BARNEGAT BAY PROSPECTUS:
MONITORING, ASSESSMENT, AND RESEARCH PRIORITIES FOR THE BARNEGAT BAY-LITTLE EGG HARBOR ECOSYSTEM TO SUPPORT SCIENCE-BASED WATERSHED MANAGEMENT

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EXECUTIVE SUMMARY

It is widely understood that the health of the Barnegat Bay-Little Egg Harbor ecosystem has declined due to eutrophication and other factors (*e.g.*, habitat loss and alteration) largely due to the tremendous increase in the human population in Ocean County since the completion of the Garden State Parkway. The Barnegat Bay Partnership (BBP), established in 1997, comprises federal, state, and local government agencies, academic institutions, nongovernmental organizations, and businesses working together to restore and protect this nationally significant estuary.

The BBP has periodically produced several important planning documents, including the 2002 Comprehensive Conservation and Management Plan (CCMP), the 2008-2012 Strategic Plan (BBNEP 2008), and the 2012-2016 Strategic Plan (BBP 2012), which provide the consensus priorities of the bay's stakeholders for protecting and restoring the watershed. Periodically, the BBP Science and Technical Advisory Committee (STAC) produces various technical documents to address priority issues, including a monitoring, assessment, and research needs "prospectus" to support watershed-based management (BBP 2010). This first BBP Prospectus (2010) provided the foundation for substantial EPA investment in Barnegat Bay research (*e.g.*, nonpoint-source assessment, criteria development) and most of the research projects funded as part of the Governor's Initiative (also known as the Ten Point Plan) for the Barnegat Bay. The Governor's Initiative substantially improved the water quality monitoring throughout the entire watershed, funded development of a hydrologic model for the bay, and addressed numerous other research gaps regarding the bay's ecology and specific biotic resources (see http://www.nj.gov/dep/barnegatbay/plan-research.htm).

This document is the second research prospectus developed by the STAC. Consistent with the priority areas identified in the 2012-2016 Strategic Plan, and building on the knowledge gained through the last several years of research, the five main categories of studies below are considered critical to advancing our understanding of the bay and monitoring the effectiveness of restoration activities.

Comprehensive Water Quality and Biotic Monitoring (Water Quality: $350,000 in installation costs, $207,000 in yearly maintenance and operation costs; Biotic Monitoring: $210,000 - $700,000)

This category forms the backbone of the monitoring and assessment skeleton for understanding changes and impacts to the bay. The water quality aspect consists of a comprehensive, multi-instrument network that continuously records water quality parameters at a number of sites throughout the bay, as well as nutrient exchange at the inlets. These data would be available via an open access website and would assist scientists in discerning the links between water quality, biological activity, and stress-induced events. The biotic monitoring proposed under this section is critical to evaluate changes in the bay's condition and its biota against a backdrop of increasing development/urbanization and other external drivers of ecosystem change (*e.g.*, sea-level rise, climate change). This monitoring is critical given the apparent decline in the distribution and abundance of a number of recreationally, commercially, and ecologically important biota, including fishes, crabs, shellfish, and seagrasses in recent years. At the same time, there has been an apparent increase in the abundance of jellyfish and sporadic outbreaks of other noxious and/or nuisance taxa (*e.g.*, brown tide).

Long term, consistently collected data are necessary to identify trends and changes over various time scales; thus, it is important that a stable funding source (*e.g.*, NJ Corporate Business Tax, Tourist or Transportation fees) be identified for funding this monitoring and assessment.

Targeted Watershed Studies ($50,000 - $600,000)

Included in this category are focused research projects that advance our understanding of watershed processes as they relate to nutrient inputs to the bay, which can lead to eutrophic conditions and subsequent adverse impacts. This includes determining the primary sources of nutrients that end up in the bay, how they are transported from throughout the watershed to the bay, the physical processes that distribute water and nutrients throughout the bay itself, the levels at which ecosystem impairment occurs, and modeling the effects of possible management actions on nutrient loads.

Water Supply/Flow Issues ($100,000 - $750,000)

As the population within the Barnegat Bay watershed continues to increase so does the consumption of freshwater from the local aquifers and surface waters. This consumption leads to a decrease in the amount of fresh water entering the bay, potentially altering temperature and salinity regimes and circulation patterns, which could have far-reaching implications. The research needs in this area involve evaluating the effect of tertiary sewage treatment and discharge to the bay against the current treatment with their ocean outfalls, the effect of sea level rise, and determining groundwater-maintained base stream flows needed to maintain healthy watersheds.

Soil Health Assessment and Restoration ($150,000 - $250,000)

With an increase in the population of the watershed comes a concomitant increase in the conversion of natural forest and agricultural areas to urban land cover. This landscape alteration has a significant impact on the function of the native soils and vegetation. Programs and demonstration projects are needed to understand how to best assess the soil health and function of stormwater basins and to identify to what specifications we should restore disturbed soils in the system.

Coastal Wetlands Monitoring and Enhancement ($300,000)

Coastal wetlands provide critical services, including flood and storm surge protection, maintenance of water quality, carbon and nutrient sequestration, and fish and wildlife habitat.

Through our ongoing systematic efforts to monitor the conditions of Barnegat Bay's wetlands as part of the Mid-Atlantic Coastal Wetlands Assessment, it has become clear that this ecosystem is critically imperiled due to sea level rise and increased storm events. High water levels, limited sediment supply, water quality impacts, increasing rate of shoreline erosions and anthropogenic impacts will continue to challenge natural resource managers and communities to seek innovative ways to protect and enhance our vulnerable coastal wetlands. Ongoing monitoring and assessment will continue to be an integral effort allowing us to better manage and protect wetlands resources and to inform restoration decisions.

The monitoring and research activities *promoted* by the first prospectus provide much of the foundation for the ongoing revision of the 2002 CCMP. Addressing the research priorities and remaining data gaps identified in this second prospectus will help ensure our collective commitment to science-based decision-making and guide future actions to protect and restore the bay and its contributing watershed.

Introduction

The BBP's Authorization and Organization

The BBP,[1] one of 28 National Estuary Programs, is a partnership of federal, state, and local government agencies, academic institutions, nongovernmental organizations, and businesses working together to restore and protect a nationally significant estuary, the Barnegat Bay. The BBP was established in 1997 pursuant to Section 320 of the Clean Water Act (33 U.S.C. 1330; as amended by P.L. 100-4, *et seq.*) following the nomination of then-Governor Whitman to the U.S. Environmental Protection Agency (USEPA) to provide an inclusive, local stakeholder-based mechanism to protect the Barnegat Bay for its economic, environmental, and cultural resources. Establishment of the BBP built upon the foundation that was provided by the State of New Jersey's Legislature via the passage of P.L. 1987, Chapter 397, which created the Barnegat Bay Study Group.

