Water Quality Monitoring Program for the Popponesset Bay and Waquoit Bay Estuaries

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BACKGROUND AND OVERVIEW:

The Mashpee Water Quality Monitoring Program is an on-going collaborative effort between the Mashpee Wampanoag Tribe, the Town of Mashpee and the Coastal Systems Program (CSP) within the University of Massachusetts – Dartmouth, School of Marine Science and Technology (SMAST). The project has a two-fold goal: 1) sustain a continuing assessment of the nutrient related water quality of the Waquoit Bay and Popponesset Bay Estuaries relative to regulatory standards (TMDL's) and 2) monitor improvements in water quality resulting from restoration efforts (e.g. oyster propagation, dredging, N removals by freshwater systems, wastewater treatment, etc.) as undertaken by the Town, Tribe and others. This is accomplished through the collection and analysis of water samples and associated field parameters relevant to assessing the health of estuarine habitats within the Waquoit Bay and Popponesset Bay Systems, Cape Cod, MA. (Figure 1). These data form the basis for: 1) gauging the short and long-term trends in water quality, 2) validating the Massachusetts Estuaries Project threshold modeling approach for Waquoit Bay + Popponesset Bay and 3) determining compliance with USEPA and MassDEP nitrogen targets set under the Clean Water Act by TMDL analysis that has been previously formalized for all of Mashpee's estuarine waters.

In order to develop a sustainable long-term program, a consortium was created whereby sample collection is by volunteers from each consortium partner and by public participants, with equipment and analytical costs distributed between the Mashpee Wampanoag Tribe and the Town of Mashpee. The Mashpee Water Quality Consortium was developed under a Memorandum of Understanding (2009) between the Mashpee Wampanoag Tribe, the Town of Mashpee and the Coastal Systems Program (CSP-SMAST). The Consortium is managed through the Mashpee Waterways Commission. It is an important part of the ongoing efforts to develop nitrogen management plans for the restoration of these systems and to determine the level of "success" through the consistent collection of key habitat quality metrics throughout each system in the most cost-effective manner possible. This program is the only method for providing a cross comparable baseline for gauging long-term changes in water quality, as the Towns of Mashpee, Falmouth and Barnstable implement their developing nitrogen management plans for the restoration of the Waquoit Bay and Popponesset Bay systems.

Nutrient related water quality decline continues to represent one of the most serious threats to the ecological health of nearshore coastal waters. Coastal embayments, because of their enclosed basins, shallow waters and large shoreline area, are generally the first indicators of nutrient loading from terrestrial sources. Although each embayment system maintains a capacity to assimilate watershed nitrogen inputs without degradation, as loading increases, a point is reached at which the assimilative capacity is exceeded and nutrient related water quality degradation occurs. Continuing increases in nitrogen inputs beyond this threshold level result in further declines in habitat quality. Because nearshore coastal salt ponds and embayments are the primary recipients of nutrients carried via surface and groundwater transport from terrestrial sources, it is clear that activities within the watershed, often miles from the water body itself, can have chronic and long lasting impacts on these fragile coastal environments.

Figure 1. Regional locus map depicting Waquoit Bay and Popponesset Bay and their source waters of Nantucket and Vineyard Sound.

Both the Waquoit Bay and Popponesset Bay Estuarine Systems are highly nitrogen enriched and show impaired nutrient related water quality over the past decade (Overview of the 2010 Water Quality Monitoring Program for the Popponesset Bay and Waquoit Bay Estuaries, June 2011). The tidal rivers (Mashpee River, Childs River, Quashnet River) and major tributary basins (Eel Pond/River, Shoestring Bay and Ockway Bay) showed poor water quality while the main basins and Jehu and Hamblin Ponds showed moderate to high water quality. The present Technical Memorandum is an update to the water quality baseline to include the results of each summer's sampling program, 2010-2014.

Protection and restoration of coastal embayments from nitrogen overloading has resulted in a focus on determining the assimilative capacity of these aquatic systems for nitrogen. While this effort is ongoing (e.g. USEPA TMDL studies), southeastern Massachusetts has been the site of intensive efforts in this area (Eichner et al., 1998, Costa et al., 1992 , Ramsey et al., 1995, Howes and Taylor, 1990, Falmouth Coastal Overlay Bylaw). These efforts resulted in the 2002 implementation of the Massachusetts Estuaries Project (MEP). The goal of the MEP has been to

determine the nitrogen thresholds for each of the estuaries in southeastern Massachusetts to support TMDL development by the USEPA and MassDEP and to set estuary specific targets for nitrogen management plans aimed at restoring/protecting these systems. MEP assessments and threshold development has been completed for both Popponesset Bay and Waquoit Bay, including the eastern embayments of Waquoit Bay.[1]

MEP analyses indicated that almost all of the estuarine reaches within the Popponesset Bay and Waquoit Bay Systems are near or beyond their ability to assimilate additional nutrients without impacting their ecological health. Nitrogen levels are elevated throughout both systems and as watershed development continues, estuarine conditions are projected to decline further until nitrogen management is implemented.

The result is that nitrogen management of these estuaries is aimed at restoration, not protection or maintenance of existing conditions. Nitrogen management within Popponesset Bay has already begun with the consistent annual maintenance of the flow through the tidal inlet, propagation of oysters within the system and capping of the Town of Mashpee landfill. In addition, watershed nitrogen management planning is nearly completed (CWMP) with the goal of reducing the major sources of nitrogen (primarily septic system discharges), conducting "in estuary" N removal by shellfish, and possibly enhancing nitrogen removed during transport from the sources to the estuary by pond and stream restoration.[2]

SITE DESCRIPTION

Popponesset Bay

The Popponesset Bay Estuarine System is located within the Towns of Mashpee and Barnstable, on Cape Cod Massachusetts. The Bay's watershed is distributed among the Towns of Mashpee and Barnstable, with a small portion of the upper-most region of the watershed located in the Town of Sandwich. The Popponesset Bay Estuarine System exchanges tidal water with Nantucket Sound through a single maintained inlet at the tip of Popponesset Spit. The Popponesset Bay estuarine system has been partitioned into five tributary sub-embayments: 1) Popponesset Bay (main basin + Popponesset Creek), 2) Pinquickset Cove, 3) Ockway Bay, 4) Mashpee River (lower or tidal region) and 5) Shoestring Bay (Figure 2). Within the Popponesset Bay System, the tidal portion of the Mashpee River functions as a Cape Cod tidal river, with extensive bordering salt marsh, tidal flats and large salinity fluctuations. In contrast, Popponesset Bay, Shoestring Bay and Ockway Bay are typical embayments, dominated by open water areas, having only fringing salt marshes, relatively stable salinity gradients and large basin volumes relative to the tidal prism (i.e. the volume of water entering on a flooding tide). Although Shoestring Bay, Ockway Bay, Mashpee River and Pinquickset Cove and the main basin of Popponesset Bay have different hydrologic characteristics, tidal forcing for all of these

[1] Massachusetts Estuaries Project Nutrient Threshold Reports can be accessed via the Web at http://www.oceanscience.net/estuaries. This site is maintained by the SMAST MEP Technical Team (SMAST, Applied Coastal, CCC) for the public.

[2] 2014. Town of Mashpee Sewer Commission, Draft Recommended Plan / Draft Environmental Impact Report. Comprehensive Watershed Nitrogen Management Plan. GHD Inc. under contract to Sewer Commission. The Draft EIR/Draft Recommended Plan received EEA approval certificate in September 2014 allowing the Town of Mashpee to proceed with preparation of its FEIR.

Figure. 2 Popponesset Bay System component basins. Tidal waters enter the Bay through the single inlet from Nantucket Sound. Freshwaters enter from the watershed primarily through 3 surface water discharges (Mashpee River, Santuit River, Quaker Run) and direct groundwater discharge.

component systems is generated from Nantucket Sound. Nantucket Sound, exhibits a moderate to low tide range, with a mean range of about 2.5 ft. Since the water elevation difference between Nantucket Sound and Popponesset Bay is the primary driving force for tidal exchange (flushing), the local tide range naturally limits the volume of nutrient enriched water flushed from the system during each tidal cycle. It should be noted that the Popponesset Bay System is more sensitive to water quality declines from nitrogen enrichment than estuaries bordering Cape Cod Bay or the outer Cape, where the tide range is much higher (tide range off Stage Harbor Chatham is ~4.5 ft, Wellfleet Harbor is ~10 ft).

In addition to the offshore tide range, tidal damping (reduction in tidal amplitude) within the embayment itself from a constricted tidal inlet or internal channels can further reduce tidal flushing. Fortunately, within the Popponesset Bay System, only minimal tidal damping has been observed. Tidal damping further magnifies the effects of watershed nitrogen inputs. It appears that the tidal inlet is operating efficiently, possibly due the Town of Mashpee's active inlet maintenance program. Given the present hydrodynamic characteristics of the Popponesset Bay System, it appears that estuarine habitat quality is primarily dependent on the level of nitrogen loading to bay waters rather than tidal characteristics within the component sub-embayments.

Nitrogen loading to the Popponesset Bay System has been assessed by the Massachusetts Estuaries Project and partitioned relative to five (5) component basins: Pinquickset Cove, Ockway Bay, Mashpee River (lower or tidal region), Shoestring Bay, and Popponesset Bay. The watershed for this estuarine system contains approximately 13,000 acres dominated by single-family residences. Commercial and residential land-uses primarily in the southern portion of Mashpee and in the Barnstable region create a large nutrient load to the Popponesset Bay System. The nitrogen loading from the more heavily populated areas of the Town of Mashpee is focused on the northern reaches of the estuarine system. System wide, approximately three quarters of the nitrogen load from single-family dwellings enters the Shoestring Bay and Mashpee River basins before entering the main basin of Popponesset Bay.

As management alternatives are being developed and evaluated, it is important to note that Popponesset Bay is a relatively dynamic system. Popponesset Spit is continually expanding and eroding, once nearly reaching the inlet channel to the Three Bays System to the north. The spit frequently experiences periodic over wash (Aubrey and Gaines 1982). The present inlet position is relatively new, resulting from a breach of the spit in the hurricane of 1954. Similarly, within the main Bay, several islands apparent 50 -100 years ago have been incorporated into other landforms with unquantifiable effects on the circulation of Bay waters. Thatch Island and Little Thatch Island within the lower main Bay have “joined” with the spit, most likely due to a combination of the natural processes of overwash of the barrier beach and shoreline retreat. Daniels Island, at the entrance to Ockway Bay, has been joined to the mainland by filled causeways, apparently filling salt marshes and changing the local circulation pattern. Hydrodynamics have also been altered within Popponesset Creek due to dredging and channelization of wetlands. Within the watershed there have been changes to the freshwater systems which attenuate nitrogen during transport to bay waters. Most notable of the changes has been the modification to riparian zones either through channelization, restriction, or filling of freshwater wetlands and, in some cases, transformation of portions of the watershed to cranberry agriculture. Most of the alterations have reduced the nutrient buffering capacity of these systems, thus magnifying the nitrogen loading to the bay. However, the predominant watershed alteration

has been the shifting of fields and pine-oak forest to residential and commercial development, with its resultant increasing nitrogen input to the watershed, aquifer and ultimately bay waters. This recent shift in land-use has likely resulted in this estuary receiving its highest rates of nitrogen loading than at any period over the past 400 years. Previous large shifts in land-use, primarily from forest to agriculture did not have the same resultant enhancement in nitrogen loading. Historically, agriculture practice generally recycled nitrogen (as opposed to modern practice of using commercial fertilizers) and the population was <10% of today. The present year-round population per square mile is greater than the entire town population of 50 years ago (total population based on 2000 census for the Towns of Mashpee, Sandwich, and Barnstable are 12,946, 20,136 and 47,821 respectively). It appears that the nitrogen attenuation capacity of the freshwater systems has been reduced, as the need to intercept the nitrogen loading to the watershed has increased. While this may be a partial cause of the present estuarine decline, it may also represent a potential opportunity for restoration of bay systems.

Waquoit Bay

The Waquoit Bay embayment system is located within the Towns of Falmouth and Mashpee, Massachusetts on Cape Cod. The Bay's watershed is distributed among the Towns of Falmouth and Mashpee, with a small portion of the upper-most region of the watershed located in Sandwich. The southern shore is a barrier beach that separates the Waquoit Bay System from adjacent Nantucket Sound (Figure 3). Waquoit Bay is composed of a main bay with multiple associated sub-embayments (Quashnet River, Hamblin Pond, Jehu Pond, Eel River/Pond, Childs River). These sub-embayments constitute important components of the region's natural and cultural resources. In addition, the large number of sub-embayments greatly increases the shoreline of the system and decreases the travel time of groundwater from the watershed recharge areas to bay regions of discharge. The main bay has two main openings to Nantucket Sound, a historically open inlet in the main bay and an ephemeral inlet that connects Eel Pond to Nantucket Sound. More recently, Hurricane Bob in 1991 created a third inlet immediately east of the Eel Pond entrance; however, this inlet has closed over the past few years. The inlet to the main bay has been fixed with jetties initially in 1918 (east) and 1937 (west), with subsequent lengthening and enhancements. This second inlet has been generally open over the past 50 years. The opening of the second inlet significantly increased the tidal range and flows within the Waquoit Bay System and caused important ecological shifts to its tidal wetlands and possibly other estuarine habitats (Orson and Howes, 1992). Overall, these important "natural and unnatural" hydrodynamic shifts, coupled to anthropogenic alteration of the watershed, supports a recently highly altered estuarine habitat.

The Waquoit Bay system is located within the Mashpee Pitted Outwash Plain that supports numerous kettle ponds (Oldale 1992). The Quashnet River Estuary is a drowned river valley estuary resulting from rising sea-level flooding the lower reaches of the Quashnet River. Hamblin and Jehu Pond appear to be drowned kettle ponds currently exchanging tidal flows with Waquoit Bay through tidal rivers, Little River and Great River respectively. Both the Hamblin Pond and Jehu Pond subsystems support significant saltwater wetland resources. The tidal reach of the Quashnet River Estuary is located within the Town of Falmouth while much of the freshwater region of the Quashnet River and its watershed is found in the Town of Mashpee. The river is one of the two major surface water inflows to the Waquoit Bay System and originates in John's Pond. Hamblin Pond is divided between the Towns of Falmouth and Mashpee, while Jehu

Figure 3. Waquoit Bay and its component sub-embayments. Tidal waters from Nantucket Sound enter the main Bay through a single inlet in the barrier beach and an unarmored inlet to the Eel Pond sub-embayment. Freshwaters enter the estuary primarily through two major surface water discharges (Childs River to Eel Pond and Quashnet River to the main basin), several smaller streams (e.g. Red Brook), and direct groundwater discharge.

