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Regional Wastewater Management Plan

Technology Assessment – Green Infrastructure & Alternative Approaches

MARCH 2013

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Introduction

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Green infrastructure, in the context of this plan, includes the use of natural systems, or strategically sited constructed systems, to help mitigate the impacts of human activities. Unlike a conventional gray infrastructure approach, which relies on piping networks and centralized treatment facilities, green infrastructure technologies mimic the processes of the natural environment by using vegetation and soil to minimize the impacts of land use on water quality. Essential elements of green infrastructure planning and implementation, including where gray and green infrastructure converge, occurs at both the regional and municipal levels. Siting requires careful site assessment and design at the neighborhood or parcel level.

Cape Cod Commission staff members have examined green infrastructure (GI) technologies as additional tools to restore water quality. These technologies can be used to remove nitrogen and other pollutants from stormwater, to remove nitrogen from wastewater, or to improve groundwater quality through increased nitrogen attenuation. Commission staff used several approaches in assessing opportunities for increasing nitrogen attenuation through natural systems or "green" technologies:

- Coastal Wetland Restoration Projects – Commission staff members examined the extensive, multi-agency effort over the last 10+ years to restore our coastal estuaries and wetland systems. These coastal restoration projects were not initiated with nitrogen removal in mind; however, improved tidal exchange within impacted embayments and the improved function of our coastal wetlands and ecosystems have contributed to the improved water quality and overall health of these systems.
- Potential Sites Analysis for Green Infrastructure Technologies – Commission staff examined opportunities for extending or expanding upon our green infrastructure network. To date, this effort has involved a GIS analysis of sites that could support a GI technology. The Commission was fortunate to receive a US EPA Green Infrastructure Program grant during the course of this planning effort, which supported the development of a site-screening tool and enabled the staff to focus on GI siting opportunities in two impacted watersheds and to identify and design pilot projects.

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- Survey of Green Infrastructure Technologies – Commission staff members are conducting an extensive literature review to understand the nature, opportunities, and limitations of green infrastructure technologies.

These approaches are discussed in more detail in this document.

Coastal Wetland Restoration Projects

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During the 400+ years of settlement on Cape Cod, many of Cape Cod's salt marsh systems have been degraded due to construction of roads and railways, infill, and other kinds of disturbances. The installation of narrow culverts under roads and rail beds has reduced tidal exchange and salinity. The decreased tidal exchange has reduced the flushing of nutrients and other pollutants from these systems, while decreased salinity has dramatically altered the composition of the upstream plant and animal communities.

The Massachusetts Division of Ecological Restoration (formerly the Wetlands Restoration Program), the US Department of Agriculture's Natural Resources Conservation Service (USDA NRCS), the National Park Service/Cape Cod National Seashore, and local agencies and non-profit organizations have worked to restore salt marshes across Cape Cod over many years. The projects typically include removal or enlargement of culverts to increase tidal exchange with the goal of restoring the ecological integrity of the salt marsh system.

The Cape Cod Atlas of Tidally Restricted Salt Marshes (Cape Cod Commission, 2001) provides an inventory of stream crossings where culverts restrict the exchange of water between the ocean and the upstream brackish and freshwater system. In 2006, the USDA NRCS completed its prioritization of impaired salt marshes, fish runs, and shellfish beds to be restored. They sought and received $30 million in federal funding and have been working to design, permit, and construct these restoration projects across Cape Cod (see Final Watershed Plan and Areawide Environmental Impact Statement for the Cape Cod Water Resources Restoration Project). Figure TAA-1 illustrates the status and scope of these projects.

These projects, together with many others designed and championed by the Massachusetts Division of Ecological Restoration (MassDER) have resulted in approximately 12,000 acres of salt marshes and estuaries in various stages of restoration. The natural attenuation sites spreadsheet itemizes and details these projects. It is important to note that these salt marsh restoration projects were not designed to remove nitrogen, and there are no data on nitrogen removal at these sites.

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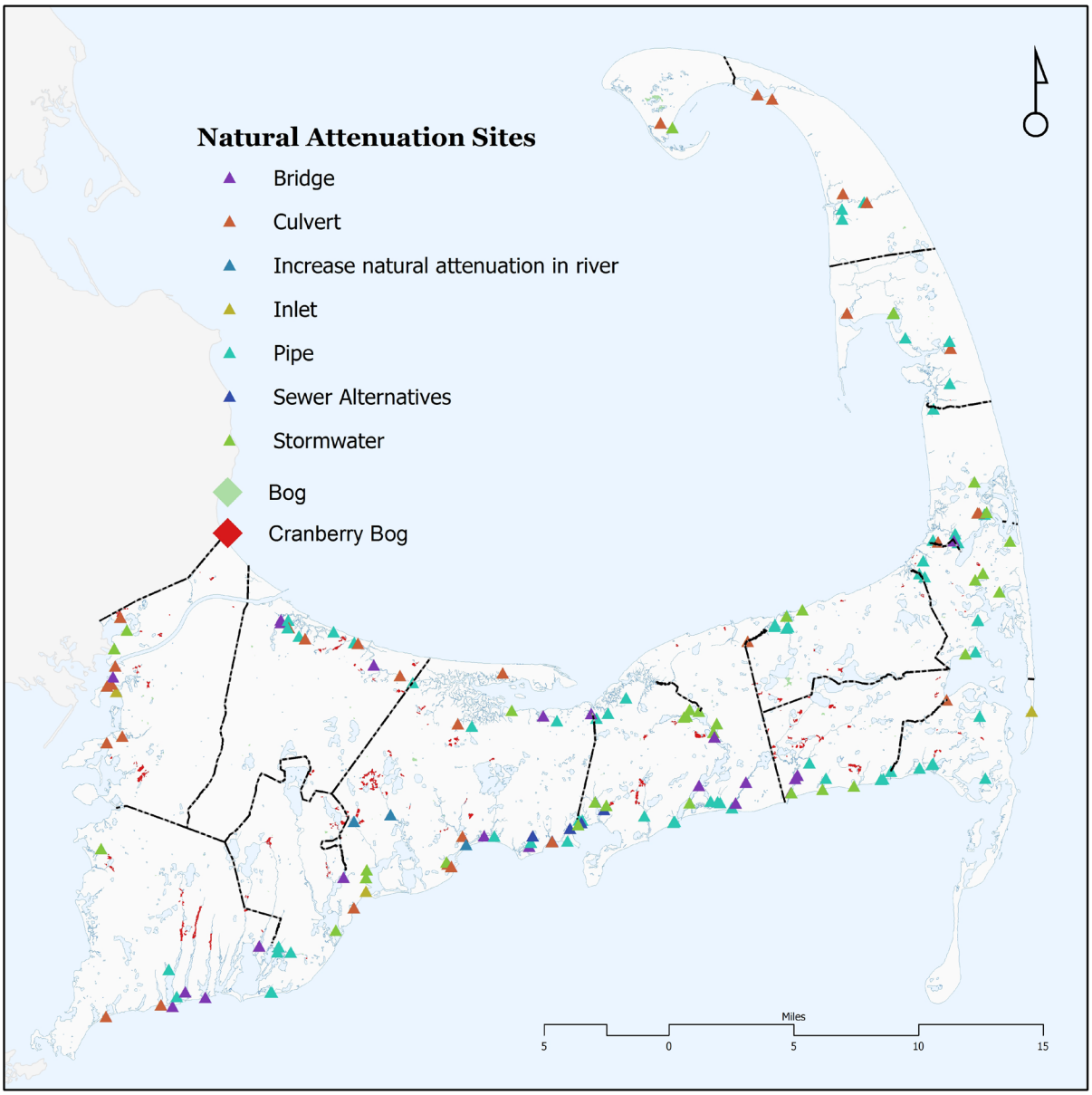
POTENTIAL SITES ON CAPE COD FOR NITROGEN ATTENUATION

The Massachusetts Estuaries Project (MEP) reports identify several projects where removal of a tidal restriction, dredging, or other action within a natural system could result in improved nitrogen attenuation within that

FIGURE TAA-1: Status and Scope of Coastal Wetland Restoration Projects on Cape Cod



SOURCE: Cape Cod Commission GIS and source data spreadsheet

embayment or water body. As shown in the list below, in some instances the MEP analysis showed that a proposed action would not improve nitrogen attenuation. The potential variation in nitrogen-removal rates within the analyzed systems indicates that generalizations should not be made about the potential benefits to nitrogen management from coastal wetland restoration projects.