The BBP's organizational structure consists of a Policy Committee, Advisory Committee, Science and Technical Advisory Committee (STAC), and Communication and Education Committee (CEC). Technical workgroups (*e.g.*, the Eutrophication Workgroup, Shellfish Workgroup, and Climate Change Workgroup) provide support on specific issues.

The Policy Committee representatives include the NJDEP Commissioner, USEPA Region 2 Regional Administrator, President of Ocean County College, an Ocean County Freeholder, Chair of the Ocean County Mayors' Association, and a Citizen Representative. The Policy Committee provides these core partners with a forum to share and discuss their concerns regarding the bay and with opportunities to build a broad consensus for actions and commitments to protect and restore the Barnegat Bay. The BBP Advisory Committee includes a core membership consisting of representatives from entities of the BBP Policy Committee, all other entities which have accepted lead responsibility for implementing a priority action in the CCMP or Strategic Plan, and the Chairs (and Co-Chairs) of other standing committees (*e.g.*, STAC, CEC). The Advisory Committee acts on behalf of the Policy Committee in the day-to-day decision-making in support of the BBP.

The BBP STAC: Ensuring Sound Science-Based Decision-Making for the Barnegat Bay

The principal purpose of the STAC is to provide the BBP and collaborating entities with objective, expert advice, and peer review for overall scientific and technical matters related to NEP activities and goals, such as those specified in the CCMP and BBP's Strategic Plan. It works with the Advisory Committee to identify and prioritize science and technical needs within the Barnegat Bay-Little Egg Harbor Estuary and its watersheds, and assists with the BBP's efforts to raise awareness and resources for addressing these needs.

Periodically, the BBP STAC also produces various technical documents to address priority issues (*e.g.*, fertilizer nutrient management; soil health, hard clam fishery), comment on projects or regulation changes with major impacts to the watershed, or identify major programmatic

[1] The BBP was originally established as the Barnegat Bay National Estuary Program and changed its name to the Barnegat Bay Partnership in 2010.

needs (*i.e.*, Barnegat Bay Prospectus for Monitoring, Assessment, and Research Needs To Support Watershed-based Management; BBP 2010).

This first BBP Prospectus (2010) provided the foundation for substantial EPA investment in Barnegat Bay research (*e.g.*, nonpoint-source assessment, criteria development) and most of the research projects funded as part of the Governor's Initiative (also known as the Ten Point Plan) for the Barnegat Bay (see Appendix 1 for a list of research projects completed by the BBP and others). The Governor's Initiative substantially improved the water quality monitoring throughout the entire watershed, funded development of a hydrologic model for the bay, and addressed numerous other research gaps regarding the bay's ecology and specific biotic resources (see http://www.nj.gov/dep/barnegatbay/plan-research.htm).

Background: the Problem

The Barnegat Bay-Little Egg Harbor watershed is recognized as suffering from a variety of ailments, with eutrophication being the main driver of degradation to the system. Haphazard planning and permitting throughout the watershed have contributed to or resulted in losses of forests and other open spaces, losses of fresh water and coastal wetlands, losses of buffers adjacent to the bay itself and its contributing streams, and shoreline hardening. Failed and/or inadequate stormwater infrastructure, boating and personal watercraft impacts on submerged aquatic vegetation, and adverse effects of Oyster Creek Nuclear Generating Station (*i.e.*, entrainment, impingement, thermal impacts, chloramine discharges) are also recognized as problems. Issues of emerging concern for the bay and surrounding watersheds are increasing annual average water temperatures, slowly rising water levels, and increases in nuisance organisms such as sea nettles.

As required by federal law, the BBP has determined and reported the status and condition of the bay roughly every five years. The reports are generated by a working group drawn from the members of the BBP's STAC. The BBP's first such State of the Bay report (SOTB), published in 2005, presented information on six indicators of the bay's overall integrity, or health: submerged aquatic vegetation, shellfish beds, bathing beaches, algal beds, freshwater inputs, and land use/land cover. The 2011 and 2016 SOTB Reports included information on a larger and more comprehensive set of indicators (19 and 17, respectively) in six general areas: estuarine eutrophication assessment, freshwater ecosystem assessment, human use impairments, protecting land and water, and conserving fisheries and wildlife. Over the 16 years covered by the three reports, the overall status of the bay's health has changed, with some indicators faring better and some worse; however, our understanding of the bay's ecology and the drivers of its continuing eutrophication improved substantially.

Supporting the CCMP and Strategic Plan

The BBP's Comprehensive Conservation and Management Plan (May 2002) and 2008-2012 and 2012-2016 Strategic Plans have provided the consensus-generated blueprints for protecting and restoring the Barnegat Bay-Little Egg Harbor estuary (BB-LEH), and undergird all of the activities promoted and undertaken by the BBP.

The 2012-2016 Strategic Plan identifies five key priorities to help restore bay structure and function:

- Improve recognition and understanding of the bay's condition, and address the causes of water quality degradation within the ecosystem, especially eutrophication in the bay and stormwater and non-point source pollution in the watershed;
- Address water supply and flow issues that affect the bay and watershed;
- Prevent habitat loss, especially of submerged aquatic vegetation, and support habitat restoration;
- Improve understanding of, and address fisheries declines;
- Identify and promote environmentally sound land-use planning and practices that will improve soil function and hydrology to restore and enhance water quality and quantity.

The projects identified in this research prospectus are consistent with these key priority areas, and support the priorities of CCMP revision, which is currently underway. This revision is needed in recognition of the progress that has been made to date and new challenges (*i.e.*, continuing population growth, climate change, sea level rise) that threaten coastal ecosystems worldwide. An assessment of the vulnerability of all proposed actions to climate change is being integrated in the development of all new CCMP priorities, and have been incorporated into the proposed projects, where applicable.

Project Specific Recommendations for Future Funding

This is the second research prospectus developed by the STAC, and utilizes the knowledge gained over the past six years to refine prior research recommendations and identify new gaps in our understanding of the Barnegat Bay. The STAC has not attempted to prioritize the importance of the general categories nor the individual projects.

Comprehensive Water Quality and Biotic Monitoring

Bay-wide continuous water-quality monitoring

A. Central Question: How do water-quality parameters (salinity, temperature, dissolved oxygen, turbidity, and freshwater input) in the estuary change in relation to longer temporal and larger spatial scales, as well as in response to discrete events (storms, hypoxia, *etc.*)?

BBP Strategic Plan Action Number: WQ2, WQ5, WQ6, WS4

Summary: A network of automated water quality sensors, tide gauges, and stream gauges in Barnegat Bay will allow scientists to discern the links between water quality, biological activity, and stress-induced events. The data from this network, when operated over a long time span, will allow scientists to identify trends in the bay's water quality, which are not available from discrete, scattered sampling. In order to maximize the use of these data the STAC encourages all partner organizations to submit the data for inclusion in the National Water Monitoring Council's Water Quality Portal.

