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Massachusetts Estuaries Project

Linked Watershed-Embayment Model to Determine Critical Nitrogen Loading Thresholds for Centerville River System Barnstable, Massachusetts

Executive Summary

1. Background

This report presents the results generated from the implementation of the Massachusetts Estuaries Project's Linked Watershed-Embayment Approach to the Centerville River embayment system, a coastal embayment within the Town of Barnstable, Massachusetts. Analyses of the Centerville River embayment system was performed to assist the Town with up-coming nitrogen management decisions associated with the Towns' current and future wastewater planning efforts, as well as wetland restoration, anadromous fish runs, shell fishery, open-space, and river/harbor maintenance programs. As part of the MEP approach, habitat assessment was conducted on the embayment based upon available water quality monitoring data, historical changes in eelgrass distribution, time-series water column oxygen measurements, and benthic community structure. Nitrogen loading thresholds for use as goals for watershed nitrogen management are the major product of the MEP effort. In this way, the MEP offers a science-based management approach to support the Town of Barnstable resource planning and decision-making process. The primary products of this effort are: (1) a current quantitative assessment of the nutrient related health of the Centerville River embayment, (2) identification of all nitrogen sources (and their respective N loads) to embayment waters, (3) nitrogen threshold levels for maintaining Massachusetts Water Quality Standards within embayment waters, (4) analysis of watershed nitrogen loading reduction to achieve the N threshold concentrations in embayment waters, and (5) a functional calibrated and validated Linked Watershed-Embayment modeling tool that can be readily used for evaluation of nitrogen management alternatives (to be developed by the Town) for the restoration of the Centerville River embayment system.

Wastewater Planning: As increasing numbers of people occupy coastal watersheds, the associated coastal waters receive increasing pollutant loads. Coastal embayments throughout the Commonwealth of Massachusetts (and along the U.S. eastern seaboard) are becoming nutrient enriched. The elevated nutrients levels are primarily related to the land use impacts associated with the increasing population within the coastal zone over the past half-century.

The regional effects of both nutrient loading and bacterial contamination span the spectrum from environmental to socio-economic impacts and have direct consequences to the culture, economy, and tax base of Massachusetts's coastal communities. The primary nutrient causing the increasing impairment of our coastal embayments is nitrogen, with its primary sources being wastewater disposal, and nonpoint source runoff that carries nitrogen (e.g. fertilizers) from a range of other sources. Nitrogen related water quality decline represents one of the most serious threats to the ecological health of the nearshore coastal waters. Coastal embayments, because of their shallow nature and large shoreline area, are generally the first coastal systems to show the effect of nutrient pollution from terrestrial sources.

In particular, the Centerville embayment system within the Town of Barnstable is at risk of eutrophication (over enrichment) from enhanced nitrogen loads entering through groundwater from the increasingly developed watershed to this coastal system. Eutrophication is a process that occurs naturally and gradually over a period of tens or hundreds of years. However, human-related (anthropogenic) sources of nitrogen may be introduced into ecosystems at an accelerated rate that cannot be easily absorbed, resulting in a phenomenon known as cultural eutrophication. In both marine and freshwater systems, cultural eutrophication results in degraded water quality, adverse impacts to ecosystems, and limits on the use of water resources.

The Town of Barnstable has recognized the severity of the problem of eutrophication and the need for watershed nutrient management and is currently developing a Comprehensive Wastewater Management Plan, which it plans to rapidly implement. The Town of Barnstable has also completed and implemented wastewater planning in other regions of the Town not associated with the Centerville River embayment system. The Town has nutrient management activities related to their tidal embayments, which have been associated with the MEP effort in the Three Bays and the Lewis Bay embayment systems. The Town of Barnstable and work groups have recognized that a rigorous scientific approach yielding site-specific nitrogen loading targets was required for decision-making and alternatives analysis. The completion of this multi-step process has taken place under the programmatic umbrella of the Massachusetts Estuaries Project, which is a partnership effort between all MEP collaborators and the Town. The modeling tools developed as part of this program provide the quantitative information necessary for the Towns' nutrient management groups to predict the impacts on water quality from a variety of proposed management scenarios.

