources as dominant (Jones 2008; Appendix B). Pets and various forms of wildlife were also identified in the MST surveys.

Septic Systems – There are an estimated 2,800 septic systems in the Hampton/Seabrook watershed (Section 3.2). Available literature suggests that typically 5 to 10% of septic systems in use are failing

(Dix and Hoxie, 2001; Noss and Billa, 1988). Thus, of the 2,800 septic systems in use in the watershed, it is likely that approximately 140 to 280 are failing to function properly. Failing septic systems may be a bacteria source in the watershed.

Wildlife – Several MST investigations have found gulls, plovers, terns, deer, and other wild animals as bacteria sources (Appendix B).

Livestock - Agricultural uses were observed somewhat inland, such as NH Route 88 west of I-95. Here, active row crops, orchards, and small horse farms were noted. Horses and hayfields were found along NH Route 85 west of I-95, as well, among forested areas marked as a drinking water protection zone. Modest numbers of horses, sheep, and beef cows were observed in the study area.

Figure 14: Seabrook and Hampton Area Beach Watersheds with Bacteria Sampling Locations Indicated.

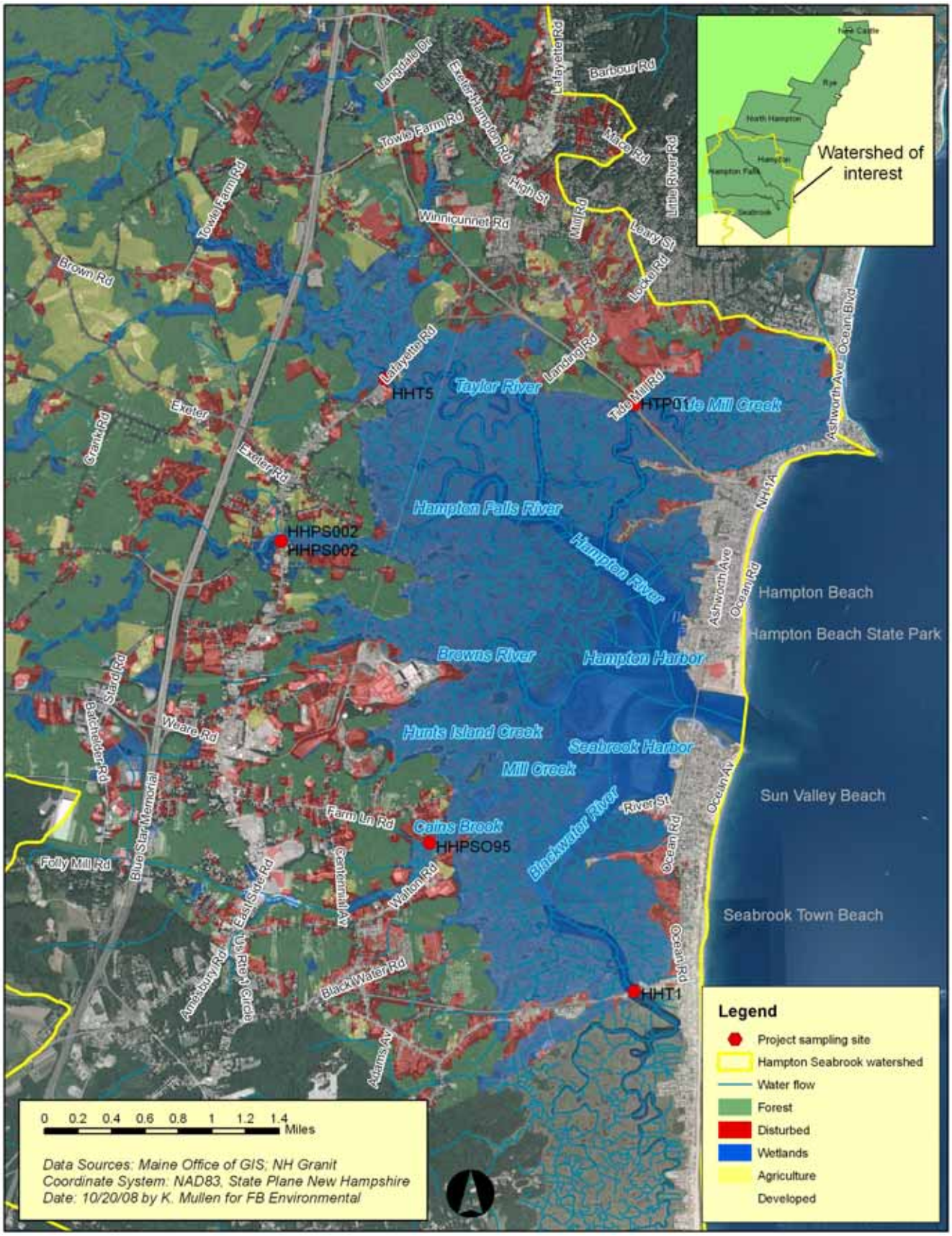

Figure 15: Seabrook and Hampton Area Beach Watersheds with Land Cover Indicated.

2.10 References

Note: Appendix A provides a bibliography for bacteria-related reports organized by watershed.

CWP. 2005. Wright, Tiffany; Chris Swann; Karen Cappiella; and Tom Schueler. Unified Subwatershed and Site Reconnaissance: A User's Manual, version 2.0. Center for Watershed Protection, Ellicott City, MD.

Dix, S.P., D.C. Hoxie. 2001. Analysis of Septic System Longevity in Maine. On-Site Wastewater Treatment: Proc. 9th Nat. Symp. Individual and Small Community Sewage Systems (11-14 March 2001, Fort Worth, Texas, USA), ed. Karen Mancl. St. Joseph, Michigan: American Society of Agricultural Engineers 701P0009. pp. 340-348.

Jones. 2008. Summary of Fecal-Borne Pollution Sources and Bacterial Data in Nine New Hampshire Coastal Beach Watersheds. September 8, 2008. Attached as Appendix B.

Nash, C. and A. Chapman. 2000. Sanitary Survey Report for the Atlantic Coast, Gulf of Maine, New Hampshire. DES Report R-WD-01-3. December 2000. 50 pp.

Noss, R.R. and M. Billa. 1988. Septic System Maintenance Management. Journal of Urban Planning and Development, 114(2):73-90.

Trowbridge, P. 2004. Total Maximum Daily Load (TMDL) Study for bacteria in Hampton/Seabrook Harbor. NHDES-R-WD-03-32. New Hampshire Department of Environmental Services, Concord, NH.

Wood, M. and C. Nash. 2008. 2007 Annual Shellfish Management Area Update for the Atlantic Coast, Gulf of Maine, New Hampshire. New Hampshire Department of Environmental Services, Water Division, Watershed Management Bureau. June 2008. 29 pp.

3.0 Bacteria Load Estimation

A goal of the beach bacteria investigation is to estimate bacteria loads in each watershed. Bacteria loads will support prioritization of bacteria sources for mitigation. A review of available estimation methods and literature values was conducted to identify appropriate bacteria source loads. A list of documents reviewed, including brief summaries, is provided in Appendix C. Selected methods and parameter values were applied to estimate the following types of bacteria source loads:

1. Developed area runoff (including pet waste);
2. Failing septic systems;
3. Agricultural area runoff from livestock; and
4. Natural area runoff from wildlife.

The process of estimating bacteria loads for each type of source is described below, including approach, methods, input parameter values, and resulting estimates. Estimated bacteria loads are then summed by type and by watershed. Once bacteria load estimates are established for sources, simple estimates of bacteria load reduction associated with source mitigation are obtained. These load reduction estimates will prove useful in compiling and prioritizing bacteria sources for mitigation as part of Phase II of the beach bacteria project.

Limitations

Estimation of bacteria loading is difficult because there are many dispersed sources and ambient bacteria counts can change dramatically and very quickly based on environmental conditions. There is significant uncertainty in terms of several components of bacteria load estimation and the resulting estimates should be considered to be order-of-magnitude types of estimates. Specifically, key source characteristics, such as magnitude of sources and their proximity to streams, and key transport information, such as bacteria die-off rates, cannot be precisely specified. The bacteria load estimates provided herein are screening level and are intended to support planning of source removal and restoration activities.

3.1 Developed Area Runoff

Developed area runoff is surface water flowing from residential and commercial areas during precipitation events and entering the stream. Roadways, parking lots, roofs, and lawns are included as developed area runoff. Bacteria load contributions from developed areas were estimated using the widely applied event mean concentration (EMC) method.

This method has been applied by the Center for Watershed Protection (CWP) (Schueler 1987) and is used within the AVGWLF watershed model (Evans et al. 2008). Input parameter values were obtained from studies conducted by the CWP and other investigators. The approach consists of estimating two components (1) runoff water volume and (2) average bacteria concentration in runoff water. As shown in Equation 1, the product of these components is the bacteria load, expressed in bacteria counts per year.

Bacteria concentrations estimated herein are for fecal coliform (FC) bacteria. FC was selected because it is the form of bacteria with the greatest amount of available research results and related available data to support load estimation. Bacteria load estimates are also provided herein on an annual basis (i.e., counts/year) to provide uniform units for comparison.

Runoff Volume

The hydrologic component is runoff volume and is estimated using developed land area, precipitation amount, and budgeting of water volume (e.g., infiltration, evaporation, and runoff). Runoff volume is calculated, as shown in Equation 1, using a method developed by Schueler (1987) at the CWP, whereby runoff fraction is a function of percent impervious cover (%IC). The Schueler method is very similar to the method applied by the AVGWLF model and was selected because it is straightforward to apply in spreadsheet form. Total precipitation was obtained from weather data at the Seabrook power plant, situated within the study area. Developed land area, annual precipitation, and runoff fractions for each watershed are shown in Table 2.

Equation 1: Developed Area Runoff

Runoff Bacteria Load (counts/year) = (Runoff Volume) x (Bacteria Concentration)

Where,

Annual Runoff Volume = (Annual Precipitation Volume) x (Runoff Fraction)

Runoff Fraction = 0.05 + (0.9 x %IC)

Event Mean Concentration

The average bacteria concentration in runoff is estimated using data provided by major investigations that have compiled over 1,000 stormwater pollutant load samples from similar land areas. Event mean concentration (EMC) is defined as the mean concentration of a pollutant over the duration of a storm event. This metric is widely applied in estimating pollutant concentrations associated with stormwater in developed areas. The Center for Watershed Protection and other investigators have compiled stormwater pollutant data and correlated pollutant concentration with land cover type and other factors. The EMC value for stormwater run-off from residential areas of 7,000 Fecal Coliform/100ml (Schueler, et al. 2007) was chosen for this application. This value was selected following a review of available data (see Appendix C) because this land cover type most closely matches the development characteristics of the beach watersheds.

Summary

Table 2 provides a summary of estimated annual developed area runoff bacteria loads by watershed.

Table 2: Estimated Developed Area Runoff Bacteria (FC) Loads

	Developed Land Area (m^2)	Developed Land Area ($mi.^2$)	Annual Precip. (cm)	Runoff Fraction	EMC (org/ 100mL)	Annual FC Load to Stream
New Castle	143,000	0.06	118.4	0.22	7000	2.6×10^{12}
Wallis & Pirates Cove	1,874,000	0.72	118.4	0.18	7000	2.8×10^{13}
Cable & Jenness	431,000	0.17	118.4	0.30	7000	1.1×10^{13}
Sawyer	1,543,000	0.60	118.4	0.19	7000	2.4×10^{13}
Bass	1,447,000	0.56	118.4	0.15	7000	1.8×10^{13}
State & Northside Park	6,105,000	2.36	118.4	0.22	7000	1.1×10^{14}
North Beach	3,430,000	1.32	118.4	0.28	7000	8.1×10^{13}
Hampton-Seabrook	23,821,000	9.20	118.4	0.38	7000	7.5×10^{14}

3.2 Failing Septic Systems

Bacteria (FC) loading from failing septic systems was estimated using two components; (1) population on failing septic systems (FSS) and (2) the associated bacteria load per person on failing systems. These estimates were then applied to each watershed to support estimation of total bacteria loading due to failing septic systems.

Population on Failing Septic Systems

To estimate the population on failing septic systems, we needed to first estimate the number of septic systems and average number of people per septic system in each watershed. These estimates were obtained for each town and each watershed using a combination of census data and GIS-based parcel maps.

First, total watershed-level population estimates were obtained using US 2007 Census estimates by town, as shown in column 2 of Table 3 below. The total number of tax parcels was also obtained, using parcel map data and GIS-analysis (column 3). To obtain an estimate of the average number of people per tax parcel (by town), the town population was divided by the total number of tax parcels (column 4). The number of people per parcel ranged from 1.5 to 3.5 people/parcel in the study area towns.

Table 3: Estimates of Population by Town and per Tax Parcel.

	US Census Population Estimate (2007)	Total Tax Parcels	People per Tax Parcel
New Castle	1,026	680	1.51
Rye	5,174	3,147	1.64
North Hampton	4,528	2,217	2.04
Hampton	15,390	6,856	2.24
Hampton Falls	2,095	1,374	1.52
Seabrook	8,509	3,120	2.73
Kensington	2,072	1,085	1.91
Exeter	14,735	4,174	3.53

Next, since town boundaries and watershed boundaries are different, the number of tax parcels per watershed needed to be obtained. Parcels per watershed were determined using GIS. Tax parcel center points (centroids) were utilized to avoid over-counting tax parcels that straddle watershed boundaries. Tax parcels within 150 feet of a sewer line (200 feet in Seabrook, per municipal ordinance) were assumed to be connected to public sewer systems and were excluded.

Using this method, the number of parcels without public sewer (and assumed to be on septic systems) was estimated and is provided in Table 4. The number of tax parcels assumed to be on septic was then multiplied by the people per tax parcel for each respective town to estimate the population on septic systems per watershed, as shown in Table 5.

Table 4: Estimated Parcels without Public Sewer by Watershed and Town

Watersheds → Towns ↓	New Castle	Wallis-Pirates Cove	Cable-Jenness	Sawyer	Bass	State-Northside Park	North Beach	Hampton-Seabrook
New Castle	43	0	0	0	0	0	0	0
Rye	0	694	290	376	138	37	0	0
North Hampton	0	0	0	33	157	1094	3	38
Hampton	0	0	0	0	0	108	126	671
Hampton Falls	0	0	0	0	0	0	0	1096
Seabrook	0	0	0	0	0	0	0	430
Kensington	0	0	0	0	0	0	0	431
Exeter	0	0	0	0	0	0	0	145
Totals by watershed	**43**	**694**	**290**	**409**	**295**	**1239**	**129**	**2,811**

Table 5: Estimated Population on Septic Systems per Watershed

Watersheds → Towns ↓	New Castle	Wallis-Pirates Cove	Cable-Jenness	Sawyer	Bass	State-Northside Park	North Beach	Hampton-Seabrook
New Castle	65	0	0	0	0	0	0	0
Rye	0	1141	477	618	227	61	0	0
North Hampton	0	0	0	67	321	2234	6	78
Hampton	0	0	0	0	0	242	283	1506
Hampton Falls	0	0	0	0	0	0	0	1671
Seabrook	0	0	0	0	0	0	0	1173
Kensington	0	0	0	0	0	0	0	823
Exeter	0	0	0	0	0	0	0	512
Total Population on Septic Systems	**65**	**1141**	**477**	**686**	**548**	**2,538**	**289**	**5,763**

It is difficult to estimate how many of the total number of septic systems are failing. After conducting a literature review and meeting with experts in seacoast bacteria studies, a range of septic system failure rates of 5 to 10% was selected. The 5 to 10% failure rate range is based on the findings of a septic system study in Maine (Dix and Hoxie 2001) and the range is applied to represent uncertainty in the actual number of failing systems. This rate may appear high, but groundwater transport of failing septic system waste to adjacent surface waters is common and is typically not detected. Several studies have shown that subsurface bacterial transport from septic leach fields is significantly increased when the leach field is saturated with groundwater (Viraraghavan 1978; McCoy and Hagedorn 1979). Thus, the 5 to 10% estimate of septic system failure rate was selected as conservative and consistent with the findings of several studies.

Bacteria Loading per Person on Failing Septic Systems

The human organism sheds approximately 2 x 10^9 fecal coliform daily (US EPA 2001). Significant attenuation within failing septic systems and in the ambient environment is believed to occur in the failing septic system scenario, likely significantly reducing the total per person loading rate of 2 x 10^9

count/day. Some ambient attenuation of bacteria (e.g., via soil filtration) likely occurs within failing systems. This attenuation is believed to occur as waste goes through the failing system, settles within a tank or cesspool, and travels through failing leach-field soils. Therefore, the loading value directly from a human organism likely overestimates the actual loading to the environment by a human organism using a failing wastewater system. For our purposes, we assumed a one order of magnitude reduction in fecal coliform loading from people served by failing septic systems. This attenuation is approximately equal to the average attenuation through groundwater presented by Viraraghavan (1978) in two test trials in Ottawa, Canada. The resulting bacteria loading rate per person is 2×10^8 fecal coliform daily.

Table 6 summarizes the population on failing septic systems and the resultant bacteria loading by watershed. The population on failing septic systems is obtained by applying a 7.5% failure rate, the midpoint of the 5 to 10% range, to the estimates presented in Table 5. The bacteria loading estimate is obtained by applying the per-person loading rate of 2×10^8 fecal coliform/person/day on failing septic systems.

Table 6: Estimated Population on Failing Septic Systems and Associated Bacteria Loading

	New Castle	Wallis-Pirates Cove	Cable-Jenness	Sawyer	Bass	State-Northside Park	North Beach	Hampton-Seabrook
Total Population on Septic by Watershed	65	1,141	477	686	548	2,538	289	5,763
Septic System Failure Rate	7.5%	7.5%	7.5%	7.5%	7.5%	7.5%	7.5%	7.5%
Population on Failing Septic Systems	5	86	36	51	41	190	22	430
Annual FC Load	3.7×10^{11}	6.3×10^{12}	2.6×10^{12}	3.7×10^{12}	3.0×10^{12}	1.4×10^{13}	1.6×10^{12}	3.1×10^{13}

3.3 Wildlife

A review of microbial source tracking (MST) studies in the seacoast was conducted to support identification of dominant wildlife. Dr. Steve Jones, a microbiologist at UNH, conducted the review and compiled a wildlife bacteria sources report, as part of this investigation (Jones 2009). The report is attached as Appendix D and identifies deer, raccoons, coyotes, foxes, otters, rabbits, Canada geese, and herring gulls as present in the study area, based on microbial source tracking results. The report also provides rough estimates of the magnitude of each wildlife source and identifies several dominant species including deer, geese, and raccoons. These three species were selected and applied to represent large mammal, bird, and small mammal bacteria loads, respectively, in the seacoast area, given their high population densities. The method of estimating each of these wildlife bacteria sources is provided below.

Equation 2: Wildlife bacteria loading estimate.

Wildlife Bacteria Load (counts/year) = (Animal Population) x (Bacteria load/animal/year) x (Die-off Rate)

Where:

Animal Population = (Habitat Land Area) x (Species density)

<u>Deer</u>

Deer bacteria loads were estimated using Equation 2 and parameter values described below. Table 7 provides a summary of bacteria loading estimates for deer by watershed. NH Fish and Game (NH F&G) biometrician Kent Gustafson provided the project team with a deer density estimate in the seacoast area of 22.5 deer per square mile. Habitat land cover types for deer were specified as forest, crop land, pasture land, forested wetlands, and sand dunes. Using GIS, the total area of deer habitat per watershed was calculated and multiplied by deer density to provide an estimated deer population per watershed. Using the equation provided above, the estimated deer population was multiplied by the estimated fecal coliform load per deer of 5.1×10^{10} counts/year (Jones 2009; Appendix D). Lastly, an overland die-off rate of 0.9 was applied to account for bacteria die-off as it is transported from the land area to the receiving waterbody. The die-off rate of 0.9 was recommended by Dr. Barry Evans, developer of the AVGWLF model.

Table 7: Estimated Bacteria (FC) Loading from Deer in Seacoast Watersheds

Watersheds	Area Deer Habitat (sq mi)	Estimated Deer Population in Watershed	Yearly FC Shed by Deer	Yearly FC Loading from Deer to Stream
New Castle	0.04	1.0	5.05×10^{10}	5.05×10^{9}
Wallis-Pirates Cove	1.55	35	1.79×10^{12}	1.79×10^{11}
Cable-Jenness	0.07	1.6	8.07×10^{10}	8.07×10^{9}
Sawyer	2.02	45	2.32×10^{12}	2.32×10^{11}
Bass	0.93	21	1.07×10^{12}	1.07×10^{11}
State-Northside Park	6.23	140	7.17×10^{12}	7.17×10^{11}
North Beach	1.36	31	1.56×10^{12}	1.56×10^{11}
Hampton-Seabrook	20.34	460	2.34×10^{13}	2.34×10^{12}

Canada Geese

Table 8 provides a summary of bacteria loading estimates for geese by watershed. New Hampshire Fish and Game estimated goose population in New Hampshire south of Franconia Notch of approximately 22,000 geese. In order to get a rough estimate of goose population in the watersheds, FB Environmental used a population estimate of 20,000 in the area south of the lakes region to determine an order of magnitude goose population density estimate. Using this population density estimate, we then estimated goose population for each watershed. Using Equation 2, the estimated goose population was multiplied by the estimated fecal coliform load per goose of 4.2×10^8 counts/year (Jones 2009; Appendix D). Lastly, an overland die-off rate of 0.9 was applied to account for bacteria die-off as it is transported from the land area to the receiving waterbody.

Table 8: Estimated Bacteria (FC) Loading from Geese in Seacoast Watersheds

Watersheds	Area Goose Habitat (sq mi)	Estimated Goose Population in Watershed	Yearly FC Loading from Goose	Yearly FC Loading from Goose to Stream
New Castle	0.02	0.9	3.74×10^9	3.74×10^8
Wallis-Pirates Cove	0.31	14	5.92×10^{10}	5.92×10^9
Cable-Jenness	0.05	2.1	9.23×10^9	9.23×10^8
Sawyer	0.24	10.	4.57×10^{10}	4.57×10^9
Bass	0.12	5.2	2.26×10^{10}	2.26×10^9
State-Northside Park	0.90	39	1.69×10^{11}	1.69×10^{10}
North Beach	0.4	17.	7.60×10^{10}	7.60×10^9
Hampton-Seabrook	5.49	240.	1.03×10^{12}	1.03×10^{11}

Raccoons

Table 9 provides a summary of bacteria loading estimates for raccoons by watershed. Raccoon population estimates could not be located for NH, so a literature value (DeGraaf and Yamanski 2001) taken from another northeastern habitat was applied. This estimate of 1 raccoon per 4.4 acres (145 per square mile) was noted as a maximum in favorable New Jersey habitat. Patrick Tate, wildlife biologist for NH F&G, assisted the project team in identifying raccoon habitat. Using GIS, the total area of raccoon habitat per watershed was determined and multiplied by density to provide a raccoon population estimate for each watershed. Using Equation 2, the estimated raccoon population was multiplied by the estimated fecal coliform load per raccoon of 4.4×10^{11} counts/year (Jones 2009). Lastly, an overland die-off rate of 0.9 was applied to account for bacteria die-off as it is transported from the land area to the receiving waterbody.

Table 9: Estimated Bacteria (FC) Loading from Raccoon in Seacoast Watersheds

Watersheds	Area Raccoon Habitat (sq mi)	Estimated Raccoon Population in Watershed	Yearly FC Loading from Raccoon	Yearly FC Loading from Raccoon to Stream
New Castle	0.03	4.7	2.08×10^{12}	2.08×10^{11}
Wallis-Pirates Cove	1.42	210	9.01×10^{13}	9.01×10^{12}
Cable-Jenness	0.06	8.5	3.73×10^{12}	3.73×10^{11}
Sawyer	1.59	230	1.01×10^{14}	1.01×10^{13}
Bass	0.60	88	3.84×10^{13}	3.84×10^{12}
State-Northside Park	5.47	790	3.48×10^{14}	3.48×10^{13}
North Beach	1.3	190	8.30×10^{13}	8.30×10^{12}
Hampton-Seabrook	17.30	2500	1.10×10^{15}	1.10×10^{14}

Other Wildlife Sources

Other wildlife, beyond deer, geese, and raccoons, are present in the study area. These species include gulls, foxes, rabbits, and otters. For example, otters have been observed to create localized bacteria "hotspots," (personal communication S. Jones). Otters use common latrines which are located in the water, and therefore their loading is considered to be highly localized and not subject to any overland die-off. They were not considered to be generally significant across the landscape and were not calculated separately.