The BBP currently maintains three shore-based automated water-quality sensors located in Barnegat Bay, which measure water level, salinity, temperature, turbidity, pH, and dissolved oxygen. The stations are located in the northern and central portions of the bay, and include Mantoloking Yacht Club, Seaside Park Yacht Club, and Beach Haven on Long Beach Island.

The data sondes and sensors at these stations were recently upgraded (2016). The NJDEP also maintains four buoy-mounted continuous water-quality sensors in the bay on a seasonal basis. All data will be posted in near real-time to the NJDEP's continuous monitoring website, and Quality Assured data will also be made available following the same data review protocols as the NJDEP buoy data. As these stations age and as new technology comes online (nutrient probes, chlorophyll–a sensors), they require sensor replacements and upgrades to continue to provide reliable data in near-real time. Furthermore, additional nodes are needed at key points throughout the bay, particularly in the southern portion and in/near the inlets to ensure adequate spatial coverage.

The NJDEP, with a variety of collaborators, has been conducting synoptic discrete water-quality monitoring throughout the bay and watershed. Currently there are 14 tributary and 14 in-bay stations. The data from this sampling has been used as part of the state's Integrated Water Quality Assessment as well as to parameterize a water-quality model for Barnegat Bay. This sampling program will remain in place until 2018, at which time its status will be revisited. Given what we have learned from this sampling regime regarding impairments to the bay, the continuation of this program is strongly recommended.

Existing stream gauges monitor freshwater inputs from four streams draining to the estuary (North Branch Metedeconk, Toms River, Cedar Creek, and Westecunk Creek); however, there are three additional streams (South Branch Metedeconk River, Oyster Creek, and Mill Creek) draining much of the watershed where monitoring is needed. Tide gauges are currently operating at six sites within the estuary (Mantoloking, Seaside Heights, Waretown, Barnegat Light, Ship Bottom, Little Egg Inlet), but there are three additional sites where tide gauges are needed: Bay Head, Forked River, and North Beach/Brant Beach.

B. Central Question: How does pH and calcium carbonate saturation state vary within Barnegat Bay-Little Egg Harbor and how are they impacted by nutrient loading, freshwater flows, and upwelling?

BBP Strategic Plan Action Number: WQ2, WQ5, WQ6, WS4

Summary: An emerging stress on marine systems is the process of Ocean Acidification (OA). OA refers to the chemical changes in carbonate chemistry that result from the uptake of anthropogenic CO_2 by the ocean (Doney *et al.*, 2009). Rising atmospheric CO_2 levels result in an increase in surface water pCO_2, a decrease in pH, and a reduction in the carbonate saturation state (Ω). Calcium carbonate undersaturation has been shown in laboratory experiments to reduce survival and growth of shellfish larvae and to impact shell formation (Gazeau *et al.*, 2013; Gobler *et al.*, 2014; Talmage and Gobler, 2010; Waldbusser 2013; Waldbusser 2014) and has been linked to failures in shellfish hatcheries in the Pacific (Barton *et al.*, 2012). In Barnegat Bay, local amplification of acidity can also result from the generation of CO_2 that is largely supported by the microbial decomposition of highly labile biomass. With high rates of photosynthesis and respiration, Barnegat Bay can be expected to experience greater fluctuations in pH and Ω compared to the open ocean. Another amplifier of acidification is coastal upwelling. During the summer, several areas along the New Jersey coast experience periodic upwelling events. As is the case along the west coast of the U.S., these events can introduce acidified water to New Jersey estuaries (Poach & Munroe, unpubl data).

As a result of local amplification, the shellfish industry in New Jersey is likely already experiencing acidification conditions stronger than the open ocean. Because shellfish production was once vitally important to the economy (Ford, 1997), the decline of shellfish populations along the New Jersey coast over the last century has prompted significant efforts at their restoration. To properly plan shellfish operations and restoration programs in Barnegat Bay-Little Egg Harbor, it becomes paramount to understand the link between acidification and its environmental drivers. As yet, little is known about the variation in pH or the interaction of nutrient loading, freshwater flows, and upwelling on acidification in this system. At this time, only the Beach Haven station includes sensors to monitor pH. Efforts should be made to upgrade current and planned monitoring stations with sensors to monitor pH and other parameters of the carbonate system. Little Egg Harbor near the mouth of Great Bay, would be an optimal location to site sensors to monitor carbonate parameters given the prevalence of summer upwelling events in that area.

Water Quality Sensors Cost: Approximately $50,000 for installation of each new shore-based station (plus an additional $30,000 for carbonate parameters), and $80,000-100,000 in recurring maintenance and operation costs (spare parts, technician/data maintenance) for all sondes per year.

Synoptic Water Quality Sampling: It costs approximately $40,000 per year to maintain the program under its current configuration.

Stream Gauges Cost: Installation costs are approximately $23,000 per station, or $69,000 total. Operation and maintenance costs are approximately $16,000 annually, or $48,000 per year for the three-station network.

Tide Gauges Cost: Installation costs are approximately $20,000 per station, or $60,000 total. Operation and maintenance costs are approximately $13,000 annually, or $39,000 per year for the three-station network.

<u>Assessment of Fishes and Crabs Responses to Climate Change Alteration of the BB-LEH System</u>

Central question: What is the influence of climate change (as reflected in temperature change, acidification, *etc.*) on the distribution and abundance of fishes and crabs in Barnegat Bay habitats?

BBP Strategic Plan Action Number: F1

Summary: Fishes and crabs make up a large component of the biomass in the BB-LEH system, components that people harvest either in recreational or commercial fisheries, and components they seek to maintain in order to conserve the basic ecological functions of this important ecosystem. At the same time, the fisheries for many species are declining. Recent research could not discern an effect of urbanization/development (as reflected in human population density, nutrients, *etc.*) on the distribution and abundance of fishes and crabs in Barnegat Bay habitats (Able *et al*., 2015). However, this and other research has indicated that northern species are generally declining and being replaced by southern species. Routine monitoring is needed to determine if these data are the result of a temporary or permanent trend. It is also necessary to predict how these changes, if permanent, will affect the bay ecosystem.

Cost: $150,000 per sampling year.

<u>Assessment of Management Actions to Control Jellyfish Polyp distribution in the BB-LEH System</u>

Central Question: What management practices effectively reduce the population of nuisance jellyfish polyps in the BB-LEH system?

