University of Massachusetts Dartmouth
The School for Marine Science and Technology

Overview of the 2009 Water Quality Monitoring Program for the Popponesset Bay and Waquoit Bay Estuaries

By:

Dr. Brian Howes
Dr. David White
Sara Sampieri

Coastal Systems Program
School of Marine Science and Technology (SMAST)
University of Massachusetts – Dartmouth

For:

Mashpee Water Quality Monitoring Consortium:

Mashpee Wampanoag Tribe
&
Town of Mashpee Waterways Commission

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1.0 BACKGROUND AND OVERVIEW:

The project goal was to collect and analyze water samples and associated field parameters relevant to assessing the nutrient related water quality of the Waquoit Bay and Popponesset Bay embayments, Cape Cod, MA (Figure 1). These data are needed to gauge the short and long term trends in water quality, to validate the Massachusetts Estuaries Project threshold modeling approach for Waquoit Bay and to determine 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.

The Mashpee Water Quality Monitoring Program is a 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 Mashpee Waterways Commission coordinated the requisite number of water sampling teams with technical support (training, protocols, sample analysis) by SMAST-CSP scientists. All sample analysis was conducted at the Coastal Systems Analytical Facility (SMAST). Each volunteer water sampling team was trained and outfitted with sampling equipment for collection of water samples at assigned sampling stations. Staff from the Coastal Systems Laboratory within SMAST were also involved in the field sampling both to assist the effort and as part of QA/QC procedures, as well as to insure proper transport and delivery of samples to the Coastal Systems Analytical Facility[1].

The Mashpee Water Quality Monitoring Program was developed and funded by the Mashpee Wampanoag Tribe and Town of Mashpee under a Memorandum of Understanding (2009) with the Coastal Systems Program. Project management is through the Mashpee Waterways Commission. The Program 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 collection of key habitat quality metrics throughout each system in the most cost effective manner possible. The program is the only method for providing a consistent 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.

[1] 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.

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

I.2 NUTRIENT LOADING

Nutrient related water quality decline represents one of the most serious threats to the ecological health of the nearshore coastal waters. Coastal embayments, because of their enclosed basins, shallow waters and large shoreline area, are generally the first indicators of nutrient pollution from terrestrial sources. By nature, these systems are highly productive environments, but nutrient over-enrichment of these systems worldwide is resulting in the loss of their aesthetic, economic and commercially valuable attributes. Each embayment system maintains a capacity to assimilate watershed nitrogen inputs without degradation. However, as loading increases a point is reached at which the capacity (termed 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. 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 2002 in the implementation of the Massachusetts Estuaries Project (MEP). The MEP's goal is to determine the nitrogen thresholds for each of southeastern Massachusetts estuaries to support TMDL development by 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 the eastern embayments of Waquoit Bay.[2]

In general, nutrient over-fertilization is termed “eutrophication” and when the nutrient loading is primarily from human activities, “cultural eutrophication”. Although the influence of human-induced changes has increased nitrogen loading to the systems and contributed to the degradation in ecological health, it is sometimes possible that eutrophication within Popponesset Bay and Waquoit Bay’s sub-embayments could potentially occur without man’s influence and must be considered in the nutrient threshold analysis. While this finding would not change the need for restoration, it would change the approach and potential targets for management. As part of future restoration efforts, it is important to understand that it may not be possible to turn each embayment into a “pristine” system.

Surface and groundwater flows are pathways for the transfer of land-sourced nutrients to coastal waters. Fluxes of primary ecosystem structuring nutrients, nitrogen and phosphorus, differ significantly as a result of their hydrologic transport pathway (i.e. streams versus groundwater). In sandy glacial outwash aquifers, such as in the watershed to the Popponesset Bay and Waquoit Bay Systems, phosphorus is highly retained during groundwater transport as a result of sorption to aquifer minerals (Weiskel and Howes 1992). Since even Cape Cod “rivers” are primarily

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[2] 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 benefit of the public.

groundwater fed, watersheds tend to release little phosphorus to coastal waters. In contrast, nitrogen, primarily as plant available nitrate, is readily transported through oxygenated groundwater systems on Cape Cod (DeSimone and Howes 1998, Weiskel and Howes 1992, Smith *et al.* 1991). The result is that terrestrial inputs to coastal waters tend to be higher in plant available nitrogen than phosphorus (relative to plant growth requirements). However, coastal estuaries tend to have algal growth limited by nitrogen availability, due to their flooding with low nitrogen coastal waters (Ryther and Dunstan 1971). Tidal reaches within Popponesset Bay and Waquoit Bay follow this general pattern, where the primary nutrient of eutrophication in these systems is nitrogen.

Unfortunately, the MEP analysis 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 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). In contrast, 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). The result is that nitrogen management of these estuaries is aimed at restoration, not protection or maintenance of existing conditions.

I.3 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 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: the 1) Popponesset (main basin + Popponesset Creek) Bay, 2) Pinquickset Cove, 3) Ockway Bay, 4) Mashpee River (lower or tidal region) and 5) Shoestring Bay (see 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 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, as 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 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 hurricanes of 1954. Similarly, within the main Bay, several islands apparent 50 -100 years ago have been incorporated into other landforms with unquantified 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 have been the modification to riparian zones either through channelization, restriction, or filling of freshwater wetlands and, in some cases, transformation to cranberry agriculture. Most of the alterations have reduced the nutrient buffering capacity of these systems, 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 as agriculture generally recycled nitrogen (as opposed to 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 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 may have 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, on Cape Cod Massachusetts. 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 System's shoreline 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). In recent years, the third inlet opened by Hurricane Bob (1991) helped to maintain the recent Waquoit Bay tidal range and circulation pattern. This important "natural" hydrodynamic shift coupled to anthropogenic alteration of the watershed support a recently highly altered estuarine habitat.

The Waquoit Bay is located in 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 kettles 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 Pond is entirely situated within the Town of Mashpee. Within the Quashnet River, Hamblin Pond, and Jehu Pond subembayments geomorphic and hydrologic alterations include the damming of the Quashnet (Moonakis) River to drive mills and alteration of riparian zone for cranberry agriculture, and 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 Child River lie within the Town of Falmouth. Their shorelines are highly developed, particularly in the area of Seacoast Shores and as a result of nitrogen entering from its watershed, Child 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 shoreline 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 at risk of eutrophication 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 decline.

Within 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 portion of Waquoit Bay and Eel Pond shows 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 only minimal tidal damping through Waquoit Bay inlet. It appears that the tidal inlet is operating efficiently, possibly due to the active inlet maintenance program and its dual inlet configuration. 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 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.

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.

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

2.0 ESTUARINE MONITORING

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 the eastern embayments of Waquoit Bay. The monitoring program has the secondary objective of supporting the current Massachusetts Estuaries Program (MEP) analysis for the entirety of the Waquoit Bay System.

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

- Waquoit Bay
    - Hamblin Pond
    - Jehu Pond
    - Main Bay
    - Childs River
    - Eel Pond
    - Quashnet River

The concept underlying the establishment of the Monitoring Program by the Mashpee Wampanoag Tribe and the Town of Mashpee is 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 effort is significantly reduced over prior programs on 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 to restore these nitrogen impaired bays. By establishing a stable, low frequency monitoring program and by using trained volunteers, there will be much lower costs of compliance monitoring to the Town and the program will be sustainable over the long-term. The reduced program builds upon the more intensive efforts conducted previously.

The Mashpee Waterways Commission (Steve Pinard) did the overall program organization with assistance from Rick York (Shellfish), including the recruiting of volunteers. The Mashpee Wampanoag Tribe Natural Resources Staff (Chuckie Green and Quan Tobey) were full partners in this effort and participated in each of the sampling events. The structure of the program relies

[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.

on volunteers, with each estuary having a "Bay Captain" who oversees the sampling teams for each event and ensures proper sample transfers and chain of custody. 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, the Coastal Systems Analytical Facility Manager. 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 (Table 1.).