Gulls are present in large numbers along the coast and have been anecdotally identified as sources of bacteria at locations such as the mouth of Parsons Creek. FC organisms / gull loading has been found to be on the order of magnitude of 10^{11} (Gould and Fletcher 1978). Gull contributions to bacteria loading are likely largest when their waste is directly deposited in surface waters. This type of source is not included in the watershed load estimation process described herein because the primary location of gulls seems to be outside of the watershed proper, in intertidal zones. Nonetheless, they may be important in the overall bacterial loading budget relative to seacoast beaches.

Several species are noted in the literature as having population densities in the seacoast, but have estimated populations much lower than deer, geese and raccoons (e.g., the red fox at 2.7 foxes per square mile). It appears reasonable to select three dominant species and sum the estimated loadings of these species. If additional analysis of wildlife bacteria sources is deemed worthwhile, then more detailed information about these species may be obtained and additional species may be added to the analysis.

Summary

Table 10 provides a summary of Bacteria loading estimates for wildlife, by species and by watershed.

Table 10: Estimated Bacteria (FC) Loading for Selected Wildlife Species by Watersheds

	New Castle	Wallis and Pirates Cove	Cable and Jenness	Sawyer	Bass	State and Northside Park	North Beach	Hampton-Seabrook
Deer	5.05×10^{9}	1.79×10^{11}	8.07×10^{9}	2.32×10^{11}	1.07×10^{11}	7.17×10^{11}	1.56×10^{11}	2.34×10^{12}
Goose	3.74×10^{8}	5.92×10^{9}	9.23×10^{8}	4.57×10^{9}	2.26×10^{9}	1.69×10^{10}	7.60×10^{9}	1.03×10^{11}
Raccoon	2.08×10^{11}	9.01×10^{12}	3.73×10^{11}	1.01×10^{13}	3.84×10^{12}	3.48×10^{13}	8.30×10^{12}	1.10×10^{14}
Total	**2.13×10^{11}**	**9.20×10^{12}**	**3.82×10^{11}**	**1.03×10^{13}**	**3.95×10^{12}**	**3.55×10^{13}**	**8.46×10^{12}**	**1.12×10^{14}**

3.4 Farm Animals

The AVGWLF model contains a well-developed farm animal bacteria loading estimation method that was used for this project. The method applied in AVGWLF requires inputs for the load estimation calculation including bacterial loading rate per animal; number of each type of farm animal per watershed; the amount of time spent by animals in barnyards, pasture, and streams; the amount of manure removed to agricultural land; manure soil incorporation rates; and runoff loss rates. The fundamental equation used by AVGWLF is provided in equation 3. Key input parameter values required to estimate farm animal bacteria loads are described and presented below.

Equation 3: Farm Animal Loading by Species

Farm Animal Bacteria Load (counts/year) = (Animal Pop.) x (Bacteria load/animal/year) x (Runoff Rate)

Total Population of Farm Animals

The total number of farm animals was estimated for each watershed, based on a combination of field observations and research into farming operations in the study area watersheds.

Table 11 provides estimated numbers of farm animals by species and by watershed.

Table 11: Estimated Number of Farm Animals by Species and Watershed

	Watershed							
Number of Animals	New Castle	Wallis & Pirates Cove	Cable & Jenness	Sawyer	Bass	State & Northside Park	North Beach	Hampton-Seabrook
Beef Cows	0	0	0	0	0	0	0	5
Milk Cows	0	0	0	0	0	0	0	0
Broilers	0	0	0	0	0	0	0	0
Layers	0	0	0	0	0	0	0	0
Pigs	0	0	0	0	0	0	0	0
Sheep	4	0	0	0	0	6	0	12
Horses	0	10	0	12	4	8	0	20
Turkeys	0	0	0	0	0	0	0	0
Buffalo	0	10	0	0	0	0	0	0

Bacteria Loading Rates per Animal

Per animal daily bacteria loading rates were obtained from the American Society of Agricultural Engineers (2003). Manure production and characteristics: section D384.1, in ASAE Standards. ASAE, St. Joseph, MI. Table 12 is taken from the ASEA document and the fecal coliform values were applied to estimate farm animal loads.

In order to include animals not in the ASAE chart below, we made the following simplifying assumptions:

- Buffalo bacteria loading is the same as beef cattle loading.
- Goats and llamas bacteria loading is the same as sheep loading.

Table 11 and these assumptions were applied to estimate bacterial loading rates per animal.

Table 12: Characteristics of Livestock Manure per 1000kg of live animal mass per day (ASAE 2003)

			Animal Type†										
Parameter	Units*		Dairy	Beef	Veal	Swine	Sheep	Goat	Horse	Layer	Broiler	Turkey	Duck
Boron	g	mean	0.71	0.88	**	3.1	0.61	**	1.2	1.8	**	**	**
		std. deviation	0.35	0.064	**	0.95	0.30	**	0.48	1.7	**	**	**
Molybdenum	g	mean	0.074	0.042	**	0.028	0.25	**	0.083	0.30	**	**	**
		std. deviation	0.012	**	**	0.030	0.38	**	0.033	0.057	**	**	**
Zinc	g	mean	1.8	1.1	13	5.0	1.6	**	2.2	19	3.6	15	**
		std. deviation	0.65	0.43	**	2.5	1.0	**	2.1	33	**	12	**
Copper	g	mean	0.45	0.31	0.048	1.2	0.22	**	0.53	0.83	0.98	0.71	**
		std. deviation	0.14	0.12	**	0.84	0.066	**	0.39	0.84	**	0.10	**
Cadmium	g	mean	0.003 0	**	**	0.027	0.007 2	**	0.005 1	0.038	**	**	**
		std. deviation	**	**	**	0.028	**	**	**	0.032	**	**	**
Nickel	g	mean	0.28	**	**	**	**	**	0.62	0.25	**	**	**
		std. deviation	**	**	**	**	**	**	**	**	**	**	**
Lead	g	mean	**	**	**	0.084	0.084	**	**	0.74	**	**	**
		std. deviation	**	**	**	0.012	**	**	**	**	**	**	**
Total coliform bacteria	colonies#	mean	1 100	63	**	45	20	**	490	110	**	**	**
		std. deviation	2 800	59	**	33	26	**	490	100	**	**	**
Fecal coliform bacteria	colonies	mean	16	28	**	18	45	**	0.092	7.5	**	1.4	180
		std. deviation	28	27	**	12	27	**	0.029	2.0	**	**	180
Fecal streptococcus bacteria	colonies	mean	92	31	**	530	62	**	58	16	**	**	590
		std. deviation	140	45	**	290	73	**	59	7.2	**	**	**

Distribution of Farm Animal Wastes and Runoff Rates

AVGWLF estimates several source areas and pathways for farm animal waste. Several agricultural source areas are estimated, including pasture, barnyard, and manure spread on cropland. This method results in Equation 3 being applied several times; once for each source area type and for each animal type.

In terms of source areas, the following assumptions were made about farm animals in New Hampshire based on observations in the watershed:

- Farm animals do not have significant direct access to streams; and
- Grazing time was limited to non-winter months.

These estimates were used to partition the animal's time between the agricultural source areas. Also, AVGWLF requires several additional input parameter values and the default (i.e., recommended) values of these parameters were applied.

Summary

Table 13 indicates the final bacteria loading results for farm animals by watershed.

Table 13: Estimated Bacteria (FC) Load from Farm Animals by Watershed

	Farm Animal FC Loading (FC/yr)
New Castle	1.02×10^{9}
Wallis & Pirates Cove	1.55×10^{12}
Cable & Jenness	0
Sawyer	1.07×10^{10}
Bass	3.57×10^{9}
State & Northside Park	2.24×10^{10}
North Beach	0
Hampton-Seabrook	4.84×10^{10}

3.5 Summary of Bacteria Load Estimates

Table 14 summarizes bacteria load estimates by source category and by watershed. These are planning level estimates and contain significant uncertainty.

Table 14: Compilation of Estimated Annual Bacteria Loads by Watershed and by Type

	Land Area (sq mi)	Total Estimated (FC/yr)	Developed Area Runoff (FC/yr)	Failing Septic Systems (FC/yr)	Wildlife (FC/yr)	Farm Animals (FC/yr)
New Castle	0.075	$3.1x10^{12}$	$2.6x10^{12}$	$3.7x10^{11}$	$1.1x10^{11}$	$1.0x10^{09}$
Wallis & Pirates Cove	2.3	$4.4x10^{13}$	$2.8x10^{13}$	$6.3x10^{12}$	$7.9x10^{12}$	$1.6x10^{12}$
Cable & Jenness	0.16	$1.3x10^{13}$	$1.1x10^{13}$	$2.6x10^{12}$	$1.0x10^{11}$	0
Sawyer	2.5	$3.7x10^{13}$	$2.4x10^{13}$	$3.7x10^{12}$	$9.6x10^{12}$	$1.1x10^{10}$
Bass	1.3	$2.5x10^{13}$	$1.8x10^{13}$	$3.0x10^{12}$	$3.6x10^{12}$	$3.6x10^{09}$
State & Northside Park	7.7	$1.4x10^{14}$	$1.1x10^{14}$	$1.4x10^{13}$	$3.2x10^{13}$	$2.2x10^{10}$
North Beach	2.5	$8.9x10^{13}$	$8.1x10^{13}$	$1.6x10^{12}$	$6.1x10^{12}$	0
Hampton-Seabrook	35.	$8.7x10^{14}$	$7.5x10^{14}$	$3.1x10^{13}$	$9.0x10^{13}$	$4.8x10^{10}$

Figure 16 provides estimated percentages of each type of bacteria load for each watershed. Developed area runoff is estimated to be the largest bacteria source in all of the study area watersheds (as shown in red below) ranging from 64% to 91%. Developed area runoff contributions originate in roadways, in yards, with pets, in illicit storm drains, and from other sources. Failing septic systems (blue) and wildlife (green) are also estimated to be significant in most watersheds. Failing septic systems are estimated to range from 1% to 19%, with larger estimated loads in unsewered communities. Farm animals are estimated to be significant only in the Wallis & Pirates Cove watershed with a 4% estimated contribution.

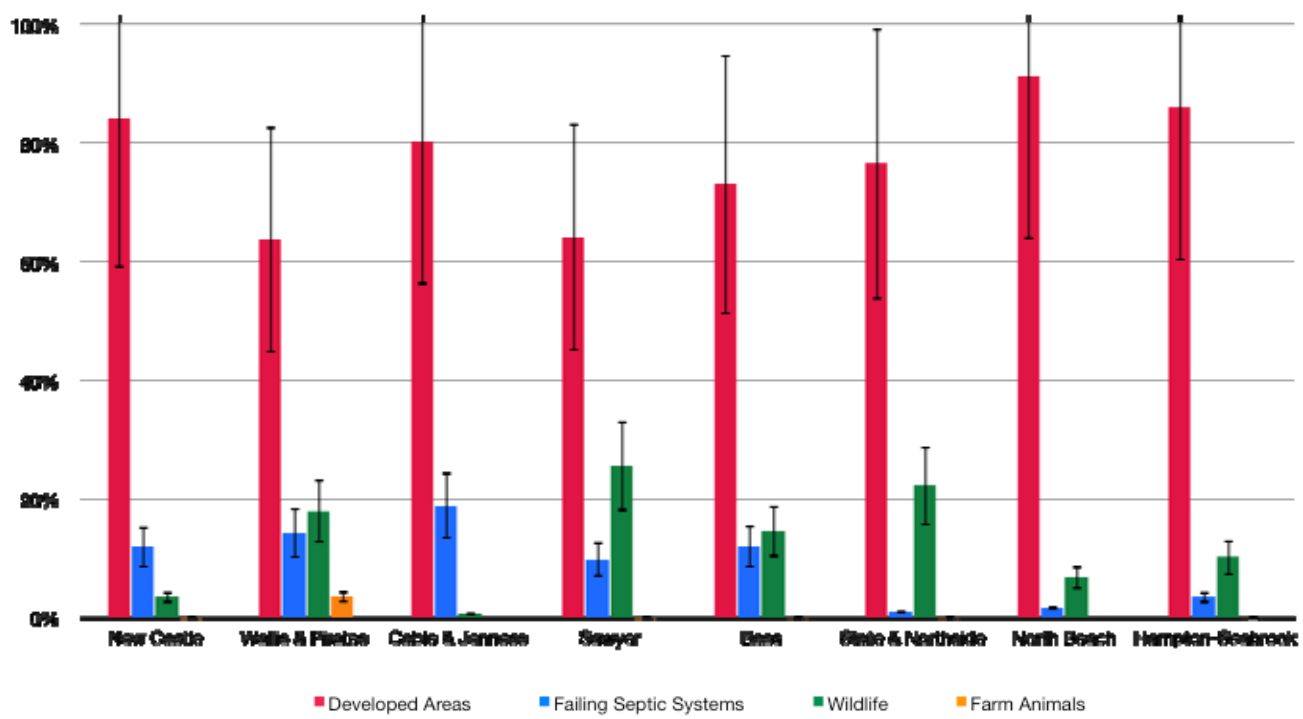

Figure 16: Estimated Bacteria Loads: Percentage of Each Type by Watershed.

There is significant uncertainty in the bacteria load estimates provided above. For failing septic systems, for example, the failure rate was estimated to range from 5% to 10%. Error bars are included in Figure 16 to represent uncertainty in the estimates. The bacteria load estimates provide useful screening level estimates, but do not represent exact characterizations of bacteria loads in the study area watershed.

3.6 Bacteria Source Area Mitigation Estimates

This section provides an estimate of the benefits of remediating one unit of bacteria source pollution, in terms of estimated FC load reduction. One unit is defined as follows:

- For Developed Area Runoff, eliminating the runoff of five acres of developed land through diversion, treatment, or other means of disconnection of the runoff source from the receiving waterbody.
- For Failing Septic Systems, eliminating five septic systems by taking the failing systems offline.
- For Farm Animal Runoff, eliminating runoff from farm land through capture, treatment, covering or other means of disconnection of source from the receiving waterbody. Farm animals in our estimates are based on numbers of animals, not acres of land. As a result, we are using a "horse farm" unit, which is equal to the FC loading from a five horses.

Wildlife sources do not require mitigation because they are "natural sources", however, many best management practices (BMPs) designed to disconnect stormwater runoff from the receiving waterbody will also reduce wildlife source contributions.

Table 15 provides estimated bacteria source mitigation reduction associated with removal of each type of bacteria source. Mitigation reductions are provided by watershed as a total load reduction and as a percentage reduction. These estimated mitigation benefits are designed to support watershed based planning. Specifically, the load reductions estimates may be applied to support prioritization of bacteria sources for mitigation and to characterize the environmental benefits associated with specific mitigative actions.

Table 15: Estimated Bacteria Source Mitigation Values by Source and Watershed

	Total Estimated FC Load	Remediation of Five Failing Septic System		Remediation of Five Acres of Developed Area Runoff		Remediation of a Five-Horse Farm	
New Castle	3.1×10^{12}	3.7×10^{11}	2.4%	3.7×10^{11}	2.4%		
Wallis & Pirates Cove	4.4×10^{13}	3.7×10^{11}	0.8%	2.9×10^{11}	0.7%	4.6×10^{9}	0.0%
Cable & Jenness	1.3×10^{13}	3.7×10^{11}	2.8%	5.0×10^{11}	3.8%		
Sawyer	3.7×10^{13}	3.7×10^{11}	1.0%	3.2×10^{11}	0.8%	4.6×10^{9}	0.0%
Bass	2.5×10^{13}	3.7×10^{11}	1.5%	2.5×10^{11}	1.0%		
State & Northside Park	1.4×10^{14}	3.7×10^{11}	0.3%	3.7×10^{11}	0.3%	4.6×10^{9}	0.0%
North Beach	8.9×10^{13}	3.7×10^{11}	0.4%	4.8×10^{11}	0.5%		
Hampton-Seabrook	8.7×10^{14}	3.7×10^{11}	0.0%	6.5×10^{11}	0.1%	4.6×10^{9}	0.0%

3.7 References

Note: Appendix C provides a bibliography of documents related to bacteria load estimation methods and estimation values.

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4.0 Statistical Analysis of Beach Bacteria Data

This section provides a summary of statistical analyses applied to establish a relationship between beach bacteria data and several potential indicator variables, including antecedent rainfall and air temperature. The goals of the analysis and selection of a method are summarized in Section 4.1. Descriptions of the method selected, the data applied, and the resulting application are then provided, as follows:

Section 4-2 - Description of the selected method, the ROC Curve method;

Section 4-3 - Description of the beach bacteria and associated data analyzed;

Section 4-4 - Results of the statistical analysis; and

Section 4-5 - Summary and recommendations.

A glossary of terms is provided in Section 4-6 to help guide the reader in using statistical terms.

4.1 Goals of Statistical Analysis and Selection of an Appropriate Method

Statistical analysis of beach bacteria data was conducted to enhance understanding of the nature and extent of bacteria sources and to improve public notification of events of elevated bacteria at seacoast beaches. Specifically, the analysis sought to identify variables (e.g., prior 24 hour rainfall) and variables levels that are reliable predictors of elevated bacteria counts at seacoast beaches. For example, a useful outcome would be that the statistical analysis revealed a high probability of elevated bacteria levels when it rains more than 0.2" during the prior 24 hours and a corresponding low probability of elevated bacteria levels when it rains less than 0.2". This information would be useful in predicting elevated bacteria events, potentially including a priori posting of warnings at beaches.

The statistical analysis results may also be useful in enhancing our understanding of the sources and causes of bacterial pollution in the seacoast. Understanding the circumstances associated with elevated bacteria levels can lend insights on the sources of bacteria. A review of statistical analysis methods was conducted to identify methods that would support achievement of the goals of this application. A summary of that review is provided below.

<u>Selection of an Appropriate Statistical Analysis Method</u>

Several statistical analysis techniques were evaluated for applicability to the beach bacteria data set, including time-series evaluations of the bacteria data set and various forms of regression. Regression techniques (linear or non-linear, with single or multiple predictor variables) are commonly applied to evaluate environmental data sets and were evaluated for this application. Regression methods seek to quantify the relationship between variables, exploring the regression of Y on X; where Y is a dependent variable and X is one or more independent variables (Snedecor and Cochran 1989). The family of regression techniques is broad and can include binary or continuous variables for both X and Y. Linear regression approaches were not selected for the beach bacteria data analysis for several reasons including statistical requirements of the data (i.e., relationships may not be linear), but most importantly, lack of transparency and simplicity. Our objective is to predict a binary response (Elevated Bacteria or Not Elevated Bacteria) with optimal reliability, and not necessarily to quantify the nature of the relationships over the entire range of values for the independent variables. The Receiver Operator

Characteristic (ROC) curve method is appropriate to support achieving this simplified objective. Application of the ROC curve analysis method shows promise to enable regulators to make statistically defensible predictions of conditions that will result in elevated bacteria levels.

4.2 Receiver Operating Characteristics Curve Analysis

The ROC curve analysis method applies a simple statistical decision theoretic approach to classify samples into two categories (i.e., suitable or unsuitable). The ROC curve method has been applied to a wide range of problems including deciphering between signal and noise in World War II radar signals, in medical decision making to evaluate the diagnostic ability of medical tests, and in environmental management and assessment. For example, Morrison et al. (2003) successfully applied the ROC curve analysis method to predict events of elevated bacteria at Boston area beaches.

For the beach bacteria application, ROC curves may be applied to evaluate the ability of a predictor (e.g., antecedent 24 hour rainfall) to accurately classify bacteria samples as Suitable or Unsuitable. Suitable is defined as below the water quality standard for bacteria and Unsuitable is defined as at or above the standard. If a strong univariate relationship is present, ROC curves can be used to empirically derive the threshold for prediction. If the relationship between the response and predictor variables is multivariate, then ROC curves provide a means for evaluating that predictive accuracy.

Given any prediction tool, we can categorize the test data into the four categories displayed in Table 16. Statistical synonyms for each of the four categories are also provided in Table 16. An ideal diagnostic tool would have high True Negatives and True Positives (shown in black), and low False Negatives and low False Positives (shown in red). It is not always possible to have both low false negatives and low false positives, however, so a policy decision must be made as to what levels are acceptable. In terms of public health, minimizing false negatives (failing to post an advisory when bacterial counts are elevated) is likely more important than false positives (posting an advisory when it is safe to swim).

Table 16: Response Categories for Bacterial Conditions

Prediction Outcome	*Normal Bacterial Counts Suitable for Swimming*	*Elevated Bacterial Counts Unsuitable for Swimming*
Decision Not to Post an Advisory	True Negatives	False Negative
Decision to Post an Advisory	False Positives	True Positives

Synonyms for the Four Categories
True positive = power = sensitivity = 1 - beta
False positive = alpha = Type I error
True negative = efficiency = specificity = 1 – alpha
False negative = beta = Type II error

Creating an ROC Curve

Data for the ROC curves are calculated as follows. For each value (C) from the prediction tool:

1. The number of Unsuitable samples with values at or above C is counted; this number divided by the total number of Unsuitable samples is the True positive rate (the y-coordinate) for that value C.
2. The number of Suitable samples with values at or above this C is counted; this number divided by the total number of Suitable samples is the False positive rate (the x-coordinate) for that C.

To assess the success of the analysis, the shape of the ROC curve is evaluated and quantified by the area under the curve (AUC). The AUC is calculated geometrically by summing the area of each rectangle. The ideal predictor has an AUC of 1, and a predictor with no discriminatory power has an AUC of 0.5. We consider AUC values greater than 0.8 to be indicative of a relatively strong predictor. ROC curves are presented and described in greater detail in Section 4.4 below.

4.3 Beach Bacteria and Associated Data Applied to Statistical Analysis

Four beaches, New Castle Town Beach, Pirates Cove Beach, Sawyer Beach, and State Beach were selected for inclusion in the statistical analysis. These beaches were selected because elevated bacteria levels at these beaches are more frequent than at other seacoast beaches. Aerial, orthophotographic maps of each of the four beaches and their adjacent watersheds are provided in Section 2. Three of the four beaches are situated near the outlet of tidal creeks and are believed to be impacted by those creeks. The remaining beach, New Castle Town Beach, is believed to be impacted by an adjacent pipe connected to a ponded area. Descriptions of each of these watersheds and potential bacteria sources are provided in Section 2.

Table 17 provides a summary of bacteria data including the beach names, their adjacent creeks, and a summary of bacteria data relative to Enterococcus bacteria water quality standards. These data were compiled by Jessica Devoid of the New Hampshire DES Beach Program. The data consist of Enterococcus bacterial colony counts in water samples collected at 3 stations, located at the left, right and center of each beach. The bacteria data set includes all samples collected over a 5 year period, 2004-2008. Start and end dates for sampling varied by year beginning in April and ending in September.

Table 17: Summary of Beach Enterococcus Data Relative to Water Quality Standards

				*Geomean Standard**		*Single Sample Standard***	
Beach	*Watershed Area (sq. mi.)*	*Adjacent Streams Or Outfalls*	*n*	*n above*	*% above*	*n above*	*% above*
New Castle	0.07	Pipe	410	60	15%	18	4%
Pirates Cove	2.28	Parsons Creek	301	20	7%	10	3%
Sawyer	2.46	Eel Pond	395	25	6%	9	2%
State	7.68	Little River	441	52	12%	20	5%

The total number of samples collected at each beach over the past 5 years is between 300 and 450. At each beach, the total number of exceedences of the Enterococcus bacteria standard (104

counts/100ml) was between 9 and 20, corresponding to 2% to 5% of total samples collected (Table 17).

- In addition to bacteria data, Jessica Devoid compiled a set of potential predictor variable data, including daily values for the following parameters over the past 5 years:
- Total rainfall accumulated during the 24 hours prior to the sampling event (i.e., antecedent 24 hour rainfall);
- Antecedent 48 hour rainfall; and
- Previous day's maximum daily temperature.

These data were tested using the ROC method as potential predictors of events of elevated bacteria at the beaches.

4.4 Statistical Analysis of Beach Bacteria Data Using the ROC Method

Receiver Operating Characteristic (ROC) curve statistical tests were applied to the dataset described above to evaluate the accuracy of potential predictor variables. ROC tests were conducted on each of the four individual beaches, as well as on sets of beaches to determine which variable predicts Enterococcus counts most accurately and at which locations.

