New Jersey Department of Environmental Protection
Division of Water Monitoring and Standards
Bureau of Water Quality Standards and Assessment

Nutrient Criteria Enhancement Plan –2010 Progress Report

November 2011

Introduction

The New Jersey Department of Environmental Protection (Department) developed a Nutrient Criteria Enhancement Plan in conformance with United States Environmental Protection Agency (USEPA) recommendations that all states outline their plans for developing nutrient criteria. USEPA had already developed Ecoregion Nutrient Criteria under Section 304(a) of the federal Clean Water Act (see 66 F.R. 1671) and recommended that states either: adopt these criteria, adopt their own numeric criteria, or develop numeric translators for narrative criteria for all waters that contribute nutrient loadings to surface waters.

New Jersey developed a plan for enhancing the existing nutrient criteria for freshwaters and developing new nutrient criteria for other (estuarine, marine) waters of the State. Under this plan, nutrient criteria (including numeric criteria and translators of narrative criteria) would be developed to address and prevent nutrient-related use impairment in New Jersey waters. The plan acknowledged that nutrient criteria development requires an understanding of the complex causal relationships between nutrient over-enrichment, various response variables, and documented impacts on attainment of designated and existing uses of New Jersey waters. This document reports New Jersey's progress to date since the New Jersey Nutrient Criteria Enhancement Plan was approved by the USEPA in June 2009.

The 2009 Nutrient Criteria Enhancement Plan included a prioritization of waterbody types for nutrient criteria development/enhancement and identified the first priority as freshwater wadeable streams, since a significant percent of these waters were listed as impaired on the 303(d) List of Water Quality Limited Waters and because sufficient information already existed to enhance the nutrient criteria for these waters and subsequently reassess them. However, the Plan also identified the preliminary actions needed to begin nutrient criteria development/refinement in other waters, including additional monitoring, modeling and research into causal indicators. Establishing a causal link between nutrient concentrations and biological responses indicative of use impairment has been identified as a Department priority. The Department has initiated several projects over the past few years designed to establish these linkages. The Department's Office of Science created a Web site to post nutrient-related research, studies, reports and presentations (see http://www.state.nj.us/dep/dsr/nutrient).

Subsequent to the publication of the 2009 Nutrient Plan, Commissioner Bob Martin appointed members to the Science Advisory Board (SAB) and charged the SAB with evaluating state-of-the-art approaches for technically sound and implementable nutrient thresholds/criteria in fresh and coastal waters. The Department also participates on the Delaware River Basin Commission's (DRBC) Nutrient Subcommittee with the States of Pennsylvania, Delaware, and New York to address nutrients impacts to the Delaware River, Estuary, and Bay. Information on this effort is

available on DRBC's Nutrient Information Web site. The Department continues to collect routine physical/chemical and biological data through New Jersey's water quality monitoring networks. This data is available on the Department's Water Quality Data Web site. This information may be used to assess water quality conditions and to develop nutrient criteria.

Lakes and Reservoirs

Lakes

Many New Jersey lakes are shallow, run-of-the-river, constructed impoundments, which renders them highly susceptible to accelerated eutrophication. As a result, many New Jersey lakes have exhibited water quality problems for decades, primarily with respect to nutrient over-enrichment. This predisposition is enhanced in lakes with large watersheds.

Data: Nutrient data is currently generated by the Department's probabilistic Ambient Lake Monitoring Network that is based on the USEPA-recommended Generalized Random Tessellation Stratified (GRTS) Spatially-Balanced Survey Design. This network involves the sampling of 200 lakes selected randomly from the State's approximately 1100 named lakes. The criteria for selecting the list includes lakes that are greater than 5 acres, accessible for sampling, of a sufficient depth, not tidally influenced, not containing brackish water, and not used as a drinking water supply. Sampling is conducted in five panels of 40 lakes each. Each panel is sampled once every five years. Each lake within a panel is sampled three times per year (Spring, Summer, and Fall) for conventional parameters including: total phosphorus (TP), dissolved oxygen (DO), pH, nitrogen series, hardness, turbidity, and chlorophyll *a*. In addition, a visual assessment on the impact of aquatic vegetation is conducted. The lake selection and monitoring protocols employed by the Department are described in more detail on the Department's Web site for the NJDEP Ambient Lake Monitoring Network. The first round of sampling all 200 lakes has been completed and the results will be evaluated in 2011.

In order to strengthen the lake assessment, an additional 20 lake sites were selected by EPA using the same probabilistic design described above and are identified as Panel Six in the NJ Ambient Lake Monitoring Network. These 20 lakes will be evaluated annually over a 10 year period. Employing proper training, equipment and quality controls, this network will aid in developing trend information. The field methods include physical, visual, and designated use parameters, including temperature, clarity, visual signs of nutrient enrichment (e.g., excess aquatic plants and algae), public access and in flow and out flow of lake. Methods followed protocols outlined in the National Lake Survey methods to maximize consistency and allow for data comparability with that gathered by the Bureau of Fresh Water and Biological Monitoring. Data gathered in the first round (collected between May 1-31, 2011) will be reviewed by Water Monitoring and Standards staff and made available via EPA's STORET. The Department plans to make the field methods available so that lake associations, county and local agencies and watershed associations can provide data on other lakes.

Cause/Response Indicators:

- **Pilot Study - Paleolimnological Analysis of Nutrient Enrichment for Criteria Development in New Jersey and New York lakes (2008):** A paleolimnological analysis of diatoms in lake sediment cores from New Jersey and New York lakes was conducted as a pilot study to support nutrient and other biological criteria development for these waters. This study was funded by the U.S. Environmental Protection Agency through an agreement with Oak Ridge National Lab. Diatoms are one of the most powerful water quality indicators used in paleolimnological studies. According to Stoermer and Smol, many diatom species have well-defined optima and tolerances for environmental variables such as lake pH, nutrient concentration, water salinity, and color (as cited in Enache M., *et al*. 2008, p. 2). This study used diatom assemblages from lake sediment cores as biological indicators of nutrient and eutrophication status of lakes. Chironomid insect remains were also collected as indicators of anoxia however that study proved inconclusive. Diatom species from top-bottom sediment cores from a total of 43 lakes from New York and New Jersey with 24 lakes in New Jersey were analyzed. These samples were combined with the National Lakes Assessment dataset to develop transfer functions for nutrients, pH, and other environmental variables of interest, based on the most recent diatom taxonomy. The final report for this pilot study concluded that diatom assemblages in top-bottom sediment cores show changes that can be linked to both anthropogenic activities and climate change. Most of the lakes studied displayed important changes in their environmental conditions since pre-industrial times. The diatom assemblages show changes associated with eutrophication in some lakes that are assessed under current methods as not impaired. This means that diatoms may be a better indicator of nutrient over-enrichment in lakes than the indicators used under current assessment methods (i.e. total phosphorus). The final report for this study, entitled: "Paleolimnological Analysis of Nutrient Enrichment for Criteria Development in New Jersey and New York Lakes - Final Report" (Enache, et al., 2008), is available on the Department's Web site. An important conclusion was that additional research was needed to quantify the modeling transfer functions (i.e. TP vs. diatom response) for a trophic diatom index (TDI) model necessary to develop a biological index of nutrient impairment in lakes using diatoms. Subsequently NJDEP initiated a trophic diatom index study in 2009 and a follow up paleolimnological study in 2011. The results for the first study are described below followed by a work plan for the latter.