Table 1. Mashpee Water Quality Monitoring Program Volunteers

Volunteer Field Teams - 2009	
Popponesset Bay	**Waquoit Bay**
Al Wickel - Bay Captain	John West - Bay Captain
Corinne Wickel	Steve Pinard
Joe Bohnenberger	Chuckie Green
Brian Howes	Quan Tobey
Hannah Howes	Rick York
Ken Molloy	Jay Finkle
Tim Leedham	Jaime Reagan
Freddy Bohnenberger	Jen Benson
Sara Sampieri	Dave Schlezinger
George Blaskenak	Gordon Stone
Gordon Stone	Kaitlyn Shaw
Steve Pinard	D. Sergio
	Alex Buckley
	Jim Hanks

Volunteers attended a training session prior to the first sampling. They received instruction on the procedures required for this effort including a brief introduction to the ecosystem and an overview of the rationale behind methods employed in sample collection and on-site measurements. Each volunteer was individually "checked-out" on each procedure. New volunteers were paired with experienced samplers for the initial samplings so that they could get supervised in-field experience.

Volunteer sampling teams were supplied with the necessary sampling equipment to conduct field measurements of physical parameters as well as collect water samples for subsequent nutrient analysis by our laboratory at SMAST. 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 2). All analytical methodologies have been previously approved for use by EPA, Mass. CZM, NOAA and NSF and the Massachusetts Estuaries Project.

Table 2. Summary of estuarine sampling and parameters analyzed:				
Location	**Dissolved Nutrients**	**Particulate Nutrients**	**Chlorophyll /Pheophytin**	**Field Parameters**
Waquoit Bay				
All CR, ER, WB 1-4 and 7-13	X	X	X	X
WB 5, 6	X	X		X
Popponesset Bay				
PB 2-15	X	X	X	X
PB 1 and SR 5	X	X		X

Sampling focused on the warmer summer period when nutrient related water quality conditions are the poorest. Sampling of both bays was on the same days and approximately followed: July (2), and August (2). This yielded a total of 4 events/year during the critical summer period. Samples were collected at mid water on an ebbing tide for nutrients at each station and surface, mid and bottom for 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 from the prior efforts is the reduction in the overall sampling effort (number of dates/year) while providing the same 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. The monitoring approaches and parameters assayed are fully consistent with the Quality Assurance Project Plan (QAPP)[4] of the Massachusetts Estuaries Project. Sampling was at 17 locations within Popponesset Bay (inclusive of offshore boundary station) and 20 locations within Waquoit Bay (inclusive of Eel Pond). Nutrients and physical parameters are collected at all stations.

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 per each combined (2 bay) sampling event. The offshore station is used as one gauge of the boundary conditions in nearshore Nantucket Sound. Samples and field data were collected from a total of 19 sample stations in Waquoit Bay and 16 stations in Popponesset Bay (Table 3).

[4] 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.

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 (Tables 4, 5). Stations were confirmed by GPS prior to sampling. Maps depicting sample station locations are provided below (Figures 4 and 5).

Table 3. Waquoit Bay and Popponesset Bay Water Quality Sampling Locations, 2009

Waquoit Bay	
CR 1-3	Childs River
ER 1-3	Eel River
WB 1	Jehu Pond
WB 2	Great River
WB 3	Little River
WB 4	Hamblin Pond
WB 5	Red Brook
WB 6-9	Quashnet River
WB 10	Hamblin Pond outlet
WB 11	Seapit River
WB 12-13	Waquoit Bay Main Basin
Popponesset Bay	
PB 1-4	Mashpee River
PB 5-7	Shoestring Bay
PB 8, 11, 12	Popponesset Bay Main Basin
PB 9, 10	Ockway Bay
PB 13	Popponesset Creek
PB 14	Off Shore
PB 15	Pinquickset Cove
SR 5	Mouth of Santuit River

Table 3. GPS coordinates and depths of nutrient sampling stations in Waquoit Bay.

Station ID	N Latitude	W Longitude	Approximate Station Depth (m)	Nutrient Samplig Depths			D.O. Sampling Depths		
				S	M	B	S	M	B
WB01	041° 34.0450'	070° 29.8850'	2.7		X		X	X	X
WB02	041° 34.1580'	070° 30.1790'	1.2		X		X	X	X
WB03	041° 33.6220'	070° 30.8840'	2.2		X		X	X	X
WB04	041° 34.4220'	070° 30.4050'	1.4		X		X	X	X
WB05	041° 34.9950'	070° 30.2070'	1.0		X		X	X	X
WB06	041° 35.5380'	070° 30.4630'	0.3		X		X	X	X
WB07	041° 35.1110'	070° 30.6710'	0.5		X		X	X	X
WB08	041° 34.9004'	070° 30.7488'	0.9		X		X	X	X
WB09	041° 34.5710'	070° 30.9440'	1.0		X		X	X	X
WB10	041° 34.1270'	070° 30.9200'	0.5		X		X	X	X
WB11	041° 34.2705'	070° 31.8480'	2.0		X		X	X	X
WB12	041° 34.2350'	070° 31.3630'	2.0		X		X	X	X
WB13	041° 33.2870'	070° 31.5990'	2.0		X		X	X	X
CR01	041° 34.9874'	070° 31.6998'	0.9		X		X	X	X
CR02	041° 34.4756'	070° 31.9713'	1.8		X		X	X	X
CR03	041° 33.6720'	070° 32.2800'	3.3		X		X	X	X
ER01	041° 34.0800'	070° 32.6000'	1.3		X		X	X	X
ER02	041° 33.6950'	070° 32.7520'	1.5		X		X	X	X
ER03	041° 33.2830'	070° 32.8900'	2.0		X		X	X	X

Table 4. GPS coordinates of nutrient sampling stations in Popponesset Bay.									
Station ID	N Latitude	W Longitude	Approximate Station Depth (m)	Nutrient Samplig Depths			D.O. Sampling Depths		
				S	M	B	S	M	B
PB01	041° 37.2009' N	070° 28.7708' W	0.5		X		X	X	X
PB02	041.6139845° N	070.4771713° W	0.8		X		X	X	X
PB03	041.6036111° N	070.4730555° W	1.0		X		X	X	X
PB04	041.5971195° N	070.4697864° W	1.2		X		X	X	X
PB05	041.6119700° N	070.4559767° W	1.1		X		X	X	X
PB06	041.6078354° N	070.4585044° W	1.0		X		X	X	X
PB07	041.5992058° N	070.4630269° W	0.8		X		X	X	X
PB08	041.5958333° N	070.4636111° W	2.0		X		X	X	X
PB09	041.5859712° N	070.4729739° W	1.5		X		X	X	X
PB10	041.5905555° N	070.4680555° W	1.3		X		X	X	X
PB11	041.5938888° N	070.4586111° W	1.3		X		X	X	X
PB12	041.5891666° N	070.4591666° W	1.0		X		X	X	X
PB13	041.5817285° N	070.4602189° W	2.2		X		X	X	X
PB14	041.5761111° N	070.4525000° W	1.7		X		X	X	X
PB15	041.6002473° N	070.4536499° W	0.8		X		X	X	X
SR5	041.6171472° N	070.4504029° W	1.3		X		X	X	X

Figure 4. Water quality sampling stations associated with the Waquoit Bay System (2001-2009). Samples were collected synopically between 5:30 - 8:30 AM on Ebbing tides.

Figure 5. Water quality sampling stations associated with the Popponesset Bay System (1997-2009). Samples were collected synopically between 5:30 - 8:30 AM on Ebbing tides.