Table 18 provides a summary of the area under the curve (AUC) values for all analyses conducted. AUC values greater than 0.8 are indicative of relatively strong predictors and relatively low values are indicative of weak predictors. Of the three potential predictor variables, 24 hour and 48 hour antecedent rainfall show promise (with AUC scores over 0.74), but prior day's maximum air temperature does not appear to be an accurate predictor (with AUC scores below 0.5).

Table 18: ROC Test Results: Area under the Curve (AUC) for all Analyses

	Beach					
Predictor Variable	*All Beaches*	*Pirates Cove, Sawyer, and State*	*Pirates Cove*	*Sawyer*	*State*	*New Castle*
24 hour rainfall	0.738	0.816	0.761	0.741	0.876	0.581
48 hour rainfall	0.752	0.806	0.781	0.814	0.820	0.639
Prior day's max temp	0.430	0.403	-	-	-	-

Of the four beaches, elevated bacteria events at Pirates Cove, Sawyer, and State Beaches were well predicted by antecedent rainfall, with AUC scores ranging from 0.741 to 0.876. In contrast, at New Castle Town Beach elevated bacteria events were poorly predicted by antecedent rainfall, with AUC scores of 0.581 and 0.639. This observation may indicate that elevated bacteria events at New Castle are not directly driven by wet weather events. At the very least, it indicates that attempting to predict elevated bacteria events at New Castle Town Beach using antecedent rainfall is not a worthwhile exercise. Thus, New Castle Town Beach was dropped from ROC testing evaluation and additional tests were conducted on the remaining three beaches.

Each ROC test result is discussed below and is presented in a uniform format, as represented by Figure 17. Figure 17 presents results of an ROC test for all bacteria data from three beaches using 24 hour

antecedent rainfall as a predictor. This and all subsequent figures contain two parts; a scatter plot and an ROC curve. The scatter plot presents bacteria count (log scale) on the y-axis and 24 hour antecedent rainfall (square root) on the x-axis. Each single dot in the plot represents the value of bacteria and associated antecedent rainfall for that sampling event. The horizontal red line represent the bacteria standard (104 counts/100 ml) with values above the line exceeding the water quality standard.

Below the scatter plot in Figure 17 is an ROC curve showing the results of the test in terms of true positive and false positive rates. These rates indicate the accuracy of the potential indicator in predicting bacterial exceedences. The true positive and false positive rates are plotted as y and x, respectively. The area under the curve (AUC) indicates the accuracy of the predictor variable, with 1.0 indicating that the predictor variable is always correct.

An ideal version of Figure 17 would feature a scatter plot with exceedences all situated above a specific rainfall amount in the scatter plot and an ROC curve with an area under the curve equaling 1. The AUC score for Figure 17 is 0.816. Figure 18 and 19 provide ROC test results for potential predictor variables 48 hour antecedent rainfall, and the previous day's maximum temperature.

The results of the 48 hour antecedent rainfall (Figure 18) are similar to the antecedent 24 hour results (Figure 17). The 24 hour rainfall metric was selected over the 48 hour metric based on its slightly better performance on the three beaches data set (AUC of 0.816 over 0.806), but the two metrics performed similarly in the ROC analysis. Figure 19 confirms that the previous day's maximum temperature is not an effective predictor.

In Figure 20, data from all four beaches are used, including New Castle Town Beach which was excluded in Figure 17 through 18. The AUC for all beaches using the 24 hour antecedent rainfall metric is 0.738, significantly lower than the 0.816 value for the three beaches exclusive of New Castle. Figure 21 provides the ROC analysis results for New Castle Town Beach only and confirms that antecedent rainfall is not a good predictor of elevated bacteria counts at this location.

Identifying Breakpoints and Predictor Values

We reviewed the ROC test results and identified antecedent 24 hour rainfall at three beaches (Pirates Cove, Sawyer, and State) as potentially strong indicator variables. At this point, we need to identify the specific rainfall amount that will serve as the best indicator of elevated bacteria counts. As previously described, the ROC test calculates true positive and false positive rates of predicting bacterial exceedence for each value of the potential predictor variable.

The true positive rate is the proportion of Enterococcus exceedences that occur at or above a given rainfall amount. It is calculated by dividing the number of exceedences that occur at or above the rainfall amount by the total number of exceedences. Conversely, the false positive rate is the proportion of Enterococcus non-exceedences that occur at or above a given rainfall amount. It is calculated by dividing the number of non-exceedences at or above the rainfall amount by the total number of non-exceedences.

The optimal breakpoint corresponds to the rainfall amount which has the best combination of true positive and false positive rates. The optimal breakpoint is determined by finding a point on the ROC curve with a high true positive and low false positive rate. If the curve is too flat, there is no reliable

breakpoint. If the curve increases sharply, the ideal breakpoint is the 'elbow', where the true positive rate has increased but the false positive rate has not.

Table 19: ROC Results: Breakpoint and Rates using 24 Hour Antecedent Rainfall

Beach	AUC	Optimal Rainfall Breakpoint (inches)	True Positive Rate (using breakpoint)	False Positive Rate (using breakpoint)
Three Beaches	0.816	0.12	0.72	0.20
Pirates Cove (a)	0.761	0.08	0.70	0.25
Pirates Cove (b)	0.761	1.02	0.60	0.03
Sawyer	0.741	0.12	0.67	0.16
State	0.876	0.12	0.80	0.22

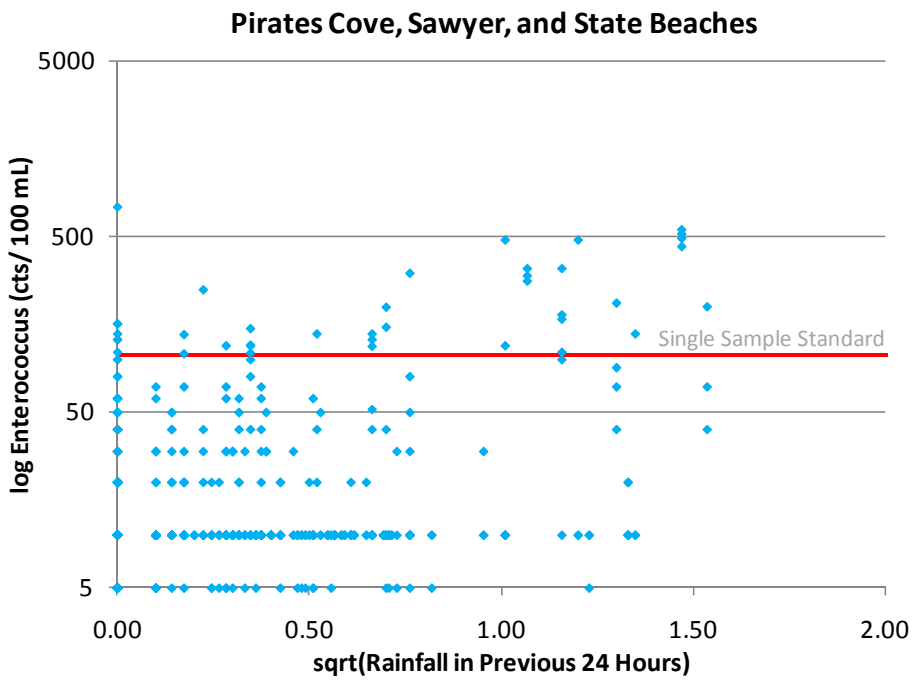
Table 19 provides optimal rainfall breakpoints, true positive rates, and false positive rates for each of the four selected indicator variable scenarios. The breakpoints selected are illustrated in Figure 22 through 25 below. The true positive rates may be interpreted as the percent accuracy. For example, for State Beach, the indicator >0.12" of rainfall is an accurate predictor of elevated bacteria in 80% of events. Using the false positive, we see that indicator >0.12" of rainfall at State Beach falsely predicts elevated bacteria in 22% of events.

Figure 22 provides ROC results for all three beaches bacteria data with a breakpoint of 0.12" identified. The true positive and false positive rates are plotted in the ROC curves with each point on the graph corresponding to a specific value of the predictor variable. The selected optimal breakpoint is illustrated in Figure 22 as a vertical dotted line on the scatter plot (the square root of 0.12 is 0.35), and a colored dot on the ROC curves. The breakpoint occurs when the true positive rate is 0.72 and the false positive rate is 0.20. Selection of a breakpoint is somewhat subjective, depending on several factors including acceptability of true positive and false positive rates.

Figure 23 provides results for Pirates Cove bacteria data and illustrates the process of selecting breakpoints. For Pirates Cove bacteria data, two potential breakpoints were selected. One is at 0.08 inches of rainfall, and is indicated by the vertical dotted red line (the square root of 0.08 is 0.28). As shown by the red dot in the figure below, the 0.08" breakpoint occurs when the true positive rate is 0.70 and the false positive rate is 0.25. The other potential breakpoint is at 1.02 inches of rainfall, which is indicated by the vertical dotted yellow line (the square root of 1.02 is 1.01). This breakpoint occurs when the true positive rate is 0.60 and the false positive rate is 0.03, and is indicated by the yellow dot in the figure below. The 1.02" breakpoint has a low false positive rate (3%), but also a lower true positive rate (60% vs. 70%), relative to the 0.08" breakpoint.

Figure 24 and 25 present ROC test results for Sawyer Beach and State Beach, each with a selected breakpoint at 0.12" of rainfall. It is interesting to note that approximately 0.1 inches of 24 hour antecedent rainfall was the optimal breakpoint for most of the beaches investigated. This is a relatively small rainfall amount and is thought provoking in terms of potential bacteria sources.

Figure 17: Pirates Cove, Sawyer, and State Beach Bacteria Data: Scatter Plot and ROC Curves using 104 col/100 mL Enterococcus as the exceedence threshold and 24 hour antecedent rainfall as the indicator



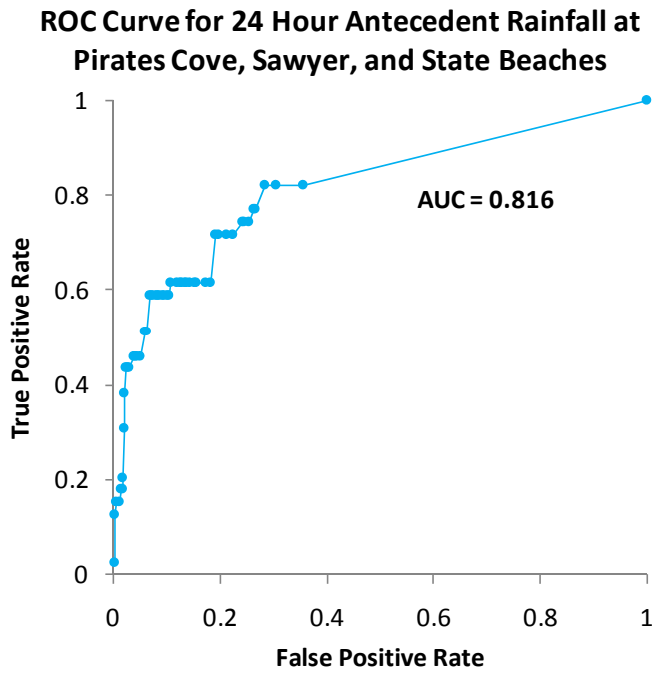
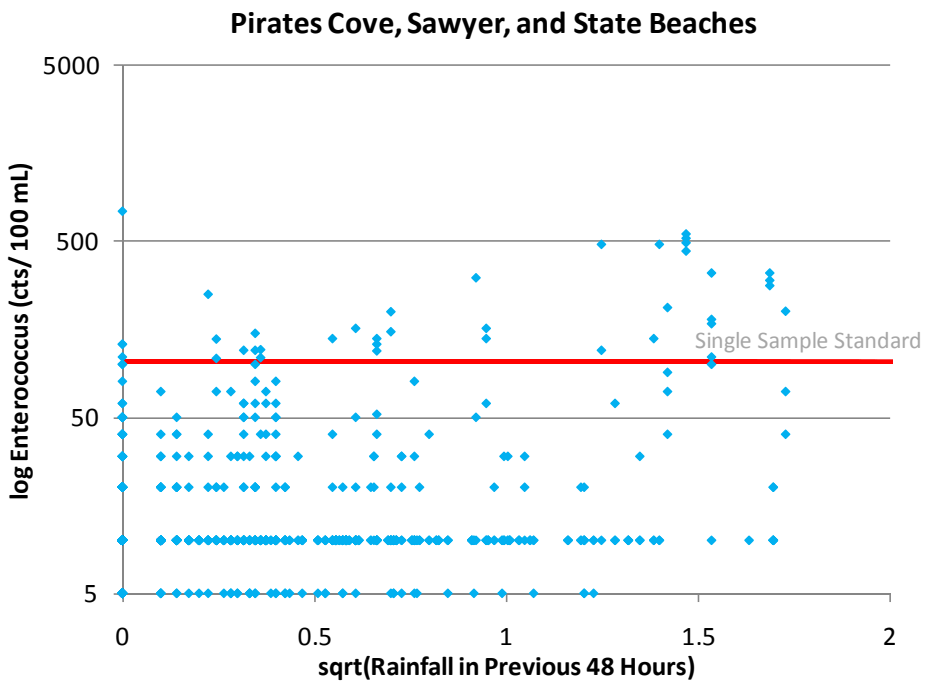


Figure 18: Pirates Cove, Sawyer, and State Beach Bacteria Data: Scatter Plot and ROC Curves using 104 col/100 mL Enterococcus as the exceedence threshold and 48 hour antecedent rainfall as the indicator



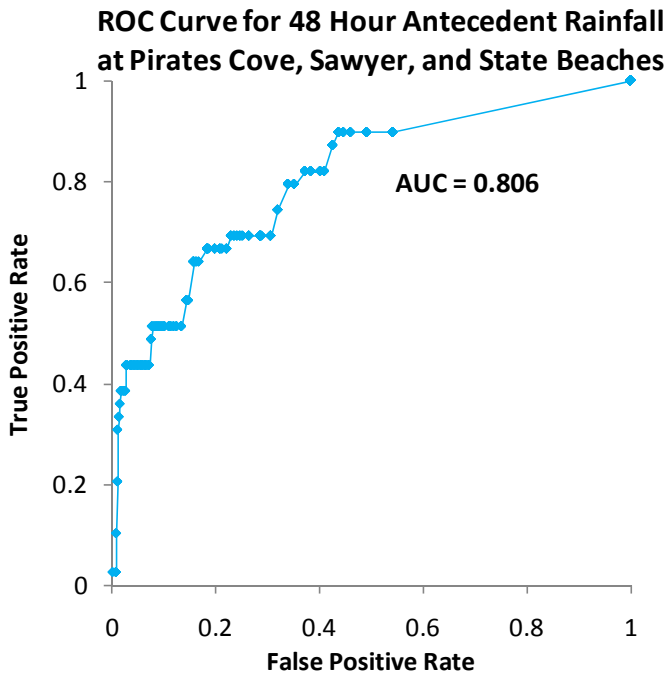
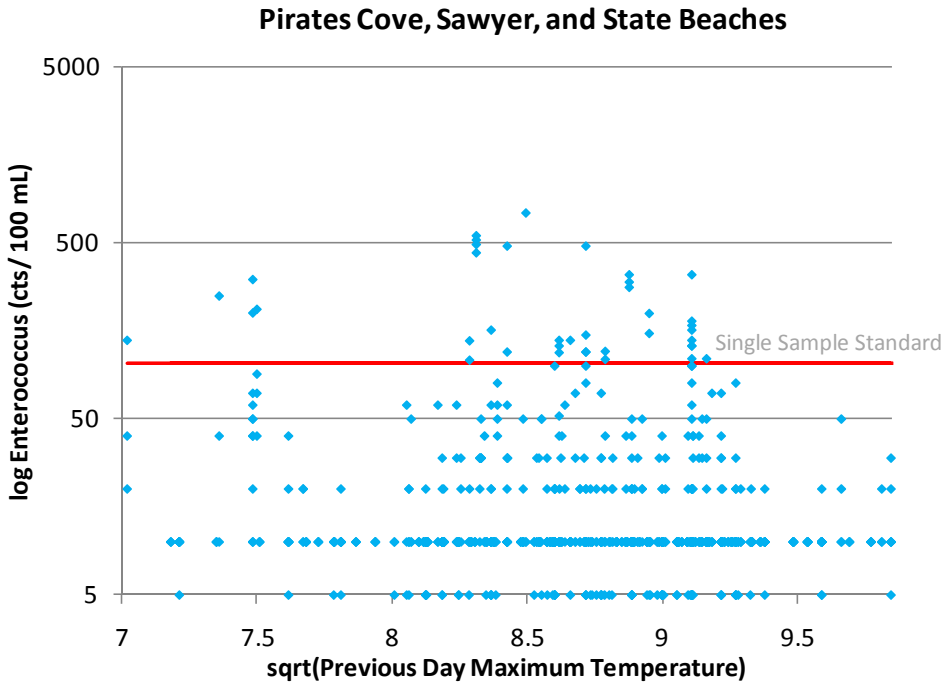


Figure 19: Pirates Cove, Sawyer, and State Beach Bacteria Data: Scatter Plot and ROC Curves using 104 col/100 mL Enterococcus as the exceedence threshold and the previous day's maximum temperature as the indicator



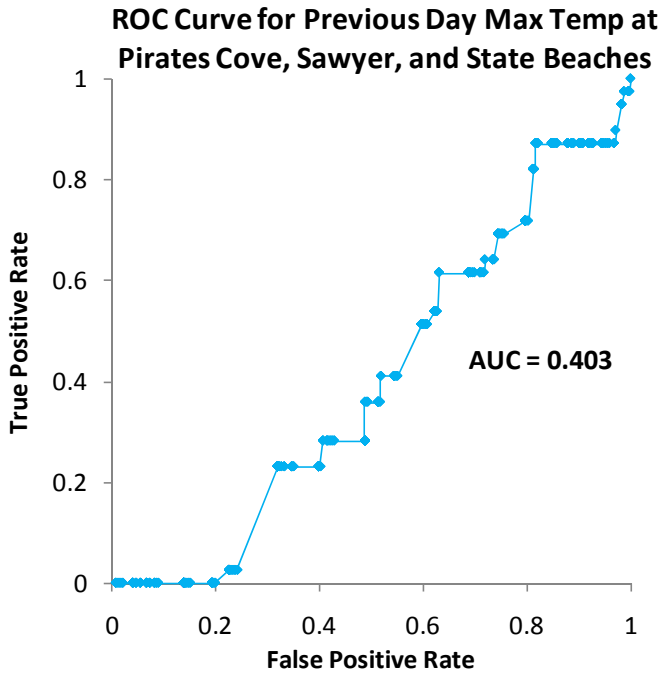
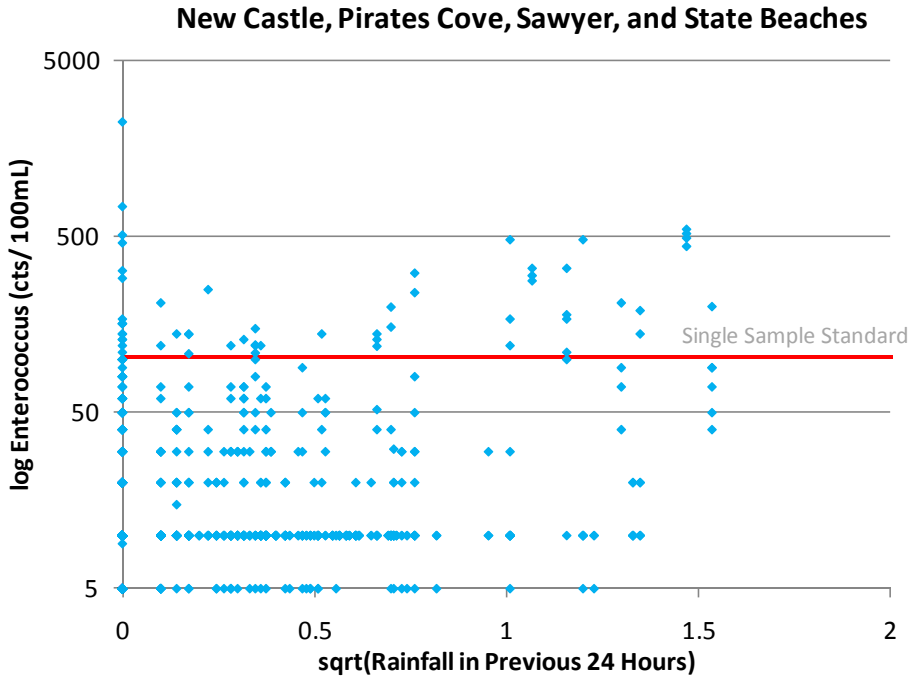


Figure 20: New Castle, Pirates Cove, Sawyer, and State Beach Bacteria Data: Scatter Plot and ROC Curves using 104 col/100 mL Enterococcus as the exceedence threshold and 24 hour antecedent rainfall as the indicator



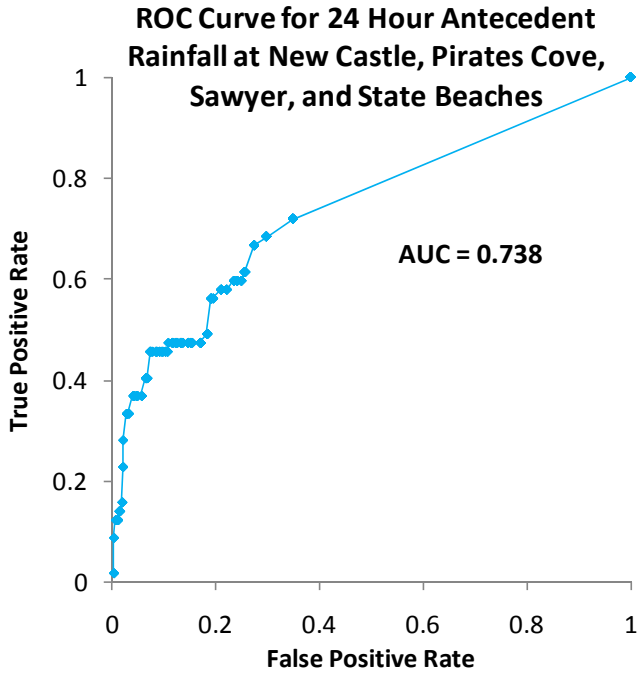
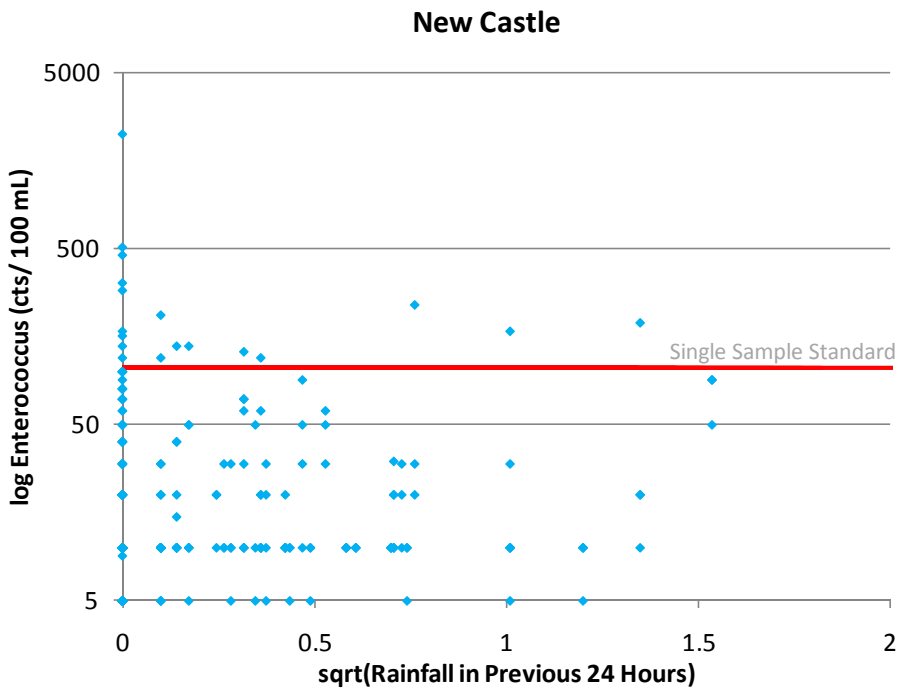


Figure 21: New Castle Bacteria Data: Scatter Plot and ROC Curves using 104 col/100 mL Enterococcus as the exceedence threshold and 24 hour prior rainfall as the indicator