BBP Strategic Plan Action Number: F1

Summary: While the populations of many species of fish and shellfish appear to be on the decline in Barnegat Bay, there appears to be an increase in the abundance and distribution of jellyfishes in the bay, stinging sea nettle (*Chrysaora quinquecirrha*) in particular. The recent three-year study on jellyfish populations in the bay concluded that understanding the distribution and abundance of the polyp stage of *C. quinquecirrha* is important for developing strategies to reduce their population (Bologna *et al.*, 2016). Understanding the dynamics and survival of polyps is necessary to develop reasonable management strategies to limit their expansion or reduce their numbers. Good candidate areas for research would be in Forked River, Waretown, and Beach Haven West where polyp populations are large and/or increasing. Transport of sea nettles throughout the bay should be investigated using the newly developed hydrodynamic and water quality models for the bay. This would provide insight into areas most at risk for colonization and help to focus management efforts.

Cost: $250,000 for a three-year program.

<u>Benthic Invertebrate Community Monitoring in the BB-LEH System</u>

Central Question: How can we best utilize a recently calibrated simple index that relates the proportion of benthic animals that belong to ecologically sensitive species to total nitrogen concentration and the dissolved oxygen saturation level in the water?

BBP Strategic Plan Action Number: WQ2, F1, F2

Summary: Multiple human and natural stressors affect the Barnegat Bay-Little Egg Harbor estuary. While the state's current determination of estuarine ecological health is based solely on dissolved oxygen measurements, it is also important to investigate benthic biotic indicators for ecosystem-based assessment of condition. A recent benthic invertebrate study in the bay developed an index for determining where impairments exist in the estuary and for delineating where environmental remediation must be focused (Taghon *et al.*, 2017). Additional research is needed to further refine and validate that model. Once validated, routine sampling should be conducted and the results used to identify impairments and focus remediation efforts.

Cost: $175,000 for each sampling year.

<u>Assessment of Hard Clam Populations in the BB-LEH System</u>

Central Question: What is the current population level of hard clams in the BB-LEH system?

BBP Strategic Plan Action Number: WQ2, F1

Summary: The hard clam, *Mercenaria mercenaria*, was once the most commercially important shellfish species in the estuary, but it has declined appreciably in abundance over the past three decades (Dacanay, 2015). It remains a recreationally important species, and is also an important indicator of estuarine ecosystem and eutrophic condition. It was recognized as an economically important species in decline in the CCMP, and identified as a key species for stock assessment in both Strategic Plans for Barnegat Bay.

A fishery-independent determination of the size of the population repeated on a species-appropriate time scale is one of the most important aspects of a properly managed fishery. While surveys in Barnegat Bay were conducted in 1985/1986, 2001, and 2011/2012, the Bricelj *et al.* (2012) report clearly identified the long lag between surveys as detrimental to our understanding of how the population has responded to environmental and fishery changes (pg. 41). A comprehensive survey of hard clams is recommended for both Barnegat Bay and Little Egg Harbor to determine current stock levels. A fishery independent survey conducted every five years will be frequent enough to allow the Bureau of Shellfisheries to adjust management policies to address changes in population size and structure and maintain a sustainable resource. A matrix of sampling stations will be established throughout the estuary, with each sampling point separated by 300 m. Sampling will be conducted by trawl with a clam dredge consistent with state standards. In accordance with the suggested sampling frequency, the next set of surveys should begin no later than 2017.

Cost: $300,000 for the hard clam surveys in the estuary, with sampling conducted in successive years at $150,000 each year (Barnegat Bay – year one; Little Egg Harbor – year two).

Collection of wild and cultured commercial and recreational harvest data

Central Question: What is the current harvest level of hard clams from the BB-LEH system?

BBP Strategic Plan Action Number: WQ2, F1

Summary: There is currently no data collected on the commercial harvest of wild or cultured hard clams, or of the recreational harvest. Harvest data, when combined with stock surveys, form the backbone of a fishery management plan, which is necessary to properly manage a fishery resource. There are a number of potential avenues for collecting the necessary information for commercial landings, but the most common is through "dealer reports," where shellfish wholesale dealers maintain records of each purchase, including the amount (number/weight/size of shellfish), harvester, general location of harvest (Barnegat Bay, Manahawkin Bay, LEH), *etc.* This information is then transmitted to the Bureau of Shellfisheries. Of the types of data needed to properly manage a fishery, the most difficult to obtain is often the recreational harvest. In New Jersey a recreational license is required to harvest hard clams, but there are currently no reporting requirements. For a resource like hard clams, where recreational harvest is often a cultural or family tradition, the recreational harvest may represent a substantial removal of biomass.

The exact methodology for the collection of harvest data should be determined by the Bureau in consultation with the industry to minimize costs and interruptions while maximizing the usefulness of the data. This data collection is also necessary to permit the development of a fishery management plan (FMP) for hard clam. Without wild harvest data, an FMP cannot be developed.

Cost: Highly variable and dependent on exact collection methodology.

Monitoring of Submerged Aquatic Vegetation's Response to Human Stressors in the BB-LEH System

Central Question: What are the drivers of the loss of seagrass beds and how does this impact the bay ecosystem? Can they be successfully restored and which conditions are best for restoration success?

BBP Strategic Plan Action Number: WQ2, F1

Summary: Submerged aquatic vegetation (SAV) is a term used to describe a variety of estuarine and marine plants, including seagrasses and macroalgae. Due to their important ecological role in the BB-LEH ecosystems, as well as their sensitivity to degraded water quality, SAV has been adopted as a primary indicator of estuarine ecosystem health (BBEP, 2003). The spatial distribution, abundance and health of SAV are important environmental indicators of the overall status of the BB-LEH system. Of special concern are the bay's two principal species of seagrass, eelgrass (*Zostera marina*) and widgeon grass (*Ruppia maritima*). The bay's seagrasses are an important element of the bay ecosystem, because they harness energy and nutrients that are consumed by other organisms. The seagrass beds also provide a critical structural component in an otherwise barren sandy bottom, serving as essential habitat for a host of organisms from shellfish and crabs to fish and waterfowl. BB-LEH seagrass habitats are important not just locally but regionally, with the BB-LEH system containing ~75% of the known seagrass habitat along the entire New Jersey coast.

To assess the changes in SAV associated with localized human induced stressors and a changing climate it is necessary to understand both the spatial and temporal extent of the seagrass beds within the bay as well as the relative conditions of those beds. This can be accomplished through the use of high-resolution digital satellite and/or airborne imagery complemented with *in situ* sampling. Routine SAV surveys will allow us to better identify the primary mechanisms driving changes to this resource and assess restoration efforts undertaken to ameliorate the issues.

Cost: $75,000 per survey year.

<u>Analysis of potential SAV restoration from a bay-wide perspective</u>

Central Question: Which sites and approaches are most suitable for future SAV restoration activities in BB-LEH?