2.1 SAMPLE COLLECTION "SUCCESS"

The Mashpee Water Quality Monitoring Program as re-established for the summer 2009 field season differed from previous monitoring programs for these 2 estuaries. First, both estuaries would be sampled simultaneously and all samples would be collected within a 3 hour time window. This required a minimum of 4 vessels for each estuary, as well as stream samplers. This required a significant increase in field teams and for the 2009 season about 1/2 of the volunteers were new to the program.

In any "new" program there can be a large disparity between the sample collection as planned and the actual sampling completed. Fortunately for the 2009 field season of the Mashpee Water Quality Monitoring Program there was a very high degree of sampling "success".[5] Of the ~1500 samples/assays to be performed in the sampling season 96% or more were successfully collected and analyzed (Table 6). This speaks to the dedication of the volunteers and magnifies the value of the program results.

Table 6. Comparison of sampling planned to actual samples collected for 2009 field season.

Mashpee Water Quality Program, 2009, Sampling "Success"

2009 Field Season	Specific Conduc	Meter D.O.	Winkler D.O.	Dissolved Nutrients PO4	NH4	NOx	DON	Particulates POC	PON	CHl-a
Waquoit Bay										
Planned # Samples:	223	223	29	80	80	80	80	80	80	80
Actual # Samples:	223	223	29	80	80	80	80	80	80	80
Popponesset Bay										
Planned # Samples:	188	188	20	68	68	68	68	68	68	68
Actual # Samples:	174	174	20	62	62	62	62	62	62	62
Summary										
% Sample Capture:	97%	97%	100%	96%	96%	96%	96%	96%	96%	96%
% Assays Completed:	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%

[5] Success is defined as the collection of sampled as scheduled in the locations designated and handled appropriately. Only scientifically valid samples are counted in this type of analysis.

3.0 MONITORING RESULTS

Nutrient related water quality decline represents the primary environmental problem facing the citizens of Mashpee, Falmouth and Barnstable concerning the Popponesset Bay and Waquoit Bay Systems. By nature, these systems are highly productive environments, but nutrient over-enrichment is occurring in estuaries world-wide and our local systems are similarly seeing loss of their aesthetic, economic and commercially valuable resources. Given the critical value of these systems both to the local economy and to the culture of Cape Cod, nitrogen management planning is 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). The results of the 2009 Mashpee Water Quality Monitoring Program indicate that both Popponesset Bay and Waquoit Bay are showing poor nutrient related water quality throughout most of their tidal reaches.

The salinity gradients within each estuary reflect 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 generally showing salinities <10 ppt (Figures 6 and 9). The consequence of the freshwater inflow rich in nitrogen from terrestrial sources is that these tidal rivers have a high potential for eutrophication.

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

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 (Figure 7 and 10). The pattern of nitrogen enrichment roughly follows the salinity gradients, as the major source of the "excess" nitrogen is from groundwater and surface water inflows. Within each subembayment nitrogen levels were highest within the headwaters and declined with decreasing distance from the tidal inlets. The lowest nitrogen levels were recorded at the stations proximate each inlet. In both systems it appears that the summer of 2009 may have supported slightly lower nitrogen waters overall compared to the average of the prior years of data collection. This small difference may have resulted from inter-annual variation in weather related factors (wind, rain, temperature, etc.) or may result from differences in the sampling program, specifically the tighter window of sampling around mid-ebb tide in 2009 than previous years. Detecting any temporal trend with certainty requires multi-year sampling, which will be provided by the new more rigorous sampling program. It is important to note that while the new program will allow better detection of small inter-annual changes in water quality, the prior sampling data is invaluable in establishing a valid base line for comparison.

Waquoit Bay does not presently have a system-wide Massachusetts Estuaries Project analysis or TMDL. However, the eastern embayments (Jehu Pond, Hamblin Pond, Quashnet River) have both assessments completed. The 2009 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 for Hamblin and Jehu Ponds to re-establish eelgrass habitat. 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.

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 2009 sampling results are consistent with the prior years in showing that nitrogen levels of these tributary basins are still well above their TMDL designated threshold. The threshold total nitrogen level for these basins varies from 0.5 mg L^{-1} for Shoestring and Ockway Bays (0.55 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.

The consequences of these elevated total nitrogen levels can be seen in the high amounts of phytoplankton biomass (measured as chlorophyll a) 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 support the largest blooms, although local factors can interfere with this response. The 2009 chlorophyll a levels support the contention that these estuaries are presently eutrophic. 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 11). While almost all waters of both systems have averages greater than 5 ug L^{-1}. These high 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 amount of phytoplankton reduces the degree of light penetrate into the water column 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 specifically.

Oxygen depletion of bottom waters was evident within both systems and was generally consistent with the distribution of nitrogen enrichment and elevated chlorophyll a. The major exception was in the Hamblin and Jehu Pond basins and associated waters. The lower oxygen in these basins than what would be anticipated from the nitrogen and chlorophyll a data results from the geomorphology of each basin. Both basins are drown kettle ponds and are deeper than much of the estuary. As a result wind driven mixing sometimes is insufficient to mix the watercolumn from surface to bottom and bottom waters can periodically become isolated. During these periods, oxygen consumption in the watercolumn and sediments exceeds the delivery of oxygen from the overlying waters and oxygen levels decline. The effect of water depth can be seen by comparing Jehu and Hamblin Pond oxygen levels to the much more eutrophic waters of the shallow upper and mid basins of Eel Pond (Table 7).

In order to integrate the various nutrient related parameters collected as part of the monitoring program 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. 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, the average summer conditions throughout the Waquoit Bay and Popponesset Bay Systems were used to parameterize the Bay Health Index (Tables 7 and 8). The scores for each parameter were calculated and the average score for each station (across the 5 parameter metric) was calculated (Table 9 and 10). These scores are then compared to a guide of "acceptable" ranges for each parameter to rank the station (Table 11). 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. The 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 high quality being adjacent 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 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.