- **Lake Diatom Trophic Index**: The Department's Ambient Lake Monitoring Network collected 207 sediment cores from its 200 randomly-selected lakes, between 2005 and 2009. (Some duplicates were taken using a larger corer, which explains why there are more than 200 samples.) Diatom species were analyzed in 65 of the sediment core samples from lakes north of the "fall line". These samples are represented by 50 sediment surface samples taken from core top (0-0.5 cm intervals = present-day, or modern samples) and 15 core bottoms that represent past, or pre-disturbance conditions if the core was of sufficient length to reach this time period. 500 diatom valves were enumerated for each sample, unless the slide did not yield sufficient specimens. The 50 surface samples were combined with a dataset derived from a previous NJ-NY paleolimnological project (see above) and a National Lake Assessment (NLA) subset of samples. This combined dataset was used to compute predictive

models for lake nutrients (TP and TN). This dataset was also used to calculate diatom trophic indices such as TP and TN optima and tolerances. Weighted-averaging partial least square (WA-PLS) techniques were used to derive transfer functions and to reconstruct TP and TN in 15 bottom samples. However, budget and time constraints did not allow for a thorough examination of the datasets used to derive inference models. Taxonomic harmonization between the current dataset and the two previous ones should contribute to refine these models and increase the TP and TN models' accuracy. These refined models could be successfully applied to reconstruct nutrients at other sites and help establish criteria for reference conditions. This will provide more precise interpretations of cultural impacts and identify reference conditions for individual lakes. Since the untimely ending of the study, the Department received funding to allow it to complete the unfinished models as explained below.

- **New Jersey Lake Diatom Trophic Index Development Study** *(2011)*: The major activities proposed for this project are to select 70 study lakes and collect sediment cores. Top and bottom core intervals will be analyzed to assess for nutrient reference conditions and how much these conditions changed in modern time. A total of 140 samples will be analyzed. Ambrosia counts (rag weed pollen) will be done in top and bottom samples (a total of 140 samples will be analyzed for pollen) to verify if the core bottoms reach the pre-European settlement (reference conditions time period). Lastly diatom-based transfer functions developed in previous projects (NLA, NJ-NY Paleo pilot and a 2009 project for NJ lakes), will be used to infer nutrient concentrations in tops and bottoms of sediment cores. The diatom-inferred nutrients from bottom cores will be used to assess natural (or reference) conditions. The results will then be summarized with findings and recommendations in a report and manuscript.

Assessment Method: Once the Lake Diatom Trophic Index (TDI) has been completed, it will be evaluated for incorporation into New Jersey's Integrated Water Quality Monitoring and Assessment Methods for use in assessing compliance with the narrative nutrient criteria. Currently, the Department uses three parameters to assess the general aquatic life use in lakes: total phosphorus (TP), dissolved oxygen (DO), and pH. Each lake is assessed as a single monitoring station along with all the stream monitoring stations located within each U.S. Geological Survey Hydrologic Unit Code (HUC) 14 subwatershed.

Criteria Development: The Department reproposed nutrient policies and narrative criteria applicable to all waters and numeric phosphorus criteria for freshwater non-tidal streams and lakes on December 21, 2009. The reproposal indicated that the phosphorus numeric criteria for both streams and lakes apply until the Department determines that the phosphorus concentration in the waterbody does not cause undesirable conditions described in the narrative criterion for nutrients. Using a narrative criterion allows the Department to address both situations where a waterbody meets the applicable numeric phosphorus criterion, but still has aquatic growth problems, as well as situations where a waterbody is above the applicable numeric phosphorus criterion, but does not actually exhibit any problems. This change will also clarify that all waterbodies and their uses will be protected by either narrative or numeric criteria, as appropriate. The Department adopted these amendments to nutrient policies and criteria on

January 18, 2011. While both narrative and numeric nutrient criteria have been promulgated for lakes, a method for assessing compliance with the narrative nutrient criteria in lakes has not yet been developed, see "Assessment Method". The Department continues to assess nutrient impairment in lakes based on the numeric criterion for total phosphorus while research is underway to identify appropriate cause/response indicators, as explained above. Additionally, the Department is evaluating the sediment diatom and probabilistic lake study data to see if the numeric nutrient criteria can be refined.

Reservoirs

There are 43 Water Supply Reservoirs in New Jersey, most of which are multiple use waterbodies. Nutrient over-enrichment may cause algal blooms and other impacts that adversely affect drinking water directly (e.g., algal toxins, taste and odor) or indirectly via water pumpage and treatment (e.g., equipment fouling, increase in disinfection by-products).

Data: Water supply reservoirs are not part of any regular statewide monitoring program and were excluded from the probabilistic lake monitoring program due to the impacts on water levels caused by pumping and withdrawals for drinking water purposes. The monitoring varies depending on the level of treatment needed for the source waters. The data that purveyors collect to update treatment needs for the water are not generally reported to the Department. This data gap has been identified in the Department's Long Term Monitoring & Assessment Strategy (NJDEP, 2004).

Cause/Response Indicators: Once biological indicators of nutrient impairment in lakes have been validated and incorporated into nutrient impact assessment method, the Department will determine if these indicators/methods are also applicable to reservoirs or if additional enhancements are needed to address nutrient impairment of reservoirs.

