State of Narragansett Bay and Its Watershed
2017 Technical Report

Condition Indicators of Public Health

INTRODUCTION
Protecting the public from harmful pathogens is a paramount objective of environmental management efforts in the Narragansett Bay Watershed. High pathogen levels in waters used for recreation, including swimming and boating, and shellfishing create unsafe conditions for public health, as people use the Bay and Watershed for these activities. Pathogen contamination includes the presence of *Escherichia coli*, a type of fecal coliform, general fecal coliform, and Enterococci bacteria. These three pathogens are monitored and regulated by federal and state departments of environmental management and health. Unsafe levels of pathogens stem from untreated human and animal feces entering the water from failing septic systems, cesspools, combined sewer overflows (CSOs) and other sources of nonpoint pollution.

Increased pathogen contamination results in beach closures, impairment of waters designated for recreational activities, and acreage reduction of approved shellfishing areas designated for direct human consumption. While wastewater treatment facilities have been successfully reducing or eliminating pathogen loads to receiving waters, especially in the last 15 years, individual failing septic systems and cesspools are considered a major culprit for pathogen contamination. However, little is known about the extent or severity of impacts on freshwaters and estuarine waters from failing septic systems and cesspools. Stressors discussed in other sections of this report can exacerbate pathogen contamination, particularly precipitation and resulting stormwater runoff from impervious cover, agricultural lands and other open fields with wildlife and pet feces, primarily. The greater intensity and volume of precipitation associated with climate change is expected to increase pathogen loading, and warmer water temperatures will encourage more pathogen growth. Efforts to reduce pathogen contamination in the Watershed include engineered retention systems, green infrastructure, pet waste management, and construction of tunnels to store CSO discharges for later treatment. These efforts have resulted in improvements to the overall water quality in the last decade.

The Narragansett Bay Estuary Program uses three indicators to monitor public health conditions in the Bay and Watershed: marine beach closures, shellfishing area closures, and water quality monitoring for recreation. The analysis results reflect the efforts by the state agencies to collect, assess, and determine whether waters are suitable for recreational use or shellfishing. Accordingly, the following chapters discuss status and trends and explore how management actions affect spatial and temporal changes in these indicators that are relevant to the daily lives of the population. This section concludes the report by coming full circle. People are the ultimate driver of water quality conditions. Through understanding how stressors can affect the wellbeing of people in the Bay and Watershed, we can also understand how the Bay and Watershed have been substantially been shaped and resources used by people over thousands of years.

Photo: Bonnet Shores Beach Club, Narragansett, RI (Ayla Fox)
BACKGROUND

- Recreational activities in estuarine and freshwaters can be hindered by pathogen pollution from stormwater runoff and the discharge of untreated or poorly treated wastewater, among other sources. Monitoring by the states reveals that the concentrations of pathogens in surface waters are typically higher following precipitation events.

KEY FINDINGS

- **Status**

  **Estuarine Waters:** Most of the estuarine waters of Narragansett Bay (85 percent) were suitable for recreational use. Some of the exceptions included estuarine waters in the Providence River, Palmer River, Newport Harbor, lower Mount Hope Bay, and some embayments in Greenwich Bay.

  **Streams and Rivers:** Over 60 percent of the freshwater streams and rivers in the Narragansett Bay Watershed were not suitable for recreational uses such as swimming and boating. In the Taunton River Basin and the Coastal Narragansett Bay Basin, more than 80 percent of streams and rivers were unacceptable for recreational use due to pathogens, whereas 67 percent in the Pawtuxet River Basin were acceptable.
Introduction

Streams, rivers, lakes, and ponds in the Narragansett Bay Watershed and the estuarine waters of the Bay itself support a variety of recreational activities such as fishing, swimming, and boating. These activities provide significant economic and cultural value to the region.

Fecal coliforms, *Escherichia coli*, and Enterococci are considered primary bacterial indicators for the presence of human pathogens in waters. Exposure to harmful microorganisms through recreation such as swimming and boating can cause health impacts such as gastroenteritis and sore throats, or even meningitis or encephalitis (Cabelli 1983 and 1989, USEPA 1986, Haile 1996, Pruss 1998). Fecal pathogens are implicated as the leading cause of water quality impairment in the country (USEPA 2016).

Various sources have been linked with elevated pathogens in water bodies, such as failing septic systems, storm runoff, agricultural activities, wildlife and waterfowl, and discharges from wastewater treatment systems particularly when combined sewer overflows (CSOs) are triggered. During precipitation events, impervious surfaces facilitate the transport of pathogens in runoff to receiving waters: freshwater streams and rivers, lakes and ponds, and ultimately the Bay. Researchers have found that impervious cover has been positively correlated, and natural land cover negatively correlated, to higher bacterial counts in streams, estuaries, and lakes (Holland et al. 2004, Dolah et al. 2007, Didonato et al. 2009, Crim et al. 2012, Haack et al. 2013, Sanger et al. 2015).

Untreated sewage was historically a major source of pollution across Narragansett Bay. In pre-colonial times and prior to industrialization, lower population densities around Narragansett Bay resulted in lower anthropogenic pathogen input. This changed when industrialization brought a threefold increase in the Watershed’s population, primarily along coastal areas of the Upper Estuary (see “Population” chapter; see the Appendix for Bay Regions). As a consequence, wastewater became the major source of pollution across Narragansett Bay. Even as sewered areas began to increase in the early 1900s, pipes funneled untreated sewage directly into Bay waters (Schumann 2015), discharging human pathogen loads from household waste, in addition to industrial waste (see “Wastewater Infrastructure” chapter). In the mid-1900s, inadequately treated sewage and raw sewage continued to be the main source of pollution in the upper Narragansett Bay (Shea 1946).

Today, wastewater treatment plants have been upgraded significantly, resulting in reduced pathogen loadings. However, wastewater systems may release pathogens when they experience sewer system overflows (SSOs) resulting from breaks in pipes or other operational problems. Onsite (individual) wastewater treatment systems (OWTS) and cesspools may also contribute to pathogen water pollution problems through failures or systems that are not properly designed, sited, and maintained (Habteselassie et al. 2011, Humphrey et al. 2011, Sowah et al. 2014 and 2017, Schneeberger et al. 2015). Adverse impacts from onsite systems, particularly cesspools or failing OWTS, generally would be expected to be localized to subembayments, river
.segments, or receiving ponds and lakes, depending on groundwater flow direction and the type of underlying soils, among other factors (see “Wastewater Infrastructure” chapter).

Discharge of non-point source stormwater runoff occurs throughout the Bay and its Watershed and is known or suspected to contribute to the water pollution that impairs recreational uses of surface waters. Combined sewer overflows (CSOs) are a major point source of pathogens; however, CSOs affect only certain portions of Narragansett Bay—waters in the Providence River Estuary, Newport Harbor, and Fall River, where their outfalls are located. Significant investment in CSO abatement has reduced, but not entirely eliminated, the volume of untreated CSO events.

Climate change will likely increase the influence of precipitation and temperature on water quality conditions (see “Precipitation” and “Temperature” chapters). Heavy precipitation and flooding associated with more frequent and intense storms may amplify pathogen transport to receiving waters. Moreover, increasing water temperatures may allow pathogens to survive for longer periods of time. Analyzing the extent and distribution of waters within the Narragansett Bay Watershed that are impacted by pathogens informs an understanding of public health risks, as well as long-term efforts to improve water quality.

In accordance with the federal Clean Water Act (CWA), Rhode Island and Massachusetts have identified and designated waters according to specific uses and periodically publish these results in Integrated Reports submitted to the Environmental Protection Agency (EPA) (MassDEP 2015, RIDEM 2015). Measurement of pathogens, in conjunction with other factors, can inform state and local management decisions to limit recreational activities including closing beaches to swimming (MassDEP 2015, RIDEM 2015). In this chapter, the Narragansett Bay Estuary Program utilized and reconciled data from the water quality assessments, compiled by both states, for both primary and secondary contact recreational use. Primary contact refers to recreational activities in which humans have direct contact with the water, such as swimming. Secondary contact refers to recreational activities occurring on the water where there is indirect contact, such as canoeing or kayaking. While both states use different pathogen criteria, they lead to similar determinations as to whether conditions are acceptable for recreational use.

RIDEM assesses non-designated bathing beach waters in Rhode Island. RIDEM's numeric criteria for fecal coliforms, Enterococci, and Escheria coli in non-designated bathing beach waters are summarized in the Extended Methods (Table 8) section at the end of this chapter. It should be noted that the Rhode Island Department of Health (RIDOH) also assesses water quality conditions at public marine and freshwater beaches during the summer season (Memorial Day to Labor Day). These assessments are used to daily notify the public whether a beach is open or closed for swimming due to high concentrations of pathogens, and are not analyzed within this chapter (see “Marine Beaches” chapter). In Massachusetts, MassDEP water quality conditions criteria vary for primary contact use testing at public bathing beaches during the bathing and non-bathing season as well as for secondary contact use testing, as discussed in the Extended Methods section (Table 9). For primary contact recreational use, Enterococci is tested in both fresh and estuarine waters, while for secondary contact recreational use, it is tested only in estuarine waters. Escherichia coli is tested only in fresh waters, for both primary and secondary contact recreational use. Moreover, marine beaches are monitored frequently during the summer season by the Massachusetts Department of Health (see “Marine Beaches” chapter), and in collaboration with local officials and entities, freshwater beaches are also tested for pathogen contamination.

In this chapter, the Estuary Program’s report focuses on the water quality assessments by the states, which include attainment of “fully supporting,” “not supporting,” or “unknown” status and causes of impairment for recreational use, largely due to pathogens as the primary indicator of public health. To measure this indicator, the Estuary Program integrated information about: (a) the extent of state water quality assessments within the broader hydrological context of the Bay and Watershed in both Massachusetts and Rhode Island, and (b) the status of water quality conditions for recreational uses in Narragansett Bay and its Watershed, as assessed by the states. Only a proportion of all waters that define and shape the Watershed and the Bay are assessed by the states, and some of these waters have sufficient information to be assessed for recreational use, primarily based on testing for pathogens.

It is important to acknowledge that while the results from this analysis are consistent with the Integrated Reports from both states (MassDEP 2015 and RIDEM 2015), the water quality conditions for this indicator as defined by the Estuary Program reflect that (a) the extent of acceptable waters is equivalent to the
extent of state-assessed waters where conditions are “fully supporting” of recreational use, (b) the extent of state-assessed waters that are impacted for recreational use differs from states’ reporting of impaired waters or the 303(d) list by reporting only on “not supporting” due to pathogens (or other parameters) for recreational use, and (c) waters identified as unknown were not assessed for recreational use by the states.

By measuring the total extent of waters that are assessed or not for recreational use, across the geographical scope of the Watershed and River Basins, these results can shed light on three issues: waters with acceptable conditions for recreational use should be protected; waters that were identified as impacted for recreational due to pathogens, primarily, can pinpoint potential sources of contamination and stressors; and waters that are unknown can be identified as data gaps within the state assessments to further evaluate other state-assessed waters for recreational use.

**Methods**

**EXTENT OF STATE-ASSESSED WATERS**

The Estuary Program calculated the total extent of fresh and estuarine waters within the Bay and Watershed to compare with the extent of state water quality assessed waters. The states do not assess every stream segment or pond or lake in the Watershed, nor all the areas in the Bay. Waters assessed by the states for a variety of uses are only a portion of the entire hydrological network in the Watershed and Bay waters due to states’ criteria for implementing water body assessments, as well as the states’ differing capacities.

For the purposes of this chapter, the total extent of freshwaters is defined by the National Hydrography Dataset (NHD). The Estuary Program calculated total extents using: (1) NHD flowlines for streams and rivers and excluding other segments (i.e., canals), and (2) NHD waterbodies greater than one acre for lakes, ponds, and reservoirs and excluding other categories (i.e., wetlands). The extent of Narragansett Bay estuarine waters was defined by the Estuary Program (see this report’s Introduction and Appendix). These data were also used to calculate total extents of fresh and estuarine waters by River Basin using an array of geospatial tools (Esri 2016).

The Estuary Program used NHD data at a high resolution (1:24,000) to best define a baseline of all the waters in the Watershed that have been delineated by the US Geological Survey (USGS). It is important to note that a portion of NHD waters may not meet states’ criteria to be tested as part of the Integrated Reports. For example, the NHD data used by the Estuary Program do not differentiate intermittent versus perennial streams, a limitation that might be considered by the states.

As a reference for this chapter, Table 1 summarizes information about the extent of waters mapped in the high-resolution NHD, and total state-assessed waters (for all uses), as shown in Figure 1.

**Table 1. Extent of state-assessed waters in Narragansett Bay and its Watershed. Total areas for National Hydrography Dataset (NHD) and Bay waters are included for reference.**

<table>
<thead>
<tr>
<th>Within Narragansett Bay and its Watershed</th>
<th>Estuarine Waters (sq. miles and percent)</th>
<th>Stream and Rivers (miles and percent)</th>
<th>Lakes and Ponds (acres and percent)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total extent of all waters (1)</td>
<td>197</td>
<td>3,578</td>
<td>40,910</td>
</tr>
<tr>
<td>Total state-assessed waters</td>
<td>156</td>
<td>1,337 (2)</td>
<td>33,795</td>
</tr>
<tr>
<td>MassDEP</td>
<td>10</td>
<td>451 (2)</td>
<td>20,586</td>
</tr>
<tr>
<td>RIDEM</td>
<td>146</td>
<td>886 (2)</td>
<td>13,210</td>
</tr>
<tr>
<td>Percent of all waters that are state-assessed (3)</td>
<td>78 percent</td>
<td>37 percent</td>
<td>82 percent</td>
</tr>
</tbody>
</table>

(1) Based on National Hydrography Dataset (NHD); the area of the Bay as defined by the Estuary Program.
(2) An estimated four miles of MassDEP-assessed segments of Rennins River and Blackstone River were removed from analysis where the features both crossed outside of the state border and were duplicated in RIDEM GIS features.
(3) Total state-assessed divided by all waters in the Bay and the Watershed. These percentages represent the extent of waters in the Bay and in the Watershed that are assessed by the state agencies (MassDEP and RIDEM).
Figure 1. The extent of freshwaters and estuarine waters in Narragansett Bay and its Watershed, and the proportion of waters that have been assessed by MassDEP and RIDEM. Additional high-resolution National Hydrography Dataset (NHD) waters show all waters that shape the Bay and its Watershed.
Across the Watershed, states assess 37 percent of NHD stream miles, 82 percent of NHD ponds and lakes greater than one acre, and 78 percent of the Bay as defined by the Estuary Program (Table 1; Figure 1). While most of the estuarine waters are assessed by the states (79 percent), 43.5 square miles of waters in Narragansett Bay between Aquidneck Island and the Rhode Island Sound are not assessed at all (Figure 1). These metrics situate this analysis within the broader hydrological context of the Bay and Watershed. However, they are not presented as a target for state assessments, as states’ have differing criteria and capacities for water quality assessment implementation.