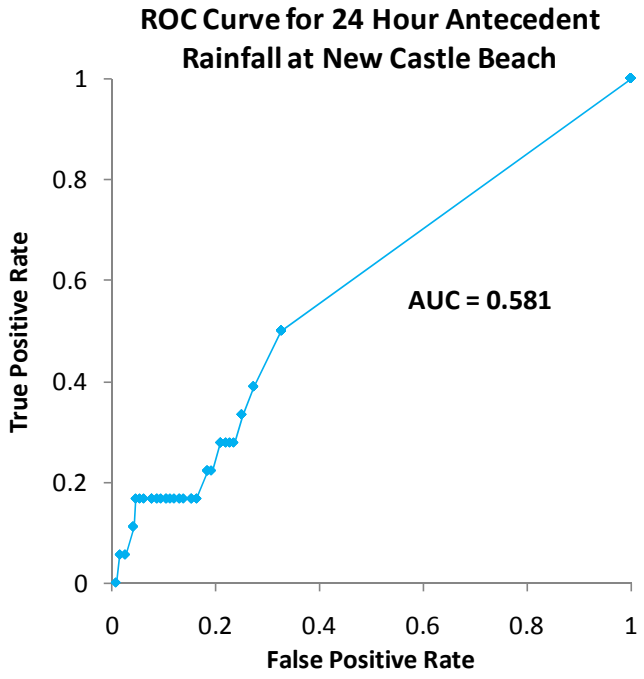
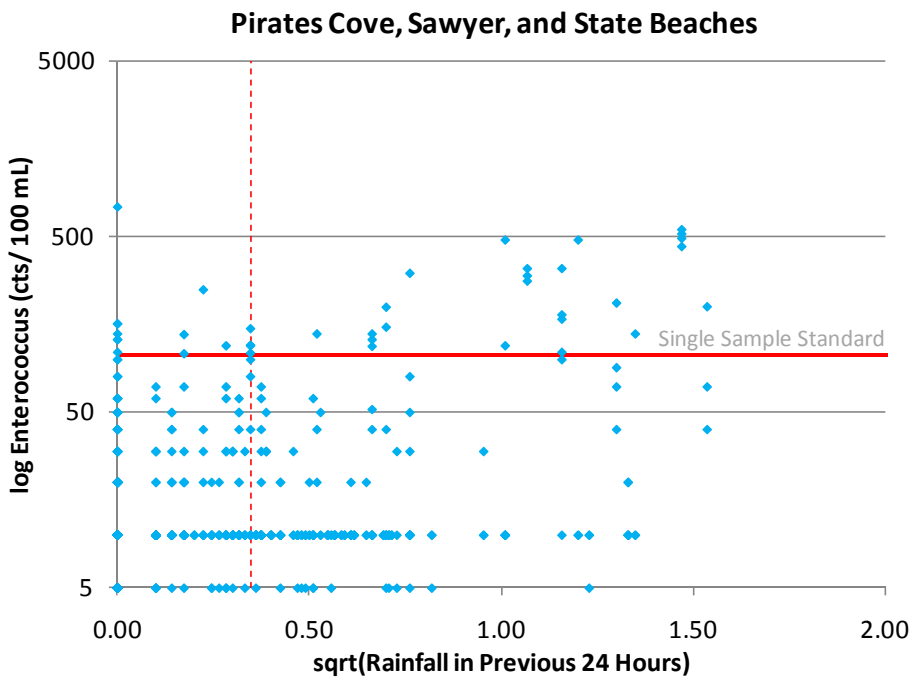


Figure 22: Pirates Cove, Sawyer, and State Bacteria Data: Scatter Plot and ROC Curves using 104 col/100 mL Enterococcus as the exceedence threshold and 24 hour antecedent rainfall as the indicator with breakpoint at 0.12" indicated



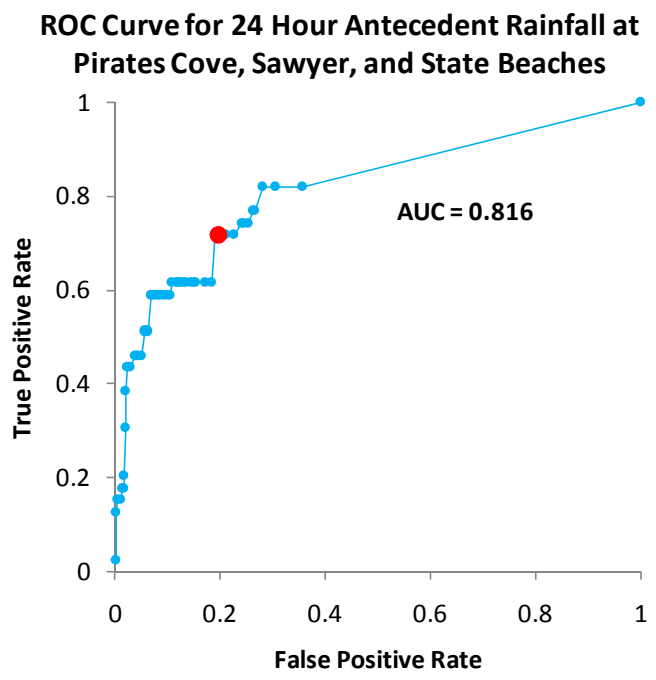
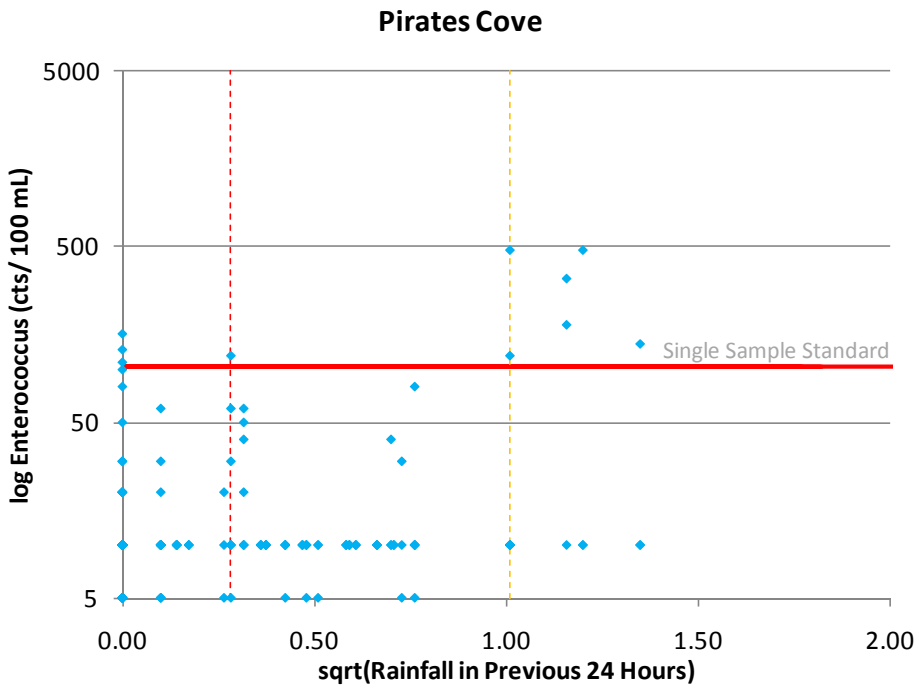


Figure 23: Pirates Cove Bacteria Data: Scatter Plot and ROC Curves using 104 col/100 mL Enterococcus as the exceedence threshold and 24 hour antecedent rainfall as the indicator with two breakpoints at 0.08" and 1.02" indicated



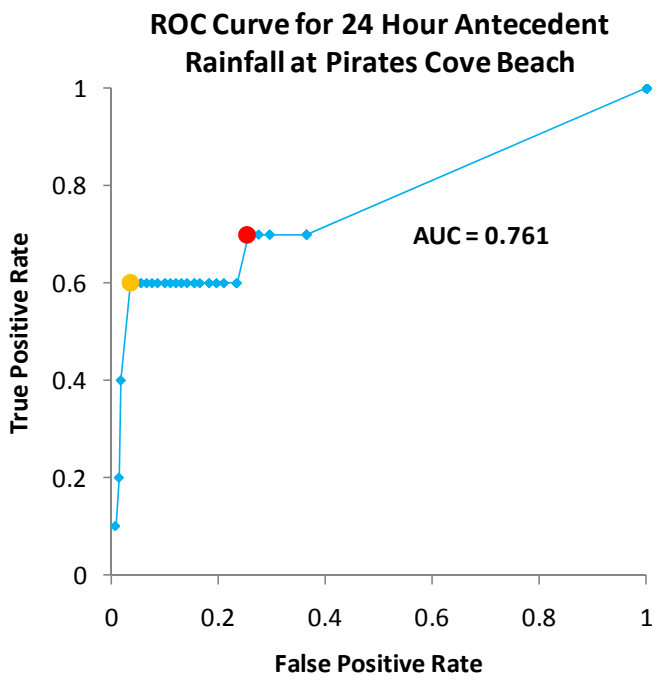
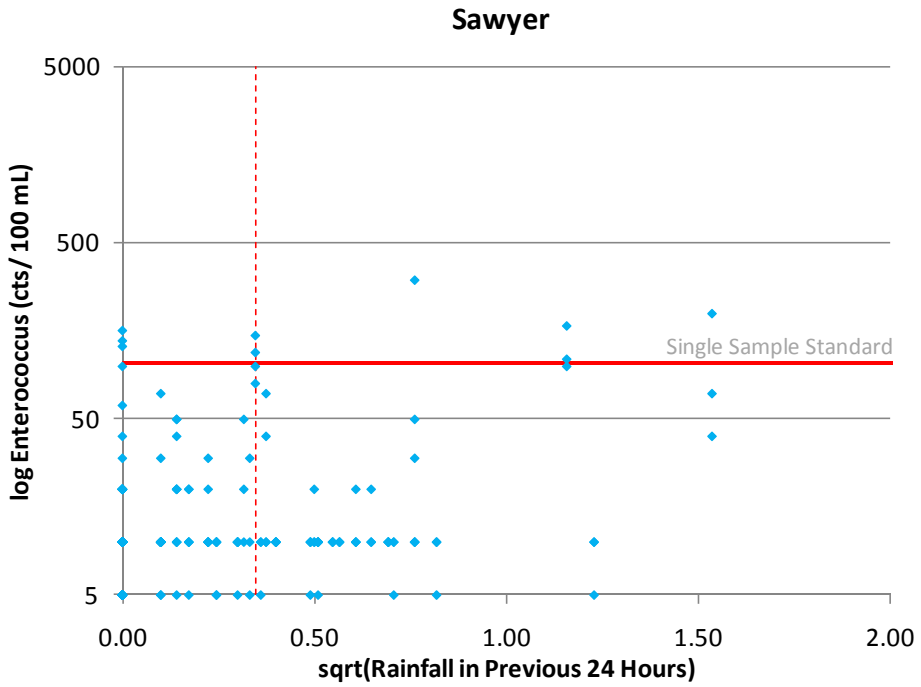


Figure 24: Sawyer Beach Bacteria Data: Scatter Plot and ROC Curves using 104 col/100 mL Enterococcus as the exceedence threshold and 24 hour antecedent rainfall as the indicator with breakpoint at 0.12" indicated



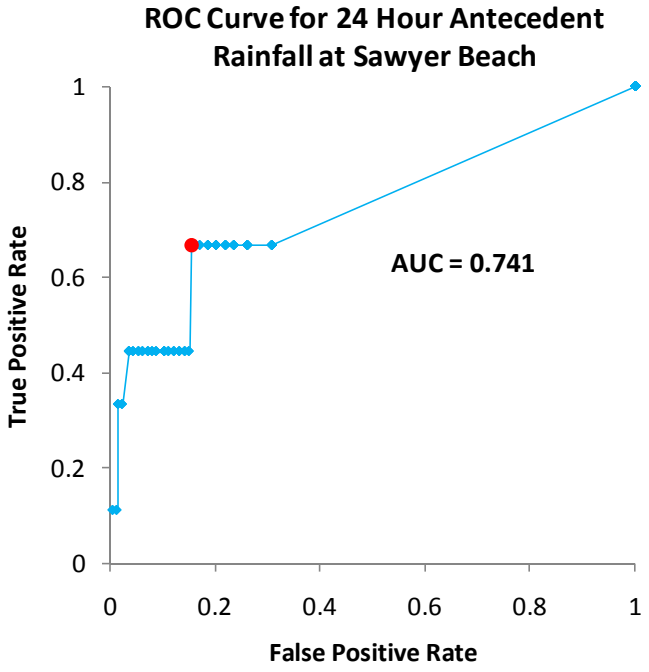
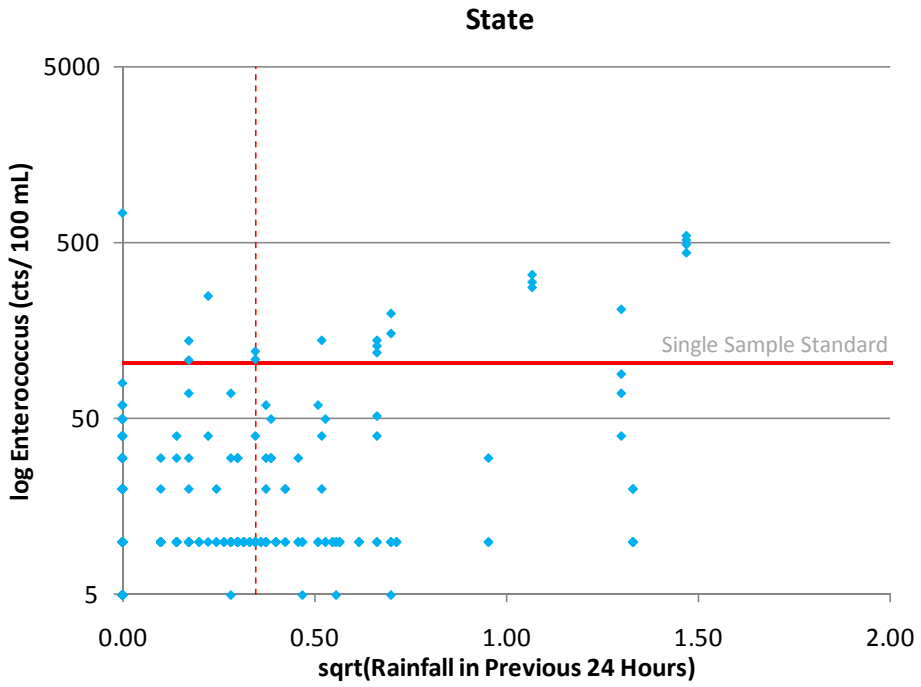
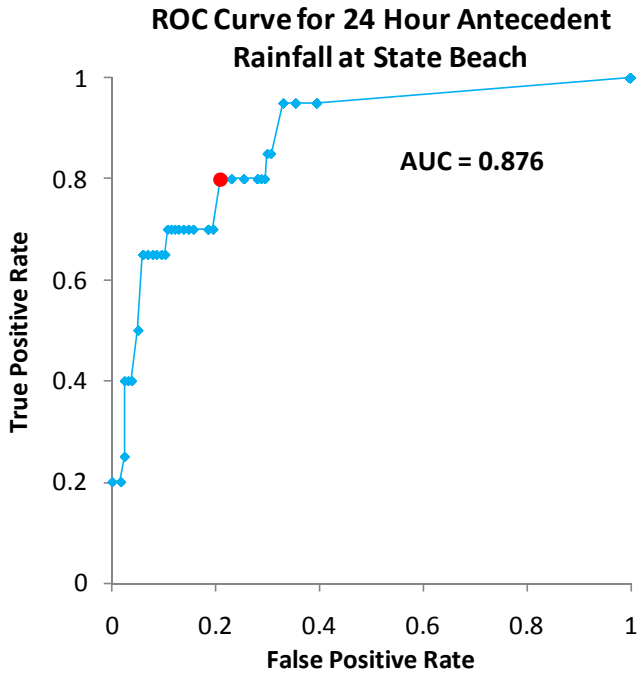


Figure 25: State Beach Bacteria Data: Scatter Plot and ROC Curves using 104 col/100 mL Enterococcus as the exceedence threshold and 24 hour antecedent rainfall as the indicator with breakpoint at 0.12" indicated





4.5 Summary and Recommendations

The ROC statistical test was successful in identifying previous rainfall as a strong predictor of elevated bacteria events at 3 of the 4 beaches investigated (Pirates Cove, Sawyer, and State Beaches). Events of elevated bacteria at New Castle Town Beach were observed to be not well-correlated with rainfall events.

An approximate rainfall amount of 0.12" in the previous 24 hours was identified as an optimal indicator value (or breakpoint) for the three beaches investigated. The true positive rate for this test was generally between 70% and 80%. The false positive rate for the test was generally between 15% and 25%. Overall, the ROC method has been demonstrated to be useful in identifying indicators of elevated bacteria at New Hampshire coastal beaches.

Recommended Next Step: Classification Trees

A classification tree is useful for predicting classification based on combinations of continuous as well as categorical predictors. Also known as "classification and regression tree models", this method offers "a rather new and compelling alternative for exploring differences among groups"(McCune and Grace 2002). Tree-based analysis is primarily an exploratory technique useful for uncovering structure in data, and can be used to devise rules for predicting the probability of presence in a particular class.

The goal of a classification tree approach is to minimize classification errors (i.e., false positives and false negatives). It provides an extension to the work done previously because multiple predictor variables can be fed into the statistical analysis and multiple thresholds identified. In the process of building the classification tree, continuous variables are converted to categories. Categories are defined to be most consistent with accurately partitioning the data into two groups of values; suitable and unsuitable. Within each partition, the set of predictor variables are re-evaluated to identify which variable(s) provides the clearest distinction between suitable and unsuitable observations. This process is repeated successively until separation of the data is complete (i.e., all suitable and unsuitable observations are found in separate 'nodes', which is called the "end of the line" in the tree diagram), or a minimum number of observations are left in the end 'nodes'.

We recommend that a classification tree approach be developed and applied to the beach project bacteria data to attempt to increase the value of the analysis in predicting events of elevated bacteria levels by incorporating multiple predictors.

Recommendations

We recommend that additional analyses be conducted to strengthen the predictive ability of the statistical analysis tool. Specifically, we recommend:

1. Compiling and analyzing additional data sets to increase the number of strong indicator variables. Additional data sets should include beach visitor population, solar irradiation, tidal height, and other variables.
2. Create a classification tree using previous rainfall metrics and additional data metrics. Classification trees allow for several steps of statistical analysis and can result in far more powerful decision-support tools.

3. Add bacteria data from additional nearby locations to the statistical analysis. Analysis of bacteria data collected in nearby shoreline locations (e.g., by the Shellfish Program) could potentially enhance the statistical analysis. This analysis could also provide insights to the spatial relationship between bacteria at beaches and adjacent locations.

The beach bacteria statistical analysis has been successful in achieving project goals. The additional tasks outlined above will strengthen the statistical analysis and will likely yield new and unforeseeable insights.

4.6 Glossary of Terms

Binary response: A binary response is a reaction or classification that can only be defined in one of two ways.

Categorical predictors: A dependent variable with categorical data. Stream class (I, II, III, or VI) is an example of a categorical variable.

Classification trees: Classification trees use categorical predictors and other data to determine how to classify a beach (Suitable/Unsuitable). A classification tree is analogous to a flow chart.

Correlation: A correlation is a statistical test that describes the strength and direction of the linear relationship between two variables.

Expected value: Expected value is the probability weighted average for a random variable.

False negative: An incorrect negative test result. For example, a result that reports bacteria levels below the permitted threshold for swimming when they are actually above the threshold is a false negative.

False positive: An incorrect positive test result.

Independent variables: These are variables that are controlled for or selected.

Logistic regression: A logistic regression predicts the probability that an event will occur by fitting data from predictor variables to a curve created using logarithm.

Log-scale: A logarithmic scale is a scale of measurement that uses the logarithm of a physical quantity instead of the quantity itself. This is useful for bacterial counts, because it makes the large range of bacterial counts more manageable.

Multiple linear regression: A multiple linear regression determines the linear relationship between several independent variables and a dependent variable. This can be used to find the independent variable that best predicts the dependent variable.

Multivariate data: Multivariate data are data collected on several variables per observation.

Receiver Operating Characteristic curves: A graphic means for evaluating the accuracy of indicator variables that are used for classification. A ROC curve plots the true positive rate (sensitivity) on the y-axis and the false positive rate (1-specifity) on the x-axis. If a point on the graph has a high true positive rate and a low false positive rate, then the indicator variable used is accurate. The area under the curve (AUC) can also be calculated for a ROC curve. The AUC ranges from 0 to 1; if the AUC is 1, the indicator variable is always accurate. As an example, the accuracy of 24 and 48 hour antecedent rainfall for predicting whether beaches will have bacteria levels suitable for swimming can be evaluated by creating a ROC curve for each variable. If the ROC curve for the 48 hour antecedent rainfall variable has an AUC closer to 1 than the AUC for the 24 hour antecedent rainfall variable, then 48 hour antecedent rainfall is a more accurate indicator variable.

Regression analysis: A statistical technique used to find relationships between variables so that future values can be predicted.

Scatter plots: A scatter plot displays the relationship between two variables. This is useful for determining if one variable is dependent on another.

Square-root transformation: Data transformation is common in statistics to ensure that the data has a normal distribution. A square root transformation uses the square roots of variables for statistical tests.

True negative: A correct negative test result.

True positive: A correct positive test result.

Univariate: Univariate data are collected on only one variable per observation.

4.7 References

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McCune, Bruce and James B. Grace. 2002. Analysis of Ecological Communities. MjM Software Design, Gleneden Beach, Oregon. 300 pp.

Morrison, Ann Michelle, Kelly Coughlin, James P. Shine, Brent A. Coull, and Andrea C. Rex. 2003. Receiver Operating Characteristic Curve Analysis of Beach Water Quality Indicator Variables, Applied and Env. Microbiology, Vol. 69, No. 11: 6405-6411.

Olyphant, Greg A. 2004. Developing a Prototypical Predictive Model for Beach Closings in Indiana. Indiana Geological Survey. Found on-line at http://igs.indiana.edu/survey/projects/BeachClosings/index.cfm

Snedecor, G. W. and W.G. Cochran. 1989. Statistical Methods. Iowa State University Press, Ames, Iowa. Eighth Edition.

5.0 Summary and Recommendations

This investigation has been successful in creating an inventory of bacteria sources in eight coastal watersheds. For each watershed, the nature and extent of bacteria sources has been characterized. Scientifically-defensible methods for estimating bacteria loads were identified and applied to support estimation of bacteria loads in each watershed. Using these methods, developed area runoff was estimated to be the largest source of watershed bacteria. Wildlife also appears to be a major source of bacteria. Failing septic systems appear to major sources of bacteria in specific, "hotspot" areas. Further, more site specific, investigation is recommended to improve the accuracy of watershed bacteria source characterization.

Statistical analyses were successful in identifying 24-hour antecedent rainfall as a good predictor of elevated bacteria levels at several coastal beaches. Specifically, rainfall amount of 0.12" or greater were associated with elevated beach bacteria events in most cases. Additional statistical analyses are recommended to improve the accuracy of predicting elevated bacteria events and to enhance understanding of bacteria sources.

Three beach watersheds, Parsons Creek watershed, Little River watershed, and New Castle Town Beach watershed, were identified as most impacted by elevated bacteria events. We recommend developing watershed based plans, including additional investigation of bacteria sources, in these three beach watersheds. Watershed based plans (WBPs) include the following components:

- Stakeholder meetings;
- Pollutant source identification field surveys;
- Revised bacteria load estimation;
- Prioritized listing of bacteria sources;
- Preliminary bacteria source mitigation measures for high priority sources; and
- A watershed based plan report.

Watershed based plans will enhance understanding of bacteria sources and help to identify appropriate remedial actions to restore these watersheds. In addition, WBPs will provide information sufficient to support application for CWA Section 319 grant funding for mitigation measures to remove top priority bacteria sources in the watershed. Successfully applying for and receiving 319 grant funding is dependent on financial local stakeholder participation and available federal funding and, therefore, cannot be guaranteed.

Statistical analyses of elevated bacteria events and associated parameter values, particularly antecedent rainfall, have shown promise for support beach water quality notification purposes. We recommend applying statistical analysis techniques, including the Classification Tree and Receiver Operating Characteristics methods, to larger data sets and assessing their ability to predict elevated bacteria events. Additional time-series data, such as solar irradiance, beach population, and tidal height, should be compiled and applied statistical analysis process. Statistical analysis can support public notification of health risk and can provide keen insights to causes of elevated bacteria events.