A review of studies of Cape Cod locations where nitrogen-retention projects could be pursued is provided below. The Woods Hole Group (WHG), Teal Partners (TP), and MEP in conjunction with the University of Massachusetts-Dartmouth School for Marine Science and Technology prepared these examples:

- Chatham (WHG & TP): The Muddy Creek area has potential land to create or enhance a wetland and needs to reduce nitrogen by 3,000 kilograms per year in the upper watershed to decrease loading to the embayment by about 40%.
- Mashpee (WHG & TP): Hamblin and Jehu ponds have potential to attenuate nitrogen if the salt marshes around the edges of the ponds could be expanded.
- Falmouth (WHG & TP): Coonamessett River has a relatively high nitrogen concentration and is a significant contribution to the coastal ponds. Upgradient, abandoned (or to be abandoned) cranberry bogs could be modified to receive river flow for denitrification, the bacterially mediated process of transforming nitrate to nitrogen gas.
- Barnstable (WHG & TP): Skunknett River had three shallow managed ponds associated with it until storms destroyed control structures in 1991. Presently, the river flows have a short residence time that is not conducive to nitrogen attenuation. Restoration of the ponds, if permittable, may enhance attenuation.
- Centerville River (MEP): Increasing natural attenuation in Skunknett River by 20% enables water quality targets to be met while reducing the threshold septic load from 80% to 75% for Centerville River East. "...Measures to increase natural attenuation are an important component to controlling the percentage of septic removal that will be necessary in the upper watershed." (Hamersley, R.M. and B. Howes, 2004)

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- Mashpee (WHG & TP): Santuit Pond in the Popponesset Bay watershed has a system of abandoned cranberry bogs that may provide some potential for attenuation. Control structures remain in place that could help manage flow and detention times.
- Barnstable (WHG & TP): Mill Pond in the Three Bays watershed have potential as a demonstration for pond management (dredging, etc.) to gather data on attenuation and design factors to enhance attenuation in ponds.
- Three Bays (MEP): Dredging the Cotuit Bay inlet results in nominal water quality improvement, although water quality improvements in Cotuit Bay, together with navigational safety improvements, may warrant no threshold septic load published for dredging scenario.
- Little Pond, Falmouth (MEP): Inlet widening reduces the amount of sewering necessary to achieve the target nitrogen reduction. Necessary threshold-attenuated septic-load reduction decreases from 60% to 30% in the Little Pond Stream watershed. A 100% threshold-attenuated septic-load reduction is still necessary for the Little Pond watershed.
- Rushy Marsh (MEP): "...Reconstruction of the tidal inlet alone will achieve the nitrogen threshold level and restoration of this system. ...Sewering alone will not achieve the nitrogen threshold levels in Rushy Marsh Pond. ...A more detailed analysis of inlet stability, maintenance requirements, and potential environmental impacts is required to fully assess inlet reconstruction."
- West Falmouth Harbor (MEP): An alternative scenario considers negative implications of buildout without sewering the watershed.
- Pleasant Bay (MEP): An alternative considers the effect of worst-case flushing scenario (old inlet) .
- Phinney's Harbor (MEP): "...Removing [80%] septic loads from the Phinney's Harbor watershed is the most practical and effective approach. ...Dredged inlet does not result in improved water quality within Eel Pond."
- Lewis Bay (MEP): Alternative sewering and effluent discharge sites have been evaluated and comparisons have been made of nitrogen attenuation in one-half dozen stream systems draining to Lewis Bay.

- Parkers River (MEP): Widening of culvert beneath Route 28 reduces the threshold septic load from 96% to 66%.
- Bass River (MEP): "The local residence time of the upper river is presently 1.9 days, which shows that it flushes very well as it exists today. ...Culverts through the railroad bridge will not have a significant effect on curtailing the effects of nutrient-rich waters in the upper part of the Bass River estuary."

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Potential Sites Analysis for Green Infrastructure Technologies

From a regional planning perspective, the Cape's natural or "green" infrastructure—its open spaces, conserved lands, ponds, wetlands, estuaries, and the buffering woodlands adjacent to these areas—could be enhanced to provide a cohesive network of natural systems that improve the natural attenuation of pollutants. The reestablishment of a natural network (akin to a circulatory system) for the Cape could be achieved through restoration of natural habitats and ecosystem functions, creating habitat linkages between currently fragmented resource areas, and enhancing open space protection. The burden on natural wetlands of processing pollutants could be reduced through the strategic placement of constructed wetlands, natural stormwater systems (rain gardens and other biofiltration systems), and other "green" technologies. Depending on design and location, these systems could provide added benefits such as carbon sequestration, air quality improvements, educational and recreational opportunities, and wildlife habitat.

With these interests in mind, Commission staff members conducted an analysis of land or resource characteristics that could support the installation of a GI technology on a watershed scale to help support or reduce the need for gray infrastructure. The initial analysis used GIS to screen parcels based on a variety of criteria, including hydrology, density, TMDLs (per MEP), sensitive resources, and opportunities to expand the existing natural landscape with new (constructed) natural systems.

During the course of this analysis, the US EPA awarded the Commission a grant to look at specific opportunities to site GI projects within two impacted watersheds in Barnstable and Yarmouth. The pilot project will allow the Commission to refine the GIS GI sites screening tool at the regional scale. A summary of the pilot project follows.

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EPA 2012 GREEN INFRASTRUCTURE COMMUNITY PARTNERS PROJECT

The consulting firm Tetra Tech is currently supporting the Commission through the US EPA's 2012 Green Infrastructure Community Partners Project to develop conceptual designs for GI projects in the Lewis Bay and Parkers River watersheds in Hyannis and Yarmouth, respectively. The technologies are specifically targeted and designed to remove nitrogen from groundwater and stormwater sources.

Tetra Tech and the Commission collaborated to develop a screening process to identify site opportunities for GI and low impact development (LID) techniques throughout the two watersheds. The screening process began with a "desktop investigation" of potential sites by using a siting criteria matrix developed by the Commission, assessing both positive siting criteria and potential constraints. The matrix tool was applied to parcels within the Lewis Bay and Parkers River watersheds. The Commission performed field assessments of the highest scoring parcels, resulting in eight potential sites (four in each town) for the development of conceptual GI designs.

SITING CRITERIA MATRIX

The siting criteria matrix consists of multiple GIS-based data layers (termed "siting criteria") along the vertical axis and a collection of potential GI and LID technologies on the horizontal axis. The technologies have been selected based on their high nitrogen-removal efficiencies and represent a range of GI and LID techniques that are applicable in a wide variety of conditions.