Nitrogen Loading Thresholds and Watershed Nitrogen Management: Realizing the need for scientifically defensible management tools has resulted in a focus on determining the aquatic system's assimilative capacity for nitrogen. The highest-level approach is to directly link the watershed nitrogen inputs with embayment hydrodynamics to produce water quality results that can be validated by water quality monitoring programs. This approach when linked to state-of-the-art habitat assessments yields accurate determination of the "allowable N concentration increase" or "threshold nitrogen concentration". These determined nitrogen concentrations are then directly relatable to the watershed nitrogen loading, which also accounts for the spatial distribution of the nitrogen sources, not just the total load. As such, changes in nitrogen load from differing parts of the embayment watershed can be evaluated relative to the degree to which those load changes drive embayment water column nitrogen concentrations toward the "threshold" for the embayment system. To increase certainty, the "Linked" Model is independently calibrated and validated for each embayment.

Massachusetts Estuaries Project Approach: The Massachusetts Department of Environmental Protection (DEP), the University of Massachusetts – Dartmouth School of Marine Science and Technology (SMAST), and others including the Cape Cod Commission (CCC) have undertaken the task of providing a quantitative tool to communities throughout southeastern Massachusetts (the Linked Watershed-Embayment Management Model) for nutrient management in their coastal embayment systems. Ultimately, use of the Linked Watershed-Embayment Management Model tool by municipalities in the region results in effective screening of nitrogen reduction approaches and eventual restoration and protection of valuable coastal resources. The MEP provides technical guidance in support of policies on nitrogen loading to embayments, wastewater management decisions, and establishment of nitrogen Total Maximum Daily Loads (TMDLs). A TMDL represents the greatest amount of a pollutant that a waterbody can accept and still meet water quality standards for protecting public health and maintaining the designated beneficial uses of those waters for drinking, swimming, recreation and fishing. The MEP modeling approach assesses available options for meeting selected nitrogen goals that are protective of embayment health and achieve water quality standards.

The core of the Massachusetts Estuaries Project analytical method is the Linked Watershed-Embayment Management Modeling Approach, which links watershed inputs with embayment circulation and nitrogen characteristics.

The Linked Model builds on well-accepted basic watershed nitrogen loading approaches such as those used in the Buzzards Bay Project, the CCC models, and other relevant models. However, the Linked Model differs from other nitrogen management models in that it:

- requires site-specific measurements within each watershed and embayment;
- uses realistic “best-estimates” of nitrogen loads from each land-use (as opposed to loads with built-in “safety factors” like Title 5 design loads);
- spatially distributes the watershed nitrogen loading to the embayment;
- accounts for nitrogen 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 nitrogen regenerated within the embayment;
- is validated by both independent hydrodynamic, nitrogen concentration, and ecological data;
- is calibrated and validated with field data prior to generation of “what if” scenarios.

The Linked Model Approach’s greatest assets are its ability to be clearly calibrated and validated, and its utility as a management tool for testing “what if” scenarios for evaluating watershed nitrogen management options.

For a comprehensive description of the Linked Model, please refer to the *Full Report: Nitrogen Modeling to Support Watershed Management: Comparison of Approaches and Sensitivity Analysis*, available for download at http://www.state.ma.us/dep/smerp/smerp.htm. A more basic discussion of the Linked Model is also provided in Appendix F of the *Massachusetts Estuaries Project Embayment Restoration Guidance for Implementation Strategies*, available for download at http://www.state.ma.us/dep/smerp/smerp.htm. The Linked Model suggests which management solutions will adequately protect or restore embayment water quality by enabling towns to test specific management scenarios and weigh the resulting water quality impact against the cost of that approach. In addition to the management scenarios modeled for this report, the Linked Model can be used to evaluate additional management scenarios and may be

updated to reflect future changes in land-use within an embayment watershed or changing embayment characteristics. In addition, since the Model uses a holistic approach (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. Unlike many approaches, the Linked Model accounts for nutrient sources, attenuation, and recycling and variations in tidal hydrodynamics and accommodates the spatial distribution of these processes. For an overview of several management scenarios that may be employed to restore embayment water quality, see *Massachusetts Estuaries Project Embayment Restoration Guidance for Implementation Strategies*, available for download at http://www.state.ma.us/dep/smerp/smerp.htm.