Pond is entirely situated within the Town of Mashpee. Within the Quashnet River, Hamblin Pond, and Jehu Pond sub-embayments geomorphic and hydrologic alterations include the damming of the Quashnet (Moonakis) River to drive mills and alteration of riparian zone for cranberry agriculture, as well as the creation of roadways altering circulation around Monomascoy Island. However, the over-riding change affecting these sub-systems appears to

have been the shift from pine/oak forest to farming to current residential land-uses, with its associated large increases in watershed nitrogen loading to the estuarine system. Most of the main basin of Waquoit Bay, as well as Eel Pond and Childs River lie within the Town of Falmouth. Their shorelines are highly developed, particularly in the area of Seacoast Shores. As a result of nitrogen entering from its watershed, Childs River is among the more highly impaired estuarine habitats within the region.

The nature of enclosed embayments in populous regions brings two opposing elements together: as protected marine shorelines they are popular regions for boating, recreation, and land development; as enclosed bodies of water, they may not be readily flushed of the pollutants that they receive due to the proximity and density of development near and along their shores. In particular, the Waquoit Bay system and its sub-embayments along the Falmouth and Mashpee shores are eutrophying from high nitrogen loads in the groundwater and runoff from their watersheds. Much of the Waquoit Bay System is currently beyond its nitrogen loading threshold and is currently showing various levels of nitrogen related habitat impairment.

The eastern Waquoit Bay basins, Quashnet River, Hamblin Pond/Little River, Jehu Pond/Great River, and Sage Lot Pond, show clear estuarine characteristics, with extensive salt marsh area, tidal flats and large salinity fluctuations. In contrast, the open water portions of Waquoit Bay and Eel Pond show more typical characteristics of open water areas, having only fringing salt marshes, relatively stable salinity gradients and a large basin volume relative to tidal prism. The tidal forcing for these subsystems, as for Popponesset Bay, is generated from Nantucket Sound. Nantucket Sound adjacent the inlets in South Cape Beach and the southern shore of Washburn Island, exhibits a moderate to low tide range, with a mean range of about 2.5 ft. Since the water elevation difference between Nantucket Sound and Waquoit Bay is the primary driving force for tidal exchange, the local tide range naturally limits the volume of water (and its entrained nutrients) flushed into and out of the Bay System during a tidal cycle. Similar to Popponesset Bay, its relatively small tide range makes Waquoit Bay proportionally more sensitive to nitrogen related water quality impairments then estuaries on Cape Cod Bay and on the outer Cape where the tide range is typically 10 ft to 4.5 ft, respectively.

Fortunately, there is minimal tidal damping through the Waquoit Bay inlet. It appears that the tidal inlet is operating efficiently, possibly due to the active inlet maintenance program and the dual inlet configuration of the overall system. Similarly, within the eastern Waquoit Bay System, the tide generally propagates through the three focal sub-embayments with little attenuation, consistent with relatively unrestricted tidal exchanges. Given the present hydrodynamic characteristics of the Waquoit Bay System, it appears that estuarine habitat quality is primarily dependent on nitrogen loading to bay waters rather than tidal characteristics within the component sub-embayments. Due to the relatively well flushed conditions observed in these three sub-embayment systems, habitat degradation is mostly a result of the high nutrient loads currently being documented in these systems, not tidal damping.

The watershed for this estuarine system contains approximately 10,250 acres, the predominant land use based on area being public service/government, including the Massachusetts Military Reservation and protected open space along the Quashnet River. Public service occupies 54% of the total watershed area to eastern Waquoit Bay. In contrast, while single-family residences occupy approximately 15% of the total watershed area to eastern Waquoit Bay, this land use

class represents 61% of all the parcels**.** Commercial properties are fairly limited within the watershed, with two small clusters located on Route 28 and Route 151. Relative to the Waquoit Bay System, residential land-uses create the major nutrient load.

ESTUARINE MONITORING PROGRAM

The Mashpee Water Quality Monitoring Program was established to collect baseline nutrient related water quality data and to track restoration and management "success" in Popponesset Bay and Waquoit Bay relative to the established MassDEP/USEPA TMDL[3] for Popponesset Bay and Waquoit Bay, inclusive of its eastern sub-embayments. The program was first established to support the current Massachusetts Estuaries Program (MEP) analysis for all of Mashpee's estuarine waters, with completion of this phase in summer 2011. The Town of Mashpee Estuarine Water Quality Monitoring Project focuses on the 2 estuaries within the Town, which provide significant recreational, fisheries and aesthetic resources to the Town's citizenry:

- Popponesset Bay
    - Mashpee River
    - Shoestring Bay
    - Ockway Bay
    - Main Bay
    - Pinquisset Cove
    - Santuit River
    - Off Shore Station

- Waquoit Bay
    - Hamblin Pond
    - Jehu Pond
    - Main Bay
    - Childs River
    - Eel Pond
    - Quashnet River
    - Red Brook
    - Great River

As stated above, the concept underlying the establishment of the Monitoring Program by the Mashpee Wampanoag Tribe and the Town of Mashpee was to establish a long-term water quality monitoring effort for Popponesset Bay and Waquoit Bay relative to the TMDL process, and compliance monitoring associated with the TMDL (Clean Water Act). The present monitoring effort is significantly reduced over prior sampling efforts for these estuaries, as the prior high frequency sampling was required to support the MEP analysis, while the present effort is to track long-term changes due to the implementation of management alternatives for restoration of these nitrogen impaired bays. By establishing a stable, low frequency monitoring program and by using trained volunteers, costs of compliance monitoring to the Town have been significantly

[3] TMDL or Total Maximum Daily Load is the regulatory requirement for restoration of an aquatic system under the Clean Water Act as proscribed by MassDEP and USEPA.

lowered making the program sustainable over the long-term. The reduced program builds upon the more intensive efforts conducted previously.

The Mashpee Waterways Commission (Steve Pinard 2009-2013; Don McDonald 2014) has been responsible for overall Phase 2 program organization with assistance from Rick York (Shellfish), including the recruiting of volunteers. The Mashpee Wampanoag Tribe Natural Resources Staff (Chuckie Green) have been full partners in this effort and participated in each of the sampling events. The structure of the program relies on volunteers, with each estuary having a "Bay Captain" who oversees the sampling teams for each sampling event and ensures proper sample transfers and submittal of chain of custody forms. The technical aspects of the project are under the direction of Dr. Brian L. Howes, Director of the Coastal Systems Program at SMAST-UMD and Sara Sampieri Horvet, the Coastal Systems Analytical Facility Manager (ssampieri@umassd.edu). Volunteers came from each of the 3 Towns bordering the 2 estuaries: Falmouth, Mashpee and Barnstable. All field team members are volunteers, regardless of their other affiliations, as all members are dedicated to the restoration and protection of Mashpee's valuable estuarine resources.

Volunteer sampling teams were supplied with the necessary sampling equipment to conduct field measurements of physical parameters as well as to collect water samples for subsequent nutrient analysis by the SMAST Analytical Facility. The physical parameters included: total depth, Secchi depth (light penetration), temperature, pond state, weather, wind speed and direction, and oxygen content. Laboratory analyses include: nitrate + nitrite, ammonium, dissolved organic nitrogen, particulate organic nitrogen, total dissolved nitrogen, chlorophyll a pigments and orthophosphate (Table 1). All analytical methodologies have been previously approved for use by EPA, Mass. CZM, NOAA and NSF and the Massachusetts Estuaries Project.

Table 1. Summary of estuarine sampling and parameters analyzed.

Location	Dissolved Nutrients	Particulate Nutrients	Chlorophyll /Pheophytin	Field Parameters
Waquoit Bay				
All CR, ER and WB	X	X	X	X
Popponesset Bay				
All PB and SR	X	X	X	X

As was the case with the prior effort, the 2014 Mashpee Water Quality Monitoring Program was very successful from the organizational aspect (and % sample recovery) and showed once again that properly implemented volunteer sampling efforts can provide high quality data for tracking the status of water quality in both Waquoit and Popponesset Bay Systems as well as support compliance with the USEPA/MassDEP TMDLS for these systems, in the most cost effective manner. In addition, under the new program structure, it should be possible to track short-term changes in nutrient related water quality with greater certainty than in previous years.

Each volunteer water sampling team was trained/re-trained and outfitted with sampling equipment for collection of water samples at assigned sampling stations. Staff from the Coastal

Systems Laboratory within SMAST conducted the training sessions and took part in the field sampling, both to assist the effort, as part of QA/QC procedures and to insure proper transport and delivery of samples to the Coastal Systems Analytical Facility[4].

As in previous years, sampling focused on the warmer summer period when nutrient related water quality conditions are the poorest. Sampling of both bays was completed on the same days in 2014: July 17, July 30, August 14 and 28. Samples were collected at each station at mid water depth on an ebbing tide for nutrients and surface, mid and bottom for physical parameters including temperature, salinity and dissolved oxygen (depending on the station depth).

The Water Quality Monitoring Program occupied the same sampling sites as sampled in previous years to allow a direct comparison of changes in nutrient related water quality within each of the different basins of each bay. The major change in the 2010-2014 program from the prior effort that was implemented to support the MEP analysis is the reduction in the overall sampling effort (number of dates/year) while providing the same spatial coverage. This approach allows for incorporation of all historical data, provides the necessary spatial distribution required for management analysis, while providing a continuing solid assessment of the current nutrient related water quality within the Town's estuaries. Monitoring locations for water quality sample collection were established in order to generate a well distributed network of sampling stations that would yield data at a high enough density with sufficient spatial distribution to ultimately resolve estuarine gradients (Station Maps, Figure 4, 5). Stations were confirmed by GPS prior to sampling.

The monitoring approaches and parameters assayed are fully consistent with the Quality Assurance Project Plan (QAPP)[5] of the Massachusetts Estuaries Project. Samples and field data were collected at 16 locations within the Popponesset Bay system (inclusive of offshore boundary station) and 19 locations within the Waquoit Bay system.

Stations are of 3 types: (1) embayment stations (2) offshore-boundary condition station and freshwater inflow stations. A total of 37 water samples for nutrients (includes 2 QA samples) were collected in 2013 and 2014 field seasons per each combined (both systems) sampling event: 20 in the Waquoit Bay system and 17 in the Popponesset Bay system. The offshore station is used as one gauge of the boundary conditions in nearshore Nantucket Sound (Table 2 and 3).

[4] The Coastal Systems Analytical Facility is sited within the School for Marine Science and Technology, UMASS-Dartmouth at 706 S. Rodney French Blvd, New Bedford, MA. 02744 (Sara Sampieri, 508-910-6325; ssampieri@umassd.edu). The laboratory supports a full range of environmental assays, with detection limits suited for natural waters. The laboratory data is accepted for both research and regulatory (USEPA, MassDEP, MCZM, NOAA) projects.

[5] Quality Assurance Project Plan is reviewed and must be accepted by MassDEP and USEPA for the information generated by a study to be seamlessly incorporated into regulatory planning or proof of compliance studies under the Clean Water Act. All of the approaches, protocols and analytical methods are part of the MEP's QAPP as well as other QAPP's for water quality monitoring in s.e. Massachusetts.

Table 2. Summary of sampling sites and schedule for the Popponesset Bay and Waquoit Bay systems, summer 2013; * Samples include one QA sample

Waquoit Bay Sub-Systems and Sampling Stations

Date	Waquoit Bay WB12, 13	Childs River CR01, 02, 03	EelRiver ER01, 02, 03	Quashnet River WB06, 07, 08, 09	Hamblin Pond WB04, 10	Jehu Pond WB01	Great River WB02, 03	Red Brook WB05	Seapit River WB11	Total
July 11	3*	3	3	4	2	1	2	1	1	20
July 25	3*	3	3	4	2	1	2	1	1	20
Aug 12	3*	3	3	4	2	1	2	1	1	20
Aug 26	3*	3	3	4	2	1	2	1	1	20
Total	12	12	12	16	8	4	8	4	4	80

Popponesset Bay Sub-Systems and Sampling Stations

Date	Mashpee River PB01, 02, 03, 04	Shoestring Bay PB05,0 6, 07	Ockway Bay PB09, 10	Popp Bay PB08, 11, 12, 13	Off Shore PB 14	Pinquickset Cove PB15	Santuit River SR05	Total
July 11	4	3	2	5*	1	1	1	17
July 25	4	3	2	5*	1	1	1	17
Aug 12	4	3	2	5*	1	1	1	17
Aug 26	4	3	2	5*	1	1	1	17
Total	16	12	8	20	4	4	4	68

Table 3. Summary of sampling sites and schedule for the Popponesset Bay and Waquoit Bay systems, summer 2014

Waquoit Bay Sub-Systems and Sampling Stations

Date	Waquoit Bay WB12, 13	Childs River CR01, 02, 03	EelRiver ER01, 02, 03	Quashnet River WB06, 07, 08, 09	Hamblin Pond WB04, 10	Jehu Pond WB01	Great River WB02, 03	Red Brook WB05	Seapit River WB11	Total
July 17	3*	3	3	4	2	1	2	1	1	20
July 30	3*	3	3	4	2	1	2	1	1	20
Aug 14	3*	3	3	4	2	1	2	1	1	20
Aug 28	3*	3	3	4	2	1	2	1	1	20
Total	12	12	12	16	8	4	8	4	4	80

Popponesset Bay Sub-Systems and Sampling Stations

Date	Mashpee River PB01, 02, 03, 04	Shoestring Bay PB05,0 6, 07	Ockway Bay PB09, 10	Popp Bay PB08, 11, 12, 13	Off Shore PB 14	Pinquickset Cove PB15	Santuit River SR05	Total
July 17	4	3	2	5*	1	1	1	17
July 30	4	3	2	5*	1	1	1	17
Aug 14	4	3	2	5*	1	1	1	17
Aug 28	4	3	2	5*	1	1	1	17
Total	16	12	8	20	4	4	4	68