GREEN INFRASTRUCTURE MATRIX APPLICATION

Once the GI and LID techniques were identified and the siting criteria matrix developed, the Commission's GIS department applied the positive siting criteria to each parcel within the two target watersheds in Yarmouth and Barnstable. The siting criteria matrix was initially applied generically. GI or LID techniques were not evaluated separately; instead, parcels were assessed using a combination of all positive siting parameters for both wastewater and stormwater applications. A total of 14 positive

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siting parameters were assessed for each site and weighted equally, giving potential sites a maximum score of 14. The Commission decided not to apply the constraints identified within the matrix to the parcels so that the number of potential sites would not be significantly reduced. Applying constraints during the screening process could eliminate high opportunity parcels if only a small piece contained a defined constraint. Instead, the Commission evaluated site constraints during the field assessments of the selected parcels.

The initial application of the siting criteria matrix resulted in 14 parcels in the two watersheds that ranked highly for all positive siting parameters. These parcels contain a mix of parameters that favor techniques to address groundwater sources, stormwater sources, or both. The Commission further refined the set of generic siting criteria to identify potential sites based on field visits. Separate screening processes were utilized to address GI techniques that favor groundwater sources and LID techniques that favor stormwater sources, independently. This iteration, separating the screening approaches, resulted in fewer positive siting criteria to evaluate but more technique-specific sites. The Commission applied the siting criteria matrix to parcels using this specific approach, which confirmed sites previously selected, and identified additional high-opportunity areas for GI and LID techniques. Figure TAA-2 shows an example screening process matrix.

FIGURE TAA-2: Screening Process Example Matrix

Siting Criteria	Constructed Wetlands	Permeable Reactive Barriers	Stormwater Treatment Wetlands	Phytoremediation	Biofiltration Strips	Bioretention/Advanced Bioretention	Infiltration	Green roof[1]	Permeable Pavement	Bioswales	Stormwater Disconnection	Gravel Wetland
Soils: disturbed	x	x		x		x						x
Soils: well drained	x	x	x	x	x	x	x		x		x	
Within open space: recreation	x	x	x	x	x							
Within open space: government	x		x	x	x							
Adjacent to open space: recreation			x		x							
Adjacent to open space: government	x		x		x							
Proximity to golf courses, athletic fields	x		x									
Impervious areas	x		x		x	x	x		x	x	x	x

[1] Green roofs have a significantly different set of siting criteria from other stormwater LID techniques

Maps of sites identified in the GIS screening process, along with a further suitability analysis examining possible constraints based on the field assessments, are included in the Constructability Assessment of Potential Project Sites. The Commission held a two-day public workshop with the towns, during which two of these sites were selected for development of conceptual designs. Final products under the US EPA grant include 30% conceptual plans, construction details, nitrogen model, and construction estimates. This information will help to better understand the potential benefits of green infrastructure on Cape Cod, and could lead to opportunities for additional research and construction of pilot projects to monitor results.

Commission staff members will continue to refine the GI siting tool for use on a regional scale.

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Survey of Green Infrastructure Technologies

Commission staff members are undertaking a survey of GI technologies within the research literature and other sources, to better understand the range of possible techniques, applications, requirements, and constraints of these technologies. A matrix of desired criteria has been established and a minimum of 10 case studies are being evaluated for each of the technologies and approaches under consideration. For example, see the case study matrix for phytoremediation.

Increased understanding of the role wetlands and other natural systems play in the management of pollutants is needed before conclusions may be drawn about how these systems may be incorporated into our nutrient-management strategies. As part of the EPA GI grant, Tetra Tech analyzed some of the technologies better suited to Cape Cod applications, providing estimates of possible nitrogen-removal rates.

CONSTRUCTED WETLANDS

Constructed wetlands are intended to simulate the functions of natural wetlands by using vegetation, soils, and microbial activity (MassDEP, 2003). Constructed wetlands are generally either surface flow (or freewater) wetlands or subsurface flow wetlands, which will be discussed in a following section. These wetland systems have the ability to treat wastewater from a range of pollutant sources, use few or no chemicals, have a lower carbon footprint, and may be less expensive in both capital costs and operation and maintenance than conventional treatment options.

High pollutant-removal efficiencies make constructed wetlands an attractive green infrastructure technique. Nitrogen removal occurs through physicochemical and biological processes, with the main nitrogen removal process being nitrification followed by denitrification, the bacterially mediated process of transforming nitrate to nitrogen gas (Lee et al., 2009).

Constructed wetlands require proper hydrology to maintain necessary plant communities and provide aerobic and anaerobic zones for nutrient

processing. This may not be possible in highly permeable upland areas unless groundwater interaction is available. Implementation in these areas could require an impermeable liner that would increase the cost and eliminate the ability to treat septic system discharges.

The two main kinds of constructed wetlands are subsurface flow wetlands and freewater wetlands. In both cases, blackwater undergoes treatment at the primary level before entering the wetlands system.

SUBSURFACE FLOW WETLANDS

In subsurface flow wetlands (Figure TAA-3), wastewater flows 3–8 inches below the surface to prevent mosquito breeding and public exposure to wastewater. Wastewater is pumped slowly through subsurface sand or gravel filtration beds where it comes in contact with the roots of macrophytes. Over time a biological film develops on the filtration bed and the roots of the plants. Wastewater is treated both by microbial action and by uptake of nutrients by the plants. An underlining is necessary if the system is sited on permeable soils or in an area that receives runoff from land uses with higher pollutant loads.

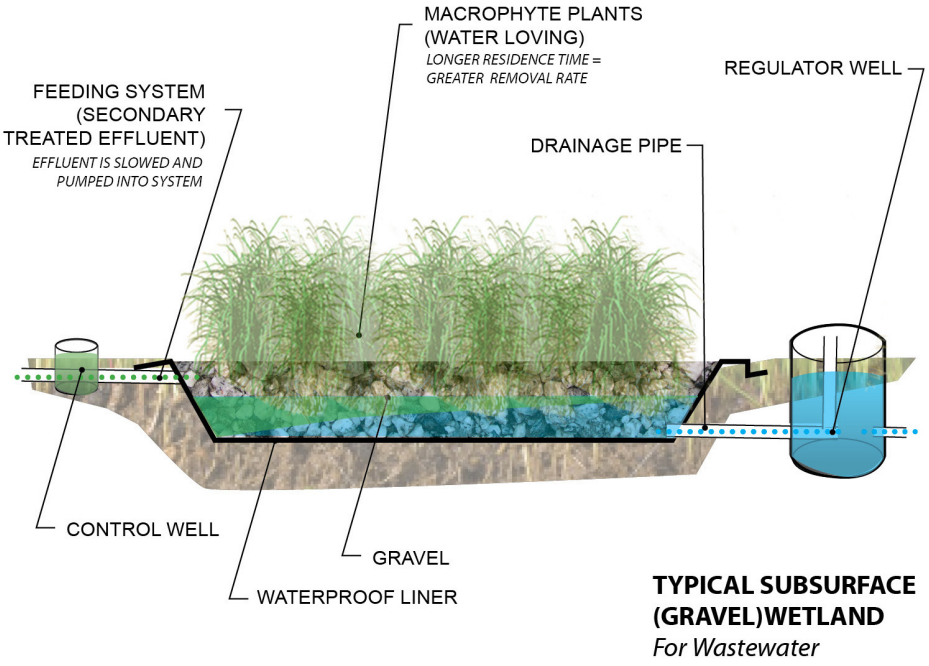

FIGURE TAA-3: A Typical Subsurface Flow Wetland

FREEWATER WETLANDS SYSTEMS

In freewater wetlands systems, wastewater is gravity fed into a constructed wetland where open water is exposed much like in a natural marsh. The length of holding time determines the treatment capacity. Large areas are necessary to treat large flows. As in subsurface flow wetlands, an underlining is required if the system is sited on permeable soils or in an area that receives runoff from land uses with higher potential pollutant loads.

