Karen Cortes, Class of 2014, Brown University
24 April 2014

A Synthesis of Water Quality Monitoring Efforts in Narragansett Bay

ABSTRACT

Narragansett Bay, one of New England's largest estuaries, provides an array of benefits to people, including commercial and recreational fishing opportunities, tourism and recreation, and coastal protection. Clean waters contribute to these benefits, and thus it is not surprising that water quality is monitored by a number of government and nongovernmental organizations (NGOs).

Here I synthesize water quality information available for the Bay, highlighting how nitrogen loading to the Bay has changed with Phase I of the Combined Sewage Overflow (CSO) project. I also identify the spatial extent and resolution of available water quality data, including information on nutrients, pathogens, chemicals and marine debris.

This data synthesis lays the foundation for calculating the Clean Water score of the Ocean Health Index (OHI) for Narragansett Bay. This framework (after Halpern et al 2012, *Nature*) provides an integrated view of how ecosystem condition relates to the many benefits provided by this heavily valued and used coastal ecosystem. An integrated index like the OHI could also be used to raise public awareness about coastal ecosystem health and as a means of assessing progress towards coastal management and conservation goals.

I end with recommendations regarding how further data collection and integration efforts could more directly contribute to the coastal management and conservation of Narragansett Bay.

**For further information about this report, please contact Karen (Karen_Cortes@brown.edu) or her research mentor, Prof. Heather Leslie (Heather_Leslie@brown.edu)*

I. Linking Estuarine Ecosystem Services and Clean Water

The Ocean Health Index (OHI) is a conceptual framework to guide and assess multi-objective, ecosystem-based coastal management (Halpern et al. 2012). The OHI is composed of 10 goals that can be considered separately or aggregated into an overall score for a region or country and compared across these scales (Fig.1, p. 14). However, for this index to be applicable on a global scale it requires that the data sources be consistent. When we apply this framework on a regional scale, there are opportunities to use geographically specific data in place of these global sources. This can be seen in Table 1 (p. 10), which describes the elements of the Clean Water Score at the global and Bay scales.

Clean Water is a component of the OHI but it can also be viewed as a foundation for other OHI goals, and therefore a strong indicator of overall ocean health (Fig. 2, p. 14).

This component is determined by four metrics: nutrients, pathogens, chemicals, and marine debris. While there are other important dimensions of water quality—including the influences of algal bloom, oil spills, point source pollution, turbidity, and floating trash—they were not available at the global scale, and thus were excluded from the initial assessment (Halpern et al. 2012).

The interactions between Clean Water and other OHI goals are most clear for goals such as Tourism & Recreation and Food Provision (Fig. 2). Clean Water affects Food Provision by influencing the health and abundance of marine life and, inversely, Food Provision affects Clean Water through port use and seafood processing plants. Tourism & Recreation depends on Clean Water for aesthetic value and business (e.g., beach closures). Industrial use is a special case because it affects Clean Water without necessarily affecting its own use of it. For example, wastewater treatment facilities release effluent into receiving waters, but these facilities are not themselves affected by changes in water quality. The same principle applies for cooling uses at power plants, industrial port use and renewable energy development. However, the US EPA, through the Clean Water Act, regulates these latter interactions (Federal Water Pollution Control Act, Title III, amended 2002).

II. Institutional and Policy Context

Water quality efforts in Rhode Island are intensively focused on nutrient and pathogen pollution. The efficacy and impacts of wastewater treatment are evaluated in terms of nutrients; there are limits on the amount of nitrogen (in mg/L) permitted in the discharged effluent. Pathogens are a public health concern; and are used to set thresholds for beach closures and conditional shellfishing area closures (BEACH Act 2000, Title 20-8.1-4 RI General Laws 1956). In addition, nutrients and pathogens are two major classes of indicators for the effects of the CSO (Combined Sewage Overflow) Abatement Project and the Narragansett Bay Commission's Nitrogen Removal Upgrades at their two wastewater treatment facilities: Field's Point and Bucklin Point.

While wastewater treatment and water quality concerns have been of interest to Providence and Rhode Island residents for more than 10 years (Nixon et al 2008), recent concerns about nutrient loading to Narragansett Bay was highlighted in 1999 with Bay-wide surveys and fixed-site monitoring that determined that summer monthly low dissolved oxygen (DO) in the Upper Bay coincided with low mixing of the neap tide period (Oviatt 2008). Then, in 2003, the widely publicized Greenwich Bay Fish Kill accelerated RI DEM plans for decreasing nitrogen at RI wastewater treatment facilities. (Oviatt 2008). Mesocosm studies show that nitrogen is the limiting factor for primary production in the Bay (Oviatt 2008). Wastewater treatment facility discharges are the largest source of nutrients to the Providence and Seekonk Rivers, delivering approximately 70% of the total nitrogen to the Upper Bay either through discharges into the estuary or its tributary rivers (Watershed Counts 2012). High nutrient supply often increases frequency and severity of algal blooms which can result in chronic hypoxia, decline of seagrass beds, shifts in community composition, loss of biodiversity, and anoxic events that can cause fish kills (Heffner 2009). In 2004, RI state law established a goal of reducing total pollutant loading of nitrogen by 50% from 11 RI wastewater treatment facilities that discharge into the Upper Bay and its tributary rivers (Watershed Counts 2012).