Assessment Method: Where data is available, reservoirs are treated like lakes and assessed as single stations along with stream monitoring stations within each HUC 14 subwatershed. Currently, the Department uses three parameters are used to assess the general aquatic life use in lakes: total phosphorus (TP), dissolved oxygen (DO), and pH. Additional information is needed to assess nutrient impairment in reservoirs. Once the Department has successfully developed a new nutrient assessment methodology for lakes, the Department will consider developing a similar methodology for assessing nutrient impairment in reservoirs.

Criteria Development: As pointed out in the "Cause/Response indicators" the results from the lake studies will be examined to determine if they are applicable to reservoirs. It is likely that because of the management practices are unique for each reservoir that site-specific criteria development will be more appropriate.

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Non-Tidal Streams and Rivers

There are roughly 18,000 miles of streams and rivers in New Jersey (at 1:24,000 scale of resolution), of which 12,000 miles are non-tidal. For monitoring and assessment purposes, streams are considered "wadeable" and rivers are considered "non-wadeable". "Wadeable" means that the waters are conducive to monitoring on foot, rather than by boat, such as rapid bioassessment of benthic macroinvertebrates. Most of New Jersey's non-tidal waterbodies are wadeable streams. Wadeable streams may exhibit a variety of habitats including shallow, weed-dominated areas and deeper pools where floating algae may occur. Rivers are larger and deeper than streams and must be monitored via bridges or by boat.

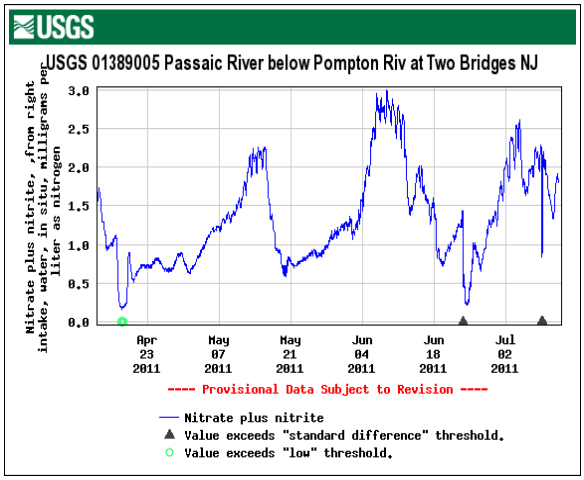
Data: Chemical and biological data related to nutrient impacts on streams and rivers are currently generated from a number of monitoring networks, including the Department's cooperative (with USGS) Ambient Surface Water Monitoring Network (ASWMN), the Delaware River Basin Commission (DRBC) Monitoring Network, the Ambient Biological Monitoring Network (AMNET), the Fish Index of Biological Integrity (FIBI) Network, as well as the Department's Volunteer Monitoring Program, and the New Jersey Watershed Ambassadors Program, which work with local communities to generate biological data for water quality assessment, and other monitoring partners.

Chemical Data:
The ASWMN network consists of 215 stations that are sampled quarterly for parameters including nutrients. Diurnal dissolved oxygen (DO) is measured annually at selected sites. ASWMN sampled 113 sites quarterly in 2009 and 106 sites quarterly in 2010. The Department monitored an additional 93 sites each (quarterly) in 2009 and 2010 for chemical/physical water quality. Sediment samples were also collected from a number of ASWMN sites. Sediment samples have been collected from a total of 282 stations since 1997 and analyzed for various parameters, including some related to nutrients, i.e., pH, total Kjeldahl nitrogen (TKN), and phosphorus. The Department continues to cooperate with other stakeholders who collect ambient water quality data to incorporate their results into assessment studies when appropriate.

New sensor technology has become available that may support expansion of New Jersey's continuous monitoring capabilities, particularly regarding nutrient-related parameters. These new monitoring devices can measure dissolved oxygen, temperature, pH, Chlorophyll *a*, conductivity/salinity, turbidity, and flow. The New Jersey Water Monitoring Council created an inventory of 63 sites that are monitored continuously. The inventory and a map showing the sites operating in 2011 are available on the Department's Web site at: http://www.nj.gov/dep/wms/wmccactivities.html.

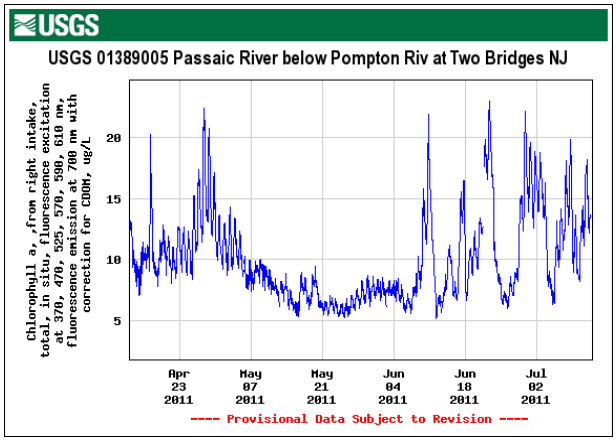
Research is underway to determine the best way to operate and install two new types of optical sensors at some or all of these sites: 1) a nitrate sensor, and 2) a Chlorophyll *a* sensor that also gives information about the water-column relative algal community composition based on the Chlorophyll *a* concentrations of four groupings of algal organisms (explained in more detail below). The United States Geological Survey (USGS) has deployed sensors to measure nitrate concentration continuously. An S::CAN Spectrolyzer ultraviolet-visible spectrum spectrophotometer nitrate sensor was installed and has been operating at three locations in the Passaic River below the confluence with the Pompton River near Two Bridges, New Jersey since July, 2009. The sensor generates a measurement of nitrate once an hour for the Passaic and the Pompton Rivers. The nitrate concentration measured ranged from 0.3 to 6.2 milligrams per liter (mg/L), as shown in Figure 1. The majority of the data collected hourly is less than 2.5 mg/L. Techniques were developed and instituted that reduced the cost of operating the nitrate sensor. The costs were reduced by increasing the time between service visits needed to clean the sensor from once every seven days to once every 19 days. The S::CAN spectrophotometer has proven to be very reliable for a period of approximately two years. This data will provide a better understanding of the fluctuation in nitrate concentration at critical water supply operations on the Passaic and Pompton Rivers. Additional information about this sensor is explained in the USGS presentation, Continuous Water Quality Monitoring in New Jersey.