ADVANTAGES AND DISADVANTAGES

Subsurface wetlands systems are generally more cost effective than freewater systems because subsurface systems use less land.

Rates of removal of nitrogen and other contaminants in freewater systems are difficult to measure due to the open nature of the constructed wetland. The inability to measure nitrogen loss in open systems is a deterrent to their use.

Freewater systems can provide habitat for birds and other wildlife. They are usually found to be aesthetically pleasing and can incorporate interpretive features and passive recreation elements, thus potentially contributing to the local economy. Freewater wetlands are also considered to be easier to design, construct, and maintain than subsurface systems.

OTHER CONSTRUCTED WETLANDS SYSTEMS

Solar Aquatic Systems™ combine aeration and clarification chambers with constructed wetlands that consist of chambers with plants suspended on racks with wastewater flowing beneath. “Wastewater is circulated inside a greenhouse through a series of clear tanks, each with its own aquatic ecosystem, and marshes. In this treatment process, sunlight, oxygen, bacteria, algae, plants, snails, and fish work together to purify the water” (SAS brochure). Sludge settles to the bottom where it is collected and fed back into the system for additional treatment. However, not all the sludge is degraded and much of it must be transported to a treatment facility. These systems are generally installed indoors in greenhouses and can include a tertiary ultraviolet (UV) disinfectant treatment. Recharge trenches can discharge to the groundwater.

In an EcoMachine, removal of solids occurs at the site. Wastewater is then pumped through wetland beds containing plants and animals. Three wetlands flow designs (tidal flow, horizontal subsurface flow, and vertical flow) can be used individually or together at one facility. These systems are usually implemented indoors.

A US EPA fact sheet (2001) reported that EcoMachines were capable of treating total nitrogen to <10 milligrams per liter, nitrate to <5 milligrams per liter, and ammonia to <1 milligram per liter.

EcoMachines (Figure TAA-4) are considered to be an innovative technology and, in some cases, may be difficult to permit.

FIGURE TAA-4:
Example EcoMachines

SOURCE: John Todd Ecological, Inc.

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PHYTOREMEDIATION

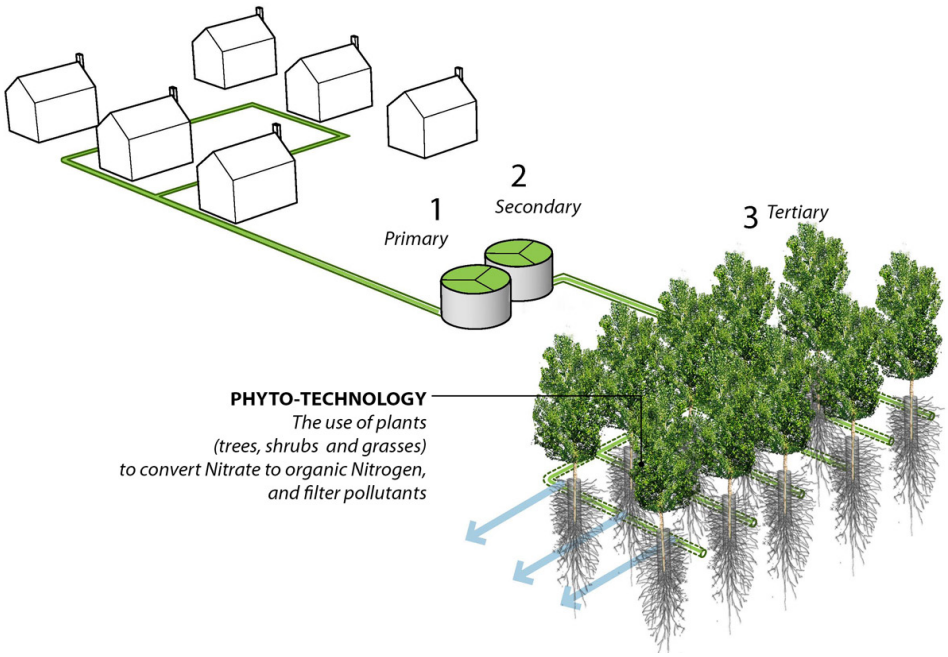
Phytoremediation (Figure TAA-5) utilizes specific plant communities to uptake and either store or process pollutants, or to change pollutants to less harmful forms by microbes located near plant roots (EPA, 2001). Phytoremediation is a low-cost, aesthetically pleasing alternative for pollutant removal. Past nitrogen-removal phytoremediation projects have focused on hazardous metals and chemicals, but recent projects have studied the nitrogen uptake capability of aquatic plants such as water hyacinth (Dar et al., 2011) and trees such as poplar and willow (Vaughn, 2012).

The key physiological processes in phytoremediation include:

- Stimulation of microorganism-based transformation by plant exudates and leachates, and by fluctuating oxygen regimes;
- Slowing of contaminant transport from the vegetated zone due to adsorption and increased evapotranspiration; and
- Plant uptake, followed by metabolism or accumulation.

Additional benefits could include erosion prevention, greenhouse gas sequestration, and creation of a visual barrier, windbreak, and wildlife habitat.

FIGURE TAA-5: Using Phyto-remediation in Conjunction with Conventional Infrastructure



Phytoremediation is a promising technique for nitrogen reduction but limited information is available on removal efficiency, especially in cold weather climates such as Cape Cod.

To be effective, trees in upland areas should have root systems that can penetrate the groundwater table. Phytoremediation can be used in sandy conditions as long as the soils can support the types of trees used and the root systems can reach the groundwater table.

PILOT DEMONSTRATION PROJECT

The Cape Cod Commission, in collaboration with the Town of Barnstable, installed a pilot phytoremediation demonstration project at the Barnstable Water Pollution Control Facility to help assess the potential of this green infrastructure option to reduce the amount of nutrients entering groundwater and estuaries.

A mixture of poplar and willow trees were planted in nine cells containing different soil media (Figures TAA-6 and TAA-7). Wastewater from the treatment facility is pumped into the cells on a fixed schedule. Bimonthly samples will be collected through December, 2012, to determine the concentration of nitrogen, phosphorus, and heavy metals in the cells' leachate.

