APPENDIX E. Compiled List of Data Gaps and Research Needs

This is a compiled list of data gaps and research needs from the 2017 *State of Narragansett Bay and Its Watershed* Technical Report. The Estuary Program has organized the data gaps and research needs from the Technical Report into two major categories: 1) **projects where data is available but needs further analysis**, or 2) **projects that need new data collected**.

Chapter 1. Temperature

1. **Continuous temperature data in rivers and streams is a major data gap. A sustained river/ stream temperature monitoring network in the Narragansett Bay Watershed needs to be established to include long-term monitoring stations in key locations. Lacking that, a conversion factor between air temperature and freshwater temperature (e.g., Morrill et al. 2005) would estimate changes in stream temperature from existing air temperature data.**
2. **An assessment is needed to determine whether the existing network of fixed sites for collecting water temperature data continuously in the Bay provides adequate information for tracking the long-term changes. Data collection in embayments is a recognized gap. Prior monitoring strategies recommended building capacity to periodically assess water quality conditions in such areas. Rising temperatures are likely to affect shallow and highly urbanized basins before the rest of Narragansett Bay (Oczkowski et al. 2015).**
3. **Further analysis of trends in air and water temperature datasets is needed. While the Estuary Program and other researchers (e.g., Nixon et al. 2004, Oviatt 2004, Pilson 2008) used 1960 as a start date for regressions, the perception of a recent acceleration in warming may be a consequence of using that date. An analysis of the datasets could determine whether this trend is meaningful and potentially identify other significant trends, such as seasonal variability (e.g., freeze/thaw cycles).**
4. **Experiments using mesocosms are needed to determine how the Narragansett Bay ecosystem may be affected by climate change (e.g., Bintz et al. 2003). Latitudinal gradient studies would be beneficial to predict future ecosystem and species shifts resulting from changing temperature trends (e.g., Crosby et al. 2017).**

Chapter 2. Precipitation

1. **The existing network of stream gages in the Narragansett Bay Watershed should be assessed to ascertain key gaps, and data records should be analyzed to characterize variability in rainfall across the watershed and identify where additional rain gages may be needed (e.g., the Pawtuxet River watershed). Sustained funding for the network is critical to ensure adequate hydrologic data is available to support management decision-making.**
2. **Extreme precipitation and drought in the Narragansett Bay Watershed need to be further investigated using a combination of approaches, such as the Palmer Drought Severity Index, the Crop Moisture Index, and Cornell University's effort to analyze frequency and intensity of precipitation (Cornell University 2016). The results of these efforts will detail the impacts that extreme precipitation and drought have on water resources management and water quality.**
3. **The frequency, amount, seasonality (freeze/ thaw cycles), and type (rain, snow) of precipitation influence physical, chemical, and biological processes within the Narragansett Bay Watershed. The impacts of climate change on precipitation need to be further explored using downscaling of climate models or other methods. Results of these efforts will increase**

knowledge of how sensitive habitats will change, and how to plan for the resiliency of infrastructure.

Chapter 3. Sea Level

1. The STORMTOOLS model should be expanded to include the Massachusetts portion of Narragansett Bay to identify and evaluate high-risk areas.
2. An analysis of the potential impacts of sea level rise on groundwater, drinking water supplies, floodplains, and individual wastewater treatment systems is needed (Walter et al. 2016).
3. Data and research are needed to evaluate the effects of sea level rise on other ecological systems at the landscape and seascape level, such the impacts on bird, mammal, and amphibian migration and breeding habitat, submerged aquatic vegetation, freshwater wetlands (palustrine and lacustrine), shellfish habitat, and fish passage habitat (diadromous and anadromous fish).
4. A sea level rise trend analysis is needed for Mount Hope Bay using data from the Fall River tide gauge, which NOAA has operated since 1955. This analysis is especially important because of the low elevations of the Taunton River watershed.
5. Enhanced bathymetry data would improve the resolution of the hydrodynamic models that are used to predict flooding potential from sea level rise and storm surge.