Appendix A: Bibliography of Available Reports Related to Bacteria at Coastal New Hampshire Beaches

The bibliography below provides a compilation of reports related to bacteria at New Hampshire beaches and associated watersheds. Reports are organized by nine New Hampshire coastal watersheds, arranged from north to south as follows:

1. New Castle Town Beach watershed
2. Wallis Sands Beach and Pirates Cove Beach watershed
3. Foss Beach watershed
4. Jenness and Cable Beach watershed
5. Sawyer Beach watershed
6. Bass Beach watershed
7. State Beach and Northside Park Beach watershed
8. North Beach watershed
9. Seabrook Harbor, Seabrook Beach and Hampton Beach watershed

Following the watershed summaries, general reports on New Hampshire beaches (but not specifically for any one beach) and general reports on bacterial impairment are listed.

New Castle Town Beach Watershed
Size: 48 acres (.08 square miles)
Town: New Castle
Tributaries: none; pipe outfall (north)

Annual Beach Bacteria Monitoring Reports

Merrifield, C., A. Carlson. 2008. *New Castle Town Beach, New Castle: Water Quality Report Summer 2007.* Report for the New Hampshire Department of Environmental Services, Concord, NH.

Bouthiette, E., S. Sumner. 2007. *New Castle Town Beach, New Castle: Beach Water Quality Report Summer 2006.* Report for the New Hampshire Department of Environmental Services, Concord, NH.

New Hampshire Department of Environmental Services: Beach Inspection Program. 2006. *New Castle Town Beach, New Castle: Beach Water Quality Report Summer 2005.* Report for the New Hampshire Department of Environmental Services, Concord, NH.

Carlson, A., S. Sumner. 2005. *New Castle Town Beach, New Castle: Beach Water Quality Report Summer 2004.* Report for the New Hampshire Department of Environmental Services, Concord, NH.

Other Reports

Jones, S. H. 2008. *Microbial Pollution Source Tracking at New Castle Beach.* Final Report to the New Hampshire Department of Environmental Services, Concord, NH.

Wallis Sands and Pirates Cove Beach Watershed

Size: 2.3 square miles
Town: Rye
Tributaries: Parsons Creek (south)

Annual Beach Bacteria Monitoring Reports

Wallis Sands Beach

Merrifield, C., A. Carlson. 2008. *Wallis Sands State Park, Rye: Water Quality Report Summer 2007.* Report for the New Hampshire Department of Environmental Services, Concord, NH.

New Hampshire Department of Environmental Services: Beach Inspection Program. 2006. *Wallis Sands State Park, Rye: Beach Water Quality Report Summer 2005.* Report for the New Hampshire Department of Environmental Services, Concord, NH.

Carlson, A., S. Sumner. 2005. *Wallis Sands State Park, Rye: Beach Water Quality Report Summer 2004.* Report for the New Hampshire Department of Environmental Services, Concord, NH.

Pirates Cove Beach

Merrifield, C., A. Carlson. 2008. *Pirates Cove Beach, Rye: Water Quality Report Summer 2007*. Report for the New Hampshire Department of Environmental Services, Concord, NH.

Bouthiette, E., S. Sumner. 2007. *Pirates Cove Beach, Rye: Beach Water Quality Report Summer 2006.* Report for the New Hampshire Department of Environmental Services, Concord, NH.

New Hampshire Department of Environmental Services: Beach Inspection Program. 2006. *Pirates Cove Beach, Rye: Beach Water Quality Report Summer 2005.* Report for the New Hampshire Department of Environmental Services, Concord, NH.

Carlson, A., S. Sumner. 2005. *Pirates Cove Beach, Rye: Beach Water Quality Report Summer 2004*. Report for the New Hampshire Department of Environmental Services, Concord, NH.

Other Reports

Jones, S.H. and N. Landry. 2004. Tracking Bacterial Pollution Sources in Little Harbor and the New Hampshire Atlantic Coast Tributaries. Final report. New Hampshire Department of Environmental Services, Concord, NH.

Jones, S.H., S. Summer and J. Connor. 2004. Identify and Mitigate Bacterial Sources at Public Beaches Using Microbial Source Tracking. . Final report. New Hampshire Department of Environmental Services, Concord, NH.

Nash, C. and M. Wood. 2006. NH Department of Environmental Services Shellfish Program Activities, January 2005 - December 2005. Final Report. NH Estuaries Project, Durham, NH.

Foss Beach Watershed

Size: 19 acres (.03 square miles)
Town: Rye
Tributaries: Rye Harbor (south)

Annual Beach Bacteria Monitoring Reports

Merrifield, C., A. Carlson. 2008. *Foss Beach, Rye Water Quality Report Summer 2007*. Report for the New Hampshire Department of Environmental Services, Concord, NH.

Bouthiette, E., S. Sumner. 2007. *Foss Beach, Rye: Beach Water Quality Report Summer 2006*. Report for the New Hampshire Department of Environmental Services, Concord, NH.

New Hampshire Department of Environmental Services: Beach Inspection Program. 2006. *Foss Beach, Rye: Beach Water Quality Report Summer 2005.* Report for the New Hampshire Department of Environmental Services, Concord, NH.

Carlson, A., S. Sumner. 2005. *Foss Beach, Rye: Beach Water Quality Report Summer 2004.* Report for the New Hampshire Department of Environmental Services, Concord, NH.

Jenness and Cable Beach Watershed

Size: 118 acres (0.2 square miles)
Town: Rye
Tributaries: Eel Pond outlet (south)

Annual Beach Bacteria Monitoring Reports

Cable Beach

Merrifield, C., A. Carlson. 2008. *Cable Beach, Rye Water Quality Report Summer 2007*. Report for the New Hampshire Department of Environmental Services, Concord, NH.

Bouthiette, E., S. Sumner. 2007. *Cable Beach, Rye: Beach Water Quality Report Summer 2006.* Report for the New Hampshire Department of Environmental Services, Concord, NH.

New Hampshire Department of Environmental Services: Beach Inspection Program. 2006. *Cable Beach, Rye: Beach Water Quality Report Summer 2005*. Report for the New Hampshire Department of Environmental Services, Concord, NH.

Carlson, A., S. Sumner. 2005. *Cable Beach, Rye: Beach Water Quality Report Summer 2004*. Report for the New Hampshire Department of Environmental Services, Concord, NH.

Jenness Beach

Merrifield, C., A. Carlson. 2008. *Jenness Beach State Park, Rye: Water Quality Report Summer 2007.* Report for the New Hampshire Department of Environmental Services, Concord, NH.

Bouthiette, E., S. Sumner. 2007. *Jenness Beach, Rye: Beach Water Quality Report Summer 2006.* Report for the New Hampshire Department of Environmental Services, Concord, NH.

New Hampshire Department of Environmental Services: Beach Inspection Program. 2006. *Jenness Beach State Park, Rye: Beach Water Quality Report Summer 2005*. Report for the New Hampshire Department of Environmental Services, Concord, NH.

Carlson, A., S. Sumner. 2005. *Jenness Beach State Park, Rye: Beach Water Quality Report Summer 2004*. Report for the New Hampshire Department of Environmental Services, Concord, NH.

Sawyer Beach

2.5 square miles
Size: 19 acres (.03 square miles)
Town: Rye
Tributaries: Eel Pond outlet (south)

Annual Beach Bacteria Monitoring Reports

Merrifield, C., A. Carlson. 2008. *Sawyer Beach, Rye: Water Quality Report Summer 2007.* Report for the New Hampshire Department of Environmental Services, Concord, NH.

Bouthiette, E., S. Sumner. 2007. *Sawyer Beach, Rye: Beach Water Quality Report Summer 2006.* Report for the New Hampshire Department of Environmental Services, Concord, NH.

New Hampshire Department of Environmental Services: Beach Inspection Program. 2006. *Sawyer Beach, Rye: Beach Water Quality Report Summer 2005.* Report for the New Hampshire Department of Environmental Services, Concord, NH.

Carlson, A., S. Sumner. 2005. *Sawyer Beach, Rye: Beach Water Quality Report Summer 2004.* Report for the New Hampshire Department of Environmental Services, Concord, NH.

Other Reports

Nash, C. and M. Wood. 2006. NH Department of Environmental Services Shellfish Program Activities, January 2005 - December 2005. Final Report. NH Estuaries Project, Durham, NH.

Bass Beach

Size: 1.3 square miles
Town: North Hampton
Tributaries: Chapel Brook (south)

Annual Beach Bacteria Monitoring Reports

Merrifield, C., A. Carlson. 2008. *Bass Beach, North Hampton Water Quality Report Summer 2007.* Report for the New Hampshire Department of Environmental Services, Concord, NH.

Bouthiette, E., S. Sumner. 2007. *Bass Beach, North Hampton: Beach Water Quality Report Summer 2006.* Report for the New Hampshire Department of Environmental Services, Concord, NH.

New Hampshire Department of Environmental Services: Beach Inspection Program. 2006. *Bass Beach, North Hampton: Beach Water Quality Report Summer 2005.* Report for the New Hampshire Department of Environmental Services, Concord, NH.

Carlson, A., S. Sumner. 2005. *Bass Beach, North Hampton: Beach Water Quality Report Summer 2004*. Report for the New Hampshire Department of Environmental Services, Concord, NH.

Other Reports

Carlson, A., S. Sumner, J. Connor. 2008. *Chapel Brook Special Study North Hampton, NH May to September 2006.* Report for the New Hampshire Department of Environmental Services, Concord, NH.

Jones, S.H. and N. Landry. 2004. Tracking Bacterial Pollution Sources in Little Harbor and the New Hampshire Atlantic Coast Tributaries. Final report. New Hampshire Department of Environmental Services, Concord, NH.

Jones, S.H., S. Summer and J. Connor. 2004. Identify and Mitigate Bacterial Sources at Public Beaches Using Microbial Source Tracking. Final report. New Hampshire Department of Environmental Services, Concord, NH.

Nash, C. and M. Wood. 2006. NH Department of Environmental Services Shellfish Program Activities, January 2005 - December 2005. Final Report. NH Estuaries Project, Durham, NH.

State Beach and Northside Park
Size: 7.7 square miles
Town: North Hampton
Tributaries: Little River (north)

Annual Beach Bacteria Monitoring Reports

State Beach

Merrifield, C., A. Carlson. 2008. *State Beach, North Hampton: Water Quality Report Summer 2007.* Report for the New Hampshire Department of Environmental Services, Concord, NH.

Bouthiette, E., S. Sumner. 2007. *State Beach, North Hampton: Beach Water Quality Report Summer 2006.* Report for the New Hampshire Department of Environmental Services, Concord, NH.

New Hampshire Department of Environmental Services: Beach Inspection Program. 2006. *State Beach, North Hampton: Beach Water Quality Report Summer 2005.* Report for the New Hampshire Department of Environmental Services, Concord, NH.

Carlson, A., S. Sumner. 2005. *State Beach, North Hampton: Beach Water Quality Report Summer 2004*. Report for the New Hampshire Department of Environmental Services, Concord, NH.

Northside Park Beach

Merrifield, C., A. Carlson. 2008. *Northside Park, Hampton: Water Quality Report Summer 2007*. Report for the New Hampshire Department of Environmental Services, Concord, NH.

Bouthiette, E., S. Sumner. 2007. *Northside Park, Hampton: Beach Water Quality Report Summer 2006.* Report for the New Hampshire Department of Environmental Services, Concord, NH.

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Jones, S.H. and N. Landry. 2004. Tracking Bacterial Pollution Sources in Little Harbor and the New Hampshire Atlantic Coast Tributaries. Final report. New Hampshire Department of Environmental Services, Concord, NH.

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Jones S.H., S. Sumner, N. Landry and J. Connor. 2006. Pollution source tracking at New Hampshire (USA) ocean beaches. Pp. 107-114, In, Micallef, A., A. Vassallo and M. Cassar (Eds.) Proceedings of the Second International Conference on the Management of Coastal Recreational Resources-Beaches, Yachting and Coastal Ecotourism. 25-27 October, 2006. Gozo, Malta. Euro-Mediterranean Centre on Insular Coastal Dynamics, Foundation for International Studies, Valletta, Malta.

North Beach

Size: 2.5 square miles
Town: Hampton
Tributaries: none

Annual Beach Bacteria Monitoring Reports

Merrifield, C., A. Carlson. 2008. *North Beach, Hampton: Water Quality Report Summer 2007.* Report for the New Hampshire Department of Environmental Services, Concord, NH.

Bouthiette, E., S. Sumner. 2007. *North Beach, Hampton: Beach Water Quality Report Summer 2006.* Report for the New Hampshire Department of Environmental Services, Concord, NH.

New Hampshire Department of Environmental Services: Beach Inspection Program. 2006. *North Beach, Hampton: Beach Water Quality Report Summer 2005.* Report for the New Hampshire Department of Environmental Services, Concord, NH.

Carlson, A., S. Sumner. 2005. *North Beach, Hampton: Beach Water Quality Report Summer 2004.* Report for the New Hampshire Department of Environmental Services, Concord, NH.

Other Reports

Nash, C. and M. Wood. 2006. NH Department of Environmental Services Shellfish Program Activities, January 2005 - December 2005. Final Report. NH Estuaries Project, Durham, NH.

Seabrook Harbor, Seabrook Beach and Hampton Beach
Size: 46 square miles
Town: Hampton and Seabrook
Tributaries: Mill Creek, Cains Brook, … via Seabrook Harbor

Annual Beach Bacteria Monitoring Reports

Hampton Beach State Park Flagship Beach

Merrifield, C., A. Carlson. 2008. *Hampton Beach State Park Flagship Beach Report 2007.* Report for the New Hampshire Department of Environmental Services, Concord, NH.

New Hampshire Department of Environmental Services: Beach Inspection Program. 2004. *Hampton Beach State Park Flagship Beach Report.* Report for the New Hampshire Department of Environmental Services, Concord, NH.

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Hampton Harbor Beach

Merrifield, C., A. Carlson. 2008. *Hampton Harbor Beach, Hampton Water Quality Report Summer 2007.* Report for the New Hampshire Department of Environmental Services, Concord, NH.

Seabrook Harbor Beach

Merrifield, C., A. Carlson. 2008. *Seabrook Harbor Beach, Seabrook: Water Quality Report Summer 2007.* Report for the New Hampshire Department of Environmental Services, Concord, NH.

Bouthiette, E., S. Sumner. 2007. *Seabrook Harbor Beach, Seabrook: Beach Water Quality Report Summer 2006.* Report for the New Hampshire Department of Environmental Services, Concord, NH.

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Carlson, A., S. Sumner. 2005. *Seabrook Harbor Beach, Seabrook: Beach Water Quality Report Summer 2004.* Report for the New Hampshire Department of Environmental Services, Concord, NH.

Seabrook Town Beach

Merrifield, C., A. Carlson. 2008. *Seabrook Town Beach, Seabrook: Water Quality Report Summer 2007.* Report for the New Hampshire Department of Environmental Services, Concord, NH.

Bouthiette, E., S. Sumner. 2007. *Seabrook Town Beach, Seabrook: Beach Water Quality Report Summer 2006.* Report for the New Hampshire Department of Environmental Services, Concord, NH.

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Carlson, A., S. Sumner. 2005. *Seabrook Town Beach, Seabrook: Beach Water Quality Report Summer 2004.* Report for the New Hampshire Department of Environmental Services, Concord, NH.

Sun Valley Beach

Merrifield, C., A. Carlson. 2008. *Sun Valley Beach, Hampton: Water Quality Report Summer 2007.* Report for the New Hampshire Department of Environmental Services, Concord, NH.

Bouthiette, E., S. Sumner. 2007. *Sun Valley Beach, Hampton: Beach Water Quality Report Summer 2006.* Report for the New Hampshire Department of Environmental Services, Concord, NH.

New Hampshire Department of Environmental Services: Beach Inspection Program. 2006. *Sun Valley Beach, Hampton: Beach Water Quality Report Summer 2005*. Report for the New Hampshire Department of Environmental Services, Concord, NH.

Carlson, A., S. Sumner. 2005. *Sun Valley Beach, Hampton: Beach Water Quality Report Summer 2004.* Report for the New Hampshire Department of Environmental Services, Concord, NH.

Other Reports

Jones. S.H. and C. Edwards. 2007. Management of Non-Human Sources of Bacterial Pollution in Hampton/Seabrook Harbor. Final report.. New Hampshire Department of Environmental Services, Concord, NH.

Jones. S.H., N. Landry and C. Edwards. 2005. Tracking Bacterial Pollution Sources in the Mill Creek Watershed, Seabrook, NH. A Final Report to the U.S. Environmental Protection Agency. New Hampshire Department of Environmental Services, Concord, NH.

Trowbridge, P. 2004. Total Maximum Daily Load (TMDL) Study for bacteria in Hampton/Seabrook Harbor. NHDES-R-WD-03-32. New Hampshire Department of Environmental Services, Concord, NH.

Nolan, S., S.H. Jones and N. Landry. 2004. Evaluating the stormwater treatment performance of AbTech industries Smart Sponge ® Plus in Seabrook, New Hampshire. Final report. New Hampshire Department of Environmental Services, Concord, NH.

Jones, S.H. and N. Landry. 2003. Tracking bacterial pollution sources in Hampton Harbor. Final report. New Hampshire Estuaries Project, Portsmouth, NH.

Jones, SH, N Landry, C Edwards. In press. Enhanced Use of Escherichia coli Ribotyping for Tracking Bacterial Pollution Sources in Coastal New Hampshire, USA. Proceedings of the 6th International Conference in Molluscan Shellfish Safety. 18 to 23 March, 2007, Blenheim, New Zealand.

Nash, C. and M. Wood. 2006. NH Department of Environmental Services Shellfish Program Activities, January 2005 - December 2005. Final Report. NH Estuaries Project, Durham, NH.

Other New Hampshire Beach Area Reports

Jones, S.H., S. Sumner, N. Landry and J. Connor. 2006. Pollution source tracking at New Hampshire (USA) ocean beaches. Pp. 107-114, In, Micallef, A., A. Vassallo and M. Cassar (Eds.) Proceedings of the Second International Conference on the Management of Coastal Recreational Resources-Beaches, Yachting and Coastal Ecotourism. 25-27 October, 2006. Gozo, Malta. Euro-Mediterranean Centre on Insular Coastal Dynamics, Foundation for International Studies, Valletta, Malta.

Jones, S.H., S. Summer and J. Connor. 2004. Identify and Mitigate Bacterial Sources at Public Beaches Using Microbial Source Tracking. Final report. New Hampshire Department of Environmental Services, Concord, NH.

Jones SH. 2008. Environmental Sources of Microbial Contaminants in Shellfish and Their Public Health Significance. J. Foodservice 19:238-244.

Jones, S.H. 2003. Tracking Bacterial Pollution Sources in Stormwater Pipes. Final Report. New Hampshire Estuaries Project, Portsmouth, NH.

Trowbridge, P. 2006. Total Maximum Daily Load (TMDL) Study for bacteria in Little Harbor. NHDES-R-WD-05-25. New Hampshire Department of Environmental Services, Concord, NH.

Jones, S.H. 2004. Microbial Source Tracking in Little Harbor and Tributaries using Escherichia coli Ribotyping. Final report. New Hampshire Department of Environmental Services, Concord, NH.

Jones, S.H. and N. Landry. 2004. Tracking Bacterial Pollution Sources in Little Harbor and the New Hampshire Atlantic Coast Tributaries. Final report. New Hampshire Department of Environmental Services, Concord, NH.

Jones, S.H. 1999. Public health significance of storm water-borne microorganisms. Final report. NH Department of Environmental Services, Concord, NH. 10 pp.

Bolster, C.H., J. M. Bromley, and S. H. Jones. 2005. Recovery of Chlorine-Exposed *Escherichia coli* in Estuarine Microcosms. Environ. Sci. Technol. 39: 3083-3089.

Jones. S.H., N. Landry and R. Ruszenas. 2006 Tracking Bacterial Pollution Sources in the Berry Brook Watershed. A Final Report to the U.S. Environmental Protection Agency. New Hampshire Department of Environmental Services, Concord, NH.

Carlson, A., S. Sumner. 2005. Star Island Beach, Rye: Beach Water Quality Report Summer 2004. Report for the New Hampshire Department of Environmental Services, Concord, NH.

Appendix B: Summary of Fecal-Borne Pollution Sources and Bacterial Data in Nine New Hampshire Coastal Beach Watersheds

Stephen Jones

September 8, 2008

INTRODUCTION

The NHDES has delineated nine watersheds bordering Atlantic Coast beaches that include Tier 1-Impaired, Tier 1, Tier, 2 and Tier 3 beaches, based on the NHDES Beach Program Risk-Based evaluation ranking system. There exists some information on actual and potential sources of fecal-borne bacterial contamination in these watersheds, and there are several aspects of water contamination that are common to most of these beaches. One is the conveyance of elevated bacterial loading during rainstorm runoff events. The focus of the present report is to inform storm water modeling efforts for the targeted watersheds by summarizing what is known about concentrations and sources of fecal indicator bacteria and the dynamics of bacterial concentrations relative to environmental, human and other influences.

This report is organized by watershed, with brief summaries of existing knowledge, data and sources of information for each of the nine watersheds. Pollution sources that are considered to be “identified” are based on the ribotyping analysis conducted as part of the MST studies, whereas those considered as “potential” sources are based on observations of the animal presence or its feces on or near the beach. In general, pollution sources as discussed here are humans or animal species, though other types of sources like wastewater effluent, boats, beach sand, and others are also noted.

WATERSHED: New Castle Town Beach

MST REPORTS: (1)

Jones, S.H. 2008. Microbial Pollution Source Tracking at New Castle Beach. Final report. New Hampshire Department of Environmental Services, Concord, NH.

NHDES BEACH REPORTS: (5)- 2003, 2004, 2005, 2006, 2007

OTHER INFORMATION: None

All of the studies at this beach have used four sampling sites: three along the beach and one at a pipe that discharges into the small rocky beach area north of the recognized town beach area. The pipe discharges from what appears to be a small wet detention pond in the residential area adjacent to the beach. The pond watershed, however, has yet to be delineated. Sampling in the pond showed elevated levels of PAHs and asbestos above State standards, as reported in the 2004 Beach Report (Carlson and Sumner 2005).

Bacterial Concentrations in Water Samples:

Sampling at the three beach sites ranged from a total of 42 to 101 samples per year from 2004 to 2007, and at the pipe from three to 13 samples per year. Enterococci concentrations exceeded the state standard of 104 cfu/100 ml at least one time each year from 2004 to 2007.

Identified Sources of Fecal Contamination: *gulls, cormorants, ducks, geese, dogs, deer, unidentified wild animal, rabbits, coyotes, raccoons, wastewater (human)*

The overall level of source species identification (48%) in the MST study (Jones 2008) conducted in 2006 was relatively low, suggesting the possibility that the some significant source species were not included in the analysis. The most commonly identified source species was gull (14 isolates), followed by unidentified wild animals (7), deer (6), wastewater/human (4), dog and unidentified livestock (3), rabbit, duck and goose (2), with single isolates identified as coming from coyote and raccoon. The number of different species identified as sources at each site was seven for the pipe, six for the left side of the beach (NWCLF), three for the center of the beach (NWCCR) and five for right side of the beach (NWCRT) (Table 8). The number of isolates identified for each source species was relatively even for the beach sites, but was dominated by gulls (7/19 isolates) at the pipe. Gulls were the only source species identified at each site; dog and unidentified wild animals were identified at three sites, while several species were identified at two sites (wastewater, deer, and duck). For all ribotyped isolates, and according to type of source species identified, birds were the most prevalent (20%) source species type, followed by wild animals (18%), humans (4%), and pets and livestock (3%).

Potential Sources of Fecal Contamination: *Gulls, cormorants, dogs, deer, unidentified wild animal*

The NHDES Beach Reports for New Castle Town Beach included observations of the presence of animals on or near the beach during sampling visits. The most common were birds,

particularly gulls and cormorants, though ducks were also observed, and all were observed in low numbers on each occasion. The Beach reports also included observations of turbid water and suspected sand re-suspension occurring, especially at the 'right' sample site, and suggested re-suspended sand may also be a source of bacterial contamination.

As part of the MST study (Jones 2008), NHDES Beach Program personnel collected feces from around the beach watershed to be used as a local source species database. The feces were identified as coming from gulls, dogs, deer, and a sample from an unidentified wild animal, containing *E. coli* concentrations of 1.1×10^{2} to 2.8×10^{10}.