Application of MEP Approach: The Linked Model was applied to the Centerville River embayment system by using site-specific data collected by the MEP and water quality data from the Water Quality Monitoring Program conducted by the Town of Barnstable, with technical guidance from the Coastal Systems Program at SMAST (see Chapter II). Evaluation of upland nitrogen loading was conducted by the MEP, data was provided by the Town of Barnstable Planning Department, and watershed boundaries delineated by USGS. This land-use data was used to determine watershed nitrogen loads within the Centerville River embayment system and each of the systems sub-embayments as appropriate (current and build-out loads are summarized in Chapter IV). Water quality within a sub-embayment is the integration of nitrogen loads with the site-specific estuarine circulation. Therefore, water quality modeling of this tidally influenced estuary included a thorough evaluation of the hydrodynamics of the estuarine system. Estuarine hydrodynamics control a variety of coastal processes including tidal flushing, pollutant dispersion, tidal currents, sedimentation, erosion, and water levels. Once the hydrodynamics of the system was quantified, transport of nitrogen was evaluated from tidal current information developed by the numerical models.

A two-dimensional depth-averaged hydrodynamic model based upon the tidal currents and water elevations was employed for the Centerville River embayment system. Once the hydrodynamic properties of the estuarine system were computed, two-dimensional water quality model simulations were used to predict the dispersion of the nitrogen at current loading rates. Using standard dispersion relationships for estuarine systems of this type, the water quality model and the hydrodynamic model was then integrated in order to generate estimates regarding the spread of total nitrogen from the site-specific hydrodynamic properties. The distributions of nitrogen loads from watershed sources were determined from land-use analysis. Boundary nutrient concentrations in Vineyard Sound source waters were taken from water quality monitoring data. Measurements of current salinity distributions throughout the estuarine waters of the Centerville River embayment system was used to calibrate the water quality model, with validation using measured nitrogen concentrations (under existing loading conditions). The underlying hydrodynamic model was calibrated and validated independently using water elevations measured in time series throughout the embayments.

MEP Nitrogen Thresholds Analysis: The threshold nitrogen level for an embayment represents the average water column concentration of nitrogen that will support the habitat quality being sought. The water column nitrogen level is ultimately controlled by the watershed nitrogen load and the nitrogen concentration in the inflowing tidal waters (boundary condition). The water column nitrogen concentration is modified by the extent of sediment regeneration. Threshold nitrogen levels for the embayment systems in this study were developed to restore or maintain SA waters or high habitat quality. High habitat quality was defined as supportive of eelgrass and infaunal communities. Dissolved oxygen and chlorophyll a were also considered in the assessment.

The nitrogen thresholds developed in Section VIII-2 were used to determine the amount of total nitrogen mass loading reduction required for restoration of eelgrass and infaunal habitats in the Centerville River system. Tidally averaged total nitrogen thresholds derived in Section VIII.1 were used to adjust the calibrated constituent transport model developed in Section VI. Watershed nitrogen loads were sequentially lowered, using reductions in septic effluent discharges only, until the nitrogen levels reached the threshold level at the sentinel stations chosen for the Centerville River system. It is important to note that load reductions can be produced by reduction of any or all sources or by increasing the natural attenuation of nitrogen within the freshwater systems to the embayment. The load reductions presented below represent only one of a suite of potential reduction approaches that need to be evaluated by the community. The presentation is to establish the general degree and spatial pattern of reduction that will be required for restoration of this nitrogen impaired embayment.