The CSO Abatement Project has been linked with improvements in ocean health, including more shellfishing access and reduced beach closures since Phase I was completed in 2008. Among the benefits credited to this project are decrease in Upper Bay fecal coliform levels and decreased outflow events. As of 2011, the DEM mandated closure of Conditional Area A with >0.8 inches of rain (previously >0.5) and Area B with >1.5inches (previously >1.0) (Comeau 2011). This change is expected to keep Area A open 65 more days per year and Area B an additional 45 days. In terms of beach closures, there has been a 73% decrease in closure days between 2006 and 2010 and the DOH is investigating the possibility of opening three currently closed beaches in the Upper Bay under the Urban Beach Initiative program (Comeau 2011). While fecal coliform data is useful in assessing the change caused by the CSO Abatement project because it is present in sewage, nutrients are also released during runoff events and would also be useful in assessing change.

As of the end of 2011, nitrogen pollutant loadings from NBC facilities were reduced by 34% since 2003 and the NBC aims to further reduce its nitrogen discharges by over 70% by 2014 compared to 2003 levels (Watershed Counts 2012). The Narragansett Bay Commission (NBC) has played a leading role in these efforts, as this utility is responsible for wastewater treatment of communities in the metropolitan Providence and Blackstone Valley areas. The NBC maintains (Uva 2013):

- 2 on-line fixed-site monitoring positions for DO, pH, chlorophyll, nitrate, etc (Phillipsdale Landing in the Seekonk River and Bullock's Reach Buoy in the Providence River)
- 19 river pathogen monitoring stations in CSO affected rivers as part of a RIPDES CSO Controls program (sampled twice weekly)
- 20 sites in the Upper Bay monitored for pathogens,
- 6 sites in the Upper Bay monitored for nutrients
- State Border nutrients monitoring
- Storm overflow events sampled annually for the CSO Abatement Project
- Periodically sample shellfishing areas with RI DEM
- Surface water mapping in the Summer to identify and track algal blooms, with plan to coordinate with NERRS, and
- Benthic species (plankton) monitoring.

Despite the recent investment from state organizations, universities and federal organizations have been interested in the Bay for much longer. In 1995, the National Estuarine Research Reserve System (NERRS) began to monitor sites year-round at Prudence Island as part of the national protocol established for all reserves in the NOAA NERRS program and they began monitoring inorganic nutrients in 2002. In 2003, URI GSO began monitoring nutrients in the West Passage as an effort to continue previous work from 1959-1996 on phytoplankton populations and nutrients.

III. What water quality data are available for Narragansett Bay?

With the support of the Voss Environmental Fellowship at Brown University in summer 2013, I created maps that illustrate the spatial extent of water quality data available for the Bay and highlighted the varied institutions involved in collecting these data (Figs. 3-4, pp. 15-16). I analyzed a subset of the data related to nutrient loading in order to illustrate a widely described (but rarely mapped) trend: nitrogen loading (NO_3+NO_2) has declined following the completion of Phase I of the Combined Sewage Overflow (CSO) Abatement project. During my research, I identified information about nutrients, pathogens, toxics and marine debris in coastal waters that would be needed to calculate the Clean Water score of the Index.

These data sources and the resulting maps are detailed in this section.

a) Nutrient Monitoring

The Narragansett Bay Commission (NBC) and the Narragansett Bay National Estuarine Research Reserve System (NBNERRS) are the two primary institutions monitoring water quality parameters in Narragansett Bay (Tables 2-3).

The NBC, as a public utility mandated to monitor the influence of its wastewater treatment on water resources, monitors stations above Conimicut Point in the Providence and Seekonk rivers (Fig. 5a). However, the NBC also monitors nutrients at riparian stations north of the Narragansett Bay proper, along both Rhode Island and Massachusetts' rivers and streams. NERRS monitors nutrients in coastal waters at three stations around Prudence Island: Potters Cove, Nags Creek, and T-Wharf.

Both of these institutions test for different forms of nitrogen (Table 2) but the NBC is the only one that tests for levels of total N (nitrogen).

Time series analyses indicate that nitrogen levels in the Bay haven't varied much between the mid-20th century and 2004, prior to nitrogen reductions enabled by the wastewater treatment updates. Spatially, total nitrogen declines exponentially down Bay with dilution and distance. It has been estimated that south of Conimicut Point a 50% decrease in total nitrogen may result in an average decrease of 50% in primary production, chlorophyll, plankton, and benthic animals (Oviatt 2008). In terms of weather, wet years tend to be characterized by low annual salinities and high nutrient levels while dry years with higher salinities resulted in low nutrient concentrations. Seasonal cycles of nutrient concentrations experience a peak in the fall (Oct-Dec) and near depletion in the spring and summer (April-Sept). The last two trends create a pattern that is consistent with the large input of nutrients during periods of heavy precipitation in the fall and the development of high phytoplankton abundances in winder and early spring that subsequently deplete nutrients through the spring and summer (Heffner 2009).

In order to evaluate the impact of the first phase of the CSO project on water quality, I synthesized nutrient data from 2005 and 2010, before and after Phase I of the CSO Project went online, and included all available nutrient sampling stations using "nitrate+nitrite" measurements. I plotted two months for each year, August and October, to capture seasonal variation. The data show that the Bay has a strong North-South nutrient gradient that decreases as the Bay meets the open ocean. However, the range of nutrient concentration decreases between the two years, which suggests that the CSO Abatement project is indeed contributing to improved water quality, as measured by this one variable (Fig. 6).

b) Pathogens

The two pathogens that are monitored in the Bay are fecal coliform and *Enterococcus* spp. These pathogens are correlated with the presence of human waste in water, which can result from sewage runoff events.