Evidence Of Storm Event Runoff Influence: YES

Jones (2008) showed that the highest recorded levels of *E. coli* occurred during the one wet weather sampling event at the pipe and at the 'right' beach sampling site, which is most distant from the pipe. *E. coli* levels exceeded the state standard (104 cfu/100 ml) only in these samples, and on all other occasions and sites levels were much lower.

WATERSHED: Wallis Sands and Pirates Cove

MST REPORTS: (2)

Jones, S.H. and N. Landry. 2004. Tracking Bacterial Pollution Sources in Little Harbor and the New Hampshire Atlantic Coast Tributaries. Final report. New Hampshire Department of Environmental Services, Concord, NH.

Jones, S.H., S. Summer and J. Connor. 2004. Identify and Mitigate Bacterial Sources at Public Beaches Using Microbial Source Tracking. . Final report. New Hampshire Department of Environmental Services, Concord, NH.

NHDES BEACH REPORTS: (8)- 2004, 2005, 2006, 2007 for each beach

OTHER INFORMATION: (1)

Nash, C. and M. Wood. 2006. NH Department of Environmental Services Shellfish Program Activities, January 2005 - December 2005. Final Report. NH Estuaries Project, Durham, NH.

The annual investigations by NHDES at this beach have used three sampling sites along Wallis Sands beach, three sites along Pirates Cove beach and one at Parsons Creek where it discharges into the southern tip of the Pirates Cove beach area. Parsons Creek drains the marsh area behind these two beaches, and the NHDES sample site designation is ACPS 5, the same site and designation used in the two referenced MST studies.

Bacterial Concentrations in Water Samples:

Sampling at the three Wallis Sands beach sites ranged from a total of 39 to 45 samples per year from 2004 to 2007, from 42 to 45 at the three Pirates Cove beach sites, and at Parsons Creek from eight to 13 samples per year. Enterococci concentrations exceeded the state standard of 104 cfu/100 ml at least one time each year from 2004 to 2007 in Parsons Creek, and on two consecutive dates during July 2006 at Pirates Cove beach.

The NH Shellfish Program also sampled at Wallis Sands and Pirates Cove beaches during 2005 (Nash and Wood 2006). Three monthly samples were collected during June to September and analyzed for fecal coliforms, which ranged from 1.8 to 13 MPN/100 ml at Wallis Sands and from <2 to 170 MPN/100 ml at Pirates Cove; the high value was recorded in June.

Identified Sources of Fecal Contamination: *humans, otters, gulls, deer, cat, fox, raccoon, cow, horse, sparrow*

Parsons Creek is the main source of contamination for Pirates Cove beach. *E. coli* concentrations in seven water samples collected from ACPS 5 during dry weather from June 2001 to September 2002 ranged from 34 to 200 cfu/100 ml (Jones and Landry 2004). The date on which the highest *E. coli* concentration occurred was considered a wet weather date because of the ~1.0 in of rain that fell in the two days prior to sampling. *E. coli* isolates from five water samples were ribotyped and source species identified for 16 of 23 isolates, a success rate of 70%. By far the most significant source was humans (10/16 isolates), followed by otter (2) then 1 isolate each for cat, deer, fox, and gull. For all ribotyped isolates, and

according to type of source species identified, humans were the most prevalent (20%) source species type, followed by wild animals (17%), then pets and birds (4% each).

NHDES conducted a follow-up MST investigation at Parsons Creek, focusing on two storm events during August and September 2003 (Jones et al. 2004). *E. coli* concentrations ranged from 80 to 600 cfu/100 ml, which is higher compared to the previous MST study conducted during mostly dry weather. *E. coli* isolates from four water samples collected during post-peak or end of storm conditions were ribotyped and source species identified for 21 of 35 isolates, a success rate of 60%. The most significant source was humans (6 isolates), followed by deer (5), fox and raccoon (3), cow (2) then 1 isolate each for horse and sparrow. For all ribotyped isolates, and according to type of source species identified, wild animals were the most prevalent (31%) source species type, followed by humans (17%), then livestock (9%) and birds (3% each).

Potential Sources of Fecal Contamination: *gulls, dogs, WWTF effluent, bathers, seaweed, red fox, otters, ducks, deer, skunks, raccoons*

The NHDES Beach Reports for Wallis Sands beach included observations of the presence of a few birds on or near the beach during sampling visits. The fact that the WWTF outfall pipe discharges to the beach area is also a potential source, though the degree of treatment and record of no detection of bacteria in the effluent mitigates that concern. The high number and density of bathers, and the high volume of seaweed that is frequently present at this beach are also potential sources of contamination. At Pirates Cove beach, reports of gulls, terns, dogs and dog feces were reported.

As part of the MST study conducted during 2002 (Jones and Landry 2004), NHDES Beach Program personnel collected feces from the Parsons Creek watershed to be included as local sources in the source species databases. The feces were identified as coming from red fox, otter, duck, deer, skunk and raccoon.

Evidence Of Storm Event Runoff Influence: YES

The results from the two MST studies provide an opportunity to compare differences for wet compared to dry weather conditions, even though the studies were conducted in different time periods. The geometric mean *E. coli* concentration was much higher in Parsons Creek during wet (273/100 ml) compared to dry (51/100 ml) weather conditions. There was also an apparent difference in occurrence for some types of sources species, with a higher incidence of livestock sources during wet weather and a higher occurrence of human sources during dry weather.

WATERSHED: Foss Beach

MST REPORTS: None

NHDES BEACH REPORTS: (4)- 2004, 2005, 2006, 2007

OTHER INFORMATION: None

All of the studies at this beach have used three sampling sites along the beach.

Bacterial Concentrations in Water Samples:

Sampling at the three beach sites ranged from a total of 21 to 42 samples per year from 2004 to 2007. Enterococci concentrations exceeded the state standard of 104 cfu/100 ml once in August 2004.

Identified Sources of Fecal Contamination: *Not known*

Potential Sources of Fecal Contamination: *gulls, dogs, crows*

The NHDES Beach Reports for New Castle Town Beach included observations of the presence of animals on or near the beach during sampling visits. The most common were gulls and dogs.

Evidence Of Storm Event Runoff Influence: YES

The one sample in August 2004 that exceeded the State standard occurred on a day when ~4 inches of rain fell in the previous three days, suggesting runoff contributed to the elevated bacterial concentrations.

WATERSHED: Jenness and Cable Beaches

MST REPORTS: None

NHDES BEACH REPORTS: (8)- 2004, 2005, 2006*, 2007 for each beach
*The file on the NHDES Beach Program website for the Jenness Beach 2006 report could not be opened

OTHER INFORMATION: None

All of the studies at this beach have used three sampling sites along the beach.

Bacterial Concentrations in Water Samples:

Sampling at the three Cable Beach sites ranged from a total of 42 to 81 samples per year from 2004 to 2007. Enterococci concentrations exceeded the state standard of 104 cfu/100 ml twice in 2004, and in single events in 2006 and 2007.

Sampling at the three Jenness Beach sites ranged from a total of 42 to 45 samples per year from 2004 to 2007, although the 2006 report could not be opened from the Beach Program web site. Enterococci concentrations did not exceed the state standard of 104 cfu/100 ml, although elevated levels were observed on July 12, 2006 when there was an exceedence at Cable Beach.

Identified Sources of Fecal Contamination: *Not known*

Potential Sources of Fecal Contamination: *gulls, dogs, plovers, terns, horses*

The NHDES Beach Reports for both beaches included observations of the presence of animals on or near the beach during sampling visits. The most common were gulls and dogs, with plovers observed at both beaches. Terns were also reported at Jenness Beach, and horse feces were observed once at Cable Beach.

Evidence of Storm Event Runoff Influence: YES

The sample in July 2006 that exceeded the State standard at Cable Beach occurred on a day prior to which >1.5 inches of rain fell. The report suggested runoff contributed to the elevated bacterial concentrations at both beaches.

WATERSHED: Sawyer Beach

MST REPORTS: None

NHDES BEACH REPORTS: (4) - 2004, 2005, 2006, 2007*
*The report on the NHDES Beach Program website was incomplete.

OTHER INFORMATION: (1)
Nash, C. and M. Wood. 2006. NH Department of Environmental Services Shellfish Program Activities, January 2005 - December 2005. Final Report. NH Estuaries Project, Durham, NH.

All of the studies at this beach have used three sampling sites along the beach and an added site at the mouth of the beach outlet of Eel Pond.

Bacterial Concentrations in Water Samples:

Sampling at the three beach sites ranged from a total of 39 to 84 samples per year from 2004 to 2007, and from 12 to 19 per year at Eel Pond. Enterococci concentrations exceeded the state standard of 104 cfu/100 ml twice in 2004 and 2006, and once in 2007 at the beach sites, while Eel Pond samples exceeded the State standard each year at least twice, though this information was not available in the incomplete report for 2007.

The NH Shellfish Program also sampled at Sawyer Beach during 2005 (Nash and Wood 2006). Four monthly samples were collected during June to September and analyzed for fecal coliforms, which ranged from <2 to 17 MPN/100 ml.

Identified Sources of Fecal Contamination: *Not known*

Potential Sources of Fecal Contamination: *gulls, dogs, plovers, rabbits, ducks, raccoons*

The NHDES Beach Reports for both beaches included observations of the presence of animals on or near the beach during sampling visits. The most common were the highly numerous gulls, especially in Eel Pond. Dogs and plovers were also observed, and a dying seal was on the beach one day in 2005. Other waterfowl frequent Eel Pond, and these are also potential sources of contamination to Sawyer Beach.

As part of the MST study conducted during 2002 (Jones and Landry 2004), NHDES Beach Program personnel collected feces from Eel Pond to be included as local sources in the source species databases. The feces were identified as coming from rabbit, duck and raccoon.

Evidence of Storm Event Runoff Influence: YES

Sample with elevated enterococci levels in 2006 and 2007 were described in the beach Reports as probably due to rainfall and associated runoff, especially as it affected Eel Pond. Elevated levels at the beach during rainfall-affected conditions were also coincident with elevated enterococci levels at the Eel Pond outlet site.

WATERSHED: Bass Beach

MST REPORTS: (2)

Jones, S.H. and N. Landry. 2004. Tracking Bacterial Pollution Sources in Little Harbor and the New Hampshire Atlantic Coast Tributaries. Final report. New Hampshire Department of Environmental Services, Concord, NH.

Jones, S.H., S. Summer and J. Connor. 2004. Identify and Mitigate Bacterial Sources at Public Beaches Using Microbial Source Tracking. . Final report. New Hampshire Department of Environmental Services, Concord, NH.

NHDES BEACH REPORTS: (4) - 2004, 2005, 2006, 2007

OTHER INFORMATION: (2)

NHDES. 2008. Chapel Brook Special Study North Hampton, NH: May to September 2006. R-WD-07-45. NH Department of Environmental services, Concord, NH.

Nash, C. and M. Wood. 2006. NH Department of Environmental Services Shellfish Program Activities, January 2005 - December 2005. Final Report. NH Estuaries Project, Durham, NH.

The annual investigations by NHDES at this beach have used three sampling sites along Bass Beach, one at Bass Beach Brook at the northern part of the beach and one at Chapel Creek where it discharges into the southern tip of the beach area. Bass Beach Brook drains the Bass beach Marsh area behind the northern part of the beach, and the NHDES sample site designation is ACPS 10, the same site and designation used in the two referenced MST studies. Chapel Brook drains the Philbrick Pond and Marsh, Chapel Pond and smaller associated tributaries behind much of the beach. The NHDES sample site designation is ACPS 11, the same site and designation used in the two referenced MST studies for Chapel Brook.

Bacterial Concentrations in Water Samples:

Sampling at the three beach sites ranged from a total of 39 to 84 samples per year from 2004 to 2007, once at Bass Beach Brook in 2005, and from 7 to 21 per year at Chapel Brook. Enterococci concentrations at the three beach sample sites exceeded the state standard of 104 cfu/100 ml once in both 2004 and 2006. Chapel Brook samples exceeded the State standard at least twice and up to eight times each year, and the one sample collected from Bass Beach brook also exceeded the standard.

The special study conducted at Chapel Brook in 2005 involved sampling from five stations in the Chapel Brook watershed from May to September 2005 (NHDES 2008). Sampling at each site occurred from a minimum of three to 14 times, with a total of 52 samples collected from the watershed. *E. coli* concentrations ranged from 9 to 5100 cfu/100 ml. The “Pond” site had consistently high *E. coli* levels and had the highest concentration (5100 cfu/100 ml). The other four sites had varying levels of *E. coli* present.

The NH Shellfish Program also sampled at Bass Beach Brook (ACPS 10) during 2005 (Nash and Wood 2006). Four monthly samples were collected during June to September and analyzed for fecal coliforms, which ranged from <2 to 6.8 MPN/100 ml.

Identified Sources of Fecal Contamination: *humans, geese, ducks, gulls, raccoons, coyotes, deer, skunks, otters, rabbits, cows, sheep and dogs*

Chapel and Bass Beach brooks are the main sources of bacterial contamination for Bass Beach.

E. coli concentrations in six water samples collected from Bass Beach Brook (ACPS 10) during dry weather from June 2001 to September 2002 ranged from 30 to 360 cfu/100 ml (Jones and Landry 2004). *E. coli* isolates from four water samples were ribotyped and source species were identified for 9 of 18 isolates, a success rate of 50%. There was no most significant source as single isolates were identified for raccoon, cow, coyote, dog, human, otter, gull, sheep and skunk. For all ribotyped isolates, and according to type of source species identified, wild animals were the most prevalent (22%) source species type, followed by livestock (11%), then pets, humans and birds (6% each).

At Chapel Brook (ACPS 11), *E. coli* concentrations in six water samples ranged from 6 to 380 cfu/100 ml (Jones and Landry 2004). *E. coli* isolates from five water samples were ribotyped and were source species identified for 8 of 17 isolates, a success rate of 47%. There was no truly significant source as two isolates were identified as being from both geese and rabbits, while single isolates were identified for deer, ducks, humans and otters. For all ribotyped isolates, and according to type of source species identified, wild animals were the most prevalent (24%) source species type, followed by birds (18%) and humans (5%).

NHDES conducted a follow-up MST investigation at Chapel Brook, focusing on two storm events during August and September 2003 (Jones et al. 2004). *E. coli* concentrations ranged from 370 to 1410 cfu/100 ml, which is much higher compared to the previous MST study conducted during mostly dry weather. *E. coli* isolates from four water samples collected during peak, post-peak or end of storm conditions were ribotyped and source species identified for 21 of 37 isolates, a success rate of 57%. The most significant source was humans (7 isolates), followed by geese and raccoons (4), coyotes and deer (2), then 1 isolate each for cows and otters. For all ribotyped isolates, and according to type of source species identified, wild animals were the most prevalent (24%) source species type, followed by humans (19%), then birds (11%) and livestock (3%).

Potential Sources of Fecal Contamination: *gulls, dogs, plovers, septic system, seaweed, otter, deer*

The NHDES Beach Reports for both beaches included observations of the presence of animals on or near the beach during sampling visits. The most common were the highly numerous dogs, gulls and terns. There was also a suspected failed septic system on Bass Beach Brook in 2004, and turbid water combined with large amounts of seaweed were also considered as potential sources. There is also a concern about the impacts of marsh restorations and their apparent negative impact on indicator bacteria levels in the marsh creeks.

As part of the MST study conducted during 2002 (Jones and Landry 2004), NHDES Beach Program personnel collected feces from Bass Beach Brook (ACPS 10) to be included as local

sources in the source species databases. The feces were identified as coming from otter and deer.

Evidence of Storm Event Runoff Influence: YES

Samples with elevated enterococci levels were described in the Beach Reports as probably due to rainfall and associated runoff, especially as it affected Chapel Brook. Elevated levels at the beach during rainfall-affected conditions were often coincident with elevated enterococci levels at the Chapel Brook outlet site.

The results from the two MST studies provide an opportunity to compare differences for wet compared to dry weather conditions, even though the studies were conducted in different time periods. The geometric mean *E. coli* concentration was much higher during wet (784/100 ml) compared to dry (18/100 ml) weather conditions. There was also an apparent difference in occurrence for some types of sources species, with a higher incidence of livestock sources during wet weather and a higher occurrence of human sources during dry weather.

WATERSHED: State Beach and Northside Park Beach

MST REPORTS: (2)

Jones, S.H. and N. Landry. 2004. Tracking Bacterial Pollution Sources in Little Harbor and the New Hampshire Atlantic Coast Tributaries. Final report. New Hampshire Department of Environmental Services, Concord, NH.

Jones, S.H., S. Summer and J. Connor. 2004. Identify and Mitigate Bacterial Sources at Public Beaches Using Microbial Source Tracking. . Final report. New Hampshire Department of Environmental Services, Concord, NH.

NHDES BEACH REPORTS: (8)- 2004, 2005, 2006, 2007 for each beach

OTHER INFORMATION: (2)

Nash, C. and M. Wood. 2006. NH Department of Environmental Services Shellfish Program Activities, January 2005 - December 2005. Final Report. NH Estuaries Project, Durham, NH.

Jones S.H., S. Sumner, N. Landry and J. Connor. 2006. Pollution source tracking at New Hampshire (USA) ocean beaches. Pp. 107-114, In, Micallef, A., A. Vassallo and M. Cassar (Eds.) Proceedings of the Second International Conference on the Management of Coastal Recreational Resources-Beaches, Yachting and Coastal Ecotourism. 25-27 October, 2006. Gozo, Malta. Euro-Mediterranean Centre on Insular Coastal Dynamics, Foundation for International Studies, Valletta, Malta.

The annual investigations by NHDES at this beach have used three sampling sites along both Northside Park and State beaches, and one at Little River at the southern part of the State Beach that drains the Little River Swamp. The NHDES sample site designation is ACPS 12, the same site and designation used in the two referenced MST studies.

Bacterial Concentrations in Water Samples:

Sampling at the three beach sites for Northside Park Beach ranged from a total of 21 to 42 samples per year from 2004 to 2007. Enterococci concentrations at the three beach sample sites never exceeded the state standard of 104 cfu/100 ml once from 2004 to 2007.

At State Beach, sampling occurred 39 to 124 times each year and from 11 to 18 times per year at Little River. Enterococci concentrations at the three beach sample sites exceeded the state standard of 104 cfu/100 ml between one to four times in 2004, 2006 and 2007, but not in 2005. Little River samples exceeded the State standard at least four times and up to eleven times each year.

The NH Shellfish Program also sampled along State Beach during 2005 (Nash and Wood 2006). Four monthly samples were collected during June to September and analyzed for fecal coliforms, which ranged from <2 to 13 MPN/100 ml.

Identified Sources of Fecal Contamination: *humans, geese, gulls, otters! raccoons, coyotes, foxes, muskrats, rabbits, horses, alpacas and dogs*

The Little River is considered a significant source of bacterial contamination for both Northside Park and State beaches.

E. coli concentrations in six water samples collected from Little River (ACPS 12) during dry weather from June 2001 to September 2002 ranged from 10 to 184 cfu/100 ml (Jones and Landry 2004). *E. coli* isolates from four water samples were ribotyped and were source species identified for 13 of 19 isolates, a success rate of 68%. The most significant source species identified was otters (5 isolates), followed by humans (3), rabbits (2), and single isolates identified for raccoons, geese and muskrat. For all ribotyped isolates, and according to type of source species identified, wild animals were the most prevalent (47%) source species type, followed by humans (16%) and birds (5%).

NHDES conducted a follow-up MST investigation at Little River, focusing on two storm events during August and September 2003 (Jones et al. 2004). *E. coli* concentrations ranged from 1280 to 2210 cfu/100 ml, which is much higher compared to the previous MST study conducted during mostly dry weather. *E. coli* isolates from five water samples collected during peak, post-peak, seep or end of storm conditions were ribotyped and source species identified for 21 of 38 isolates, a success rate of 55%. The most significant source was otters (9 isolates), followed by humans (3), fox and raccoons (2), then 1 isolate each for alpacas, coyotes, dog, gulls and horses. For all ribotyped isolates, and according to type of source species identified, wild animals were the most prevalent (37%) source species type, followed by humans (8%), livestock (5%) then birds and pets (3%).

Potential Sources of Fecal Contamination: *gulls, dogs, seaweed, beach sand*

The NHDES Beach Reports for both beaches included observations of the presence of animals on or near the beach during sampling visits. The most common were gulls and dogs. Seaweed was also mentioned as a potential source at State Beach.

Bacterial pollution sources that may not be from the Little River discharges have also been a concern. A small study was conducted by UNH/JEL on enterococci concentrations in water, beach sand and seaweed wrack near ACPS 12 at North Hampton State Beach (Jones et al. 2006). Seaweed wrack was collected monthly from the wrack line before high tide in the afternoon from June to August, 2004. Beach sand was also collected from below the wrack, midway in the intertidal zone and at 0.5 m water depth, where a water sample was also collected. Enterococci were detected in water at levels less than the single sample maximum of 104/100 ml except during July. Enterococci concentrations in intertidal and submerged beach sand were also relatively low, with a geometric mean of 42 MPN/g dry weight. Consistently high enterococci levels were harbored in beach wrack ($2.0 \pm 0.9 \times 10^5$/g DW) and underlying sand ($6.0 \pm 9.5 \times 10^3$/g DW). The high enterococci concentrations in the wrack and underlying sand suggest that washing of the wrack at high tide could impact water quality.

Evidence of Storm Event Runoff Influence: YES

Samples with elevated enterococci levels at State Beach were described in the Beach Reports as probably due to rainfall and associated runoff, especially as it affected the Little River.

Elevated levels at the beach during rainfall-affected conditions were often coincident with elevated enterococci levels at the Little River outlet site at both beaches.

The results from the two MST studies provide an opportunity to compare differences for wet compared to dry weather conditions, even though the studies were conducted in different time periods. The geometric mean *E. coli* concentration was much higher during wet (993/100 ml) compared to dry (31/100 ml) weather conditions. There was also an apparent difference in occurrence for some types of sources species, with a higher incidence of livestock sources during wet weather and a higher occurrence of human sources during dry weather.

WATERSHED: North Beach

MST REPORTS: None

NHDES BEACH REPORTS: (4) - 2004, 2005, 2006, 2007

OTHER INFORMATION: (1)
Nash, C. and M. Wood. 2006. NH Department of Environmental Services Shellfish Program Activities, January 2005 - December 2005. Final Report. NH Estuaries Project, Durham, NH.

All of the studies at this beach have used three sampling sites along the beach.

Bacterial Concentrations in Water Samples:

Sampling at the three beach sites ranged from a total of 36 to 42 samples per year from 2004 to 2007. Enterococci concentrations never exceeded the state standard of 104 cfu/100 ml from 2004 to 2007.

The NH Shellfish Program also sampled at North Beach during 2005 (Nash and Wood 2006). Four monthly samples were collected during June to September and analyzed for fecal coliforms, which ranged from <2 to 4.5 MPN/100 ml.

Identified Sources of Fecal Contamination: *Not known*

Potential Sources of Fecal Contamination: *gulls, dogs, plovers, ducks, seals*

The NHDES Beach Reports for both beaches included observations of the presence of animals on or near the beach during sampling visits. The most common were gulls and dogs, though plovers, ducks and a seal were also observed and can be considered as potential sources.

Evidence of Storm Event Runoff Influence: YES

Two samples with slightly elevated enterococci levels (50-60 cfu/100 ml) in 2006 were described in the Beach Report as probably due to rainfall and associated runoff, especially as it affected the whole coastline on that day.

WATERSHED: Hampton Beach State Park, Hampton Harbor, Seabrook Harbor, Sun Valley and Seabrook Town Beaches

MST REPORTS: (5)

Jones, S.H. and N. Landry. 2003. Tracking bacterial pollution sources in Hampton Harbor. Final report. New Hampshire Estuaries Project, Portsmouth, NH.

Jones, S.H. 2003. Tracking Bacterial Pollution Sources in Stormwater Pipes. Final Report. New Hampshire Estuaries Project, Portsmouth, NH.

Jones. S.H., N. Landry and C. Edwards. 2005. Tracking Bacterial Pollution Sources in the Mill Creek Watershed, Seabrook, NH. A Final Report to the U.S. Environmental Protection Agency. New Hampshire Department of Environmental Services, Concord, NH.

Jones. S.H. and C. Edwards. 2007. Management of Non-Human Sources of Bacterial Pollution in Hampton/Seabrook Harbor. Final report. New Hampshire Department of Environmental Services, Concord, NH.