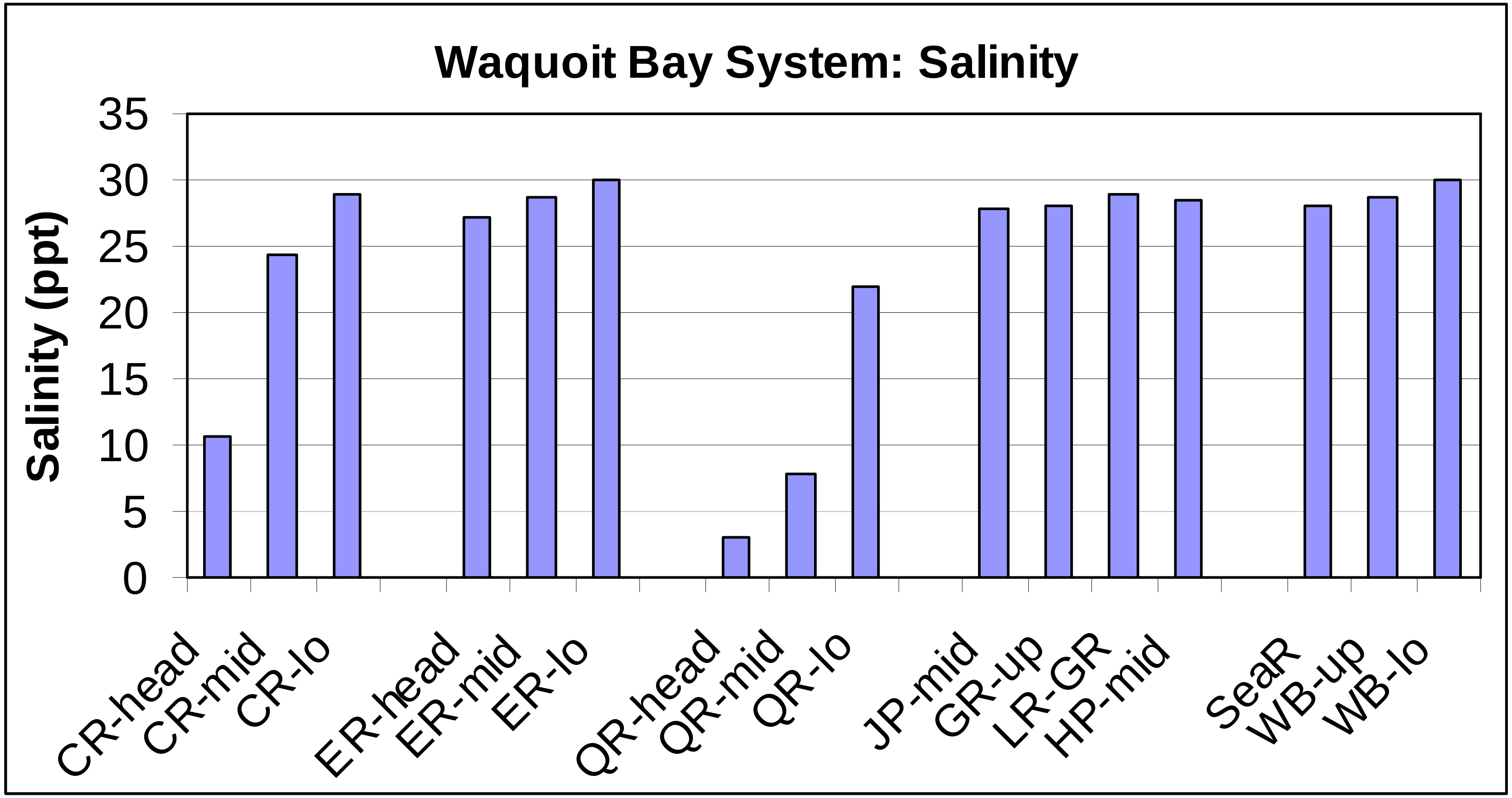

Figure 6. Salinity Distribution throughout the Waquoit Bay Estuarine System. Freshwater enters through groundwater all along the shoreline, with additional "point" inflows from the Moonakis River, Childs River, and Red Brook. These freshwaters mix with the saline waters of Nantucket Sound entering through 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.

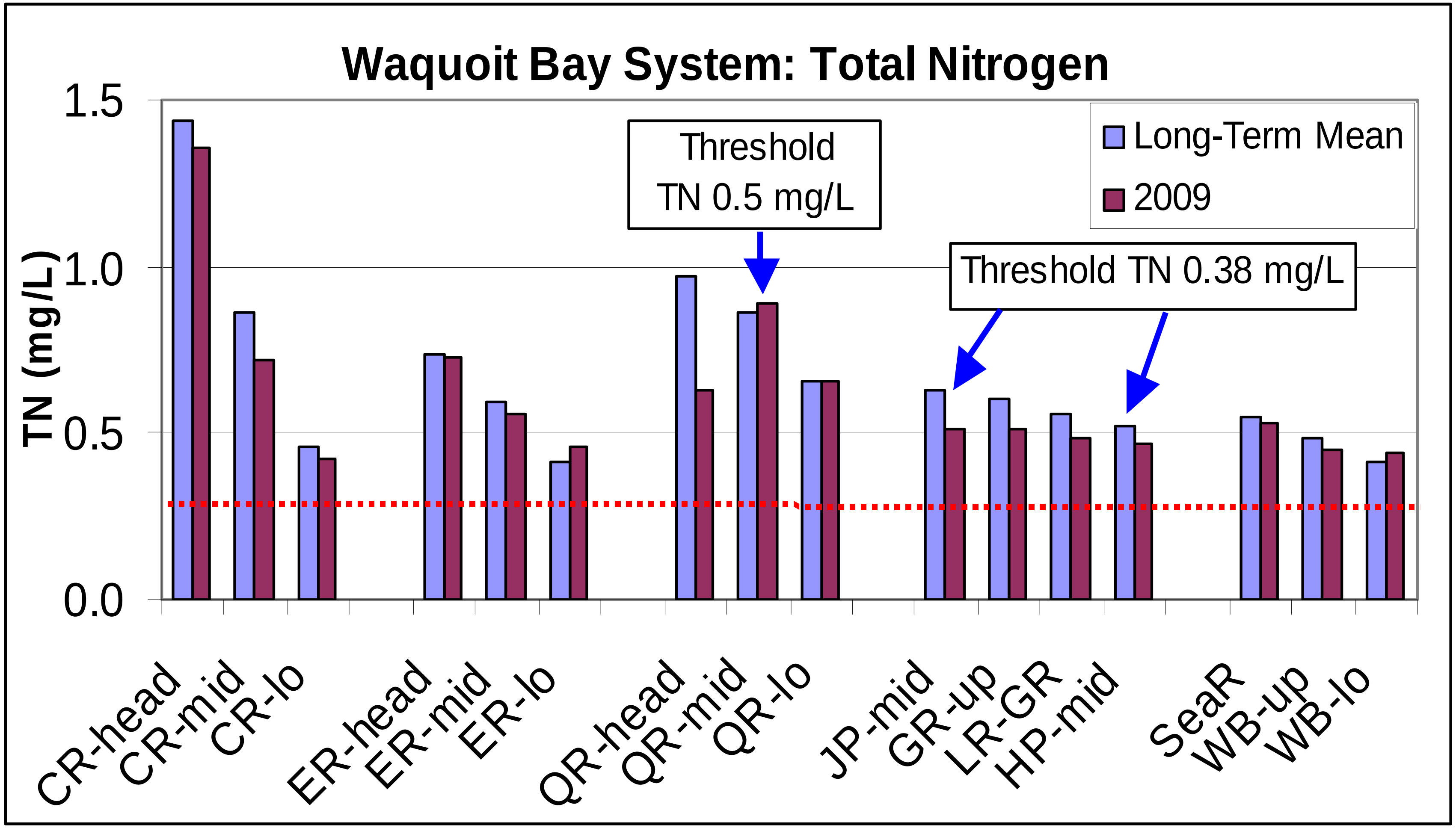

Figure 7. Distribution of Total Nitrogen within the Waquoit Bay Estuarine System. Nitrogen enters through groundwater inflows all along the shoreline, with additional "point" loads from the upper regions of the watershed via Moonakis River, Childs River, and Red Brook. These nitrogen loads plus recycling 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. TN levels in 2009 are compared to the long-term average.

