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Wareham River Estuary System Total Maximum Daily Load for Total Nitrogen

Commonwealth of Massachusetts
Executive Office of Energy and Environmental Affairs
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August 2023
CN 549.00
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MassDEP

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Prepared by:
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Massachusetts Department of Environmental Protection

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Massachusetts Department of Environmental Protection

MassDEP's mission is to protect and enhance the Commonwealth's natural resources – air, water, and land – to provide for the health, safety, and welfare of all people, and to ensure a clean and safe environment for future generations. In carrying out this mission MassDEP commits to address and advance environmental justice and equity for all people of the Commonwealth; provide meaningful, inclusive opportunities for people to participate in agency decisions that affect their lives; and ensure a diverse workforce that reflects the communities we serve.

Watershed Planning Program

The Watershed Planning Program is a statewide program in the Division of Watershed Management, Bureau of Water Resources, at MassDEP. We are stewards of the water resources of Massachusetts. Together with other state environmental agencies, we share in the duty and responsibility to protect, enhance, and restore the quality and value of the waters of the Commonwealth. We are guided by the federal Clean Water Act and work to secure the environmental, recreational, and public health benefits of clean water for the residents of Massachusetts. The Watershed Planning Program is organized into five Sections that each have a different technical focus under the Clean Water Act: (1) Surface Water Quality Standards; (2) Surface Water Quality Monitoring; (3) Data Management and Water Quality Assessment; (4) Total Maximum Daily Load; and (5) Nonpoint Source Pollution.

Acknowledgements

The Wareham River Estuary System TMDL for Total Nitrogen was developed with data collected, compiled, and analyzed by the University of Massachusetts Dartmouth's School of Marine Science and Technology (SMAST), the Southeast Regional Planning & Economic Development District (SRPEDD), the Buzzards Bay Coalition (BBC) BayWatchers Water Quality Monitoring Program, and the Town of Wareham, as part of the Massachusetts Estuaries Project (MEP).

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References to trade names, commercial products, manufacturers, or distributors in this report constituted neither endorsement nor recommendations by MassDEP.

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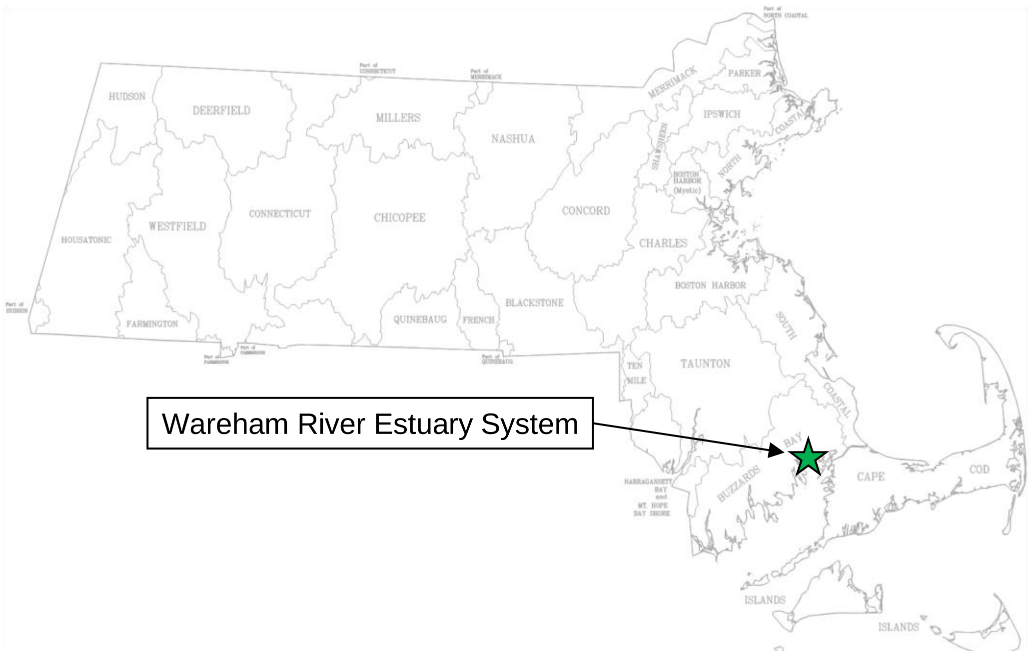

Key Feature:	Total Nitrogen TMDL for the Wareham River Estuary System
Location:	EPA Region 1 – MA Towns of Wareham, Plymouth, & Carver
Land Type:	New England Coastal
2022 Integrated List of Waters Category 5 303d Listings:	Wareham River (MA95-03) - *Total Nitrogen* - *Chlorophyll-a* - *Estuarine Bioassessments* Agawam River (MA95-29) - *Total Nitrogen* - *Algae* - *Nutrient/Eutrophication Biological Indicators*
Data Sources:	University of Massachusetts Dartmouth - School for Marine Science and Technology; US Geological Survey; Applied Coastal Research and Engineering, Inc.; Southeast Regional Planning & Economic Development District, Cape Cod Commission, Buzzards Bay Coalition (BBC) Baywatchers
Data Mechanism:	Massachusetts Surface Water Quality Standards, Ambient Data, and Linked Watershed-Embayment Nitrogen Model
Monitoring Plan:	Buzzards Bay Coalition (BBC) BayWatchers Water Quality Monitoring Program with assistance from SMAST-UMD
Control Measures:	Sewer Network Expansion, Wastewater Treatment Facility Improvements, Stormwater Management, Attenuation by Impoundments and Wetlands, Fertilizer Use By-laws

Executive Summary

The Massachusetts Department of Environmental Protection (MassDEP) is responsible for monitoring the waters of the Commonwealth, identifying those waters that are impaired, and developing a plan to bring them back into compliance with the Massachusetts Surface Water Quality Standards. The list of impaired waters, also referred to as Category 5 of the State Integrated List of Waters or the "303d list", identifies river, lake, and coastal waters and the cause for impairment. All impaired waters listed in Category 5 require the development of a Total Maximum Daily Load (TMDL).

Once a waterbody is identified as impaired (i.e., not supporting designated uses as established in the Massachusetts Surface Water Quality Standards), MassDEP is required by the federal Clean Water Act (CWA) to essentially develop a "pollution budget" designed to restore the health of the impaired waterbody. The process of developing this pollution budget, generally referred to as a TMDL, includes identifying the source(s) of the pollutant from direct discharges (point sources) and indirect discharges (nonpoint sources), determining the maximum amount of the pollutant that can be discharged to a specific waterbody to meet water quality standards, and developing a plan to meet that goal.

This report develops total nitrogen TMDLs for an interconnected set of six waterbodies within the Wareham River, Broad Marsh, and Marks Cove Embayment System and its upstream waters, hereinafter referred to as the "Wareham River Estuary System".

Problem Statement

Excessive nitrogen (N) originating from a range of sources has impaired the Wareham River Estuary System. In general, excessive N in these waters are indicated by:

- Loss of eelgrass beds, which are critical habitats for macroinvertebrates and fish;
- Undesirable increases in macroalgae, which are much less beneficial than eelgrass;
- Periodic decreases in dissolved oxygen concentrations that threaten aquatic life;
- Reductions in the diversity of benthic animal populations; and
- Periodic algae blooms.

With proper management of nitrogen inputs these trends can be reversed. Without proper management more severe problems might develop, including:

- Periodic fish kills;
- Unpleasant odors and scum; and
- Benthic communities reduced to the most stress-tolerant species, or in the worst cases, near loss of the benthic animal communities.

While the estuary is located entirely within the Town of Wareham, its watershed is located within the three towns of Wareham, Carver, and Plymouth. The communities surrounding the Wareham River Estuary System rely on clean, productive, and aesthetically pleasing marine and estuarine waters for recreational boating and swimming, as well as fishing and shellfishing. Failure to reduce and control N loadings will result in complete replacement of eelgrass by macroalgae, a higher frequency of decreases in dissolved oxygen concentrations and fish kills, widespread occurrence of unpleasant odors and visible scum, and a complete loss of benthic macroinvertebrates throughout most of the embayment. As a result of these environmental impacts, commercial and recreational uses of the Wareham River Estuary System coastal waters will be greatly reduced.

Sources of Nitrogen

Nitrogen enters the waters of coastal embayments from the following sources:

- The watershed
  - on-site subsurface wastewater disposal (septic) systems
  - natural background
  - runoff from impervious surfaces
  - fertilizers
  - wastewater treatment facilities (WWTF)
  - landfills
  - agricultural activities
- Atmospheric deposition
- Nutrient-rich bottom sediments in the embayments/ponds

Figure ES-A illustrates the percent contribution of all the sources of N and the *controllable* N sources to the estuary system, respectfully. Values are based on Table IV-2 and Figure IV-5 from the Massachusetts Estuaries Project (MEP) Technical Report (Howes *et. al*, 2014). Most of the present *controllable* load to this system comes from agriculture and septic systems.

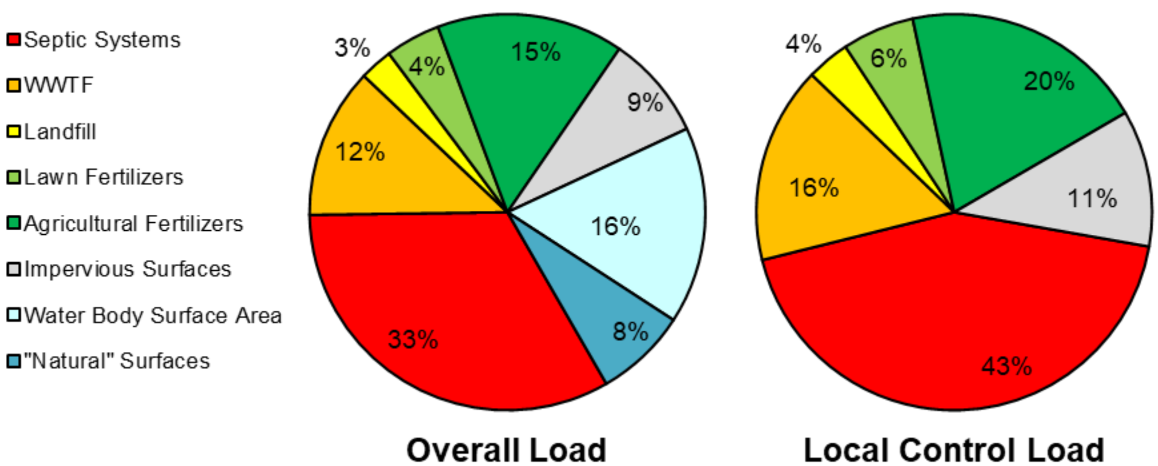

Figure ES-A: Nitrogen loading sources in the Wareham River Estuary System watershed

Target Threshold Nitrogen Concentrations and Loadings

The Wareham River Estuary System and its associated watershed is located primarily within the Town of Wareham, in southeastern Massachusetts. A portion of the watershed to the estuarine system extends into the Towns of Plymouth and Carver. The N that enters the estuary each day (N load) is 232.72 kg/day [1]. The total N load includes the present watershed load in addition to direct atmospheric deposition and benthic flux (Howes *et al.,* 2014, Table ES-1).

The resultant average annual N concentration was 0.50 mg/L (milligrams per liter of N) within the Wareham River Estuary System and ranged from 0.408 to 0.649 mg/L at the 15 monitoring stations where data were collected from 2005 through 2011. The average of the separate yearly means at each station, as reported in Table VI-1 of the MEP Technical Report, are included in Appendix B of this report.

[1] *MassDEP set negative benthic fluxes to zero when developing nitrogen TMDLs from the MEP loading analysis.*

To restore and protect the estuarine system, N loadings, and subsequently N concentrations in the water, must be reduced to levels below the thresholds that cause the observed environmental impacts. These concentrations will be referred to as the *target threshold N concentrations*. It is the goal of the TMDL to reach these target threshold N concentrations, as it has been determined for each impaired waterbody segment. The MEP has determined that total N (TN) concentrations of 0.40 mg/L and 0.42 mg/L at the Lower Wareham River (WR-6) and Upper Wareham River (WR-3) sentinel stations, respectively, are the appropriate threshold values for the restoration of eelgrass at locations within the system where it has historically been present. To ensure restoration of infaunal habitat throughout the embayment and tributaries, secondary target concentrations were established at two locations within the Wareham River Estuary System: a TN level of 0.5 mg/L at the Upper Wareham River (WR-2) and at Lower Broad Marsh River (BR-4) sentinel stations.

Based on sampling and modeling analysis provided in the MEP Technical Report, the N TMDL to meet the target threshold N concentrations is 165.52 kg/day[1] for the entire system (Howes *et al.,* 2014, Table VIII-4). To meet the TMDL and achieve the target concentrations at the sentinel stations, an approximately 38% reduction of the total watershed N load for the system will be required. This document presents the TMDL for this waterbody and provides guidance to the communities of Wareham, Carver, and Plymouth on possible ways to reduce N loadings to within the recommended TMDL and protect the waters of this estuarine system.

Impaired waters within Wareham River Estuary System include the Wareham River (MA95-03) and Agawam River (MA95-29). The 2022 Integrated List of Waters includes the Wareham River as impaired for TN, chlorophyll-a, and estuarine bioassessments (i.e., loss of eelgrass habitat) and the Agawam River as impaired for TN, excess algal growth, and nutrient/eutrophication biological indicators (i.e., benthic habitat impairment) (MassDEP, 2023). Table ES-1 provides a summary of the MassDEP assessment units located within the Wareham River Estuary System and the total nitrogen TMDLs assigned to each waterbody.

Table ES-1: Waterbodies and associated TMDLs within the Wareham River Estuary System

Waterbody	**Assessment Unit ID**	**Waterbody Type**	**TMDL Type**	**TMDL** *kg N/day*
Wareham River	MA95-03	Estuary	Restorative	75.80
Agawam River	MA95-29	Estuary	Restorative	20.92
Agawam River	MA95-28	Freshwater	Protective[2]	22.11
Wankinco River	MA95-50	Estuary	Protective[2]	25.85
Broad Marsh River	MA95-49	Estuary	Protective[2]	17.95
Crooked River	MA95-51	Estuary	Protective[2]	2.88

[1] *MassDEP set negative benthic fluxes to zero when developing nitrogen TMDLs from the MEP loading analysis.*
[2] *Pollution Prevention TMDLs (kg-N/day) for community planning and to prevent further downstream impairment.*

Implementation

The primary goal of the TMDL implementation is to lower N concentrations in the Wareham River Estuary System. The MEP linked model has shown that the load reduction combination necessary to achieve the threshold N concentrations include a **79% removal of septic load** (associated with direct groundwater discharge to the embayment) as well as a reduction of N load from the Wareham Wastewater Control Facility to **4,300 kg/year (11.78 kg N/day).**

Local officials can explore other load reduction scenarios through additional modeling as part of their Comprehensive Wastewater Management Plan (CWMP). Implementing best management practices (BMPs) to reduce N loadings from fertilizers and runoff where possible will also help to lower the total N load to the system. Methodologies for reducing N loading from septic systems, stormwater runoff and fertilizers are provided in detail in the "*MEP Embayment Restoration and Guidance for Implementation Strategies*" (MassDEP, 2003). The appropriateness of any of the alternatives will depend on local conditions and will have to be determined on a case-by-case basis, using an adaptive management approach. Finally, growth within the communities of the Wareham River Estuary System, which would exacerbate the problems associated with N loading, should be guided by considerations of water quality-associated impacts.

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Introduction

Section 303(d) of the Federal Clean Water Act requires each state (1) to identify waters that are not meeting water quality standards and (2) to establish Total Maximum Daily Loads (TMDLs) for such waters for the pollutants of concern. The TMDL allocation establishes the maximum loadings of these pollutants of concern, taking into consideration all contributing sources to that waterbody, while allowing the system to meet its applicable water quality standards, including compliance with numeric and narrative water quality criteria to support designated uses. The TMDL development process may be described in four steps, as follows:

1) Determination and documentation of whether a waterbody is presently meeting applicable water quality standards and designated uses.

2) Assessment of present water quality conditions in the waterbody, including estimation of present loadings of pollutants of concern from both point sources (discernable, confined, and concrete sources such as pipes) and nonpoint sources (diffuse sources that carry pollutants to surface waters through runoff or groundwater).

3) Determination of the loading capacity of the waterbody. EPA regulations define the loading capacity as the greatest amount of loading that a waterbody can receive without violating water quality standards. If the waterbody is not presently attaining its designated uses, then the loading capacity will represent a reduction relative to present loadings.