FIGURE TAA-6: Installation of the Phytoremediation Cells at the Barnstable Water Pollution Control Facility

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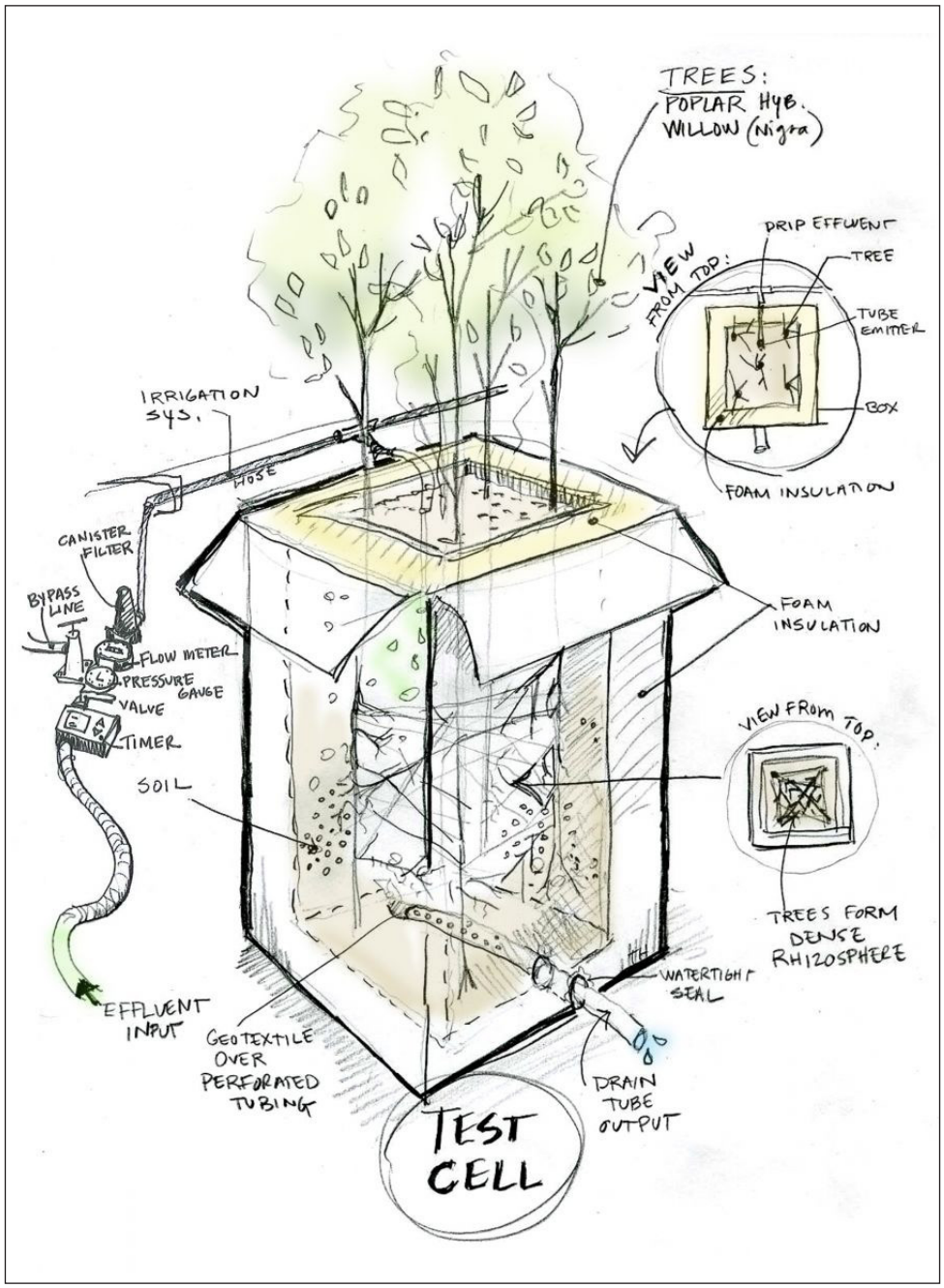
FIGURE TAA-7: Schematic of the Components of an Individual Cell in the Phytoremediation Pilot Project Installed at the Barnstable Water Pollution Control Facility



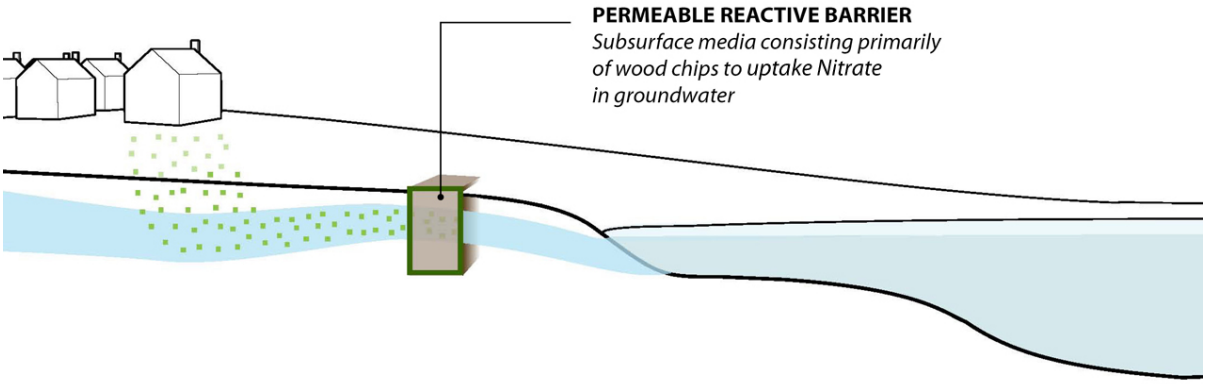
PERMEABLE REACTIVE BARRIERS

An alternative to treating nitrogen on site or at an off-site treatment facility is to intercept nitrate in groundwater at the coastline before it enters an embayment (Figure TAA-8). A Permeable Reactive Barrier (PRB) is a stratified multimedia biofilter containing sand, expanded clay, and lignocellulosics, and/or elemental sulfur. PRBs using organic energy sources use sawdust and/or wood chips placed in a trench to intercept inflows for removal by denitrification (Ecosite, 2011). To be effective, PRBs must be able to intercept the nitrogen source without getting bypassed either below or around the barrier (ITRC, 2011). This requirement results in placement of PRBs generally where the groundwater is shallow. Since PRBs are a passive in-situ technique, they are reliant on the natural groundwater gradient for treatment and require a higher permeability than the surrounding soil to ensure transport through the PRB. The lignocellulosics used in nitrogen-removal PRBs have a high porosity, improving the groundwater transport through the systems.

PRBs have been successfully used to remove nitrate from groundwater from septic plumes and agricultural drainage fields (Robertson et al., 2000). Treatment effectiveness is not reduced by seawater but PRBs placed in tidal zones can be affected by density-driven circulation, which can result in the nitrate plume undercutting the PRB (Vallino et al., 2008).

This technology can provide effective removal at runoff concentrations. Total nitrogen reductions of greater than 95% can be achieved at retention

FIGURE TAA-8: A Permeable Reactive Barrier Intercepts Nitrate in Groundwater at the Coastline



times less than 10 hours (Ecosite, 2011). NITREX™ PRBs have been installed in locations on Cape Cod and have a specific media mix to remove nitrogen. Studies have shown that these proprietary systems can remove 99% of groundwater nitrate concentrations.

PRBs require a higher permeability than the surrounding soil to prevent bypass flows around the system. Implementation in sandy soils could limit the effectiveness or require a much larger PRB.

PERMEABLE REACTIVE BARRIER PILOT STUDIES ON CAPE COD

Recently PRBs were installed at two sites in Falmouth, Massachusetts, to evaluate their efficacy in removing nitrate from groundwater as it nears the coast. PRBs were installed in trenches in the aquifer above the high-tide level along the shores of Childs River and Waquoit Bay. Results of the pilot studies demonstrated a high level of nitrate removal as groundwater passed through the PRBs; however, it is uncertain whether the removal was due to denitrification or other processes (Vallino et al., 2008).

SHELLFISH GROWING AND HARVESTING

Several studies have examined the potential of shellfish cultivation as a means to remove nitrogen from the water column. The research indicates that shellfish incorporate nitrogen into their tissues—which is removed at harvest—and also deposit nitrogen on the bottom sediments where it may promote denitrification.