A combined analysis of state water quality assessments in Massachusetts and Rhode Island must be informed by important differences between the states. A large part of Rhode Island (63 percent) falls within Narragansett Bay Watershed boundaries compared to only 13 percent of Massachusetts; however, Massachusetts comprises 60 percent of the Watershed area. The Pawtuxet River Basin is completely within Rhode Island, and the Taunton River Basin is completely within Massachusetts. Both the Coastal Narragansett Bay Basin and the Blackstone River Basin span the Rhode Island-Massachusetts border (Figure 1).

Additionally, Massachusetts has a much larger network of streams and rivers under its jurisdiction, and as a result Rhode Island’s assessments reflect the capacity of its programs to analyze a greater number of streams and rivers per unit area compared to Massachusetts. Due to the larger size of Massachusetts, many water bodies are not yet assessed for recreational use within the Massachusetts portion of the Bay’s watershed. Most of the assessed waters by MassDEP are at public bathing beaches for primary contact use. MassDEP assesses very few non-bathing waters for secondary use in the Watershed and in the estuarine waters of Mount Hope Bay (Figure 1).

**EXTENT OF STATE-ASSESSSED WATERS FOR RECREATIONAL USE**

The Estuary Program calculated total extent of “state-assessed waters” using the states’ 2014 Assessment Databases. Extents were also broken down by River Basin. The Estuary Program also calculated the subset of all “state-assessed” waters that are tested to determine water quality conditions for swimming and boating recreational uses (Figure 2). Waters tested for recreational use consist of either (1) “fully supporting,” i.e., acceptable, for recreational use, or (2) “not supporting” recreational use due to impacts by one or more parameters. Many waterways and waterbodies are assessed for other

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**Figure 2.** Conceptual diagram of the Estuary Program’s methodology representing the breakdown of state-assessed waters for measuring water quality conditions for recreational use.
designated uses (i.e., aquatic wildlife and habitat; see “Water Quality Conditions for Aquatic Life” chapter) and not for recreational use. The Estuary Program defines these waters to be “not assessed” for recreational use although they are included in the total extent of “state-assessed” waters (Figure 2). The extent of state waters that are “not assessed” for recreational use was calculated to better understand the geographical data gaps in state assessments across the Watershed. However, the strategy to determine which waters should be tested and therefore assessed for recreational use may differ among states; waterbodies for which insufficient data or information are available regarding parameters that can affect primary and secondary contact recreational use, primarily pathogens, are not assessed and thus conditions are unknown.

**WATER QUALITY CONDITIONS FOR RECREATIONAL USE**

Within the portion of waters that states assess for recreational use, the states identify when water quality conditions are “fully supporting” or “not supporting” based on state water quality standards (Extended Methods, Tables 8 and 9). The states have multiple parameters, including pathogens, that can be used to assess waterbodies as primary or secondary contact recreational waters. When one or multiple causes of impairment are identified by the state agencies, the waterbody does not support recreational use and may be added to the List of Impaired Waters (CWA Section 303(d)) and prioritized for development of restoration plans known as Total Maximum Daily Loads (TMDLs) (RIDEM 2016). The state reports reflect assessments derived from data generated in multiple years (within a timeframe of five years). Not all waters are monitored within the same year, as both MassDEP and RIDEM conduct testing and assessments on a rotating-Basin basis. Dates for Basin assessments were not readily available, but the states can provide this information for later reports.

The Estuary Program’s methods for reporting water quality conditions were designed in coordination with Rhode Island and Massachusetts state agencies to reconcile the differences between states water quality assessments. Rhode Island uses the same criteria for primary and secondary contact use assessments (Extended Methods, Table 8). In Massachusetts, most public bathing beaches are tested for primary contact use, while non-bathing waters are tested for secondary contact use, meaning that they are not designated for swimming but can be used for recreational boating. Massachusetts tests a larger variety of parameters in state assessments of water quality conditions for primary and secondary recreational use (Extended Methods, Table 9). The Estuary Program analyzed the extent of waters that are supporting of recreational use, or not supporting, focused on parameters related to pathogen impacts, because pathogens are a public health indicator assessed similarly by both states (Table 2).

For the purpose of this indicator, the Estuary Program combined the Massachusetts assessments of primary and secondary recreational use so that results could be comparable to Rhode Island. In most cases, Massachusetts determinations of primary and secondary contact recreation were the same. For the limited instances where attainments for primary and

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**Table 2. List of parameters that are assessed by MassDEP and RIDEM for primary and secondary contact recreation to determine whether waterbodies are impacted by pathogens.**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Massachusetts</th>
<th>Rhode Island</th>
</tr>
</thead>
<tbody>
<tr>
<td>A total of 29 parameters are tested across the state waters for Primary and Secondary Contact Recreation as assessed by MassDEP</td>
<td>A total of three parameters are tested across the state waters for Primary and Secondary Contact Recreation as assessed by RIDEM</td>
<td></td>
</tr>
<tr>
<td>For waterbodies that are impacted by pathogens, the Estuary Program used the following causes of impairment:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>✓ Enterococci for fresh waters and estuarine waters</td>
<td>✓ Fecal coliform for fresh waters and estuarine waters</td>
<td></td>
</tr>
<tr>
<td>✓ Fecal coliform for fresh waters and estuarine waters</td>
<td>✓ <em>Escherichia coli</em> for fresh waters</td>
<td></td>
</tr>
</tbody>
</table>


*Not all parameters are tested on all waters.*
secondary uses were different for the same stream segment or waterbody, the Estuary Program used the primary contact use determination from Massachusetts.

The Estuary Program defined categories of conditions that are comparable across states by relying on the determinations made by the states rather than raw data for bacteria counts, which could not be used given the inherent differences among the state programs and the timeframe when data were collected. From these determinations made by the states, the Estuary Program calculated the extent of state-assessed waters for recreational use as:

1. miles of streams and rivers,
2. acres of lakes and ponds, and
3. square miles of estuarine waters.

Using an array of geospatial tools (Esri 2016) to integrate and reconcile bi-state data, these metrics were calculated at the entire Narragansett Bay and its Watershed and for freshwaters within individual River Basins, and reported as the percentage of state-assessed waters that are acceptable, impacted by pathogens, and impacted by other parameters for recreational use.

- **Acceptable for Recreational Use:** Waters that fully support recreational use for swimming and boating. This is equivalent to a “fully supporting” determination by the states. These are waters that, because of good water quality conditions, can be targeted for further protection.

- **Impacted by Pathogens:** Waters that are “not supporting” of recreational use, due to impact by pathogens. These are waterbodies that, because of adverse pathogen concentrations (bacteria counts), can be targeted for restoration and can assist to identify potential sources of pathogen contamination (e.g., proximity to areas of high density of onsite systems; see “Wastewater Infrastructure” chapter). Note that this differs from the reporting by the states for impaired waters.

While the focus of this chapter is on pathogens as a primary indicator of public health, the remaining extent of other waters that are “not supporting” for recreational use due to other parameters was also calculated to provide a complete picture of water quality impacts.

- **Impacted by Other Parameters:** Waters that are “not supporting” of recreational use, due to other parameters and not by pathogens. Rhode Island does not test for parameters other than pathogens when determining conditions for primary and secondary contact recreational use. Massachusetts tests up to 29 parameters across the state’s waters in addition to pathogens (Table 2). Note that waters impacted by pathogens can also be impacted by other parameters.

In this chapter, the “not supporting” waters for recreational use are broken down into these two category conditions. While the condition-categories defined in this chapter to measure this indicator (acceptable for recreational use, impacted by pathogens, or impacted by other parameters) are derived from the state assessments, the results presented differ from the five reporting categories of assessed waters by the states for the Integrated List of Waters. Accordingly, the results from this chapter and the state reports should not be compared.

The Estuary Program used the Assessment Database for 2014 from each state to extract, synthesize, compute, and analyze the status of each water quality condition. From the Assessment Databases, which were used to develop the Integrated Reports of 2015 (MassDEP 2015, RIDEM 2015), data were selected and synthesized by watershed, designated water use (primary and secondary recreational use), attainment (fully supporting and not supporting), and cause of impairment (pathogens and other parameters; see Table 2).

### Status

#### THE EXTENT OF STATE-ASSESSED WATERS

The Estuary Program quantified that 95 percent (146 square miles out of 154 square miles) of state-assessed estuarine waters were assessed for recreational use, compared to 59 percent of state-assessed streams and rivers and 48 percent of state-assessed lakes and ponds (Figures 3 and 4).

Estuarine waters that were not assessed for recreational use because of insufficient data or no data at all, but were assessed by the states for other uses (e.g., aquatic life), include the Taunton River, Cole River, and Palmer River, all within Massachusetts (Figures 1 and 3).

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1 For example, a waterbody can be listed as Category 5, which means it was impaired for one or more uses. Waterbodies in Category 5 constitute the 303(d) list (MassDEP 2015, RIDEM 2015).
Figure 3. The extent and proportion of state-assessed waters that were either assessed or not assessed for recreational use in Narragansett Bay and its Watershed. For the waters assessed by the states for recreational use, the Estuary Program further calculated proportions with different water quality conditions (Table 5; Figure 5).
Figure 4. Proportion of state-assessed waters (not all waters) that were either assessed or not assessed (due to insufficient data) for recreational use in Narragansett Bay and its Watershed.
### Table 3. Total (miles) of state-assessed streams and rivers that were either assessed or not assessed for recreational use in the Narragansett Bay Watershed’s River Basins.

<table>
<thead>
<tr>
<th>Streams and Rivers By River Basins</th>
<th>Blackstone River</th>
<th>Pawtuxet River</th>
<th>Coastal Narragansett Bay</th>
<th>Taunton River</th>
</tr>
</thead>
<tbody>
<tr>
<td>Assessed for Recreational Use&lt;sup&gt;(1)&lt;/sup&gt;</td>
<td>215</td>
<td>236</td>
<td>249</td>
<td>89</td>
</tr>
<tr>
<td>Unassessed for Recreational Use&lt;sup&gt;(2)&lt;/sup&gt;</td>
<td>136</td>
<td>93.6</td>
<td>181.4</td>
<td>137.3</td>
</tr>
<tr>
<td>Total State-Assessed Waters</td>
<td>351</td>
<td>330</td>
<td>430</td>
<td>226</td>
</tr>
</tbody>
</table>

<sup>(1)</sup> This is the total extent of waterbodies that have been assessed for recreational use by the states, which is further broken down into water quality conditions.

<sup>(2)</sup> This is the total extent of waterbodies that have been assessed for other designated uses (e.g., aquatic life use) but have not been assessed by the states for recreational use, and thus conditions are unknown.

### Table 4. Total (acres) of state-assessed lakes and ponds that were either assessed or not assessed for recreational use in the Narragansett Bay Watershed’s River Basins.

<table>
<thead>
<tr>
<th>Lakes and Ponds By River Basins</th>
<th>Blackstone River</th>
<th>Pawtuxet River</th>
<th>Coastal Narragansett Bay</th>
<th>Taunton River</th>
</tr>
</thead>
<tbody>
<tr>
<td>Assessed for Recreational Use&lt;sup&gt;(1)&lt;/sup&gt;</td>
<td>3,322</td>
<td>5,701</td>
<td>3,432</td>
<td>3,772</td>
</tr>
<tr>
<td>Unassessed for Recreational Use&lt;sup&gt;(2)&lt;/sup&gt;</td>
<td>4,511</td>
<td>1,196</td>
<td>4,569</td>
<td>7,290</td>
</tr>
<tr>
<td>Total State-Assessed Waters</td>
<td>7,833</td>
<td>6,897</td>
<td>8,003</td>
<td>11,062</td>
</tr>
</tbody>
</table>

<sup>(1)</sup> This is the total extent of waterbodies that have been assessed for recreational use by the states, which is further broken down into water quality conditions.

<sup>(2)</sup> This is the total extent of waterbodies that have been assessed for other designated uses (e.g., aquatic life use) but have not been assessed by the states for recreational use, and thus conditions are unknown.
For the total state-assessed waters in each River Basin, Tables 3 and 4 shows the total extent of fresh waters that were assessed or unassessed for recreational use (Figure 3).

The Pawtuxet River Basin had the highest percentage of total state-assessed waters that were assessed for recreational use (72 percent of streams and rivers, and 83 percent of lakes and ponds). This is likely reflective of Rhode Island’s capacity as a smaller state to assess more waterbodies per unit area, as the Pawtuxet River Basin is the only Basin completely within Rhode Island (Tables 3 and 4; Figure 3). A majority (61 percent) of streams and rivers and 66 percent of lakes and ponds in the Taunton River Basin remained not assessed for recreational use. In the Coastal Narragansett Bay Basin and Blackstone River Basin, nearly half of streams and rivers (42 percent and 39 percent, respectively) (Table 3) and greater than half of ponds and lakes (57 percent and 58 percent, respectively) remained not assessed (Table 4).

**WATER QUALITY CONDITIONS FOR RECREATIONAL USE**

**Narragansett Bay and its Watershed**

Of the 146 square miles of estuarine waters assessed by the states for recreational use (Figures 3 and 4), the large majority of Narragansett Bay’s estuarine waters were identified as acceptable for recreational use (89 percent) (Table 5; Figure 5). Areas characterized as impacted by pathogens (11 percent) included the upper portion of the Providence River Estuary, parts of Mount Hope Bay, and some areas with high-density development (e.g., Newport, Barrington/Warren) (Figure 5).

Of the 789 stream miles that are assessed by the states for recreational use (Figure 4), more were identified as impacted by pathogens (61 percent) than acceptable for recreational use (34 percent) (Table 5; Figure 5). Parameters other than pathogens, including nuisance aquatic vegetation, are also impacting recreational use along the upper reaches of the Watershed in some tributaries of the Blackstone River, in Massachusetts (Figure 5).

**River Basins**

The Pawtuxet River Basin had the highest percentage (of freshwaters assessed by the states for recreational use within this Basin) of streams and rivers that were suitable for swimming and boating (67 percent), and the lowest percentage of streams and rivers impacted by pathogens (33 percent), compared with the other River Basins. Meanwhile, the Taunton River Basin was characterized by the lowest percentage of waters identified as acceptable for recreational use such as swimming and boating (18 percent) and the highest percentage of pathogen-impacted streams (82 percent), followed by the Coastal Narragansett Bay Basin (80 percent impacted) (Table 6; Figure 5).