4) Specification of load allocations, based on the loading capacity determination, for nonpoint sources and point sources that will ensure that the waterbody will not violate water quality standards.

After public comment and final approval by EPA, the TMDL will serve as a guide for future implementation activities. MassDEP will work with the towns of Carver, Plymouth, and Wareham to develop specific implementation strategies to reduce nutrient loadings and will assist in developing a monitoring plan for assessing the success of the nutrient reduction strategies.

In the Wareham River Estuary System, the pollutant of concern for this TMDL (based on observations of eutrophication) is nitrogen (N) because it is the limiting nutrient in coastal and marine waters, which means that plant productivity increases as the N concentration increases. Increased plant productivity leads to nuisance populations of macroalgae, increased phytoplankton and epiphyton abundance, and impairment of the affected waterbodies.

The total N TMDL for the Wareham River Estuary System is based primarily on data collected, compiled, and analyzed by the University of Massachusetts Dartmouth's School of Marine Science and Technology (SMAST), the Southeast Regional Planning & Economic Development District, Buzzards Bay Coalition (BBC) BayWatchers Water Quality Monitoring Program, and the Town of Wareham, as part of the Massachusetts Estuaries Project (MEP). The data were collected over a study period from 1999 through 2011. This study period will be referred to as the "Present Conditions" in the TMDL since it contains the most recent data available. The accompanying MEP Technical Report presents the results of the analyses of the coastal embayment system using the MEP Linked Watershed-Embayment Nitrogen Management Model (Linked Model): https://www.mass.gov/guides/the-massachusetts-estuaries-project-and-reports.

The analyses were performed to assist towns within the Wareham River Estuary System watershed with decisions on current and future wastewater planning, wetland restoration, anadromous fish runs, shellfisheries, open-space, and harbor maintenance programs. Critical elements of this approach are the assessments of water quality monitoring data, historical changes in eelgrass distribution, time-series water column oxygen measurements and benthic community structure that were conducted on this embayment. These analyses served as the basis for generating an N loading threshold for use as a goal for watershed N management. The TMDL is based on the site-specific target threshold N concentration generated for this embayment. Thus, the MEP offers a science-based management approach to support the wastewater management planning and decision-making process in the towns that comprise the system's watershed.

Description of Waterbodies and Priority Ranking

Watershed Characterization

The Wareham River Estuary System is an approximately 797-acre complex estuarine system tributary to Buzzards Bay on its northwestern shore. The estuary is located within the town of Wareham in southeastern Massachusetts (Figure 1) and its watershed is located within the Towns of Carver, Plymouth, and Wareham (Figure 2). The large upper watershed is drained by two large river systems, the Wankinco River and Agawam River, which run in a north-south manner. Both the Agawam River and Wankinco River discharge to the head of the estuary and are among the largest rivers discharging to Buzzards Bay. The central estuary, the Wareham River, is a drowned river valley estuary, with smaller tributary basins: Broad Marsh Cove, Crooked River, and Marks Cove. The Town of Wareham also operates the Wareham Wastewater Control Facility (NPDES Permit No. MA0101893**)** that discharges directly to the headwaters of the Agawam River estuary. The entire system constitutes an important component of the Town's natural, cultural, and marine resources.

Composing 44% of the overall land area in the watershed, public service land is the dominant land use throughout both the upper and lower sections of the overall Wareham River Estuary System watershed. The majority of this public service land within the upper areas of the watershed is the Myles Standish State Forest. Land use within the Wankinco River and Parker Mills Pond sub-watershed, located in the western portion of the overall watershed, is comprised primarily of agricultural land uses. 54% of this western sub-watershed area is classified as agricultural land with cranberry bogs as the dominant form of agricultural land use. In the watershed area that contributes directly to the estuary, the total area of residential land use is slightly lower than the total area of public service land use; 32% of this lower watershed area is residential land use while 34% is classified as public land use. 8% of the overall watershed area is classified as undeveloped, and the majority of this land is located within the lower portion of the watershed that contributes directly to the estuary (Howes *et. al,* 2014). Figure 2 presents the land use in the Wareham River watershed – land use classifications are based on Massachusetts Department of Revenue group classifications, as assigned by individual town assessors.

The accompanying MEP Technical Report builds upon any earlier draft version of MEP Linked Watershed-Embayment Approach, which was first completed in 2007. The groundwater flow directions in the 2007 draft MEP Technical Report varied from groundwater flow directions reported in other studies (e.g. USGS, Scientific Paper 2009-5063, and SMAST, 2012 White Island Pond Water Quality and Management Options Assessment). The MEP Technical Report was updated to include the revised watershed delineations completed by the United States Geological Survey (USGS) during the USGS upgrade of the Plymouth-Carver Aquifer Model. Figure 2 presents the sub-watershed delineations for the Wareham River Estuary System. The lightly shaded sub-watersheds were included in the previous 2007 draft report but are no longer included in the 2014 updated MEP Technical Report and associated modeling.

Horsley Witten was contracted by the MassDEP to evaluate the updated 2014 MEP Technical Report groundwater flow paths and identify the most scientifically defensible sub-watershed delineations in the geographic area. The Horsley Witten analysis focused specifically on whether the water exiting the White Island Pond would predominantly travel southwest to the Wareham River or travel southeast to Buttermilk Bay. The results of their groundwater modeling indicated that water leaving White Island Pond ultimately discharges to Buttermilk Bay and little to no outflow from White Island Pond is likely to contribute to the Wareham River Estuary. Horsley Witten concluded that their analysis is consistent with the SMAST interpretation of contributing area within the 2014 MEP Technical Report and that no new N loading scenarios would need to be evaluated for the purpose of TMDL development (Horsley Witten, 2021).

Description of Waterbodies

The nature of enclosed embayments in populous regions exposes an inherent challenge: as protected marine shoreline they are popular regions for boating, recreation, and land development; as enclosed waterbodies, 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 Wareham River Estuary System, like many other embayment systems in the region, is at risk of eutrophication from high N loads in the groundwater and runoff from their watersheds. The estuary system has historically supported high quality habitats associated with high nutrient-related water quality, such as eelgrass beds. But as in many other embayments in southeastern Massachusetts, the Wareham River Estuary System is presently an N-enriched shallow water estuarine system.

The 2022 Integrated List of Waters (the “Integrated List”) includes the Wareham River (MA95-03) as impaired for TN, chlorophyll-a, and estuarine bioassessments (i.e., loss of eel grass habitat) and the estuarine portion of the Agawam River (MA95-29) as impaired for TN, excess algal growth, and nutrient/eutrophication biological indicators (i.e., benthic habitat impairment). The dissolved oxygen levels found by MEP in Wareham River and Agawam River were not considered sufficient to impair in the most recent Integrated List.

In addition to the nutrient-related impairments, the majority of the waters within the Wareham River Estuarine system are currently listed as impaired for fecal coliform. Wareham River (MA9503), Broad Marsh River (MA95-49), Wankinco River (MA95-50), Agawam River (MA95-29), Cedar Island Creek (MA95-52), and Crooked River (MA95-51) have an impairment for fecal coliform addressed by CN 251.1 - Final Pathogen TMDL for the Buzzards Bay (MassDEP, 2009).

Table 1 provides a summary of the MassDEP assessment units located within the Wareham River Estuary System and associated impairments for each waterbody. A more complete description of this embayment system is presented in Chapters I and IV of the MEP Technical Report. Additional information on the nutrient-related health parameters assessed during the MEP study are summarized in Table 2, the Problem Assessment section below, and Chapter VII of the associated MEP Technical Report (Howes *et. al,* 2014).

Figure 1: Overview of Wareham River Estuary System, Wareham, MA

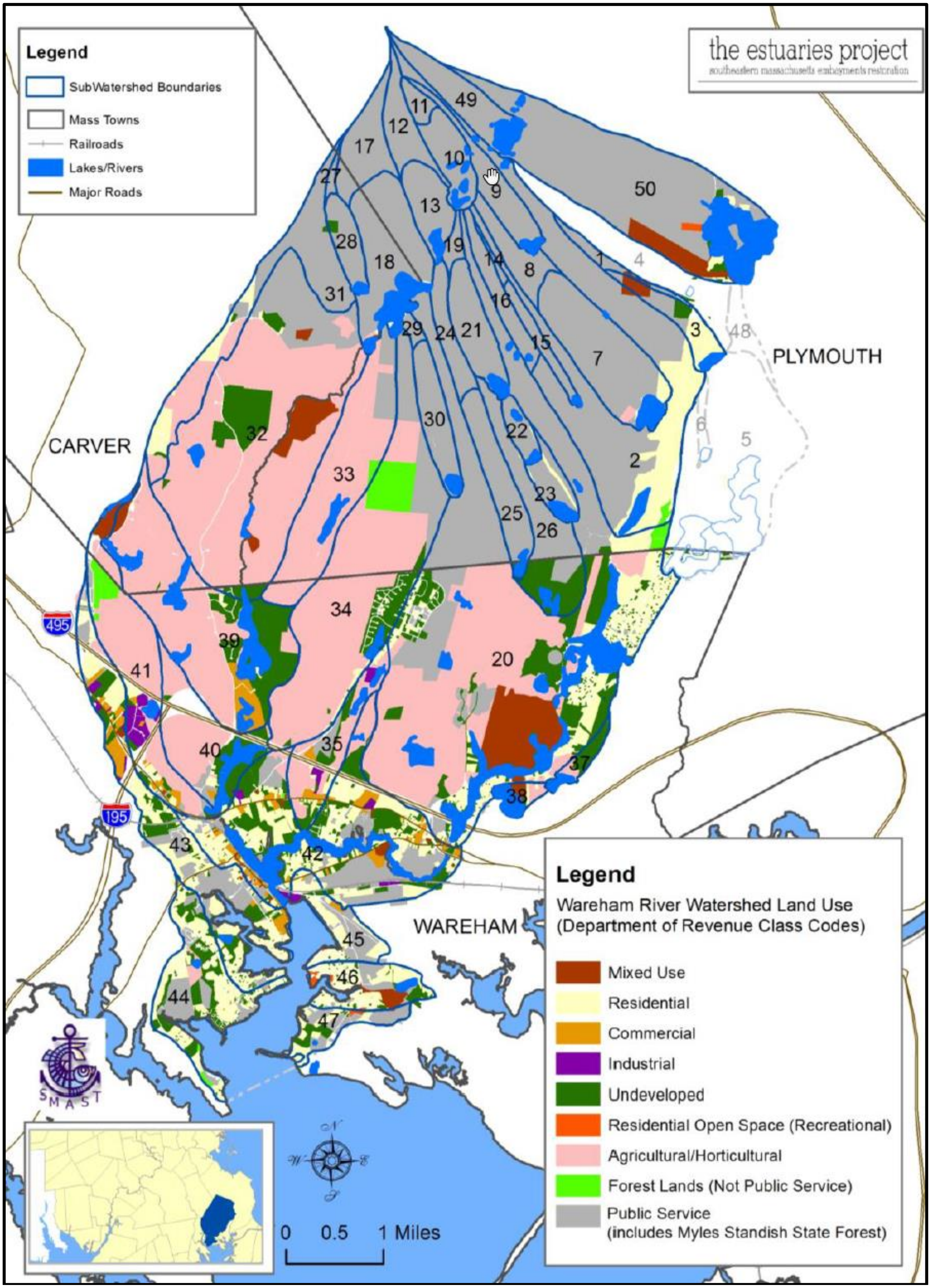

Figure 2: Wareham River Estuary System Watershed and Sub-watershed Delineations
Figure reprinted from MEP Technical Report (Howes et. al, 2014, Figure IV-1)

Table 1: MassDEP Assessment Units (AUs) within the Wareham River Estuary System

MassDEP AU Name & AU ID	**MassDEP AU Description**	**MassDEP AU Type, Class, & Size**	**MassDEP 2022 Integrated List Impairment Parameters & (Category)**	**MEP Nutrient Related Habitat Health Indicators**
Wareham River *MA95-03*	From confluence of Wankinco and Agawam Rivers at Route 6 bridge, Wareham to Buzzards Bay (at an imaginary line from Cromeset Point to curved point east/southeast of Long Beach Point), Wareham. Including Marks Cove, Wareham.	Estuary *Class SA* 1.18 sq.mi.	- Total Nitrogen (5) - Estuarine Bioassessments (5) - Chlorophyll-a (5) - Fecal Coliform (4A)*	- Benthic Fauna - Chlorophyll *a* - Eelgrass Loss
Agawam River *MA95-29*	Wareham WWTP outfall, Wareham to confluence with Wankinco River (forming headwaters of the Wareham River) just north of the Route 6 bridge, Wareham.	Estuary *Class SB* 0.16 sq.mi	- Total Nitrogen (5) - Algae (5) - Nutrient/Eutrophication Biological Indicators (5) - Fecal Coliform (4A)*	- Benthic Fauna - Chlorophyll *a* - Macroalgae
Agawam River *MA95-28*	Outlet Mill Pond, Wareham to Wareham WWTP outfall, Wareham.	Freshwater *Class B\WWF* 0.61 mi.	- Fish Passage Barrier (4c)	- *Not assessed*
Broad Marsh River *MA95-49*	Headwaters in salt marsh south of Marion Road and Bourne Terrace, Wareham to confluence with the Wareham River, Wareham.	Estuary *Class SA* 0.17 sq.mi.	- Fecal Coliform (4A)*	- *Not impaired*
Wankinco River *MA95-50*	From outlet of Parker Mills Pond, south of Elm Street, Wareham to the confluence with the Agawam River (at a line between a point south of Mayflower Ridge Drive and a point north of the railroad tracks near Sandwich Road (forming headwaters of the Wareham River)) just north of Route 6 bridge, Wareham.	Estuary *Class SA* 0.05 sq.mi.	- Fecal Coliform (4A)*	- *Not impaired*
Cedar Island Creek *MA95-52*	Estuarine portion southwest of the intersection of Parker Drive and Camardo Drive, Wareham to the mouth at Marks Cove, Wareham.	Estuary *Class SA* 0.01 sq.mi.	- Fecal Coliform (4A)*	- *Not assessed*
Crooked River *MA95-51*	Estuarine portion east of Indian Neck Road, Wareham to the confluence with the Wareham River, Wareham.	Estuary *Class SA* 0.04 sq.mi.	- Fecal Coliform (4A)* - Enterococcus (4A)*	- Assessed for Benthic Fauna: *Not impaired*

* Addressed by *CN 251.1 - Final Pathogen TMDL for the Buzzards Bay* (MassDEP, 2009).

Description of Hydrodynamics of the Wareham River Estuary System

Wareham River Estuary System is a sinuous estuary open to the northern extent of Buzzards Bay, made up of several smaller tidal sub-embayments, including Broad Marsh River, Crooked River, and the estuarine waters of Wankinco River and Agawam River. Located within the estuary system is nearly 300 acres of salt marsh that borders the Wankincco River, Agawam River, and the Broad Marsh River. These sub-estuaries function as shallow tidal salt marsh systems that generally have a higher tolerance for nutrient loading. The mainstem of the Wareham River is deep, well-flushed embayment that serves as a mixing zone for the freshwater inflows from contributing watershed and the saline tidal flow from Buzzards Bay. From the farthest estuarine reach of the system, it is approximately 5.5 miles to the mouth on Buzzards Bay.

The MEP project evaluated the tidal circulation and flushing characteristics of this embayment system using both direct measurements and the RMA-2 model, a well-established model for estuaries (Norton et al., 1973). Tide data records were collected concurrently at a station in Buzzards Bay, at five locations in the Wareham River, and at a single station in the Weweantic River. The Temperature Depth Recorders (TDR) used to record the tide data were deployed for a 50-day period to measure tidal variations through an entire neap-spring cycle.

The computed flushing rates for the estuary system show that the system flushes moderately well. The MEP project calculated local residence times of 0.66 days for the Wareham River, 0.45 days for the Broad Marsh River, and 0.39 days for the estuarine portions of the Agawam River. These local flushing times of under 0.7 days for each sub-embayment show that on average, water is resident in each subsystem less than one day. However, the system residence times for the Broad Marsh River and Agawam River were calculated to be 4.17 days and 5.65 days, respectively. These longer system residence times indicate that these estuarine tributaries are more sensitive to the water quality as they do not experience the same efficient rate of tidal exchange with Buzzards Bay when compared to the mainstem of the Wareham River (Howes *et. al,* 2014).