The NBC monitors bimonthly, year round, for *Enterococcus* and fecal coliform in the rivers of the Upper Bay and the Upper Bay itself. Sampling is also carried out at all beaches and conditional shellfishing areas by the Rhode Island Department of Health (RI DOH). The Beach Monitoring Program occurs from Memorial Day to Labor Day with standards set by the Rhode Island Department of Environmental Management (RI DEM) and the EPA. Water samples are analyzed for *Enterococcus* numbers which, for saltwater, cannot exceed the single sample standard of 104 cfu/100mL (cfu = colony forming units). The conditional shellfishing areas, managed by RI DEM, sample monthly, year round, for fecal coliform. The NBC periodically samples these areas in cooperation with the RI DEM.

c) Chemicals /Toxics

Chemical data for the Bay is scarce. The NBC monitors heavy metals in its effluent at its two wastewater treatment facilities in the Upper Bay: Field's Point and Bucklin Point. Sediment analysis of heavy metals is also available through the URI GSO with locations throughout the entirety of the Bay. They offer data for organic contaminants from 1997-1998 and trace metal concentrations from 1985-2003.

d) Marine Debris

Monitoring of marine debris is available through the environmental organization Save the Bay from its Beach Cleanups, which are conducted throughout the bay and throughout the year.

e) Other water quality monitoring efforts in Narragansett Bay

In addition to the efforts described above, the RI DEM has a Fixed Site Monitoring Program (NBFSMN) that tracks the spatial and temporal distribution of hypoxia from May to October. This program monitors dissolved oxygen (DO), chlorophyll, pH, and salinity and is conducted in collaboration with the NBC, NERR, URI GSO, and Roger Williams University.

The Insomniacs—a partnership between the RI DEM, Narragansett Bay Estuary Program (NBEP), and Brown University since 1999—conducts DO surveys at about 75 stations throughout the Bay.

III. What do the available data tell us about water quality in the Bay?

By focusing my analysis of water quality around a management action, the CSO Abatement project, I was able to identify temporal and spatial changes in nutrient levels (nitrate + nitrite)(Fig. 6, p. 17). My analysis illustrates how current water quality monitoring efforts can be harnessed to inform management actions and progress.

While data collection should be standardized across the Bay, environmental decisions often require place-based finer-scale knowledge of human uses and environmental variation (Leslie and McLeod 2007). The distinct social and ecological contexts in different regions of the Bay suggest that it might be productive to treat the bay as a series of finer geographic areas (Fig. 4, p. 16).

When all sampling stations in Narragansett Bay are mapped (excluding the Insomniac boat surveys which only test for DO), it is clear that sampling effort is quite uneven (Fig. 3, p. 15). Measurements of pathogens, chemicals, and nutrient loading primarily come from the Upper Bay while the East Passage, Sakonnet River, and Mount Hope Bay are little sampled (Fig. 5a-b). If we are to effectively manage the whole system, there is a need to standardize data collection and effort.

IV. How could the available data be better leveraged to support coastal management?

1. <u>Increasing spatial and temporal extent of sampling with a more comprehensive set of variables would enable more integrated ecosystem-based management of Narragansett Bay.</u> For example, while DO monitoring is a good way to track nutrient management and emergency responses for hypoxic events, this variable is highly coupled with environmental factors (e.g. temperature, tides, etc.) in addition to anthropogenic loadings. Furthermore, the institutions involved in sampling have different priorities as to why they are involved in water quality monitoring. This manifests in the frequency of their sampling and the parameters tested which, when trying to generate a comprehensive mapping of Bay health, results in having to exclude some data for the sake of consistency. For water quality monitoring efforts to be widely applicable, a protocol must be developed so that frequency, variables tested, and procedure is standardized.

2. <u>A more comprehensive map of Narragansett Bay would aid scientific collaboration and ecosystem-based management (Fig. 4)</u>. Ideally, it would include the Narragansett Bay watershed, rivers, beaches, fishery areas, and the locations of facilities with permits to discharge or utilize Bay waters. This is something that could be done in conjunction with RI GIS, building on this report and Desbonnet & Costa-Pierce (2008). In addition, port use of the Bay would need to be integrated in terms of oil spills and traffic volume. Inclusion of water quality monitoring data also would be beneficial (Fig. 3, 5a-5b).

3. <u>Application of the Ocean Health framework is possible and could advance management and public education.</u> A Clean Water score for the Upper Bay (NBC Service Area) would make it possible to assess in more detail how the CSO

Abatement Project has affected the Bay ecosystem and the benefits it produces to people since it went online in 2008. However, a Clean Water score depends on more than just the four components discussed in this report. Pressures and resilience are also part of the OHI formula and finding regional measurements for these will be a challenge. Consideration of climate change impacts will also be important. Applying the OHI would provide a systematic means of assessing water quality changes and possible changes in the associated ecosystem services.

Literature Cited

Codiga, D., Stoffel, H., Deacutis, C., Kiernan, S. and Oviatt, C. 2009. Narragansett Bay hypoxic event characteristics based on fixed-site monitoring network time series: intermittency, geographic distribution, spatial synchronicity, and interannual variability. Estuaries and Coasts: 621-241.