Of the 16,227 acres of ponds and lakes that are assessed by the states for recreational use (Figure 4), most ponds and lakes (78 percent) were acceptable for recreational use, and very few were impacted by pathogens (2 percent) (Table 7). The Pawtuxet River Basin supported the greatest extent of acceptable ponds and lakes, amounting to nearly all waterbodies assessed for recreational use (96 percent) (Table 7). The Blackstone River Basin supported the least relative extent of ponds and lakes identified as acceptable for recreation (50 percent). Notably, in Massachusetts where additional parameters are assessed, between 40 and 50 percent of the waters

<table>
<thead>
<tr>
<th>Water Quality Conditions in Narragansett Bay and its Watershed</th>
<th>Estuarine Waters</th>
<th>Stream and Rivers</th>
<th>Lakes and Ponds</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Square miles</td>
<td>Miles</td>
<td>Acres</td>
</tr>
<tr>
<td>Total state-assessed for recreational use</td>
<td>146</td>
<td>789</td>
<td>16,227</td>
</tr>
<tr>
<td>Acceptable for recreational use</td>
<td>130.4 (89)</td>
<td>272 (34)</td>
<td>12,733 (78)</td>
</tr>
<tr>
<td>Impacted by pathogens</td>
<td>15.4 (11)</td>
<td>481 (61)</td>
<td>333 (2)</td>
</tr>
<tr>
<td>Impacted by other parameters&lt;sup&gt;0&lt;/sup&gt;</td>
<td>0</td>
<td>36 (5)</td>
<td>3,161.4 (19)</td>
</tr>
</tbody>
</table>

<sup>0</sup>Waters identified as impacted for recreational use for parameters other than pathogens.
Figure 5. The extent and proportion of water quality conditions for recreational use that were assessed by the states in the Narragansett Bay Watershed’s River Basins. For each River Basin, pie charts show the percentage of fresh waters in each category-condition for recreational use (acceptable, impacted by pathogens, or impacted by other parameters).
### Table 6. Total (miles) and percent of streams and rivers in the Narragansett Bay Watershed’s River Basins by water quality conditions for recreational use.

<table>
<thead>
<tr>
<th>Streams and Rivers (Miles) by Basins</th>
<th>Blackstone River</th>
<th>Pawtuxet River</th>
<th>Coastal Narragansett Bay</th>
<th>Taunton River</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total state-assessed streams and rivers for recreational use&lt;sup&gt;(1)&lt;/sup&gt;</td>
<td>351</td>
<td>330</td>
<td>430</td>
<td>226</td>
</tr>
<tr>
<td>Acceptable for recreational use</td>
<td>48</td>
<td>157</td>
<td>51</td>
<td>16</td>
</tr>
<tr>
<td>(22 percent)</td>
<td>(67 percent)</td>
<td>(20 percent)</td>
<td>(18 percent)</td>
<td></td>
</tr>
<tr>
<td>Impacted by pathogens&lt;sup&gt;(2)&lt;/sup&gt;</td>
<td>131</td>
<td>79</td>
<td>198</td>
<td>73</td>
</tr>
<tr>
<td>(61 percent)</td>
<td>(33 percent)</td>
<td>(80 percent)</td>
<td>(82 percent)</td>
<td></td>
</tr>
<tr>
<td>Impacted by other parameters&lt;sup&gt;(3)&lt;/sup&gt;</td>
<td>36</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>(17 percent)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<sup>(1)</sup> Waters identified as impacted for recreational use for parameters other than pathogens.

### Table 7. Total (acres) and percent of lakes and ponds in the Narragansett Bay Watershed’s River Basins by water quality conditions for recreational use.

<table>
<thead>
<tr>
<th>Lakes and Ponds (Acres) by Basins</th>
<th>Blackstone River</th>
<th>Pawtuxet River</th>
<th>Coastal Narragansett Bay</th>
<th>Taunton River</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total state-assessed waterbodies for recreational use&lt;sup&gt;(1)&lt;/sup&gt;</td>
<td>3,322</td>
<td>5,701</td>
<td>3,432</td>
<td>3,772</td>
</tr>
<tr>
<td>Acceptable for recreational use</td>
<td>1,665</td>
<td>5,484</td>
<td>3,339</td>
<td>2,245</td>
</tr>
<tr>
<td>(50 percent)</td>
<td>(96 percent)</td>
<td>(97 percent)</td>
<td>(60 percent)</td>
<td></td>
</tr>
<tr>
<td>Impacted by pathogens</td>
<td>38</td>
<td>217</td>
<td>42</td>
<td>36</td>
</tr>
<tr>
<td>(1 percent)</td>
<td>(4 percent)</td>
<td>(1 percent)</td>
<td>(1 percent)</td>
<td></td>
</tr>
<tr>
<td>Impacted by other parameters&lt;sup&gt;(1)&lt;/sup&gt;</td>
<td>1,619</td>
<td>0</td>
<td>51</td>
<td>1,491</td>
</tr>
<tr>
<td>(49 percent)</td>
<td></td>
<td></td>
<td>(2 percent)</td>
<td>(40 percent)</td>
</tr>
</tbody>
</table>

<sup>(1)</sup> Waters identified as impacted for recreational use for parameters other than pathogens.
assessed for recreational use in the Taunton River and Blackstone River Basins are impacted for parameters other than pathogens (Figure 5).

**Discussion**

There are sufficient data to assess water quality conditions for recreation in most of Narragansett Bay and a significant portion of its Watershed. Overall, estuarine waters in Narragansett Bay largely support recreational uses, with 89 percent of assessed waters found to be acceptable for swimming and boating. The Providence River Estuary, the Palmer River, several coves within Greenwich Bay, and Newport Harbor, all in Rhode Island, are all areas that were exceptions to good water quality and were found to be impacted by pathogens for swimming and other recreational uses (Figure 4). Additionally, water quality conditions for recreational use remain unknown in the northeastern portions of Mount Hope Bay near Fall River and the Taunton River estuary, where waterbodies have not been assessed by Massachusetts, due to insufficient information to determine whether waters are suitable for swimming and/or boating. However, the southeastern portion of Mount Hope Bay, located in Rhode Island, was identified as being impacted by pathogens.

The heavily urbanized sections of Narragansett Bay have historically been affected by pathogens from the CSOs in Fall River and the greater Providence area. The City of Fall River and the Narragansett Bay Commission (NBC), serving the Providence region, have both invested significantly in CSO abatement during the last fifteen or more years. NBC has completed two phases of improvements including construction of a tunnel built in Providence that stores 65 million gallons of stormwater and untreated wastewater. Fall River also built a tunnel that can store 38 million gallons. Untreated wastewater and stormwater are diverted to these tunnels during large rain events and later pumped to their respective treatment plants. As a result, the volume of combined sewage that flows untreated into Narragansett Bay has been significantly reduced. NBC is continuing with a third phase of improvements planned over the next two decades. It is anticipated that pathogen levels in these urbanized areas of the Bay will decrease. The water quality improvements achieved in the Upper Bay region have spurred the City of East Providence and partners to explore establishing a public beach at Sabin Point Park adjacent to the Providence River.

The Pawtuxet River Basin supported the largest extent of fresh waters found to be acceptable for swimming and boating. Excluding its mainstem, this Basin is mostly vegetated and sparsely developed, which are characteristics that typically support low pathogen loading (Didonato et al. 2009, Crim et al. 2012; see “Impervious Cover” and “Land Use” chapters). Vegetation and infiltration control runoff into receiving waters, filtering pathogens from localized sources, such as failing septic systems, pet wastes, and wildlife. The efforts to protect lands (see “Open Space” chapter) around surface waters as natural buffers can be evidenced in the results for the Pawtuxet River Basin.

Conversely, the coastal areas around the Bay—which comprise the Taunton River Basin and Coastal Narragansett Bay—contained the highest relative proportion of impacted rivers and streams (Table 5). This is likely because dense urban development and impervious cover generate higher volumes of stormwater that carries pathogens into receiving waters (see “Impervious Cover” chapter). Generally, few ponds and lakes were impacted by pathogens across all River Basins (Table 6). However, the large percentages of ponds and lakes remaining not assessed for recreational use (52 percent) may have skewed this result (Table 3; Figure 2).

It is noteworthy to mention that while the Estuary Program used the database for the 2014 state assessments, the assessments may not reflect data available after 2013. When the states present assessments results in the Integrated Reports, the data and time period being assessed lag behind the year of the assessment cycle. Because it takes more than a year to do the assessments, the states generally use data from the five prior years. For the Rhode Island’s 2014 water quality assessments, the data reviewed were primarily from 2008 to 2013.

Recreational use in Narragansett Bay and surrounding watersheds depends upon good water quality. Climate change will likely pose increasing risks to public health by amplifying pathogen transport to Narragansett Bay and its Watershed via more frequent and intense storms and increased water temperatures (see “Precipitation” and “Temperature” chapters). It is important to the protection of public health to ensure monitoring efforts are both sustained and expanded to support a comprehensive assessment. To date, the large proportion of state-assessed waters remaining not assessed for recreational use reflects an important data gap. Identifying impairment triggers management responses
that may include implementation of pollution control actions and the development of TMDLs. These management responses can be used to reduce pressures on polluted waters, allowing natural systems to recover and build resilience. Above all, reducing public health risks from pathogens and promoting the economic and cultural benefits arising from recreational uses of the Bay by residents and visitors alike is a primary objective of the states to protect water quality for human use, and for the long-term management of Narragansett Bay and its Watershed.

Data Gaps and Research Needs

- Data gaps exist with respect to assessing the recreational use of waters in the Taunton River and Blackstone River Basins in Massachusetts and the Coastal Narragansett Bay Basin in Rhode Island. Monitoring efforts need to be expanded to address these gaps.
- Additional research into the fate and transport of pathogens discharged into the ground from onsite wastewater systems is a need. Research should focus on those subwatersheds or drainage areas in which onsite wastewater treatment systems, including cesspools, are known to or suspected of contributing to pathogen pollution problems.

Acknowledgments

This chapter was written by Eivy Monroy, Watershed and GIS Specialist, and Julia Twichell, GIS Environmental Analyst, with the Narragansett Bay Estuary Program. We thank our state partners at the Massachusetts Department of Environmental Protection and the Rhode Island Department of Environmental Management who provided all the data and feedback to develop this indicator.

References


Extended Methods

Numeric criteria used by the state agencies to assess water quality for recreational use:

Table 8. RIDEM’s numeric criteria for fully supporting recreational/swimming of non-designated bathing beach waters.

<table>
<thead>
<tr>
<th>Numerical Criteria</th>
<th>Freshwaters</th>
<th>Estuarine Waters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fecal coliform(1)</td>
<td>The geometric mean of 200 MPN/100 ml is met and not more than 10 percent of the total samples taken exceed 400 MPN/100 ml.</td>
<td>The geometric mean of 50 MPN/100 ml is met and not more than 10 percent of the total samples taken exceed 400 MPN/100 ml.</td>
</tr>
<tr>
<td>Enterococci</td>
<td>The geometric mean of 54 colonies per 100 ml is met.</td>
<td>The geometric mean 35 colonies per 100 ml for salt waters is met.</td>
</tr>
<tr>
<td><em>Escherichia coli</em></td>
<td>The geometric mean of 126 colonies per 100 ml is met.</td>
<td></td>
</tr>
</tbody>
</table>

Source: RIDEM 2014

(1) Most Probable Number (MPN) of coliform per 100 ml.
Table 9. MassDEP’s numeric criteria for recreational/swimming during the bathing and non-bathing season for waters at public beaches for primary contact use or waters designated as secondary contact use.

<table>
<thead>
<tr>
<th>Numerical Criteria</th>
<th>Freshwaters</th>
<th>Estuarine Waters</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Enterococci</strong> for Primary Contact Recreational Use</td>
<td>The geometric mean of the five most recent samples taken during the same bathing season shall not exceed 33 colonies/100 ml and no single Enterococci sample taken during the bathing season shall exceed 61 colonies/100 ml.</td>
<td>No single Enterococci sample taken during the bathing season shall exceed 104 colonies/100 ml and the geometric mean of the five most recent Enterococci samples taken within the same bathing season shall not exceed 35 colonies/100 ml.</td>
</tr>
<tr>
<td>Public bathing beaches</td>
<td></td>
<td></td>
</tr>
<tr>
<td>During the non-bathing season, for waters at public bathing beaches</td>
<td>The geometric mean of all Enterococci samples taken within the most recent six months shall not exceed 33 colonies/100 ml, typically based on a minimum of five samples, and no single sample shall exceed 61 colonies/100 ml.(1)</td>
<td>No single Enterococci sample shall exceed 104 colonies/100 ml and the geometric mean of all samples taken within the most recent six months, typically a minimum of five samples, shall not exceed 35 colonies/100 ml.(2)</td>
</tr>
<tr>
<td><strong>Enterococci</strong> for Secondary Contact Use</td>
<td></td>
<td>The geometric mean of all Enterococci samples taken within the most recent six months shall not exceed 175 colonies/100 ml, typically based on the five most recent samples, and 10 percent of such samples shall not exceed 350 colonies/100 ml.</td>
</tr>
<tr>
<td><strong>Escherichia coli</strong> for Primary Contact Recreational Use</td>
<td>The geometric mean of the five most recent E. coli samples taken within the same bathing season shall not exceed 126 colonies/100 ml and no single sample taken during the bathing season shall exceed 235 colonies/100 ml.(3)</td>
<td></td>
</tr>
<tr>
<td>Public bathing beaches as defined by MA DPH</td>
<td></td>
<td></td>
</tr>
<tr>
<td>During the non-bathing season, for waters at public bathing beaches</td>
<td>The geometric mean of all E. coli samples taken within the most recent six months shall not exceed 126 colonies/100 ml, typically based on a minimum of five samples, and no single sample shall exceed 235 colonies/100 ml.(4)</td>
<td></td>
</tr>
<tr>
<td><strong>Escherichia coli</strong> for Secondary Contact Recreational Use</td>
<td>The geometric mean of all E. coli samples taken within the most recent six months shall not exceed 630 E. coli/100 ml, typically based on a minimum of five samples, and 10 percent of such samples shall not exceed 1260 E. coli/100 ml.(5)</td>
<td></td>
</tr>
</tbody>
</table>

Source: MassDEP 2012

(1) This criterion may be applied on a seasonal basis at the discretion of the Massachusetts Department of Public Health.
Condition Indicators of Public Health

CHAPTER 23: MARINE BEACHES


Photo: North Kingstown Town Beach, RI (Ayla Fox)
BACKGROUND

• Marine beaches are an important part of Narragansett Bay’s recreational appeal, and beach closures caused by poor water quality reduce the quality of life for residents and visitors alike. Beach closures occur when water tests show high counts of bacteria that indicate contamination from wastewater and/or stormwater. Growth of the human population and changes in land use, especially more impervious cover, can lead to declines in water quality and increases in beach closures. Climate change stressors including increased rainfall, warmer water temperatures, and sea level rise are likely to exacerbate conditions leading to beach closures.