Figure 1: Nitrate Sensor Results



In July 2010, the USGS also installed a BBE Algal Guard fluorometer Chlorophyll *a* at the same location on the Passaic River below the confluence with the Pompton River near Two Bridges, New Jersey where a nitrate sensor was already installed. This sensor measures the Chlorophyll *a* of four groups of algae (green, blue-green, *Chryptophyta* and diatoms) and the total Chlorophyll *a* as the sum of the four groups. This sensor indicates the total algal biomass in the water column as indicated by total Chlorophyll *a* (see Figure 2). In addition, this sensor can measure changes in the relative composition of the algal community as indicated by the four algal groups listed above. Hourly measurements have shown the changes in total Chlorophyll *a* after storm events, as well as, seasonal changes in total Chlorophyll *a* and changes in the relative composition of the algal community. The Algal Guard has proven to be reliable and does not need much maintenance. This data will provide

Figure 2: Chlorophyll *a* Sensor Results



a better understanding of the fluctuation in Chlorophyll *a* concentrations at critical water supply operations on the Passaic and Pompton Rivers. Data is available from the USGS Web site at: http://waterdata.usgs.gov/nj/nwis/current/%20?type=qw&group_key=basin_cd.

The USGS plans to install sensors to monitor nitrate and the Chlorophyll *a* at two sites located in the Barnegat Bay Watershed based on the successful installation and operation in the Passaic River watershed. These deployments will be used to evaluate performance in salt water conditions. The Toms River will be continuously monitored for nitrate. Barnegat Bay near the Mantoloking Bridge will be monitored for total Chlorophyll *a* and the relative composition of the water-column algal community.

Biological Data:

- Benthic Macroinvertebrates**:** The Ambient Biological Network (AMNET) consists of over 800 stream sites that provide long-term biological data reflecting the quality of surface waters throughout the State. Sites in each of the State's five Water Regions (Upper Delaware, Northeast, Raritan, Atlantic, and Lower Delaware) are sampled on a five-year rotational basis to establish trends in water and habitat quality. The AMNET program routinely samples and analyzes benthic macroinvertebrate populations at each site, employing USEPA-developed Rapid Bioassessment methods to provide an index of stream water and habitat quality. In addition, several watershed groups also collect and analyze benthic samples and provide results to the Department for use in the Integrated Report. Three different metrics are used to assess the State's benthic macroinvertebrates to reflect regional ecological differences. A High Gradient Macroinvertebrate Index (**HGMI**) is employed in waters above the Fall Line, a Coastal Plain Macroinvertebrate Index (**CPMI**) is used in the low gradient New Jersey coastal plain excluding the Pinelands, and a Pinelands Macroinvertebrate Index (**PMI**) is employed in waters within and immediately surrounding the Pinelands region of the state. All current assessments employ identifications down to the genus level. Results from each of the three indices fall into one of four assessment descriptive categories: "Excellent", "Good", "Fair", and "Poor" as explained in the Assessment Scoring Criteria available in Standard Operating Procedures - Ambient Biological Monitoring Using Benthic Macroinvertebrates, Appendix B. All three metrics compare benthic communities found at a site in question to communities found in relatively undisturbed reference waters. The degree of diversion from the reference community is an indication of the degree of biological degradation at the site.

  Currently, the data is used to assess aquatic life use attainment. These data are used as indicators of biological impairment but are not sufficient to identify the specific source causing the biological disturbance. Biological monitoring programs, including both ambient and intensive surveys, were initiated by the Department because the micro and macro flora and fauna of various trophic levels can integrate the effects of water quality changes over time, thus making them effective pollution indicators. As of November 2008, all of the network stations have been sampled three times and 30% of the network stations have been sampled four times.

- Fish**:** The Department's Fish Index of Biotic Integrity (FIBI) network consists of 100 fixed stations contained within the northern part of the state and monitored on a five-year rotation

(twenty stations per year). Stream segments selected for sampling must have a minimum of one riffle, run, and pool sequence to be considered representative. The FIBI is an index that measures the health of a stream based on multiple attributes of the resident fish assemblage. The Department uses FIBI data to, among other things, assess water quality trends and aquatic life use impairment. Fish biotic integrity may also be used as an indicator of anthropogenic stressors including impervious cover, siltation, and increased run-off from stormwater outfalls.

Each site sampled is scored based on its deviation from reference conditions (i.e., what would be found in an non-impacted stream) and classified as "poor", "fair", "good" or "excellent". In addition, habitat is evaluated at each site and classified as "poor", "marginal", "suboptimal," or "optimal". Once fish from sample collections have been identified, counted, examined for disease and anomalies, and recorded several biometrics are applied to evaluate biotic integrity. Fish community analysis is accomplished using a regional modification of the original FIBI (Karr *et al*,. 1986), which is explained in detail in the Bureau of Freshwater and Biological Monitoring's document Fish IBI. In the southern portion of the state, the Department is building on work initially performed to develop an IBI for the inner coastal plain (southern New Jersey exclusive of the Pinelands Area). "Least impacted" sites have been sampled while stressed and validation site sampling is ongoing. The Department sampled 92 FIBI sites in the northern portion of the State covering the Counties of Sussex, Warren, Hunterdon, Passaic, Bergen, Union, Essex, Mercer, Middlesex, and Somerset between years 2000 and 2004. The Department sampled 63 FIBI sites in the same counties but added Morris County in 2005-2007. In the southern portion of the state, the Department is building on work initially performed to develop an IBI for the inner coastal plain (southern New Jersey exclusive of the Pinelands Area).

- Periphyton/Diatoms**:** NJDEP recognized that additional research was needed to correlate biological impairment with nutrient over-enrichment in wadeable streams. The Department realizes that benthic macroinvertebrates and fish while useful in evaluating aquatic life conditions also reflect affects from other stressors (e.g., pH, erosion/siltation, toxics, etc.). NJDEP investigated the utility of using macroinvertebrates as an index of nutrient status in New Jersey streams, but found that algal diatoms appear to be more robust and predictive (see Application of an Index of Nutrient Status Based on Macroinvertebrate Assemblages to New Jersey Streams and Application of a Macroinvertebrate Nutrient Biotic Index (NBI) to New Jersey Streams and Comparison to Diatom Indices). Subsequent research conducted by the Patrick Center for Environmental Research, Academy of Natural Sciences, (Academy) showed algal diatoms as a promising indicator of nutrient enrichment (see New Jersey Periphyton Bioassessment Development Projects Trophic Diatom Inference Models and Index Development for New Jersey Wadeable Streams (2000-2005)). Primary data were collected by the Academy between 2000-2005 as part of a state-wide monitoring study to develop protocols and an assessment methodology for using algal diatoms to assess freshwater quality and the correlation to nutrients and cultural eutrophication. The objective of this five-year assessment was to bolster NJ's nutrient criteria (and narrative policies) through establishment of scientifically defensible response indicators (trophic diatom index