The Massachusetts Estuaries Project's thresholds analysis, as presented in this technical report, provides the site-specific nitrogen reduction guidelines for nitrogen management of the Centerville River embayment system in the Town of Barnstable. Future water quality modeling scenarios should be run which incorporate the spectrum of strategies that result in nitrogen loading reduction to the embayment. The MEP analysis has initially focused upon nitrogen loads from on-site septic systems as a test of the potential for achieving the level of total nitrogen reduction for restoration of each embayment system. The concept was that since septic system nitrogen loads generally represent 85% - 90% of the controllable watershed load to the Centerville River embayment system and are more manageable than other of the nitrogen sources, the ability to achieve needed reductions through this source is a good gauge of the feasibility for restoration of these systems.

2. Problem Assessment (Current Conditions)

A habitat assessment was conducted throughout the Centerville River system based upon available water quality monitoring data, historical changes in eelgrass distribution, time-series water column oxygen measurements, and benthic community structure. At present, the Centerville River system is showing variations in nitrogen enrichment and habitat quality among its various component basins. In general the system is showing healthy to moderately impaired benthic habitat. However, the lower basins (e.g. lower Centerville River, East Bay) are clearly significantly impaired based on eelgrass criteria, as historical eelgrass beds have been lost and eelgrass is no longer present within the System.

The effect of nitrogen enrichment is to cause oxygen depletion; however, with increased phytoplankton (or epibenthic algae) production, oxygen levels will rise in daylight to above atmospheric equilibration levels in shallow systems (generally ~7-8 mg L^{-1} at the mooring sites). Overall, oxygen depletion was observed at each of the mooring sites (Table VII-1a), but the degree of depletion varied between sites. East Bay generally maintained oxygen levels above 4 mg L-1, but with frequent excursions below 5 mg L^{-1}. These oxygen conditions represent a moderate level of impairment to benthic infaunal communities associated with embayments. Oxygen levels in the upper reach of the Centerville River showed even lower levels periodically into the 2-3 mg L^{-1} range, although generally with daily minima above 4 mg L^{-1}. The central region of Scudder Bay was clearly nitrogen enriched, but generally maintained daily oxygen minima above 4 mg L^{-1} and typically above 5 mg L^{-1}. This basin showed its enrichment mainly through the large daily excursions with daily maxima typically >11 mg L^{-1}.

The level of oxygen depletion and the magnitude of daily oxygen excursion and chlorophyll a levels indicate highly nutrient enriched waters and impaired habitat quality within the estuary. The spatial pattern of oxygen depletion within the Estuary was consistent with the measured chlorophyll a levels (Table VII-2, Figures VII-6 –VII-8). The level of oxygen depletion was directly related to the amount of chlorophyll a in the watercolumn. This is consistent with nitrogen enrichment resulting in increased phytoplankton biomass and subsequent organic matter deposition and decay being the process controlling oxygen level in the Centerville River System. Chlorophyll a levels in East Bay were indicative of a relatively healthy to moderately enriched basin. In East Bay chlorophyll a averaged on 5.1 ug L^{-1} and was almost always <10 ug L^{-1}. The upper reach of the Centerville River and Scudder Bay supported higher phytoplankton biomass with average levels ~20 ug L^{-1} and blooms producing consistent levels of 30 ugL^{-1}.

The present lack of eelgrass throughout the Centerville River System is consistent with the observed oxygen depletions in each basin and the chlorophyll levels and functional basin types comprising this estuary. The upper estuarine reaches, which are strongly influenced by surrounding wetlands, do not typically support eelgrass habitat, due to their naturally nutrient enriched shallow waters and salt marsh function. However, basins like the Centerville River channel (from the Town Landing to East Bay), and especially the sub-embayment of East Bay, typically do support eelgrass habitat under low to moderate nitrogen loading conditions. The distribution of eelgrass in 1951 is fully consistent with this functional analysis and the conclusion that the lower region of this Estuary (e.g. downstream of Bumps River mouth) is currently over its nitrogen threshold level that supports healthy eelgrass habitat.