Chapter 4. Population

1. There are no critical data gaps or research needs, assuming that detailed US Census Bureau data continue to be collected each decade and that funds are made available to conduct geospatial analyses. This research is needed to provide a more comprehensive understanding of trends and to provide context for other indicators of stressors and conditions in Narragansett Bay and its Watershed. More robust data analyses should be performed to interrelate total population changes with developed area per capita and housing density, two factors that are linked to the effects of population on other landscape and chemical indicators.

Chapter 5. Land Use

1. Data from the NOAA Coastal Change Analysis Program (C-CAP) should be utilized to improve the spatial and classification accuracy of land cover classes and change analysis for the Watershed.
2. Further data analysis to correlate land use and other attributes of the landscape with water quality and habitat conditions is needed to improve understanding of such relationships.
3. Additional research is needed to provide better tools for estimating the value of ecosystem services provided by forest lands in the Watershed. Examples of these ecosystem services are water quality protection for both surface and groundwater, wildlife habitat conservation, climate change adaptation, and stormwater mitigation.

Chapter 6. Impervious Cover

1. Data on sites where stormwater best management practices have been installed are not readily available. To address this important data gap, information could be compiled from state and local permitting records. Mechanisms to capture the data moving forward need to

be developed. The data should include location, drainage area being captured, type of treatment provided, and effectiveness of treatment.

2. Research is needed to examine hydrological regimes and runoff to major rivers and streams at appropriate subwatershed scales to evaluate the relationship between percent impervious cover and various water quality and habitat indicators, such as water temperature, water quality for aquatic life, stream invertebrates, fish communities, and all public health indicators. Likewise, spatial data on impervious cover, in conjunction with other indicators such as land use, should be investigated as a proxy to estimate nutrient loadings from non-point sources at varying watershed scales.

Chapter 7. Wastewater Infrastructure

1. To improve data quality, a more systematic means of periodically updating public sewer service information should be developed, and the information should be made easily accessible and shareable. It should include data on buildings and population that have been connected to the sewer systems over time.
2. There is a need to improve the capacity to compile data from state (Rhode Island) and local (Massachusetts) records to map locations and types of onsite wastewater treatment systems (OWTS), including traditional and advanced systems and cesspools. Data should include buildings that have converted from cesspools to conventional or advanced septic systems, or from conventional to advanced septic systems. This information would allow for further analyses related to water quality and climate change vulnerabilities.
3. To address the above data gaps, one option that can be standard and trackable, for both sewered areas and onsite systems, is to include in the parcel data an attribute or attributes that define the type of sewage treatment, across all towns within the Watershed, when parcel data are updated.
4. There is a need to integrate other readily available data such as soils, natural buffers, streams, and land use, among others, to identify whether groundwater at areas where onsite systems are estimated to be located, based on the preliminary results in this chapter, is likely at higher or lower risk of sewage contamination due to soil properties, proximity to resources of concern, or other constraints. A study similar to the one by Sowah and colleagues (2017) should be replicated in the Narragansett Bay Watershed to develop more robust mapping and information related to high-density onsite systems and their effects on water quality for aquatic life and human health. The Estuary Program has already advanced in this research need, by engaging soil scientists in both Massachusetts and Rhode Island with the US Department of Agricultural, Natural Resources Conservation Service (USDANRCS) to start compiling soil data and properties to develop a suitability map for the Watershed.
5. There is limited data analysis on groundwater across the Watershed, except for areas in Greenwich Bay. This is an outstanding data need that is imperative for understanding groundwater direction, flow, and attenuation, and other factors that can provide a more complete picture of the risks of sewage contamination to surface waters or the Bay, via onsite systems, whether septic systems or cesspools. Alternatively, or while methods are developed for groundwater monitoring, other approaches can be undertaken, such as coordinating with partners at the University of Connecticut to follow their methods to start gathering information about groundwater inputs to the Bay, and consequently assess the

impacts of onsite systems to public health (due to pathogen loadings, primarily) and habitat (due to increase of nitrogen or phosphorus loadings to freshwaters and the estuary).