or TDI); and to augment the state's routine water quality monitoring network. This project assessed the relationship between benthic diatoms and water chemistry samples collected from over a hundred sites in five New Jersey ecoregions: Northern Piedmont, Northeastern Highlands, Ridge and Valley, and Inner and Outer Coastal Plains. Multivariate analysis showed that nutrient concentrations explained significant proportions of the variation in diatom species composition. Nutrient inference models and the two TDIs developed (northern and southern New Jersey) provided good measures of biological response to nutrient conditions (Ponader et al 2007 and Ponader et al 2008). Currently, the New Jersey Science Advisory Board is reviewing the final reports and evaluating this approach for its utility in developing nutrient criteria for wadeable streams.

Cause/Response Indicators:

- **Northern New Jersey Stream Diatom Trophic Index Development Study (2009):** In the Summer of 2009, the Department initiated periphyton monitoring in northern New Jersey steams (above the fall line) following protocols developed by the Academy to further support development of biological indicators that correlate with water quality impairment caused by nutrients. Samples were collected by NJDEP at 40 stations; 20 randomly-selected existing status stations and 20 additional locations where total phosphorus is suspected of rendering the waters unsuitable for designated uses. The goals of this project were to determine a.) if the northern New Jersey trophic diatom index for both total phosphorus (TP) and total nitrogen (TN) was applicable to a wider range of NJ rivers and streams, b.) were collection methods effective and efficient, and c.) was there agreement between inferred and measured nutrient values for these new sites comparable to results of the original model (Ponader et al 2007). A report is pending but a preliminary analysis of this data shows that the model accuracy based on the new samples was comparable to original results; that TP models perform better than TN models; both models related best to non-growing season concentrations (October to April); and the models are applicable to a wide variety of NJ rivers and streams.

- **Southern New Jersey Stream Diatom Trophic Index Development Study (2010)**: Following the northern streams study, the Department subsequently initiated periphyton monitoring in southern New Jersey streams (below the fall line in Coastal Plain). Sites located below the Fall Line were chosen on streams with pH levels above 5.5, which excludes the Pinelands and many South Jersey streams, since low pH waters impact the periphyton community and would not result in a valid metric (See: Ponader et al 2008). Twenty additional monitoring locations were selected for sampling in Summer 2010; however, the lack of natural substrates in these waters required the deployment of artificial substrates that were deployed for 2-3 weeks before samples were collected. However, a stream scouring rainfall event just prior to sample collection eliminated the opportunity to collect samples based on the project sampling protocol. Because the growing season was ending, samples were not collected in 2009 and were rescheduled for Summer 2011. Unfortunately, the Hurricane Irene washed away the sampling baskets. Decisions about incorporating these monitoring/analysis methods into the Department's routine monitoring programs will be made after the data is reviewed.

Biological Condition Gradient: Following the initial TDI studies, the Academy convened a workgroup to develop a Biological Condition Gradient (BCG) for diatom communities in New Jersey. A BCG is used to describe biological communities that reflect changes (from pristine to degraded) caused by increased anthropogenic impacts. The goal of this project was to establish a BCG to determine which trophic diatom index (TDI) values represent impairment of diatom communities caused by excessive nutrient inputs. Seven expert diatomists from across the country convened at an expert-panel workshop to determine BCG Category boundaries to specify ranges of TDI index values that distinguish sites with acceptable and unacceptable nutrient conditions. The results can be found in the BCG report, Diatoms and the Biological Condition Gradient in New Jersey Rivers and Streams: A Basis for Developing Nutrient Guidance Levels (Charles, D.F., Tuccillo, A.P., Belton, T.J., 2010)

Trophic Diatom Index Enhancement: During the BCG development, it was evident that additional data was needed to strengthen the BCG tiers. A second phase of the TDI study will use data from 80 new sites to validate and enhance the development of New Jersey diatom BCG tiers and their associations within stream nutrient levels. PANS will analyze the samples and calibrate the TDI for North and South Jersey streams. Final "rules" (mathematical statements) will be employed to assign diatom communities to BCG tiers and results will be presented at an appropriate scientific meeting including a manuscript for publication in a scientific journal. Samples were collected in 2009 but conditions were not favorable in 2010 and 2011, therefore further work has been deferred to 2012.

New Assessment Method: The Department developed a new nutrient impact assessment method for wadeable streams as part of the 2010 Integrated Water Quality Monitoring and Assessment Methods Report to determine if aquatic life use impairment is due to phosphorus over-enrichment. This method considers dissolved oxygen (DO) and biological data as indicators of nutrient-caused impairment of the aquatic life use. This method is based upon the assumption that biological impacts evidenced by changes to the composition of aquatic ecosystems coupled with low dissolved oxygen levels and abnormal diurnal fluctuations (taking into account percent saturation and changes in temperature), provide an indication that the waters are rendered unsuitable for aquatic life uses due to excessive phosphorus. While the existing monitoring networks provide extensive information on water chemistry, as well as an increasing amount of biological data, there is very little co-located and/or contemporaneous biological and chemical data necessary for nutrient impact assessment.

Biological monitoring and continuous dissolved oxygen readings for this type of assessment must be obtained during summer growing season. The selected response variables take into consideration the site-specific factors and are consistent with the narrative criterion established in the Surface Water Quality Standards for nutrients which include "abnormal diurnal fluctuations in dissolved oxygen or pH" and "changes to the compositions of the aquatic ecosystem". Achieving compliance with the narrative criteria by means of these response variables and thresholds is the overall water quality objective.

The Department recognizes that a poor biological condition may not be due to the levels of nutrients present. However, when poor biological condition is coupled with dissolved oxygen

levels that exceed criteria, and the waterbody experiences significant diurnal dissolved oxygen swings, the Department believes that these response variables indicate excessive photosynthetic activity. In this situation, it is appropriate to conclude that the phosphorus concentration is a significant contributor to the poor biological condition. If the biological data indicates impairment, but the minimum dissolved oxygen concentration is not violated or the diurnal fluctuation is not excessive, then the cause of the aquatic life use impairment would not be classified as phosphorus. This method was utilized to assess and develop 303(d) and 305(b) lists for the 2010 Integrated Water Quality Monitoring and Assessment Report. The Department evaluated 37 subwatersheds where sufficient data was available to apply the new method. None were delisted for phosphorus based on this method.