Analysis of the eelgrass beds which have persisted just outside of the tidal inlet and extended in 1951 into East Bay and up the Centerville River to the mouth of Bumps River, supports the contention that the recent loss of eelgrass is the result of nitrogen enrichment, as the well flushed outer beds have been extremely stable over the past half century. These beds are at similar water depths and have the same tidal excursion as the historical bed areas within the lower estuary. Therefore, the major environmental differences between the sites appear to be directly related to nitrogen enrichment. The recent loss of beds from within the Centerville River System is also consistent with the lower nitrogen loading and the resultant higher sustained oxygen levels and lower chlorophyll levels (high light penetration) that should have existed at that time, based upon population data.

It appears from the eelgrass and water quality information that eelgrass beds within East Bay and the lower Centerville River should be the target for restoration and that this habitat should be recovered with appropriate nitrogen management. .

The infaunal study indicated an overall system supporting generally healthy to only moderately impaired infaunal habitat relative to the ecosystem types represented (i.e. embayment versus salt marsh creek/pond).

The Bumps River estuarine reach and the lower Centerville River currently support healthy infaunal animal habitat for a coastal embayment/tidal river on Cape Cod. The basin of East Bay, which is depositional and receives the ebb tidal waters from the entire Estuarine System, is presently showing moderate impairment. This moderate impairment is seen primarily in the dominance of amphipod mats throughout the central basin (*Amplesca*). Amphipod mats represent a valuable and productive resource, but transitional between healthy and stressful conditions, particularly as relates to organic matter loading from nitrogen enrichment. The upper Centerville River and the associated mid reach of the Centerville River

are dominated by salt marsh conditions. The species present are typical of salt marsh creeks, which generally have organic matter tolerant species (e.g. *Streblospio*) and crustaceans and mollusks. The upper reaches of the Centerville River appear to be currently supporting healthy infaunal habitat. Similarly, Scudder Bay exhibits infauna habitat quality indicative of organic matter enrichment. However, this basin supports salt marsh areas around its margins and a shallow central basin. It appears that this basin is functioning at least partially as a salt marsh pond and was evaluated as such by the MEP Technical Team. Therefore, this basin appears to be presently moderately impaired, based upon its moderate-low number of species and moderate-low (100) numbers of individuals. The nutrient enriched conditions within this basin appear to be beyond the accommodation of the infaunal community and nitrogen management will be needed to restore this benthic resource.

3. Conclusions of the Analysis

The threshold nitrogen level for an embayment represents the average watercolumn concentration of nitrogen that will support the habitat quality being sought. The watercolumn nitrogen level is ultimately controlled by the integration of the watershed nitrogen load, the nitrogen concentration in the inflowing tidal waters (boundary condition) and dilution and flushing via tidal flows. The water column nitrogen concentration is modified by the extent of sediment regeneration and by direct atmospheric deposition.

Threshold nitrogen levels for this embayment system were developed to restore or maintain SA waters or high habitat quality. In this system, high habitat quality was defined as possibly supportive of eelgrass and supportive of diverse benthic animal communities. Dissolved oxygen and chlorophyll *a* were also considered in the assessment.

Watershed nitrogen loads (Tables ES-1 and ES-2) for the Town of Barnstable Centerville River embayment system was comprised primarily of wastewater nitrogen. Land-use and wastewater analysis found that generally about 85% - 90% of the controllable watershed nitrogen load to the embayment was from wastewater.

A major finding of the MEP clearly indicates that a single total nitrogen threshold can not be applied to Massachusetts' estuaries, based upon the results of the Great, Green and Bournes Pond Systems, Popponesset Bay System, the Hamblin / Jehu Pond / Quashnet River analysis in eastern Waquoit Bay, the analysis of the adjacent Rushy Marsh system and the Pleasant Bay and Nantucket Sound embayments associated with the Town of Chatham. This is almost certainly going to be true for the other embayments within the MEP area, as well.