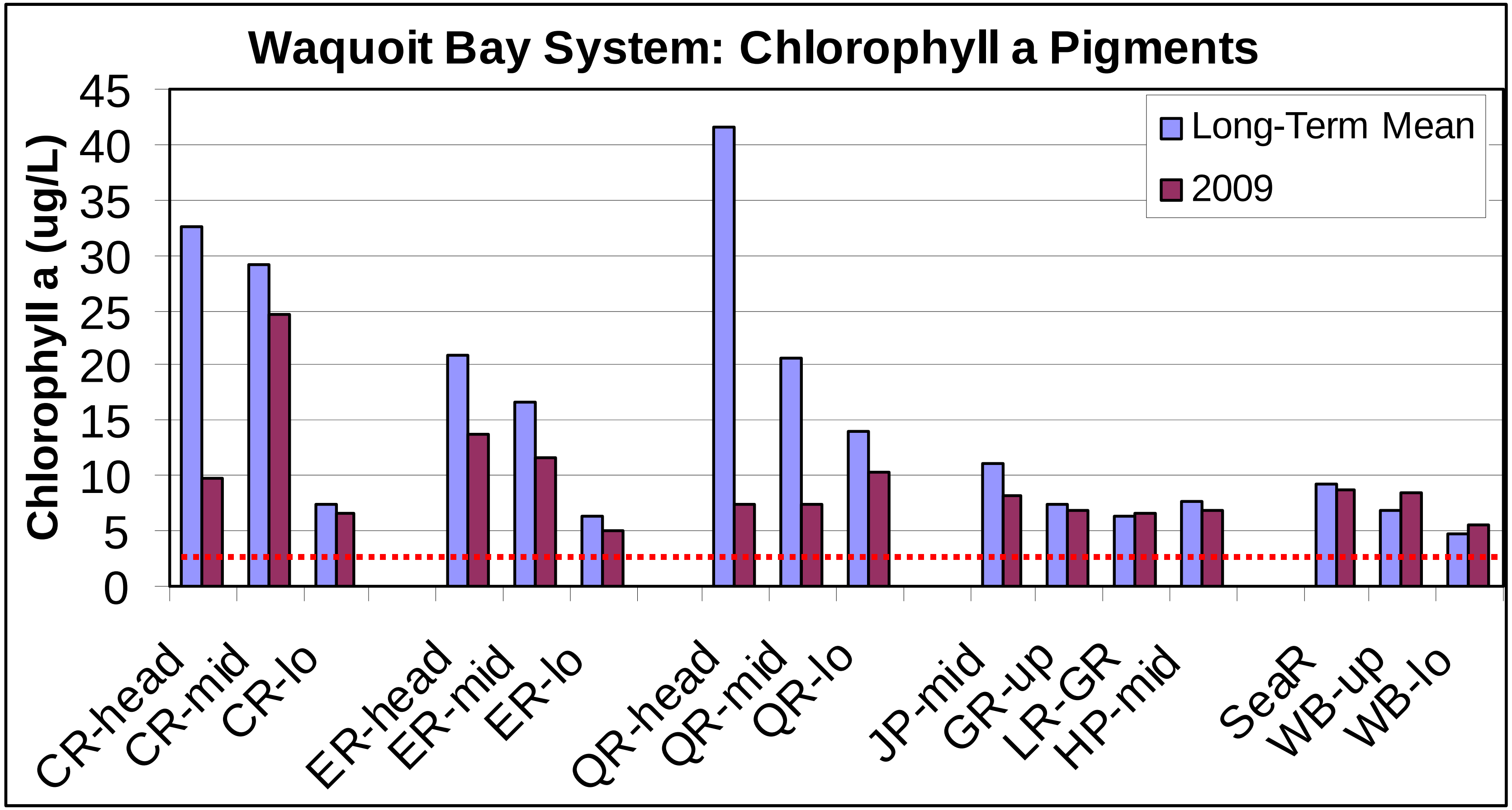

Figure 8. Total Chlorophyll a pigment levels throughout the Waquoit Bay Estuarine System over the long-term and in summer 2009. Phytoplankton pigment levels are a gauge of phytoplankton biomass, which is a response to nitrogen loading. Values over 10 indicate nitrogen enrichment, values ≤3 represent 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.

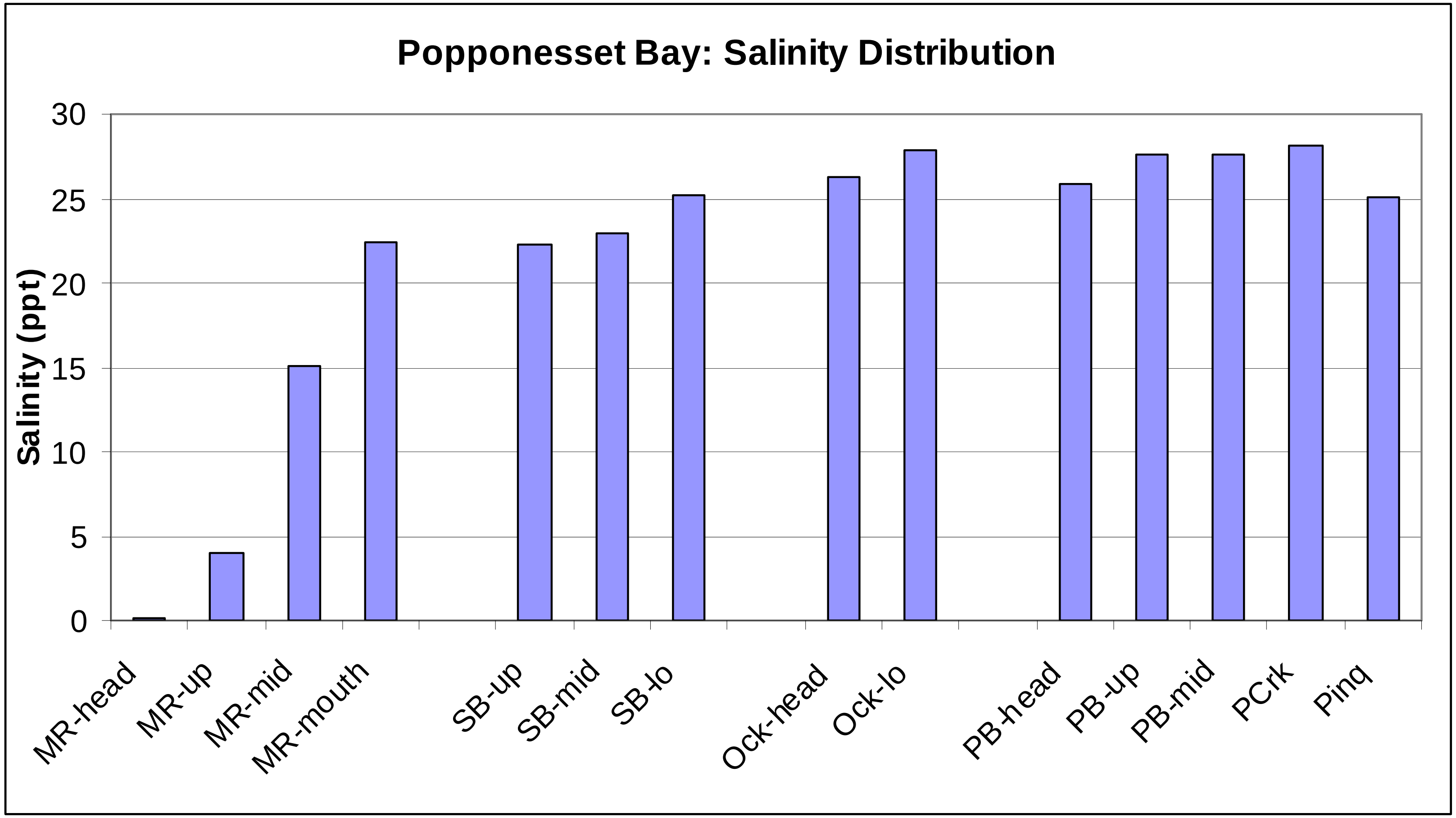

Figure 9. Salinity Distribution throughout the Popponesset Bay Estuarine System. Freshwater enters through groundwater all along the shoreline, with additional "point" inflows from the freshwater reach of the Mashpee River and from the Santuit River to Shoestring Bay. These freshwaters mix with the saline 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.