Studies in the Mashpee River, Waquoit Bay, and Wellfleet Harbor have indicated potential for this method of nitrogen removal. Additional studies are planned in Falmouth to further examine the efficacy of shellfish harvesting. Information is needed on the effects of seasonality on nitrogen-removal rates as well as aesthetic impacts from shellfish culture equipment.

In addition to contributing to water quality improvements, additional aquaculture could provide economic benefits to Cape Cod.

Aquaculture regulations include requirements for:

- Shellfish license, issued by the town and certified by the Massachusetts Division of Marine Fisheries
- Notice of Intent, Order of Conditions from the local conservation commission regulated under the Massachusetts Wetlands Protection Act
- Massachusetts Waterways License under Massachusetts General Laws Chapter 91
- Massachusetts Environmental Policy Act filing, dependent on the size of the proposed project

NON-STRUCTURAL ALTERNATIVES

The increase in impervious surface areas for roads, paved driveways, and roofs that accompanies development results in a greater volume of runoff from precipitation. Stormwater runoff is a source of many pollutants including nutrients, nitrogen, and phosphorus. Although the state manages stormwater from certain types of re-development and development (i.e., projects that require a state water quality permit or those that fall under the Wetlands Protection Act), most stormwater impacts are managed locally.

Non-structural alternatives is a term commonly used to describe systems, strategies, guidelines, and policies focused on the reduction of surface runoff from impervious surfaces. The term non-structural is somewhat of a misnomer in that many of the non-structural approaches (i.e., stormwater management systems) contain a "structural" component including piping networks and containment systems. See Table TAA-1 for a list of potential non-structural alternative solutions.

The use of stormwater management as a non-structural component for nitrogen reduction will have some impact, but by far the largest contributor of controllable nitrogen to groundwater is from septic systems. Renovation of stormwater recharge to the aquifer is a desirable goal for other purposes. A number of Low Impact Development (LID) descriptions for stormwater treatment follow.

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Table TAA-1: Examples of Non-structural Alternatives

STRATEGY	DESCRIPTION
Land Use	Open space protection, changes to zoning
Fertilizer Reduction Strategy	Policy/outreach campaign to reduce fertilizer/pesticide use and educate on sustainable maintenance practices
Stormwater Management	Low impact development (LID) and stormwater management systems that are designed to capture and, in many cases, treat runoff from impervious surfaces
Landscape Design Guidelines	Design standards for infiltration trenches; biofilters; riparian buffer restoration; tree buffers; rain gardens to utilize plants that uptake nitrogen in key areas
Municipal Maintenance Policies	Implementation of maintenance policies such as street sweeping, de-icing, and landscaping that minimize the release of Nitrogen into the atmosphere and ground

BIOFILTRATION STRIPS

Biofiltration strips, or vegetated buffer strips, are densely vegetated areas of land that accept runoff as sheet flow and facilitate sediment attenuation and pollutant removal (Clar et al., 2004). Biofiltration strips are often used to treat runoff from roads, parking lots, rooftops, and other impervious surfaces or are used as pretreatment for other LID techniques such as bioretention.

If flow rates are kept low, biofiltration strips are effective at removing sediment and phosphorus. Nitrogen removal rates are significantly lower, with only 10% removal of nitrate/nitrite. Nitrogen removal can be maximized in areas of high infiltration.

Biofiltration strips are most efficient at reducing pollutants if installed in highly permeable soils. This technique, then, is highly suitable to many areas of Cape Cod, especially as a pretreatment technique for other green infrastructure features.

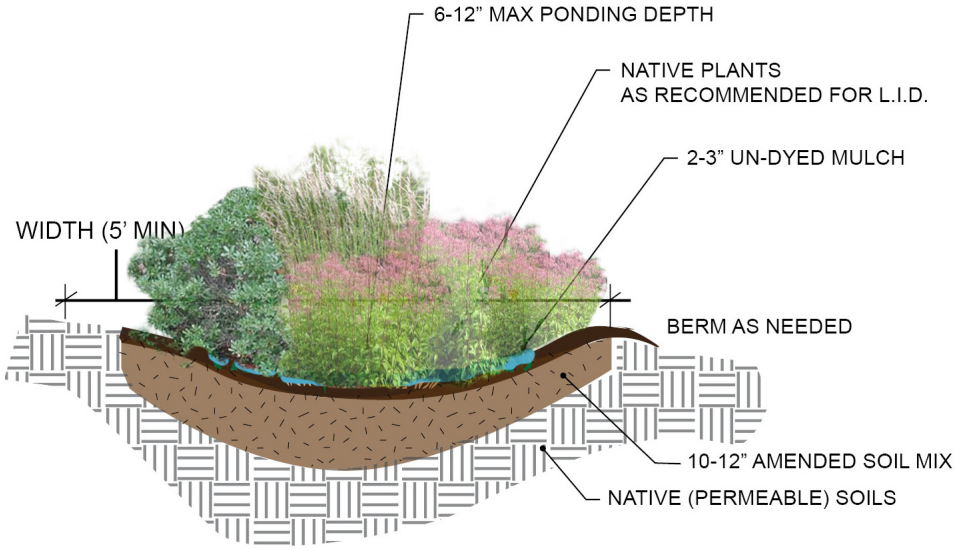
BIORETENTION

Bioretention is a method of treating stormwater by ponding water in shallow depressions underlain by a sandy, engineered soil media through which most of the runoff passes (Clar, 1993). Also called a "rain garden," it can easily be incorporated into the landscape to address and maintain many of the natural hydrologic functions (Figure TAA-9).

Bioretention systems also impede effective nutrient retention. Negatively charged dissolved phosphorus and nitrogen are actively repelled by the negative binding sites that dominate typical bioretention media. Furthermore, particulate nitrogen has many components that break down and are eventually transformed into negatively charged dissolved forms. As a result, retention of these forms of phosphorus and nitrogen is much less effective.

Bioretention tends to work best in sandy soils, which are present in many areas of Cape Cod. Sandy soils allow bioretention systems to be designed as infiltration systems, which perform better than filter designs. Properly designed bioretention systems have been shown to achieve 40% nitrogen removal (UNHSC, 2012).

FIGURE TAA-9: Cross Section of a Rain Garden



BIOINFILTRATION RAIN GARDEN
For stormwater

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INFILTRATION

Infiltration describes both a process whereby stormwater is infiltrated into the soil, and a series of stormwater practices whose primary function is to infiltrate stormwater runoff. These stormwater practices include infiltration trenches, infiltration basins, landscape infiltration, and dry wells. In addition, a number of LID stormwater practices also use infiltration as part of the design when suitable soils are present. These practices include bioretention, bioswales, and filter strips.

Infiltration practices require well-drained sandy soils, which are present in many areas of Cape Cod. The presence of high water tables will limit the use of this practice.

VEGETATED ROOFS

Vegetated roofs are alternative surfaces that replace conventional construction materials and include a protective covering of planting media and vegetation. Also known as green roofs, roof gardens, or eco-roofs, these may be used in place of traditional flat or pitched roofs to reduce impervious cover and more closely mimic natural hydrology, mitigating stormwater impacts caused by new development.