Priority Ranking

The embayment addressed by this TMDL was determined to be a high priority based on three significant factors:

1) the initiative that the towns have taken to assess the conditions of the estuarine system;
2) the commitment made by the towns to restore and preserve the embayment; and
3) the extent of impairment in the embayment.

This embayment is at risk of further degradation from increased N loads entering through groundwater and surface water runoff from the increasingly developed watershed. In both marine and freshwater systems an excess of nutrients results in degraded water quality, adverse impacts to ecosystems, and reduced use of water resources. Observations are summarized in Table 2, the Problem Assessment section, and Chapter VII - Assessment of Embayment Nutrient Related Ecological Health of the MEP Technical Report.

Problem Assessment

The populations of three towns in the Wareham River Estuary System watershed (Wareham, Plymouth, and Carver) have been steadily growing over the past several decades (Figure 3). Declines in water and habitat quality often parallel population growth in the watershed. Water quality problems associated with this development result primarily from on-site wastewater treatment systems and to a lesser extent from wastewater treatment facility (WWTF) discharge, fertilizers, and runoff from these developed areas.

The primary ecological threat to Wareham Harbor is degradation resulting from nutrient enrichment. Most of the total N load (43%) is from septic systems, with other "controllable" N contributions coming from fertilizers (20%), WWTF discharge (16%), and impervious surface runoff (11%). Other sources that are not locally controllable include atmospheric deposition to the surface of the estuary and natural surfaces. N from these sources migrates downward to groundwater and eventually enters the estuary system.

The Wareham River Estuary System is a complex estuary composed of three functional types of component basins: an embayment (Wareham River-Marks Cove), a salt marsh pond/embayment (Broad Marsh River), and a tidal river with significant marginal wetlands (Agawam-Wankinco estuarine reaches). Each of these three functional components has different natural sensitivities to N enrichment and organic matter loading. The MEP project reported the Wareham River Estuary System is showing variations in N enrichment and habitat quality among its various component basins.

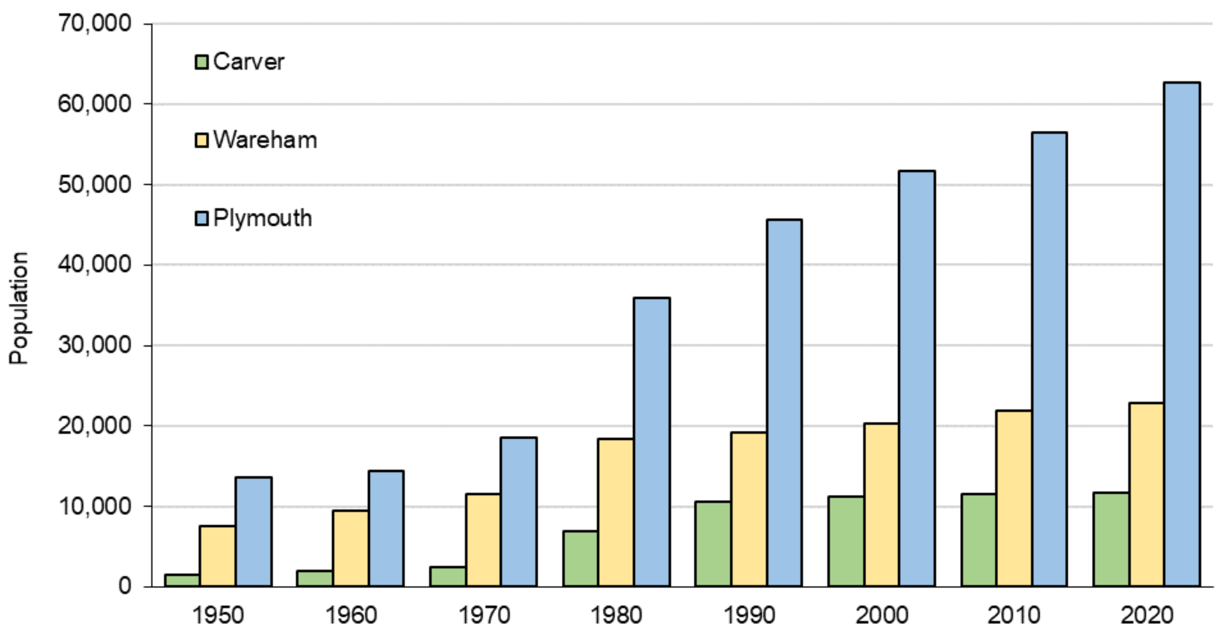

Figure 3: Towns of Carver, Wareham, and Plymouth Historic Residential Population
Source: United States Census records and Population Estimates Program data

Table 2: General Summary of Conditions Related to the Major Indicators of Habitat Impact

MassDEP Waterbody	Overall Health	MEP Identifier	Eelgrass [1]	Dissolved Oxygen	Chlorophyll *a*[2]	Macroalgae	Benthic Fauna [3]
Wareham River *MA95-03*	Impacted due to significant loss of eelgrass habitat, occasional moderate D.O. depletions, moderate/high chlorophyll *a* concentrations, and poor infaunal habitat quality. **[SI]**	Upper Wareham River	Moderate eelgrass habitat loss between 1985-2001 **[MI]**	Concentrations rarely below 5 mg/L **[HH]**	Moderate/high concentration average of 15 µg/L **[MI]**	Very sparse presence or absence of drift algae **[HH]**	Low number of individuals, high diversity and evenness **[SI]**
		Lower Wareham River	Significant eelgrass habitat loss between 1985-2001 **[SI]**	Concentrations rarely below 6 mg/L **[HH]**	Moderate/high concentration average of 10 µg/L **[MI]**	Very sparse presence or absence of drift algae **[HH]**	High number of individuals, low diversity and evenness **[MI]**
		Mark's Cove	Significant eelgrass habitat loss between 1985-2001 **[SI]**	*Not assessed*	*Not assessed*	Very sparse presence or absence of drift algae **[HH]**	High number of individuals, low diversity and evenness **[MI]**
Agawam River *MA95-29*	Impacted due to regularly elevated chlorophyll *a* concentrations, moderate D.O. depletions, and poor infaunal habitat with moderate number of species and low diversity. **[SI]**	Upper Agawam River	No historic evidence of eelgrass habitat **[NS]**	*Not assessed*	*Not assessed*	Very sparse presence or absence of drift algae **[HH]**	Moderate/low numbers of species and individuals low diversity and evenness **[SI]**
		Lower Agawam River	No historic evidence of eelgrass habitat **[NS]**	Salt marsh basin habitat; concentrations rarely below 4 mg/L and often climbed above 10 mg/L **[HH]**	High levels of chlorophyll *a*: Concentrations greater than 25 µg/L for 48% of time **[SI]**	Drift algae present; filamentous red and Ulva **[MI]**	Moderate/ high numbers of species and individuals, moderate diversity and evenness. **[MI]**
Wankinco River *MA95-50*	Benthic fauna indicative of healthy tidal river fringing a salt marsh. **[HH]**	Agawam-Wankinco	No historic evidence of eelgrass habitat **[NS]**	*Not assessed*	*Not assessed*	*Insufficient data*	High number of species and individuals, high diversity and evenness **[HH]**
Broad Marsh River *MA95-49*	Water quality and infauna are indicative of a healthy salt marsh habitat. **[HH]**	Broad Marsh River	No historic evidence of eelgrass habitat **[NS]**	Salt marsh basin habitat; concentrations only rarely below 5 mg/L **[HH]**	Concentrations below 12 µg/L, generally daily averages of 7 µg/L or less **[HH]**	Absence of drift algae; small patches of Codium **[HH]**	Salt marsh basin habitat; high numbers of species and individuals **[HH]**

[1] Based on comparison of present conditions to 1951 survey data
[2] Algal blooms are consistent with chlorophyll *a* levels above 20 µg/L
[3] Based on observations of the type of species, number of species, and number of individuals

[HH] Healthy Habitat Conditions*
[MI] Moderately Impacted*
[SI] Significantly Impacted * – considerably and appreciably changed from normal conditions
[SD] Severe Degraded* – critically or harshly changed from normal conditions
[NS] Non-supportive habitat*

** These terms are more fully described in the MEP report "[Site-Specific Nitrogen Thresholds for Southeastern Massachusetts Embayments: Critical Indicators]" December 22, 2003*

Table adapted and excerpted from MEP Report (Howes et. al, 2014, Table VIII-1)

Broad Marsh River (MA95-49)

The Broad Marsh River (MA95-04) was determined to be non-supportive of eelgrass habitat due to the naturally nutrient enriched shallow waters and salt marsh environment. The system generally supported oxygens levels greater than 5 mg/L and average chlorophyll a levels less than 12 µg/L. The infaunal communities consisted of a moderate number of individuals, and species indicative of an organic rich environment. The MEP determined the water quality and benthic results to be consistent with a high quality, healthy salt marsh basin habitat.

Wankinco River (MA95-50)

Similar to the Broad Marsh River, there is no evidence that eelgrass has colonized the estuarine reach of the Wankinco River (MA95-50), and the benthic invertebrate analysis demonstrated communities consistent with a nutrient-rich, estuarine sediment. The high number of infaunal species and diversity in this area indicates that the Wankinco River supports the high quality benthic habitat of a wetland-influenced tidal river.

Agawam River (MA95-29)

The MEP classified the estuarine portions of Agawam River (MA95-29) to be a tidal river with significant bordering wetlands, similar to the estuarine portions of the Wankinco River. Unlike the neighboring Wankinco, the Agawam River was determined to be significantly impaired in terms of both water quality and benthic habitat.

Chlorophyll *a* concentrations were recorded to be greater than 25 µg/L for 48% of the observed time period. Dissolved oxygen rarely went below 4 mg/L, but concentrations often climbed above 10 mg/L and occasionally above 12 mg/L, consistent with the high phytoplankton biomass. The MEP determined that the observed periodic oxygen depletion during summer is consistent in part with the river system’s role as a tidal river bordered by extensive wetlands. MEP reported that the benthic fauna analysis clearly indicated a stressful environment with poor benthic habitat quality, as it featured low species numbers and a moderate density of individuals with low diversity and evenness. Due to the observed elevated chlorophyll *a* concentrations and poor benthic habitat, the MEP determined the Agawam River to be significantly impaired.

Wareham River (MA95-03)

The largest waterbody in the Wareham River Estuary System, the Wareham River (MA95-03) embayment featured the greatest area of historic eelgrass habitat. For the MEP technical report, the results of eelgrass mapping efforts were available for the years 1988, 1995, and 2001. The 1988 mapping estimated that eelgrass colonized most of the shoals of the lower basin of the Wareham River (those waters located south of Broad Marsh River). These eelgrass beds located within the Lower Wareham River were limited to the shallow margins of the basin and were not present within the deeper channel that runs along the centerline of the estuary.

The 1995 and 2001 results of the MassDEP Eelgrass Mapping Program indicated a complete loss of those marginal beds in the Lower Wareham River. The 1995 & 2001 mapping captured the emergence of fringe eelgrass beds in upper basin of the Wareham River (those waters located north of Broad Marsh River). Like those beds located in the Lower Wareham River, the eelgrass beds within the Upper Wareham River were limited to the shallow margins of the upper basin.

Although unavailable to the MEP during their assessment of eelgrass habitat quality, MassDEP's more recent 2013 and 2017 eelgrass mapping products captured the expansion of the fringe eelgrass beds located in the Upper Wareham River. The expanded eelgrass habitat appears to be constrained to the shallow depths of the northern edges of the estuary basin. Despite the expansion of beds in the upper basin, the more recent eelgrass mapping did not capture the return of the historic eelgrass beds within the lower basin of the Wareham River. Figure 5 presents the historic extent of eelgrass within the Wareham River (MA95-03).

Dissolved oxygen observations were generally high (greater than 5 mg/L) with rare moderate depletions. Chlorophyll *a* concentration averaged 15 µg/L in the upper region of the river and 10 µg/L in the central/lower region of the river. Specifically, concentrations were recorded to be greater than 10 µg/L for 42% of observed time period in the Wareham Narrows, which is upstream region of the Wareham River mainstem. In the Hamilton Beach area, located approximately in center of the Wareham River, concentrations were recorded to be greater than 10 µg/L for 45% of observed time period. The high chlorophyll *a* concentration coincided with observed phytoplankton blooms and oxygen depletions.

The MEP reported that the lower basin of the Wareham River showed high numbers of benthic species and individuals, with high diversity. However, the upper basin of the Wareham River was determined to have a poor benthic habitat likely due to transport of low-quality waters from the Agawam River on receding tides. The MEP determined the Wareham River to be impaired due to significant loss of eelgrass habitat, moderate elevated chlorophyll *a* concentration, and poor infaunal habitat quality.

MEP concluded that the benthic habitat in the Wareham River and Agawam River ranges from moderately to significantly impaired. Both waterbodies are also considered impaired due to elevated chlorophyll *a* concentration. Additionally, the Wareham River is significantly to moderately impaired based on the loss of historic eelgrass beds. The distribution of these habitat impairments throughout the Wareham River Estuary system is consistent with the observed N and the chlorophyll levels and the functional basin types comprising this estuary. As a result, both eelgrass and infaunal animal habitats are impaired in this estuary system, and N management is required for their restoration (Howes *et. al,* 2014).

Pollutant of Concern, Sources, and Controllability

In the Wareham River Estuary System, as in most marine and coastal waters, the limiting nutrient is nitrogen (N). N concentrations above those expected naturally contribute to undesirable water quality and habitat conditions (such as those described previously). Wareham River Estuary System has had extensive data collected and analyzed through the MEP, with the cooperation and assistance from the BBC Baywatchers Water Quality Monitoring Program. Data collection included both water quality and hydrodynamics as described in Chapters I, IV, V, and VII of the MEP Technical Report. These investigations revealed that nutrient loading, especially for N, are much larger than they would be under natural conditions and, as a result, the water quality has deteriorated.

Most of the watershed N loading to the estuary is from on-site subsurface wastewater disposal systems (septic systems, 33%), atmospheric deposition (16%), agricultural fertilizers (15%) and the wastewater treatment facilities (WWTFs, 12%). Less N originates from impervious surfaces, natural surfaces, lawn fertilizers, and landfills. The N loading that is considered controllable affecting this system originates predominately from on-site subsurface wastewater disposal systems (43%), agricultural fertilizers (20%), and the Wareham WWTF (8%). Figure 4 illustrates the percent contributions of N sources to the Wareham River Estuary System. Values are based on Table IV-2 and Figure IV-5 from the MEP Technical Report (Howes *et. al,* 2014). The level of "controllability" of each source, however, varies widely as shown in Table 3. Cost/benefit analyses will have to be conducted for all possible N loading reduction methodologies in order to select the optimal control strategies, priorities, and schedule.