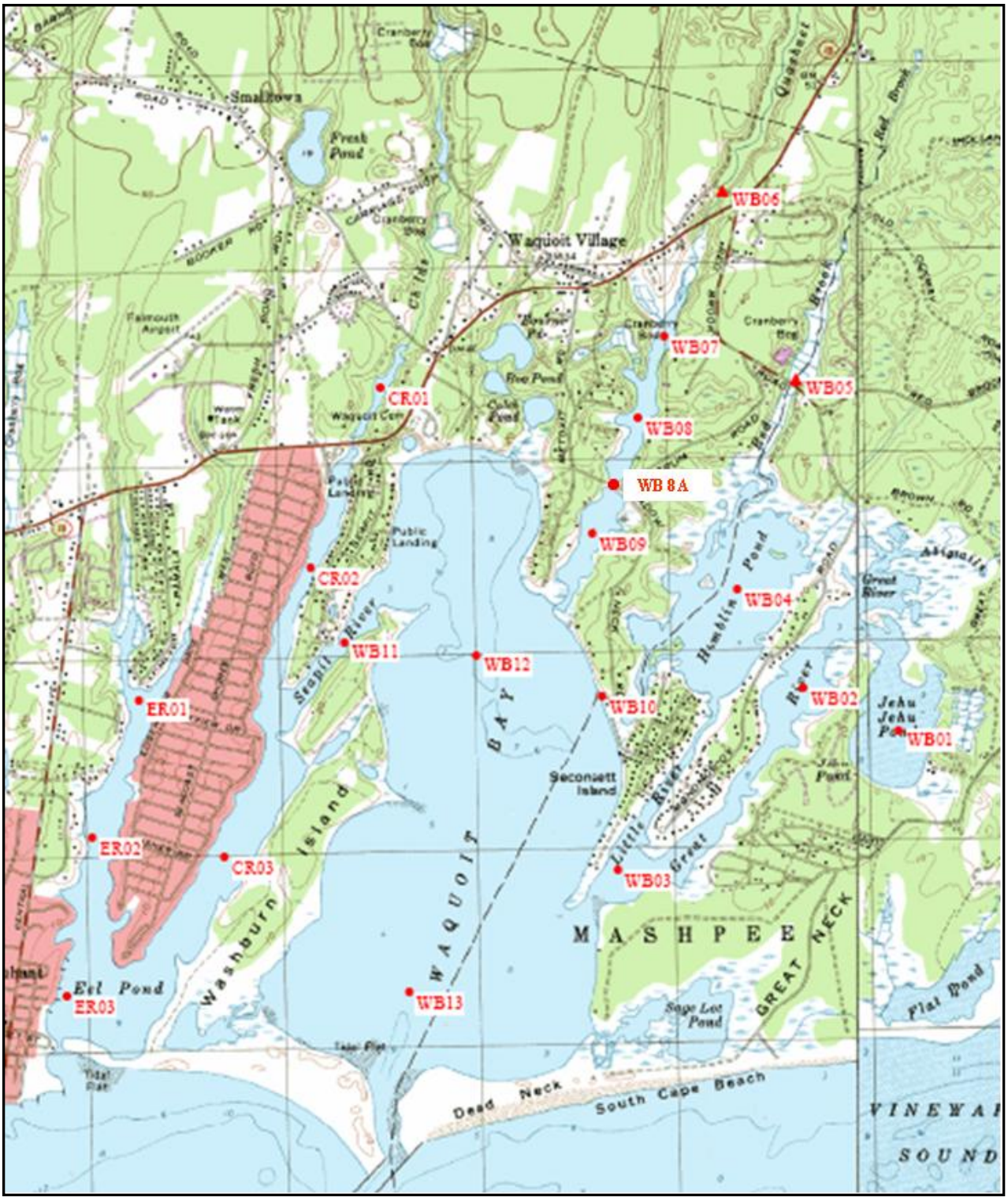

Figure 4. Water quality sampling stations associated with the Waquoit Bay System (2001-2014). Samples were collected synoptically between 5:30 - 8:30 AM on ebbing tides.

Figure 5. Water quality sampling stations associated with the Popponesset Bay System (1997-2014). Samples were collected synoptically between 5:30 - 8:30 AM on ebbing tides.

MONITORING RESULTS

In regard to the Popponesset Bay and Waquoit Bay Systems, nutrient related water quality decline continues to represent the primary environmental problem facing the citizens of Mashpee, Falmouth, Barnstable and Sandwich. Nitrogen management planning and implementation are underway and the Mashpee Water Quality Monitoring Program is tracking short and long term changes resulting from continued watershed nitrogen loading increases, variation in tidal flushing and implementation of nitrogen management alternatives (including propagation of oysters). As implementation is still in its initial stages, it is not surprising that the results of the 2010-2014 Mashpee Water Quality Monitoring Program still indicate that both Popponesset Bay and Waquoit Bay continue to show poor nutrient related water quality throughout most of their tidal reaches. However, with the collection of multi-year high quality data, it appears that the more impaired areas of Popponesset Bay and Waquoit Bay are showing some improved water quality, while the higher quality areas appear to be stable (see below). Unfortunately both estuaries still support impaired habitats and remain below the water quality levels set by the MassDEP/EPA TMDL.

The salinity gradients within each estuary in 2010-2014 are consistent with historical levels (Figures 6 and 10). The gradients show the concentration of freshwater discharges at the headwaters of the upper tributary basins. For example, the Childs River and Quashnet River estuarine reaches in Waquoit Bay and the Mashpee River in Popponesset Bay are functionally tidal rivers with drowned river valley morphology and significant stream discharge to the headwaters. As a result the saline waters entering on the flooding tide from the adjacent main basin is significantly diluted, the upper reaches showing salinities generally $\leq$10 ppt (Figures 6 and 10). These freshwater inflows are rich in nitrogen from terrestrial sources and provide much of the high potential for eutrophication in the more estuarine areas downstream. It should be noted that the Quashnet River above the bridge was relatively fresh in both 2013 and 2014 summers (~5 ppt), lower than previously measured, suggesting a potential restriction to tidal exchange which should be further investigated. Brackish salinities within this upper basin have been observed in past years, but recent years suggest a freshening. If this basin further freshens, phosphorus management may need to be evaluated (Figure 18).

In contrast to these riverine habitats, the larger more open basins within both Waquoit and Popponesset Bay Systems generally show only small salinity gradients. This pattern results from their larger volumes, proportionally lower freshwater inflow rates and closer proximity to the lower nitrogen, higher salinity waters of Nantucket Sound, especially the lower main basins of Popponesset Bay, Waquoit Bay and Eel Pond. The generally high salinities (~25 ppt) of these major basins is typical of these types of estuaries throughout southeastern Massachusetts where major rivers are generally absent and tidal volumes are large relative to freshwater discharges.

Monitoring results from summers 2010-2014, show that total nitrogen levels throughout the Waquoit Bay and Popponesset Bay Systems are significantly enriched over the high quality waters of Nantucket Sound entering during flooding tides and are generally consistent with prior historical data (Figure 7 and 11). The pattern of nitrogen gradients in both systems roughly follows the salinity gradients, as the major source of the "excess" nitrogen is from groundwater and surface freshwater inflows. Within each sub-embayment, nitrogen levels were highest

within the headwaters and declined with decreasing distance from the tidal inlets, with the lowest nitrogen levels being recorded at the stations proximate each inlet. In both systems there are inter-annual differences, probably the result of inter-annual variation in weather related factors (wind, rain, temperature, etc.) or may result from differences in the sampling. In 2010-2012, for example, there is a very high average TN value at the head of the Quashnet River, much higher than in the long-term historical data (Figure 7). On two (2) of the sampling dates, particulate nitrogen values are much higher than on the other two (2) samplings. This variability results in the higher average PON and TN values for the 2010-12 seasons. However, this "peak" in TN was not repeated in 2013 and 2014, the cause of this variability is being examined relative to projected stream flows. However, this variation supports the need for long-term monitoring, as short-term events can be misleading as to trends in estuarine health.

In general, the 2010-2014 sampling results are consistent with the prior years in showing that these tributary basins are still well above their assimilative capacity with total nitrogen levels well above their TMDL designated threshold. The threshold total nitrogen level for these basins varies from 0.5 mg L^{-1} for Quashnet to restore bottom animal habitat to 0.38 mg L^{-1} for Hamblin and Jehu Ponds to re-establish eelgrass habitat (Figure 7). It should be noted that Hamblin and Jehu Pond only recently lost their eelgrass habitat and therefore may be able to be restored more quickly than other larger basins that are much farther beyond their acceptable nitrogen thresholds. In addition, there is a possible trend of declining TN in both tributary ponds which will be followed closely as oysters are deployed in these basins.

Popponesset Bay has a completed system-wide Massachusetts Estuaries Project analysis and MassDEP/USEPA TMDL. Popponesset Bay and its component basins have lost their historical eelgrass habitat (prior to 1995) and the upper tributaries presently support impaired or degraded habitat for benthic animal communities. The 2012-2014 sampling results are consistent with the prior years in showing that nitrogen levels of these tributary basins are still well above their TMDL designated thresholds, which vary from 0.5 mg L^{-1} for Shoestring and Ockway Bays (0.55 mg L^{-1} in upper Mashpee River) and 0.38 mg L^{-1} for Popponesset Bay main basins (sentinel station near tip of Mashpee Neck) to re-establish eelgrass habitat (Figure 11).

The consequences of these elevated total nitrogen levels can be seen in the high amounts of phytoplankton biomass (measured as chlorophyll-a pigments) and depletion of bottom water oxygen. Since estuarine phytoplankton, including those in Waquoit and Popponesset Bays, are stimulated by nitrogen additions, the effect of the nitrogen enrichment is to cause phytoplankton blooms and turbid waters within both estuaries. Generally, the reaches with the highest nitrogen (Figures 7, 11) support the highest chlorophyll-a pigment levels (Figures 8, 12), although local factors can interfere with this response. Analysis of the total chlorophyll-a and particulate organic nitrogen (PON) data indicate that the PON is directly related to the chlorophyll-a concentration (R^2=0.96). This underscores the contention that the particulate matter in the watercolumn of these estuaries in not "imported" but comprised of phytoplankton growing within the watercolumn, providing a direct link between nitrogen additions and poor water clarity. This supports the management plan, which indicates that lowering the nitrogen levels within the estuaries will reduce phytoplankton biomass and improve water and habitat quality and likely eelgrass restoration.

The 2012-2014 chlorophyll-a levels are generally consistent with the long-term historical data, supporting the contention that these estuaries are presently nitrogen enriched, resulting in high levels of phytoplankton production. Average levels of ~3 ug L^{-1} are typical of high quality coastal waters, with average levels of <5 ug L^{-1} in summer in shallow estuaries still indicative of moderately healthy waters. Average chlorophyll-a levels >10 ug L^{-1} indicates some impairment. Chlorophyll-a levels within the tidal rivers of both systems and Eel Pond in the Waquoit Bay System and Shoestring and Ockway Bays in the Popponesset Bay System are showing significantly impaired conditions (Figures 8 and 12). While the western basins of Waquoit Bay tend to have relatively high chlorophyll-a levels, the eastern basins (Hamblin Pond, Jehu Pond) support only moderate levels. This is consistent with these basins only losing eelgrass recently and having only moderate nitrogen enrichment. However, most waters of both estuarine systems have averages greater than 5 ug L^{-1}. These levels of phytoplankton biomass result in enhanced deposition of organic matter to the bottom sediments which results in higher amounts of oxygen uptake, negative impacts of organic matter loading on the bottom dwelling organisms and at highest levels, bottom sediments comprised of sulfidic, organic rich soft sediments after many years of nitrogen enrichment. Also, the higher amounts of phytoplankton in the water column increases the amount of oxygen being consumed during periods of low light or darkness adding to oxygen depletion and loss of fish, shellfish and bottom dwelling animals and the other organisms that feed upon them. Equally significant, the higher amounts of phytoplankton increase turbidity in the water column and reduce the amount of light that can penetrate to support eelgrass plants that are rooted to the bay bottom. This shading effect is one of the primary proximate causes of eelgrass loss world-wide, and in Popponesset Bay and Waquoit Bay in specific. Eelgrass has not been observed for over a decade in Popponesset Bay and has been reduced in Waquoit Bay to a few remaining patches in Hamblin Pond and Jehu Pond (Short and Burdick, 1996). Concomitantly, observed macroalgal growth and accumulations stimulated by high nitrogen inputs have been significant across Waquoit Bay and portions of Popponesset Bay with the associated negative effects of smothering the benthic habitat and overwhelming eelgrass habitat. Eelgrass has not been observed in the Quashnet River sub-embayment for decades; instead high levels of macroalgae have been documented (Curley et al., 1971, Valiela et al., 1992).

Oxygen depletion of bottom waters was variable but still evident within both systems in 2012-2014 and were generally consistent with historical data, following the distribution of nitrogen enrichment and elevated Chlorophyll-a levels (Figures 9, 13). The linkage of oxygen depletion to nitrogen enrichment is seen in each years results with higher oxygen levels at lower levels of nitrogen enrichment and greater depletion in basins with higher nitrogen enrichment. In 2014 oxygen depletion tended to be greater than in previous years in the less well flushed basins of the Waquoit Estuary, with half of the stations recording lower D.O. than the long term average and 10 of the 16 stations being lower than the previous few years. This may be due to the higher chlorophyll-a levels in 2014, indicative of organic loading to the sediments and elevated night-time respiration. However, it is likely that the basins of this estuary are nutrient and organic matter enriched to the point where oxygen depletion will occur when vertical mixing of the watercolumn decreases or a period of low light occurs (Sawabini et al. 2014). Both factors are inter-related and both likely in effect in these eutrophic waters. Popponesset Bay showed a parallel pattern to Waquoit Bay, with higher chlorophyll-a and lower D.O. in 2014 than the long-term average in most of its basins. The causes appear to be the same in both estuaries, the

linkage of nitrogen enrichment to organic matter load (chlorophyll-a) to low D.O in bottom waters. Again the inter-annual difference can be enhanced by meteorological conditions of low light and wind resulting in less oxygen input through photosynthesis and vertical mixing of oxygen rich surface waters to the bottom. This phenomenon has been quantified for many estuaries throughout the region and is likely true for estuaries in general. However, if this observed levels in 2014 persist over the next few seasons, it will indicate a further decline in nutrient related health of these estuaries. However, since meteorology is playing a partial role, 2014 may represent a transient condition. Note that even if conditions improve slightly, it is the nutrient and organic enrichment of these estuarine basins which makes each system poised for low oxygen when other external factors become operative (storms, low light, wind, temperature, etc).