Comeau, C. 2011. Evaluating the Narragansett Bay Commission CSO Abatement Project. NBC, Providence. pp. 1-35. pdf

Halpern et al. 2012. An index to assess the health and benefits of the global ocean. Nature 488: 615-620.

Heffner, L. 2009. Nutrients in Mid-Narragansett Bay: A Spatial Comparison of Recent and Historical Data. Technical Reports Series 2009:1. NBNERR, Providence. pp.1-49.

Leslie, H. M. and K. L. McLeod. 2007. Confronting the challenges of implementing marine ecosystem-based management. Frontiers in Ecology and the Environment 5: 540-548.

Millennium Ecosystem Assessment. 2003. Ecosystems And Human Well-Being: A Framework For Assessment, Island Press, Washington, DC.

Narragansett Bay Commission. 2008. The Narragansett Bay Commission CSO Abatement Project. NBC,Providence.pp. 1-13.

Narragansett Bay Commission. "Programs & Projects" http://www.narrabay.com/en/ProgramsAndProjects.aspx (accessed 2013)

Narragansett Bay Commission. "Snapshot of Upper Narragansett Bay: Monitoring Initiatives". http://snapshot.narrabay.com/app/MonitoringInitiatives (accessed 2013)

NarrBay. "RI Marine Data Download". http://www.narrbay.org/chemical_data.htm (accessed 2013)

Narragansett Bay Estuary Program. "NBEP:Bay Science". http://www.nbep.org/bay-science-intro.html (accessed 2013)

Nixon et al. 2008. Nitrogen and Phosphorus Inputs to Narragansett Bay: Past, Present, and Future. 101-175 *in* A. Desbonnet and B.A. Costa-Pierce, editors. Science for Ecosystem-Based Management : Narragansett Bay In The 21st Century. Springer, NY, NY, USA.

Oviatt, C.A. 2008. Impact Of Nutrients On Narragansett Bay Productivity: A Gradient

Approach. 523-543 *in* A. Desbonnet and B.A. Costa-Pierce, editors. Science for Ecosystem-Based Management : Narragansett Bay In The 21st Century. Springer, NY, NY, USA.

RI BRWCT. 2008. Rhode Island Bays, Rivers, And Watersheds System Level Plan, 2009- 2013, BRWCT Strategic Planning Work Group, Providence, RI

RI GIS. "The RIGIS Geospatial Data Catalog". http://www.edc.uri.edu/rigis/data/ (accessed 2013)

State of Rhode Island Department of Health. "Beach Monitoring Program". http://www.health.ri.gov/programs/beachmonitoring/index.php. (accessed 2013)

State of Rhode Island Department of Environmental Management. "Bay Assessment & Response Team-Bart". http://www.dem.ri.gov/bart/stations.htm (accessed 2013)

US EPA. 2008. Health of Narragansett Bay for Human Use. In: National Condition Report. 2013. 3rd ed. EPA, Providence, pp. 250-266.

Uva, T. No date. Narragansett Bay Commission Monitoring Initiatives. NBC, Providence. pp. 1-11. http://snapshot.narrabay.com/app/LearnMore/PowerPoint (accessed 2013)

Table 1: Data required at global and bay scales to calculate the OHI Clean Water Score

	Pathogens	**Nutrients**	**Chemicals**	**Marine Debris**
Halpern et al. 2012 Clean Water (CW) score components	Number of people without access to improved sanitation facilities	Modeled input of land-based nitrogen	Land-based organic pollution Land-based inorganic pollution	Ocean Conservancy Coastal beach cleanup data (weight trash collected per year divided by length of coastline cleaned)
Adapting the CW score to Narragansett Bay	Fecal Coliform data 2004-2012 NBC *Enterococci* data 2008-2012 NBC RI DOH (beaches)	Nutrient Testing 2005-2012 NBC 2002-2012 NERRS Water Quality 2007-2012 NBC 1995-2013 NERRS	Effluent heavy metals data 2003-2012 NBC Pretreatment Program 2 wastewater treatment facilities Sediment Data (NarrBay.org)	Save The Bay shoreline cleanup (lbs trash collected) 2008-2012

Table 2: Water Quality Data Available for Narragansett Bay

Water Quality Component	Institution	Variables measured (units)	No. Stations	Location	Sample	Years	Data Source *All accessed June-August 2013*
Nutrient	NBC	Nitrite, Ammonia, (NH3), Orthophosphate, Silicate, Total dissolved nitrogen, (NO_3 +NO_2) (ppb)	6	Upper Bay	Bimonthly	2005-2013	NBC Nutrient Monitoring http://snapshot.narrabay.com/app/MonitoringInitiatives/NutrientMonitoring
	NERRS	Nitrite, Ammonium, Orthophosphate, Nitrate, Dissolved Inorganic Nitrogen, (NO_3+NO_2), Silicate (mg/L)	3	Prudence Island	Monthly	2002-2012	NERRS Centralized Data Management Office http://cdmo.baruch.sc.edu/get/export.cfm
	URI GSO (Dock) 8	SiO_4, NO_3, NO_2, NH_4, PO_4	1	West Passage	Weekly	1976-2012	URI GSO MERL Datasets http://www.gso.uri.edu/merl/data.htm
Pathogen	NBC	Fecal coliform (MPN/100ml)	20	Upper Bay	Bimonthly	2004-2012	NBC Pathogen Monitoring http://snapshot.narrabay.com/app/MonitoringInitiatives/PathogenMonitoring
	NBC	Enterococci (MPN/100ml)	5	Upper Bay	Bimonthly	2006-2012	NBC Pathogen Monitoring http://snapshot.narrabay.com/app/MonitoringInitiatives/PathogenMonitoring