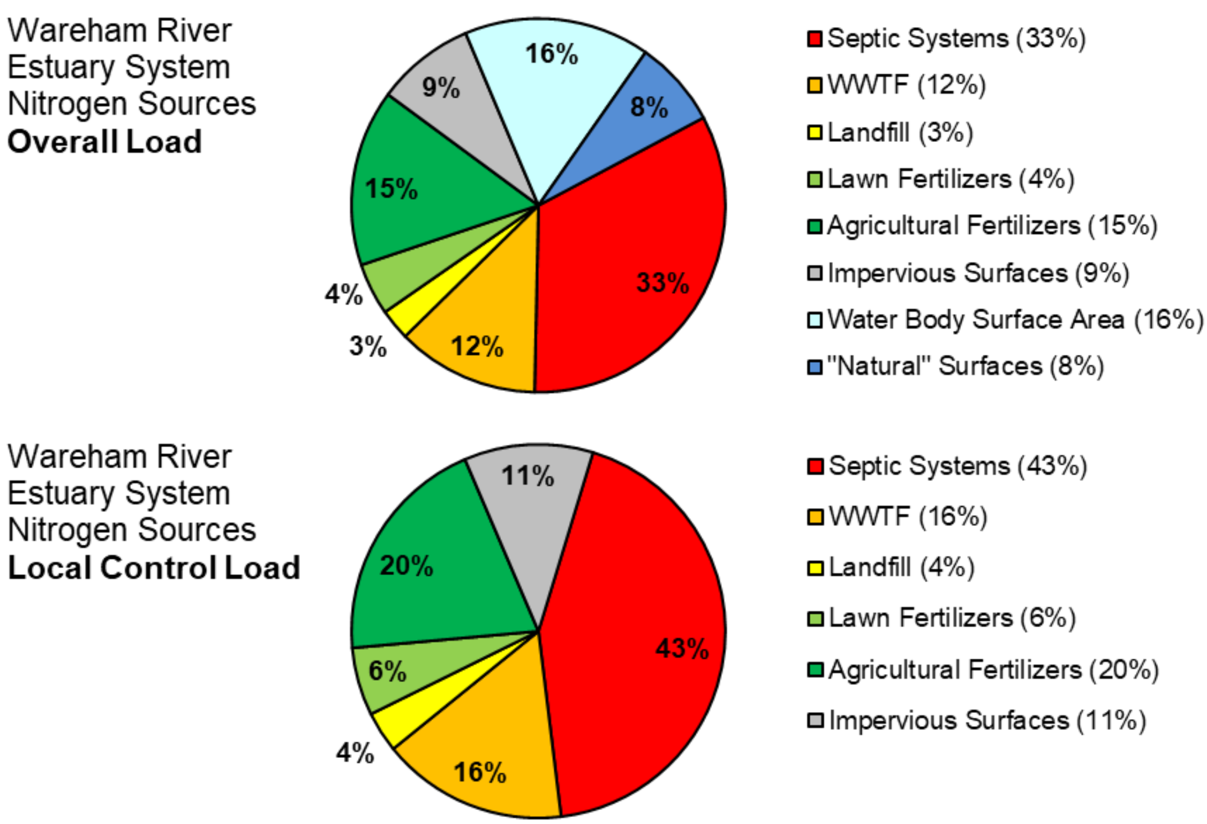

Figure 4: Contribution of Watershed Nitrogen Sources to Wareham River Estuary System

Table 3: Sources of Nitrogen and their Controllability

Nitrogen Source	Degree of Controllability at Local Level	Reasoning
Agricultural fertilizer and animal wastes	Moderate	These N loadings can be controlled through appropriate agricultural Best Management Practices (BMPs).
Atmospheric deposition to the estuary surface	Low	It is only through region- and nationwide air pollution control initiatives that significant reductions are feasible. Local control although helpful is not adequate.
Atmospheric deposition to natural surfaces (forests, fields, fresh waterbodies) in the watershed	Low	Atmospheric deposition (loadings) to these areas cannot adequately be controlled locally. However, the N from these sources might be subjected to enhanced natural attenuation as it moves toward the estuary.
Fertilizer	Moderate	Lawn and golf course fertilizer and related N loadings can be reduced through BMPs, bylaws, and public education.
Landfills	Low	Related N loadings can be controlled through appropriate BMPs and management techniques.
Septic system	High	Sources of N can be controlled by a variety of case-specific methods including: sewering and treatment at centralized or decentralized locations, transporting and treating septage at treatment facilities with N removal technology either in or out of the watershed, or installing N-reducing on-site wastewater treatment systems.
Sediment	Low	N loadings are not feasibly controlled on a large scale by such measures as dredging. However, the concentrations of N in sediments, and thus the loadings from the sediments, will decline over time if sources in the watershed are removed, or reduced to the target levels discussed later in this document. In addition, increased dissolved oxygen will help keep N from fluxing.
Stormwater runoff from impervious surfaces	Moderate	This N source can be controlled by BMPs, bylaws and stormwater infrastructure improvements and public education. Stormwater NPDES permit requirements help control stormwater related N loadings in designated communities.
Wastewater treatment facility (WWTF)	High	WWTFs as point sources of pollution to surface water are permitted under the National Pollution Discharge Elimination System. Treated wastewater effluent discharged to groundwater disposal systems are permitted by MassDEP. There is a high degree of regulatory certainty that within the limits of technology, nutrient sources at these facilities can be controlled.

Description of Applicable Water Quality and Pollutant Standards

Wareham River, Crooked River, Broad Marsh River, and Wankinco River are classified as Class SA waterbodies based on the Massachusetts Surface Water Quality Standards (MassDEP, 2021). The estuarine portion of the Agawam River is classified as Class SB and the freshwater portion of the Agawam River is classified as a Class B\WWF waterbody.

Massachusetts currently has narrative standards for nutrients (nitrogen and phosphorus) for waters of the Commonwealth such that "*all surface waters shall be free of nutrients in concentrations that would cause or contribute to impairment of existing or designated uses and shall not exceed site specific criteria developed in a TMDL or otherwise, established by the department*" (MassDEP, 2021). A more thorough explanation of the applicable water quality standards can be found in Appendix A.

The assessment of eutrophication is based on site-specific information within a general framework that emphasizes impairment of uses and preservation of a balanced indigenous flora and fauna. This approach is recommended by the U.S. Environmental Protection Agency in their Nutrient Criteria Technical Guidance Manual for Estuarine and Coastal Marine Waters (EPA, 2001). The guidance manual notes that lakes, reservoirs, streams, and rivers may be subdivided by classes, allowing reference conditions for each class and facilitating cost-effective criteria development for nutrient management. However, individual estuarine and coastal marine waters tend to have unique characteristics, and development of individual waterbody criteria is typically required.

Methodology – Linking Water Quality and Pollutant Sources

Extensive data collection and analyses have been described in detail in the MEP Technical Report. These data were used by SMAST to assess the loading capacity of each sub-embayment. Physical (Chapter V), chemical, and biological (Chapters IV, VII, and VIII) data were collected and evaluated. The primary water quality objective was represented by conditions that:

1) Restore the natural distribution of eelgrass to provide habitat for shellfish and finfish;
2) Prevent algal blooms;
3) Protect benthic communities from impairment or loss; and
4) Maintain dissolved oxygen concentrations that protect estuarine communities.

The details of the data collection, modeling and evaluation are presented and discussed in Chapters IV, V, VI, VII and VIII of the MEP Technical Report. The main aspects of the data evaluation and modeling approach of this study are summarized below.

The core analytical method of the MEP is the Linked Watershed-Embayment Management Modeling Approach. It fully links watershed inputs with embayment circulation and N characteristics and is characterized as follows:

- Requires site-specific measurements within the watershed and each sub-embayment;
- Uses realistic "best-estimates" of N loads from each land-use (as opposed to loads with built-in "safety factors" like Title 5 design loads);
- Spatially distributes the watershed N loading to the embayment;
- Accounts for N attenuation during transport to the embayment;
- Includes a 2D or 3D embayment circulation model depending on embayment structure;
- Accounts for basin structure, tidal variations, and dispersion within the embayment;
- Includes N regenerated within the embayment;
- Is validated by both independent hydrodynamic, N concentration, and ecological data; and
- Is calibrated and validated with field data prior to generation of "what if" scenarios.

The Linked Model has previously been applied to watershed N management in over 65 embayments throughout Southeastern Massachusetts. In these applications it became clear that the model can be calibrated and validated and has use as a management tool for evaluating watershed N management options.

The Linked Model, when properly calibrated and validated for a given embayment, becomes an N management planning tool as described in the model overview below. The model can assess solutions for the protection or restoration of nutrient-related water quality and allows testing of management scenarios to support cost/benefit evaluations. In addition, once a model is fully functional it can be refined for changes in land-use or embayment characteristics at minimal cost. Also, since the Linked Model uses a holistic approach that incorporates the entire watershed, embayment and tidal source waters, it can be used to evaluate all projects as they relate directly or indirectly to water quality conditions within its geographic boundaries. This approach includes high-order, watershed and sub-watershed scale modeling necessary to develop critical N targets for each major sub-embayment. The models, data and assumptions used in this process are specifically intended for the purposes stated in the MEP Technical Report, upon which this TMDL is based. As such, the Linked Model process does not contain the type of data or level and scale of analysis necessary to predict the fate and transport of N through groundwater from specific sources. In addition, any determinations related to direct and immediate hydrologic connection to surface waters are beyond the scope of the MEP's Linked Model process.

The Linked Model provides a quantitative approach for determining an embayment's:
1) N sensitivity
2) N threshold loading levels (TMDL)
3) response to changes in loading rate

The approach is fully field validated and unlike many approaches, accounts for nutrient sources, attenuation, and recycling and variations in tidal hydrodynamics (Figure I-2 of the MEP Technical Report). This methodology integrates a variety of field data and models, specifically:
- Monitoring
  - multi-year embayment nutrient sampling
- Hydrodynamics
  - Embayment bathymetry (depth contours throughout the embayment)
  - Site-specific tidal record (timing and height of tides)
  - Water velocity records (in complex systems only)
  - Hydrodynamic model
- Watershed Nitrogen Loading
  - Watershed delineation
  - Stream flow (Q) and N load
  - Land-use analysis (GIS)
  - Watershed N model
- Embayment TMDL
  - Synthesis
  - Linked Watershed-Embayment Nitrogen Model
  - Salinity surveys (for linked model validation)
  - Rate of N recycling within embayment
  - Dissolved oxygen record
  - Macrophyte survey
  - Infaunal survey (in complex systems)

Application of the Linked Watershed-Embayment Model

The approach developed by the MEP for applying the linked model to specific embayments for the purpose of developing target threshold N loading rates includes:

1) Selecting one or two stations or sampling locations within the embayment system located close to the inland-most reach or reaches that typically has/have the poorest water quality within the system. These are called “sentinel” stations.
2) Using site-specific information and a minimum of three years of sub-embayment-specific data to select target threshold N concentrations for each sub-embayment. This is done by refining the draft target threshold N concentrations that were developed as the initial step of the MEP process. The target threshold N concentrations that were selected generally occur in higher quality waters near the mouth of the embayment system.
3) Running the calibrated water quality model using different watershed N loading rates, to determine the loading rate that will achieve the target threshold N concentration at the sentinel station. Differences between the modeled N load required to achieve the target threshold N concentration, and the present watershed N load represent N management goals for restoration and protection of the embayment system.

Previous sampling and data analyses, and the modeling activities described above, resulted in four major outputs that were critical to the development of the TMDL.

Two outputs are related to N **concentration**:

- The present N concentrations in the sub-embayments
- Site-specific target threshold N concentrations

Two outputs are related to N **loadings**:

- The present N loads to the sub-embayments
- Load reductions necessary to meet the site-specific target N concentrations

In summary, by reducing the N concentration (and thus the N load) at the sentinel station(s) to meet the applicable water quality standards, the water quality goals will be met throughout the entire system. A brief overview of each output is listed below.

Nitrogen concentrations in the embayment

1) <u>Observed “present” conditions:</u>

Table 4 presents the average concentrations of N measured in this system from data collected at 15 MEP monitoring stations from 2005 through 2011. Average yearly N concentrations at the 15 stations ranged from 0.408 – 0.649 mg/L with the lowest average concentration found in the Lower Wareham River (Station WR-7) and the highest average within the Upper Broad Marsh River (Station BR-1). The standard deviation of the averages and number of samples are presented in Appendix B (reprinted from Table VI-1 of the MEP Technical Report).

The primary sentinel stations are WR-3 and WR-6, located in the mainstem of the Wareham River. Threshold concentrations for tidally averaged TN of 0.40 mg/L at the Lower Wareham River (WR-6) and 0.42 mg/L at Upper Wareham River (WR-3) were selected to restore eelgrass habitat based upon the depth and TN levels surrounding the eelgrass bed located in the upstream region of the Wareham River. Target concentrations were also established at secondary sentinel stations within the Wareham River Estuary System.

The secondary sentinel stations are WR-2 in the Wareham River and BR-4 in the Broad Marsh River. Threshold concentrations for tidally averaged TN of 0.5 mg/L at the Upper Wareham River (WR-2) and at Lower Broad Marsh River (BR-4) were selected to ensure restoration of infaunal habitat throughout the embayment. Figure 5 presents the location of each monitoring station within the Wareham River Estuary System. Monitoring stations that serve as primary sentinel threshold stations are highlighted in red and stations that serve as secondary sentinel threshold stations are highlighted in yellow.

Table 4: Observed Sentinel Station N Concentrations and Threshold N Target Concentration

MEP Sub-Embayment	Monitoring Station	Mean Concentration[1] (mg/L N)	Target Threshold Nitrogen Concentration (mg/L N)
Marks Cove	MC-3	0.420	-
Marks Cove	MC-2	0.440	-
Marks Cove	MC-1	0.464	-
Lower Wareham River	WR-7	0.408	-
Lower Wareham River [2]	WR-6	0.453	0.40
Upper Wareham River	WR-5	0.459	-
Upper Wareham River	WR-4	0.469	-
Upper Wareham River [2]	WR-3	0.477	0.42
Upper Wareham River [2]	WR-2	0.490	0.50
Lower Broad Marsh	BR-6	0.541	-
Lower Broad Marsh [2]	BR-4	0.560	0.50
Upper Broad Marsh	BR-3	0.586	-
Upper Broad Marsh	BR-1	0.649	-
Lower Agawam River	AG-2	0.533	-
Middle Agawam River	AG-1	0.554	-

[1] Mean concentration values are calculated as the average of the separate yearly means
[2] This monitoring station serves as a sentinel station.

Table adapted and excerpted from MEP Report (Howes et. al, 2014, Table VII-1)

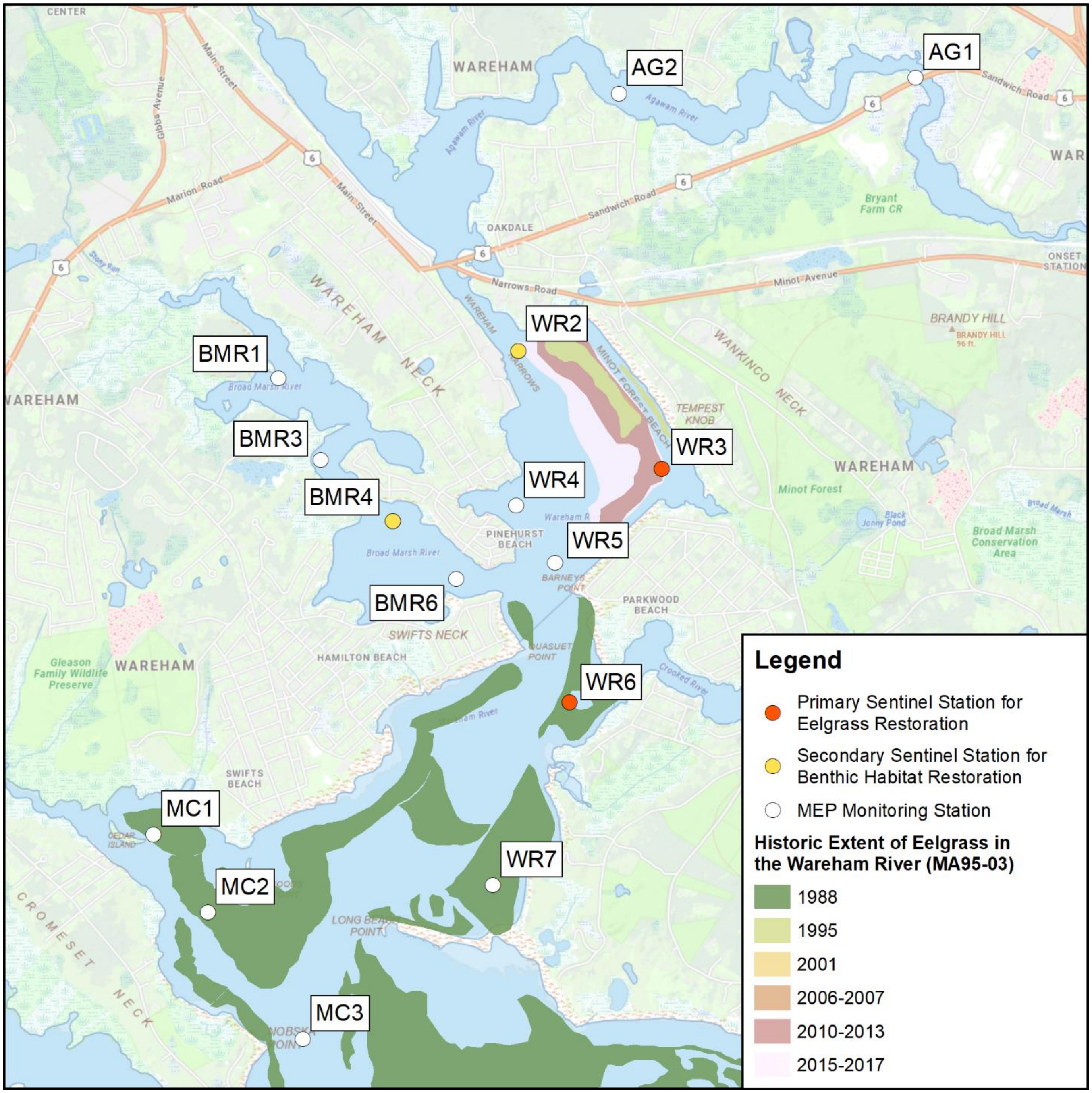

Figure 5: *Location of Monitoring Stations, Sentinel Threshold Stations, & The Historic Extent of Eelgrass Habitat in the Wareham River (MA95-03)*

2) Modeled site-specific target threshold N concentrations:

A major component of TMDL development is the determination of the maximum N concentrations (based on field data) that can occur without causing unacceptable impacts to the aquatic environment. This is called the *target threshold nitrogen concentration*. Prior to conducting the analytical and modeling activities to determine this target threshold N concentration as described below, SMAST selected appropriate nutrient-related environmental indicators and tested the qualitative and quantitative relationship between those indicators and N concentrations. The Linked Model was then used to determine site-specific threshold N concentrations by using the specific physical, chemical, and biological characteristics of each sub-embayment. The approach for determining N loading rates, which will maintain acceptable habitat quality throughout an embayment system, is to first identify a sentinel location within the embayment and second to determine the N concentration within the water column that will restore the sentinel location to the desired habitat quality. The sentinel location is selected such that the restoration of that one site will necessarily bring the other regions of the system to acceptable habitat quality levels. Once the sentinel site and its target threshold N concentration are determined, the MEP study modeled N loads from the watershed until the targeted N concentration was achieved.