Integrating the various nutrient related parameters collected as part of the monitoring program in order to provide a simple view of the general nutrient related water quality of the Waquoit Bay and Popponesset Bay Estuarine Systems, the Bay Health Index was used again in 2012, 2013 and 2014. The Bay Health Index was developed for Buzzards Bay embayments based upon levels of nitrogen (inorganic and organic), chlorophyll-a, bottom water oxygen and the depth of light penetration (Secchi depth). While the index does not provide a quantitative assessment of habitat health and is not suitable for salt marsh dominated estuaries, it does give a useful picture of the general level of estuarine water quality and spatial gradients within estuaries. Since it is not yet possible to develop temporal trends from the available monitoring data (Tables 4 and 5), the average summer conditions throughout the Waquoit Bay and Popponesset Bay Systems were used to parameterize the Bay Health Index. The Scores for each parameter were calculated and the average score for each station (across the 5 parameters) calculated (Tables 6 and 7). These scores are then compared to a guide of "acceptable" ranges for each parameter to rank the station (Table 8). It should be understood that the Bay Health Index and the designation of acceptable ranges for each parameter are approximate and provide less certainty than site-specific analysis. However, the Index does provide a convenient tool for comparing regions within an estuary and between estuaries.

It is clear that there are strong gradients in nutrient related water quality within each estuary in 2014 and that they are similar to the long-term pattern (Figures 14, 16). The overall pattern is similar to that of the separate parameters used in calculating the Index. Both systems show poor nutrient related water quality within the tidal rivers and tributary basins, with modest improvement within the main basins and the only regions showing moderate to high quality being adjacent to the tidal inlets. The region adjacent the tidal inlet is typically the last reach of an estuary to degrade as a result of watershed nitrogen loading, since this area is being swept with the high quality waters of Nantucket Sound (Figure 16, outer station) for almost the entire flooding tide. For this reason, the final areas of eelgrass habitat or high quality benthic animal habitat in a eutrophying estuary are typically found adjacent the tidal inlet.

The Health Index, as a composite of all major nutrient related water quality parameters, also allows for a tracking of temporal trends in water quality. Given the natural variation in water quality associated data sets, it is difficult to determine short term changes. This is particularly true if changes result from a number of small and/or dispersed improvements in tidal flushing, nitrogen source reductions, etc. However, it is possible to examine if change is occurring (rather

than the rate). To this end, the Index data from Waquoit Bay from 2010-2014 and the historical baseline can be compared (Figure 15) and a similar analysis for Popponesset Bay was be conducted (Figure 17). These comparisons show the variation in the Index at the different sites between years. Values falling above the 1:1 line show an improvement, values below the line a decline and on the line suggests, no change at that site in that year from historical conditions. This approach yields more information on change than the color coded mapping of results (Figures 14 and 16) which are based on Index ranges. The direct comparisons are based on individual sites for individual years compared to the baseline conditions. This comparison indicates that for Waquoit Bay (Figure 15), the intermediate areas of impairment tended to show poorer water quality in 2014, consistent with the observed higher chlorophyll-a and oxygen depletions in 2014. Popponesset Bay showed a similar pattern (Figure 17) of slightly lower water quality in 2014 than over the long term with similar patterns in the chlorophyll a and dissolved oxygen levels. One year does not indicate a trend, but more analysis is needed to detect the underlying cause and continued sampling to evaluate if this is a trend or not.

MONITORING CONCLUSIONS AND RECOMENDATIONS

Overall, both the Waquoit Bay and Popponesset Bay Estuarine Systems were highly nitrogen enriched and showed impaired nutrient related water quality in 2010-2014, similar to the long-term pattern over the past decade. The tidal rivers (Mashpee River, Childs River, Quashnet River) and major tributary basins (Eel Pond/River, Shoestring Bay and Ockway Bay) are all showing poor water quality as evidenced by the Bay Health Index. Only the main basins and Jehu and Hamblin Ponds are showing moderate - high water quality. With watershed development continuing, estuarine conditions have been projected to decline further until nitrogen management is implemented. Nitrogen management within Popponesset Bay has already begun with the maintenance of the flow through the tidal inlet, propagation of oysters within the system and capping of the Town of Mashpee landfill. In addition, watershed nitrogen management planning is underway to reduce the major sources of nitrogen (primarily septic system discharges) and possibly enhancing nitrogen removed during transport from the sources to the estuary by pond and stream restoration.

Specific findings:

(1) Both Waquoit Bay and Popponesset Bay appear to be showing few additional impairments (although 2014 was a poor water quality year) and overall the systems continue to support impaired habitat quality. However, recently, water quality metrics generally have been showing slight improvements or are stable except for 2014. The improvements have been typically in the most impaired basins, much less in the moderately impaired areas, with little change in the high quality areas as determined from historic baseline. In 2014 the declines were generally in the transitional areas. Unfortunately, both estuaries still support impaired habitats and remain below the water quality levels set by the MassDEP/EPA TMDL.

(2) Quashnet River above the bridge was relatively fresh in 2014, continuing the trend of prior years. This further supports the need to investigate a potential restriction to tidal exchange in this region of the Quashnet River. Brackish salinities within this upper basin have been observed in past years, but recent years suggest a freshening. If this basin further freshens, phosphorus, in

addition to nitrogen, may need to be evaluated for proper management and restoration.

(3) Analysis of the total chlorophyll-a and particulate organic nitrogen (PON) data indicate that the PON is directly related to the chlorophyll-a concentration (R^2=0.96). This underscores the contention that the particulate matter in the watercolumn of these estuaries in not "imported" but comprised of phytoplankton growing within the watercolumn. This supports the management plan, which indicates that lowering the nitrogen levels within the estuaries will reduce phytoplankton biomass and improve water and habitat quality.

(4) Oxygen depletion of bottom waters (Figures 9, 13) was variable but still evident within both systems in 2012-2014 and were generally consistent with historical data, following the distribution of nitrogen enrichment and elevated Chlorophyll-a levels. The linkage of oxygen depletion to nitrogen enrichment is seen in each years results with higher oxygen levels at lower levels of nitrogen enrichment and greater depletion in basins with higher nitrogen enrichment. In addition, oxygen data from 2014 supports the linkage between nitrogen enrichment, organic matter loading and oxygen depletion, with enhanced depletion likely due to meteorological forcing factors (wind, light intensity, temperature) as seen in other estuaries in throughout the region.

(5) Results to date indicate that the monitoring program will be able to detect changes within the estuaries in response to implementation of management alternatives. Also, the natural variation obscuring detection of year to year changes is overcome by continued long-term monitoring.

Improvements:

Because of the variability in the dissolved oxygen data, we have made some recommendations to strengthen the oxygen data base in the Waquoit and Popponesset systems.

Because dissolved oxygen in the water column, especially bottom waters, are subject to periodic episodes of hypoxia/anoxia and because D.O. is such an important component in structuring aquatic ecosystems, we feel that two possible approaches can be taken to improve the oxygen data collection:

1) Continue of Winkler Titrations on water samples where meter readings of D.O. are < 5mg/L. Winkler titration is a more accurate and precise method for quantifying dissolved oxygen concentrations in samples expected to have low DO levels,
2) Deploy in situ oxygen meters (sondes) on the bottom of specific estuaries at several strategic locations for the summer months when periodic hypoxic or anoxic events in bottom waters can occur. These sites should also have light records such that meteorological factors can be evaluated relative to nutrient related water quality.

The Mashpee Water Quality Monitoring Program has grown to be one of the most successful programs in the region and has provided a sound assessment of the present health of the bays. The Monitoring Program has again proven that it can provide high quality data for tracking the status of both Waquoit and Popponesset Bay Systems and for determining compliance with the USEPA/MassDEP TMDLS for these systems, all in a cost effective manner.

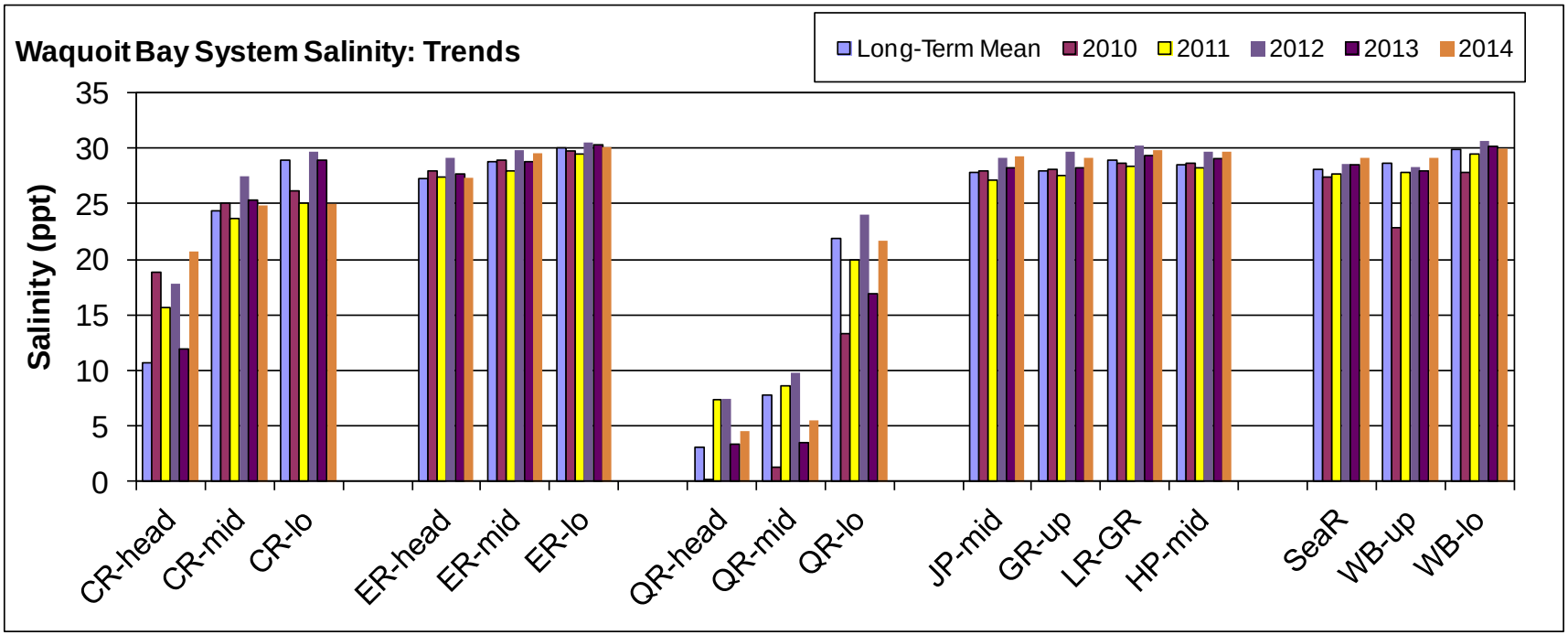

Figure 6. Salinity Distribution throughout the Waquoit Bay Estuarine System long-term and in the summers of 2010-2014. Freshwater enters through groundwater all along the shoreline, with additional "point" inflows from the Moonakis River, Childs River, and Red Brook. These freshwaters mix with the saline waters of Nantucket Sound entering through the tidal inlets. CR - Childs River, ER - Eel River, QR - Quashnet River, JP - Jehu Pond, GR - Great River, LR-GR - Little River-Great River confluence, HP - Hamblin Pond, SeaR - Seapit River, WB - Waquoit Bay main basin; head - uppermost reach, mid - middle reach, lo - lower basin near mouth or inlet.

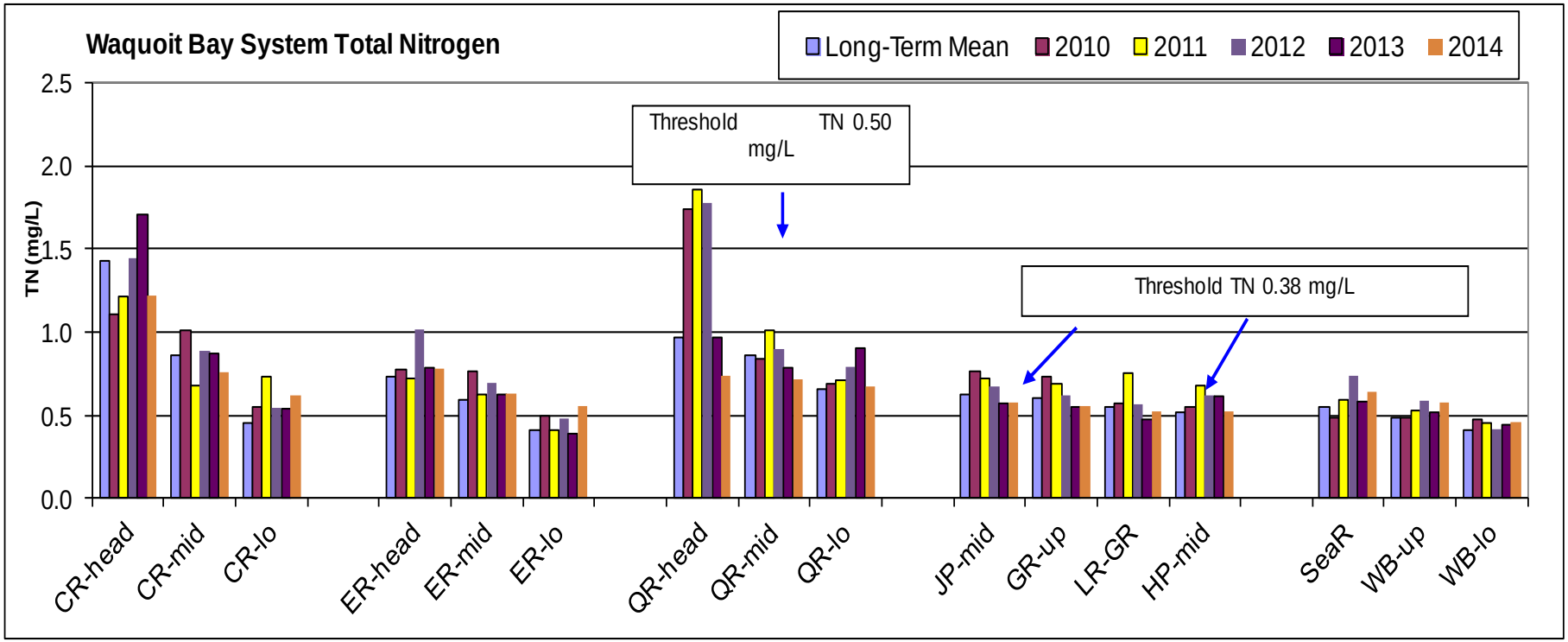

Figure 7. Distribution of Total Nitrogen within the Waquoit Bay Estuarine System, long-term and during the summers of 2010 through 2014. Nitrogen enters through groundwater inflows all along the shoreline, with additional "point" loads from the upper regions of the watershed via Moonakis River, Childs River, and Red Brook. These nitrogen loads plus recycling within the estuary mix with the low nitrogen waters of Nantucket Sound entering through the tidal inlets to create the observed gradient. CR - Childs River, ER - Eel River, QR - Quashnet River, JP - Jehu Pond, GR - Great River, LR-GR - Little River-Great River confluence, HP - Hamblin Pond, SeaR - Seapit River, WB - Waquoit Bay main basin; head - uppermost reach, mid - middle reach, lo - lower basin near mouth or inlet. The red line shows the offshore TN concentration and "Threshold" is the TMDL target for restoration.