• This indicator, developed in collaboration with state health departments, classified the 37 marine beaches in Narragansett Bay as High Concern or Low Concern, referring to beaches at high or low risk for pathogen contamination, based on the level of use, monitoring frequency, and history of closure rates.

KEY FINDINGS

• Status

  High Concern Beaches: In 2015, there were 38 beach closure events at the fourteen High Concern beaches, and 42 percent of the events occurred in the Upper Estuary.
**Introduction**

Marine beaches provide significant economic, cultural, recreational, and aesthetic value. Beach waters are susceptible to contamination with harmful microorganisms that can cause health impacts such as gastroenteritis and sore throats, or even meningitis or encephalitis (Cabelli 1983, USEPA 1986, Haile 1996, Pruss 1998). State departments of health, supported by the federal Beaches Environmental Assessment and Coastal Health Act of 2000 (BEACH Act), conduct microbiological monitoring. The goal of the BEACH Act, administered by the United States Environmental Protection Agency (USEPA), is to reduce risks of illness in coastal waters and the Great Lakes by improving beach testing and availability of information to the public. USEPA annually awards grants to eligible states, territories, and Tribal nations to develop and implement beach water quality monitoring and notification programs for recreational beaches.

As most microbiological pathogens are difficult to measure directly, the fecal indicator bacteria Enterococci (typically found in the feces of warm-blooded animals and humans) serve as a proxy for pathogens in beach water monitoring. In Narragansett Bay, the Rhode Island Department of Health (RIDOH) and the Massachusetts Department of Public Health (MDPH), with BEACH Act support, monitor 37 public marine beaches for Enterococci.

Sources of microbial pathogens include discharges of raw sewage from combined sewer overflows (CSOs), failing septic systems, cesspools, and wild and domestic animals. High bacterial counts are driven by watershed conditions at local and regional scales. Precipitation and impervious cover contribute to the delivery of wastewater pathogens via stormwater runoff and/or groundwater directly into Narragansett Bay and tributaries. Changes in land use have been shown to influence the number of beach closures; urbanization near beaches can negatively affect beach microbial water quality, whereas natural lands such as forests and wetlands may reduce the number of beach closures (Wu and Jackson 2016).

Increasingly, pathogenic loads are being reduced through management practices. Engineered retention systems, green infrastructure, pet waste management, and upgrades to CSO facilities have been implemented in the Narragansett Bay Watershed. CSO abatement programs are being implemented in the two largest cities in the Bay to increase storage capacity of both sewage and rainwater from stormwater runoff during heavy rain events, with a holding capacity of 65 million gallons in Providence, Rhode Island, and 38 million gallons in Fall River, Massachusetts.

The Narragansett Bay Commission (NBC) presented results of the CSO project’s phase I improvements, from pre-phase I (2004 to October 2008) through

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**Low Concern Beaches:** In 2015, there were six beach closure events at the 23 Low Concern beaches, and 48 percent of the events occurred in the Upper Estuary.

- **Trends**

**High Concern Beaches:** From 2000 to 2015, the High Concern marine beaches in the Upper Estuary had the highest percentage of closure events (over 40 percent) compared with the other Bay Regions. Prior to 2009, closure events at High Concern beaches intensified during wet seasons, as expected. After 2009, however, precipitation did not strongly correlate with the number of closure events. In addition, there is not a clear upward or downward trend of beach closures over the sixteen years of beach monitoring.

**Low Concern Beaches:** While spikes of beach closure events across the Bay seem to have been linked to wet seasons, there was no pattern at specific beaches or in Regions of the Bay. From 2000 to 2015, the Low Concern marine beaches in the East Passage had a higher percentage of closure events (42 percent) compared with the other Bay Regions.
post-phase I (November 2008 to 2014), showing that 50 percent of the CSO volume was captured and treated annually and that there was between 42 and 51 percent reduction of fecal coliform bacteria loads, post-improvements (NBC, presentation by Pamela Reitsma 2015, NBC 2016), discharging to the Lower Providence and Upper Providence River (see map of Narragansett Bay Segments and Sections in the Appendix). However, as of 2015, Enterococci results post-phase I showed that standards had not met the primary contact criteria for designated beaches in the Upper Providence River. In addition, no effects had been shown in the Lower Providence River, since the Enterococci bacteria standards were met an nearly equal number of years, pre- and post-phase I. Although CSO project improvements had a stronger effect on fecal coliform levels than Enterococci bacteria in the Providence River Estuary, reducing CSO discharges into receiving waters is likely to have had at least some impact on reducing pathogen loading at urban beaches in the northern sections of the Bay.

Based on observations of positive changes in the upper Providence River Estuary, the RIDOH launched the Urban Beach Initiative in 2010 to investigate the possibility of re-opening Sabin Point, Rosa Larisa, and Gaspee Point beaches to swimming and other recreational uses. These beaches have been subject to long-term closure due to nearby sources of pathogens and high counts of Enterococci.

For this chapter, the Narragansett Bay Estuary Program and partners analyzed the status (as of 2015) and trends (2000 to 2015) in beach closure events at licensed marine beaches categorized as High or Low Concern beaches. High Concern beaches are more frequently monitored than Low Concern beaches because of the higher likelihood of pathogen contamination. This indicator measures summer beach closure events at the Bay Region scale, as opposed to the local (individual beach) scale, to compare Bay Regions that have been adversely impacted by pathogens. Using the total number of beach closure events and a scale of zero to 100 percent (normalized closure events by Bay Region), the Estuary Program compared the percent of closures between the Bay Regions. In addition, the Estuary Program plotted total seasonal rainfall against total beach closure events in Narragansett Bay and in Bay Regions to explore the effects of rainfall on beach closures.

**Methods**

The Narragansett Bay Estuary Program collaborated with RIDOH and MDPH to examine beach closure days (Rhode Island) and postings (Massachusetts), sampling locations, and level of concern that dictates frequency of monitoring for all the licensed public marine beaches within Narragansett Bay. The water quality data for public marine beaches in Rhode Island included results from 2000 through 2003 (tested for *Escherichia coli*) and 2004 through 2015 (tested for Enterococci). Data for public marine beaches in Massachusetts included results from 2000 through 2015 (tested for Enterococci).

To analyze how marine beaches have been indicative of water quality for human uses in the Bay, the Estuary Program: (1) standardized and reconciled beach closure data from Massachusetts and Rhode Island for consistency across the Bay; (2) grouped all licensed public marine beaches in Narragansett Bay into two defined beach categories, High Concern and Low Concern, based on current monitoring frequency and history of closure events; and (3) conducted geospatial analysis for the five Regions of the Bay to summarize and calculate:

- total of beach closure events at High Concern beaches and
- total of beach closure events at Low Concern beaches.

The Estuary Program examined the percentage of total beach closure events in Narragansett Bay across the five Bay Regions (Upper Estuary, East Passage, West Passage, Sakonnet Rover, and Mouth of the Bay) in order to compare changes over time among and within Bay Regions.

The analysis conducted for this chapter did not focus on changes in closures of individual public beaches primarily because preliminary analysis by the Estuary Program and partners have shown that those changes are more likely due to localized impacts. The analysis also did not focus on changes at the scale of the entire Bay because changes in water quality at marine beaches, based on beach closure data, are not representative of the Bay as a whole. Rather, the analysis quantified the percentage of beach closure events in Regions of the Bay because the results can provide a better understanding of watershed-level effects on water quality for human use of marine beaches.
WATER QUALITY MONITORING AT PUBLIC MARINE BEACHES

Water quality at public marine beaches is sampled by the state departments of health during the summer season (Memorial Day through Labor Day) and analyzed using either the Modified Enterococci Method 1600 plate method or Enterolert®, a defined substrate method, to estimate counts of viable Enterococci. For beaches in Rhode Island, the single sample standard is 60 cfu per 100 ml (colony forming units per 100 milliliters) of salt water. Prior to 2015, however, the standard was 104 cfu per 100 ml for all marine beaches (RIDOH 2016). In Massachusetts, the state health department has adopted and continues to use the standard for Enterococci in marine waters at 104 cfu per 100 ml for a single sample and 35 cfu per 100 ml for the geometric mean, which is calculated based on the last five non-rain-impacted samples over a 30-day period (MDPH 2016). At the majority of Massachusetts beaches, water quality is considered unsafe for swimming when two samples collected on consecutive days exceed the water quality standard. Beaches with a history of multi-day elevated bacteria levels are still required to post warnings after a single exceedance. For Rhode Island beaches, exceeding the standard is a trigger for beach closure consideration. Beach closures in Rhode Island take additional factors into account, including history of contamination, precipitation, flushing rates, and any additional evidence of contamination (i.e., water quality data from stormwater outfalls).

There are limitations in the assessment of water quality at marine beaches. Management actions to close beaches are often delayed due to the 24 hours of laboratory analysis needed for the approved analytical methods used to measure Enterococci bacteria. This delay means that closures are asynchronous with adverse conditions. The conditions at many beaches change significantly in a single tidal cycle, often making the bacterial count obsolete before results are available. New technical solutions are being tested and faster methods may be available soon. For instance, Rhode Island is investigating a qPCR (quantitative polymerase chain reaction) method that amplifies and measures fecal indicator bacterial DNA in water samples. This method could reduce the time between sampling and the availability of results to as little as six hours. The results from this investigation will provide information on the acceptability of this method and the inherent constraints, such as costs and logistics.

BEACH CLOSURE EVENTS

The Estuary Program standardized the beach closure data from both Massachusetts and Rhode Island into “beach closure events,” for public marine beaches within Narragansett Bay (Figure 1). The method for standardizing beach closure events was defined by the Estuary Program in coordination with partners at the state departments of health. Regardless of the duration of a beach closure (e.g., one day or consecutive days in one week), beach closure events were considered equal for the purposes of this analysis. This was necessary given that beach closure data from both states are not consistent in the way the departments of health track and report beach closures. RIDOH quantifies the number of days, whereas MDPH quantifies the number of postings, which can be one day or multiple consecutive days (MDPH 2016, RIDOH 2016).

Length of closure is often dependent on logistical factors related to sampling and lab analysis. It is of note that closure events most likely co-vary to some extent with the frequency of sampling at a given beach location. Thus, a closure event was defined as follows: (1) One beach may have been closed for one day, and another beach for a week, but each case was attributed as a single event. (2) If a beach re-opened one day after closure, and then closed again three days later, the second closing, no matter how many days, was referred to as a separate closure event. (3) While some public beaches are monitored more frequently than others according to state-assigned tiers relating to degree of risk for contamination (Table 1), if a closure is posted, water sampling will continue regardless of the tier until bacterial concentration meets the department’s criteria for swimming, based on each state’s department of health protocols.

HIGH AND LOW CONCERN BEACHES

Direct comparison of available Massachusetts and Rhode Island beach data poses a challenge because monitoring frequency is variable across beaches and between the states. Monitoring frequency may be driven by multiple objectives and is generally greater for the most at-risk locations. For this analysis encompassing sixteen years of data, normalization to sampling frequency was neither practical nor supportable.

To reconcile beaches in both states within a unified context of relative health concerns, the Estuary Program used a classification system derived...
Table 1. Estuary Program classification for marine beaches analogous to tier classification by MDPH and RIDOH.

<table>
<thead>
<tr>
<th>State Tier</th>
<th>Monitoring Frequency*</th>
<th>Estuary Program Classification</th>
<th>Monitoring Frequency**</th>
<th>Estuary Program Classification</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Twice per week</td>
<td>High Concern</td>
<td>More than once per week***</td>
<td>High Concern</td>
</tr>
<tr>
<td>2</td>
<td>Twice per month</td>
<td>Low Concern</td>
<td>Once per week</td>
<td>High or Low Concern, determined by historical pattern of beach closures</td>
</tr>
<tr>
<td>3</td>
<td>Once per month</td>
<td>Low Concern</td>
<td>Every two weeks or less often</td>
<td>Low Concern</td>
</tr>
</tbody>
</table>

* RIDOH Tier Classification as of 2015  
** MDPH Tier Classification as of 2015  
*** There were no marine beaches in Narragansett Bay classified as Tier 1 using MDPH criteria.

Table 2. High and Low Concern marine (licensed) beaches by Bay Region in Narragansett Bay. Italics indicate Massachusetts marine beaches.

<table>
<thead>
<tr>
<th>Bay Region</th>
<th>High Concern</th>
<th>Low Concern</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper Estuary</td>
<td>BARRINGTON TOWN BEACH, BRISTOL TOWN BEACH, CITY PARK BEACH, CONIMICUT PT BEACH, GODDARD MEMORIAL STATE PARK, OAKLAND BEACH, PIERCE BEACH, WARREN TOWN BEACH</td>
<td>CEDAR COVE, COLES RIVER CLUB, LEGSIDE, SANDY BEACH, Swansea TOWN BEACH</td>
</tr>
<tr>
<td>Mouth of the Bay</td>
<td>ATLANTIC BEACH CLUB BEACH, EASTON'S BEACH, SCARBOROUGH NORTH, SCARBOROUGH SOUTH</td>
<td>CAMP GROSVENOR, DUNES CLUB, GOOSEBERRY BEACH, HAZARDS BEACH, NARRAGANSETT TOWN BEACH, SACHUEST BEACH, SPOUTING ROCK BEACH ASSOCIATION</td>
</tr>
<tr>
<td>Sakonnet River</td>
<td>PEABODYS BEACH, THIRD BEACH</td>
<td>FOGLAND BEACH, GRINELLS BEACH, SANDY POINT BEACH</td>
</tr>
<tr>
<td>East Passage</td>
<td></td>
<td>CAMP ST. DOROTHY, KING PARK SWIM AREA, FORT ADAMS STATE PARK, MACKEREL COVE BEACH</td>
</tr>
<tr>
<td>West Passage</td>
<td></td>
<td>BONNET SHORES BEACH CLUB, NORTH KINGSTOWN TOWN BEACH, PLUM BEACH CLUB, SAUNDERSTOWN YACHT CLUB</td>
</tr>
</tbody>
</table>
from current Rhode Island and Massachusetts tier classifications. Both states have three tiers of beach classifications with Tier 1 being the highest concern and Tier 3 lowest, although they use different criteria for classification (Table 1). From those rankings, the Estuary Program consolidated all public marine beaches within Narragansett Bay into two groups—High Concern and Low Concern—based on 2015 monitoring frequency as a proxy for degree of risk and an analysis of beach closure history (Table 1).