6. Additional data on the performance of advanced treatment OWTS should be collected. Analysis of data should be completed to evaluate whether advanced systems are achieving expected treatment efficiencies during actual use.
7. Improved field studies and models to estimate nutrient and pathogen loadings from onsite systems are needed to quantify and evaluate the impacts on streams and embayments, such as Greenwich Bay.

Chapter 8. Nutrient Loading

1. A monitoring strategy is needed to address data gaps in the information required to ascertain the ecosystem response to nutrient reductions. It would be expected to include additional monitoring of biological and water quality parameters, such as benthic species and phytoplankton species composition and productivity—two ecosystem components that are expected to be responsive to the changes in nutrient loading. Data should be suitable to validate relevant water quality and ecosystem models.
2. Data used to estimate the contribution to nutrient budgets from nonpoint sources need to be refined. The data should include atmospheric deposition, stormwater contributions, agriculture, and other nonpoint sources.
3. Continued development and validation of a water quality/ecosystem model for Narragansett Bay is needed to provide an additional tool for evaluating nutrient dynamics. Such models need to be linked with validated hydrodynamic modeling and may also need to be appropriately applied to sub-regions of the Bay, particularly embayments.
4. Groundwater inputs of nutrients to estuarine and surface fresh waters in the Watershed continue to be a major data gap.
5. An assessment should be conducted to determine whether there is a need to standardize monitoring of total nitrogen and total phosphorus concentrations year-round at wastewater treatment facilities.
6. Further refinement of nutrient budgets is needed to provide insight into differences among seasonal load changes (winter, summer, and spring) at different scales aligned with potential ecosystem impacts, such as limiting the productivity of the Bay.

Chapter 9. Legacy Contaminants

1. The concentration of legacy contaminants, including mercury, in estuarine and freshwater fish and shellfish is a data gap. More studies using an approach similar to that used by Taylor et al. (2012) and Taylor and Williamson (2017) for mercury are needed to determine the human health risk posed by the uptake of legacy contaminants by fish and other human-consumed biota (e.g., shellfish). Future work would be to expand the state monitoring programs to include estuarine and near-shore fish (i.e., Taylor's work) to create a holistic assessment of mercury in commercially and recreationally important species throughout the Bay. Other legacy contaminants that need to be assessed include, at a minimum, PCBs, pesticides, and cadmium.
2. The concentration of legacy contaminants in river sediments within the Narragansett Bay Watershed is a data gap that can contribute to delays in pursuing riverine restoration actions. Studies like Cantwell et al. (2014) need to be conducted to assess the amount of contaminants in the sediments and water column before and after dam removals.

3. **Brayton Power Plant maintained metals-monitoring data in quahogs (*Mercenaria mercenaria*) that could be incorporated into the status and trends analyses. Given Brayton Power Plant's pending shut down, it is unlikely this monitoring program will continue. Adding a Mussel Watch monitoring station to Mount Hope Bay would be useful in tracking legacy contaminants in that region.**
4. **These results are framed around a north-to-south gradient, with the study sites reflecting that preference. However, sediment contaminant maps have pinpointed localized hotspots throughout the Bay—such as near the East Greenwich Wastewater Treatment Facility in Greenwich Bay—that warrant further research (Figures 2 and 4).**
5. **The climate change section of this chapter showed that there is little knowledge of how these legacy contaminants will behave under a changing climate. While release into the environment is decreasing, these contaminants may still pose health risks due to relic deposits in sediments. Understanding how climate change will affect mobility and toxicity of these contaminants both directly and indirectly is important to inform human and environmental risk assessments.**