	RI DOH Beach Monitoring Program (2011 Report, pg 70)	Enterococci (CFU/100ml)	69 (licensed saltwater beaches)	NB	Annual Geomean	2000-2012	Parris A. and Toracinta, L., 2012. Rhode Island Department of Health Beach Program: 2011 Season Report. RI DOH, Providence. pp. 61. http://www.health.ri.gov/publications/annualreports/2011BeachProgram.pdf
Chemicals	NBC	Cadmium Chromium Hex. Chromium Copper Kead Mercury Nickel Silver Zinc Cyanide (ppb)	2	Upper Bay WWTF	Annual average	2003-2012	NBC. Pretreatment Program: Annual Report. NBC, Providence. http://www.narrabay.com/en/ProgramsAndProjects/PretreatmentProgram/Annual%20Report.aspx
Trash	Save The Bay	Pounds collected	-----	Bay	Throughout the year	2008-2012	Personal correspondence with (June 2013): July Lewis, volunteer manager jlewis@savebay.org Save The Bay 100 Save The Bay Dr. Providence, RI 02905
Environmental Variables	NBC	Depth Temperature Salinity Dissolved Oxygen Density PAR	5	Upper Bay	Bimonthly	2007-2013	NBC Water Quality Profiles http://snapshot.narrabay.com/app/MonitoringInitiatives/Profiles
	NERRS	Depth Temperature Conductivity Salinity	3	Prudence Island	Bimonthly	1995-2013	NERRS Centralized Data Management Office http://cdmo.baruch.sc.edu/get/export.cfm

		Dissolved Oxygen pH Turbidity Chlorophyll					
	RI DEM BART GSO Stations	Dissolved Oxygen Chlorophyll Conductivity	10	Bay	Seasonal	2003-2011	RI DEM Bay Assessment & Response Team Fixed-Site Monitoring Stations Network Data http://www.dem.ri.gov/bart/netdata.htm

Figure 1. The Ocean Health Index

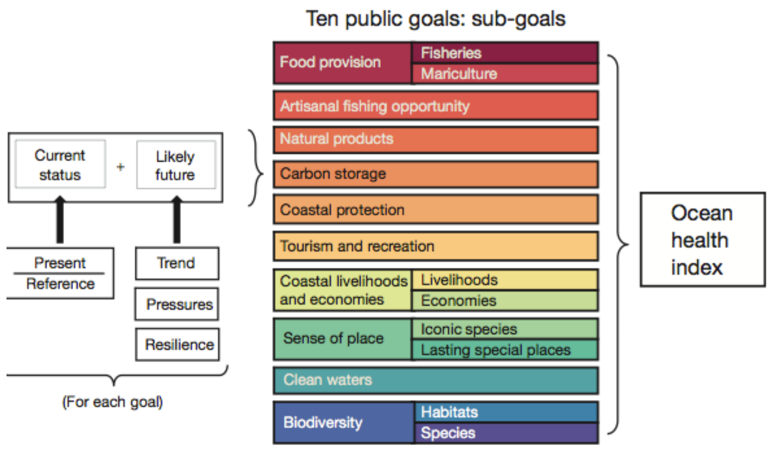

Figure 2. Clean water activities and services.