The threshold nitrogen levels for the Centerville River embayment system in Barnstable were determined as follows:

Centerville River Threshold Nitrogen Concentrations

- Following the MEP protocol, the restoration target for the Centerville River system should reflect both recent pre-degradation habitat quality and be reasonably achievable. Based upon the assessment data (Chapter VII), the Centerville River System is presently supportive of infaunal habitat throughout its 4 component basins. However, there is a moderate level of infaunal habitat impairment within Scudder Bay and the mid region of the Centerville River, requiring nitrogen management for restoration. The primary habitat issue within the Centerville River System relates to the loss of eelgrass from the lower estuary, specifically from the Centerville River west of the entrance to

Bumps River and in East Bay. This loss of eelgrass classifies these areas as "significantly impaired", although they presently support healthy to moderately healthy infaunal communities. Further impairment to both the infaunal habitat in Scudder Bay and the eelgrass habitat in the lower estuary are supported by the variety of other indicators which support the conclusion that these impairments are the result of nitrogen enrichment, primarily from watershed nitrogen loading.

- The target nitrogen concentration (tidally averaged TN) for restoration of eelgrass at the sentinel location within the lower reach of the Centerville River (region seaward of the mouth of the Bumps River) was determined to be 0.37 mg TN L^{-1}. This nitrogen level is based upon the absence of eelgrass in the Lower Centerville River at a tidally averaged TN of 0.395 mg N l^{-1} and comparison to a stable eelgrass system in a similarly configured basin, the lower Oyster River (Chatham) at 0.37 mg N L^{-1}. Note that this level is only slightly lower than that determined by the MEP Technical Team for nearby Popponesset Bay (0.38 mg N L^{-1}). This difference relates to the much shallower water in Popponesset Bay then in the Centerville River. Water depth is important as the same phytoplankton concentration that results in shading of eelgrass in deep water, will allow sufficient light to support eelgrass in shallow water. The need for a lower threshold in deeper versus shallower water was seen in the MEP eelgrass habitat assessment for Bournes Pond, Falmouth.

- The threshold nitrogen level at the sentinel station within the Centerville River System is within the range found for other complex systems such as 0.38 mg N L^{-1} for Stage Harbor, 0.38 N/L^{-1} for Bournes Pond and nearby Popponesset Bay and 0.35 mg N L^{-1} for West Falmouth Harbor and Phinneys Harbor. The sentinel station under present loading conditions supports a tidally corrected average concentration of 0.395 mg TN L^{-1}, so watershed nitrogen management will be required for restoration of the estuarine habitats within this system

- Although the nitrogen management target is restoration of eelgrass habitat (and associated water clarity, shellfish and fisheries resources), benthic infaunal habitat quality must also be supported as a secondary condition. At present, in the regions with impaired infaunal habitat, the tidally averaged total nitrogen (TN) level under existing conditions is 0.526 mg N L^{-1} in Scudder Bay and between 0.543-0.465 mg N L^{-1} in the middle reach of the Centerville River (bridge to Bumps River). The observed moderate impairment at these sites is consistent with observations by the MEP Technical Team in other enclosed basins along Nantucket Sound (e.g. Perch Pond, Bournes Pond, Popponesset Bay) where levels <0.5 mg N L^{-1} were found to be supportive of healthy infaunal habitat and in deeper enclosed basins in Buzzards Bay (e.g. Eel Pond in Bourne) where healthy infaunal habitat had a slightly lower threshold level, 0.45 mg N L^{-1}, due to those being a "deep" depositional basin. The higher TN levels observed in the upper Centerville River salt marshes are within the nitrogen threshold to support the observed healthy infaunal habitat in this estuarine reach. To ensure that meeting the nitrogen threshold at the sentinel station (BC-T, just seaward of the mouth of the Bumps River within the Centerville River, upgradient from BC-9) results in restoration of the moderately impaired infaunal habitats in Scudder Bay and the middle reach of the Centerville River, nitrogen criteria for secondary infaunal "check" stations were developed by the MEP Technical Team. Based upon the Centerville River system showing moderate impairment at tidally averaged TN levels of 0.526 mg N L^{-1} in Scudder Bay (BC-3) and 0.543 at the inland end of the middle reach of the Centerville River (BC-7) and the results from nearby embayments to Nantucket Sound (noted above), it was

concluded that an upper limit of 0.50 mg N L-1 tidally averaged TN would support healthy infaunal habitat in these inner regions.