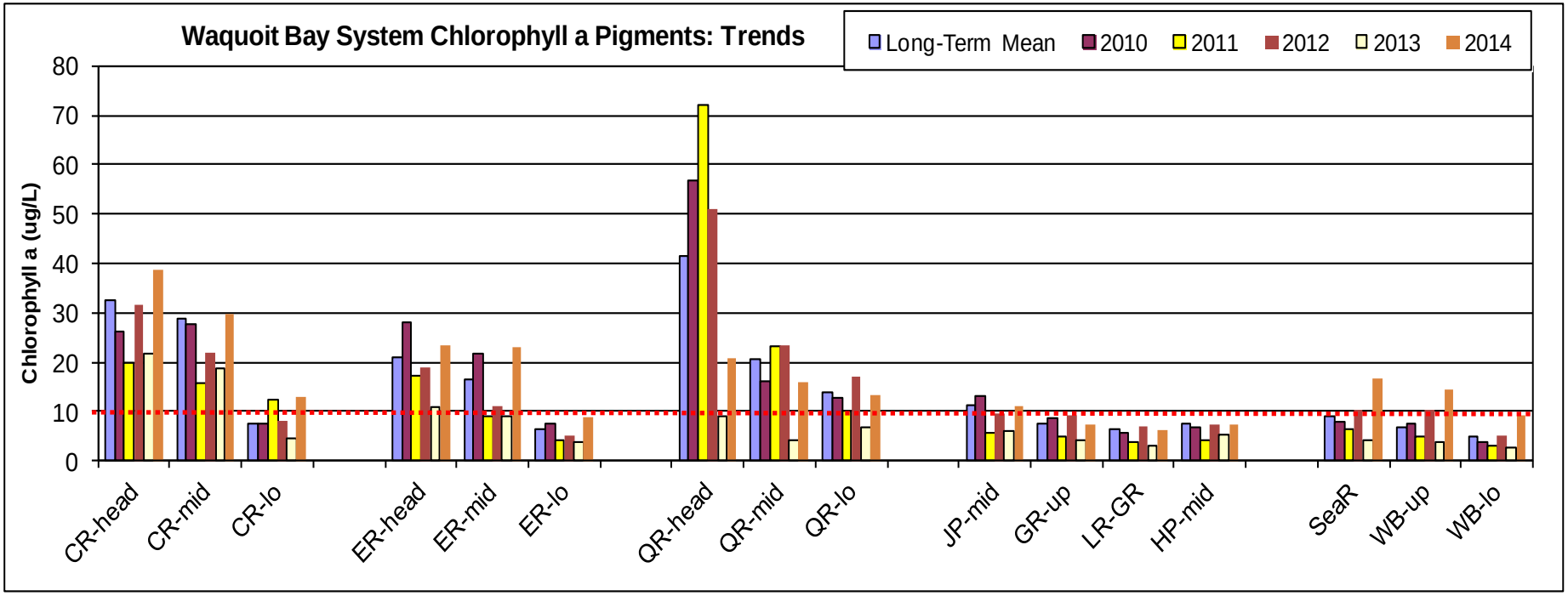

Figure 8. Total Chlorophyll a pigment levels throughout the Waquoit Bay Estuarine System over the long-term and in summers of 2009 through 2014. Phytoplankton pigment levels are a gauge of phytoplankton biomass, which is a response to nitrogen loading. Values over 10 indicate nitrogen enrichment, values ≤3 represent low nitrogen enriched waters (red line). CR - Childs River, ER - Eel River, QR - Quashnet River, JP - Jehu Pond, GR - Great River, LR-GR - Little River-Great River confluence, HP - Hamblin Pond, SeaR - Seapit River, WB - Waquoit Bay main basin; head - uppermost reach, mid - middle reach, lo - lower basin near mouth or inlet.

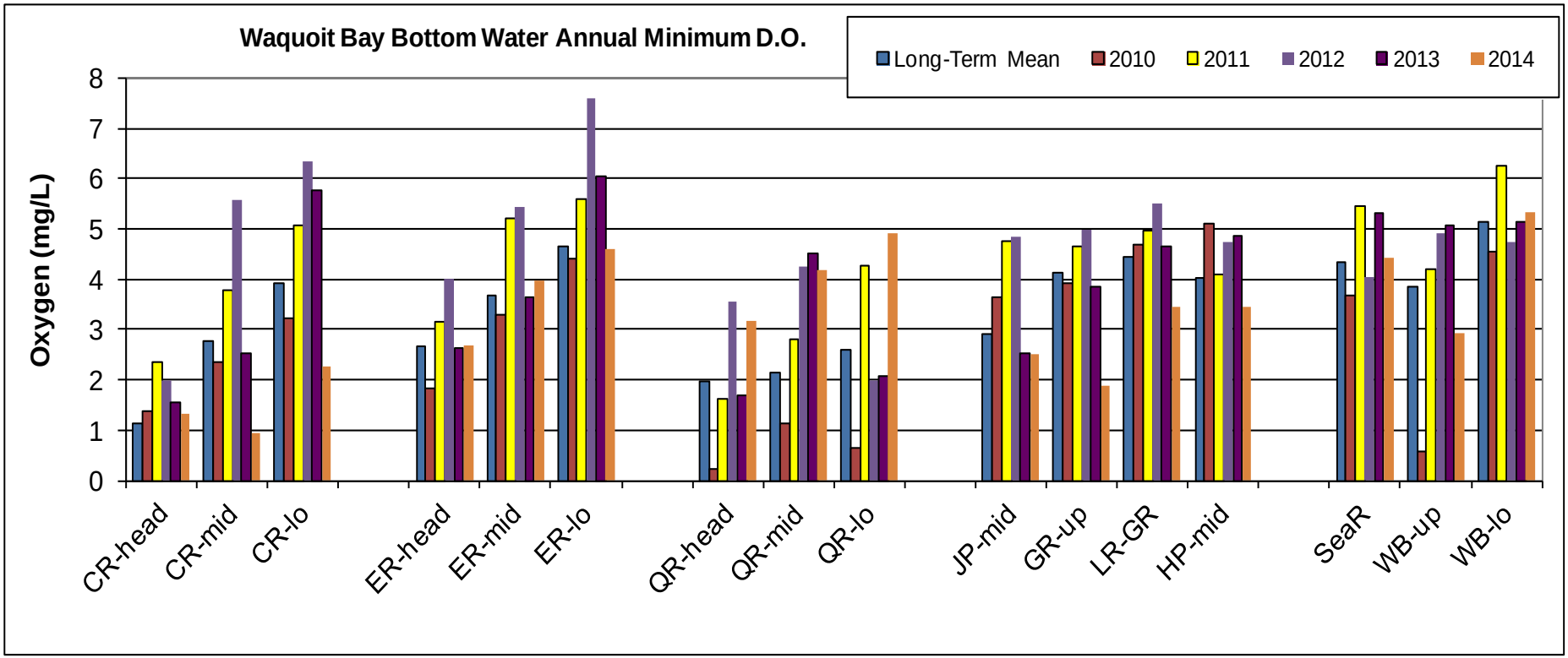

Figure 9. Minimum Dissolved Oxygen (D.O.) levels throughout the Waquoit Bay Estuarine System over the long-term and in the summers of 2010-2014. CR - Childs River, ER - Eel River, QR - Quashnet River, JP - Jehu Pond, GR - Great River, LR-GR - Little River-Great River confluence, HP - Hamblin Pond, SeaR - Seapit River, WB - Waquoit Bay main basin; head - uppermost reach, mid - middle reach, lo - lower basin near mouth or inlet.

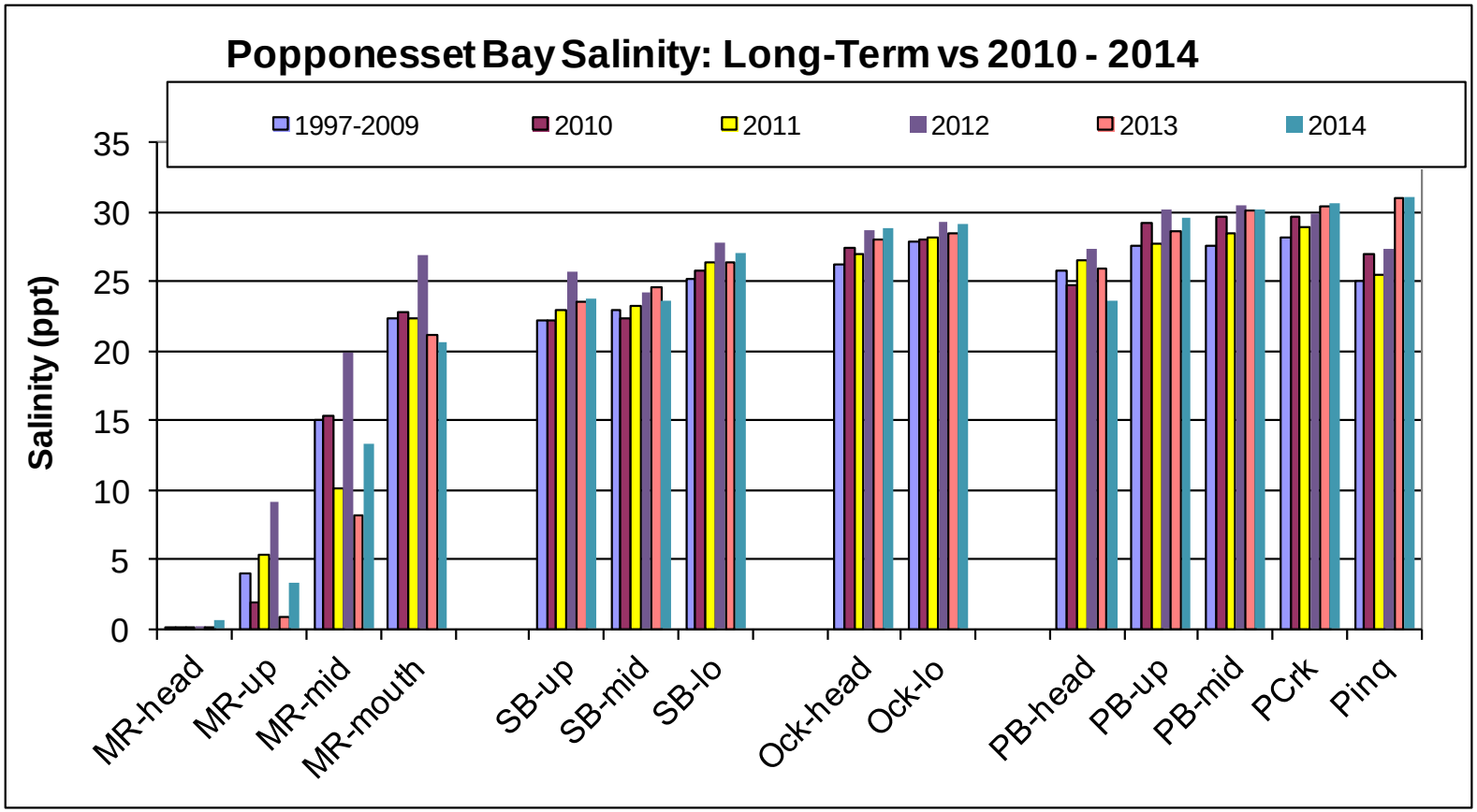

Figure 10. Salinity Distribution throughout the Popponesset Bay Estuarine System. Freshwater enters through groundwater all along the shoreline, with additional "point" inflows from the freshwater reach of the Mashpee River and from the Santuit River to Shoestring Bay. These freshwaters mix with the saline waters of Nantucket Sound entering through the single tidal inlet. MR - Mashpee River, SB - Shoestring Bay, Ock - Ockway Bay, PB - Popponesset Bay, PCrk - Poppenesset Creek, Pinq - Pinquickset Cove.