BBP Strategic Plan Action Number: WQ2, F1

Summary: As activities within estuarine waters are permitted, unavoidable impacts to SAV are required to be mitigated. Currently this is done on a piecemeal basis, with a variety of different approaches to selecting suitable restoration/mitigation sites and activities. This leads to varying levels of success between individual projects, and can create user and resource conflicts. With the recent completion of detailed bathymetric surveys, subaqueous soil surveys, hydrodynamic models, water-quality models, and SAV seedbank and restoration models, it is now feasible to create a comprehensive planning document for SAV restoration/mitigation in the estuary. Pilot projects to verify the applicability of the strategies should be implemented following an initial development year.

Cost: $600,000 over four years ($100,000 for strategy development, $500,000 for studies).

<u>Determining the suitability of various SAV habitats for fish and invertebrates in BB-LEH</u>

Central Question: Are eelgrass, widgeon grass, and drift macroalgae equivalent habitats for fish and invertebrates?

BBP Strategic Plan Action Number: WQ2, F1

Summary: Recent seagrass surveys within the BB-LEH have noted an increase in widgeon grass in the central portion of the bay, an area previously dominated by eelgrass (BBP, 2016). Furthermore, drift macroalgae is becoming a more common component of the submerged aquatic vegetation community throughout the system. While eelgrass is well recognized as important habitat for a number of juvenile fish and invertebrate species, far less is known regarding the suitability of widgeon grass and drift algae. If the transition from eelgrass to widgeon grass in the northern and central portions of the bay continues, and the prevalence of drift algae increases, how will that affect the recreationally and commercially important species that rely on eelgrass?

To evaluate the response of fish and invertebrates to this vegetative transition, a three-year study is proposed. The study will compare fish and invertebrate community structure and productivity between each of the vegetative habitats in the northern (widgeon grass dominated, sparse eel grass), central (mixed widgeon grass/eel grass), and southern (eel grass dominated, sparse widgeon grass) portions of the estuary. Analysis will include the annual and seasonal variation between years, seasons, and habitat types relative to environmental variables. The results of this study will help to inform the types and degree of ecosystem services that may be provided by the changing SAV structure in the bay.

Cost: $600,000 for three years.

Targeted Watershed Studies

Identify nutrient sources

Central question: What are the primary sources of nutrient loads, and what is the relative importance of each source?

BBP Strategic Plan Action Number: WQ2, WQ3

Summary: USGS has completed a project which evaluated sources of nutrients in samples collected from a limited number of streams and groundwater wells using stable isotopes of oxygen and nitrogen. At least one second-phase project of similar magnitude will be needed to confirm major nutrient sources, resolve ambiguous results, and identify specific human activities (including septic systems) contributing to excessive nutrient loads. A second-phase effort would include sampling five additional streams and five wells. The second phase would have a narrower focus, and tributaries of a single major stream, such as the Toms or Metedeconk River, with varying watershed land uses would be targeted. The suite of analytes would include at least one additional isotope, most likely boron.

Additional research should also be done to look at atmospheric deposition in the watershed (*i.e.*, a fixed station in the northern part of the watershed) together with additional studies on a finer scale (on different landscape types at different distances from roadways) and for different sources (*e.g.*, fossil-fuel burning power plants, automobile, and outboard exhaust).

Cost: approximately $185,000 for radioisotope study; $150,000 for atmospheric deposition, fixed station, and fine-scale study.

Evaluate distribution of nitrate in groundwater

Central question: What are the primary sources of nutrient loads, and what is the relative importance of each source?

BBP Strategic Plan Action Number: WQ2, WQ3

Summary: Previous studies have demonstrated that much of the nitrogen load in streams discharging to the estuary is transported via groundwater flowing from recharge areas to streams (Wieben *et al.*, 2013). Additionally, nitrate-N in direct groundwater discharge to the estuary is estimated to account for 12% of the total nitrogen load to the estuary. The distribution of nitrate in groundwater needs to be characterized so that past, present, and future nitrogen loads delivered to the estuary through groundwater transport can be better estimated. The number of wells in the watershed that have been sampled as part of recent subsurface investigations is limited. However, a large amount of untapped information on nitrate in groundwater has been generated through the Private Well Testing Act and previous county-wide regulations. This source of valuable data needs to be mined and processed to help characterize the distribution of nitrate in groundwater in the Barnegat Bay watershed and the delivery of nutrients to the bay through groundwater transport. The project would include data screening and quality-assuring, compilation of well-construction information, field-checking site locations, GIS processing, geo-database creation, and preparation of maps of subsurface nitrate distribution.

Cost: Approximately $50,000.

Quantification of Ocean/Estuary Nutrient Exchange

Central question: What is the magnitude and timing of nutrient exchange between the estuary and the ocean, and to what extent do nutrient inputs from the ocean contribute to the nutrient load?

BBP Strategic Plan Action Number: WQ2

Summary: A major gap in the nutrient budget for the bay is the magnitude of mass exchange of nutrients between the bay and the ocean. Previous monitoring of nitrate in Barnegat Inlet suggests that variability in this exchange may be substantial (Guo and Psuty, 2000; recent work). Exchange of water and chemical loads between the ocean and the bay occurs primarily at three locations: Barnegat Inlet, Point Pleasant-Bay Head Canal, and Little Egg Inlet at Holgate. Monitoring nitrate concentration and flow at these sites on a continuous basis for at least 12 months can provide the information needed to understand the importance of this potential nutrient transport process. This project can utilize nitrate probes and acoustic-doppler current profilers (ADCPs) associated with the water quality network to collect information at Barnegat Inlet and the Point Pleasant-Bay Head Canal. Fixed ADCP installation is problematic at Little Egg Inlet, and so at this site, flow would need to be measured periodically using a boat-towed ADCP, and measured flows would be correlated with tide elevation and phase, as measured at the continuous tide gauge operating nearby at the Rutgers University Marine Field Station.

Cost: Approximately $485,000 for installation, maintenance, and operation for 12 months.

Develop and Apply a Capability to Predict Changes in Nutrient Loading and Freshwater Inputs

Central question: What are the likely effects of possible management actions on nutrient loads and freshwater inputs?