This method currently relies upon benthic macroinvertebrates as a measure of biological health and periphyton Chlorophyll *a* as a measure of nutrient effects. In the future, other biological indicators (such as diatoms) and nutrient response indicators (such as diurnal pH swings) may also be considered.

Criteria Development: As stated under "Lakes Criteria Development", the Department proposed amendments to the nutrient policies, and phosphorus criteria for freshwater streams and lakes in April 20, 2009. As part of the proposal, nutrient concerns in non-tidal streams would be addressed through utilization of an assessment method established in the 2010 Integrated Water Quality Monitoring and Assessment Methods (2010 Methods Document) explained above. This approach allows the Department to perform a case-specific examination of water conditions. The Department anticipates several rulemakings to revise and enhance nutrient policies, establish criteria for additional nutrient related parameters, and develop methods to implement the policies and criteria for wadeable streams as more data and research become available. In the meantime, the Department is evaluating whether diatom inference model can be used to refine TP criteria state-wide or for those waters located above the fall line.

Currently, the Delaware River Basin Commission is studying the development of nutrient criteria for the Delaware River above Trenton. Criteria may include narrative and numeric limits for total phosphorus, total nitrogen, water clarity, chlorophyll *a* and biocriteria consisting of selected algal (i.e., periphyton) and macroinvertebrate (i.e., benthic) metrics. The DRBC report entitled Nutrient Criteria Strategy for the Tidal and Non-Tidal Delaware River is available on the DRBC web site. The Department will develop a new methodology to assess the impact of nutrient over-enrichment on biological indicators in freshwater non-tidal rivers excluding the Delaware River above Trenton, but this is a very low priority since there are not many river miles in this category. The Department may also use response indicators such as DO, pH, and chlorophyll *a* to evaluate nutrient impairment in rivers through specialized studies such as Total Maximum Daily Loads (TMDLs).

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Coastal Waters – Estuaries and Ocean

New Jersey's coastal waters include 6,000 square miles of tidal waters and 260 square miles of estuaries, 127 linear miles of ocean coast, and 454 square miles of ocean coast (jurisdictional waters).

Estuaries

Data: The Department's Coastal Water Quality Monitoring Network provides basic measures of the ecological health of New Jersey's coastal waters, which include tidal river, estuarine, and ocean waters. Samples are collected four times per year (once each quarter) at approximately 270 locations. Parameters include dissolved oxygen, salinity, nitrogen, phosphorus, Secchi depth, temperature, Chlorophyll *a*, and suspended solids. The Department has also been working in cooperation with the New Jersey Forest Fire Service, Rutgers University, and USEPA Region 2 to implement aircraft remote sensing for estimating chlorophyll levels in New Jersey's coastal waters. Since chlorophyll is a plant pigment, high levels of chlorophyll in the water are typically associated with an algal bloom. The plane flies six days a week during the summer months, in favorable weather conditions, over the coastal waters of New Jersey. These flights provide a valuable perspective on water conditions and trends and enable the Department to target boat sampling to locations where algal blooms might be occurring. Results of remote sensing for algal blooms are available at NJDEP and Rutgers University Chlorophyll Remote Sensing website. In addition, phytoplankton samples are routinely collected at 16 sites in estuarine and ocean waters to measure Chlorophyll *a* concentrations and to determine the dominant species present, including toxic species. This information is available on the Department's Phytoplankton Monitoring Web site.

Data collection in estuarine waters includes the National Coastal Assessment (NCA), a federally funded program to assess the ecological condition of the nation's estuarine resources, which conducts annual summer sampling that collects water, sediment, and benthic invertebrate samples at 35 locations in New Jersey's coastal bays including the Delaware Bay. Samples are analyzed for water chemistry (e.g., nutrients, dissolved oxygen), sediment chemistry/toxics, sediment toxicity, and benthic diversity. NCA data is available on USEPA's NCA Map Server web site.

Cause/Response Indicators:

Currently, there are concerns regarding the use support within the Barnegat Bay Estuary derived in part from observed loss of sea grasses, episodic occurrences of macro algae and brown tides, the decline of hard clams, and the increasing number of invasive species such as sea nettles. The stressors and biological/chemical/physical processes responsible for these impairments including habitat alteration, loss of biological diversity, and loss of support of designated uses are not entirely known. Shoreline alteration, hydrologic modification, resource harvesting, boating, the effects of the Oyster Creek nuclear generating facility, and declining water quality are all suspected causes. With regard to water quality, available data indicate that there are areas within the bay where there are excursions from existing water quality standards including dissolved oxygen. Governor Chris Christie has made addressing the degradation of Barnegat Bay one of

his top environmental priorities. The input gained from extensive stakeholder involvement as well as scientific data and research conducted by the Department and other researchers provided the basis for the Governor's Action Plan for the Barnegat Bay. The Action Plan is available on the Department's Barnegat Bay web site and includes "Adopt More Rigorous Water Quality Standards" as one of ten priority actions.

Key to advancing this action item is a comprehensive monitoring and modeling initiative in conjunction with other on-going and planned research to help assess the current condition of the bay, link loading with water quality response, identify appropriate water quality concentration and/or loading targets and identify pollutant reductions needed to achieve the targets and restore the water quality of the bay. The Department along with USGS, USEPA Region 2, the Barnegat Bay Partnership, Monmouth University's Urban Coast Institute, the Pinelands Commission, Brick Township Municipal Utilities Authority, the MATES Academy at Ocean County Vocational Technical School, the Ocean County Health Department, and the Ocean County Utilities Authority launched the comprehensive ambient water quality monitoring program for this effort on June 6, 2011. This program will provide water quality data, including real-time diurnal DO pH, temp, salinity, turbidity and Chlorophyll-a data, along with discrete samples measuring a suite of other parameters in the tributaries and the bay. Water quality monitoring is taking place twice a month through October and once per month in November and December of 2011 at 13 locations on tributaries to the bay and 14 locations within the bay itself. In addition, stream flow is being monitored at the 13 tributary locations throughout the watershed and will also be measured within the bay and at key inlets. The monitoring initiative will continue through 2012 and will be refined/modified based on an evaluation of the results of the 2011 sampling. Bathymetry, hydrodynamic and water quality modeling, and sediment toxicity components of the program are expected to be initiated by the end of 2011. Visit the Barnegat Bay web site for more details.