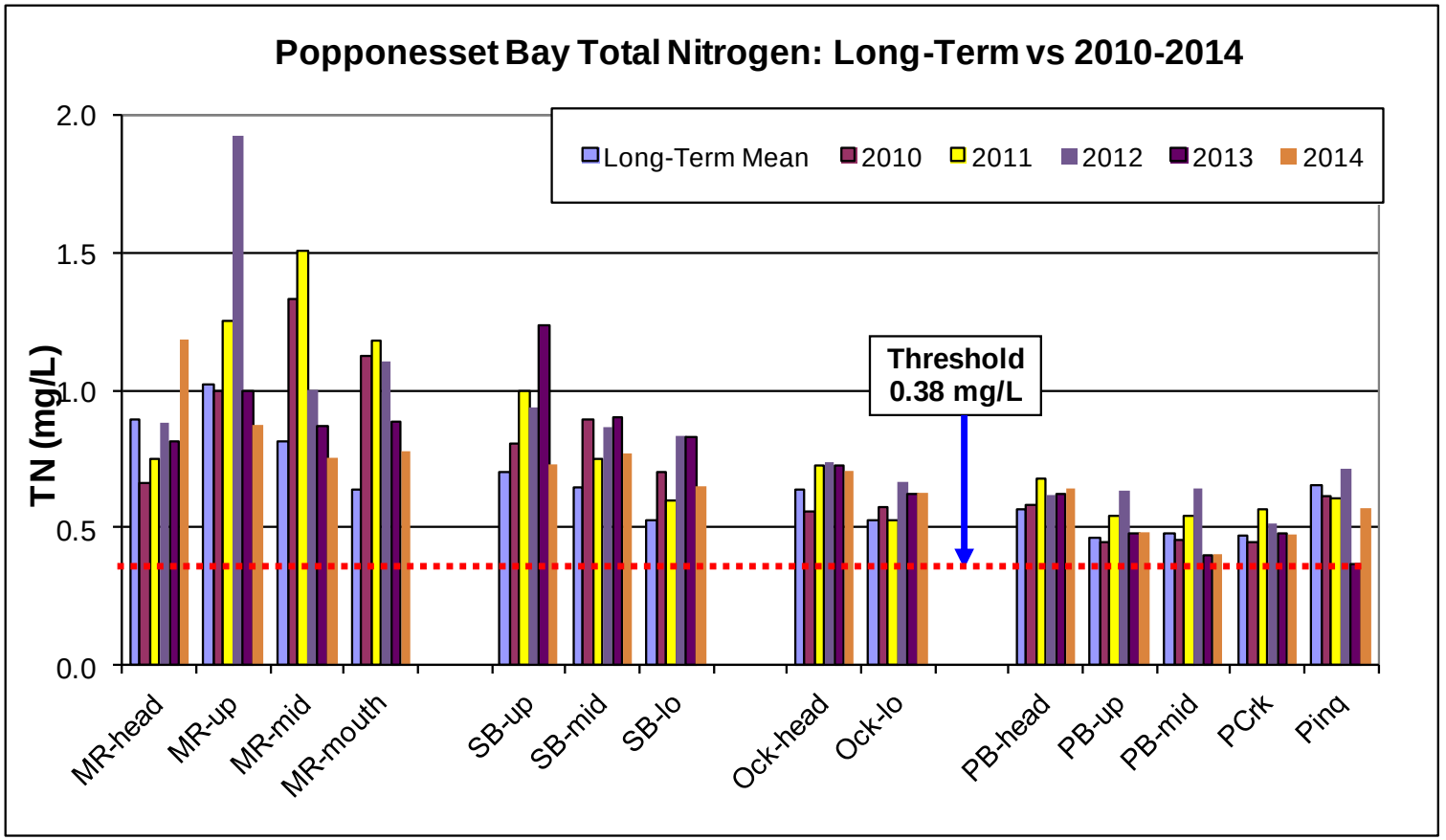

Figure 11. Distribution of Total Nitrogen within the Popponesset Bay Estuarine System. Nitrogen enters through groundwater inflows all along the shoreline, with additional "point" loads from the upper regions of the watershed via the Mashpee River and Santuit River to Shoestring Bay. These nitrogen loads plus recycling within the estuary mix with the low nitrogen waters of Nantucket Sound entering through the single tidal inlet to create the observed gradient. MR - Mashpee River, SB - Shoestring Bay, Ock - Ockway Bay, PB - Popponesset Bay, PCrk - Poppenesset Creek, Pinq - Pinquickset Cove. The red line shows the offshore TN concentration; "Threshold" is the TMDL target for restoration. TN levels in 2010-2014 are compared to the long-term average.

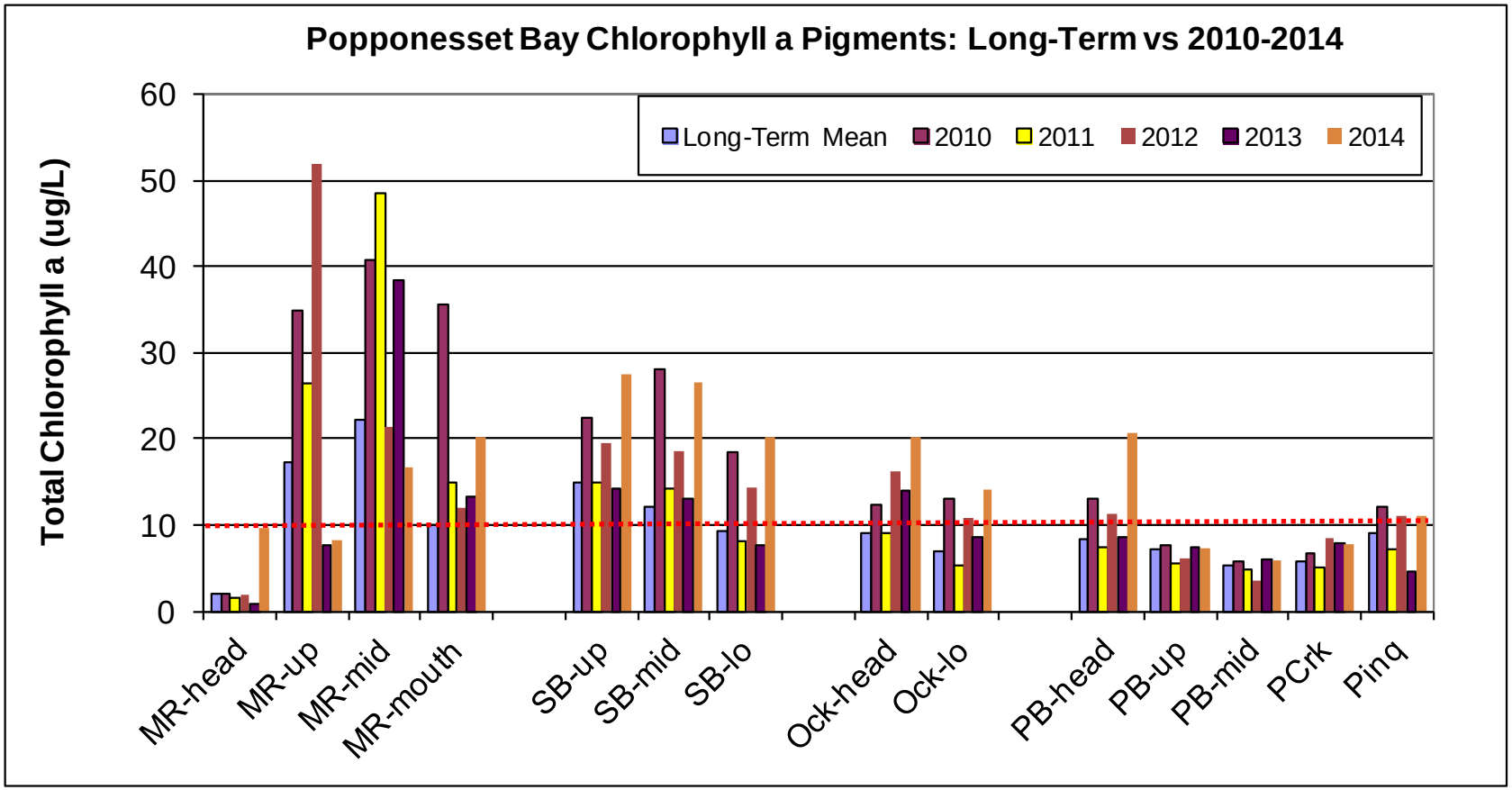

Figure 12. Total Chlorophyll a pigment levels throughout the Popponesset Bay Estuarine System over the long-term and in summer 2010-2014. Phytoplankton pigment levels are a gauge of phytoplankton biomass, which is a response to nitrogen loading. Values over 10 indicate nitrogen enrichment, values ≤ 3 represent low nitrogen enriched waters (red line). MR - Mashpee River, SB - Shoestring Bay, Ock - Ockway Bay, PB - Popponesset Bay, PCrk - Poppenesset Creek, Pinq - Pinquickset Cove.

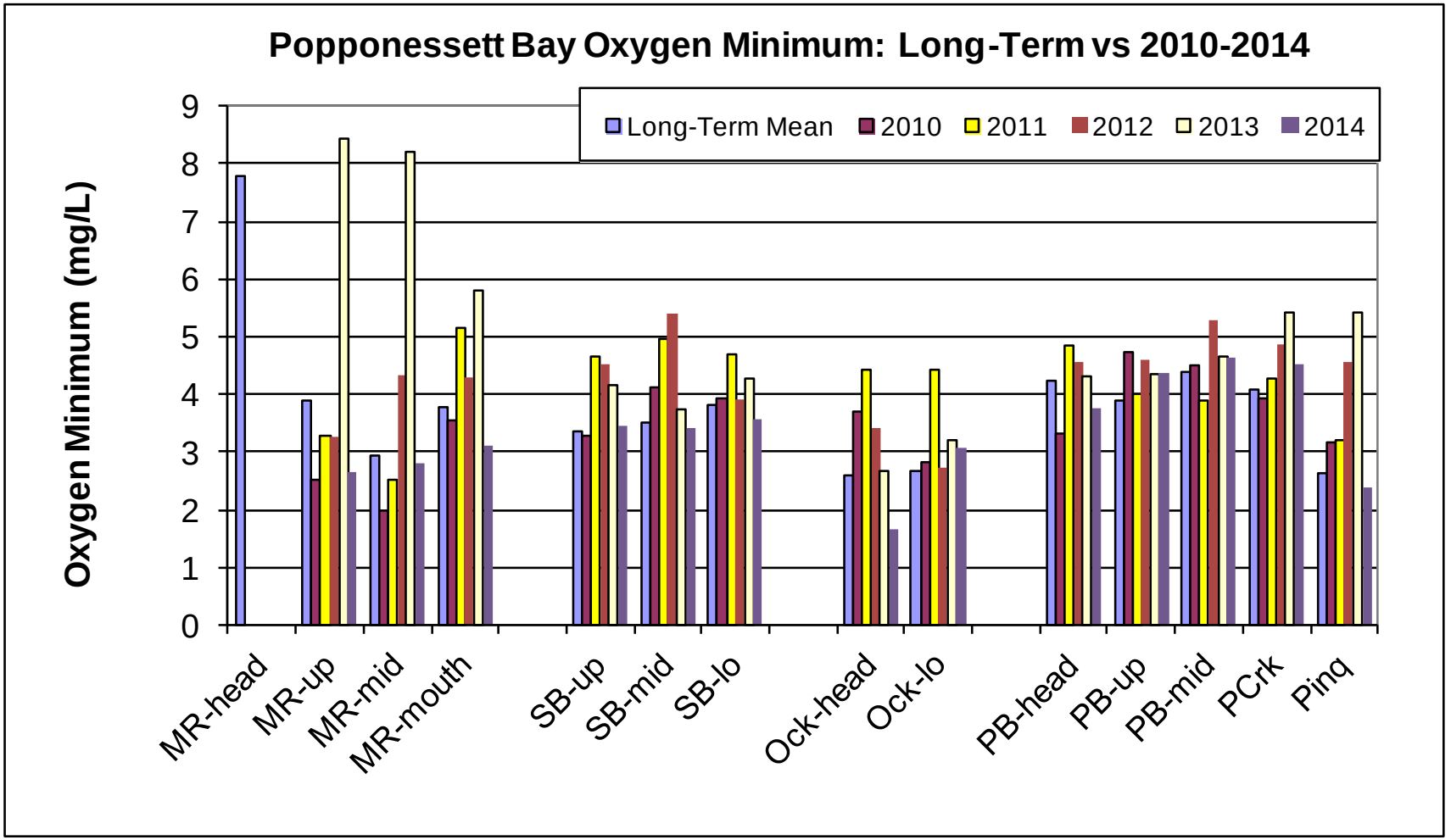

Figure 13. Minimum Dissolved Oxygen levels throughout the Popponesset Bay Estuarine System over the long-term and in the summers of 2010 through 2014. MR - Mashpee River, SB - Shoestring Bay, Ock - Ockway Bay, PB - Popponesset Bay, PCrk - Poppenesset Creek, Pinq - Pinquickset Cove.

Table 4. Summary of water quality parameters in Waquoit Bay. Summer 2014.

Sample ID	Secchi Depth (m)	Total Depth (m)	Secchi as % W.C.	SALINITY (ppt)	20% Low D.O. (mg/L)	20% Low D.O. (% Sat)	PO4 (mg/L)	NH4 (mg/L)	NOX (mg/L)	DIN (mg/L)	DON (mg/L)	PON (mg/L)	TON (mg/L)	TN (mg/L)	DIN/DIP Molar	T-pig (ug/L)
Childs River																
CR01	0.6	1.0	71%	11.9	1.6	17%	0.035	0.029	0.211	0.240	0.485	0.979	1.464	1.704	7	21.6
CR02	0.9	1.6	63%	25.3	2.5	31%	0.012	0.009	0.010	0.019	0.408	0.448	0.856	0.875	2	18.9
CR03	1.5	2.9	50%	28.9	5.8	72%	0.021	0.029	0.010	0.039	0.333	0.171	0.504	0.543	2	4.7
Eel River																
ER01	1.0	1.2	82%	27.7	2.6	33%	0.009	0.009	0.004	0.013	0.351	0.421	0.772	0.785	1	10.8
ER02	1.1	1.3	82%	28.8	3.6	42%	0.006	0.007	0.002	0.009	0.349	0.265	0.613	0.622	1	9.2
ER03	Btm	1.6	100%	30.3	6.1	73%	0.017	0.013	0.001	0.014	0.255	0.126	0.381	0.395	1	3.9
Waquoit Bay																
WB01	1.7	2.3	76%	28.2	2.5	37%	0.026	0.012	0.001	0.012	0.371	0.194	0.565	0.577	0	6.0
WB02	Btm	1.4	100%	28.3	3.9	61%	0.027	0.015	0.001	0.016	0.384	0.146	0.530	0.546	1	4.2
WB03	2.1	1.9	100%	29.4	4.6	67%	0.027	0.016	0.001	0.017	0.340	0.116	0.456	0.473	1	3.2
WB04	ND	1.2	100%	29.0	4.9	71%	0.028	0.008	0.000	0.008	0.389	0.222	0.611	0.619	0	5.2
WB05	NS	NS	NS	0.2	NS	NS	0.016	0.039	0.021	0.061	0.639	0.267	0.907	0.967	4	7.7
WB06	NS	NS	NS	0.1	NS	NS	0.009	0.025	0.225	0.250	0.272	0.073	0.345	0.595	26	1.7
WB07	Btm	0.4	100%	3.4	1.7	63%	0.011	0.039	0.183	0.222	0.413	0.333	0.746	0.968	20	9.0
WB08	Btm	0.9	100%	3.5	4.5	61%	0.011	0.047	0.202	0.249	0.384	0.154	0.538	0.787	23	4.3
WB09	Btm	1.2	96%	16.9	2.1	39%	0.020	0.053	0.032	0.085	0.551	0.270	0.821	0.907	4	6.8
WB10	NS	NS	NS	27.8	NS	NS	0.033	0.050	0.006	0.056	0.486	0.188	0.673	0.729	2	4.8
WB11	1.4	2.0	74%	28.5	5.3	66%	0.018	0.023	0.013	0.035	0.397	0.152	0.549	0.584	2	4.1
WB12	1.1	1.5	99%	27.9	5.1	65%	0.016	0.020	0.007	0.027	0.339	0.151	0.490	0.517	2	4.0
WB13	2.4	1.8	100%	30.2	5.1	63%	0.019	0.013	0.003	0.016	0.324	0.105	0.429	0.446	1	2.7

Secchi as % of WC is the % of the watercolumn above the secchi depth, values of 100% means that the Secchi was at or below the bottom.
Lowest 20% of D.O. records for a site over the project period.
Btm means that Secchi Disk as on bottom and therefore the depth of disk diappearance could not be determined (never disappears)

Table 5. Summary of water quality parameters in Popponesset Bay. Summer 2014.