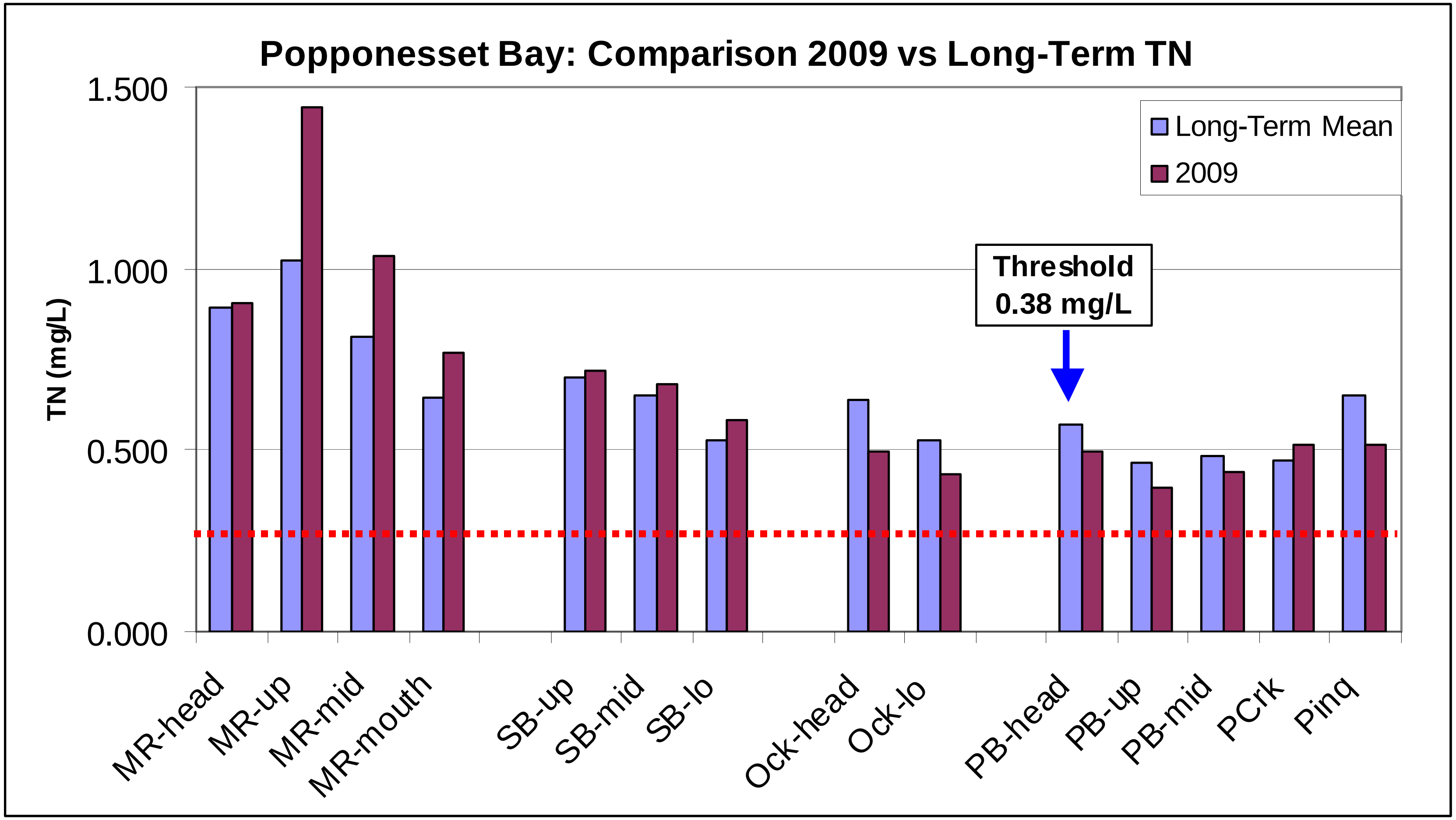

Figure 10. Distribution of Total Nitrogen within the Popponesset Bay Estuarine System. Nitrogen enters through groundwater inflows all along the shoreline, with additional "point" loads from the upper regions of the watershed via the Mashpee River and Santuit River to Shoestring Bay. These nitrogen loads 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 2009 are compared to the long-term average.

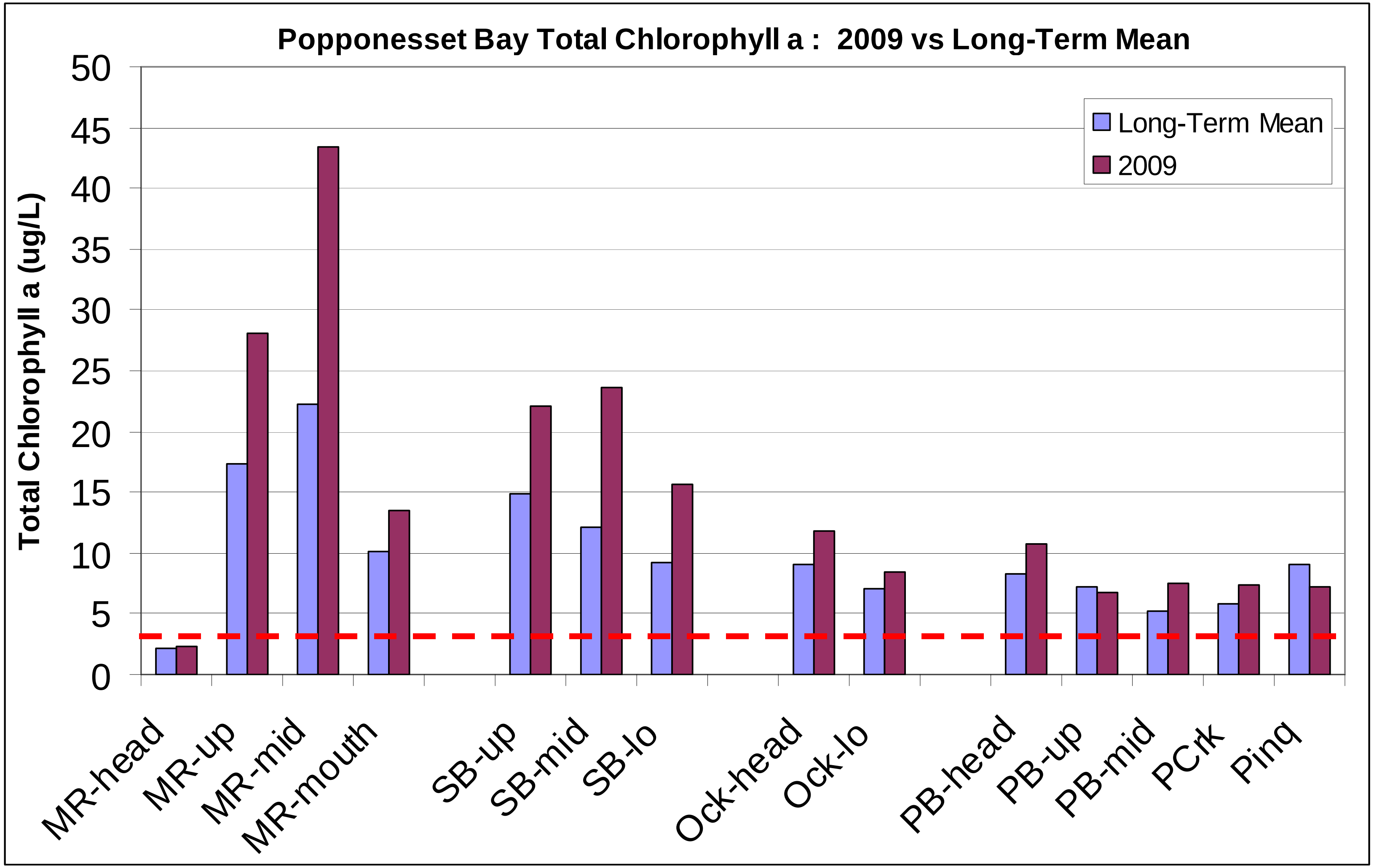

Figure 11. Total Chlorophyll a pigment levels throughout the Popponesset Bay Estuarine System over the long-term and in summer 2009. Phytoplankton pigment levels are a gauge of phytoplankton biomass, which is a response to nitrogen loading. Values over 10 indicate nitrogen enrichment, values <u><</u>3 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.

Table 7. Summary of water quality parameters in Waquoit Bay. Summers 2001-2009.