In addition, the Department has been working with state universities, the U.S. Geological Survey, the U.S. Environmental Protection Agency, and the Barnegat Bay Partnership to develop and fund other research projects that will address filling in the data gaps, help address how we improve water quality and advance habitat restoration on the Bay, and establish baseline conditions of the Bay. Over the years, extensive research has been conducted on Barnegat Bay but the work has not been fully coordinated - resulting in some key gaps in the data. The first step in filling this gap was to do an inventory of existing research and assess the conclusions of the various studies. This process resulted in the development of an extensive bibliography that catalogues ecological and land use studies performed on Barnegat Bay. The second phase of the effort was to evaluate the data and determine what could be used to advance further action toward recovery of the Bay's decline. The research agenda that has emerged will help address how we improve water quality through nutrient bio-criteria development and advance habitat restoration on the Bay, and establish baseline conditions of the Bay.

There are ten research projects identified to meet these needs and are described at the following link (Barnegat Bay Comprehensive Research 2011-2012). The projects expected to provide information related to nutrient criteria development and are described below:

- **Benthic Invertebrate Community Monitoring and Indicator Development for the Barnegat Bay-Little Egg Harbor Estuary:** Benthic or bottom-dwelling invertebrate insects are currently used by NJDEP in freshwater streams to show aquatic life impairment. This project will investigate the same scientifically defensible approach for estuaries using bottom invertebrate species (e.g., clams, worms, crabs, etc.) specifically to assess nutrient impairment from nitrogen and phosphorus in the overlying waters. The Department is working with Rutgers, USEPA Region 2, USEPA Office of Research and Development, and NOAA to evaluate existing indicators and establish New Jersey-specific benthic indicators to assess aquatic life use in New Jersey's shallow coastal bays. Sampling began in Summer 2010. A technical assessment committee (TAC) meeting was held on February 8, 2011 at USEPA's Edison office to review progress to date: the 2011 summer sampling plan was reviewed and a contract extension to mid-2012 was requested.

- **Barnegat Bay Diatom Nutrient Inference Model:** NJDEP water quality monitoring of Barnegat Bay for nutrients (nitrogen and phosphorus) did not start until 1989. Salt marsh sediments hold signatures of past nutrient loads going back hundreds of years as well as the remains of microscopic plant algae that can act as indicators of past pollution. This information will be evaluated for the development of biologically-defensible nutrient criteria for New Jersey bays and related restoration goals.

- **Baseline Characterization of Phytoplankton and Harmful Algal Blooms:** In coastal bays, phytoplankton are microscopic plants that float in the water column or live on the bottom forming the base of a complex food web. Algal blooms are often directly linked to nutrient loading that can cause fish kills and/or a reduction in some important fishery resources. This study will investigate the complex interactions between nutrient loadings, phytoplankton responses, and toxic/harmful algal blooms.

- **Multi-Trophic Level Modeling of Barnegat Bay:** Historically, natural resource management within Barnegat Bay has occurred on a species (e.g., hard clam) or sector level (e.g., approved shellfish beds). Recently the principles of ecosystem-based management have given rise to more holistic management tools. The goal of this project is to develop dynamic models to help us understand how natural and human changes to Barnegat Bay have affected the structure and function of the bay's biota and to determine how those components are linked and to predict how components will respond to management actions (e.g., reduced nutrients, clam/fish population recovery).

- **Tidal Freshwater and Salt Marsh Wetland Studies of Changing Ecological Function and Adaptation Strategies:** Over 28% of Barnegat Bay's tidal marshes were lost to development between 1940 and 1970. However, recent studies show that wetlands in Barnegat Bay can adsorb and bury 80 % of the nitrogen entering it from upland sources buffering the waters from potential eutrophication effects (e.g., harmful algal blooms, anoxia, fish kills). Specifically, the study will enhance our understanding of the nitrogen uptake, burial and removal services provided by the coastal wetlands.

Other Barnegat Bay Research

- **Nutrient and Ecological Histories in Barnegat Bay, New Jersey:** In 2009, The Department received a grant from USEPA to collect sediment cores from the tidal region of Barnegat Bay and reconstruct water quality conditions based upon diatom community assemblages in the wetland sediment (See: Nutrient and Ecological Histories in Barnegat Bay, New Jersey). The primary objective of this project was to collect sediment cores from tidal regions of Barnegat Bay and determine the chronology of nutrient changes (i.e., nitrogen and phosphorus) and associated ecosystem level responses. Algal diatoms indicated major shifts toward more eutrophic conditions starting in the 1940-1950s consistent with an increase in sediment nutrients and appear to indicate impacts from increasing population and land use in the northern part of Barnegat Bay, an area with urban and suburban land use. The southern site is situated in a rural or semi-rural area and was the least impacted. Wetlands in Barnegat Bay can sequester approximately 79 % of the nitrogen and 54 % of the phosphorus estimated to be entering the Bay from upland sources. This illustrates the important ecosystem services that marshes can perform and how important it is to maintain and enhance marshes within Barnegat Bay. Overall, the shifts recorded by diatom species suggest that, despite the fact that the Barnegat Bay wetlands are protected by both federal and state laws, these sites remain impacted by anthropogenic disturbances with habitat deterioration and pollution increasing. Results from this study can be used to support developing nutrient load limit goals for the estuary.

Rutgers University received funding from the New England Interstate Water Pollution Control Commission (NEIWPCC) to conduct research that played an important role in the Department understanding of nutrients in coastal waters. This research has provided initial data and has identified additional studies needed which are now being funded and described above.

- **Assessment of Nutrient Loading and Eutrophication in Barnegat Bay-Little Egg Harbor:** Rutgers University has contracted with the NEIWPCC to conduct an interdisciplinary research project of Barnegat Bay-Little Egg Harbor that will integrate models of the coupled watershed-estuary system to estimate levels of nutrient loading and will employ a suite of key water quality, biotic, and habitat indicators for quantifying and characterizing estuarine responses and eutrophic conditions associated with these environmental stressors at local and estuary-wide scales. Nutrient loading to the bays will be quantified from water-quality data, atmospheric data, and loading models and related to biotic indicators of eutrophication for biotic-index development to define the estuarine ecosystem condition. Results will include thresholds of biotic and numerical loading criteria to support nutrient management planning. Recent sampling during the summer of 2011 included water quality and SAV data at 150 stations throughout the bay. Data collection and modeling work continues and is expected to integrate with DEP's modeling and other research projects.