Jones, SH, N Landry, C Edwards. In press. Enhanced Use of Escherichia coli Ribotyping for Tracking Bacterial Pollution Sources in Coastal New Hampshire, USA. Proceedings of the 6th International Conference in Molluscan Shellfish Safety. 18 to 23 March, 2007, Blenheim, New Zealand.

NHDES BEACH REPORTS: (17)- 2004, 2005, 2006, 2007 for all beaches except Hampton Harbor Beach, for which there is only a 2007 Beach Report

OTHER INFORMATION: (3)

Nolan, S., S.H. Jones and N. Landry. 2004. Evaluating the stormwater treatment performance of AbTech industries Smart Sponge ® Plus in Seabrook, New Hampshire.

Trowbridge, P. 2004. Total Maximum Daily Load (TMDL) Study for bacteria in Hampton/Seabrook Harbor. NHDES-R-WD-03-32. New Hampshire Department of Environmental Services, Concord, NH.

Nash, C. and M. Wood. 2006. NH Department of Environmental Services Shellfish Program Activities, January 2005 - December 2005. Final Report. NH Estuaries Project, Durham, NH.

The annual investigations by NHDES at these beaches have used the same established sampling sites along each beach. The number of sites is five for Hampton Beach State Park (referred to as Hampton Beach hereafter), three each for Hampton Harbor, Seabrook Harbor and Seabrook Town beaches, and two for Sun Valley Beach.

Bacterial Concentrations in Water Samples:

Sampling at the five beach sites for Hampton Beach ranged from a total of 60 to 135 samples per year from 2004 to 2007. Enterococci concentrations exceeded the state standard of 104 cfu/100 ml only on two dates in May, 2004 during the pre-season. Enterococci concentrations

never exceeded the standard at Hampton Harbor Beach (19 samples/y) in 2007 and at Sun Valley (14-28 samples/y) from 2004 to 2007. Enterococci concentrations did exceed the standard at Seabrook Harbor Beach (42-81 samples/y) twice each year in 2005 and 2006, and once each year at Seabrook Town Beach (39-45 samples/y) in 2004 and 2006.

The NH Shellfish Program also sampled along Hampton Beach during 2005 (Nash and Wood 2006). Four monthly samples were collected during June to September and analyzed for fecal coliforms, which ranged from <2 to 33 MPN/100 ml.

Hampton/Seabrook Harbor has three NPDES permitted discharges, the main one being the Hampton municipal wastewater treatment facility (WWTF). The other two permitted sources for bacteria discharges, EnviroSystems, Inc. (NPDES # NH0022055) and Aquatic Research Organisms, Inc. (NPDES # NH0022985), are considered negligible sources (Trowbridge 2004). Estimated fecal coliform (FC) loads from the Hampton WWTF were based on Discharge Monitoring Reports from 1989 to 2001 and conversion of data for total coliform concentrations in the effluent. The geometric mean loading rate from the WWTF decreased from ~0.8 billion FC/d in 1989 TO 0.3 billion FC/d in 2001. In addition, MS4 stormdrains discharged an estimated average of ~3500-6100 FC/100 ml in July and October 2002, with a range of 50 to 14,200 FC/100 ml. This translated to a loading of 120 to 630 billion FC/d during the July and October storm events, respectively. This is much higher than the calculated loading from the Hampton WWTF, though, of course, it only occurs during storm events.

Mill Creek is considered to be a chronic source of fecal-borne bacteria to Hampton/Seabrook Harbor. *E. coli* concentrations from 104 water samples collected from 8 study sites in the Cains Brook/Mill Creek watershed on 13 dates during June to November 2004 ranged from 1 to 12,100 *E. coli*/100 ml (Jones et al. 2005). Concentrations increased at sites going downstream and the highest geometric mean concentration was at the most downstream site closest to the harbor. This is consistent with Trowbridge (2004) where the only harbor site that did not meet the shellfish geometric mean standard was the site at the mouth of Mill Creek.

Identified Sources of Fecal Contamination: *humans: boat discharges, wastewater effluent (Hampton WWTF), deer, coyote, fox, raccoon, otter, rabbit, skunk, muskrat, horse, cow, goat, chicken, dog, cat, cormorant, goose, gull, duck, pigeon, robin, wild turkey, dry weather nonpoint and tributary storm sources*

An early MST study was conducted on the whole Hampton/Seabrook Estuary to address shellfish harvesting concerns. Fecal coliform concentrations in 310 water samples collected from ten sampling sites in Hampton/Seabrook Harbor during dry and wet weather from August 200 to October 2001 ranged from <1 to 168 cfu/100 ml (Jones and Landry 2003). *E. coli* isolates from water samples collected from all sites and 30 of the sample dates were ribotyped and source species were identified for 236 of 391 isolates, a success rate of 60%. The most significant source species identified was humans (102 isolates), followed by deer (29), coyote (23), horse (20), dog (14), goose (11), gull (10), cow and fox (8), duck (5), chicken (4), and single isolates identified for pigeon and robin. For all ribotyped isolates, and according to type of source species identified, humans were the most prevalent (26%) source species type, followed by wild animals (15%) livestock (8%), birds (7%) and pets (4%). Little difference in source types was observed for isolates collected during wet compared to dry weather or for

autumn (September-November) compared to the rest of the year.

Trowbridge (2004) reported the results of a TMDL for Hampton/Seabrook Harbor. The TMDL was focused on shellfish harvesting impairments, and recognizes that contact recreation (swimming) impairments were not evident at the time of the study for this area. As a result, the data analysis excludes data during June-August, the primary recreation period. Nonetheless, the information on pollution sources is useful for this report. Overall, the percent of annual bacterial loading was estimated to be 7% for boat discharges, 52% for dry weather non-point sources and 41% for stormwater loading, with 0% for the Hampton WWTF. Some of the stormwater loading also came from tributaries.

As part of the Hampton/Seabrook Harbor TMDL, NHDES collected samples from two stormwater sources and these were also used for ribotyping analysis (Jones 2003). The pipes included HHPS069 in Hampton, which drains multiple catch basins along Ashworth Avenue, and HHPS182 in Seabrook, which receives stormwater runoff via the River Street pump station. Five samples from each source were collected at hourly intervals during a large rainstorm on October 16, 2002. Birds (cormorants> geese> gull> pigeon) were the largest relative source of bacteria for both pipes, accounting for 21 (36%) of the total 59 ribotyped isolates. Humans accounted for 20% of the isolates, followed by wild animals (15%; fox, raccoon, coyote) and pets (7%; cat, dog). Sources were identified for 78% of the isolates, leaving 22% unidentified. These results are somewhat different from the relative source strengths determined by Jones and Landry (2003), probably due to the obvious differences in timing, duration and spatial extent of the two studies. The data from the two pipes is still useful for designing remediation plans for these two sources and, importantly, for identifying the presence of human-sourced bacteria in storm water.

A more spatially focused MST study took place during 2004 in the Cains Brook and Mill Creek watersheds (Jones et al. 2005) of Seabrook, NH and Salisbury, MA. *E. coli* isolates from 32 water samples collected from 7 of the 8 study sites on 10 of the 13 sample dates were ribotyped. Source species identified for 151 of 283 isolates, a success rate of 53%. The most significant source species identified was chickens (25 isolates), followed by human (22), horse (16), cow (12), deer and dog (10), cat, coyote and unidentified wild animals (8), goose and raccoon (7), otter and gull (3), rabbit (2) and single isolates identified for fox, unidentified livestock, skunk and wild turkey. For all ribotyped isolates, and according to type of source species identified, livestock/chickens were the most prevalent (19%) source species type, followed by wild animals (12%), humans (8%), pets (6%) and birds (4%). Distinct difference in source types were observed for isolates collected in areas characterized by different land uses.

Yet another MST study focused on identifying non-human sources of pollution at two sites, including the HHPS069 pipe (Jones 2003), in Hampton during 2005 (Jones and Edwards 2007). *E. coli* isolates from 24 of 61 total water samples collected from the 7 study sites on 9 of the 10 sample dates were ribotyped. Source species identified for 95 of 189 isolates, a success rate of 50%. The most significant source species identified was humans (26 isolates), followed by unidentified wild animal(s) (14), raccoons (14), deer and geese (7), horses (6), cats (5), gulls (4), foxes and dogs (3), ducks, cows and goats (2) and single isolates identified for muskrats and otters. For all ribotyped isolates, and according to type of source species

identified, wild animals were the most prevalent (20%) source species type, followed by humans (14%), birds (7%), livestock (5%) and pets (4%). A high prevalence of human-borne bacteria was observed at the HHPS069 pipe (42%) whereas wild animals were more prevalent in the study area on the outskirts of downtown Hampton.

Potential Sources of Fecal Contamination: *gulls, dogs> seaweed, plovers, terns, cats, bathers, moored boats, fish, marinas*

The NHDES Beach Reports for both beaches included observations of the presence of animals on or near the beach during sampling visits. The most common sources, observed at all five beaches, were the typical gulls and dogs. A variety of other potential sources were also observed, including seaweed, plovers, terns and cats. High density and numbers of bathers were cited as a potential source at Hampton Beach, while moored boats and fish from fishing were considered to be potentially significant sources at Seabrook Harbor Beach and dredged sediments at Seabrook Town Beach. The influence of spring tides on bacterial contamination was mentioned for Seabrook Harbor Beach.

In two of the MST studies, feces samples were collected in the study areas to provide local source material for building source species databases. For the Mill Creek/Cains Brook study, *E. coli* was isolated from wastewater, and the feces of dogs, chickens, horses and geese found in the watershed, and these were included in the source species database (Jones et al. 2005). Jones and Edwards (2007) included isolates from raccoons, muskrats and an unidentified wild animal in the source species database for that study. All of these were identified as sources in MST studies, so they are already listed as identified sources for this watershed.

Evidence Of Storm Event Runoff Influence: YES

Samples with elevated enterococci levels at Hampton Beach were described in the Beach Reports as possibly associated with rainfall and associated runoff. Little other mention of runoff as a factor was made for the other four beaches, though the close proximity to urbanized areas and impervious surfaces is obviously a consideration.

Trowbridge (2004) reported an analysis of long-term fecal coliform data for sites in Hampton/Seabrook Harbor showed an increase with increasing size (rainfall amount) of storms. In addition, the prevalence of elevated 90th percentile values for fecal coliforms in harbor sites suggests unacceptably high variability in FC due to periodic spikes from wet weather runoff. The estimated FC loading based on modeling during different size storms ranged from ~1600 billion FC/d for storms of 0.02-0.5 in to ~29,000 billion FC/d for storms >1 in for the harbor.

Jones et al. (2005) reported little difference on geometric mean *E. coli* concentrations at 8 sites in the Cains Brook/Mill Creek watersheds. The geometric mean for dry weather was 102/100 ml, and that for wet weather was 99/100 ml. There were marked differences, however, for the incidence of the different types of source species under wet and dry weather. Considering only identified isolates, the incidence of wild animals was much higher during dry (31%) compared to wet (13%) weather, while the incidence of birds was much higher during wet (21%) compared to dry (6%) weather (Jones et al. In press). There was little to no

difference in the incidence of other source types for wet and dry weather.

A detailed study was conducted in the HHPS069 stormwater pipe (Jones 2003) to evaluate the pollutant removal efficiencies of a commercial material installed in an existing stormwater treatment system to remove bacterial from stormwater runoff (Nolan et al. 2004). The technology tested was AbTech Smart Sponge® Plus material installed into the main stormwater drain pipe upstream of HHPS069 outfall and the River St. pump station. Enterococci concentrations ranged from 150 to 50,000 cfu/100 ml in the influent and effluent stormwater from September 2003 to May 2004. The overall load reductions for the bacterial indicators were 50.3% for fecal coliforms, 51.3% for *E. coli* and 43.2% for enterococci, suggesting that post-treatment stormwater would still result in discharge of elevated bacterial levels that would continue to limit uses in receiving waters.

REFERENCES

MST REPORTS: (8)

Jones, S.H. and N. Landry. 2003. Tracking bacterial pollution sources in Hampton Harbor. Final report. New Hampshire Estuaries Project, Portsmouth, NH.

Jones, S.H. 2003. Tracking Bacterial Pollution Sources in Stormwater Pipes. Final Report. New Hampshire Estuaries Project, Portsmouth, NH.

Jones, S.H. and N. Landry. 2004. Tracking Bacterial Pollution Sources in Little Harbor and the New Hampshire Atlantic Coast Tributaries. Final report. New Hampshire Department of Environmental Services, Concord, NH.

Jones, S.H., S. Summer and J. Connor. 2004. Identify and Mitigate Bacterial Sources at Public Beaches Using Microbial Source Tracking. . Final report. New Hampshire Department of Environmental Services, Concord, NH.

Jones. S.H., N. Landry and C. Edwards. 2005. Tracking Bacterial Pollution Sources in the Mill Creek Watershed, Seabrook, NH. A Final Report to the U.S. Environmental Protection Agency. New Hampshire Department of Environmental Services, Concord, NH.

Jones. S.H. and C. Edwards. 2007. Management of Non-Human Sources of Bacterial Pollution in Hampton/Seabrook Harbor. Final report. New Hampshire Department of Environmental Services, Concord, NH.

Jones, S.H. 2008. Microbial Pollution Source Tracking at New Castle Beach. Final report. New Hampshire Department of Environmental Services, Concord, NH.

Jones, SH, N Landry, C Edwards. In press. Enhanced Use of Escherichia coli Ribotyping for Tracking Bacterial Pollution Sources in Coastal New Hampshire, USA. Proceedings of the 6th International Conference in Molluscan Shellfish Safety. 18 to 23 March, 2007, Blenheim, New Zealand.

NHDES BEACH REPORTS: (1)

Carlson, A. and S. Sumner. 2005. New Castle Town Beach, New Castle, New Hampshire. Beach Water Quality Report. Summer 2004. NH Department of Environmental Services, Concord, NH.

ALSO Beach Reports for all beaches from 2004, 2005, 2006, 2007 except Hampton Harbor Beach, for which there is only a 2007 Beach Report, were used but not cited.

OTHER INFORMATION: (5)

Nolan, S., S.H. Jones and N. Landry. 2004. Evaluating the stormwater treatment performance of AbTech industries Smart Sponge ® Plus in Seabrook, New Hampshire.

Trowbridge, P. 2004. Total Maximum Daily Load (TMDL) Study for bacteria in Hampton/Seabrook Harbor. NHDES-R-WD-03-32. New Hampshire Department of Environmental Services, Concord, NH.

Nash, C. and M. Wood. 2006. NH Department of Environmental Services Shellfish Program Activities, January 2005 - December 2005. Final Report. NH Estuaries Project, Durham, NH.

Jones S.H., S. Sumner, N. Landry and J. Connor. 2006. Pollution source tracking at New Hampshire (USA) ocean beaches. Pp. 107-114, In, Micallef, A., A. Vassallo and M. Cassar (Eds.) Proceedings of the Second International Conference on the Management of Coastal Recreational Resources-Beaches, Yachting and Coastal Ecotourism. 25-27 October, 2006. Gozo, Malta. Euro-Mediterranean Centre on Insular Coastal Dynamics, Foundation for International Studies, Valletta, Malta.

NHDES. 2008. Chapel Brook Special Study North Hampton, NH: May to September 2006. R-WD-07-45. NH Department of Environmental services, Concord, NH.

Appendix C: List of Literature Reviewed for Bacteria-Related Estimation Methods and Parameters

List of Literature Reviewed for Bacteria-Related Estimation Methods and Parameters

Our goal was to find and select the best bacteria source and transport parameter values available to support the beach load estimation. To support achievement of that goal, many journal articles were reviewed. A compilation of these articles, along with brief summaries, is provided below.

Agourdis, C.T., S.R. Workman, R.C. Warner, and G.D. Jennings, 2005. Livestock Grazing Management Impacts on Stream Water Quality: A Review. J. Amer. Water Res. Assoc., pp. 591-606.

AgouridisJAWRA2005.pdf

Cites Larsen et al 1994 on WQ benefits of having cattle manure deposited away from streams, citation found but not article.

States filter strips removed 95% of fecal coliform from animal runoff, citing Johnson et al 1982 and Risse *et al* 1996.

States that clay particles in sediment delivery increases survival of fecal coliforms.

States that density of animals on the landscape was correlated with bacterial WQ problems; specifically when calf/cow pairs exceeded 1.75 per hectare, significant increase in fecal coliforms observed in streams.

Discuses use of alternate water supplies in pastures to entice animals out of streams.

American Society of Agricultural Engineers, 2003. Manure production and characteristics: section D384.1, in ASAE Standards. ASAE, St. Joseph, MI.

ASAEStandard_2003.pdf

Table of manure characteristics by 1000 lbs. and by 1000 kg of live animal mass for various animals. Includes nutrients and fecal coliform.

Bai, S. and Lung W. 2006. Three-Dimensional Modeling of Fecal Coliform in the Tidal Basin and Washington Channel, Washington, DC. Journal of Environmental Science and Health Part A, 41:1327–1346.

Bai_tidalbasin_3Dmodel_2006.pdf

3D, hydrodynamic fecal coliform modeling study for Tidal Basin in Washington DC. Uses EFDC model framework. Model not fully calibrated due to sparse data. Assumes that fecal coliform die off very quickly after entering the water, and that mixing is not complete. Model incorporates a sediment storage component. Application of die-off equation, presents a table of die-off constants from around the country. Comparison of model results and field data suggest FC sources other than stormwater (for example, birds which introduce FC directly to water). Model also suggests bottom shear or scouring in channel may cause high FC concentrations from FC stored in sediments (i.e., without external source), and states that without

considering sediment deposition and re-suspension dynamics, TMDL models may fail to provide reliable results.

Bowie, G.L., W.B. Mills, D.B. Porcella, C.L. Campbell, J.R. Pagenkopf, G.L. Rupp, K.M. Johnson, P.W.H. Chan, and S.A. Gherini. 1985. Rates, constants, and kinetic formulations in surface water quality modeling. 2nd edition. EPA/600/3-85/040. Environmental Research Laboratory, Athens, GA.

folder: Bowie_rates-constants-WQmodeling; see chapter 8

Excellent discussion regarding modeling bacterial die-off. Good summary of factors affecting bacterial decay: in order of strength of correlation, these include

light (via near-UV chromophores endogenous to coliforms which damage cells in presence of sunlight, plus exogenous factors like algal pigments, lignins, humic and fulvic acid, and turbid and colored water which may have damaging effects on coliforms when exposed to sunlight),

adsorption/coagulation/sedimentation (especially with clays, with negative implications for sediment water quality)

temperature (higher temp → faster die-off),

metals, which exhibit antibacterial properties,

oxygen shock (going from sewage or septic tank to well-oxygenated waters) which damages bacterial cells,

level of nutrients (contradictory relationships, including more nutrients → more chelation of metals and thus slower die-off, more nutrients → more predator action and thus faster die-off, more nutrients → more algae which have antibacterial agents and thus faster die-off.

The paper steps through progressively more complex models that account for each of these factors, and presents brief discussion of some *in-situ* verification methods, such as tracer and sampling regimes.

One basic conclusion is that in colder waters (such as NH), bacteria are likely to die-off more slowly. See equation 3-98 for a temperature-adjusted bacterial die-off model.

Cahoon, L.B., J.C. Hales, E.S. Carey, S. Loucaides, K.R. Rowland, and J.E. Nearhoof. 2006. Shellfishing Closures in Southwest Brunswick County, North Carolina: septic tanks vs. storm-water runoff as fecal coliform sources. Journal of Coastal Research. 22(2), 319-327. West Palm Beach (Florida).

Cahoon_septic_v_stormwater_2004.pdf

North Carolina FC source study driven by shellfish closures.

Purpose of study was to test two hypotheses: 1) stormwater is causing bacterial impairments; 2) failing septic systems are causing bacterial impairments.

Methods were:

water quality sampling (FC, plus suite of nutrients, chl-a, turbidity, salinity, pH)

wet/dry weather analysis

soils analysis

graphical and statistical analysis, analysis of soil types relative to septic locations.

Generally found no significant difference between wet & dry results thus concluded that stormwater runoff not significant contributor of FC.

Carpenter, S.R., N.F. Caraco, D.L. Correll, R.W. Howarth, A.N. Sharpley, and V.H. Smith, 1998. Nonpoint Pollution of Surface Waters with Phosphorus and Nitrogen. Ecological Applications, Vol. 8, No. 3, pp. 559-568.

Carpenter_NPS_1998_issue3.pdf

Consensus of six scientists (i.e., not a peer-reviewed journal article) of freshwater eutrophication. Cites runoff of applied N and P fertilizer to be less than 5% of original amount applied, while manure runoff contains up to 20%. Does not address bacteria.

Cassell ,E.A., D.W. Meals, S.G. Aschmann, D.P. Anderson, B.H. Rosen, R.L. Kort, and J.M. Dorioz. 2002. Use of Simulation Mass Balance Modeling to Estimate Phosphorus and Bacteria Dynamics in Watersheds. Water Science and Technology. 45(9):157–168.

Cassell_massbalance_bact_P_2002.pdf

Alternative model, Watershed Ecosystem Nutrient Dynamics (WEND). Not particularly relevant to AVGWLF needs, because discussion is too general. Does not deal with finding data for source parameters.

Center for Coastal Environmental Health and Bimolecular Research. 2007. Nutrient and Coliform Loading: A database of available bacteria and nutrient loading data. Online and Excel database at http://www.chbr.noaa.gov/ncl/default.aspx, accessed January 8, 2009.

NOAA_fecal_loading_database.xls

This literature review appears to have consisted of a keyword search performed on Cambridge Scientific Abstracts and Science Direct databases. While not comprehensive, it does provide additional resources for follow up.

Crane, S.R. and J. A. Moore. 1986. Modeling enteric bacterial die-off: A review. Water, Air, and Soil Pollution. 27:411-439.

Crane_modeling_bact_dieoff_1985.pdf

Well organized and authoritative treatment of factors which influence bacterial die-off, based on extensive literature review. Presents varying die-off models and discusses real-world situations in which they have been observed to apply.

DeGraaf, RM and M. Yamanski. 2001. New England Wildlife: habitat, natural history, and distribution. University Press of New England, Hanover, NH.

Dix, S.P., D.C. Hoxie. 2001. Analysis of Septic System Longevity in Maine. On-Site Wastewater Treatment: Proc. 9th Nat. Symp. Individual and Small Community Sewage Systems (11-14 March 2001, Fort Worth, Texas, USA), ed. Karen Mancl. St. Joseph, Michigan: ASAE 701P0009. Pp. 340-348. NA

Available for purchase at: http://asae.frymulti.com/abstract.asp?aid=6043&t=2

Easton, J.H, J.J. Gauthier, M.M. Lalor, and R.E. Pitt, 2005. Die-Off of pathogenic E. Coli O157:H7 in sewage contaminated waters. J. Amer. Water Res. Assoc., Vol. 41, No. 5, pp. 1187-1194.

Easton_E.coli_Dieoff_Weftec1999.pdf
In-situ study of pathogenic *E. coli* and *Giardia* cysts fate and transport in AL. Showed rapid initial die-off, then a trend toward equilibrium with environment, which contradicts literature indicating a constant die-off rate.

Evans, B.M. and K.J. Corradini, 2007. AVGWLF, Version 7.0: A Guide to Creating Software-Compatible Data Sets. Penn State Institutes of the Environment, 34 pp.

AVGWLFFormatGuide.pdf
Evans and Corradini, 2007. How to create animal-related loading file, among other AVGWLF specific information.

Garcia-Armisen, T., J. Prats, and P. Servais. 2007. Comparison of culturable fecal coliforms and *Escherichia coli* enumeration in freshwaters. Can. J. Microbiol. 53:798–801.

Garcia-Armisen_ecoli-fecal-ratio_2007.pdf
E. coli / FC ratio of 0.77 found (n=166) in freshwater samples. Used membrane filtration for FC and MPN microplate for *E. coli.*

Glasoe, S. and A. Christy. 2005. Literature Review and Analysis of Coastal Urbanization and Microbial Contamination of Shellfish Growing Areas.

Glasoe_litreview_bact_urbanization_2005.pdf
Brief lit review citing eight sources. One of which, Weiskel *et al.*, was found and appears below.

Gould, D. G., and M. R. Fletcher, 1978. Gull Droppings and their Effects on Water Quality. Water Research. Vol. 12, No. 9, Pg. 665-672. September 1978.

Hubbard, R.K., G.L. Newton, and G.M. Hill, 2004. Water quality and the grazing animal. J. Animal Science, Vol. 82, pp. 255-263.