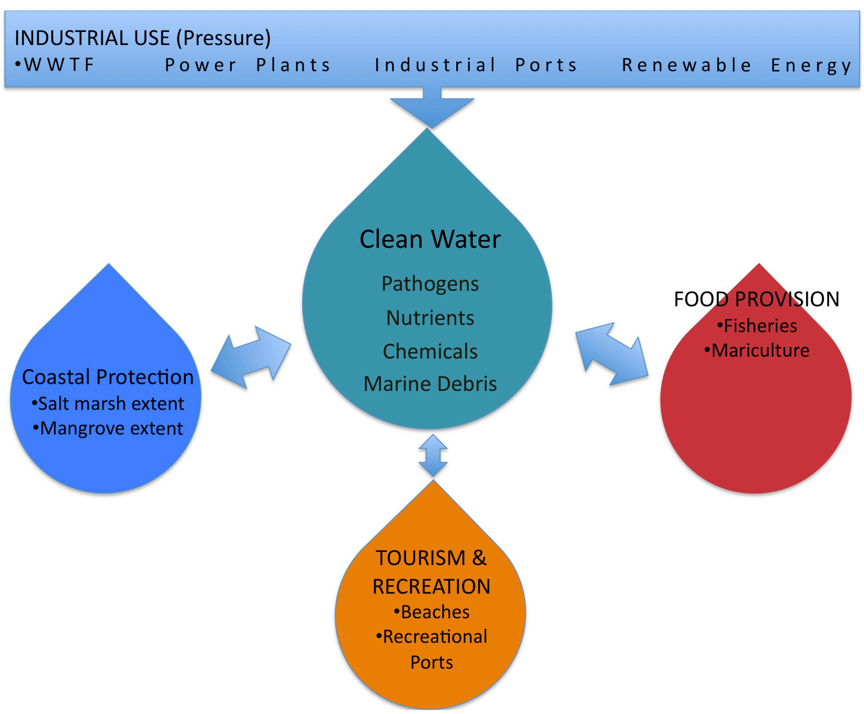

Figure 3. Water quality monitoring entities in Narragansett Bay

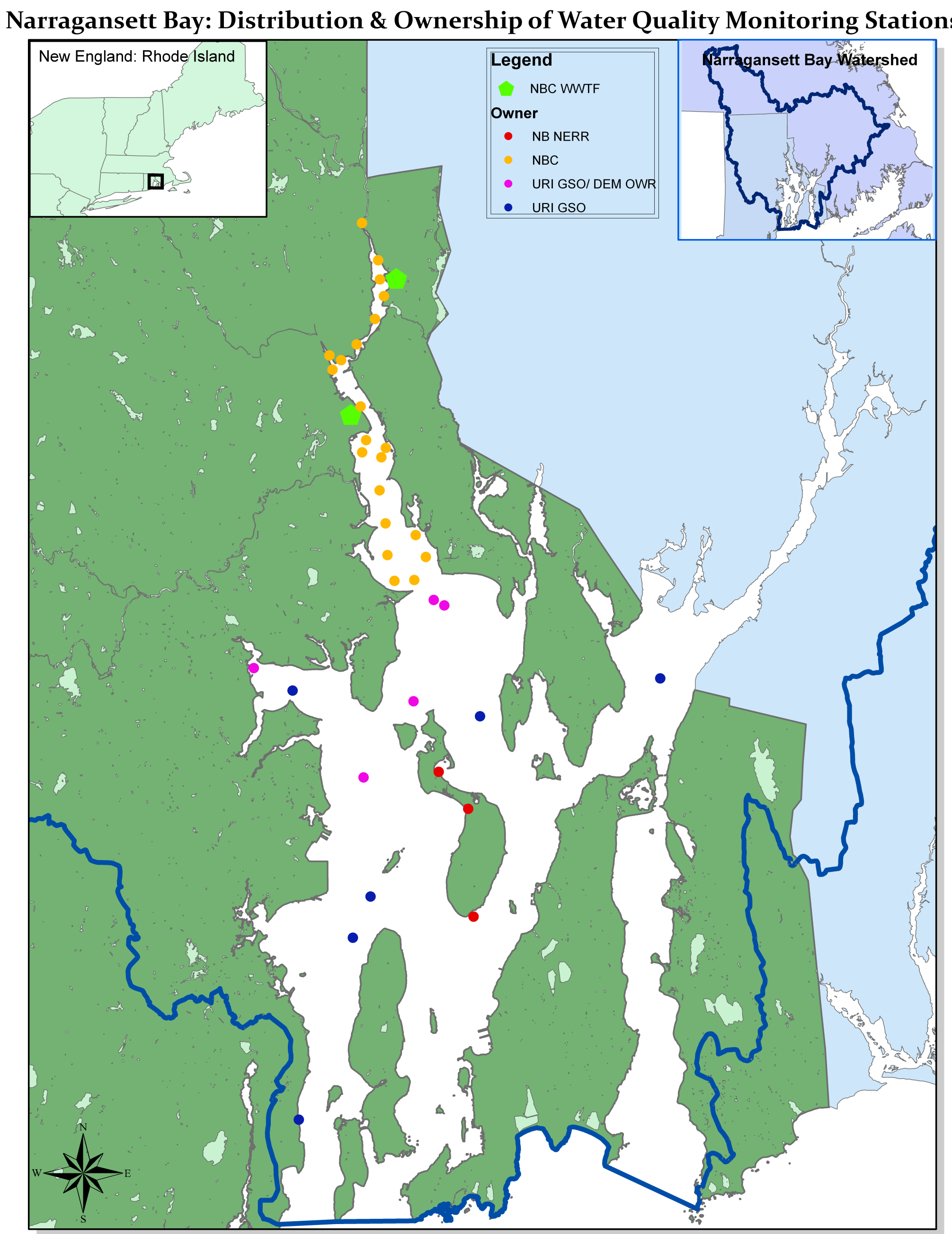

Figure 4. Sub regions of Narragansett Bay, based on the environmental and social context