- **Submerged Aquatic Vegetation (SAV):** An initial study by Rutgers University examined the demographics of *Zostera marina* in the Barnegat Bay Estuary over the 2008 study period

to determine its status and trends. A total of 120 sampling sites along 12 transects in four disjunct seagrass beds were sampled between June and November, 2008. The sampling included determining seagrass density, biomass, blade length, areal cover measurements of seagrass and macroalgae. Water quality parameters (temperature, salinity, dissolved oxygen, pH, and turbidity) were also measured at all sampling station including nitrate, ammonium, total dissolved nitrogen, phosphate, and silica concentrations. More than 1000 biotic and abiotic measurements were obtained during the study period. The final report, entitled: Rutgers University - Assessment of Eutrophication in the Barnegat Bay Little Egg Harbor System: Use of SAV Biotic Indicators of Estuarine Condition (Bilinski, J. J., Kennish, M. J., Haag, S. M., Sakowicz, G. P., 2010).

Criteria Development: Assessing the impact of nutrient over-enrichment in tidal waters is extremely complicated, as it requires an assessment methodology that distinguishes between the levels of nutrients and response indicators that would be present in a healthy, well-functioning wetland environment and the complex conditions associated with saline/freshwater ecosystems. The Department has identified estuarine nutrient criteria development as the priority for the state as our estuaries are critical to our economic vitality. Substantial resources are being committed toward developing numeric criteria or loading targets for nutrients and it is expected that the knowledge gained from the Barnegat Bay research will provide the necessary requirements needed to develop standards that will also serve as the template for further criteria development of other impacted estuarine waters.

In the NY/NJ Harbor Estuary, nutrient impacts to tidal waters will be addressed as part of the Harbor Estuary TMDL. The New Jersey Harbor Dischargers Group (NJHDG), a group of entities who discharge wastewater to the tidal tributaries of and directly to the New York/New Jersey Harbor Estuary, is monitoring in tidal waters of the Harbor Estuary, including long-term monitoring of ambient water quality data in the Hackensack River, New Jersey portion of the Hudson River, Passaic River, Rahway River, Elizabeth River, Raritan River, Newark Bay, Upper New York Harbor, Raritan Bay, and the Arthur Kill. This data will improve characterization of the general water quality and variability of receiving waters in the New Jersey portion of the New York/New Jersey Harbor Estuary and associated tributaries by supplementing prior studies of harbor water quality used to develop a water quality model for the harbor.

The Delaware River Basin Commission (DRBC) is developing nutrient criteria for the Delaware Estuary and Bay that will address tidal tributaries to the Delaware at and below Trenton. DRBC is generating chemical water quality data for the Delaware River tidal tributaries as part of this effort. Biological indicators need to be developed and integrated with this chemical water quality data to assess nutrient impairment of aquatic life uses in these tidal waters. The Department plans to work cooperatively with the other state and federal agencies to evaluate and develop nutrient criteria and/or management measures for these waters (see “Estuarine Waters”, below).

Ocean Waters

Data: Ocean waters are sampled as part of the Department's Coastal Water Monitoring Network described above. In addition, the USEPA collect grab samples via helicopter through the coastal monitoring program. Through this program, the Department has found benthic low DO conditions off the New Jersey Coast for most of its length during the quiescent periods of the summer and early fall. These low DO conditions are brought about by thermal stratification that establishes during this period. Storms and the onset of autumn bring about surface to bottom mixing resulting in a breakup of these low DO conditions until the onset of warmer temperatures in June. In order to better understand the ocean dynamics, the Department recently received USEPA funding to purchase a glider for continuous DO monitoring to learn more about the conditions along the coast as well as help develop a new benthic indicator for aquatic life use in near shore ocean waters. The glider captures continuous dissolved oxygen, salinity, and temperature transect measurements as it travels along the coast.

Cause/Response Indicators: The Department currently assesses aquatic life use attainment in ocean waters based on dissolved oxygen grab sample measurements since benthic indicators or other biological measures are not yet available for assessment purposes. Biological indicators need to be developed and integrated with chemical water quality monitoring data to assess aquatic life uses in coastal waters. In order to address this issue, the Department has been working cooperatively with other state and federal agencies to develop a biotic index for near shore ocean waters. Since 2007, this project has collected data on benthic communities in the ocean waters of New Jersey and is in the final process of developing an index

- **Biotic Index for Nearshore Ocean Waters:** The Department is working with Rutgers University, USEPA Region 2, USEPA Office of Research and Development, and NOAA to develop indicators of ecosystem health for the benthic communities in near shore ocean waters. A total of 100 stations were sampled in 2007 collecting benthic macroinvertebrate samples. In 2009, a workshop with national experts was convened to assess the 2007 data. The panel recommended that the Department add some impaired locations because all the 2007 data represented non-impaired conditions. Additional sampling was conducted at 53 stations in 2009, including nine samples near three selected ocean outfalls, and four from the six-mile and 12-mile dumpsites. In 2010, additional sampling was conducted at 100 stations. A total of 42 stations were located near the ocean outfalls. Three samples at different distances at each outfall were collected. In addition, 20 stations that were sampled in 2007 or 2009 were revisited. The remaining sites were new locations.

  The Department's contractor, Versar, completed the analysis of the samples collected in 2007 and 2009. The 2009 sample analysis took longer than expected because the abundance of individual specimens collected in each sample was significantly higher than in 2007. The samples from the six-mile and 12-mile dump sites contained species expected at healthy locations, suggesting that the capping has been effective. The 2007 and 2009 data has been provided to Rutgers University to evaluate index options. Staff are currently working to enter benthic counts into New Jersey's Water Quality Data Exchange (WQDE) System database.

A final index for nearshore ocean waters is expected to be provided to the Department by the end of 2011. Additional monitoring data from 2010 will be used to validate and modify the Nearshore Ocean Index.

Criteria Development: The development of the Nearshore Ocean Index along with the collection of water quality data such as continuous dissolved oxygen will facilitate our understanding of nutrient effects in marine waters. In addition, as the Department focuses on the Barnegat Bay research and modeling, it is anticipated that the knowledge gained about estuary physical, chemical, and biological processes that determine nutrient fate and transport will also support the criteria development for ocean waters.