BBP Strategic Plan Action Number: WQ2

Summary: Ongoing monitoring and research is providing insight to important nutrient transport processes and the delivery of fresh water to the bay under current conditions. The capacity to predict potential future changes in inputs of nutrients and fresh water is proposed through further development and use of existing hydrologic models to evaluate the potential outcome of various management actions. Linkage of these models with the proposed estuarine circulation model will facilitate evaluation of the estuary response to human impacts. The three predictive modeling components are listed below:

a. Groundwater nutrient inputs: Groundwater has been shown to be an important transport pathway for nutrients, and the capacity to predict potential nutrient loads transported through groundwater in the future is needed in order to evaluate management alternatives and understand the likely timeframe for changes in delivered loads. An ongoing project is using a detailed groundwater-flow model (developed using the MODFLOW code in cooperation with the NJDEP Division of Water Supply) with a newly developed particle-tracking capability using the MODPATH code to estimate nitrogen concentrations in groundwater discharge to surface water, based on relations between land use and the concentration of nitrogen in aquifer recharge. A new modeling phase using this technique is needed to identify groundwater "hot spots" with elevated nitrogen concentrations and to simulate changes over time in groundwater transport of nitrate to streams. These results and results of prior investigations will be used to: 1) assist in identifying areas for groundwater and stream baseflow sampling for isotopic analysis and source identification; and 2) determine the capability of the model to hindcast observed trends in nitrogen load in stream base flow in the Toms River. The model will then be used to 3) predict nitrogen inputs through groundwater transport under alternative land-use planning and management strategies in the watershed (such as build-out conditions, BMP application, fertilizer ordinances, *etc*.)

b. Surface water nutrient inputs: An existing PLOAD model of the Barnegat Bay watershed has been developed that is capable of evaluating changes in surface-water nutrient loads to the estuary in response to changes in land use and water-supply development. The PLOAD model simulates surface-water nutrient loads based on event-mean concentrations derived from field data and land-use characteristics. This model will be used to simulate changes in nutrient loads delivered by surface water that can be expected to occur under different land use planning and management strategies. The PLOAD model results, together with results from the groundwater MODFLOW/ MODPATH model described above, will be used to evaluate the relative contribution of loads transported slowly through groundwater and the loads transported relatively rapidly through surface-water runoff, providing an understanding of the timeframe for the system response to management actions.

c. Freshwater inputs: The MODFLOW groundwater-flow model described earlier simulates groundwater conditions in the Barnegat Bay-Little Egg Harbor watershed and includes critical hydrologic processes such as spatially and seasonally variable recharge patterns, groundwater withdrawals, discharge to streams and discharge to the estuary. The model can be used to simulate changes in groundwater discharge to streams and the estuary in response to changes in human stresses, such as groundwater withdrawals and land alterations (such as impervious surfaces and stormwater-management facilities) that affect groundwater recharge and runoff patterns. Application of the model to predict potential future changes in freshwater inputs to the bay in response to these stresses is proposed.

Cost: Approximately $150,000 - year one; $70,000 - year two.

Determining Direct Groundwater Discharge to Barnegat Bay

Central Question: Is the bottom of Barnegat Bay acting as a freshwater discharge zone or a saltwater recharge zone?

BBP Strategic Action Plan Number: **WQ2**

Summary: Historically, recharge to the shallow aquifer of the Barnegat Bay watershed flowed along short pathways to nearby streams or along long pathways to discharge at the bottom of Barnegat Bay or the surrounding saltwater wetlands. The ongoing land use conversions in the watershed accompanied by increasing impermeable land cover and other features promote an environment where less precipitation becomes recharge. As a result, less recharge flows along long pathways to the Barnegat Bay. The result is the bottom of Barnegat Bay, which was likely a freshwater discharge zone is now a saltwater recharge zone. This can have tremendous effects on the benthic communities (SAV, shellfish) of the estuary.

This study will measure the location of and discharge rates of fresh groundwater into tidal marshes and bay bottom regions, and to measure the location of and recharge rates of saltwater in adjacent regions.

Cost: $200,000 over three years.

<u>Estuarine Biotic Response to Nutrient Inputs from the BB-LEH Watershed</u>

Central Question: What is the estuarine response associated with changes in nutrient inputs from watershed sources?

BBP Strategic Plan Action Number: WQ2

Summary: Over the course of the past five years a suite of models have been developed related to Barnegat Bay: a hydrodynamic model of the bay, a water quality model based on those hydrodynamics and watershed loadings, and a trophic-based biotic model. While there are linkages being developed between the hydrodynamic and water-quality model, the biotic aspect of the water-quality model stops at the level of primary producers. In order to understand how the effects of nutrient loads will propagate through the food web to upper-level biota it will be necessary to link the outputs of the water-quality model into the trophic model. This can be done through different modelling mechanisms, and can be spatially explicit or averaged across the estuary.

Cost: Approximately $60,000 to $100,000 depending on the spatial resolution of the model.

<u>Determining the nitrogen assimilative capacity of Barnegat Bay</u>

Central Question: What is the nitrogen load threshold after which the bay suffers from the adverse impacts of eutrophication?

BBP Strategic Plan Action Number: **WQ2**

Summary: The results of a number of prior studies suggest that the Barnegat Bay has an excessive rate of primary production stimulated by nutrient loading to the bay, primarily nitrogen. While recent regulations and restoration activities have attempted to reduce the amount of nitrogen reaching the bay, the degree to which nitrogen loads need to be reduced to have an effect are not known. The purpose of this research would be to identify the amount of nitrogen which can be utilized by aquatic organisms in the bay before crossing a threshold after which primary production becomes excessive. This threshold could then be used as the basis for determining targets for nutrient removal activities.

Cost: $100,000.

<u>Coastal Zone Soil Mapping of Barnegat Bay</u>

Central Question: What types of soils underlie the coastal zone adjacent to Barnegat Bay?

BBP Strategic Plan Action Number: H3

Summary: Coastal zone soil surveys include near shore or subaqueous soils along with adjacent terrestrial soils including upland tidal marshes or barrier beaches. The purpose of the project is to provide soils information following the National Soil Survey Standards based, in this case, on depths, position, and physical and chemical properties of the soils. The soil survey can provide information for planning, recreation, aquatic vegetation restoration, tidal wetland restoration, alternative shoreline protection techniques, flood hazard mapping, and disposal and management of dredge material.

Cost: Approximately $200,000 for fieldwork, mapping, and education/outreach.

<u>Assessment of Stormwater Best Management Practices (BMPs) for Nitrogen Removal</u>

Central Question: Which stormwater BMPs are most effective at reducing nutrient loads to the bay?

BBP Strategic Plan Action Number: WQ5

Summary: One important action in the efforts to improve water quality in Barnegat Bay is to reduce nitrogen inputs from stormwater runoff. To accomplish this, BMPs can be established. BMPs are behaviors or structures implemented to mitigate the release of nutrients and other pollutants carried via surface runoff. Structural BMPs act by intercepting contaminated runoff and treating it before it has the opportunity to reach receiving waters. While many BMP options exist for managing and mitigating stormwater runoff, nearly all are inadequate for removing total nitrogen from stormwater for areas subject to excessive nitrogen loads such as the Barnegat Bay Watershed.