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)
Childs River																
CR01	0.7	0.7	97.2%	10.6	1.14	16.0%	0.021	0.073	0.413	0.487	0.355	0.592	0.947	1.434	50	32.647
CR02	1.2	1.6	77.1%	24.4	2.78	35.0%	0.012	0.023	0.040	0.062	0.355	0.445	0.800	0.862	12	29.002
CR03	1.8	3.0	62.2%	28.9	3.91	55.5%	0.021	0.035	0.007	0.042	0.281	0.136	0.417	0.459	4	7.542
Eel River																
ER01	1.1	1.2	86.2%	27.2	2.66	45.1%	0.006	0.026	0.010	0.036	0.374	0.326	0.700	0.736	13	20.835
ER02	1.1	1.3	83.4%	28.7	3.69	54.7%	0.007	0.009	0.003	0.013	0.335	0.242	0.577	0.590	4	16.605
ER03	1.7	1.8	94.0%	30.1	4.66	69.3%	0.016	0.012	0.003	0.015	0.263	0.136	0.399	0.413	2	6.47
Waquoit Bay																
WB01	1.9	2.3	85.3%	27.8	2.90	43.7%	0.016	0.019	0.004	0.023	0.429	0.173	0.602	0.625	3	11.22
WB02	1.3	1.3	100.0%	27.9	4.14	60.7%	0.019	0.025	0.005	0.030	0.430	0.146	0.575	0.602	3	7.41
WB03	1.7	1.9	93.7%	28.9	4.44	63.9%	0.026	0.024	0.005	0.029	0.401	0.121	0.525	0.554	2	6.35
WB04	1.2	1.2	98.3%	28.5	4.03	60.5%	0.028	0.016	0.004	0.020	0.362	0.141	0.504	0.524	2	7.68
WB05	1.0	1.0	98.4%	0.3	1.80	11.7%	0.016	0.016	0.015	0.031	0.480	0.157	0.624	0.655	4	9.82
WB06	0.4	0.3	100.0%	0.4	7.54	ND	0.011	0.015	0.177	0.192	0.244	0.095	0.356	0.520	39	5.16
WB07	0.5	0.4	99.7%	3.0	1.98	24.7%	0.017	0.047	0.153	0.200	0.272	0.517	0.795	0.971	26	41.62
WB08	0.9	0.9	96.7%	7.8	2.15	27.6%	0.020	0.042	0.065	0.107	0.341	0.416	0.757	0.864	12	20.54
WB08A	1.0	1.1	93.6%	9.1	5.94	77.8%	0.016	0.002	0.036	0.038	0.373	0.914	1.287	1.325	5	30.81
WB09	1.0	1.0	97.6%	21.9	2.61	36.9%	0.030	0.029	0.018	0.046	0.356	0.250	0.610	0.655	3	14.05
WB10	0.4	0.4	100.0%	28.4	3.03	44.7%	0.031	0.034	0.006	0.040	0.387	0.156	0.543	0.583	3	8.42
WB11	1.6	1.8	89.7%	28.0	4.33	59.5%	0.027	0.032	0.008	0.041	0.356	0.153	0.509	0.550	3	9.20
WB12	1.8	1.9	94.0%	28.6	3.87	53.4%	0.022	0.014	0.005	0.020	0.337	0.132	0.468	0.488	2	6.83
WB13	1.8	1.9	96.1%	30.0	5.13	79.6%	0.020	0.013	0.003	0.017	0.295	0.104	0.399	0.416	2	4.81

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 8. Summary of water quality parameters in Popponesset Bay. Summers 1997-2009.

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	0.5	0.5	100.0%	0.2	7.8	83.1%	0.010	0.094	0.410	0.502	0.330	0.062	0.393	0.893	111	2.08
PB02	0.5	0.5	100.0%	4.0	3.9	43.0%	0.012	0.067	0.269	0.336	0.299	0.383	0.688	1.023	64	17.29
PB03	0.8	0.8	99.2%	15.1	2.9	37.7%	0.016	0.056	0.080	0.136	0.366	0.324	0.685	0.812	19	22.29
PB04	1.1	1.1	99.4%	22.4	3.8	50.0%	0.016	0.045	0.029	0.074	0.357	0.210	0.568	0.643	10	10.09
PB05	0.8	0.8	98.3%	22.3	3.4	47.0%	0.014	0.036	0.028	0.064	0.322	0.316	0.639	0.703	10	14.84
PB06	0.8	0.8	98.3%	23.0	3.5	48.2%	0.015	0.030	0.017	0.049	0.326	0.275	0.600	0.648	7	12.04
PB07	0.8	0.8	99.7%	25.3	3.8	53.2%	0.017	0.033	0.013	0.046	0.287	0.198	0.489	0.529	6	9.18
PB08	1.9	3.7	78.5%	25.8	4.2	59.2%	0.016	0.035	0.013	0.048	0.351	0.173	0.523	0.570	7	8.24
PB09	1.0	1.0	98.7%	26.2	2.6	36.2%	0.015	0.023	0.010	0.034	0.417	0.195	0.607	0.641	5	9.00
PB10	1.0	1.0	98.9%	27.8	2.7	37.8%	0.015	0.024	0.008	0.033	0.334	0.157	0.492	0.525	5	6.98
PB11	1.1	1.1	99.8%	27.6	3.9	54.2%	0.016	0.030	0.010	0.040	0.285	0.142	0.425	0.465	6	7.28
PB12	1.2	1.2	99.9%	27.6	4.4	60.7%	0.015	0.027	0.009	0.036	0.326	0.122	0.447	0.483	5	5.19
PB13	2.1	2.3	95.4%	28.2	4.1	57.0%	0.015	0.035	0.010	0.045	0.333	0.099	0.426	0.470	7	5.84
PB14	2.2	2.2	99.8%	28.1	5.7	79.6%	0.011	0.025	0.007	0.031	0.268	0.088	0.355	0.380	6	3.87
PB15	0.8	0.8	100.0%	25.1	2.7	35.9%	0.019	0.025	0.004	0.031	0.378	0.246	0.624	0.654	4	8.98
Santuit River																
SR01	ND	1.2	ND	ND	ND	ND	0.003	0.012	0.072	0.084	0.309	0.116	0.420	0.495	69	ND
SR02	0.1	0.1	62.5%	ND	ND	ND	0.012	0.048	0.264	0.313	0.301	0.106	0.415	0.711	57	ND
SR03	0.2	0.2	81.3%	0.2	ND	ND	0.014	0.058	0.673	0.731	0.228	0.108	0.339	1.054	115	ND
SR04	0.2	0.2	88.0%	1.2	ND	ND	1.069	0.112	0.709	0.920	0.222	0.227	0.416	1.345	2	27.33
SR05	0.6	0.7	93.3%	7.8	2.9	36.9%	0.024	0.081	0.396	0.479	0.276	0.340	0.614	1.097	45	16.11

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

Station	SALINITY (ppt)	SECCHI SCORE	Low20% Oxsat SCORE	DIN SCORE	TON SCORE	T-Pig SCORE	EUTRO Index	HEALTH STATUS
CR01	10.6	5.6	0.0	0.0	0.0	0.0	1.4	Fair/Poor
CR02	24.4	43.9	0.0	35.2	0.0	0.0	19.8	Fair/Poor
CR03	28.9	66.6	40.3	52.1	47.7	23.4	51.7	Moderate
ER01	27.2	35.9	14.7	58.9	0.0	0.0	27.4	Fair/Poor
ER02	28.7	35.6	38.7	100.0	5.1	0.0	44.8	Moderate
ER03	30.1	63.2	67.8	98.4	53.7	36.2	70.8	High
WB01	27.8	70.5	10.9	78.2	0.0	0.0	39.9	Moderate
WB02	27.9	46.9	51.4	67.0	5.5	24.9	42.7	Moderate
WB03	28.9	65.4	57.8	68.4	17.6	37.7	52.3	Moderate
WB04	28.5	42.2	51.0	84.5	23.0	22.0	50.2	Moderate
WB07	3.0	0.0	0.0	0.0	0.0	0.0	0.0	Fair/Poor
WB08	7.8	21.7	0.0	11.6	0.0	0.0	8.3	Fair/Poor
WB08A	9.1	33.6	82.0	56.7	0.0	0.0	43.1	Moderate
WB09	21.9	33.6	0.0	48.0	0.0	0.0	20.4	Fair/Poor
WB10	28.4	0.0	13.8	54.2	13.0	14.3	20.3	Fair/Poor
WB11	28.0	61.5	49.0	53.8	21.5	7.0	46.4	Moderate
WB12	28.6	67.1	35.5	84.9	32.5	31.7	55.0	Moderate
WB13	30.0	69.5	84.8	92.3	53.4	60.8	75.0	High

High Quality = >69; High/Moderate = 61-69; Moderate = 39-61; Moderate/Fair = 31-39; Fair/Poor = <31

Table 10. Trophic Health Index Scores and status for water quality monitoring stations in Popponesset Bay based upon open water embayment (not salt marsh) habitat quality scales (described in Howes et al. 1999) at www.savebuzzardsbay.org).