It is important to note that the analysis of future nitrogen loading to the Centerville River estuarine system focuses upon additional shifts in land-use from forest/grasslands to residential and commercial development. However, the MEP analysis indicates that significant increases in nitrogen loading can occur under present land-uses, due to shifts in occupancy, shifts from seasonal to year-round usage and increasing use of fertilizers (presently less than half of the parcels use lawn fertilizers). Therefore, watershed-estuarine nitrogen management must include management approaches to prevent increased nitrogen loading from both shifts in land-uses (new sources) and from loading increases of current land-uses. The overarching conclusion of the MEP analysis of the Centerville River estuarine system is that restoration will necessitate a reduction in the present (2004) nitrogen inputs and management options to negate additional future nitrogen inputs.

Table ES-1. Existing total and sub-embayment nitrogen loads to the estuarine waters of the Centerville River system, observed nitrogen concentrations, and sentinel system threshold nitrogen concentrations.

Sub-embayments	Natural Background Watershed Load [1] (kg/day)	Present Land Use Load [2] (kg/day)	Present Septic System Load (kg/day)	Present WWTF Load [3] (kg/day)	Present Watershed Load [4] (kg/day)	Direct Atmospheric Deposition [5] (kg/day)	Present Net Benthic Flux (kg/day)	Present Total Load [6] (kg/day)	Observed TN Conc. [7] (mg/L)	Threshold TN Conc. (mg/L)
CENTERVILLE RIVER SYSTEM										
Scudder Bay	2.433	9.347	43.277	0.00	52.624	0.685	-2.125	51.184	0.57-0.66	--
Centerville River	6.148	12.965	57.981	0.00	70.946	1.167	8.891	81.004	0.33-0.79	--
East Bay	1.458	2.326	6.301	0.00	8.627	1.126	12.694	22.447	0.33-0.46	--
Centerville River System Total	**10.039**	**24.638**	**107.559**	**0.00**	**132.197**	**2.978**	**19.460**	**154.635**	**0.33-0.79**	**0.370[8]**

[1] assumes entire watershed is forested (i.e., no anthropogenic sources)
[2] composed of non-wastewater loads, e.g. fertilizer and runoff and natural surfaces and atmospheric deposition to lakes
[3] existing wastewater treatment facility discharges to groundwater
[4] composed of combined natural background, fertilizer, runoff, and septic system loadings
[5] atmospheric deposition to embayment surface only
[6] composed of natural background, fertilizer, runoff, septic system atmospheric deposition and benthic flux loadings
[7] average of 2001 – 2005 data, ranges show the upper to lower regions (highest-lowest) of an sub-embayment. Individual yearly means and standard deviations in Table VI-1.
[8] Threshold for sentinel site located at confluence of Bumps River and Centerville River at water quality station BC-T.

Table ES-2. Present Watershed Loads, Thresholds Loads, and the percent reductions necessary to achieve the Thresholds Loads for the Centerville River system, Centerville, Massachusetts.

Sub-embayments	Present Watershed Load [1] (kg/day)	Target Threshold Watershed Load [2] (kg/day)	Direct Atmospheric Deposition (kg/day)	Benthic Flux Net [3] (kg/day)	TMDL [4] (kg/day)	Percent watershed reductions needed to achieve threshold load levels
CENTERVILLE RIVER SYSTEM						
Scudder Bay	52.624	52.624	0.685	-2.125	51.184	0.00%
Centerville River	70.946	34.181	1.167	7.781	43.129	-51.80%
East Bay	8.627	8.627	1.126	12.694	22.447	0.00%
Centerville River System Total	**132.197**	**95.432**	**2.978**	**18.350**	**116.76**	**-51.80%**

(1) Composed of combined natural background, fertilizer, runoff, and septic system loadings.
(2) Target threshold watershed load is the load from the watershed needed to meet the embayment threshold concentration identified in Table ES-1.
(3) Projected future flux (present rates reduced approximately proportional to watershed load reductions).
(4) Sum of target threshold watershed load, atmospheric deposition load, and benthic flux load.