Tier designation is the primary factor governing frequency of sampling; however, each state has made occasional changes in risk-based tier assignments. In Massachusetts, tier classification by beach was available for each year between 2000 and 2015, while tier classifications for each year were not readily available for each beach in Rhode Island. Thus, one caveat for this analysis is that the frequency of monitoring at any given beach may have changed over time, limiting the comparability of beach closure within beach categories over time. In general, however, the frequency of routine sampling has been consistent at each beach from one year to the next, making comparisons between years reasonable.

To address this inconsistency issue, the Estuary Program calculated the mean of closure events over the sixteen years of beach monitoring (total beach closures divided by years monitored) and compared the means to the 2015 tier designations. The combination of 2015 tier assignments and mean closure events allowed for more rigorous classification of High and Low Concern beaches.

Thus, the Estuary Program’s classification scheme developed with RIDOH and MDPH (Table 1) used the following criteria:

- **High Concern Beaches:** Frequently monitored. Frequent closure events. Mean closure events per year greater than 1.5.
- **Low Concern:** Infrequently monitored. Fewer closure events over time. Mean closure events per year less than 1.5.

Based on each criterion, each beach was categorized as a High Concern or Low Concern beach. In Rhode Island\(^1\), High Concern beaches were verified to have historically high closure frequency (more than 1.5 closure events per year). All Massachusetts beaches except Pierce Beach were excluded from the High Concern category due to low mean closure history.

Of the 37 monitored marine beaches in Narragansett Bay, fourteen beaches were classified as High Concern (13 RI, 1 MA) and 23 as Low Concern (18 RI, 5 MA) (Figure 1, Table 2).

**DATA ANALYSIS**

The total of beach closure events was calculated for marine beaches within Narragansett Bay and by Bay Regions, for High and Low Concern beaches (Figure 1), and plotted against seasonal rainfall over the sixteen years of data. The mean of beach closure events over time was calculated to quantify the number of years in which the total number of beach closures exceeded the average.

To compare beach closure events between Bay Regions, the Estuary Program choose to normalize the total of closure events by the number of beaches within each Bay Region that are High or Low Concern. By normalizing beach closure events, each Bay Region can be compared to other Bay Regions equally on a scale of 0 to 100 or as the percentage of normalized beach closure events; the latter is presented in this chapter.

The use of normalization reduces a biased representation. As an example, the Upper Estuary has the greatest number of High Concern beaches, and without normalization it would appear to be more affected by pathogen pollution than the other Bay Regions. The Upper Estuary has four times as many beaches as the Sakonnet River, and if the percent of closure events (after normalization) in each of these Bay Regions was 50 percent in any given year, this indicates that both Regions had equivalent impacts on the marine beaches in their respective Region. After normalization, if the Upper Estuary has a higher percentage of beach closure events, this would indicate that this Bay Region has been impacted more than the other Regions by pathogen contamination in that given year or across the years.

It is important to emphasize that this approach provides a comparison of the total of beach closure events on a Bay Region scale as opposed to a local scale, and therefore the results will not reflect trends of closures at individual marine beaches. Information

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\(^1\) For public marine beaches in Rhode Island, the Estuary Program estimated monitoring history based on the assumption that sampling began in 2002, when the number of licensed beaches in Rhode Island more than doubled. After 2002, the number of marine beaches monitored became relatively stable (±2 between 2002 and 2015).
on individual beaches is collected by the respective state health departments, MADPH and RIDOH. In addition, the Estuary Program performed Pearson’s product-moment correlation analysis to determine trends of total beach closure events, across years, in Narragansett Bay and by Bay Regions, for High and Low Concern marine beaches.

WET AND DRY WEATHER

Total seasonal rainfall was plotted to explore temporal patterns of beach closure events and precipitation. Precipitation data were obtained from T.F Green Airport, Rhode Island, for the period between Memorial Day and Labor Day in each year from 2000 to 2015.

The Estuary Program calculated total rainfall in inches for each season. Wet years were defined as those with total rainfall over fourteen inches during the summer season. That definition was selected to align as closely as possible with wet and dry years as designated in other chapters of this report (see “Dissolved Oxygen” chapter). However, since the definition used in other chapters was based on monthly averages of streamflow, and not daily precipitation, some years differ as wet and dry across chapters.

Status and Trends

HIGH CONCERN BEACHES

Status

During the 2015 beach season, a dry season in terms of rainfall, High Concern beaches (Figure 1) were closed for a total of 38 distinct events across Narragansett Bay (Table 3; Figure 2). For High Concern beaches, closure events in 2015 were the sixth highest annual total during the period from 2000 to 2015. Overall, the Upper Estuary had the greatest percent of beach closure events (42 percent) when compared with the other two Bay Regions where marine beaches were impacted by unsafe pathogen levels. Closure events were normalized by the number of beaches in each Bay Region.

Trends

Analysis of High Concern beaches from 2000 to 2015 suggested that higher numbers of beach closure events corresponded with higher total precipitation through 2009, but not after 2009 (Figure 2). The highest numbers of beach closure events in Narragansett Bay occurred in 2006 and 2009, two wet years with 66 and 64 closures respectively. These wet years saw consistently high total closure events among High Concern beaches across all three Bay Regions (Figures 3, 4, and 5). The Upper Estuary had the greatest percentage of beach closure events in 2006 compared with the other two Bay Regions. In 2009, a wet year, the percentage of beach closure events was nearly even among the three Bay Regions (Figure 6), but the Sakonnet River had the highest percentage (38 percent).

In addition, even though beach closure events are shown to be increasing, from 2000 to 2015, there is no significant trend (p≥0.005) in closure events in Narragansett Bay (Figure 2) and within Bay Regions (Figures 3 and 5), except for the Sakonnet River Region (p=0.004) (Figure 4).

Using the average of total beach closure events over sixteen years of data, the Estuary Program used a yearly comparison to identify when beach closures were above average. Total beach closure events were above average (mean=32.5) in five of the sixteen years, three of which were wet seasons, including 2009 (Figure 2). Similarly, by grouping marine beaches based on their location, by Bay Regions, the patterns are different from or similar to

<table>
<thead>
<tr>
<th>Bay Region</th>
<th>Total Beach Closure Events</th>
<th>Number of Beaches</th>
<th>Normalized Beach Closure Events</th>
<th>Percent of Beach Closure Events</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper Estuary</td>
<td>25</td>
<td>8</td>
<td>3.13</td>
<td>42</td>
</tr>
<tr>
<td>Sakonnet River</td>
<td>4</td>
<td>2</td>
<td>2.00</td>
<td>27</td>
</tr>
<tr>
<td>Mouth of the Bay</td>
<td>9</td>
<td>4</td>
<td>2.25</td>
<td>31</td>
</tr>
</tbody>
</table>
Figure 1. Locations of High and Low Concern marine (licensed) beaches in Narragansett Bay.
Figure 2. Total beach closure events (and trend line) from 2000 to 2015 in Narragansett Bay at High Concern beaches, and total seasonal rainfall in inches. Horizontal dashed line indicates average number of beach closure events across all years. Wet years were defined as years with total rainfall greater than fourteen inches during the summer season. The regression of total beach closure events was not significant (p≥0.05, $R^2=0.099$).
Figure 3. Total beach closure events (and trend line) from 2000 to 2015 in the Upper Estuary at High Concern beaches, and total seasonal rainfall in inches. Wet years were defined as years with total rainfall greater than fourteen inches during the summer season. The regression of total beach closure events was not significant (p≥0.05, R²=0.064). Color of bars corresponds to color of Bay Region on map in Figure 1.
Figure 4. Total beach closure events (and trend line) from 2000 to 2015 in the Sakonnet River at High Concern beaches and total seasonal rainfall in inches. Wet years were defined as years with total rainfall greater than fourteen inches during the summer season. The regression of total beach closure events was statistically significant at p=0.004, R²=0.267). Color of bars corresponds to color of Bay Region on map in Figure 1.
the Bay. In the Upper Estuary and Sakonnet River, the total beach closure events surpassed the average (mean=21 and mean=3, respectively) in six of the sixteen years (Figures 3 and 4), and the Mount of the Bay (mean=9) in eight of the sixteen-year record (Figure 5). For the Upper Estuary and Mouth of the Bay, three of these spikes occurred in wet seasons (2003, 2006, 2009), the same pattern as for the entire Narragansett Bay (Figures 2, 3 and 5). After 2009, wet years do not appear to correspond to above average total beach closure events. While most of the spikes for the Sakonnet River were during dry seasons, the only wet year was 2009 (Figure 4).

In comparing beach closure events between Bay Regions, the percentage of closure events by Bay Region is based on normalized beach closure events. In eight of the sixteen years of beach monitoring, the Upper Estuary had the highest percentage of beach closures compared with the other two Bay Regions. This is not including 2001 and 2002, when all beach closure events occurred in the Upper Estuary. Two of the eight years were wet seasons (2006 and 2013). In these years, 46 and 58 percent of beach closure events were in the Upper Estuary, indicating that pathogen contamination had a greater impact on overall High Concern beaches of this Bay Region when compared with the other two Bay Regions. During the remaining five years of beach monitoring, the Sakonnet River had the highest percentage of beach closure events in 2009, 2011, and 2012 (all wet seasons), and the Mouth of the Bay had the highest percentage in 2003 (wet) and 2004 (dry) (Figure 6). Even though total beach closure events by Bay Region have been normalized, the Upper Estuary had the highest percent of closure events across years, among the three Bay Regions with High Concern beaches.

Furthermore, the analysis of percent closure events by Bay Region showed that 2015 is a representative year of overall closure events, as percentages across years and in 2015 alone for each Bay Region (Tables 3 and 4) are similar.

### Table 4. Total and average of beach closure events at High Concern marine beaches in Narragansett Bay and Bay Regions and percent of normalized beach closure events by Bay Region from 2000 to 2015.

<table>
<thead>
<tr>
<th>Bay Region (Number of Beaches)</th>
<th>Total (Average) beach closure events across years</th>
<th>Normalized beach closure events across years (normalized by number of beaches)</th>
<th>Percent of beach closure events across years by Bay Region (normalized)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper Estuary (8)</td>
<td>337 (21.1)</td>
<td>42.1</td>
<td>43</td>
</tr>
<tr>
<td>Sakonnet River (2)</td>
<td>43 (2.7)</td>
<td>21.5</td>
<td>22</td>
</tr>
<tr>
<td>Mouth of the Bay (4)</td>
<td>140 (8.7)</td>
<td>35.0</td>
<td>35</td>
</tr>
<tr>
<td>Narragansett Bay (14)</td>
<td>520 (32.5)</td>
<td>43.0</td>
<td>43</td>
</tr>
</tbody>
</table>
Figure 5. Total beach closure events (and trend line) in the Mouth of the Bay at High Concern beaches and total seasonal rainfall in inches. Wet years were defined as years with total rainfall greater than fourteen inches during the summer season. The regression of total beach closure events was not significant (p≥0.05, R²=0.046). Color of bars corresponds to color of Bay Region on map in Figure 1.
Figure 6. Percent of normalized beach closure events by Bay Region at High Concern beaches. Wet years were defined as years with total rainfall greater than fourteen inches during the summer season.
LOW CONCERN BEACHES

Status

At the Low Concern beaches (Table 2; Figure 1), only six beach closure events occurred in 2015. The Upper Estuary had the highest percent of normalized closure events (48 percent), followed by the West Passage (40 percent), compared with the other Bay Regions; however, there were no beach closure events at the Low Concern beaches in the Sakonnet River or East Passage (Table 5; Figure 7).

Trends

For Low Concern beaches in Narragansett Bay, total beach closure events appeared to follow precipitation patterns in most years (Figure 7). Greater than twelve beach closure events occurred in Narragansett Bay across Low Concern beaches during each of the wet years, at the same time exceeding average of closure event across the sixteen years of beach monitoring (mean=9.9) (Table 6; Figure 7). However, as is true for High Concern beaches, more work will be needed to pinpoint what factors drive closures among Low Concern beaches given the variability of the data across years, the factors that determine the number of closure events, and the inherent limitations of the data.

The magnitude of total beach closure events at Low Concern beaches was much lower compared to High Concern beaches (Figures 2-5, 7). The maximum total beach closure events observed in the beach monitoring record for Low Concern beaches never exceeded ten closure events per Bay Region. However, High and Low Concern categories should not be compared directly as High Concern beaches are more frequently monitored.

The trend of beach closure events across the sixteen years of water quality monitoring at marine beaches is not significant at p≥ 0.05 (Figure 7).

Among Bay Regions and across years of beach water quality monitoring, the percent of normalized beach closures was the highest in the East Passage (42 percent). Next highest was the West Passage with 19 percent. These percentages should be used cautiously since factors such as monitoring frequency during a single season or across seasons is expected to be highly variable at Low Concern beaches.

On the other hand, the total of beach closure events at Low Concern beaches within each Bay Region exceeded the average (Table 6) in at least seven of the sixteen years of data record (Figure 7). For example, in the Upper Estuary the average of beach closure events across years, from 2000 to 2015, is 2.4 (Table 6). This can be compared with the total of beach closure events each year in Figure 7, and in 2006 this total doubled the average.

Nonetheless, the percent of normalized beach closure events in Low Concern beaches by Bay Region shows that no single Bay Region stands out as the most impacted by pathogen contamination, over the sixteen years of water quality monitoring during the beach seasons (Figure 8). However, the East Passage had the highest percentage of (normalized) beach closures from 2000 to 2004, compared with the other Bay Regions, while the Sakonnet River generally had the lowest (except in 2013) (Figure 8). The Upper Estuary had the greatest percentage of Low Concern beach closure events, compared with the other Bay Regions, in 2010, 2011, and 2015 (two wet years and one dry year), and this pattern does not match the highest closure years for High Concern beaches in the Upper Estuary.

Table 5. Total and percent of 2015 normalized beach closure events at Low Concern marine beaches by Bay Region.

<table>
<thead>
<tr>
<th>Bay Region</th>
<th>Total Beach Closure Events</th>
<th>Number of Beaches</th>
<th>Normalized Beach Closure Events</th>
<th>Percent of the Bay's Beach Closure Events</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper Estuary</td>
<td>3</td>
<td>5</td>
<td>0.6</td>
<td>48.3</td>
</tr>
<tr>
<td>East Passage</td>
<td>0</td>
<td>4</td>
<td>0.0</td>
<td>0</td>
</tr>
<tr>
<td>West Passage</td>
<td>2</td>
<td>4</td>
<td>0.5</td>
<td>40.2</td>
</tr>
<tr>
<td>Sakonnet River</td>
<td>0</td>
<td>3</td>
<td>0.0</td>
<td>0</td>
</tr>
<tr>
<td>Mouth of the Bay</td>
<td>1</td>
<td>7</td>
<td>0.1</td>
<td>11.5</td>
</tr>
</tbody>
</table>
Figure 7. Total beach closure events (and trend line) in Narragansett Bay at Low Concern beaches, by Bay Region, and total seasonal rainfall in inches. Wet years were defined as years with total rainfall greater than fourteen inches during the summer season. The regression of total beach closure events for Low Concern beaches across Narragansett Bay was not significant (p≥0.05, R²=0.134). The colors of the bars for the Bay Regions correspond to areas shown on map in Figure 1.