Determination of the critical N threshold for maintaining high quality habitat within the Wareham River Estuary System is based primarily on the nutrient levels, oxygen levels, water column depth, temporal trends in eelgrass distribution, and benthic community indicators. The N threshold for Wareham River Estuary System is based upon the primary goal of restoring eelgrass habitat within the central estuary with the parallel goal of restoring and protecting benthic habitat for infaunal animals throughout the system.

The principal habitat degradation within the Wareham River Estuary System relates to loss of eelgrass beds in the central Wareham River – specifically from the mouth of the Broad Marsh River to Buzzards Bay. The eelgrass habitat presence and loss are consistent with the observed oxygen depletions and elevated chlorophyll *a* concentrations, as well as the three functional basin types recognized within the system. Therefore, the primary objective of the site-specific target threshold N concentration is the restoration of eelgrass habitat within the Wareham River.

As listed in Table 4, the primary site-specific target threshold N concentrations for eelgrass habitat restoration are 0.40 mg/L at WR-6 and 0.42 mg/L at WR-3 sentinel stations. Lowering the level of N enrichment at the sentinel station will lower N levels throughout the estuary with the parallel effect of protecting and improving infaunal habitats in the inner reaches of the system (Howes *et. al* 2014, Section VIII-3). The secondary threshold N concentrations are 0.5 mg/L at the WR-2 and BR-4 sentinel stations. These secondary values were designed to provide a check on the acceptability of conditions within the tributary basins. The analytical and modeling MEP investigations were used to develop target threshold N concentrations specific to the Wareham River Estuary System.

To meet the primary objective of eelgrass restoration, WR-6 was selected as a sentinel threshold station based upon its position within the upper most region of the documented 1988 historical extent that ranged from Broad Marsh River to Buzzards Bay. The WR-6 sentinel station is a long-term BayWatcher Water Quality Monitoring station located within the Lower Wareham River, near the mouth of Broad Marsh River and Crooked River. Positioned north of WR-6 in the Upper Wareham River, WR-3 was also selected as a sentinel threshold station based upon its proximity to the emerging 1995 fringe eelgrass beds within the shallow upper reaches of the estuary system.

Prior MEP analyses, including the Bournes Pond Estuary in Falmouth (Howes *et. al,* 2005), Lewis Bay in Barnstable & Yarmouth (Howes *et. al,* 2008), Swan Pond River Estuarine System in Dennis (Howes *et. al*, 2017), and the Westport River Embayment System in Westport (Howes *et. al*, 2013), were taken into consideration when developing N threshold concentrations for eelgrass restoration. For regions within these estuary systems, the MEP identified stable beds of eelgrass at tidally averaged N concentrations ranging from 0.40 to 0.50 mg/L.

Based upon data that the MEP collected within the Wareham River Embayment System and from other systems in the Buzzards Bay region, threshold concentrations for tidally averaged total N (TN) of 0.40 mg/L at the Lower Wareham River (WR-6) and 0.42 mg/L at Upper Wareham River (WR-3) were selected to restore eelgrass habitat in these areas. Lowering the level of N enrichment at the sentinel station will lower N levels throughout the estuary with the parallel effect of improving infaunal habitats in the inner reaches of the system.

While the primary N management target is the restoration of eelgrass habitat, the restoration and protection of benthic infaunal habitat quality is a secondary target. In addition to the primary threshold concentrations for tidally averaged TN at WR-3 and WR-6, the MEP established secondary sentinel stations as a check to ensure that all impaired regions within the Wareham River Estuary System are restored. Secondary target concentrations were established at two locations within the Wareham River Estuary System: a tidally averaged TN concentration of 0.5 mg/L at the Upper Wareham River (WR-2) and at Lower Broad Marsh River (BR-4) stations.

Regions within the system that were determined to be impaired for benthic habitat quality include the northern area of the Wareham River and the estuarine portion of the Agawam River. Based on the water quality observations, the present average TN concentration in these areas is 0.524 mg/L and 0.573 mg/L, respectively. While not determined to be impaired, the lower area of the Broad Marsh River displayed a present average TN concentration of 0.529 mg/L. Due to its classification a tidal salt marsh basin, the Broad Marsh River was determined to be naturally nutrient enriched due to its shallow waters and salt marsh environment. The Lower Broad Marsh River (BR-4) station and Upper Wareham River (WR-2) were selected as secondary sentinel stations based upon their proximity to major tributary basins of the Wareham River Estuary System with elevated TN levels and benthic habitat impairments.

Based upon data that the MEP collected from similar estuary systems in the Buzzards Bay region, an upper concentration limit of 0.50 mg/L tidally averaged TN would support healthy infaunal habitat in this system and was therefore set at the secondary sentinel stations of WR-2 and BR-4.

Nitrogen loadings to the embayment

1) Present loading rates

In the Wareham River Estuary System, the highest N loading from controllable sources is from on-site wastewater treatment systems (septic systems). The MEP Technical Report calculates that septic systems account for 43% of the controllable N load to the overall system. Other controllable N sources include agricultural fertilizers (20%), WWTF discharge (16%), and runoff from impervious surfaces (11%). Table 5 presents a further breakdown of present N loading by source for each sub-watershed of the estuary system.

As previously indicated, the present N loadings to Wareham River Estuary System must be reduced in order to restore conditions and to avoid further nutrient-related adverse environmental impacts. The critical final step in the development of the TMDL is modeling and analysis to determine the loadings required to achieve the target threshold N concentrations.

Table 5: Present Nitrogen Loadings within the Wareham River Estuary System Watershed

MEP Watershed	**Land Use Load**[1] (kg/day)	**Present Attenuated Septic System Load** (kg/day)	**Present WWTF Load**[2] (kg/day)	**Present Total Attenuated Watershed Load**[3] (kg/day)	**Direct Atmospheric Deposition**[4] (kg/day)	**Benthic Flux** (kg/day)	**Total N Load from All Sources**[5] (kg/day)
Broad Marsh River	3.674	4.271	-	7.945	1.681	15.656	25.282
Marks Cove	3.271	1.603	-	4.874	0.959	2.987	8.820
Crab Cove	1.049	2.499	-	3.548	1.614	0[6]	5.162
Crooked River	1.351	4.000	-	5.351	0.333	0[6]	5.684
Wareham River (Lower)	0.219	0.499	-	0.718	5.18	73.028	78.926
Wareham River (Upper)	5.526	18.140	18.523	42.189	1.803	0[6]	43.992
Agawam River	22.112	12.156	-	34.268	-	-	34.268
Wankinco River	25.909	4.677	-	30.586	-	-	30.586
System Total	**63.111**	**47.845**	**18.523**	**129.479**	**11.57**	**91.671**	**232.72**

[1] Composed of fertilizer, runoff, and atmospheric deposition to freshwater and natural surfaces
[2] Existing wastewater treatment facility discharges
[3] Composed of the sum of land use, septic, and WWTF loading
[4] Atmospheric deposition to embayment surface only.
[5] Composed of background, fertilizer, runoff, septic system, WWTF, atmospheric deposition and benthic flux loadings
[6] Negative benthic flux set to zero.

Table adapted and excerpted from MEP Report (Howes et. al, 2014, Table ES-1)

2) Nitrogen loads necessary for meeting the site-specific target threshold N concentrations

The N threshold developed by SMAST summarized above was used to determine the amount of total N mass loading reduction required for restoration and protection of eelgrass and benthic invertebrate habitats in the Wareham River Estuary System. Tidally averaged total N concentrations were used to calibrate the water quality model (Section VI in the MEP Technical Report). Modeled watershed N loads were sequentially lowered until the N levels reached the threshold levels at the primary sentinel stations (WR-3 & WR-6) and secondary sentinel stations (WR-2, BR-4) chosen for the Wareham River Estuary System. Load reductions can be produced by reduction of any or all sources of N and/or by increasing the natural attenuation of N within the freshwater systems to the embayment. Table 6 includes the present and target threshold watershed N loadings to Wareham River Estuary System and the percentage reduction necessary to meet the target threshold N concentration at the sentinel station.

The approach described above is only one scenario that will meet the target N concentration enough to restore habitat throughout the system, which is the goal of the TMDL. There can be variations depending on the chosen sub-watershed and which controllable source is selected for reduction. Alternate scenarios will result in different amounts of N being reduced in different sub-watersheds. For example, removing N upstream will impact how much N must be removed downstream. The towns of Wareham, Plymouth, and Carver should take any reasonable effort to reduce the controllable N sources.

Table 6: Present Watershed Nitrogen Loading Rates, Calculated Loading Rates that are Necessary to Achieve Target Threshold Nitrogen Concentrations and the Percent Reductions of the Existing Loads Necessary to Achieve the Target Threshold Loadings

MEP Watershed	**Present Total Watershed Load** [1] (kg/day)	**Target Threshold Watershed Load**[2] (kg/day)	**Percent Watershed Load Reductions Needed to Achieve Target**
Broad Marsh River	7.945	4.101	-48.4%
Marks Cove	4.875	4.073	-16.4%
Crab Cove	3.548	2.299	-35.2%
Crooked River	5.351	2.551	-52.3%
Wareham River (Lower)	0.718	0.468	-34.7%
Wareham River (Upper)	42.189	19.121	-54.7%
Agawam River	34.268	22.112	-35.4%
Wankinco River	30.586	25.851	-15.5%
System Total	**129.479**	**80.634**	**-37.7%**

[1] Composed of fertilizer, runoff, atmospheric deposition to lakes and natural surfaces and septic system loadings.
[2] Target threshold watershed load is the load from the watershed needed to meet the target threshold N concentrations as identified above in Table 4.

Table adapted and excerpted from MEP Report (Howes et. al, 2014, Tables ES-2 & VII-3)

Total Maximum Daily Loads

A total maximum daily load (TMDL) identifies the loading capacity of a waterbody for a pollutant. EPA regulations define loading capacity as the greatest amount of loading that a waterbody can receive without violating water quality standards. The TMDLs are established to protect and/or restore the estuarine ecosystem, including eelgrass, the leading indicator of ecological health, thus meeting water quality goals for aquatic life support. Because there are no generally applicable or site-specific numeric N criteria for the Wareham River Estuary System in the Massachusetts Surface Water Quality Standards, the TMDL calculates the loads that would correspond to specific N concentrations determined to be protective of the water quality and ecosystems. Bioavailable nutrients - such as nitrogen - in point and nonpoint discharges can stimulate algal growth, which then die and decompose though the action of bacteria, depleting oxygen in the water. Reducing the bioavailability of N in the estuarine system through the implementation of this TMDL will result in less algal growth, which will ensure chlorophyll *a* concentrations are reduced and dissolved oxygen levels are increased.

The development of a TMDL requires detailed analyses and mathematical modeling of land use, nutrient loads, water quality indicators, and hydrodynamic variables (including residence time) for each waterbody system. The results of the mathematical model are correlated with estimates of impacts on water quality, including negative impacts on eelgrass (the primary indicator), as well as dissolved oxygen, chlorophyll, and benthic infauna.

The TMDL can be defined by the equation:

TMDL = WLAs + LAs + MOS

where:

TMDL = loading capacity of receiving water
WLAs = portion allotted to point sources
LAs = portion allotted to (cultural) nonpoint sources
MOS = margin of safety

Background Loading

Natural background N loading is included in the loading estimates but is not quantified or presented separately. Background loading was calculated on the assumption that the entire watershed is forested with no anthropogenic sources of N. It is accounted for in this TMDL but not defined as a separate component. The MEP Technical Report includes estimated loading due to natural conditions.

Waste Load Allocations

Waste load allocations (WLA) identify the portion of the loading capacity allocated to existing and future wastewater point sources. There is a permitted surface water discharge in the watershed. The Wareham Wastewater Control Facility (MA0101893) discharges into the Agawam River (MA95-28). The MEP estimated waste load from this facility is 18.52 kg N/day (Figure 6). A TMDL may establish a specific WLA for an identified source or, as in the case of stormwater, may establish an aggregate WLA that applies to numerous sources. EPA interprets 40 CFR 130.2(h) to require that allocations for National Pollutant Discharge Elimination System (NPDES) regulated discharges of stormwater also be included in the waste load component of the TMDL.

Areas of the Wareham River Estuary System watershed that contain EPA designated "urbanized areas" and are required to obtain coverage under the NPDES Phase II General Permit for stormwater discharges from Small Municipal Separate Storm Sewer Systems (MS4s). In addition, there are directly connected impervious areas (DCIAs) that discharge stormwater directly to waterbodies via a conveyance system such as a swale, pipe, or ditch throughout the entire watershed as identified by the EPA in: https://www.epa.gov/npdes-permits/regulated-ms4-massachusetts-communities. This TMDL treats stormwater discharge from all DCIA (even those outside of regulated urbanized areas) as part of a waste load allocation.

The Linked Model accounts for stormwater and groundwater loadings in one aggregate allocation as a nonpoint source – combining the assessments of wastewater and stormwater (including stormwater that infiltrates into the soil and direct discharge pipes into waterbodies) for the purpose of developing control strategies. Based on land use, the Linked Model accounts for loading from stormwater, but does not differentiate stormwater into a load and waste load allocation. In order to distinguish the point source or waste load allocation of stormwater originating from DCIAs from the nonpoint source stormwater contribution (LA or load allocation), the percent of the impervious area (IA) that was identified as DCIA was determined and multiplied by the impervious surface N load (kg N/day) as reported in Table IV-5 of the MEP Technical Report.

DCIA was calculated in accordance with EPA methodology (EPA, 2010) using the "Sutherland Equations" (Sutherland, 2000). As outlined in the methodology: the IA of each sub-watershed was determined using the MassGIS 2005 Impervious Surface data layer, the land use categories in the MassGIS Land Use 2005 datalayer were reclassified into commonly used land use categories that correspond with the Sutherland watershed selection criteria, and the "Sutherland Equations" were applied to the IA to calculate DCIA as a percentage of IA in each sub-watershed.

The WLAs for stormwater nitrogen contribution (kg N/day) was determined using the DCIA for each sub-embayment divided by total IA in the sub-embayment, then multiplying the total impervious surfaces runoff N load for the sub-watershed (Table IV-2 of the MEP Technical Report) per EPA methodology. The remaining impervious surfaces loads were assigned as the LA. Table 7 shows the existing WLA and LA from stormwater runoff from impervious surfaces in the Wareham River Estuary System watershed.

Load Allocations

Load allocations identify the portion of loading capacity allocated to existing and future nonpoint sources. In the case of the Wareham River Estuary System, the controllable nonpoint source loadings are primarily from on-site subsurface wastewater disposal systems. Additional N sources include stormwater runoff (except from impervious cover classified as "directly connected" to the waterbody, which is defined above as part of the waste load), fertilizers, and landfill runoff.