The primary goal of this research is to determine the effectiveness of various BMP designs to reduce nitrogen pollution in stormwater runoff before it enters the Barnegat Bay. To adequately assess the BMPs, stormwater sampling could be conducted at the inlet and outlet of each BMP and analyzed for a suite of nutrients (*i.e.*, ammonia-nitrogen, nitrate-nitrogen, nitrite-nitrogen, total Kjeldahl nitrogen, total phosphorus, dissolved ortho-phosphorus) and total suspended solids. In addition, ambient monitoring of these same parameters could be conducted before and after construction of these BMPs to determine the impact on tributaries' water quality and determine any potential impact on watershed health, although it should be noted that a noticeable change in ambient water quality may take several years and may be offset by new nutrient inputs.

Cost: The design, construction, and installation of the BMPs will vary depending on the BMP chosen and the modifications needed to remove nitrogen, and can range from $50,000 to $1.1 million, not including annual maintenance. The monitoring of these systems will also vary depending on the numbers of parameters and the frequency of sampling, and can range from $1,000 to $25,000.

Water Supply

Assessment of the Benefits of Tertiary Treatment at the Regional Sewage Treatment Plants

Central Question: What would be the effect of upgrading the three regional sewage treatment plants to tertiary treatment and discharging treated effluent to the bay?

BBP Strategic Plan Action Number: WS4

Summary: The three regional treatment plants operated by the Ocean County Utilities Authority currently pump approximately 50 million gallons of treated wastewater per day into the coastal ocean. This activity, while helping to remove the direct discharge of pollutants into the bay, has also substantially reduced freshwater inputs into the bay. Since the construction of the regional plants, additional technologies have been developed that reduce pollutant loadings to near ambient levels, allowing for discharge into the bay. The feasibility of installing this technology, and its potential effects on the bay's water quality, will be assessed.

Cost: $100,000.

Assessment of Sea Level Rise on Regional Water Supplies

Central Question: What would be the effect of projected sea level rise for maintaining a fresh water supply to municipalities?

BBP Strategic Plan Action Number: WS4

Summary: It is likely that sea level rise will negatively impact both surface water and groundwater supplies along the heavily-populated coastal areas of Ocean County and the Barnegat Bay watershed. The Metedeconk River is the only surface-water supply within the watershed and the Brick Township Municipal Utilities Authority (BTMUA), the largest public water purveyor in Ocean County, relies on the Metedeconk as its primary source of drinking water. The close proximity of BTMUA's water supply intake to the estuary is a critical concern as the intake will become increasingly susceptible to disrupted operations from saltwater encroachment as sea level increases. The majority of the Barnegat Bay watershed relies on groundwater supplies for drinking water and increases in sea level may impact the confined and unconfined coastal aquifers by exacerbating the vulnerability of water supply wells to saltwater intrusion. The situation will be further stressed by increasing water demands from a growing Ocean County population. The assessment(s) will examine the vulnerabilities of surface water and/or groundwater supplies to sea level rise, establish timeframe projections for any impacts based upon scenarios of the predicted ranges of sea level rise, and propose management, mitigation and adaptation strategies for water supply resilience.

Cost: $300,000-$750,000.

Identification or calculation of environmental flow standards for rivers and streams within the Barnegat Bay watershed

Central Question: What streamflows are needed to maintain ecosystem functioning within the Barnegat Bay watershed?

BBP Strategic Plan Action Number: **WS1**

Summary: As land use changes continue to add impervious surfaces to the watershed and groundwater recharge rates continue to fall, the biota that rely on ecologically relevant rates of streamflow are stressed. A number of different streamflow models, incorporating a variety of ecologically relevant hydrologic indices, have been developed. In New Jersey, a process known as the Hydroecological Integrity Assessment Process (HIP) was developed, which includes a suite of software tools for classifying unclassified streams, establishing a baseline time period, comparing and contrasting past and proposed streamflow alterations, and providing options for setting environmental flow standards at the reach scale. This study will use the HIP to develop recommendations for stream flow standards within the watershed.

Cost: $100,000.

Soil Health Assessment

Researching, Developing, and Piloting Cost-Effective Tools and Procedures to Assess Soil Conditions

Central Question: How can the soil health (and function) of stormwater basins be assessed simply and effectively, without costly and specialized testing, equipment, and procedures?

BBP Strategic Plan Action Number: WQ6A, WQ6B

Summary: A. There have been numerous projects and an ongoing commitment to restore and retrofit county-owned stormwater basins throughout the watershed (Ocean County Soil Conservation District, Ocean County Planning Department, NJDEP) and a current initiative by Rutgers University/CRSSA/JCNERR to develop a GIS database and web portal (WQ6D.) The data to identify (and eventually prioritize) the basins that are not functioning, and therefore would benefit most from restoration is not currently available. With an estimated cost of $100,000/basin restoration, it is both economically and strategically practical to focus on the basins that are exhibiting symptoms of poor soil health. Stormwater basins can only be considered a Best Management Practice if they are properly functioning as such.

Cost: $240,000.

B. The existing Ocean County Soil Survey published by the National Cooperative Soil Survey (NCSS) is an Order 2 Survey utilizing a scale between 1:12,000 and 1:24,000. It is not intended to provide detailed and/or use-dependent information. Mapping soils information at a smaller scale less than 1:12,000 would provide site-specific information along with a use-dependent assessment of soil conditions for disturbed lands, including stormwater management basins. As noted in Summary A, basin restoration is very costly. It is paramount that the proper assessment techniques are utilized in developing recommendations for restoring disturbed turf lands/basins. With nearly 3,000 stormwater basins in the watershed, a site-specific soil survey would be very helpful in assessing and in prioritizing basins for potential restoration. This proposal would develop an urban soil series to recognize the presence or absence of compacted layers and massive soil structure with specific criteria related to soil depth and soil bulk density. It would establish interpretations for soil restorations to rebuild pore space in compacted and/or disturbed lands and basins. Conventional soil taxonomy would be applied as related to soil classifications and anthropogenic influences on soil. This would be a pilot project to demonstrate how urban soil interpretations could be used in determining basins for potential restoration techniques.

Cost: $250,000.

Developing Post-Construction Soil Health Inspection Guidelines

Central Question: What are the optimal specifications for soils in the BB-LEH system?

BBP Strategic Plan Action Number: WQ10B, WQ10C

Summary: The amount and type of organic material needed to optimize soil health and thereby improve soil function, is site-specific and dependent on a number of factors and soil properties. To improve soil health throughout the Barnegat Bay watershed, methods and protocols must be developed. Once determined, specifications can be developed to assist in soil restoration. A long-term goal of this project is to help transfer restoration technology to local communities, to build natural resource stewardship capacity and help empower municipalities to implement local guidelines that sustain soil health. The primary product of this component is to develop guidelines for soil health restoration for the Barnegat Bay watershed.