Table 6. Total and average of beach closure events at Low Concern marine beaches in Narragansett Bay and Bay Regions and percent of normalized beach closure events by Bay Region from 2000 to 2015.

<table>
<thead>
<tr>
<th>Bay Region (Number of Beaches)</th>
<th>Total (Average) beach closure events across years (1)</th>
<th>Normalized beach closure events across years by number of beaches</th>
<th>Percent of beach closure events across years by Bay Region (normalized)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper Estuary (5)</td>
<td>31 (2.4)</td>
<td>6.2</td>
<td>17</td>
</tr>
<tr>
<td>East Passage (4)</td>
<td>61 (3.8)</td>
<td>15.3</td>
<td>42</td>
</tr>
<tr>
<td>West Passage (4)</td>
<td>28 (1.8)</td>
<td>7.0</td>
<td>19</td>
</tr>
<tr>
<td>Sakonnet River (3)</td>
<td>11 (0.7)</td>
<td>3.7</td>
<td>10</td>
</tr>
<tr>
<td>Mouth of the Bay (7)</td>
<td>27 (1.7)</td>
<td>3.9</td>
<td>11</td>
</tr>
<tr>
<td>Narragansett Bay (14)</td>
<td>158 (9.9)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(1) For the Upper Estuary, the average is based on data from 2003 through 2015 because data were not available prior to 2003. For the other four Bay Regions, the average of beach closure events encompassed the entire period from 2000 to 2015.
Figure 8. Percent of normalized beach closure events by Bay Region at High Concern beaches. Wet years were defined as years with total rainfall greater than fourteen inches during the summer season.
Discussion

Regional analysis of sixteen years of marine beach closure data in Massachusetts and Rhode Island revealed a striking record of numerous beach closure events concentrated among the eight High Concern beaches in the Upper Estuary (Tables 3 and 4; Figure 3), a Bay Region with historically high pathogen loading. In fact, the Upper Estuary had the highest percentage of normalized beach closure events in 2015 and across years of beach water quality monitoring—more than 40 percent higher than the other Bay Regions with High Concern Beaches (Tables 3 and 4; Figure 6).

Historical patterns in beach closure event frequency at High Concern beaches indicate that closure events may correspond to seasonal precipitation (Figures 2 through 5). During heavy rainfall, stormwater runoff can become contaminated by multiple sources including animal feces (wild and pet) and untreated or poorly treated sewage (failing septic systems, cesspools, and CSOs). This runoff can discharge to waterways, bringing harmful pathogens to beaches. Results suggest that fewer beach closure events occur during dry seasons, perhaps driven by localized and transient factors such as subsurface transport of pathogen-contaminated groundwater (Lipp at al. 2001) or contamination directly from humans, wildlife, or pets. As evidenced in the wet seasons of 2006 and 2009, rainfall exceeded the capacity of the ecosystem to absorb or capture runoff, resulting in a high frequency of beach closure events. However, after 2009 the frequency of beach closure events did not appear to spike during wet seasons such as 2011, 2012, and even 2013 (the wettest season in this record) (Figures 2 through 5).

The Estuary Program performed an exploratory Pearson’s product-moment correlation analysis of High Concern beaches based on observations that beach closure events were higher in wet years across the Bay and Bay Regions prior to 2009. These observations suggested that precipitation was a driver of beach closure events prior to 2009. No such pattern was observed after 2009. In the analysis of the entire period from 2003 to 2015, which included all years with reliable monitoring frequency, precipitation was not correlated with mean beach closure events \( r=0.323, p=0.223, N=13 \). However, between 2003 and 2008 precipitation was positively correlated to mean beach closure events \( r=0.828, p=0.006, N=7 \), and between 2009 and 2015 no correlation was observed \( r=-0.375, p=0.400, N=6 \). This preliminary analysis suggests a strong positive relationship between closure events and seasonal precipitation prior to 2009, and no relationship after 2009. Following further development of this beach health indicator, a robust statistical analysis that also accounts for rainfall variability will be necessary to further test the validity of this observation (see Data Gaps and Research Needs).

The weakened response to precipitation among High Concern beaches after 2009 was perhaps related to reduced loads of harmful pathogens to those beaches. Watershed stressors such as impervious cover and wastewater infrastructure that exacerbate pathogen transport to receiving waters during rain events can be mitigated by local and regional management actions (e.g., stormwater retention technology, wastewater system upgrades). However, additional data analysis will be needed to determine the effects of management actions on beach closure events as well as on actual pathogen loadings in Narragansett Bay waters (see Data Gaps and Research Needs).

In addition, another exploratory analysis was conducted for High Concern beaches, where beach closure events showed an increasing trend between 2000 and 2008, and a declining trend thereafter. The relationship of total beach closure events over the sixteen years of beach water quality monitoring, shows a significant evidence that the number of events increased from 2000 to 2008, across Narragansett Bay \( r=0.685, p=0.035 \) and the Upper Estuary Region \( r=0.668, p=0.041 \), but not in the other Bay Regions \( p<0.05 \). The declining trend, between 2009 and 2015, was not significant at \( p<0.05 \), for High Concern beaches across the Bay or beaches within the Bay Regions (Figure 9 through 12).

Following these findings (pre- and post-2009) and to complement the results in this chapter, the Estuary Program conducted an exploratory analysis to evaluate the apparent upward trend in closures from 2000 to 2008 and the apparent decline thereafter at High Concern beaches. The relationship of total beach closure events over the sixteen years of beach water quality monitoring shows significant evidence that the number of events increased from 2000 to 2008 across Narragansett Bay \( r=0.685, p=0.035 \) and the Upper Estuary Region \( r=0.668, p=0.041 \), but not in the other Bay Regions \( p<0.05 \). The declining trend, between 2009 and 2015, was not significant at \( p>0.05 \) for High Concern beaches across the Bay or beaches within the Bay Regions (Figures 9-12).

Therefore, the apparent reduction or loss in association of closure events with total seasonal precipitation after 2009 is perhaps a positive sign with respect to source reduction. The combined effect of localized management actions to date appears to have reduced the source loads associated with rainfall. Nevertheless, as reflected in the results of
this analysis, trends of beach closure events should not be explored across the entire Bay, but instead by areas such as the Bay Regions. In addition, it should also be recognized that new baselines for trend analysis should be defined based on the preliminary results pre- and post-2009.

While management actions can mitigate localized stressors, the hydrodynamic characteristics of a beach can also have a strong impact on water quality. Translating or interpolating the outcomes of localized management actions from one location to another part of the Bay that are not geographically, hydrologically, or hydraulically connected can be misleading. Beachfronts that are exposed and well-flushed, like those in the Mouth of the Bay, are less likely to have bacterial contamination (Coakley et al. 2016). Beaches in or near the Mouth of the Bay have greater wave action and water circulation and experience fewer beach closures than those in the Upper Estuary (Table 4). However, High Concern beaches near the Mouth of the Bay continue to see closures despite the benefits of greater circulation. Beaches in enclosed embayments of the Upper Estuary (e.g., Greenwich Bay) with reduced circulation may experience higher closure events comparatively even if pathogen inputs were reduced.

On the landscape spectrum, watershed stressors such as impervious cover and wastewater infrastructure that exacerbate pathogen transport to receiving waters during rain events can be mitigated by local and regional management actions (e.g., stormwater retention technology, wastewater system through CSOs improvements, onsite wastewater system upgrades). However, additional data analysis will be needed to determine the effects of management actions on beach closure events as well as on actual pathogen loadings in Narragansett Bay waters (see Data Gaps and Research Needs).

The Town of Bristol, Rhode Island, has set an example to demonstrate water quality improvements at public beaches. In 2013, the Town completed restoration and implementation of stormwater best management practices (BMPs). Pre-BMPs, the total number of closure days at Bristol Town Beach were linked directly to rainfall events. The number of beach closures declined post-BMPs, despite an increasing trend in precipitation, from an average of eight days per season (metric used by RIDOH) before restoration efforts to zero days following the restoration. These efforts have had ancillary benefits such as improvement of water quality at shellfish beds immediately offshore (USEPA 2015).

Low Concern beaches were characterized by fewer closure events than High Concern beaches (Tables 4 and 6; Figures 2–5, 7). This is in part because Low Concern beaches are monitored less frequently and also because Low Concern beaches are at a lower risk for pathogen contamination. Total closure events at Low Concern beaches closely followed seasonal rainfall almost all years, both across Narragansett Bay and by Bay Region, which could indicate that pathogen contamination is triggered by precipitation, and the magnitude or the frequency of precipitation events.

A majority of the beaches in Narragansett Bay have closed at least once in the past sixteen years, suggesting that beach closures may be difficult to fully eliminate in a highly developed watershed like Narragansett Bay. While reductions in stormwater sources have importantly reduced pathogen loadings associated with rain events, particularly in the Upper Bay, residual and intermittent sources remain. Often these are associated with localized factors and climatic, pollution-related events.

Nevertheless, recent observations made by the Estuary Program and partners indicate that efforts to mitigate contaminated stormwater runoff through sewer improvements, green infrastructure, waste management initiatives, and other BMPs have had positive effects and have contributed to supporting the vital role that beaches play in supporting quality of life, tourism, and the economy.

Regarding climate change stressors, marine beaches are likely to be susceptible. More frequent and intense storms may increase the supply of contaminated stormwater runoff to beaches, particularly if heavy rainfall events exceed the capacity of existing gray and green infrastructure (see “Precipitation” chapter). Additionally, warmer temperatures increase bacterial growth, which may be an additional impact of climate change on beach water quality (Michalak 2016; see “Temperature” chapter). Increased pathogen loads and warmer conditions will likely impact beach closures.

In addition, harmful algal blooms (including microalgae and cyanobacteria) have increasingly garnered attention. Cyanobacteria blooms are more common in freshwater systems but also occur in salt water (Paerl et al. 2011). The toxins potentially associated with bloom events can pose risks to public health and aesthetic enjoyment. More frequent and intense storms expected as a result of climate change may increase nutrient loading from contaminated stormwater runoff, creating conditions favorable to harmful algal blooms (see “Water Quality Conditions for Aquatic Life” chapter).
Figure 9. Total beach closure events (and trend line) in Narragansett Bay at High Concern beaches from 2009 to 2015. The regression of total beach closure events was not significant at $p < 0.05$ ($R^2=0.310$).

Figure 10. Total beach closure events (and trend line) in Upper Estuary at High Concern beaches from 2009 to 2015. The regression of total beach closure events was not significant at $p < 0.05$ ($R^2=0.138$). Color of bars corresponds to color of Bay Region on map in Figure 1.
Figure 11. Total beach closure events (and trend line) in the Sakonnet River at High Concern beaches from 2009 to 2015. The regression of total beach closure events was not significant at p< 0.05 ($R^2=0.248$). Color of bars corresponds to color of Bay Region on map in Figure 1.

Figure 12. Total beach closure events (and trend line) in the Mouth of the Bay at High Concern beaches from 2009 to 2015. The regression of total beach closure events was not significant at p< 0.05 ($R^2=0.488$). Color of bars corresponds to color of Bay Region on map in Figure 1.
Climate change may also physically alter the structure of coastlines through sea level rise, storms, storm surge, nuisance flooding, and erosion (see “Sea Level” chapter). These changes in the coastline may contribute to higher levels of pathogen contamination as stormwater and wastewater infrastructure located along the coastline will likely be burdened by higher sea levels. Many beaches are increasingly squeezed between rising seas and expanding coastal development.

**Data Gaps and Research Needs**

- The beach indicator should be refined by the development of other metrics. One option to explore is the development of a bi-state dataset that uses bacterial counts normalized by monitoring frequency (number of samples per season per beach) for the period of 2000 to the present to develop a more consistent and sensitive metric. Further analysis using bacteria counts associated with sampling dates will allow for cross-comparison between years with differing monitoring frequency and regulatory stringency. A protocol is needed to evaluate bacterial counts in the context of sampling frequency. Furthermore, the results of future analyses should be compared to current findings to corroborate the preliminary trends noted in this report.

- Further work is needed to develop appropriate metrics for freshwater beaches in the Narragansett Bay Watershed. Data are limited and were not reviewed for this report.

- As recent preliminary trends indicate a weakening relationship between rainfall and beach closure events, it will be important to continue to evaluate beach closures in wet years. With an indicator based on bacterial counts, the Estuary Program anticipates that a robust statistical analysis could address temporal trends and relationships with precipitation. Additional factors that influence microbial contamination and its persistence at beaches can be used to develop predictive models on a beach-specific basis. These include wind direction and speed, water temperature, wave height, changes in wastewater infrastructure and land use (Wu and Jackson 2016), and patterns in human use.

- For High Concern beaches, development of models to support management is of interest. With appropriate input data and validation, predictive models can drive better management to reduce exposure to high-risk conditions. Unlike current microbiological analyses which typically characterize water quality on the previous day, models can predict when a beach should be closed (i.e., at the times when adverse conditions result in high levels of enteric microbes).

- Detailed analyses of existing management actions such as CSO abatement projects, stormwater infrastructure improvements, and waste management initiatives based on bacterial counts and sampling history as metrics are likely to be useful in informing BMPs. Improvements at specific beaches are likely related to localized management actions. Pinpointing successful management strategies that target sources of contamination will be beneficial from economic, social, and public health perspectives.

- While continuing to build on the information gained through both state beach monitoring programs, it will also be imperative to relate beach assessments to other programs that evaluate microbial contamination in the Bay’s waters. These include assessments of long-term and comprehensive water quality characterizations of the Bay’s waters to meet standards for recreational uses, including primary and secondary contact, as well as designations of shellfishing areas.

**Acknowledgments**

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Rhode Island Department of Health (RIDOH). 2016. 2015 Rhode Island Beach and Recreational Water Quality Report. Available upon request to RIDOH.


Condition Indicators of Public Health

CHAPTER 24: SHELLFISHING AREAS
BACKGROUND

- Harvesting of shellfish plays an important role in the economy and culture of Narragansett Bay. To protect public health from contaminated shellfish, primarily due to harmful pathogens, state agencies regulate where shellfish can and cannot be harvested for direct human consumption. The status of shellfishing areas serves as an indicator of public health conditions in the Bay. Contamination enters the Bay primarily in discharges from wastewater treatment infrastructure and in runoff of precipitation from land.