Station	Secchi Depth (m)	Total Depth (m)	Secchi as % W.C.	Salinity (ppt)	20% Low D.O. (mg/L)	20% Low D.O. (% Sat)	PO4 (mg/L)	NH4 (mg/L)	NOx (mg/L)	DIN (mg/L)	DON (mg/L)	PON (mg/L)	TON (mg/L)	TN (mg/L)	DIN/DIP Molar	T-Pig (ug/L)
Mashpee River/Popponesset Bay																
PB01	NS	NS	NS	0.1	NS	NS	0.013	0.040	0.393	0.433	0.304	0.078	0.382	0.815	33	0.8
PB02	0.55	0.55	100%	0.8	8.45	99%	0.017	0.053	0.346	0.400	0.464	0.137	0.600	1.000	23	7.6
PB03	0.69	0.72	96%	8.2	8.20	81%	0.013	0.015	0.078	0.093	0.381	0.393	0.774	0.867	7	38.5
PB04	0.84	0.84	99%	21.1	5.80	70%	0.018	0.029	0.025	0.053	0.444	0.385	0.829	0.882	3	13.2
PB05	0.84	1.03	83%	23.6	4.16	52%	0.014	0.030	0.022	0.053	0.570	0.611	1.151	1.233	4	14.3
PB06	0.90	0.95	95%	24.7	3.75	47%	0.012	0.029	0.009	0.038	0.435	0.429	0.865	0.903	3	13.0
PB07	0.76	0.76	100%	26.4	4.28	54%	0.013	0.024	0.000	0.024	0.467	0.340	0.806	0.831	2	7.6
PB08	1.36	1.84	77%	25.9	4.31	50%	0.013	0.009	0.002	0.011	0.338	0.276	0.614	0.625	1	8.6
PB09	1.10	1.30	85%	28.0	2.66	31%	0.011	0.004	0.000	0.004	0.336	0.386	0.903	0.727	0	14.1
PB10	0.93	0.93	100%	28.5	3.20	37%	0.011	0.006	0.000	0.006	0.297	0.317	0.614	0.620	1	8.5
PB11	1.34	1.34	100%	28.7	3.42	49%	0.017	0.040	0.004	0.044	0.356	0.179	0.744	0.578	3	4.4
PB12	1.64	1.64	100%	30.1	3.66	42%	0.019	0.053	0.017	0.070	0.342	0.136	0.478	0.548	4	3.6
PB13	2.10	2.38	88%	30.4	3.75	47%	0.022	0.056	0.002	0.058	0.384	0.155	0.539	0.597	3	4.8
PB14	1.84	1.86	99%	31.1	6.50	79%	0.015	0.022	0.004	0.025	0.322	0.109	0.432	0.457	2	1.9
PB15	0.80	0.80	100%	25.6	3.25	40%	0.015	0.030	0.003	0.033	0.430	0.251	0.681	0.714	2	5.6
Santuit River																
SR5	NS	NS	NS	6.3	NS	NS	0.023	0.139	0.577	0.716	0.427	0.768	1.195	1.911	32	24.1

Secchi as % of WC is the % of the watercolumn above the secchi depth, values of 100% means that the Secchi was at or below the bottom.
Lowest 20% of D.O. records for a site over the project period.

Table 6. Trophic Health Index Scores and status for marine water quality monitoring stations in Waquoit Bay, 2014 and Long-Term, based upon open water embayment (not salt marsh) habitat quality scales (described in Howes et al. 1999) at www.savebuzzardsbay.org).

Sample ID	Secchi Depth (m)	20% Low D.O. (% Sat)	DIN (mg/L)	TON (mg/L)	Total Pigments (ug/L)	Secchi SCORE	Low20% Oxsat SCORE	DIN SCORE	TON SCORE	T-Pig SCORE	2014 EUTRO Index	2014 Health Status	Long-Term EUTRO Index	Long-Term Health Status
CR01	1.0	17%	0.314	0.907	38.78	34.5	0.0	0.0	0.0	0.0	6.9	Fair/Poor	1.1	Fair/Poor
CR02	1.3	12%	0.069	0.691	29.85	45.6	0.0	30.5	0.0	0.0	15.2	Fair/Poor	15.8	Fair/Poor
CR03	1.4	35%	0.073	0.557	12.91	53.2	0.0	28.5	9.7	0.0	18.3	Fair/Poor	46.0	Moderate
ER01	btm	39%	0.044	0.732	23.39	100.0	0.0	49.8	0.0	0.0	30.0	Fair/Poor	21.9	Fair/Poor
ER02	1.2	55%	0.023	0.608	22.93	42.1	39.9	78.7	0.0	0.0	32.2	Moderate/Fair	35.9	Moderate
ER03	btm	63%	0.048	0.505	8.88	Btm	56.6	46.6	22.5	9.9	33.9	Moderate/Fair	63.8	High
WB01	2.5	43%	0.031	0.546	10.97	88.2	8.1	65.1	12.3	0.0	34.7	Moderate/Fair	31.9	Moderate
WB02	btm	27%	0.041	0.513	7.25	Btm	0.0	53.6	20.7	26.8	25.3	Fair/Poor	39.1	Moderate
WB03	btm	57%	0.043	0.478	6.11	100.0	43.0	51.7	29.8	40.9	53.1	Moderate	49.4	Moderate
WB04	btm	57%	0.026	0.493	7.29	Btm	43.5	72.5	25.7	26.3	42.0	Moderate	44.5	Moderate
WB05	NS	NS	0.043	2.600	137.21	Btm	ND	51.5	0.0	0.0	17.2	Fair/Poor	19.9	Fair/Poor
WB06	NS	NS	0.276	0.328	4.13	Btm	ND	0.0	79.1	73.4	50.9	Moderate	30.8	Fair/Poor
WB07	btm	48%	0.243	0.496	20.80	Btm	23.0	0.0	25.1	0.0	12.0	Fair/Poor	0.0	Fair/Poor
WB08	btm	51%	0.200	0.513	15.90	Btm	30.0	0.0	20.5	0.0	12.6	Fair/Poor	6.7	Fair/Poor
WB09	1.1	63%	0.067	0.603	13.27	Btm	56.4	32.2	0.0	0.0	22.1	Fair/Poor	16.3	Fair/Poor
WB10	NS	NS	0.062	0.743	11.91	Btm	ND	35.7	0.0	0.0	11.9	Fair/Poor	19.1	Fair/Poor
WB11	1.5	61%	0.031	0.611	16.78	58.0	52.8	66.1	0.0	0.0	35.4	Moderate/Fair	38.5	Moderate
WB12	1.7	40%	0.020	0.560	14.52	64.4	0.6	83.8	9.1	0.0	31.6	Moderate/Fair	50.3	Moderate
WB13	2.0	74%	0.030	0.432	9.33	75.6	76.0	66.6	43.1	5.7	53.4	Moderate	72.2	High

Table 7. Trophic Health Index Scores and status for marine water quality monitoring stations in Popponesset Bay, 2014 and long-term, based upon open water embayment (not salt marsh) habitat quality scales (described in Howes et al. 1999) at www.savebuzzardsbay.org).

Station	Secchi Depth (m)	20% Low D.O. (% Sat)	DIN (mg/L)	TON (mg/L)	T-Pig (ug/L)	Secchi SCORE	Low20% Oxsat SCORE	DIN SCORE	TON SCORE	T-Pig SCORE	2014 EUTRO Index	2014 Health Status	97-09 EUTRO Index	97-09 Health Status
PB01	N/A	N/A	0.646	0.539	9.6	ND	ND	0.0	14.1	3.3	5.8	Fair/Poor	36.4	Mod/Fair
PB02	btm	29%	0.404	0.449	8.1	ND	0.0	0.0	38.0	17.2	13.8	Fair/Poor	2.2	Fair/Poor
PB03	btm	37%	0.197	0.560	16.6	100.0	0.0	0.0	9.1	0.0	21.8	Fair/Poor	4.0	Fair/Poor
PB04	btm	41%	0.169	0.608	20.3	100.0	3.3	0.0	0.0	0.0	20.7	Fair/Poor	24.3	Fair/Poor
PB05	0.91	46%	0.064	0.664	27.6	26.1	17.2	33.8	0.0	0.0	15.4	Fair/Poor	18.2	Fair/Poor
PB06	0.90	47%	0.054	0.715	26.7	25.4	18.8	41.2	0.0	0.0	17.1	Fair/Poor	21.4	Fair/Poor
PB07	btm	50%	0.049	0.604	20.3	100.0	27.3	45.9	0.0	0.0	34.6	Moderate/Fair	31.3	Mod/Fair
PB08	btm	23%	0.069	0.639	20.2	100.0	0.0	30.5	0.0	0.0	26.1	Fair/Poor	46.4	Moderate
PB09	btm	43%	0.041	0.583	14.1	100.0	8.1	53.0	3.8	0.0	33.0	Moderate/Fair	22.8	Fair/Poor
PB10	btm	45%	0.049	0.600	20.6	on btm	13.4	45.2	0.0	0.0	14.7	Fair/Poor	30.6	Fair/Poor
PB11	btm	60%	0.042	0.441	7.4	on btm	49.2	52.5	40.3	25.5	41.9	Fair/Poor	43.1	Moderate
PB12	1.87	64%	0.041	0.361	6.0	on btm	ND	53.6	66.8	42.8	54.4	Moderate	46.6	Moderate
PB13	2.36	27%	0.039	0.440	7.8	85.0	0.0	55.7	40.6	20.6	40.4	Moderate/Fair	54.2	Moderate
PB14	1.90	75%	0.020	0.348	4.6	71.6	76.9	84.7	71.6	64.2	73.8	High	75.2	High
PB15	btm	31%	0.038	0.531	11.1	100.0	0.0	56.8	16.1	0.0	34.6	Fair/Poor	20.7	Fair/Poor

Table 8. Reference values used in the Bay Health Index. Scores are generated for each parameter and the mean score computed. In some cases where Secchi data is not available, the mean of the other 4 parameters may be used.

Score	Secchi Depth M	Oxygen Saturation %	Inorganic N mg/L	Total N mg/L	Total Chlorophyll a Pigments ug/L
%	0.6	0.40	0.140	0.600	10.0
100%	3.0	0.90	0.014	0.280	3.0
The relationship between 0% to 100% for each parameter is logarithmic.					

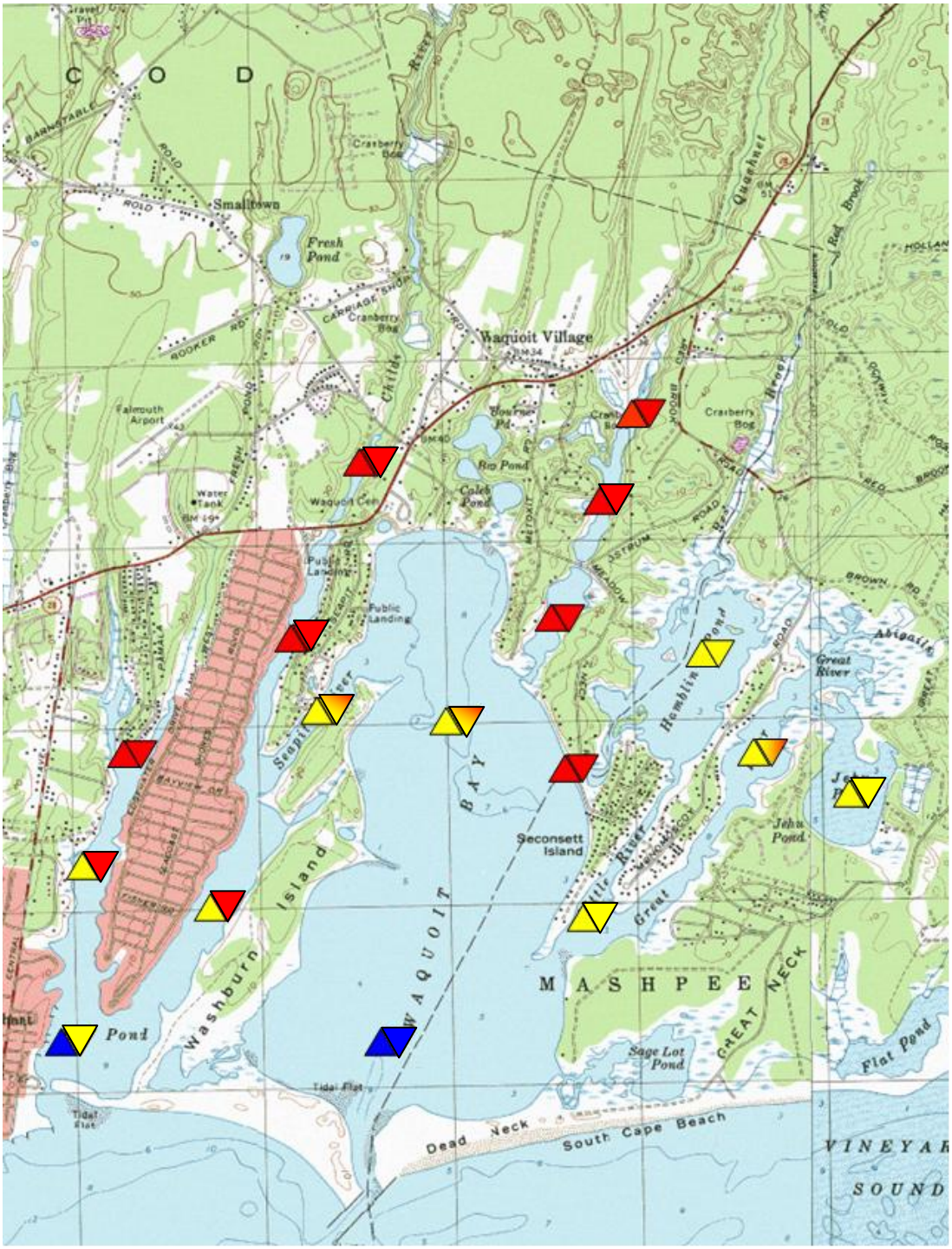

Figure 14. Nutrient related water quality of the Waquoit Bay system, based upon monitoring data from stations in Figure 4. The Health Index was developed for Buzzards Bay open water embayments. Note the gradient in nitrogen related water quality with lowest quality within the inland tidal reaches and highest nearest the tidal inlets. The Index colors are red=poor, yellow=moderate decline, blue high quality.