Table 7: Existing Stormwater WLA and LA as determined by Percentage of Directly Connected Impervious Area (DCIA) in the Wareham River Estuary System watershed

MEP Watershed	DCIA as % of Impervious Area (%) [1]	Watershed Impervious Load (kg N/day) [2]	Stormwater WLA (kg N/day) [3]	Stormwater LA (kg N/day)
Broad Marsh	75.0%	1.773	1.331	0.44
Marks Cove	68.8%	1.559	1.073	0.49
Crab Cove	57.3%	0.568	0.325	0.24
Crooked River	50.3%	0.657	0.331	0.33
Wareham River (Lower)	15.6%	0.065	0.010	0.06
Wareham River (Upper)	64.3%	2.562	1.647	0.92
Agawam River	24.2%	3.562	0.862	2.70
Wankinco River	24.0%	2.084	0.500	1.58
System Total	**39.0%**	**12.830**	**6.079**	**6.75**

[1] *DCIA calculated using GIS and EPA methodology (EPA, 2010) divided by Total Impervious Area*
[2] *From MEP Technical Report, Table IV-2*
[3] *The DCIA as % of Total Impervious Area multiplied by the MEP Total Unattenuated Watershed Impervious Load*

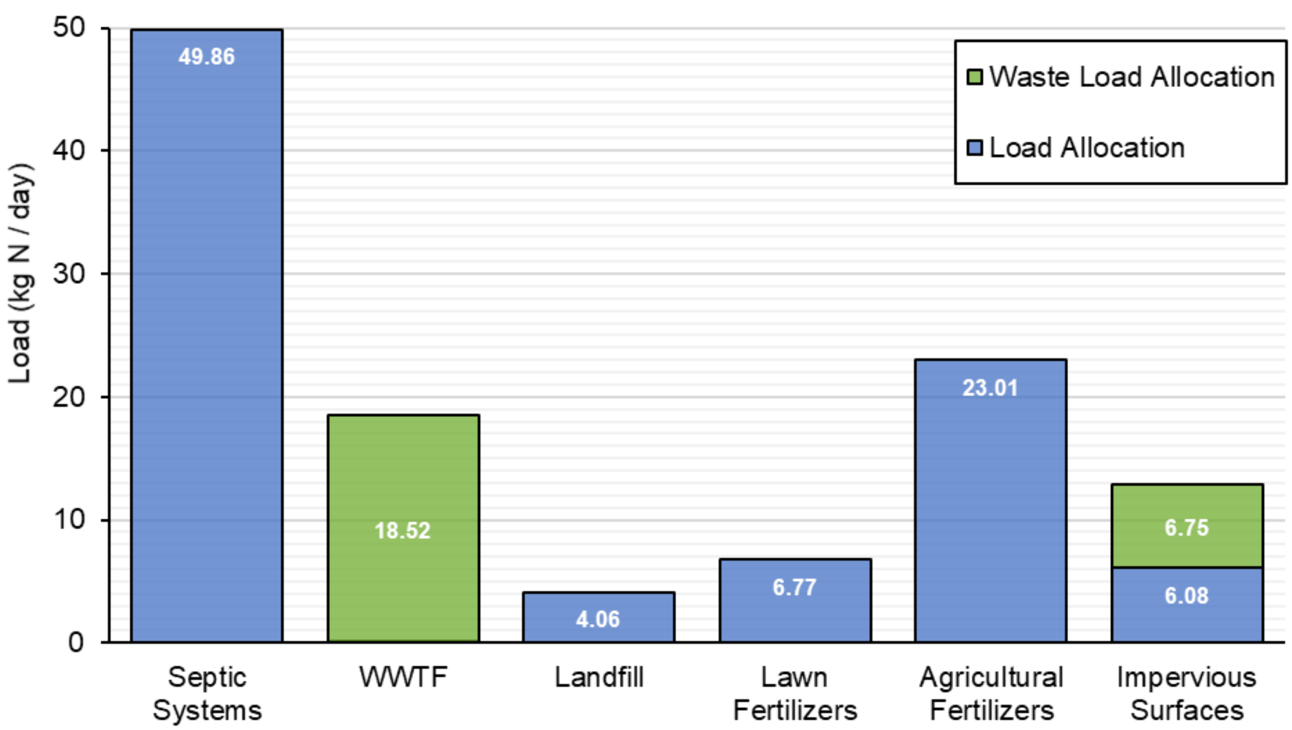

Figure 6: Wareham River Estuary System - *Present* Locally Controllable N Sources

Benthic Flux and Atmospheric Deposition

Sediment loading rates incorporated into the TMDL are different than the existing sediment flux rates because projected reductions of N loadings from the watershed will result in reductions of nutrient concentrations in the sediments, and therefore, over time, reductions in loadings from the sediments will occur. Benthic flux of N from bottom sediments is a critical (but often overlooked) component of N loading to the shallow estuarine systems, therefore determination of the site-specific magnitude of this component was also performed (see Section VI of the MEP Report).

Benthic N flux is a function of N loading and particulate organic N (PON). Projected benthic fluxes are based upon projected PON concentrations and watershed N loads and are calculated by multiplying the present N flux by the ratio of projected PON to present PON using the following formulae:

Projected N flux = (present N flux) (PON projected / PON present)

$$PON\ projected = (R_{load})\ (D_{PON}) + PON_{present\ offshore}$$

$$R_{load} = (projected\ N\ load) / (Present\ N\ load)$$

D_{PON} is the PON concentration above background determined by:

$$D_{PON} = (PON_{present\ embayment} - PON_{present\ offshore})$$

Benthic loading is affected by the change in watershed load. The benthic flux modeled for the Wareham River Estuary System is reduced (towards zero) from existing conditions based on the N load reduction from controllable sources. Since there was a negative benthic flux (nutrient uptake) recorded in the Upper Wareham River, Crab Cove, and Crooked River sub-embayments under present conditions, a more conservative approach was used for these segments in the TMDL by assuming zero benthic flux for these segments in the future. This conservative approach was used and is considered part of the margin of safety in the TMDL. Since benthic loading varies throughout the year and the values shown represent "worst case" summertime conditions, loading rates are presented in kilograms per day.

The loadings from atmospheric sources incorporated into the TMDL are the same rates presently occurring because, as discussed above, significant control of atmospheric loadings at the local level is not considered to be feasible.

Margin of Safety

Statutes and regulations require that a TMDL include a margin of safety (MOS) to account for any lack of knowledge concerning the relationship between load and waste load allocations and water quality [CWA para 303 (d) (20C, 40C.G.R. para 130.7C(1)]. The MOS must be designed to ensure that any uncertainties in the data or calculations used to link pollutant sources to water quality impairment modeling will be accounted for in the TMDL and ensure protection of the beneficial designated uses. The EPA's 1991 TMDL Guidance explains that the MOS may be implicit, i.e., incorporated into the TMDL through conservative assumptions in the analysis, or explicit, i.e., expressed in the TMDL as loadings set aside for the MOS. An explicit MOS quantifies an allocation amount separate from other load and waste load allocations. An explicit

MOS can incorporate reserve capacity for future unknowns, such as population growth or effects of climate change on water quality. An implicit MOS is not specifically quantified but consists of statements of the conservative assumptions used in the analysis. The MOS for the Wareham River Estuary System TMDL is implicit. MassDEP used conservative assumptions to develop numeric model applications that account for the MOS. These assumptions are described below, and they account for all sources of uncertainty, including the potential impacts of climate change.

While the general vulnerabilities of coastal areas to climate change can be identified, specific impacts and effects of changing estuarine conditions are not well known at this time (https://www.mass.gov/adapting-to-climate-change). Because the science is not yet available, MassDEP is unable to analyze climate change impacts on streamflow, precipitation, and nutrient loading with any degree of certainty for TMDL development. Considering these uncertainties and informational gaps, MassDEP has opted to address all sources of uncertainty through an implicit MOS. MassDEP does not believe that an explicit MOS approach is appropriate under the circumstances or will provide a more protective or accurate MOS than the implicit MOS approach, as the available data simply does not lend itself to characterizing and estimating loadings to derive numeric allocations within confidence limits. Although the implicit MOS approach does not expressly set aside a specific portion of the load to account for potential impacts of climate change, MassDEP has no basis to conclude that the conservative assumptions that were used to develop the numeric model applications are insufficient to account for the lack of knowledge regarding climate change.

Conservative assumptions that support an implicit MOS:

1) Use of conservative data in the linked model

The watershed N model provides conservative estimates of N loads to the embayment. N transfer through direct groundwater discharge to estuarine waters is based upon studies indicating negligible aquifer attenuation and dilution, i.e., 100% of load enters embayment. This is a conservative estimate of loading because studies have also shown that in some areas less than 100% of the load enters the estuary. N from the upper watershed regions which travel through ponds or wetlands almost always enters the embayment via stream flow and is directly measured (over 12-16 months) to determine attenuation. In these cases, the land-use model has shown a slightly higher predicted N load than the measured discharges in the streams/rivers that have been assessed to date. Therefore, the watershed model as applied to the surface water watershed areas again presents a conservative estimate of N loads because the actual measured N in streams was lower than the modeled concentrations.

MEP conducted long-term measurements of natural attenuation relating to surface water discharges at the two major surface water sources of the Wareham River Estuary System: the Agawam and Wankinco Rivers. Based upon the total N loads discharged from the Agawam River (12,461 kg/yr) and Wankinco River (11,139 kg/year) compared to that added by the various land-uses to the watershed (13,537 kg/yr), the integrated attenuation in passage through ponds, streams and freshwater wetlands prior to discharge to the estuary is approximately 8% for the Agawam River and 18% for the Wankinco River (Howes *et. al*, 2014)

Within the Wareham River Estuary System study area, there are 20 freshwater ponds with delineated watersheds. None of these ponds has available pond-wide bathymetric data or sufficient water quality data collection outside of the MEP to provide a basis for an alternative N attenuation rate. Assignment of the standard MEP 50% attenuation in all the ponds with delineated sub-watersheds resulted in attenuated N loads at the gages that were significantly less than the measured N loads. In order to be conservative and match the measured data, MEP staff assigned no attenuation to any of the pond N loads. Instead, all attenuation is determined based on measured N loads at the gages for the Agawam and Wankinco Rivers.

The hydrodynamic and water quality models have been assessed directly. For the water quality model, it was possible to conduct a quantitative assessment of the model total N results as fitted to a baseline dataset - computed root mean squared (RMS) error is less than 0.03 mg/l, which demonstrates a good fit between modeled and measured data for this system (Howes *et. al,* 2014). Since the water quality model incorporates all the outputs from the other models, this excellent fit indicates a high degree of certainty in the result. The high level of model accuracy provides a high degree of confidence in the output and reduces the margin of safety required.

Similarly, the water column N validation dataset was also conservative. The model is calibrated to measured water column N and validated to salinity. However, the model predicts average summer N concentrations. Very high or low measurements are marked as outliers. The effect is to make the N threshold more accurate and scientifically defensible. If a single measurement two times higher than the next highest data point in the series raises the average by 0.05 mg/L N, this would allow for a higher "acceptable" load to the embayment. Marking the very high outlier is a way of preventing a single and rare bloom event from changing the N threshold for a system. This effectively strengthens the dataset so that a higher margin of safety is not required.

Additionally, the predicted reductions of the amount of N released from the sediments are most likely underestimates, i.e., conservative. The reduction is based solely on a reduced deposition of particulate organic nitrogen (PON) due to lower primary production rates under the reduced N loading in these systems. As the N loading decreases and organic inputs are reduced, it is likely that rates of coupled remineralization-nitrification, denitrification, and sediment oxidation will increase. It was also conservatively assumed that the negative benthic flux in the sub-embayments of Crab Cove, Crooked River, and Upper Wareham River (-35.4, -216.8, and -413.6 kg N/year, respectively) does not exist under future loading conditions and as such was designated as "0" for purposes of the TMDL.

Benthic regeneration of N is dependent upon the amount of PON deposited to the sediments and the percentage that is regenerated to the water column as opposed to being denitrified or buried. The regeneration rate projected under reduced N loading conditions was based upon two assumptions:(1) PON in the embayment exceeding that of inflowing tidal water (boundary condition) results from production supported by watershed N inputs; and (2) presently enhanced production will decrease in proportion to the reduction in the sum of watershed N inputs and direct atmospheric N input. The latter condition would result in equal embayment versus boundary condition production and PON concentrations if watershed N loading and direct atmospheric deposition could be reduced to zero, which is impossible. This proportional reduction assumes that the proportion of remineralized N will be the same as under present conditions, which is almost certainly an underestimate. Future N regeneration rates are therefore overestimated, which adds to the margin of safety.

Finally, decreases in air deposition through continuing air pollution control efforts are unaccounted for in this TMDL and provides another component of the margin of safety.

2) Conservative sentinel station/target threshold nitrogen concentration

Conservatism was used in the selection of the sentinel station and target threshold N concentration. The sites were chosen that had stable eelgrass or benthic infaunal communities, and not those just starting to show impairment, which would have slightly higher N concentration. Meeting the target threshold N concentration at the sentinel station will result in reestablishment of eelgrass and benthic habitat throughout the rest of the system.

3) Conservative approach

The target loads were based on tidally averaged N concentrations on the outgoing tide which is the worst-case condition because that is when the N concentrations are the highest. The N concentrations will be lower on the flood tides; therefore, this approach is conservative.

In addition to the margin of safety within the context of setting the N threshold levels described above, a programmatic margin of safety also derives from continued monitoring of this embayment to support adaptive management. This continuous monitoring effort provides the ongoing data to evaluate the improvements that occur over the multi-year implementation of the N management plan. This will allow refinements to the plan to ensure that the desired level of restoration is achieved.

Seasonal Variation

The TMDLs for the waterbody segments are protective for all seasons because they are based on the most critical time period, i.e., the summer growing season. The daily loads can be converted to annual loads by multiplying by 365 (the number of days in a year). Nutrient loads to the embayment are based on annual loads for two reasons. The first is that primary production in coastal waters can peak in both the late winter-early spring and in the late summer-early fall periods. Second, as a practical matter, the types of management necessary to control the N load do not lend themselves to intra-annual manipulation since a considerable portion of the N is from nonpoint sources. Thus, calculating annual loads is most appropriate, since it is difficult to control nonpoint N sources on a seasonal basis, and N sources can take considerable time to migrate to impacted waters.

TMDL Values for the Wareham River Estuary System

As outlined above, the total maximum daily N loads that would provide for the restoration and protection of the embayment were calculated by considering all N sources grouped by natural background, point sources, and nonpoint sources. A more meaningful way of presenting the loads from an implementation perspective is shown in Table 8 and Appendix D.

Table 8: Nitrogen Total Maximum Daily Loads for the Wareham River Estuary System

MEP Watershed	**Target Threshold Watershed Load** [1] (kg N/day)	**Atmospheric Deposition** (kg N/day)	**Load from Sediments**[2] (kg N/day)	**TMDL**[3] (kg N/day)
Broad Marsh River	4.101	1.681	12.168	17.95
Marks Cove	4.073	0.959	2.407	7.44
Crab Cove	2.299	1.614	0[4]	3.91
Crooked River	2.551	0.333	0[4]	2.88
Wareham River (Lower)	0.468	5.18	58.8	64.45
Wareham River (Upper)	19.121	1.803	0[4]	20.92
Agawam River	22.112	-	-	22.11
Wankinco River	25.851	-	-	25.85
System Total	**80.634**	**11.57**	**73.375**	**165.52**

[1] *Target threshold watershed load is the load from the watershed needed to meet the embayment target threshold Nitrogen concentration identified in Table 4.*
[2] *Projected future flux (present rates reduced approximately proportional to watershed load reductions).*
[3] *Sum of target threshold watershed load, atmospheric deposition load, and sediment load.*
[4] *Negative benthic flux is set to zero.*

In this table, N loadings from the atmosphere and from nutrient rich sediments are listed separately from the target watershed threshold loads. The target watershed load is composed of locally controllable N from landfills, on-site subsurface wastewater disposal systems (septic systems), WWTF discharges, stormwater runoff, and fertilizer sources. In the case of the Wareham River Estuary System, the TMDL was calculated by projecting reductions in locally controllable watershed sources of N. The target load identified in this table represents one alternative loading scenario to achieve that goal, but other scenarios may be possible and approvable as well. It must be demonstrated, however, that any alternative implementation strategies will be protective of the entire embayment system. Once again, the goal of this TMDL is to achieve the identified target threshold N concentration at the identified sentinel station.