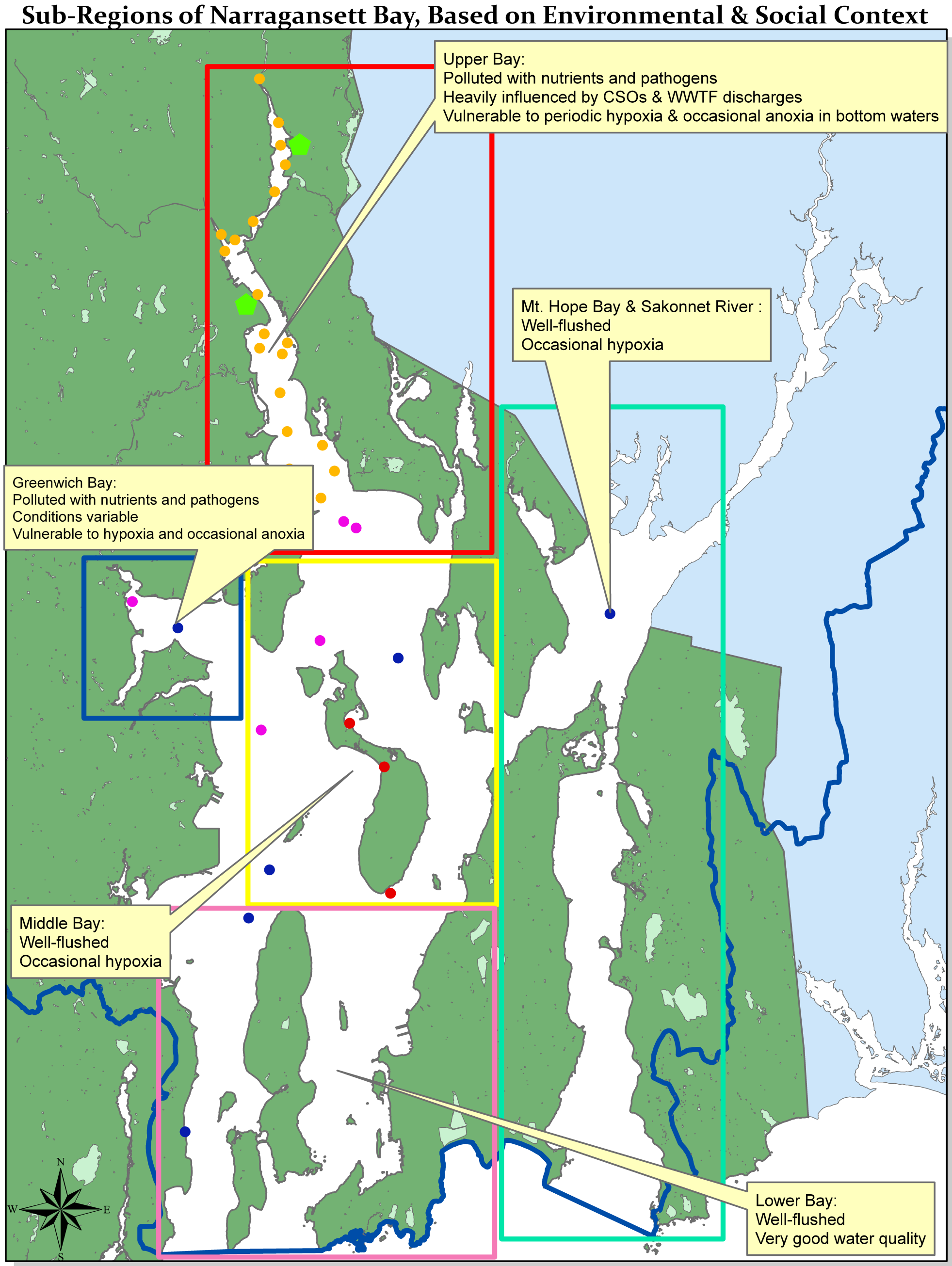

Figure 5a. The Upper Bay, Narragansett Bay Sub-Region

Station ownership legend can be seen in Figure 2

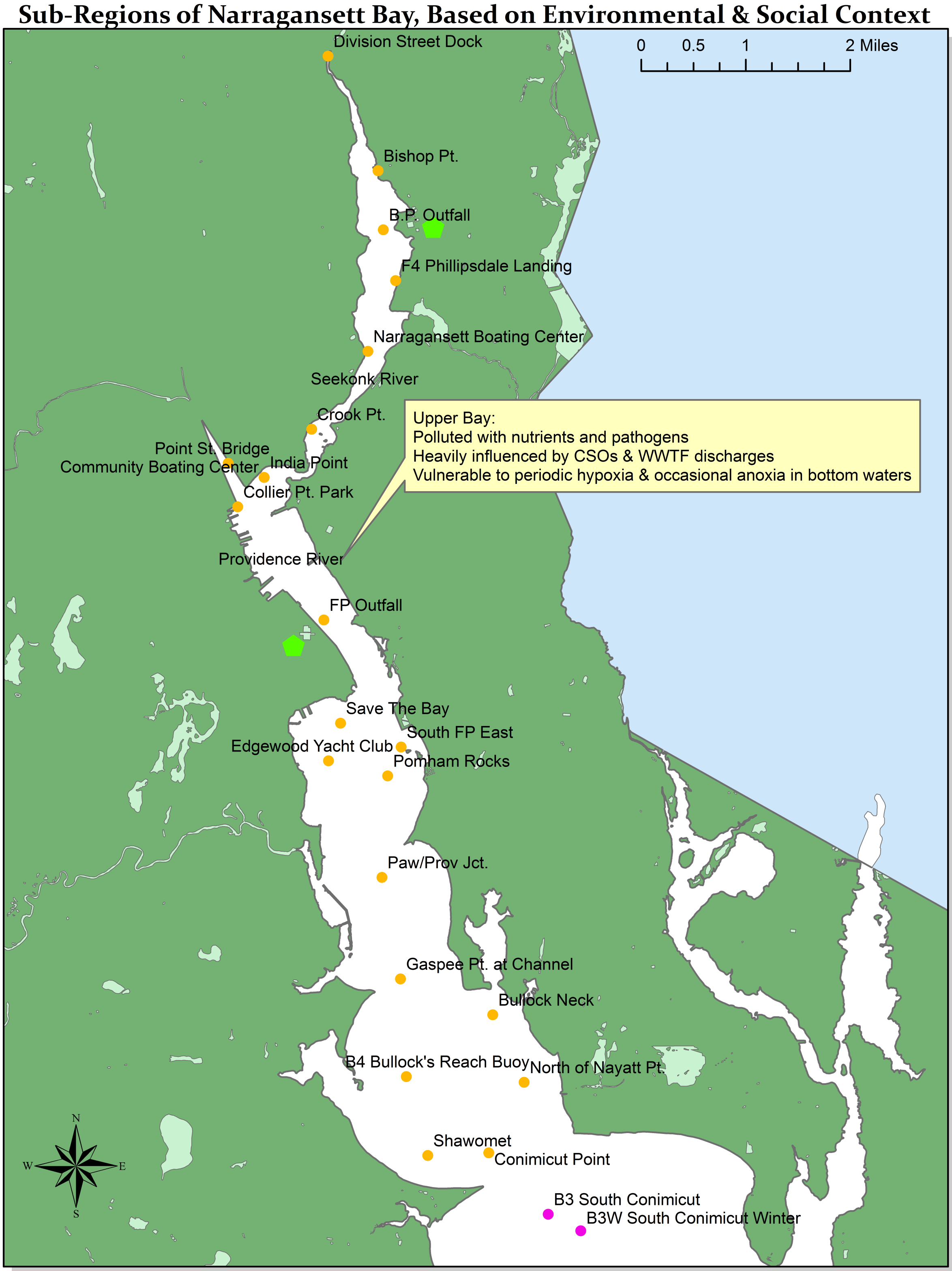

Figure 5b: The Lower Bay, Compilation of Narragansett Bay Sub-Regions