PERMEABLE PAVEMENT

Permeable pavements are alternatives that may be used to reduce imperviousness. Many different materials are commercially available, and permeable pavements may be divided into three basic types: porous bituminous asphalt, porous concrete, and interlocking concrete paving blocks or grid pavers. Permeable pavements typically consist of a porous surface overlaying a course and uniformly graded stone or sand drainage system. Stormwater drains through the surface course, is captured in the drainage system, and infiltrates into the surrounding soils. Permeable pavements significantly reduce the amount of impervious cover, provide water quality and groundwater recharge benefits, and may help mitigate temperature increases.

Permeable pavement stormwater practices are essentially infiltration techniques and, as such, work best with well-drained sandy soils, which

are present in many areas of Cape Cod. The presence of high water tables will limit the use of this practice.

BIOSWALES

Bioswales are channels that provide conveyance, water quality treatment, and flow attenuation of stormwater runoff. Bioswales provide pollutant removal through vegetative filtering, sedimentation, biological uptake, and infiltration into the underlying soil media. Both wet and dry bioswales can be implemented, the appropriate type being dependent upon site soils, topography, and drainage characteristics.

Bioswale stormwater practices work best with well-drained soils that encourage infiltration as part of the water quality treatment approach; well-drained soils are present in many areas of Cape Cod. The presence of high water tables may require the use of a wet swale.

STORMWATER DISCONNECTION

Stormwater disconnection describes a process whereby stormwater from impervious surfaces is directed to pervious areas, such as lawns, where the runoff filters and infiltrates into the soil. Stormwater disconnection can also refer to a series of stormwater practices that achieve this objective. Commonly used practices include rooftop disconnection, impervious non-rooftop area disconnection, and discharge to conservation areas (MDE, 2009). A number of techniques can be used to achieve the disconnection, including rain gardens, dry wells, and stone diaphragms.

Stormwater disconnection practices work best with well-drained sandy soils, which are present in many areas of Cape Cod.

CONSTRUCTED WETLANDS/STORMWATER TREATMENT WETLANDS

Constructed wetlands are intended to simulate the functions of natural wetlands by using vegetation, soils, and microbial activity (MassDEP, 2003). Constructed wetlands are typically separated into surface flow wetlands and subsurface flow wetlands, as previously discussed. These

wetland systems have the ability to treat wastewater from a range of pollutant sources, use few or no chemicals, have a lower carbon footprint, and may be less expensive in both capital costs and operation and maintenance costs than conventional treatment options.

SUBSURFACE GRAVEL WETLAND

The subsurface gravel wetland is designed as a series of flow-through treatment cells, preceded by a sedimentation basin. It is designed to attenuate peak flows and provide subsurface anaerobic treatment. The subdrains distribute the incoming flow, which passes through the gravel substrate and to the opposite subdrains into the adjacent cell, and then exits the treatment system by gravity. In the event of a high-intensity event, the water quality volume is stored above the wetlands and drains into the perforated riser on one end of the wetland and into the substrate. Biological treatment occurs through plant uptake and soil microorganism activities. This is followed by physical-chemical treatment within the soil, including filtering and absorption with organic matter and mineral complexes.

Annual nitrogen-removal efficiency rates of approximately 75% have been shown in a similar New England climate (UNHSC, 2012).

The gravel wetland must be lined at the bottom to maintain anaerobic conditions and is not dependent on soil type.

FERTILIZER MANAGEMENT

Strategies adopted by municipal government or private industry (i.e., golf clubs and resorts) designed to minimize usage and mitigate the effect of fertilizers and pesticides on Cape Cod's water bodies will help improve overall water quality. Strategies that may help reduce the impacts of fertilizer use on water quality include:

- Adoption of municipal policies to limit/manage fertilizer use on municipal properties, including athletic fields, parks, and cemeteries;
- Targeting of private golf courses through education or regulatory standards to minimize fertilizer use. Depending on the

watershed, golf courses can contribute significantly to the total nitrogen loading of an impacted estuary.

- Enforcement of at least a 50-foot "no disturb" buffer to wetlands and water bodies (the regional standard is a 100-foot "no disturb" buffer);
- Pursuit of outreach and education techniques for year-round residents, second-home owners, and landscape professionals to encourage improved fertilizer practices;
- Training for turf grass managers to encourage fertilizer and landscaping practices to minimize use of nitrogen; and
- Consideration of regulations to limit lawn size, specify topsoil requirements, fertilizer application rates, and use of native species.

SYSTEM ALTERATION (ENHANCED NATURAL ATTENUATION OF NITROGEN)

Numerous studies have shown that a significant amount of nitrogen can be removed in wetlands and water bodies via denitrification. The model of nitrogen-loading from watersheds on Cape Cod used by the Massachusetts Estuaries Project includes a nitrogen removal or attenuation factor of 50% for ponds, 30% for streams, and 40% for salt marshes (if site-specific information is not available).

Attenuation occurs as groundwater passes through Cape Cod's wetlands and surface water bodies. The possibility of using natural attenuation as a cost-effective component of wastewater treatment is creating high interest in this technique.

An extensive literature review commissioned by the MassDEP (Teal, 2007) identified the nitrate-removal capability of different types of wetlands and water bodies and the most important physical characteristics (relatively high nitrate loading rate, long detention time, anoxic conditions, supply of organic carbon, warm temperature, and slightly acidic pH) that lead to high rates of denitrification. The authors also discussed the role of climate and described the modifications that could be made to wetland systems to enhance denitrification. They concluded that "natural nitrogen attenuation projects can be designed and implemented such that the high level of nitrogen (nitrate) carried by stream, rivers, and estuaries can be artificially introduced into some wetlands and water bodies such

that the excess nitrate will be denitrified efficiently with low amounts taken up by plants, stored in sediment, or lost to outflow."

The anticipated positive benefits of nitrogen attenuation through Cape Cod's natural systems may be limited. Recent research on the effects of nitrogen flow through salt marshes suggests that the long-term effects of increased nitrogen on coastal wetland systems are not yet adequately understood. Research completed in Narragansett Bay and recently undertaken by staff of the Waquoit Bay National Estuarine Research Reserve indicates that nitrogen flow through salt marshes may result in higher greenhouse gas emissions (methane and CO2) and lower carbon sequestration. Increased nitrogen may also increase leafy plant growth while limiting root growth, thereby changing the marsh structure. More research is needed to understand the impacts of nutrient loading on our salt marshes (nerrs.noaa.gov/sciencecollaborative.aspx).