Implementation Plan

The critical element of this TMDL process is achieving the sentinel station specific target threshold N concentration presented in Table 4. This is necessary for the restoration and protection of water quality, benthic invertebrate habitat, and eelgrass within the Wareham River Estuary System. To achieve these target threshold N concentrations, N loading rates must be reduced throughout the Wareham River Estuary System and its upstream waters. Table 8 lists the target threshold watershed N load for this system.

Septic Systems

The vast majority of controllable N load is from individual septic systems for private residences. The Comprehensive Wastewater Management Plan (CWMP) should therefore assess the most cost-effective options for achieving the target threshold N watershed loads, including, but not limited to, sewering and treatment for N control of sewage and septage at either centralized or de-centralized locations and denitrifying systems for all private residences. The CWMP should include a schedule of the selected strategies and estimated timelines for achieving those targets. However, MassDEP realizes that an adaptive management approach may be used to observe implementation results over time and allow for adjustments based on those results. The appropriateness of any of the alternatives will depend on local conditions and will have to be determined on a case-by-case basis, using an adaptive management approach.

Table 9 summarizes the present loadings from septic systems and the reduced loads that would be necessary to achieve the target threshold N concentration in the Wareham River Estuary System under the scenario modeled here, which includes both reductions to the Wareham Wastewater Control Facility load and septic loads. A 79% reduction in present septic loading combined with the Wastewater Control Facility load described below achieved the target threshold N concentrations at the primary and secondary sentinel stations This septic load change will result in an 30% decrease in the total watershed load to the Wareham River Estuary System.

Table 9: Reductions Necessary to Achieve the TMDL by Reducing Septic System Loads

MEP Watershed	**Present Septic Load** (kg N/day)	**Threshold Septic Load** (kg N/day)	**Threshold Septic Load % Change**
Broad Marsh	4.27	0.43	-90%
Wareham River (Marks Cove)	1.60	0.80	-50%
Crab Cove	2.50	1.25	-50%
Crooked River	4.00	1.20	-70%
Wareham River (Lower)	0.50	0.25	-50%
Wareham River (Upper)	18.14	1.81	-90%
Agawam River (from Mill Pond)	12.16	0.00	-100%
Wankinco River (from Parker Mills Pond)	4.68	3.27	-30%
Wareham River Estuary System (total)	**47.85**	**9.01**	**-79%**

WWTF and Outfall

As shown in Table 9, the N load reductions within the system necessary to achieve the threshold N concentrations required a combined 79% removal of septic load (associated with direct groundwater discharge to the embayment) for the river watershed. In addition, the Wareham Wastewater Control Facility load will require reduction to 4,300 kg N/year (11.78 kg N/day), from the MEP estimated present discharge of 6,761 kg N/year (18.52 kg N/day). The CWMP should assess the most cost-effective options to meet this reduction in WWTF loading.

The modeling results provide one scenario of achieving the threshold level for the sentinel site within the estuarine system. This example does not represent the only method for achieving this goal. The communities located within the Wareham River Estuary System watershed are encouraged to evaluate other load reduction scenarios and take any reasonable steps to reduce the controllable N sources.

Stormwater

EPA and MassDEP authorized most of the watershed communities within the Wareham River Estuary System watershed for coverage under the NPDES Phase II General Permit for Stormwater Discharges from Small Municipal Separate Storm Sewer Systems (MS4s) in 2003. EPA and MassDEP reissued the MS4 permit effective July 1, 2018 (with modification effective January 6, 2021). The NPDES permits issued in Massachusetts do not establish numeric effluent limitations for stormwater discharges, rather, they establish narrative requirements, including best management practices, to meet the following six minimum control measures and to meet the Massachusetts Surface Water Quality Standards.

1) Public education and outreach particularly on the proper disposal of pet waste;
2) Public participation/involvement;
3) Illicit discharge detection and elimination;
4) Construction site runoff control;
5) Post construction runoff control; and
6) Pollution prevention/good housekeeping.

As part of their applications for Phase II permit coverage, communities must identify the best management practices they will use to comply with each of these six minimum control measures and the measurable goals they have set for each measure. Therefore, compliance with the requirements of the Phase II stormwater permit in the Wareham River Estuary System watershed towns will contribute to the goal of reducing the N load as prescribed in this TMDL for the estuarine system watershed.

Climate Change

MassDEP recognizes that long-term (25+ years) climate change impacts to southeastern Massachusetts, including the area of this TMDL, are occurring based on known science. Massachusetts Executive Office of Energy and Environmental Affairs 2011 Climate Change Adaptation Report (EOEEA, 2011), predicts that by 2100 the sea level could be from 1 to 6 feet higher than the current position and precipitation rates in the Northeast could increase by as much as 20 percent. However, the details of how climate change will affect sea level rise, precipitation, streamflow, sediment and nutrient loading in specific locations are generally unknown. The ongoing debate is not about whether climate change will occur, but the rate at and the extent to which it will occur, and the adjustments needed to address its impacts. EPA's 2012 Climate Change Strategy states: "Despite increasing understanding of climate change, there still remain questions about the scope and timing of climate change impacts, especially at the local scale where most water-related decisions are made" (EPA, 2012). For estuarine TMDLs in southeastern Massachusetts, MassDEP recognizes that this is particularly true, where water quality management decisions and implementation actions are generally made and conducted at the municipal level on a sub-watershed scale.

EPA's Climate Change Strategy identifies the types of research needed to support the goals and strategic actions to respond to climate change. EPA acknowledges that data are missing or not available for making water resource management decisions under changing climate conditions. In addition, EPA recognizes the limitation of current modeling in predicting the pace and magnitude of localized climate change impacts and recommends further exploration of the use of tools, such as atmospheric, precipitation and climate change models, to help states evaluate pollutant load impacts under a range of projected climatic shifts.

In 2013, EPA released a study entitled, "Watershed modeling to assess the sensitivity of streamflow, nutrient, and sediment loads to potential climate change and urban development in 20 U.S. watersheds." (EPA, 2013). The closest watershed to southeastern Massachusetts that was examined in this study is a New England coastal basin located between Southern Maine and Central Coastal Massachusetts. These watersheds do not encompass any of the watersheds in the Massachusetts Estuary Project (MEP) region, and it has vastly different watershed characteristics, including soils, geography, hydrology and land use – key components used in a modeling analysis. The initial "first order" conclusion of this study is that, in many locations, future conditions, including water quality, are likely to be different from experience. However, most significantly, this study did not demonstrate that changes to TMDLs (the water quality restoration targets) would be necessary for the region. EPA's 2012 Climate Change Strategy also acknowledges that the Northeast, including New England, needs to develop standardized regional assumptions regarding future climate change impacts. EPA's 2013 modeling study does not provide the scientific methods and robust datasets needed to predict specific long-term climate change impacts in the MEP region to inform TMDL development.

MassDEP believes that impacts of climate change should be addressed through TMDL implementation with an adaptive management approach in mind. Adjustments can be made as environmental conditions, pollutant sources, or other factors change over time. Massachusetts Coastal Zone Management (CZM) has developed a StormSmart Coasts Program to help coastal communities address impacts and effects of erosion, storm surge and flooding which are increasing due to climate change. The program, offers technical information, planning strategies, legal and regulatory tools to communities to adapt to climate change impacts. As more information and tools become available, there may be opportunities to make adjustments in TMDLs in the future to address predictable climate change impacts. When the science can support assumptions about the effects of climate change on the N loadings to the Wareham River Estuary System, the TMDL can be reopened, if warranted.

Implementation Guidance

The watershed communities of Wareham, Plymouth, and Carver are urged to meet the target threshold N concentrations by reducing N loadings from any and all sources, through whatever means are available and practical, including reductions in on-site subsurface wastewater disposal system loadings as well as reductions in stormwater runoff and/or fertilizer use within the watershed through the establishment of local by-laws and/or the implementation of stormwater Best Management Practices (BMPs).

MassDEP's MEP Implementation Guidance report (MassDEP, 2003) provides N loading reduction strategies that are available to Wareham, Plymouth, and Carver that could be incorporated into the implementation plans. The following topics related to N reduction are discussed in the Guidance:

- Wastewater Treatment;
    - On-Site Treatment and Disposal Systems
    - Cluster Systems with Enhanced Treatment
    - Community Treatment Plants
    - Municipal Treatment Plants and Sewers
- Tidal Flushing;
    - Channel Dredging
    - Inlet Alteration
    - Culvert Design and Improvements
- Stormwater Control and Treatment*;
    - Source Control and Pollution Prevention
    - Stormwater Treatment
- Attenuation via Wetlands and Ponds;
- Water Conservation and Water Reuse;
- Management Districts;
- Land Use Planning and Controls;
    - Smart Growth
    - Open Space Acquisition
    - Zoning and Related Tools
- Nutrient Trading.

**The towns Wareham, Plymouth, and Carver are members of the 237 communities in Massachusetts with urbanized areas regulated by the MS4 General Stormwater Permit requirements*

Monitoring Plan

MassDEP is of the opinion that there are three forms of monitoring that are useful to determine progress towards achieving compliance with the TMDL. MassDEP's position is that implementation will be conducted through an iterative process where adjustments may be needed in the future. The three forms of monitoring include:

1) tracking implementation progress as approved in the town CWMP plan (as appropriate);
2) monitoring ambient water quality conditions, including, but not limited to, the sentinel station identified in the MEP Technical Report; and
3) monitoring and tracking the extent of eelgrass habitat.

If necessary, to achieve the TMDL, the CWMP will evaluate various options to achieve the goals set out in the TMDL and Technical Report. It will also make a final recommendation based on existing or additional modeling runs, set out required activities and identify a schedule to achieve the most cost-effective solution that will result in compliance with the TMDL. Once approved by MassDEP, tracking progress on the agreed-upon plan will, in effect, also be tracking progress towards water quality improvements in conformance with the TMDL.

Relative to water quality, MassDEP believes that an ambient monitoring program, much reduced from the data collection activities needed to properly assess conditions and to populate the model, will be important to determine actual compliance with water quality standards. Although the TMDL load values are not fixed, the target threshold N concentrations at the sentinel stations are considered fixed. Through discussions amongst the MEP project partners, it is generally agreed that existing monitoring programs which were designed to thoroughly assess conditions and populate water quality models can be substantially reduced for compliance monitoring purposes. Although more specific details need to be developed on a case-by-case basis, MassDEP's current thinking is that about half the current effort (using the same data collection procedures) would be sufficient to monitor compliance over time and to observe trends in water quality changes. In addition, the benthic habitat and communities would require periodic monitoring on a frequency of about every 5+ years. Finally, in addition to the above, existing monitoring conducted by MassDEP for eelgrass should continue to observe any changes that may occur to eelgrass populations as a result of restoration efforts.

MassDEP will continue working with the watershed communities to develop and refine monitoring plans that remain consistent with the goals of the TMDL. Through the adaptive management approach ongoing monitoring will be conducted and will indicate if water quality standards are being met. If this does not occur other management activities would have to be identified and considered to reach the goals outlined in this TMDL. However, development and implementation of a monitoring plan will take some time, but it is more important at this point to focus efforts on reducing existing watershed loads to achieve water quality goals. Finally, additional monitoring efforts within the adaptive management framework that indicate water quality standards are not being met may inform revised threshold concentrations and loadings to the Wareham River Estuary System, such that the TMDL can be reopened, if warranted.

Reasonable Assurances

MassDEP possesses the statutory and regulatory authority, under the Massachusetts Clean Waters Act and Massachusetts Surface Water Quality Standards, to implement and enforce the provisions of the TMDL through its many permitting programs, including requirements for N loading reductions from on-site subsurface wastewater disposal systems. However, because most nonpoint source controls are voluntary, reasonable assurance is based on the commitment of the locality involved.

The Towns of Wareham, Plymouth, and Carver have demonstrated this commitment through the comprehensive wastewater planning initiated well before the generation of the TMDL. The towns expect to use the information in this TMDL to generate support from their citizens to take the necessary steps to remedy existing problems related to N loading from wastewater treatment facility discharge, on-site subsurface wastewater disposal systems, stormwater, and runoff (including fertilizers) and to prevent any future degradation of these valuable resources.

Moreover, reasonable assurances that the TMDL will be implemented include enforcement of regulations, availability of financial incentives and local, state, and federal programs for pollution control. Stormwater NPDES permit coverage will address discharges from municipally owned stormwater drainage systems. Enforcement of regulations controlling nonpoint discharges include local implementation of the Commonwealth's Wetlands Protection Act and Rivers Protection Act; Title 5 regulations for on-site subsurface wastewater disposal systems and other local regulations such as the Town of Rehoboth's stable regulations.

Financial incentives include federal funds available under Sections 319, 604(b), and 104(b) programs of the CWA, which are provided as part of the Performance Partnership Agreement between MassDEP and EPA. Wareham River Estuary System watershed towns are encouraged to investigate the use of Coastal Zone Management Coastal Pollutant Remediation grants and the EPA Southeast New England Program grants and technical assistance to improve water quality impaired by nonpoint sources, including stormwater. Other potential funds and assistance are available through the Massachusetts Department of Agriculture's Enhancement Program and the US Department of Agriculture's Natural Resources Conservation Services. Additional financial incentives include income tax credits for Title 5 upgrades and low interest loans for Title 5 on-site subsurface wastewater disposal system upgrades available through municipalities participating in this portion of the state revolving fund program.

As the town implements this TMDL document, the TMDL values (kg/day of N) will be used by MassDEP as guidelines for permitting activities and should be used by local communities as a management tool.

Public Participation

To be completed.

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Appendix A: Overview of Applicable Water Quality Standards

Water quality standards that govern surface water conditions that may result from cultural eutrophication are dissolved oxygen, nutrients, bottom pollutants or alterations, aesthetics, excess plant biomass, and nuisance vegetation. The Massachusetts Surface Water Quality Standards (SWQS, 314 CMR 4.00) contain numeric criteria for dissolved oxygen, site-specific numeric and narrative standards for nutrients, and solely narrative standards for the other variables. This summary does not supersede or replace 314 CMR 4.00. A complete version of the SWQS is available online (MassDEP 2021).

Applicable Narrative Standards

The following narrative standards are excerpted from the SWQS:

> 314 CMR 4.05(5)(a): *Aesthetics*. All surface waters shall be free from pollutants in concentrations that settle to form objectionable deposits; float as debris, scum, or other matter to form nuisances, produce objectionable odor, color, taste, or turbidity, or produce undesirable or nuisance species of aquatic life.
>
> 314 CMR 4.05(5)(b): *Bottom Pollutants or Alterations*. All surface waters shall be free from pollutants in concentrations or combinations or from alterations that adversely affect the physical or chemical nature of the bottom, interfere with the propagation of fish or shellfish, or adversely affect populations of non-mobile or sessile benthic organisms.
>
> 314 CMR 4.05(5)(c): *Nutrients*. Unless naturally occurring, all surface waters shall be free from nutrients in concentrations that would cause or contribute to impairment of existing or designated uses and shall not exceed the site-specific criteria developed in a TMDL or as otherwise established by the Department pursuant to 314 CMR 4.00 including, but not limited to, those established in 314 CMR 4.06(6)(c): *Table 28: Site-specific Criteria*. Any existing point source discharge containing nutrients in concentrations that would cause or contribute to cultural eutrophication, including the excessive growth of aquatic plants or algae, in any surface water shall be provided with the most appropriate treatment as determined by the Department, including, where necessary, highest and best practical treatment (HBPT) for POTWs and BAT for non POTWs, to remove such nutrients to ensure protection of existing and designated uses. Human activities that result in the nonpoint source discharge of nutrients to any surface water may be required to be provided with cost effective and reasonable best management practices for nonpoint source control.

Description of Coastal and Marine Classes and Numeric Dissolved Oxygen Standards

The following class descriptions and numeric standards are excerpted from the SWQS:

> 314 CMR 4.05(4)(a): *Class SA*. Those Coastal and Marine Waters so designated pursuant to 314 CMR 4.06; including, without limitation, 314 CMR 4.06(2) and (5), and certain qualified waters designated in 314 CMR 4.06(6)(b). These waters are designated as an excellent habitat for fish, other aquatic life and wildlife, including for their reproduction, migration, growth and other critical functions, and for primary and secondary contact recreation. In certain waters, excellent habitat for fish, other aquatic life and wildlife may include, but is not limited to, seagrass. Where designated for shellfishing in 314 CMR 4.06(6)(b), these waters shall be

suitable for shellfish harvesting without depuration (Approved and Conditionally Approved Shellfish Areas). These waters shall have excellent aesthetic value.