KEY FINDINGS

- **Status:** In 2015, 63 percent of Narragansett Bay was classified as approved for shellfishing for direct human consumption (although one-third of the approved area may not be suitable for shellfishing because of water depth, commercial navigation channels, or other reasons). Thirteen percent of the Bay was classified as conditionally approved, and 24 percent as prohibited; shellfishing growing areas with these two classifications were located primarily in the Upper Estuary.

- **Trends:** Between 1995 and 2005, the total area approved for shellfishing declined three percent from 82,386 acres to 79,753 acres, while prohibited areas increased. Conversely, prohibited areas decreased in the subsequent ten years from 31,667 acres in 2005 to 30,542 acres in 2015, while conditionally approved areas increased. In 2017, 3,711 acres in the Upper Estuary at the mouth of the Providence River were upgraded from conditionally approved to approved. Most of the positive changes in the last decade have occurred in the Upper Estuary, where water quality historically was poor.
Introduction

State agencies in Massachusetts and Rhode Island administer shellfish management programs that assess water quality conditions and regulate shellfish harvesting for commercial and recreational purposes throughout Narragansett Bay. Each of the states classifies shellfishing areas based on water quality levels of fecal coliform bacteria and other management factors. The classifications are designed to protect public health and ensure the safe consumption of shellfish. Approved waters are areas where harvesting is allowed on a regular basis, conditionally approved waters allow shellfish harvest under certain conditions, and in prohibited waters shellfish harvest for human consumption is not allowed at any time (CRC 2014).

The importance of good water quality for shellfishing in Narragansett Bay was recognized over a century ago, when water pollution was a primary cause of the collapse of a vibrant oyster industry. At its height in the early 1900s, the local oyster industry employed over a thousand people and had an annual harvest of 1.4 million bushels (Schumann 2015). Total acreage leased to private growers peaked in 1912 at 20,846 acres, representing seventeen percent of the estuarine waters of Narragansett Bay. Oyster landings in Rhode Island collapsed by the 1950s (Oviatt et al. 2003).

In 1910, an investigation into contamination in oyster beds found traces of sewage and fecal coliform bacteria in many upper Bay oyster beds, a result of the four hundred percent increase from 1850 to 1900 in human population in coastal areas around the Bay (see “Population” chapter; Vadeboncoeur et al. 2010). Following a nationwide typhoid epidemic, caused in part by the consumption of polluted shellfish, the National Shellfish Sanitation Program was established in 1925. This national program created standards for shellfish intended for consumption and required states to sample all shellfish waters and to close areas that did not meet standards. In 1926, Massachusetts closed the waters of the Taunton River and the northern portion of Mount Hope Bay. Between 1937 and 1985, thousands of bushels of quahogs and oysters were relayed or transported from the Taunton River to various towns in Rhode Island and Massachusetts for depuration or cleansing before harvest for human consumption.

Shea (1946) outlined Rhode Island’s early water classifications for shellfish areas. Waters suitable for the cultivation of market shellfish were primarily in the West and East Passages, Sakonnet River, lower Mount Hope Bay, Palmer River, Barrington River, Kickemuit River, and parts of Bristol Harbor and Greenwich Bay. Areas that were suitable for culture of seed oysters were identified in Mount Hope Bay and the lower Providence River. Waters in the upper Providence River, north of Field’s Point, were defined as grossly polluted. By the 1970s, waters in the Providence River were closed half of the time for shellfishing. As a result of the growing population in the upper Bay and the limited flow capacity of the Field’s Point wastewater treatment facility, untreated and partially treated sewage were discharged directly to the upper Bay, raising public health concerns regarding the consumption of shellfish from those waters (Schumann 2015).

Massachusetts regulates the portions of Mount Hope Bay and the Palmer River that lie within its state boundary (MADMF 2013), representing approximately five percent of Narragansett Bay. The Rhode Island Department of Environmental Management (RIDEM) Office of Water Resources and the Division of Fish and Wildlife Marine Fisheries Section determine shellfish harvest restrictions for the remaining 95 percent of Narragansett Bay (RIDEM 2015). All approved and conditionally approved areas are sampled for fecal coliform and harmful algal blooms six to twelve times per year. There are more than 110 fixed stations in the approved growing areas, with nearly 2,000 samples collected annually by the two states.

Estuarine waters for shellfish harvesting are designated by the states pursuant to the Federal Clean Water Act. Class SA waters are designated for shellfishing for direct human consumption; they may be approved or conditionally approved. Class SB waters are suitable for shellfish harvesting for controlled relay and depuration (RIDEM 2010, MassDEP 2012). The maximum level of fecal coliform bacteria allowed in Class SA waters is a geometric mean of 14 organisms per 100 mL, and the maximum for Class SB waters is 88 organisms per 100 mL (MassDEP 2012). Shellfish classifications are also based on sanitary surveys and shoreline surveys conducted by the state shellfish programs.

In this chapter, the Narragansett Bay Estuary Program examines the status of shellfishing areas as of 2015, and identifies trends from 1995 to 2015 in the areas of Narragansett Bay that are classified as approved, conditionally approved, or prohibited for the harvest of shellfish for direct human consumption.
Methods

The Estuary Program coordinated bi-state meetings with representatives from the Massachusetts Division of Marine Fisheries (MADMF) and the Rhode Island Department of Environmental Management (RIDEM) to examine various approaches for using shellfishing areas as a proxy indicator of public health and water quality. Through these discussions, it was determined that shellfish growing areas (area and percent change) can be measured consistently between the two states to track changes (improvements or declines) in water quality in the Bay, as the state data are consistent in purpose and the classification systems are comparable. For this analysis, the Estuary Program defined three categories derived from the shellfish growing area classification systems used by Massachusetts and Rhode Island:

- **Approved:** Growing areas where shellfish harvesting is allowed for direct human consumption all year round (some exceptions may apply)
- **Conditionally Approved:** Growing areas where shellfish harvesting is allowed for direct human consumption with some restrictions, depending on each state’s shellfish program criteria
- **Prohibited:** Waters where shellfish harvesting is not allowed for direct human consumption

For the purposes of this chapter, shellfish growing areas used for controlled relay and depuration in Massachusetts and Rhode Island are considered prohibited. The prohibited category also includes small portions of the Bay in Rhode Island that are classified as unassessed or where shellfishing is prohibited for other reasons not related to monitored water quality. Examples include areas located within marinas, near discharges from wastewater treatment facilities, in waters impacted by actual or potential sources of deleterious substances, or in waters where pollution impacts are not predictable. Harvesting of shellfish in certain approved waters may be restricted by RIDEM’s Division of Fish and Wildlife Marine Fisheries Section for shellfish management purposes, even when the area is not classified as prohibited.

Data on shellfishing areas in Massachusetts were available for 2005 through 2015, and the Rhode Island dataset covered 1995 through 2015. For this analysis, although data for Massachusetts were not available prior to 2005, all of its waters within the Bay were closed before that year, so the Estuary Program included all Massachusetts waters in the prohibited classification category from 1995 through 2005.

Following direction from the Massachusetts Division of Marine Fisheries, the Estuary Program updated the most current Massachusetts shellfishing growing areas to reflect annual changes and status in Mount Hope Bay, which had been closed to shellfishing from the 1980s to 2009. Because only slight changes occurred from one year to the next, the Estuary Program analyzed the data at five-year intervals to identify changes in acreage of shellfish growing areas. The analysis was conducted for the entire Narragansett Bay and for five regions within the Bay: (1) the Upper Estuary (including Mount Hope Bay, Greenwich Bay and other estuarine waters north of Prudence Island and Aquidneck Island), (2) West Passage, (3) East Passage, (4) Sakonnet River, and (5) the Mouth of the Bay including the Narrow River.

The Estuary Program calculated metrics at five-year intervals between 1995 and 2015 for Narragansett Bay and for regions within the Bay. The metrics for each of the three classification categories—approved, conditionally approved, and prohibited—included the following:

1. Total extent (acres) and percentage of the Bay or region
2. Gross change: total change in area (acres)
3. Percentage net change: change in acreage relative to the previous year

Data from Rhode Island and Massachusetts were reconciled to obtain a seamless shellfish growing area dataset at different time steps. Data provided as paper and digital maps were converted into GIS using heads-up digitizing and geo-referencing to a common coordinate system. The Estuary Program used geospatial tools in the GIS platform (Esri 2016) to cross-tabulate the area and percentage of each category of shellfish growing area by Bay Region at each time step.

It is important to note that while every effort was made to ensure accuracy in digitizing paper and digital maps, the data are imperfect, and it was estimated that any changes of one percent or less between years were likely attributable to digitization error, and therefore they were not interpreted as actual changes. This error was computed by the total area of the Bay and each Bay Region across years. Other limitations and sources of error for the analysis are derived from the data sources.
**Status and Trends**

**Status**

In 2015, approximately 63 percent of the Bay’s waters were classified as approved shellfish growing areas, and thirteen percent were conditionally approved. In 24 percent of the Bay, shellfish harvesting for direct human consumption was prohibited (Table 1; Figure 1).

In 2015, the Upper Estuary had by far the lowest percentage (six percent) and acreage (2,249 acres) of approved shellfish growing area, compared to the other four Bay regions (Table 2; Figure 1). The other regions had 68 to 95 percent of their area classified as approved. Conditionally approved areas accounted for 44 percent of the Upper Estuary, in contrast to the other regions, which had one percent or less of their area classified as conditionally approved. Half of the Upper Estuary and 31 percent of the East Passage were classified as prohibited (Table 2; Figure 1).

Looking at the Bay as a whole, most of the prohibited areas (58 percent) and nearly all conditionally approved areas (97 percent) were in the Upper Estuary. Approved areas for shellfishing without conditions were located mainly in the West Passage (29 percent) and Mouth of the Bay (35 percent) (Table 3). However, it should be noted that 35 percent of the approved area of Narragansett Bay consisted of

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**Table 1. Area (acres) and percentage of shellfish growing areas in Narragansett Bay by category in 2015.**

<table>
<thead>
<tr>
<th>Categories of Shellfish Growing Areas</th>
<th>Total Acreage</th>
<th>Percent of Narragansett Bay</th>
</tr>
</thead>
<tbody>
<tr>
<td>Approved</td>
<td>79,253</td>
<td>63</td>
</tr>
<tr>
<td>Conditionally Approved</td>
<td>16,297</td>
<td>13</td>
</tr>
<tr>
<td>Prohibited</td>
<td>30,542</td>
<td>24</td>
</tr>
<tr>
<td>Narragansett Bay</td>
<td>126,092</td>
<td></td>
</tr>
</tbody>
</table>

**Table 2. Area (acres) and percentage of shellfish growing areas by category in Bay regions in 2015.**

<table>
<thead>
<tr>
<th>Bay Region</th>
<th>Area (acres)</th>
<th>Approved</th>
<th>Conditionally Approved</th>
<th>Prohibited</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Acreage</td>
<td>Percent</td>
<td>Acreage</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Acreage</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Acreage</td>
</tr>
<tr>
<td>Upper Estuary</td>
<td>35,803</td>
<td>2,249</td>
<td>6</td>
<td>15,755</td>
</tr>
<tr>
<td>West Passage</td>
<td>25,364</td>
<td>22,760</td>
<td>90</td>
<td>387</td>
</tr>
<tr>
<td>East Passage</td>
<td>20,519</td>
<td>14,029</td>
<td>68</td>
<td>105</td>
</tr>
<tr>
<td>Sakonnet River</td>
<td>13,090</td>
<td>12,429</td>
<td>95</td>
<td>0</td>
</tr>
<tr>
<td>Mouth of the Bay</td>
<td>31,052</td>
<td>27,784</td>
<td>90</td>
<td>0</td>
</tr>
</tbody>
</table>

(1) Due to inconsistencies between data sources at different time steps, the total of the regional acreages listed here does not equal the total Bay acreage in Table 1 (0.2 percent error).

**Table 3. Distribution of shellfishing categories among regions of Narragansett Bay in 2015. The table shows the proportion of each category that is located in each region relative to the total acreage of that category across the entire Bay.**

<table>
<thead>
<tr>
<th>Bay Region</th>
<th>Approved (percentage)</th>
<th>Conditionally Approved (percentage)</th>
<th>Prohibited (percentage)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper Estuary</td>
<td>3</td>
<td>97</td>
<td>58</td>
</tr>
<tr>
<td>West Passage</td>
<td>29</td>
<td>2</td>
<td>7</td>
</tr>
<tr>
<td>East Passage</td>
<td>18</td>
<td>1</td>
<td>21</td>
</tr>
<tr>
<td>Sakonnet River</td>
<td>16</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>Mouth of the Bay</td>
<td>35</td>
<td>0</td>
<td>11</td>
</tr>
<tr>
<td>Narragansett Bay</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
</tbody>
</table>

(1) ((Total acreage of a category in region/Total acreage of that category in Narragansett Bay)*100). See also Table 1.
Figure 1. Shellfish growing areas in Narragansett Bay by category in 2015. Labels in capital letters indicate the Bay Regions used for data analysis and reporting. Classification changes that took place in Rhode Island in 2017 in some areas of the Bay are not reflected on this map; see RI Shellfish Harvest Restrictions for most recent updates.
Table 4. Area (acres) and percentage of shellfish growing areas by category in Narragansett Bay at five-year intervals from 1995 to 2015.

<table>
<thead>
<tr>
<th>Category</th>
<th>Approved Acreage</th>
<th>Approved Percent</th>
<th>Conditionally Approved Acreage</th>
<th>Conditionally Approved Percent</th>
<th>Prohibited Acreage</th>
<th>Prohibited Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>1995</td>
<td>82,386</td>
<td>66</td>
<td>14,807</td>
<td>12</td>
<td>27,903</td>
<td>22</td>
</tr>
<tr>
<td>2000</td>
<td>80,856</td>
<td>65</td>
<td>14,322</td>
<td>11</td>
<td>29,938</td>
<td>24</td>
</tr>
<tr>
<td>2005</td>
<td>79,753</td>
<td>63</td>
<td>14,612</td>
<td>12</td>
<td>31,667</td>
<td>25</td>
</tr>
<tr>
<td>2010</td>
<td>79,180</td>
<td>63</td>
<td>15,175</td>
<td>12</td>
<td>31,578</td>
<td>25</td>
</tr>
<tr>
<td>2015</td>
<td>79,253</td>
<td>63</td>
<td>16,297</td>
<td>13</td>
<td>30,542</td>
<td>24</td>
</tr>
</tbody>
</table>

Table 5. Percent net change of shellfish growing areas by category in Narragansett Bay at five-year intervals from 1995 to 2015.