DATA NEEDS AND DECISION-MAKING

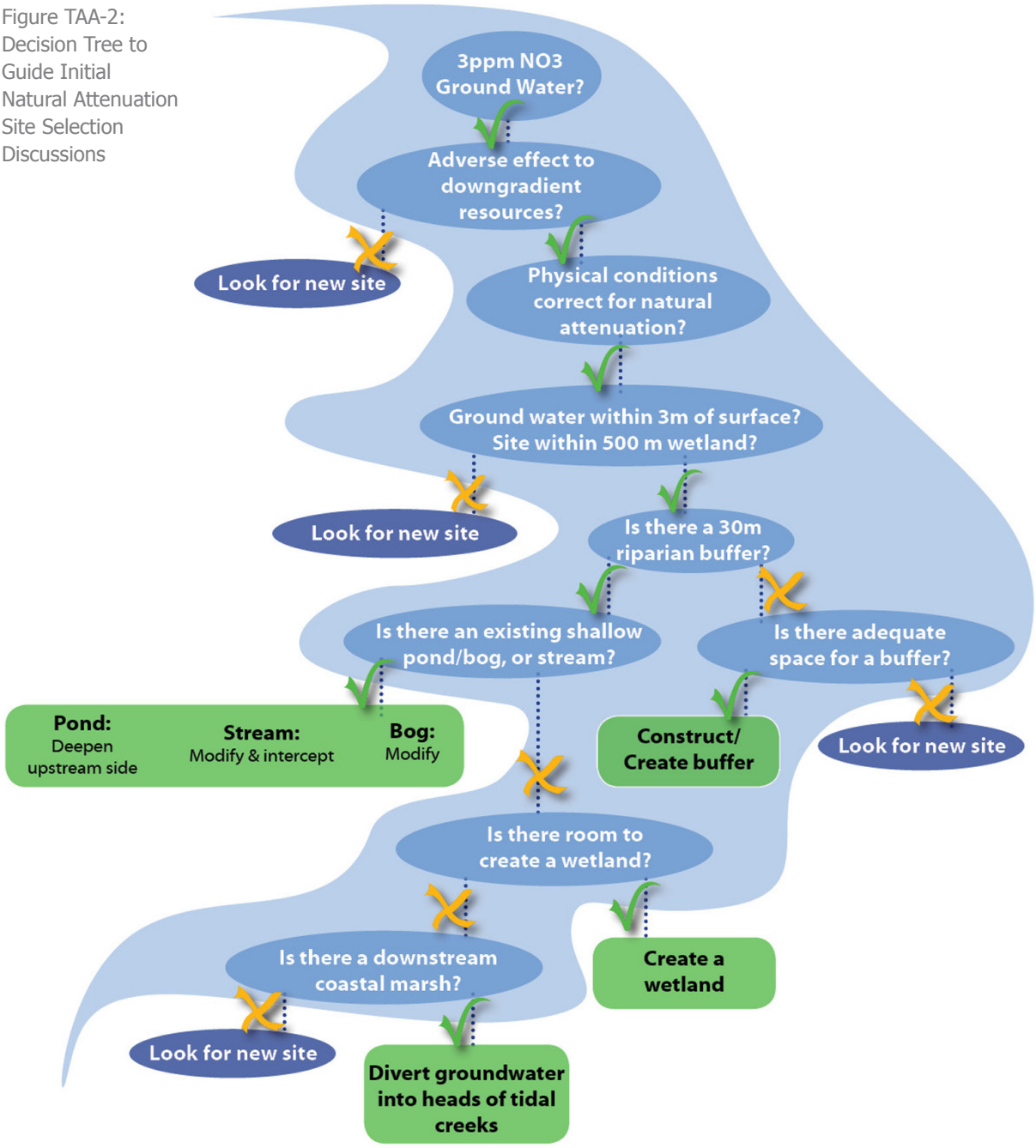
The Woods Hole Group and Teal Partners recommended the following information be assembled before considering a natural attenuation project:

- Agreement on nitrogen sources (percent airborne, stormwater, groundwater, point source);
- Maps of nitrogen concentrations in groundwater and surface water (measured and estimated), water flow (volumes, travel times, etc.), wetlands and water bodies showing ownership (public, private, protected, etc.), rare and endangered unique habitat, and wetland plant distribution downstream of the proposed project;
- Estimates of the amount of nitrogen that could potentially be removed, costs, and cost per unit of nitrogen removed;
- Evaluation of whether the project would produce a net benefit, considering the changes to the existing ecosystem the project would create; and
- Assessment of whether the project could be permitted under existing laws and regulations.

The decision tree in Figure TAA-10 may help guide initial site selection discussions.

The decision tree highlights important considerations in siting natural attenuation projects, but may not adequately reflect regulatory constraints

Figure TAA-2: Decision Tree to Guide Initial Natural Attenuation Site Selection Discussions



SOURCE: Teal, 2007

and/or reflect consideration for maintaining the health of natural wetland systems. Some of these considerations are addressed in the summaries of natural attenuation technologies.

REGULATORY FRAMEWORK FOR ENHANCED NITROGEN ATTENUATION

The Cape Cod Water Protection Collaborative commissioned Golledge Strategies & Solutions LLC (2010) to review the existing regulatory framework governing nitrogen removal through natural attenuation. The findings are summarized below. The report was restricted to projects that involved:

- the removal of sediment that has accumulated in open water or behind an impoundment;
- improvement of tidal exchange/hydraulic connectivity of coastal waters by increasing the size or depth of a channel or culvert; and
- alteration of the physical characteristics of an existing wetland (active, fallow, or abandoned cranberry bog) and enhancing the water quality by creating a diverse wetlands.

Proposed projects that involved altering natural wetland systems were not considered because regulatory agency staff indicated that altering natural wetland systems "would be extremely difficult to permit and would likely require regulatory changes and/or a long, drawn-out process, with low probability of success."

Federal, state, regional, and local governments regulate the protection of wetlands. In particular, the Massachusetts Environmental Policy Act (MEPA), the Massachusetts Wetland Protection Act, and the Federal Clean Water Act contain key provisions pertaining to any alteration or restoration of existing wetlands.

Agencies across jurisdictions collaborate on wetlands protection. The Clean Water Act delegates primary responsibility for program administration to the US Army Corps of Engineers (USACE) through the Massachusetts Programmatic General Permit (PGP). The USACE PGP relies on the MassDEP review process and performance standards, which are implemented by local conservation commissions. Projects required through MEPA to prepare an Environmental Impact Report fall under the

mandatory jurisdiction of the Cape Cod Commission to be reviewed for consistency with the Cape Cod Regional Policy Plan.

Massachusetts state regulatory agencies have "signaled" that enhanced natural-attenuation restoration projects that do not trigger review under programs like the Massachusetts Natural Heritage and Endangered Species Program or other state programs that protect historic resources of regional or statewide interest could be eligible for permitting under the resource improvement provisions in the Wetlands Protection Act regulations and the provisions of the 401 Water Quality Certification Program: "Such projects include, but are not limited to, the removal of aquatic nuisance vegetation to retard pond and lake eutrophication and the thinning or planting of vegetation to improve habitat value."

To be considered for permitting under the USACE PGP, a project must meet "Category 2" provisions, which limit eligible projects to "aquatic habitat restoration, establishment, and enhancement of tidal wetlands and riparian areas provided those activities result in net increases in aquatic resource functions and services." Eligible activities may include the "removal of accumulated sediments; the installation, removal, and maintenance of small water control structures, dikes, and berms; the installation of current deflectors; the enhancement, restoration, or establishment of riffle and pool stream structure; the placement of in-stream habitat structures; modifications of the stream bed and/or banks to restore or establish stream meanders; the backfilling of artificial channels and drainage ditches; the removal of existing drainage structures; the construction of small nesting islands in inland waters; the construction of open water areas; the construction of native shellfish species habitat over un-vegetated bottom for the purpose of habitat protection or restoration in tidal waters; shellfish seeding; activities needed to reestablish vegetation, including plowing or discing for seed bed preparation and the planting of appropriate wetland species; mechanized land clearing to remove non-native invasive, exotic, or nuisance vegetation; and other related activities. Only native plant species should be planted at the site."

The above suggests that projects that would remove accumulated sediment or increase tidal exchange would fall under the PGP Category 2 provisions, but enhancing or restoring a cranberry bog may not. If the latter, an "individual permit would be triggered, which would most likely trigger an individual Environmental Impact Statement (EIS), which is governed by the National Environmental Policy Act (NEPA). If an EIS is triggered, the project costs and timeframe would likely render the project(s) moot.

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Therefore, it is absolutely essential to work with all regulatory agencies proactively and to ensure that the project(s) are eligible for a Category 2 project under the PGP."