Station ownership legend can be seen in Figure 2

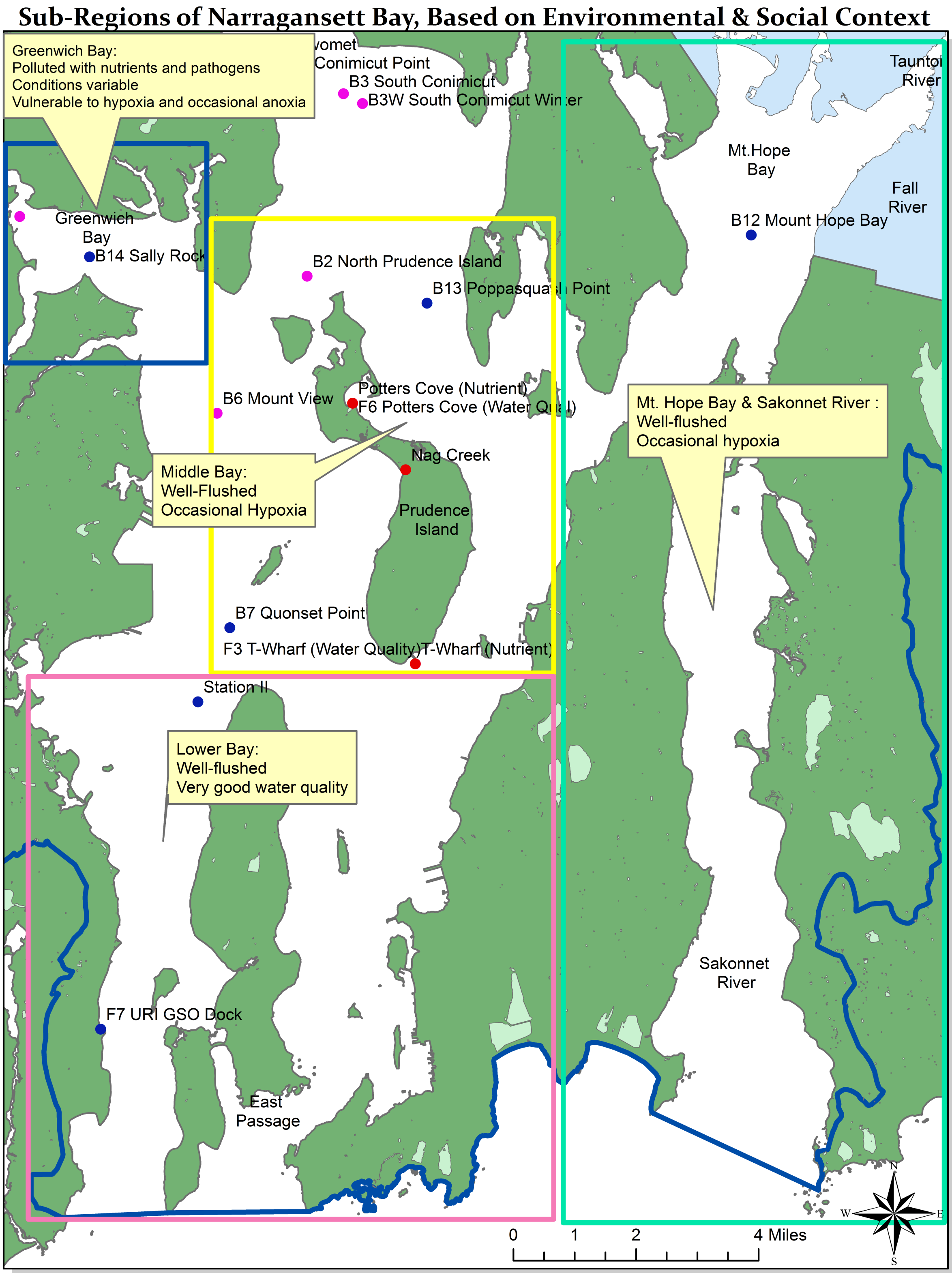

Figure 6: Nutrient Comparison Before and After the CSO Abatement Project
**Project went online in 2008*