Chapter 10. Emerging Contaminants

1. **Continued research is needed to better understand the potential exposure and assess the likelihood of ecological and human health risks resulting from existing and newly identified contaminants of emerging concern (CECs). This includes research into the fate and transport of CECs in the environment.**
2. **An assessment should be performed to identify key CECs prior to further investment in initiating a monitoring program. Any monitoring program will need to adapt to changes in the use of CECs. For example, as compounds are banned or phased out from use, compounds that may replace them should be considered for inclusion in monitoring.**
3. **For CECs that are highly soluble and remain in the dissolved phase of the water column for extended periods of time, it would be beneficial to have an improved understanding of the hydrodynamic processes within Narragansett Bay. This information along with eco-toxicity and bioaccumulation data, the direct measurement of CECs, and the use of spatial models will help to identify potential locations of concern as well as ascertain the transport, behavior, and ultimately the fate of CECs within Narragansett Bay.**

Chapter 11. Seagrasses

1. **The Rhode Island Eelgrass Task Force's recommendations for a three-tiered approach to seagrass mapping and monitoring (Raposa and Bradley 2009) need to be implemented in order to conduct seagrass analysis more systematically, including more refined methods to examine extent and condition.**
2. **Warming temperatures, changes in precipitation patterns, and sea level rise can all affect how seagrass beds survive from year to year. Research is needed to fully understand how Narragansett Bay's seagrass beds will respond.**
3. **A better understanding is needed of the life history traits of eelgrass and widgeon grass in Narragansett Bay. More knowledge of the life history traits will aid in conservation and restoration of seagrass beds to maintain or increase acreage or condition of the beds. Of particular interest is widgeon grass, as it is far less studied than eelgrass. Extensive mesocosm experiments on the response of eelgrass to nutrients, temperature, and other interactive factors have been conducted in Rhode Island (e.g., Bintz et al. 2003, Taylor et al.**

1999). These types of studies should be pursued for widgeon grass, as well as for seagrass communities composed of both eelgrass and widgeon grass.

Chapter 12. Salt Marsh

1. **The multi-parameter Rhode Island Salt Marsh Monitoring Strategy (Raposa et al. 2015) needs to be fully implemented, including refining methods, in order to document status and trends in salt marsh extent in Narragansett Bay, and changes in marsh cover types (after Watson et al. 2017). This information is needed to assess the effects of sea level rise and other stressors on the long-term sustainability of marshes.**
2. **Research and monitoring is needed to evaluate methods that will facilitate salt marsh resilience to sea level rise (e.g., thin layer deposition; preservation of upland to allow for migration). A cost-benefit analysis coupled with multi-year monitoring could be used to help determine the best methods to improve long-term sustainability.**
3. **The existing SLAMM maps (RICRMC 2015) identify areas where marshes could migrate landward. Field research and modeling are needed to better understand the process of landward marsh migration under regimes of accelerated rates of sea level rise.**
4. **Sea level rise is a major factor contributing to the recent trend of Narragansett Bay's marshes tending toward submergence, but there are also many other factors interacting with sea level rise (e.g., nutrients, grazing, sediment supply, increasing temperature, increasing carbon dioxide). Additional empirical research and modeling are required to understand the complexity of these interactions so that effective adaptation strategies can be implemented.**

Chapter 13. Benthic Habitat

1. **The sites characterized in 1988 and 2008 should be revisited every five years using sediment profile imagery to quantify benthic habitat type, conspicuous species, and sediment oxygen penetration to link benthic habitat quality with water column conditions.**
2. **The sediment profile imaging technique used in this analysis may not adequately represent the presence of shellfish such as quahogs, soft-shell clams, and blue mussels, or larger fauna such as mantis shrimp and lobster. There is a need to coordinate benthic monitoring efforts in the upper Bay—such as any future sediment profile imagery surveys, the Narragansett Bay Commission's benthic video work, and the RIDEM's fish habitat projects—to provide a more complete assessment of benthic habitats.**
3. **There is a need for future assessments of benthic habitat quality to incorporate measurements of benthic biogeochemistry, and for future benthic biogeochemistry studies to take a habitat-based approach.**

Chapter 14. Estuarine Fish Communities

1. **Analyses are needed to better characterize the comparability of the GSO and RIDEM trawl data over time, including an examination of the timing and effects of any gear changes.**
2. **There is a need to convene experts to advise on other approach(es) to use in the future to characterize changes in estuarine fish communities, including consideration of different or additional focal species, and different or additional metrics, such as a weighted-mean preferred temperature metric (e.g., Collie et al. 2008).**
3. **Data on estuarine fish communities in the Upper Bay, including the Providence River Estuary and Greenwich Bay, were not included in this analysis. Existing data on those areas**

need to be compiled and analyzed to provide a more complete understanding of Bay-wide trends.