Hubbard_WQ_grazing_E255.pdf
Overview of nutrients and pathogens associated with grazing livestock. Table of per animal unit values, with "n." Discussion of health effects of high N in drinking water. Cites livestock as a likely source of *Cryptosporidium parvum* pathogens, otherwise a very brief treatment of bacteria.

Hubbs, A.K.B. 2002. Fecal Coliform Concentration in Surface Runoff from Pastures with Applied Dairy Manure. Masters Thesis for Louisiana State University and Agricultural and Mechanical College.

Hubbs_MSthesis_fecal-dairy_2002.pdf
Found fecal coliform counts up to 10^7 in run-off from pastures amended with dairy manure.
Contains a literature review in introduction.

Kellogg, R.L., C.H. Lander, D.C. Moffitt, and N. Gollehon. 2000. Manure Nutrients Relative to the Capacity of Cropland to Assimilate Nutrients. USDA Pub. No. NPS00-0579.

Kellogg_2000_marnntr.pdf

Contains an "animals per animal unit (1000 lbs.)" conversion table. Extensive explanation of methodology for calculating numbers of animals based on the USDA National Agricultural Statistics Service 5-year census. Quantifies trend toward fewer, more concentrated livestock operations. Series of national maps showing livestock and nutrient statistics by county (NH has low numbers of livestock compared to nation).

Kelsey, H., G. Scott, D.E. Porter, B. Thompson and L. Webster. 2003. Using Multiple Antibiotic Resistance and Land Use Characteristics to Determine Sources of Fecal Coliform Bacterial Pollution. Environmental Monitoring and Assessment. 81(1-3):337-348.

Available to purchase at: http://www.springerlink.com/content/p5p4413ku0082707/

Kelsey, H., D.E. Porter, G. Scott, M. Neet and D. White. 2004. Using Geographic Information Systems and Regression Analysis to Evaluate Relationships Between Land Use and Fecal Coliform Bacterial Pollution. Journal of Experimental Marine Biology and Ecology. 298(2):197-209. NA

Available to purchase at: sciencedirect.com

Kirby-Smith, W.W. and N.M. White. 2006. Bacterial Contamination Associated with Estuarine Shoreline Development. Journal of Applied Microbiology 100:648–657.

Kirby-Smith_shorelinedevelopment-bact_2005.pdf

NC study addressing five land-use types: old developed shore, new developed shore, undeveloped shore, pseudo-marina, real marina.

Found both old and new development had high bacterial counts, as did marinas. Concludes that marsh surface flooding led to suspension of wildlife fecal bacteria on estuary and near-shore surfaces, on the basis of positive correlation between high water levels due to wind tides and bacteria counts.

Kloot, R.W., B. Radakovich, X. Huang, and D. Brantley. 2006. A Comparison of Bacterial Indicators and Methods in Rural Surface Waters. Environmental Monitoring and Assessment. 121:275–287

Kloot_compare_FC_Ecoli_2005.pdf

Found ratios *E. coli* to fecal coliform between 1.63 and 0.84 in rural SC, and urges caution in comparing data obtained by divergent test methods (membrane filtrations vs. enzymatic techniques).

Lipp, E.K., R. Kurz, R. Vincent, C. Rodriquez-Palacios, S.R. Farrah and J.B. Rose. 2001. The Effects of Seasonal Variability and Weather on Fecal Pollution and Enteric Pathogens in a Subtropical Estuary. Estuaries. 24(2): 266-276. NA

Lowe, K.S., N. Rothe, J. Tomaras, K. DeJong, M Tucholke, J. Drewes, J. McCray, and J. Munakata-Marr. 2007. Influent Constituent Characteristics of the Modern Waste Stream from Single Sources: Literature Review. Water Environment Research Foundation. 04-DEC-1.

Report: *04DEC1P1.pdf*
Excel spreadsheet: *04DEC1aDatabase.xls*
Extensive literature review and spreadsheet detailing the constituents (FC, nutrients, oil and grease, organics, etc) of raw wastewater, septic tank effluent, municipal wastewater, etc. Results identified by region.

Mallin, M.A., S.H. Ensign, M.R. McIver, G.C. Shank and P.K. Fowler. 2001. Demographic, Landscape, and Meteorological Factors Controlling the Microbial Pollution of Coastal Waters. Hydrobiologia. 460:185-193. NA

Mallin, M.A., K.E. Williams, E.C. Esham and R.P. Lowe. 2000. Effect of Human Development on Bacteriological Water Quality in Coastal Watersheds. Ecological Applications. 10(4):1047-1056. NA

Manache G., C.S. Melching, and R. Lanyon. 2007. Calibration of a Continuous Simulation Fecal Coliform Model Based on Historical Data Analysis. Journal of Environmental Engineering. 133:7 p. 681.

Manache_FC_calibration_data_2007.pdf
Calibration study for Chicago Waterway fecal coliform model, fit historical data to die-off model. Notes historical fact that disinfection of waterway was discontinued since recreational water contact was virtually nonexistent, and disinfection did not reduce end-of-waterway bacterial levels. Furthermore, after chlorine disinfection was halted, number and variety of fish were greatly improved.
Cites Mancini (1978) model as most complete to describe fecal coliform decay in water.
Also cites a "literature" value for decay rate *k* of 0.8 in Thomann and Mueller 1987, p. 235.

Maxfield, M., W.E. Daniell, C.D. Treser, and J. VanDerslice. Aerobic Residential Onsite Sewage Systems: An Evaluation of Treated-Effluent Quality. 2003. Journal of Environmental Health. 66(3):14-19.

Maxfield_ATU_malfunction_2005.pdf
Study indicates that aerobic septic systems (advanced treatment units) had a high failure rate for BOD and fecal coliform in WA, even just one year from installation.

McCoy, E.L. and C. Hagedorn. 1979. Quantitatively Tracing Bacterial Transport in Saturated Soil Systems. Water, Air, and Soil Pollution. 11:467-479.

Noss, R.R. and M. Billa. 1988. Septic System Maintenance Management. Journal of Urban Planning and Development, 114(2):73-90.

Pollutant Removal Database.

CWP BMP Performance Dbase 20Sep07.pdf
Paper that compiles statistics on the ability of various types of stormwater BMP's to remove a suite of contaminants from stormwater.

Moore, J.A., J. Smyth, S. Baker, and J.R. Miner. 1988. Evaluating coliform concentrations in runoff from various animal waste management systems. Special Report 817, Agricultural Experiment Station, Oregon State University, Corvallis.
Moore_coliform_livestock_SR817_ocr1988.pdf
Examination of bacteria fate and transport from livestock / manure to water body, with focus on developing the MWASTE model. Several tables indicating FC/100mL in various agricultural runoff, concentration of FC in various manures, daily manure production for various animals. Discussion of various bacterial die-off models and situations where they have been observed.

Neitsch, S.L., J.G. Arnold, J.R. Kiniry, J.R. Williams. 2005. Soil and Water Assessment Tool (SWAT) Theoretical Documentation Version 2005. Agricultural Research Service, and Texas Agricultural Experiment Station, Temple, Texas.
Neitsch_swat_theory_2005.pdf
Descriptions of equations specific to the SWAT model, not so useful for general modeling parameterization.

North Carolina Dept. Environment and Natural Resources, 2004. Total Maximum Daily Load for Fecal Coliform for Crowders Creek, North Carolina and South Carolina. Final Report.
NCDENR_Crowders Creek TMDL Final to EPA.pdf
States a decay rate of 1.0 per day in-stream for fecal coliform, citing median value in Bowie *et al* 1985. However, upon reviewing Bowie, I cannot see the basis for this statement.
Also states: "Decomposition of fecal coliform in the soil was initially set at 0.27 day-1 based on the median value for the soil environment in Crane and Moore (1986)." I haven't reviewed Crane and Moore.

Paul, S., M. Matlock, P.K. Haan, S. Mukhtar, and S. Pillai. 2002. Uncertainty Analysis as a First Step of Developing a Risk-Based Approach to Nonprofit Source Modeling of Fecal Coliform Pollution for Total Maximum Daily Load Estimates. Technical Report No. 192, Texas Water Resources Institute, Texas A&M University, College Station, Texas.
Paul_uncertaintyanalysis_FC_model_2002.pdf
TX application of an HSPF model for FC TMDL. Potentially useful information on how to quantify uncertainty in models.

Noble, R.T., S.B. Weisberg, M.K. Leecaster, C.D. McGee, K. Ritter, K.O. Walker, and P.M. Vainik. 2003. Comparison of Beach Bacterial Water Quality Indicator Measurement Methods. Environmental Monitoring and Assessment. 81:301–312.

noble_comparison_fecal_methods_2003.pdf
Study comparing membrane filtration, multiple tube fermentation, IDEXX methods. Found membrane filtration tends to underestimate somewhat.

Schueler, T. 1987. Controlling Urban Runoff: A Practical Manual for Planning and Designing Urban Best Management Practices. Metropolitan Washington Council of Governments. Washington, D.C.

Schueler, T., D. Hirschman, M. Novotney and J. Zielinski. 2007. Urban Stormwater Retrofit Practices. Manual 3 in the Urban Subwatershed Restoration Manual Series, Appendix. Center for Watershed Protection, Ellicott City, MD.

Urban_SW_Retro_Practices_Apps.pdf
Appendix B is highly useful. Provides EMC's for fecal coliform for various land uses.

Smith, J., and J. Perdek. 2004. Assessment and management of watershed microbial contaminants: Critical Reviews in Environmental Science and Technology. 34:109-139.

Smith_assess_manage_microbes_2004.pdf
Overview of diseases and epidemics associated with different sources of bacterial contamination (urban stormwater, CSO, manure runoff, septics, WWTF / sludges). Beyond the list of disease by source, treatment is very general.

Sobratee, N., R. Mohee, M.F. Driver, and A. Mudhoo. 2008. Survival Kinetics of Faecal Bacterial Indicators in Spent Broiler Litter Composting. Journal of Applied Microbiology. 104:204–214.

Sobratee_broiler_poop_2007.pdf
Probably far more detail about bacterial kinetics in chicken manure than we will ever need.

South Nation Conservation Authority, 2003. Phosphorus Loading Algorithms for the South Nation River. SNCA, Ontario, Canada, 57 pp.

SouthNation_PAlgorithms_Jan03.pdf
Literature review and modeling document dealing entirely with phosphorous loading, hitting these topics:
Milk-house cleaning methods
Streambank erosion
Manure storage, table and discussion of average animal weights for conversion between AEU and number of animals
Feedlot manure
Dairy pile manure

Clean water diversion (roof runoff, sheet runoff, etc) away from manure
Livestock access (exclusion from streams, etc): figure given of 2% of cow's annual load goes directly to stream (assuming they have access).
Septic systems: discussion, references, calculations, figure of 0.6 kg of P / person / year given.
Conservation tillage, with extensive tables showing runoff values (P only) for various practices, with citations.
Buffer strips
Provides good summary table at end of document that shows modeling equations developed.
NOTE: This document is a good candidate for further literature review, esp septic systems section.

Sullivan, T.J., J.A. Moore, D.R. Thomas, E. Mallery, K.U. Snyder, M. Wustenberg, J. Wustenberg, S.D. Mackey, D.L. Moore. 2007. Efficacy of Vegetated Buffers in Preventing Transport of Fecal
Coliform Bacteria from Pasturelands. Environmental Management. 40:958–965.
Sullivan_buffers-pastureland_2007.pdf
OR study shows that vegetative buffers are effective at reducing FC loads in runoff.

Thomann, R. V., and Mueller, J. A. 1987. Principles of surface water quality modeling and control, Harper Collins, New York. NA (KH has it)
Cited by Manache as providing a "literature" value for decay rate of fecal coliform of 0.8.

U.S. Environmental Protection Agency, 2001. Protocols for developing nutrient TMDLs. EPA 841-R-00-002. Office of Water (4503 F), Washington, D.C.
EPA_pathogenTMDL_all.pdf
Extensive treatment of pathogen water quality issues, modeling, source assessment, monitoring. Especially useful is section on source assessment.

U.S. Soil Conservation Service, 1992. Agricultural Waste Management Field Handbook, SCS-USDA, Wash. D.C., Chap. 4.
SCS_AgWasteChara_awmfh-chap4.pdf
Tables and discussion of nutrient and oxygen-demand characteristics of manure and waste, organized by animal, with section on residential and municipal waste water. No bacteria information.

Van Kessel, J.S., Y.A. Pachepsky, D.R. Shelton and J.S. Karns. 2007. Survival of Escherichia coli in cowpats in pasture and in laboratory conditions. Journal of Applied Microbiology 103:1122–1127.
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Die off rates of fecal coliform compared to *E. coli* from cow patties, under three different temperature regimes, comparison of field vs. laboratory.

Viraraghavan, T. 1978. Travel of Microorganisms from a Septic Tile. Water, Air, and Soil Pollution. 9:355 -362.

Weiskel, P., B. Howes and G. Heufelder. 1996. Coliform Contamination of a Coastal Embayment: Sources and Transport Pathways. Environmental Science and Technology. 30(6):1872-1881.

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Thorough, watershed-scale study in which quantified FC loading (number of organisms and percent of total) contribution to Buttermilk Bay, MA. Categories examined include: direct loading (waterfowl, straight pipes, boats), surface waters (storm drains, streams), groundwater (septic systems, cesspools), and protected reservoir (wrack, subtidal sediments). Most sources empirically sampled.

Concludes that direct contribution by waterfowl (present predominately in winter) to bay waters is a very small fraction of total fecal coliform in bay, due primarily to the observation that incoming stream densities of FC are much higher than those in the bay or nearshore. Hypothesizes that fecal pellets remain intact long enough to allow significant internal die-off, predation of protozoa on bacteria may be high in biologically active substrates; bacteria may undergo thermal shock during cool-water season.

Reports storm drain FC densities of about 10^4/100mL.

Calculates wet weather FC loads for:

a high density residential area, median = $10^{6.56}$ FC $m^{-2}cm^{-1}$, n = 16

a moderate density residential area, median = $10^{5.87}$ FC $m^{-2}cm^{-1}$, n = 23

commercial areas, median = $10^{5.12}$ $m^{-2}cm^{-1}$, n = 8

a low density residential area, median = $10^{4.02}$ $m^{-2}cm^{-1}$, n = 7

Notes that illicit wastewater connections in storm drains not present, based on inspection of system.

Indicated bacterial levels in dog poop did not show declines in bacterial levels after 7, 14, and 30 days. Provides a cursory calculation of dog loading, noting that using reasonable assumptions, it was easily sufficient to account for observed loads.

Wildlife on landscape not quantified.

States that bacteria from wildlife are known to enter streams from saturated wetlands, having been observed in undeveloped watersheds, citing Jensen, *et al.* (1979). I could not find that source.

Strong evidence that functioning septic systems reduce FC in groundwater to insignificant levels within 1m horizontal distance from leach field.

Yang, L., B. Lin and R.A Falconer. 2008. Modeling enteric bacteria level in coastal and estuarine waters. Engineering and Computational Mechanics. 161(4):179-186 NA

Available to purchase: www.atypon-link.com

Abstract says paper discusses theoretical basis for numerical modeling of enteric bacteria, with emphasis on in-stream and sediment processes.

Young, KD, EL Thackston. 1999. Housing Density and Bacterial Loading in Urban Streams Journal of Environmental Engineering. 125(12):1177-1180 NA

Not_Cited_but_Relevant\young_thackston_urban_bacteria1999.pdf

Abstract appears more heavily focused on multiple-antibacterial resistance than land use.

Zehnder, C.M. and A. DiCostanzo, 1997. Estimating Feedlot Nutrient Budgets and Managing Manure Output. Minnesota Cattle Feeder Report B-450, 7 pp.

Zehnder_feedlot_cfr02.pdf

Discussion aimed primarily at helping farmers reduce nutrient loads in livestock operations, emphasis on diet, bedding material, and discussion of nutrient loss in manure by management strategy. No bacterial info.

Mancini, J.L. 1978. Numerical Estimates of Coliform Mortality Rates Under Various Conditions. JWPCF, 50(11):2477-2484.

Crane, S.R. and J. A. Moore. 1986. Modeling enteric bacterial die-off: A review. Water, Air, and Soil Pollution. 27:411-439.

Appendix D: Daily Bacterial Load Estimates for Wild Animals in the Seacoast Beaches of New Hampshire

Steve Jones
March 20, 2009

INTRODUCTION

In the application of the model for characterizing bacterial loading to NH coastal beaches, data for accurate bacterial loading has posed a challenge. Of particular problem is estimation of the bacterial load from wild animals, which is dependent on numerous factors that make estimation difficult without their consideration.

The basic factors involved with estimating bacterial loading from wild animals are the number of animals, their proximity to surface waters and likelihood of fecal contamination, the amount of feces and bacteria eliminated with time, and the effects of environmental factors on bacterial numbers between the time of defecation and exposure to surface waters. Past microbial source tracking studies are a useful resource of information for some of these factors, particularly related to the amount of bacteria eliminated in feces. Many of the NH Seacoast MST studies have information on the *Escherichia coli* concentrations (per unit weight feces) in the feces of a range of local source species. These data, with estimation of the amount (weight) of feces produced per day by key wild animal species, is the topic of this study.

The specific objectives for this report are as follows:

A. Summarize bacteria source terms for wildlife, i.e., provide more accurate bacteria load estimates (e.g., counts/day) for wild animals as bacteria sources.

B. Provide some sense of prioritization of species (e.g., larger contributors) for the study areas, based on past MST studies in the NH coastal beaches area.

FINDINGS

The MST-ribotyping studies conducted at UNH/Jackson Estuarine Lab have been conducted in areas of the NH Seacoast since 2001. In each study, the most important, or the most frequently identified, source species have been identified. An assessment of these for a given study area suggests a subset of all identified source species from all studies may be more significant (Table 1). There were nine of the 16 species identified that were considered to be dominant sources for the eight studies listed. Although cormorants were considered a dominant source in the storm water pipe study published in 2004, it was the only study in which they were identified. Conversely, deer, Canada geese, raccoons, herring gulls, coyotes and foxes were identified both as dominant sources and in five or more of the studies. Otters were dominant source species in two studies, and identified in two others, so their geographical spread may not be as wide as other source species. When they are detected, however, they tend to be significant because of their tendency to defecate in one place as a group.

As part of the local ribotyping studies, samples of animal feces have been collected and *E. coli* strains have been isolated from these samples. In the process of isolating the bacteria, the concentrations of *E.*

coli in the feces samples have been quantified. The *E. coli* concentration data for a given species typically varies over a wide range as a result of many factors, especially the condition/sex/age/size of the individual animal, the length of time the feces has been on the ground and its exposure to sunlight, rainfall and other environmental factors, the animal behavior and its tendency to defecate near surface water, and the time of year as it relates to the diet of the animal. From the standpoint of MST studies, any feces containing *E. coli* that is found in a study area must be considered as potential sources, so collecting samples over a range of actual environmental conditions provides a more accurate assessment what is contaminating surface waters.

A review of a portion of the *E. coli* concentrations data from source species found in the NH Seacoast provides estimates of *E. coli* concentrations for 17 source species (Table 2). The *E. coli* concentrations ranged from 4.9/g wet weight for robins to 960,000,000 cfu/g WW for skunks, though both of these source species had but one sample as a basis for calculating concentrations. *E. coli* concentrations for other species were based on more samples (N = 2-25), and typically ranged from the 10^4 to 10^6 cfu/g WW range.

Estimation of the amount of feces defecated per day by wild animal species was very difficult to research or find any information. Most of the literature on wild animal defecation rates is focused on how many times per day a species defecates, to enable estimation of how many individuals are present in a study area. For the purposes of this study, the amount of feces shed per day by individuals of a given species is the information that is most critical. Consultation with wild animal experts at UNH provided some 'best guess' estimates for the most significant source species found in ribotyping studies. These estimates were based on assumptions for average body weight, daily energy expenditure (kcal/d), energy content per diet (kcal/plant or meat) and digestible energy coefficients for each species, all of which is used to calculate forage consumption and fecal production. For animals in the NH Seacoast area, estimates were calculated for 11 of the identified source species (Table 2). These were converted to dry weights and multiplied by the *E. coli* concentrations to provide estimates of the daily fecal-borne bacteria shed by each wild animal species. Nine of the eleven species had estimated *E. coli* loads that ranged between 10^7 to 10^8 cfu/g WW per d. The lowest estimates were for otters and ducks, the latter being considered a less significant source species in the Seacoast, and the former being a significant source where the otters congregate and defecate in one location.

Deer pellets were collected during February 2009 from pellet groups deposited on this winter's snow at one location in Durham, NH. The average number of pellets per group was 118 (N = 9), and the pellets weighed an average of 0.3 g WW (N = 25). Using a literature estimate for the number of pellet groups shed per day per deer of 26.5, the amount of feces shed per day per deer during this winter was 781 g WW/deer per d (Table 2-Deer field data). Using the same average *E. coli* concentration data used for all deer sources from local ribotyping studies, the *E. coli* load from deer for winter is only 23% of the overall average load. This helps to illustrate the importance of season for these estimates.

CONCLUSION

Based on the described estimation procedures, the most important source species in the NH Seacoast area are:

Deer, raccoons, coyotes, foxes, otters and rabbits
(birds) Canada geese, herring gulls

Table 1. Dominant and low-incident identified source species from ribotyping studies conducted in the NH Seacoast area.

Study-authors		Study area	DOMINANT SOURCES						LOW INCIDENCE SOURCES					
Jones Landry	2003	Hampton Harbor	deer	coyote	goose	gull			duck	pigeon	robin			
Jones	2004	Hampton & Seabrook	cormorant	goose	fox				raccoon	coyote	sea gull			
Jones Edwards	2007	Hampton	raccoon	goose	deer				gull	fox	duck	muskrat	otter	
Jones Landy Edwards	2005	Mill Creek, Seabrook	deer	coyote	raccoon	goose			otter	gull	rabbit	skunk	turkey	
Jones Sumner Connor	2004	Coastal beaches	otter	raccoon	deer	fox	goose	coyote	gull	sparrow				
Jones Landry	2004	Coastal beaches	otter	rabbit	gull	deer	geese	raccoon	coyote	duck	fox	muskrat	skunk	turkey
Jones Landry Ruszenas	2006	Berry Brook	raccoon						rabbit	gulls	deer	muskrat	fox	
Jones	2008	New Castle	gull	deer					rabbit	duck	goose	raccoon	coyote	

FREQUENCY OF DETECTION			
	Dominant	Low	TOTAL
deer	6	1	7
goose	6		6
raccoon	5	2	7
gull	3	4	7
coyote	3	3	6
fox	2	3	5
otter	2	2	4
cormorant	1		1
rabbit	1	3	4
duck		4	4
muskrat		3	3
skunk		2	2
turkey		2	2
pigeon		1	1
robin		1	1
sparrow		1	1

Table 2. Measured *E. coli* concentrations and estimated *E. coli* daily loads for wild animals found in the NH Seacoast area.

		***E. coli* concentration**			**Daily *E. coli* load**		
		average	stdev	N	Feces amount	Feces amount	*E. coli* load
Species		cfu/g ww	cfu/g ww		g DW/d per animal	g WW/d*	cfu/g ww per d
Canada geese	!!	4.2E+04	1.7E+02	11	60	300	1.2E+07
Cormorant†	!!	8.5E+05	4.6E+01	3	24	120	1.0E+08
Coyote	!!	6.5E+04	9.3E+04	2	168	840	5.5E+07
Deer	!!	4.3E+04	3.1E+02	25	670	3350	1.4E+08
Deer (field data)	!!	"	"	"	-	781	3.4E+07
Gull†	!!	1.0E+06		1	24	120	1.2E+08
Otter	!!	5.9E+03	6.7E+02	5	95	475	2.8E+06
Rabbit	!!	3.0E+06	1.9E+03	8	21	105	3.1E+08
Raccoon	!!	2.9E+05	1.7E+02	21	80	400	1.2E+08
Red fox	!!	2.0E+06	6.0E+02	20	69	345	6.8E+08
Muskrat		1.3E+06	2.1E+00	2	21	105	1.4E+08
Duck†		7.7E+04	9.0E+02	11	24	120	9.2E+06
Robin		4.9E+00		1			
Squirrel		5.2E+03		1			
Starling		1.1E+04		1			
Sparrow		7.0E+07		1			
Skunk		9.6E+08		1			

!! Observed to be a significant source of fecal contamination in NH ribotyping studies

*Estimate wet weight from dry weight calculations assuming 20% dry weight

†Assumes same body weight for each bird type/species.