<table>
<thead>
<tr>
<th>Category</th>
<th>Approved Percent Change</th>
<th>Conditionally Approved Percent Change</th>
<th>Prohibited Percent Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>1995–2000</td>
<td>-1.9</td>
<td>-3.3</td>
<td>7.3</td>
</tr>
<tr>
<td>2000–2005</td>
<td>-1.4</td>
<td>2.0</td>
<td>5.8</td>
</tr>
<tr>
<td>2005–2010</td>
<td>-0.7</td>
<td>3.8</td>
<td>-0.3</td>
</tr>
<tr>
<td>2010–2015</td>
<td>0.1</td>
<td>7.4</td>
<td>-3.3</td>
</tr>
</tbody>
</table>

Figure 2. Acreage change in shellfish growing areas by category in Narragansett Bay at five-year intervals.
areas where little or no shellfishing occurs, including some areas within these two regions. Those areas included deeper waters (south of Aquidneck Island and north of the line between Point Judith and Sakonnet Point), regulated navigation channels, and other precautionary areas. For this analysis, these areas were included as approved—and included in the total approved area of 79,253 acres—because data were not readily available to distinguish areas of the Bay that had good water quality but were not suitable for harvest for other reasons.

**Trends for Narragansett Bay**

The Estuary Program calculated the acreages and percentages of the three categories of shellfishing growing areas in the entire Narragansett Bay at five-year intervals between 1995 and 2015 (Table 4; Figure 2). The relative amount of each shellfishing growing area by category in the Bay changed only slightly between time-steps (Table 4). Figure 2 shows changes in the total acreage in each category, and Table 5 shows the net percent change.

The approved shellfishing areas varied only slightly within each time-step when calculating acreage across the Bay. However, there were reductions in prohibited areas from 2005 to 2015 and increases in conditionally approved areas (Table 5). Table 6 shows where these changes occurred in Bay regions.

**Trends in Regions of Narragansett Bay**

The Estuary Program also calculated the amount of change within each of the five Bay regions at five-year intervals from 1995 to 2015 (Table 6). Of note, the

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**Table 6. Changes in shellfish growing areas (acreage and percent net change) by category in Narragansett Bay regions at five-year intervals.**

<table>
<thead>
<tr>
<th>Bay Regions</th>
<th>Category of Shellfish Growing Area</th>
<th>Five-year Interval</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Approved</td>
<td>Conditionally Approved</td>
</tr>
<tr>
<td></td>
<td>Acres</td>
<td>Percent</td>
</tr>
<tr>
<td>Upper Estuary</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1995–2000</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2000–2005</td>
<td>32</td>
<td>1.5</td>
</tr>
<tr>
<td>2005–2010</td>
<td>2</td>
<td>0.1</td>
</tr>
<tr>
<td>2010–2015</td>
<td>24</td>
<td>1.1</td>
</tr>
<tr>
<td>West Passage</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1995–2000</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2000–2005</td>
<td>-238</td>
<td>-1.0</td>
</tr>
<tr>
<td>2005–2010</td>
<td>-238</td>
<td>-1.0</td>
</tr>
<tr>
<td>2010–2015</td>
<td>-116</td>
<td>-0.5</td>
</tr>
<tr>
<td>East Passage</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1995–2000</td>
<td>-1,530</td>
<td>-10</td>
</tr>
<tr>
<td>2000–2005</td>
<td>162</td>
<td>1.2</td>
</tr>
<tr>
<td>2005–2010</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2010–2015</td>
<td>162</td>
<td>1.2</td>
</tr>
<tr>
<td>Sakonnet River</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1995–2000</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2000–2005</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2005–2010</td>
<td>-301</td>
<td>-2.4</td>
</tr>
<tr>
<td>2010–2015</td>
<td>-3</td>
<td>0</td>
</tr>
<tr>
<td>Mouth of the Bay</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1995–2000</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2000–2005</td>
<td>-1,059</td>
<td>-3.7</td>
</tr>
<tr>
<td>2005–2010</td>
<td>-32</td>
<td>0.1</td>
</tr>
<tr>
<td>2010–2015</td>
<td>3</td>
<td>0</td>
</tr>
</tbody>
</table>
Upper Estuary from 2010 to 2015 had an increase of approximately 1,100 acres in conditionally approved areas, as prohibited areas decreased by approximately the same amount (Table 6; Figure 3).

Discussion

The most noteworthy changes in shellfishing areas in Narragansett Bay occurred in the Upper Estuary over the last decade. Acreage of conditionally approved growing areas began to increase in 2000 and continued this trend through 2015, while prohibited areas declined at a comparable rate from 2005 through 2015 (Figure 3). The greatest percent change in the Upper Estuary occurred between 2010 and 2015 when conditionally approved areas gained 7.5 percent and prohibited areas declined by 5.8 percent; this change was twice as large and opposite the change that occurred from 1995 to 2000, when conditionally approved areas declined 3.4 percent and prohibited areas increased 2.8 percent (Table 6). These changes in the Upper Estuary suggest an improvement in water quality conditions. Ninety-seven percent of the 16,297 acres of conditionally approved areas in the entire Narragansett Bay occurred in the Upper Estuary (Table 3).

While the shift from prohibited areas to conditional areas indicated improvement, the Upper Estuary still had a very limited area—only six percent—that was fully approved without conditions as of 2015 (Table 2). At that time, the Upper Estuary’s approved areas were limited primarily to waters at the northern portions of Prudence Island (Figure 1). However, as this chapter was being finalized in spring 2017, RIDEM announced that restrictions for portions of the upper Bay were lifted for the first time since 1947, with 3,712 acres of conditionally approved areas upgraded to approved status. This area encompassed upper Bay waters between Warwick Point and Colt State Park in Bristol, north of Prudence Island. This is an extremely positive indicator of Narragansett Bay water quality improvements, considering that this area of the upper Bay had not had a significant increase in waters with an approved status in decades (Table 4; Figure 3).

Of the 30,542 acres where shellfish harvesting was prohibited in Narragansett Bay in 2015, almost 60 percent (17,799 acres) were in the Upper Estuary (Table 2 and 3), where water quality impairments were likely due to loadings from Providence, Fall River, and surrounding urban areas (Figure 1). It is important to note that the prohibited areas in the Estuary Program’s analysis included waters with a restricted classification by MADMF, at the mouth of the Taunton River. An upgrade from prohibited to restricted classification indicates water quality improvements in this area (MADMF 2013), but it is still in the classification of not suitable for harvesting shellfish for human consumption. Shellfish in these areas may be allowed for removal to grow out in approved areas.

While the majority of prohibited areas (17,799 acres) were located in the Upper Estuary, large prohibited areas also occurred in other Bay regions. These classifications were not related exclusively to documented water quality concerns. Some of them resulted from National Shellfish Sanitation Program prohibitions on shellfishing in waters near marinas, wastewater treatment facility outfalls, and other regulated areas that are potential sources of contamination by pathogens and other pollutants.

In addition, the East Passage included 6,385 acres of prohibited areas, and much of that acreage was located in and around Newport Harbor (Table 2; Figure 1), an area where shellfishing was prohibited for safety reasons because of the high concentration of commercial, industrial, and military activities. The largest percent change of acreage in the East Passage occurred between 1995 and 2000 with a 30 percent increase in prohibited areas for shellfishing (Table 6). Similarly, a prohibited area was established in the West Passage for safety reasons around the Quonset Business Park (Figure 1). Other prohibited areas in the West Passage were based on water quality concerns, including smaller enclosed areas such as the Potowomut River in Greenwich Bay and Sheffield Cove in Jamestown. Most the changes to prohibited areas in the West Passage region occurred between 2000 and 2010, as prohibited areas increased over 20 percent within each five-year interval (Table 6). Water quality issues were the reason for the prohibited areas in the Sakonnet River, including the northern section near Tiverton and Portsmouth, as well as in small coves and embayments; the greatest change occurred from 2005 to 2010 when prohibited areas increased by 18.5 percent (Table 6). In the Mouth of the Bay, prohibited waters have been located in the Narrow River, at two safety zones around sewer outfalls on the western shore, and by 2005 Easton’s Beach in Newport also was downgraded to prohibited status, along with an increase of area of the two safety zones.

Urban landscapes and combined sewer overflows are prime contributors of pathogen loadings to the Bay (see “Wastewater Infrastructure” chapter), but there are many sources to consider, including stormwater runoff, septic systems, and waterfowl, among others. In many instances, stormwater from rainfall triggers temporary closures. This varies by growing area and
by criteria set forth by the state shellfish programs (RIDEM 2015, MADMF personal communication 2017). Within a suburban coastal embayment in nearby Buzzards Bay, investigators found significant loading of fecal coliform from storm drains and small streams during rain events (Weiskel et al. 1996). Others report that septic systems can be a source of pathogens to coastal waters (e.g., Lipp et al. 2001), although Weiskel and colleagues (1996) found that the bacteria were substantially attenuated during transport to coastal waters via groundwater. As progress is made to address fecal coliform contamination from point sources and nonpoint sources, additional upgrades from prohibited to conditionally approved shellfish growing areas can be expected. While the oyster fishery appears to be returning and quahog landings have fluctuated historically (Oviatt et al. 2003), these industries are important to the Bay’s economy (Schumann 2015), and opening prohibited areas or upgrading conditionally approved areas to approved would be beneficial to the fishery.

Improvements in water quality in the Upper Estuary, including the Providence River estuary and Mount Hope Bay, started to be evident from a substantial increase of conditionally approved areas and decline of prohibited acreage from 2005 through 2015, most likely due to upgrades in the wastewater treatment plant facilities and combined sewer overflow (CSO) abatement efforts. Tunnels for temporary storage of stormwater and untreated waste, installed by the Narragansett Bay Commission and the City of Fall River, have significantly reduced combined sewer overflows. In recent years, RIDEM’s Office of Water Resources has conducted targeted post-storm monitoring in the upper Bay to evaluate water quality improvements resulting from the completion of two phases of the Narragansett Bay Commission’s (NBC) combined sewer overflow abatement project. Water quality data from NBC’s monitoring program show an overall decrease of 24 percent in fecal coliform concentrations in the lower Providence River at all stations downstream of the CSOs post-Phase I (NBC 2016). An agreement between RIDEM and the United States Food and Drug Administration allows the state to re-open the upper Bay’s conditionally approved areas to shellfish harvesting as soon as post-storm monitoring data demonstrate that it is safe to do so.

Though not well documented, considerable improvements of water quality in Mount Hope Bay have also been attributed to CSO abatement. Most

Figure 3. Acreage change in shellfish growing areas by category in the Upper Estuary region at five-year intervals. Bars represent the magnitude of acreage gain or loss by time-steps.
of the upgrades of prohibited areas to conditionally approved areas between 2005 and 2015 occurred in waters of Mount Hope Bay.

Overall, the major improvements in stormwater and sewer infrastructure, which were conducted to reduce pathogen loadings to the Bay, have been linked to upgrades in classification of shellfish growing areas in the Upper Estuary and also to changes in wet weather criteria (e.g., magnitude of precipitation events) as a major factor used to determine the status of conditionally approved areas. However, quantitative analyses to correlate factors that trigger closure of conditionally approved areas and water quality improvements such as reduced pathogen loadings resulting from infrastructure improvements have not been conducted or published to date.

Changes of classification for the shellfish growing areas remain driven by water quality and shoreline survey data, as well as management actions. While the shellfish indicator used by the Estuary Program in this chapter measures areas defined by three classification categories for growing areas, changes in classification within the conditional approved status can also imply water quality improvements, as areas can be upgraded within the same classification, but with different criteria. In addition to the 2017 newly approved areas in the upper Bay in Rhode Island, two conditionally approved areas—Conimicut Triangle and Conditional Area A (Figure 4)—were merged. Previously, these areas would be closed after 0.5 inches and 0.8 inches of rain, respectively (RIDEM 2017; see RI Shellfish Harvest Restrictions online map). Now this area of approximately of 5,980 acres will be closed after 1.2 inches of rain—a significantly higher threshold. Even though the shellfish growing area status has been kept as conditionally approved, the change in wet weather criteria is expected to result in an increased number of days when the waters can be opened for harvesting shellfish (RIDEM 2017). No changes in shellfish classification have occurred in Mount Hope Bay or Palmer River since 2015 (MADMF personal communication 2017).

RIDEM also indicated that the lower portion of the Providence River holds potential as a new conditionally approved area, perhaps implemented when the NBC completes Phase III of the CSO abatement project (RIDEM 2017). Likewise, these improvements could influence marine beaches and recreational uses of the Bay (see “Marine Beaches” and “Water Quality Conditions for Recreation” chapters), which are also evaluated using pathogen concentrations as a metric and have similar stressors as the shellfishing areas.

In addition to high concentrations of pathogens, there are other reasons for which areas of the Bay may be closed to shellfishing. Approved and conditionally approved shellfish growing areas can be closed on an emergency basis due to harmful algal blooms (HAB). In October 2016, a shellfish closure was triggered in Narragansett Bay by a harmful algal bloom of the phytoplankton Pseudo-nitzschia spp. RIDEM conducted an intensive program of phytoplankton sampling and shellfish meats collection. Approximately 176 plankton samples and 150 shellfish samples were tested for domoic acid, the toxin produced by Pseudo-nitzschia cells that causes amnesic shellfish poisoning. A similar closure, lasting three weeks, occurred in March 2017. In response to the state’s first Pseudo-nitzschia bloom in October 2016, RIDEM in coordination with the RIDOH is revising its Harmful Algal Bloom Monitoring and Contingency Response Plan to include more frequent routine phytoplankton monitoring to detect HAB blooms. When blooms are detected, the revised plan calls for more intensive monitoring of phytoplankton and shellfish to track spatial extent and intensity of the bloom and the presence of biotoxins, among other provisions (RIDEM personal communication 2017). In addition, Rhode Island Sea Grant is funding research to understand this concerning phenomenon.


**Data Gaps and Research Needs**

- Conditionally approved areas are monitored frequently, but fewer data are available for prohibited areas. Additional sampling in certain areas may be needed to better document progress of these areas toward water quality improvement goals.
- Synthesis of existing data and development of site-specific models would improve understanding of relationships among land use, point and non-point sources, and bacterial concentrations in receiving waters.
- Recent changes showing a decline of prohibited areas and an increase of approved and conditionally approved areas in the Upper Estuary have been attributed to wastewater and other infrastructure improvements to capture and treat combined sewage and stormwater overflows, and other pollution control efforts.
- Refinement of this indicator using pathogen data could provide a metric more sensitive to water quality improvements, such as by discerning partial progress toward water quality goals.
- Post-storm monitoring of the Mount Hope Bay and Kickemuit River estuary is needed to evaluate water quality improvements associated with construction of the Fall River CSO control structures, and to revise rainfall thresholds that trigger closures of these conditionally approved waters.

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