4. This chapter only analyzed the RIDEM and GSO datasets through 2012. Data collected since 2012 need to be analyzed to identify more recent changes in the estuarine fish community.

Chapter 15. Dissolved Oxygen

1. A major gap with the Narragansett Bay Fixed Site Monitoring Network and spatial survey is the lack of resource commitment (e.g., funding and personnel) to continue these field monitoring and data processing efforts. The NBFSMN and spatial survey require constant equipment maintenance and costly upgrades. Additionally, gaps in the NBFSMN for dissolved oxygen exist for portions of Mount Hope Bay, the Sakonnet River, and the Lower East Passage where there are no monitoring stations.
2. High inter-annual variability limits the discernment of temporal trends in available datasets. Additional data synthesis studies or longer-term monitoring are needed to further explore the different temporal and spatial scales of dissolved oxygen variability and their relationships to other forcing factors (e.g., seasonal rainfall or temperature) and the physical structure of the water column.
3. The Phillipsdale site, which has unique circulation patterns and is proximal to a major freshwater source (the Blackstone River), was not analyzed for the Hypoxia Index or the Chlorophyll Bloom Index (see "Chlorophyll" chapter). In light of nutrient reductions and changes to the dissolved oxygen and chlorophyll concentrations in other sections of the Bay, the Phillipsdale data need to be analyzed to see how this upper section of the Seekonk River is changing.
4. The combination of dissolved oxygen data and hydrodynamic modeling efforts can provide a better understanding of how hydrodynamic properties of the Bay are influenced by physical forces, such as wind, precipitation, and river flow, and how dissolved oxygen levels respond. Models should be used to better understand the connection between benthic conditions and overlying dissolved oxygen conditions.

Chapter 16. Chlorophyll

1. Collection of additional chlorophyll data is needed in order to be representative of all major sub-regions of Narragansett Bay and improve the spatial resolution of existing datasets.
2. High interannual variability makes it difficult to detect temporal trends in existing datasets. Synthesis studies are needed to further explore the different temporal and spatial scales of chlorophyll variability and their relationships to other influencing factors (e.g., sunlight, pH, and temperature) as well as the physical structure of the water column.
3. Further analysis of the Chlorophyll Bloom Index is needed, including whether the 80th percentile fully encompasses the definition of a bloom, or if a second percentile should be added (such as the 20th percentile). Additionally, all three methods show high variability, and a sensitivity analysis should be done to reduce this variability.
4. Analysis of changes in phytoplankton species composition and abundance over time is needed to understand how species composition impacts chlorophyll concentration trends. The results will also inform any monitoring or analysis for phytoplankton nuisance or harmful algal blooms. Species composition has been studied before (Windecker 2010), and the GSO Phytoplankton Survey and NBC continue to record species-specific information.

5. **Controlled mesocosm studies should be done to evaluate the response of the benthic community to increased water clarity and decreased phytoplankton production (i.e., decreased input of organic matter to the benthos). This would address how the ecosystem is responding to nutrient reductions and inform a discussion regarding an appropriate balance of nutrient levels and ecosystem response.**