Station	SALINITY (ppt)	SECCHI SCORE	Low20% Oxsat SCORE	DIN SCORE	TON SCORE	T-Pig SCORE	EUTRO Index	HEALTH STATUS
PB02	4.0	0.0	9.0	0.0	0.0	0.0	2.2	Fair/Poor
PB03	15.1	14.9	0.0	1.1	0.0	0.0	4.0	Fair/Poor
PB04	22.4	34.8	27.6	27.4	7.1	0.0	24.3	Fair/Poor
PB05	22.3	18.9	19.8	34.0	0.0	0.0	18.2	Fair/Poor
PB06	23.0	16.8	23.1	45.6	0.0	0.0	21.4	Fair/Poor
PB07	25.3	14.6	35.3	48.3	26.9	7.1	31.3	Mod/Fair
PB08	25.8	72.7	48.3	46.5	18.1	16.1	46.4	Moderate
PB09	26.2	29.3	0.0	62.0	0.0	8.7	22.8	Fair/Poor
PB10	27.8	33.1	0.0	63.2	25.9	29.8	30.6	Fair/Poor
PB11	27.6	35.7	37.4	54.3	45.1	26.3	43.1	Moderate
PB12	27.6	42.6	ND	58.6	38.7	54.5	46.6	Moderate
PB13	28.2	79.3	43.7	48.8	45.1	44.6	54.2	Moderate
PB14	28.1	81.5	84.9	65.6	68.7	78.9	75.2	High
PB15	25.1	17.8	0.0	65.2	0.0	9.0	20.7	Fair/Poor
SR05	7.8	2.8	0.0	0.0	0.0	0.0	0.7	Fair/Poor

High Quality = >69; High/Moderate = 61-69; Moderate = 39-61; Moderate/Fair = 31-39; Fair/Poor = <31

Table 11. 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
0%	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 logrithmic.

Figure 12. Nutrient related water quality of the Popponesset Bay system, based upon monitoring data from stations in Figure 3. 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.

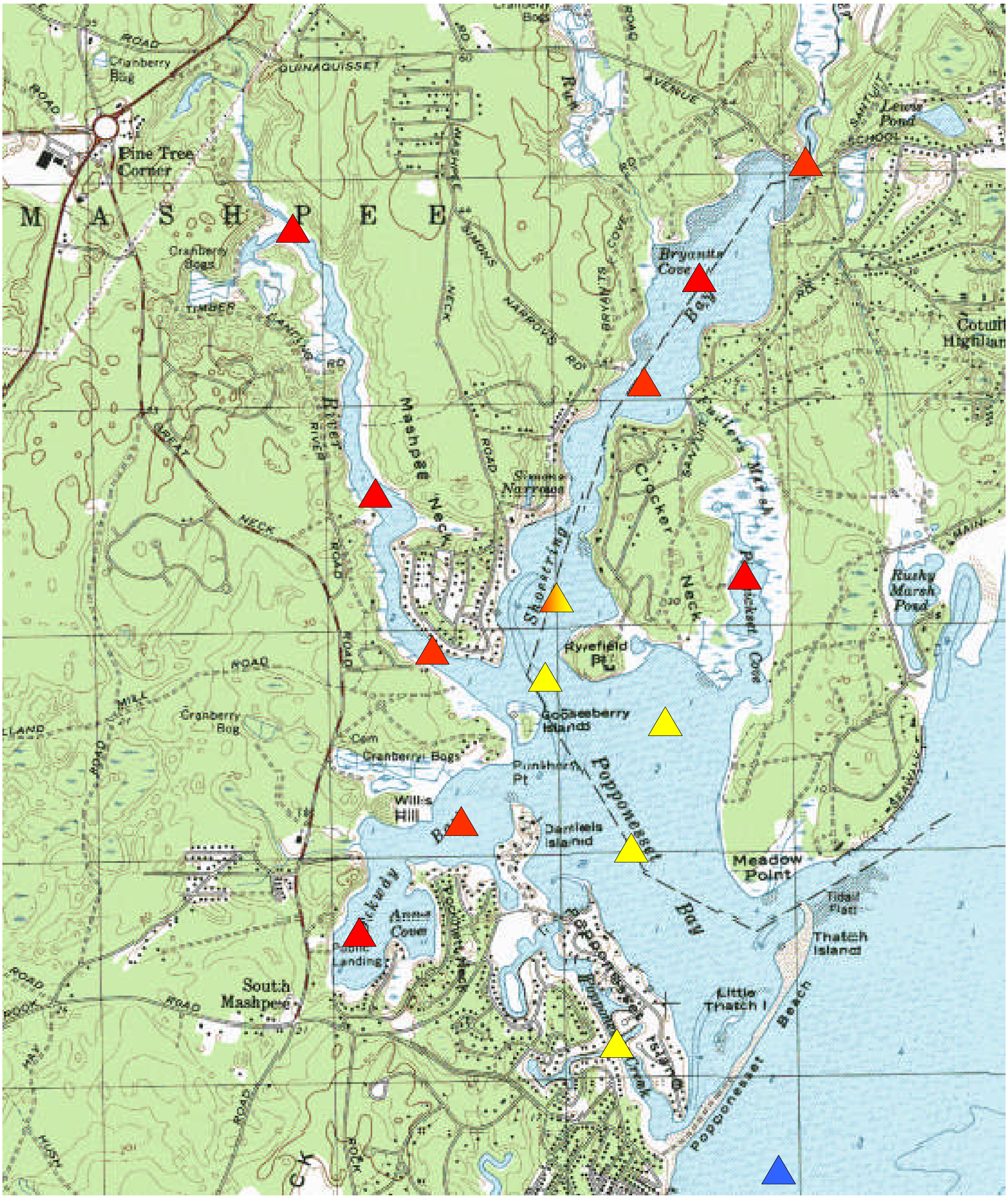

Figure 13. Nutrient related water quality of the Popponesset Bay system, based upon monitoring data from stations in Figure 3. The Health Index was developed for Buzzards Bay open water embayments. Note the gradient in nitrogen related water quality with lowest quality within the inland tidal reaches and highest nearest the tidal inlet. The Index colors are red=poor, yellow=moderate decline, blue high quality.

4.0 SUMMARY

Overall, both the Waquoit Bay and Popponesset Bay Estuarine Systems are highly nitrogen enriched and showing impaired nutrient related water quality, both over the past decade and again in 2009. 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.

The first year of the Mashpee Water Quality Monitoring Program was very successful in a number of ways. From an organizational aspect the full complement of volunteers were recruited, trained and collected 96%+ of the planned samples. Equally important, the information generated provides a sound assessment of the present health of the bays. The Monitoring Program has 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 achieved 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 that previously. The effort is a testament to the dedication of the volunteers the Mashpee Wampanoag Tribe and the Town of Mashpee to the protection and restoration of the important coastal systems.