▲ Long-Term Data ▼ 2014 Data

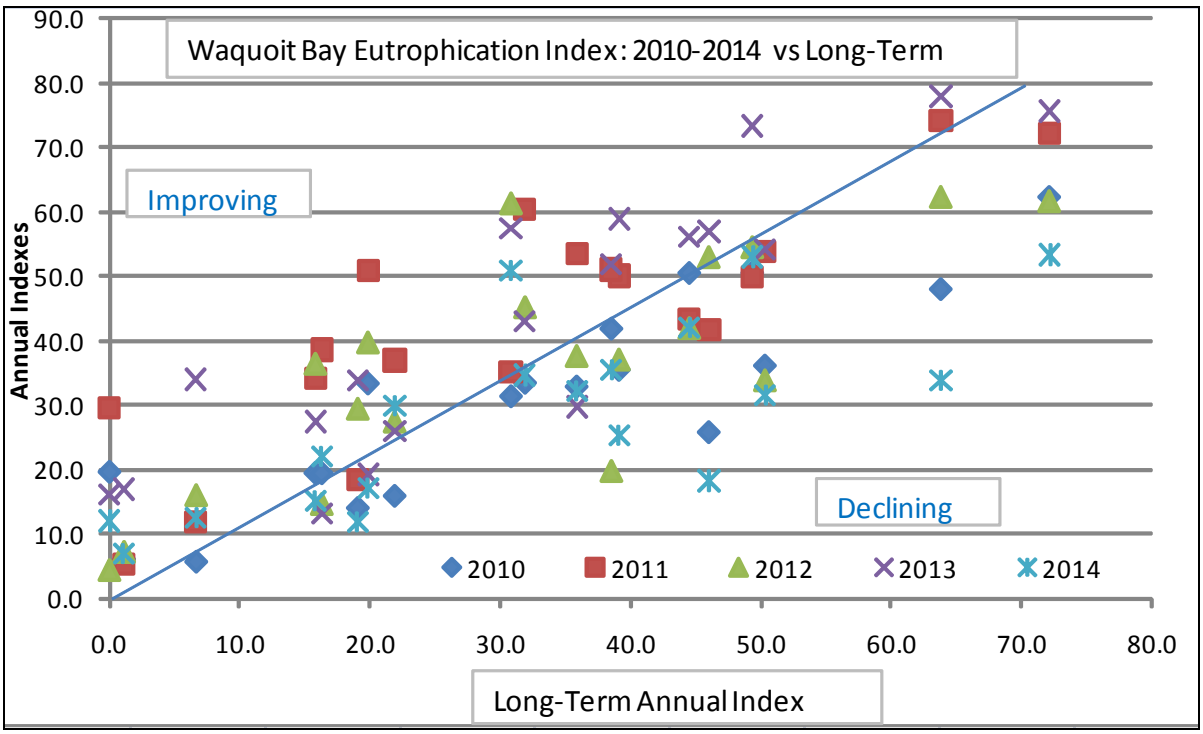

Figure 15. Eutrophication Index for each Waquoit Bay site from 2010-2014 (Y axis) versus the long term average for these sites (X axis). The 1:1 line represents not change, points above the line indicate improved conditions and points below the line indicate increased impairment.

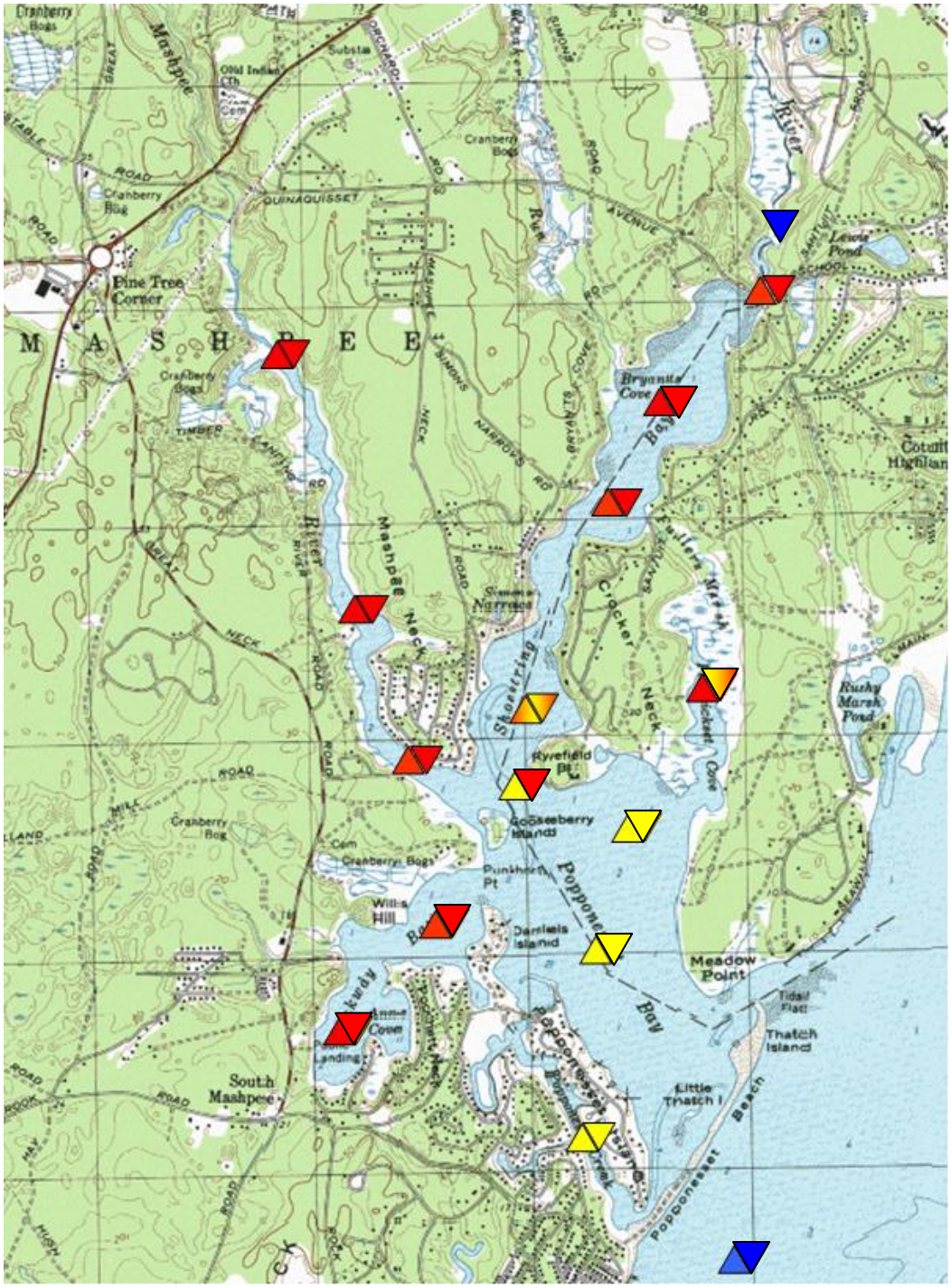

Figure 16. Nutrient related water quality of the Popponesset Bay system, based upon monitoring data from stations in Figure 5. The Health Index was developed for Buzzards Bay open water embayments. Note the gradient in nitrogen related water quality with lowest quality within the inland tidal reaches and highest nearest the tidal inlets. The Index colors are red=poor, yellow=moderate decline, blue high quality.

▲ Long-Term Data ▼ 2014 Data

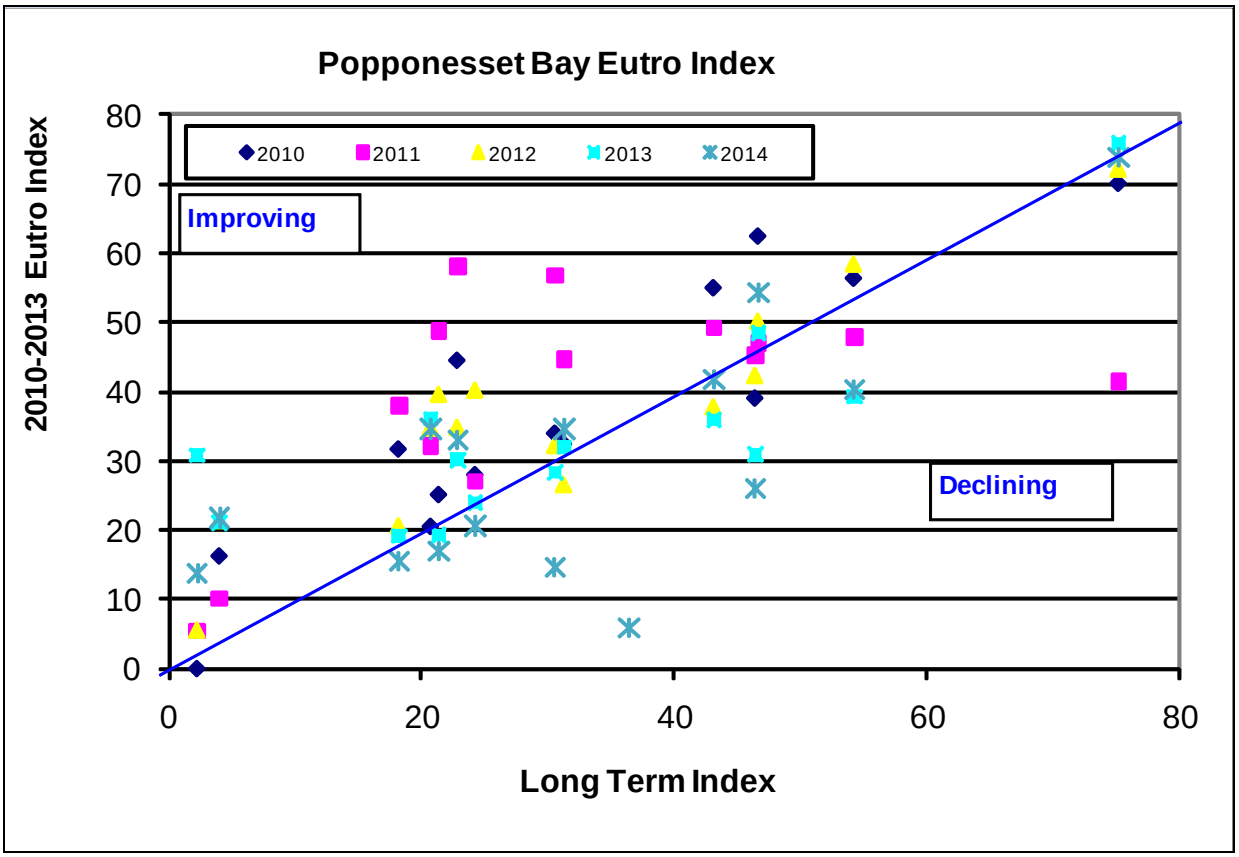

Figure 17. Eutrophication Index for each Popponesset Bay site from 2010-2014 (Y axis) versus the long term average for these sites (X axis). The 1:1 line represents not change, points above the line indicate improved conditions and points below the line indicate increased impairment.

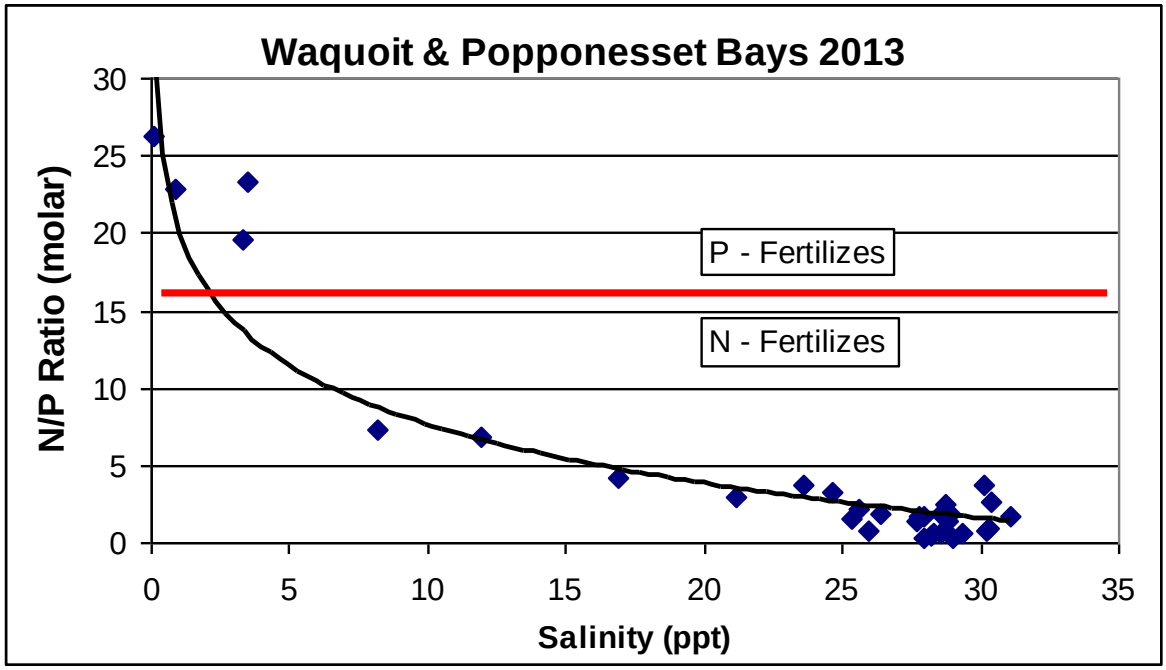

Figure 18. Changes in the nutrient causing eutrophication with watercolumn salinity. Typically phosphorus is the nutrient to be managed in freshwater systems and nitrogen in marine systems. The indications of phosphorus limitation are all within or adjacent discharging streams within either the Waquoit Bay or Popponesset Bay Estuaries. It appears that saline waters of both estuaries are nitrogen limited (N/P<16).