Chapter 17. Water Clarity

1. **There are gaps in the availability of clarity data for portions of the Bay, especially the embayments. Devising a plan to achieve more consistent methods, greater frequency of sampling, and better spatial coverage throughout the Bay is appropriate.**
2. **In devising a sampling plan, attention should be paid to the appropriate sampling intervals in order to reduce variability in the datasets and to enhance the ability to detect change. Accordingly, it would be valuable to conduct a careful analysis of the various datasets and/or a field study to determine an optimal sampling frequency to detect changes in water clarity.**
3. **The Estuary Program compared *k* values for both Secchi depth and PAR to maximize the use of available data. Ideally, one monitoring method—either Secchi depth or PAR—would be used throughout the Bay. However, the Estuary Program will continue to evaluate the comparison between Secchi depth and PAR using data collected in Narragansett Bay. Comparison of *k* values from the two monitoring methods would facilitate accurate use of *k* as a water clarity metric throughout the Bay.**
4. **Improving the spatial resolution of coastal water clarity measurements based on satellite remote sensing would reduce the need to take field measurements and would allow for a Bay-wide assessment, including embayments.**
5. **An event-based study of water clarity is needed to determine how closely total suspended solid loading is related to storm events, and how to manage those loads.**

Chapter 18. Water Quality Conditions for Aquatic Life

1. **Bi-state coordination across state agencies, MassDEP and RIDEM, could improve and streamline sample water quality of specific streams/rivers/lakes that share state boundaries to provide data that can reflect the most current water quality conditions of individual state-assessed waterbodies; however, limitations by the states and the nature of the assessments, including those discussed in this chapter, should be considered.**
2. **Coordination between the Estuary Program and state partners is needed to share data that can streamline the tracking of this indicator by linking the time of sampling (year, season) and assessment for each individual waterbody, freshwater or estuarine areas; also, to track new listings and de-listing of water impairments as they occur between cycles of water quality assessments, with the goal of quantifying changes overtime; these can shed light on water quality improvements or decline for aquatic life, more precisely due to the response of increased or reduced nutrient loadings.**
3. **Many different entities, particularly watershed NGOs and universities, monitor and routinely collect data on nutrients and dissolved oxygen parameters at varying frequencies (i.e., monthly) and scales (i.e., Taunton River watershed). Further evaluation is needed to determine whether water quality data from these efforts could be reconciled, combined, and standardized with the state datasets to improve temporal and spatial coverage for this indicator.**

4. Research is needed to understand how landscape stressors (e.g., impervious cover, land use) and climate change stressors (e.g., precipitation, temperature) relate to increases in nutrient enrichment in waterbodies that can result in eutrophication and hypoxia events, harmful to aquatic life, in freshwaters of the Watershed and estuarine waters of the Bay. This should be explored on a variety of scales from larger watersheds to individual catchment areas.
5. There is a need to develop or utilize available tools to allow evaluation of the efficacy of stormwater management practices, including retrofitting of existing infrastructure, at appropriate scales (e.g., sub-Basin). This includes practices designed to treat/retain nitrogen and phosphorus loadings as well as those designed to address peak flows, as precipitation exacerbates the impacts of nutrient enrichment.
6. While cyanobacteria blooms are primarily a public health issue, monitoring cyanobacteria blooms in freshwaters and other harmful algal blooms in marine waters is needed. Data on harmful algal blooms, including inventory of waterbodies with history of blooms, frequency of events, and collection of other parameters during these events, can augment the understanding of the causes and consequences of blooms and the dynamics of bloom suppression, whether nutrient enrichment, oxygen depletion, low stream flows, water levels or flushing, or high-water temperatures, or a combination, can result or predict these blooms.

Chapter 19. Stream Invertebrates

1. Existing macroinvertebrate sampling protocols are not appropriate for all rivers and streams in the watershed. To address coastal streams left unassessed, a multi-year effort of data collection and evaluation is needed and should be conducted at a regional scale to sample a sufficient number of locations in the lowland ecoregion streams. The data should be used to develop a robust biotic index for use in the lowland ecoregions for which the current rapid bioassessment protocol is not appropriate.
2. Further analysis of existing data is needed to evaluate how well the existing monitoring strategies represent the conditions of the wadeable rivers and streams throughout the entire Watershed.
3. Characterization of stream segments (by calculating stream miles) and drainage area (by defining the contributing catchment area to the site) is needed to study the influences of landscape stressors and other factors on stream conditions. The characterization should focus on sites where macroinvertebrate health was poor but habitat conditions were good. The findings could be used to help identify and ameliorate potential threats at sites with good macroinvertebrate health and good habitat quality that need protection.