Cost: $180,000.

Implementing a Pilot Program in Ocean County for Soil Health Restoration

Central Question: How can we efficiently transfer the soil restoration guidelines to the on-the-ground agencies, organizations, and businesses that will actually implement these practices?

BBP Strategic Plan Action Number: WQ8, WQ10A, WQ10B, WQ10C, P9

Summary: Develop and implement a Soil Health Certification Program for contractors, landscapers, and engineers to ensure that BMPs and stormwater practices are properly constructed to sustain the soil's physical, chemical and biological functions. Prepare inspection procedures and inspection forms as a basis for uniform inspections to evaluate soil conditions.

The most effective method is to provide training opportunities that include site visits, demonstrations, and hands-on experiences for the trainees. This is a continuation and further advancement of the "Blue Card for the Blue Crab Program," the Barnegat Bay Soil Health Card (NJDEP/DWM/CBT project), and additional regional training initiatives for Soil Health Restoration. Soil health training would include workshops and field trips to demonstrate soil restoration guidelines to township engineers, public works officials, athletic field managers, and the public.

Cost: $150,000 + (additional funds for annual workshops and training).

Coastal Wetlands Monitoring and Enhancement

Coastal Wetlands and Shoreline Stabilization

Central Question: Which techniques are most effective in enhancing elevation capital on wetlands and to stabilizing high-energy shorelines in New Jersey? How do we continue to sustain long-term monitoring of coastal wetlands and nature-based implementation projects?

BBP Strategic Plan Action Number: H1, H3, H4, H5

Summary: Because coastal wetlands provide critical services, including flood protection, maintenance of water quality, carbon and nutrient sequestration, and fish and wildlife habitat, it becomes even more imperative that we assess, manage, and enhance this resource as the sea level continues to rise. Sea level rise and increasing trends in severe weather events continue to impact coastal wetlands at an accelerated rate. Vertical losses, or those driven by platform elevation declines, can be largely attributed to functional impairment. Horizontal loss, also a large contributor to wetland acreage decline, is governed by factors such as edge erosion.

Since 2010, BBP has been systematically monitoring and assessing the condition and trends in our coastal marshes as part of the Mid-Atlantic Coastal Wetlands Assessment. Other BBP partners are also conducting a wide range of wetlands assessment activities that continue to broaden our collective understanding. Baseline wetlands conditions have been established. Continued monitoring will allowing us to detect changes and characterize trends over time and adaptively manage these resources over time.

A number of restoration techniques are being considered including natural shoreline, thin layer sediment placement, and hydrological alteration. Nature-based approaches to wetlands and shoreline stabilization should incorporate wetlands function and the unique characteristics into project design to help ensure better success and increased habitat value. Long-term monitoring will also help increase our collective understanding of what techniques are successful in our coastal estuaries. Innovative approaches can reduce the loss of valuable waterfront land, protect property, and decrease the amount of sediment entering the bay's waters. In many cases, the vegetated marsh fringe serves as a buffer strip that works as a filter for runoff and pollutants. These "natural approaches" for wetlands enhancement and shoreline erosion can be highly successful, but each case should be evaluated separately.

Implementing wetlands enhancement and shoreline erosion control projects with natural components has definite benefits for the health of Barnegat Bay's economic and ecological value (*e.g.*, restore marine habitat and spawning areas, maintain water quality, prevent bank erosion and property loss, provide protection from storm surges and sea level rise).

Costs: $300,000 over a three-year period.

CONCLUSION

Taken together, the research, monitoring, and implementation projects detailed in this prospectus address the most pressing of the BBP's Strategic Plan Priorities, which will be captured in some form in the next CCMP. First, we must build on the science foundation provided by the last prospectus and subsequent federal and state-funded initiatives; secondly, we must factor in future impacts of a changing climate at a local scale. We must continue to work together to:

(1) maintain adequate monitoring programs of the bay's water quality;
(2) take proactive measures to ensure adequate water supplies for people and the bay's ecology and the economy it sustains;
(3) protect and restore the bay's critical habitats, which are also critical components of the green infrastructure which helps makes communities resilient to future climate change and sea level rise;
(4) assess and manage the bay's biotic resources; and
(5) promote more responsible land use, especially along the water's edge and other areas vulnerable to sea level rise and climate change.

In order to implement these priority actions, we strongly encourage the State of New Jersey to establish a stable funding mechanism for implementing CCMP priorities, including monitoring and periodic assessment, to protect and restore the bay.

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Appendix 1: Completed studies/reports identified in the BBP's 2008 Prospectus

Bay-wide water quality monitoring - http://www.nj.gov/dep/barnegatbay/bbmapviewer.htm

Assessment of Fishes and Crabs Responses to Human Alteration of the BB-LEH System **-** http://nj.gov/dep/dsr/barnegat/final-reports/fish-crabs-reports.htm

Assessment of Stinging Sea Nettles (Jellyfishes) in Barnegat Bay - http://nj.gov/dep/dsr/barnegat/final-reports/sea-nettles-reports.htm

Benthic Invertebrate Community Monitoring and Indicator Development for the BB-LEH Estuary - http://nj.gov/dep/dsr/barnegat/final-reports/benthic-invertebrate-reports.htm

Assessment of Hard Clam Populations in the BB-LEH System - http://www.nj.gov/dep/fgw/shelhome.htm

Assessing the Status of Barnegat Bay Submerged Aquatic Vegetation - http://bbp.ocean.edu/pages/143.asp

Concentrations, loads, and yields of total nitrogen and total phosphorus in the Barnegat Bay-Little Egg Harbor watershed, New Jersey, 1989–2011, at multiple spatial scales - https://pubs.usgs.gov/sir/2014/5072/

Nutrient concentrations in surface water and groundwater, and nitrate source identification using stable isotope analysis, in the Barnegat Bay-Little Egg Harbor watershed, New Jersey, 2010–11 - https://pubs.er.usgs.gov/publication/sir20125287

Quantifying the Residence Time and Flushing Characteristics of a Shallow, Back-Barrier Estuary: Application of Hydrodynamic and Particle Tracking Models - http://link.springer.com/article/10.1007/s12237-014-9885-3

Assessment of nutrient loading and eutrophication in Barnegat Bay - Little Egg Harbor, NJ in support of nutrient management planning – http://neiwpcc.org/nynj-assessment.asp

Subaqueous Soil Mapping of Barnegat Bay - https://www.nrcs.usda.gov/wps/portal/nrcs/detail/nj/newsroom/releases/?cid=NRCSEPRD1302453

Soil Health Improvement Project - http://www.soildistrict.org/healthy-yards/jakes-branch-ship-project/