314 CMR 4.05(4)(a)1.: *Dissolved Oxygen*. Shall not be less than 6.0 mg/l. Where natural background conditions are lower, DO shall not be less than natural background. Natural seasonal and daily variations that are necessary to protect existing and designated uses shall be maintained.

314 CMR 4.05(4)(b): *Class SB*. Those Coastal and Marine Waters so designated pursuant to 314 CMR 4.06; including, without limitation, 314 CMR 4.06(2) and certain surface waters designated in 314 CMR 4.06(6)(b). These waters are designated as a habitat for fish, other aquatic life and wildlife, including for their reproduction, migration, growth and other critical functions, and for primary and secondary contact recreation. In certain waters, habitat for fish, other aquatic life and wildlife may include, but is not limited to, seagrass. Where designated for shellfishing in 314 CMR 4.06(6)(b), these waters shall be suitable for shellfish harvesting with depuration (Restricted and Conditionally Restricted Shellfish Areas). These waters shall have consistently good aesthetic value.

314 CMR 4.05(4)(b)1.: *Dissolved Oxygen*. Shall not be less than 5.0 mg/l. Where natural background conditions are lower, DO shall not be less than natural background. Natural seasonal and daily variations that are necessary to protect existing and designated uses shall be maintained.

Surface Waters Not Specifically Designated in 314 CMR 4.06

Note many waterbodies do not have a specific water quality designation in 314 CMR 4.06: *Classification, Figures, and Tables***.** Those that do not have a specific designation are classified by category. Coastal and Marine Classes of water are designated as Class SA and presumed High Quality Waters as described in 314 CMR 4.06 (5).

314 CMR 4.06(5): *Other Waters*. Unless otherwise designated in 314 CMR 4.06: *Classification, Figures, and Tables*, other waters are Class B, and presumed High Quality Waters for inland waters and Class SA, and presumed High Quality Waters for coastal and marine waters. Inland fisheries designations and coastal and marine shellfishing designations for unlisted waters shall be made on a case-by-case basis as necessary.

Applicable Antidegradation Provisions

Applicable antidegradation provisions are detailed in 314 CMR 4.04: *Antidegradation Provisions*, from which an excerpt is provided:

314 CMR 4.04(1): *Protection of Existing Uses*. In all cases existing uses and the level of water quality necessary to protect the existing uses shall be maintained and protected.

314 CMR 4.04(2): *Protection of High Quality Waters*. High Quality waters are waters whose quality exceeds minimum levels necessary to support the national goal uses, low flow waters, and other waters whose character cannot be adequately described or protected by traditional criteria. These waters shall be protected and maintained for their existing level of quality unless limited degradation by a new or increased discharge is authorized by the Department pursuant to 314 CMR 4.04(5). Limited degradation also may be allowed by the Department where it determines that a new or increased discharge is insignificant because it does not have the

potential to impair any existing or designated water use and does not have the potential to cause any significant lowering of water quality.

314 CMR 4.04(3): *Protection of Outstanding Resource Waters*. Certain waters are designated for protection under this provision in 314 CMR 4.06. These waters include Class A Public Water Supplies (314 CMR 4.06(1)(d)1.) and their tributaries, certain wetlands as specified in 314 CMR 4.06(2) and other waters as determined by the Department based on their outstanding socio-economic, recreational, ecological and/or aesthetic values. The quality of these waters shall be protected and maintained.

(a) Any person having an existing discharge to these waters shall cease said discharge and connect to a Publicly Owned Treatment Works (POTW) unless it is shown by said person that such a connection is not reasonably available or feasible. Existing discharges not connected to a POTW shall be provided with the highest and best practical method of waste treatment determined by the Department as necessary to protect and maintain the outstanding resource water.

(b) A new or increased discharge to an Outstanding Resource Water is prohibited unless:

1. the discharge is determined by the Department to be for the express purpose and intent of maintaining or enhancing the resource for its designated use and an authorization is granted as provided in 314 CMR 4.04(5). The Department's determination to allow a new or increased discharge shall be made in agreement with the federal, state, local or private entity recognized by the Department as having direct control of the water resource or governing water use; or

2. the discharge is dredged or fill material for qualifying activities in limited circumstances, after an alternatives analysis which considers the Outstanding Resource Water designation and further minimization of any adverse impacts. Specifically, a discharge of dredged or fill material is allowed only to the limited extent specified in 314 CMR 9.00: *401 Water Quality Certification for Discharge of Dredged or Fill Material, Dredging, and Dredged Material Disposal in Waters of the United States within the Commonwealth* and 314 CMR 4.06(1)(d). The Department retains the authority to deny discharges which meet the criteria of 314 CMR 9.00 but will result in substantial adverse impacts to the physical, chemical, or biological integrity of surface waters of the Commonwealth

314 CMR 4.04(4) *Protection of Special Resource Waters*. The quality of Special Resource Waters shall be protected and maintained. No new or increased discharge to an SRW, and no new or increased discharge to a tributary to an SRW that would result in lower water quality in the SRW, may be allowed, except where:

(a) the discharge results in temporary and short term changes in the quality of the SRW, provided that the discharge does not permanently lower water quality or result in water quality lower than necessary to protect uses; and

(b) an authorization is granted pursuant to 314 CMR 4.04(5).

314 CMR 4.04(5): *Authorizations*.

(a) An authorization to discharge to waters designated for protection under 314 CMR 4.04(2) may be issued by the Department where the applicant demonstrates that:

1. The discharge is necessary to accommodate important economic or social development in the area in which the waters are located;

2. No less environmentally damaging alternative site for the activity, receptor for the disposal, or method of elimination of the discharge is reasonably available or feasible;

3. To the maximum extent feasible, the discharge and activity are designed and conducted to minimize adverse impacts on water quality, including implementation of source reduction practices; and

4. The discharge will not impair existing water uses and will not result in a level of water quality less than that specified for the Class.

(b) An authorization to discharge to the narrow extent allowed in 314 CMR 4.04(3) or 314 CMR 4.04(4) may be granted by the Department where the applicant demonstrates compliance with 314 CMR 4.04(5)(a)2. through 314 CMR 4.04(5)(a)4.

(c) Where an authorization is at issue, the Department shall circulate a public notice in accordance with 314 CMR 2.06: *Public Notice and Comment*. Said notice shall state an authorization is under consideration by the Department and indicate the Department's tentative determination. The applicant shall have the burden of justifying the authorization. Any authorization granted pursuant to 314 CMR 4.04 shall not extend beyond the expiration date of the permit.

(d) A discharge exempted from the permit requirement by 314 CMR 3.05(4) (discharge necessary to abate an imminent hazard) may be exempted from 314 CMR 4.04(5) by decision of the Department.

(e) A new or increased discharge specifically required as part of an enforcement order issued by the Department in order to improve existing water quality or prevent existing water quality from deteriorating may be exempted from 314 CMR 4.04(5) by decision of the Department.

314 CMR 4.04(6): The Department applies its Antidegradation Implementation Procedures to point source discharges subject to 314 CMR 4.00.

314 CMR 4.04(7): *Discharge Criteria*. In addition to the other provisions of 314 CMR 4.00, any authorized Discharge shall be provided with a level of treatment equal to or exceeding the requirements of 314 CMR 3.00: *Surface Water Discharge Permit Program*. Before authorizing a discharge, all appropriate public participation and intergovernmental coordination shall be conducted in accordance with 314 CMR 2.00: *Permit Procedures*.

Appendix B: Nitrogen Monitoring Summary

Table B-1: Summary of the Nitrogen Concentrations* for the Wareham River Estuary System *(Reprinted from Table VI-1 of the MEP Technical Report, Howes et al., 2014)*

MEP Sub-embayment	Monitoring Station	Data Mean	Standard Deviation (all data)	N	Model Min	Model Max	Model Average
Marks Cove	MC-3	0.420	0.082	22	0.344	0.445	0.37
Marks Cove	MC-2	0.440	0.090	24	0.347	0.451	0.396
Marks Cove	MC-1	0.464	0.093	24	0.432	0.502	0.468
Lower Wareham River	WR-7	0.408	0.065	21	0.348	0.497	0.407
Lower Wareham River	WR-6	0.453	0.072	23	0.358	0.536	0.442
Upper Wareham River	WR-5	0.459	0.084	22	0.372	0.549	0.464
Upper Wareham River	WR-4	0.469	0.091	25	0.392	0.551	0.477
Upper Wareham River	WR-3	0.477	0.098	23	0.428	0.56	0.494
Upper Wareham River	WR-2	0.490	0.078	68	0.448	0.588	0.524
Lower Broad Marsh	BR-6	0.541	0.094	47	0.371	0.63	0.479
Lower Broad Marsh	BR-4	0.560	0.121	25	0.403	0.703	0.529
Upper Broad Marsh	BR-3	0.586	0.118	48	0.448	0.812	0.603
Upper Broad Marsh	BR-1	0.649	0.117	24	0.487	0.907	0.666
Lower Agawam River	AG-2	0.533	0.137	22	0.554	0.597	0.573
Middle Agawam River	AG-1	0.554	0.178	26	0.558	0.595	0.573
Buzzards Bay - Boundary	*MC-3*	*0.345*	-	-	-	-	-

**Measured data and modeled nitrogen concentrations for the Wareham River Estuary System. All concentrations are given in mg/L N. "Data mean" values are calculated as the average of the separate yearly means. Data represented in this table were collected in the summers of 2005 through 2011. The Buzzards Bay boundary condition was developed using data from station MC-3, and represents the lowest quartile of measurements.*

Appendix C: Stormwater Loading Information

Impervious surfaces such as roadways, parking lots, rooftops, sidewalks, driveways, and other pavements impede stormwater infiltration and generate surface runoff. The amount of impervious area (IA) in a watershed is correlated with a decrease in water and habitat quality, including increased flood peaks and frequency; increased sediment, nutrient, and other pollutant levels; channel erosion; aquatic biota impairments; and reduced groundwater recharge. Directly connected impervious area (DCIA) is the portion of IA with a direct hydraulic connection to the waterbody via continuous paved surfaces, gutters, drain pipes, or other conventional conveyance and detention structures that do not reduce runoff volume.

DCIA does not include:

- Impervious area draining to stormwater practices designed to meet recharge and other volume reduction criteria.
- Isolated impervious area with an indirect hydraulic connection to the Small Municipal Separate Storm Sewer Systems (MS4s), or that otherwise drain to a pervious area.
- Swimming pools or man-made impoundments, unless drained to an MS4.
- The surface area of natural waterbodies (e.g., wetlands, ponds, lakes, streams, rivers).

When determining the TMDL for a pollutant, MassDEP has decided that stormwater from all areas defined as DCIAs should be considered part of the stormwater waste load allocation (WLA) regardless of whether the area is part of an EPA designated “urbanized area” and as such subject to the NPDES Phase II General Permit for stormwater discharges from MS4s. The WLA consists of the stormwater DCIA contribution and the Wareham Wastewater Control Facility Outfall point source.

DCIA was calculated in accordance with EPA methodology (EPA, 2010) using the “Sutherland Equations” (Sutherland, 2000). As outlined in the methodology: the IA of each sub-watershed was determined using the MassGIS 2005 Impervious Surface data layer (MassGIS, 2007), the land use categories in the MassGIS Land Use 2005 datalayer (MassGIS, 2009) were reclassified into commonly used land use categories that correspond with the Sutherland watershed selection criteria, and the “Sutherland Equations” were applied to the IA to calculate DCIA as a percentage of IA in each sub-watershed.

The WLAs for stormwater nitrogen contribution (kg N/day) was determined using the DCIA for each sub-embayment divided by total IA in the sub-embayment, then multiplying the total impervious surfaces runoff N load for the sub-watershed (Table IV-2 of the MEP Technical Report) per EPA methodology. The remaining impervious surfaces loads were assigned as the LA. Table 7 shows the existing WLA and LA from stormwater runoff from impervious surfaces in the Wareham River Estuary System watershed.

To complete the WLA calculation, the total stormwater load from impervious surfaces as determined by the MEP study (12.8 kg N/day from Table IV-2 in the MEP Technical Report) was multiplied by 0.39 (the percentage of IA that was determined to be DCIA in the watershed - see Table C-1). The resulting value of 6.1 kg N/day is the WLA and the remaining 6.7 kg N/day is assigned to the nonpoint source contribution to the load allocation (LA).

Table C-1: Directly Connected Impervious Area (DCIA) and Stormwater WLA for the Wareham River Estuary System

MEP Watershed	**Total Watershed Land Area** (acres)	**Total Impervious Area in Watershed**[1] (acres)	**Impervious Area as % of Total Watershed Area** (%)	**DCIA Area**[2] (acres)	**DCIA as % of Total Impervious Area** (%)	**MEP Total Unattenuated Watershed Impervious Load**[3] (kg N/day)	**MEP Total Unattenuated Watershed Load** [3,4] (kg N/day)	**WLA** (kg N/day)[5]	**WLA as % of MEP Total Unattenuated Watershed Load**[6] (%)
Broad Marsh	982.4	232.7	23.7%	174.7	75.0%	1.773	11.942	1.331	11.1%
Wareham River (Marks Cove)	638.1	109.1	17.1%	75.1	68.8%	1.559	7.471	1.073	14.4%
Crab Cove	263.4	47.3	18.0%	27.1	57.3%	0.568	4.620	0.325	7.0%
Crooked River	309.2	52.1	16.8%	26.2	50.3%	0.657	6.609	0.331	5.0%
Wareham River (Lower)	204.9	8.4	4.1%	1.3	15.6%	0.065	1.552	0.010	0.6%
Wareham River (Upper)	2,089.2	362.3	17.3%	232.9	64.3%	2.562	43.983	1.647	3.7%
Agawam River	14,193.3	667.3	4.7%	161.6	24.2%	3.562	37.089	0.862	2.3%
Wankinco River	10,197.4	814.3	8.0%	195.5	24.0%	2.084	37.294	0.500	1.3%
System Total	**28,878**	**2,293**	**7.9%**	**894.2**	**39.0%**	**12.830**	**150.559**	**6.079**	**4.0%**

[1] Total Impervious Area calculated using MassGIS 2005 Impervious cover datalayer (MassGIS, 2007).
[2] DCIA calculated per MEP sub-embayment using GIS and EPA methodology (EPA, 2010).
[3] From MEP Technical Report, Table IV-2.
[4] This includes the unattenuated nitrogen loads from wastewater from septic systems, landfills, fertilizer, agriculture, runoff from both natural and impervious surfaces, atmospheric deposition to freshwater waterbodies.
[5] The DCIA Area as % of Total Impervious Area multiplied by the MEP Total Unattenuated Watershed Impervious Load (kg N/day).
[6] The WLA (kg N/day) divided by the total watershed load (kg N/day) then multiplied by 100.

Appendix D: Wareham River Estuary System Total Nitrogen TMDLs

Table D-1: TMDLs for Wareham River Estuary System – Two Total Nitrogen TMDLs and Four Protective TMDLs

MassDEP Assessment Unit Name & ID	**MassDEP AU Type & Class**	**MEP Watershed**	**MassDEP Impairment Parameters Associated with the TMDL**	**Action Type**	**TMDL** *kg N/day*
Wareham River MA95-03	Estuary *Class SA*	Wareham River (Lower) Crab Cove Marks Cove	- Total Nitrogen - Chlorophyll-a - Estuarine Bioassessments	Restorative TMDL	75.80
Agawam River MA95-29	Estuary *Class SB*	Wareham River (Upper)	- Total Nitrogen - Algae - Nutrient/Eutrophication Biological Indicators	Restorative TMDL	20.92
Agawam River MA95-28	Freshwater *Class B\WWF*	Agawam River	-	Protective TMDL [1]	22.11
Wankinco River MA95-50	Estuary *Class SA*	Wankinco River	-	Protective TMDL [1]	25.85
Broad Marsh River MA95-49	Estuary *Class SA*	Broad Marsh River	-	Protective TMDL [1]	17.95
Crooked River MA95-51	Estuary *Class SA*	Crooked River	-	Protective TMDL [1]	2.88
				System Total:	**165.52**

[1] *Pollution Protection TMDLs (kg-N/day) for community planning and to prevent further downstream impairment.*