Chapter 20. Freshwater Fish Communities

1. Further development of freshwater fish communities as an indicator for status and trends reporting will require an expanded effort to collect fish community data. Evaluation of the resources to support the desired level of fish data collection across the Watershed is an appropriate next step.
2. Targeted collection of data on brook trout is needed to better refine brook trout habitat and clarify coldwater stream designations and support the integration and update of the Eastern Brook Trout Joint Venture Salmonid Catchment Assessment and Habitat Patch Layers model.

3. Additional data for freshwater habitats that were not considered here, but may have ecological significance to maintain healthy habitat for fish, should be gathered, created, defined, and analyzed, including intermittent streams, freshwater reaches of tidal rivers, wetlands, and riparian areas. Specialized methods for collection of fishes in these habitats may need to be identified or developed.
4. Development of an indicator related to stream connectivity should be explored. It could reflect stream continuity in miles open, partially open, and obstructed for freshwater fish and other aquatic life communities, following other efforts already started in the Watershed, such as those led by the U.S. Army Engineer Research and Development Center (Foran et al. under review).
5. Provided data collection can be expanded, bi-state efforts and approaches to refine the freshwater fish indicator could involve the development of an IBI or MMI for the Narragansett Bay Watershed. These resulting metrics can be related to the Biological Condition Gradient framework, as has been done in Connecticut (Stamp and Gerritsen 2013).
6. Future data analysis should explore and quantify the relationships between freshwater fish metrics and stressors at appropriate scales (e.g., site, watershed, catchment areas). Armstrong and colleagues (2011) quantified the effects on fluvial fish abundance in response to alterations on stream flow and impervious cover, among other anthropogenic stressors.

Chapter 21. Open Space

1. Geospatial tools should be used to identify unprotected open space parcels adjacent to currently protected open space parcels. Protecting these natural areas would augment habitat connectivity, increase natural buffers to receiving waters, and improve the resilience of the ecosystem to land use stressors and climate change.
2. In addition to CAPS, other tools are useful for open space decision making. Critical Linkages (2012) identifies locations in the landscape that can provide greater ecological benefits to increase connectivity and continuity of habitats. Mass Audubon's Mapping and Prioritizing Parcels for Resilience tool identifies priority parcels for open space protection based on habitat quality, climate change resilience, parcel size, and adjacency to existing protected parcels. Use of such tools should be pursued to assist with planning efforts in the Narragansett Bay Watershed.
3. Further analyses of riparian buffer protection and restoration opportunities should be developed at a range of watershed scales, including Watershed Planning Areas.
4. Further refinement via a parcel-based analysis is needed to more specifically identify unprotected lands that may provide restoration opportunities such as areas for salt marsh migration as sea levels rise.
5. Spatial analyses of open space changes conducted at intervals of a decade or less, with a focus on protected ecologically significant natural lands, are necessary to track advances and spatial trends in conservation in the Narragansett Bay Watershed.

Chapter 22. Water Quality Conditions for Recreation

1. 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.
2. 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 sub watersheds

or drainage areas in which onsite wastewater treatment systems, including cesspools, are known or suspected of contributing to pathogen pollution problems.

Chapter 23. Marine Beaches

1. 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.
2. 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.
3. 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.
4. 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).
5. Detailed analyses of existing management actions such as CSO abatement projects, storm-water 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.
6. 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.

Chapter 24. Shellfishing Areas

1. 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.

2. **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.**
3. **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 improvements at wastewater combined sewer overflows abatement and other pollution control efforts. However, additional data collection and analysis are needed to reassess the relationship between precipitation and pathogens as conditions continue to change. Additionally, further data synthesis and analysis could be conducted to relate water quality improvements to reduced pathogen loadings due to non-point source management actions.**
4. **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.**