THREE BAYS ESTUARY (BARNSTABLE, CAPE COD) WATERSHED RESTORATION PLAN: A GREEN INFRASTRUCTURE APPROACH

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INTRODUCTION

This paper presents an approach described as "non-traditional" for restoring water quality and ecosystem services that have been degraded as a result of excess nitrogen. It focuses on emerging technologies often referred to as green infrastructure. These technologies may provide cost effective alternatives to traditional, gray infrastructure such as sewering and is likely to provide significant co-benefits including the creation of local jobs, the preservation of real estate values, and habitat enhancement.

The paper focuses on the Three Bays estuary on Cape Cod to illustrate the benefits and potential of green infrastructure technologies. The Three Bays estuary is presented as a case study and as a representative example of implementation of the broader Cape Cod Water Quality Management Plan Update (208 Plan Update) – a nationally-recognized watershed planning project designed to provide a pathway for the fifteen towns of Cape Cod to achieve compliance with Section 208 of the Clean Water Act.

The Three Bays estuary and embayment system is a scenic Cape Cod bay that hosts sailing, kayaking, swimming and shellfishing and is located in the Town of Barnstable. It is comprised of three primary segments that include West Bay, North Bay and Cotuit Bay. Sub-systems include Prince Cove that flows into North Bay, the Narrows that flows between North Bay and Cotuit Bay and Eel Pond that flows into East Bay (see Figure 1).

The Massachusetts Estuaries Project (MEP) is a state-sanctioned watershed-modeling project that assesses the conditions of the state's estuaries and required restoration goals. Its technical report (2006) indicates that the water quality of the Three Bays system has resulted in seriously degraded to moderately degraded habitat. The system is listed as an impaired water body on the US Environmental Protection Agency (EPA) 303d list of impaired waters. An approved Total Maximum Daily Load (TMDL) for nitrogen has been established for the embayment.

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This assessment is supported by more recent empirical water quality data collected within the embayment. The more current data documents a continuing decline in water quality with more common algae blooms (see Figure 2).

KEYWORDS
water quality, green infrastructure, ecosystem services, stormwater management, floating constructed wetlands, nitrogen management, permeable reactive barriers, urine diversion technology

FIGURE 1: Map of the Three Bays Watershed.

THE STUDY AREA

The Three Bays watershed is 12,458 acres in area. It contains 7,093 parcels of which 92% are residential. The watershed has a parcel density of approximately 0.5 parcels per acre (or 2 acres per parcel). An economic impact analysis of the study area suggests that real estate values are impacted as a result of water quality degradation. The study found a 0.61% decline in real estate value for every 1% decline in water quality.

There are two small wastewater treatment facilities in the watershed serving Cotuit Landing and the Marstons Mill Elementary School and an affordable housing development. However, the vast majority of homes rely upon on-site septic systems to dispose of wastewater.

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FIGURE 2: Trend in nitrogen levels over time in Three Bays Water (MGL).

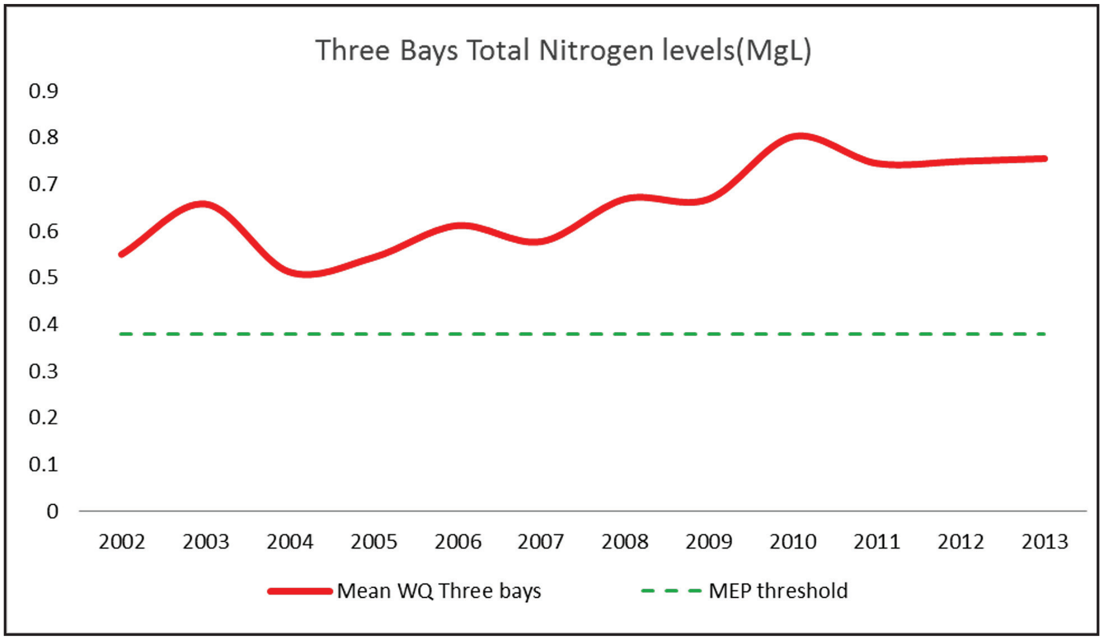

FIGURE 3: Floating algae in Cotuit Bay at the mouth of the Little River (August 2015).

The wastewater flow from the entire watershed is 538 million gallons per year (MGY), resulting in a nitrogen load of 74,567 kilograms per year (kg/yr). The MEP accounts for natural attenuation of nitrogen in the watershed including ponds, streams, and wetlands and estimates the load to the embayment at 44,592 kg/yr. The relative sources of controllable nitrogen are 77% wastewater, 13% stormwater, and 10% fertilizer (Figure 4). According to the MEP Technical report, the Three Bays system exceeds its critical threshold of 25,643 kg/yr.

The 208 Plan Update recommends that consideration be given to both traditional and non-traditional approaches to reduce the appropriate amount of nitrogen from each of Cape Cod's watersheds. The traditional approach consists of centralized collection, treatment and

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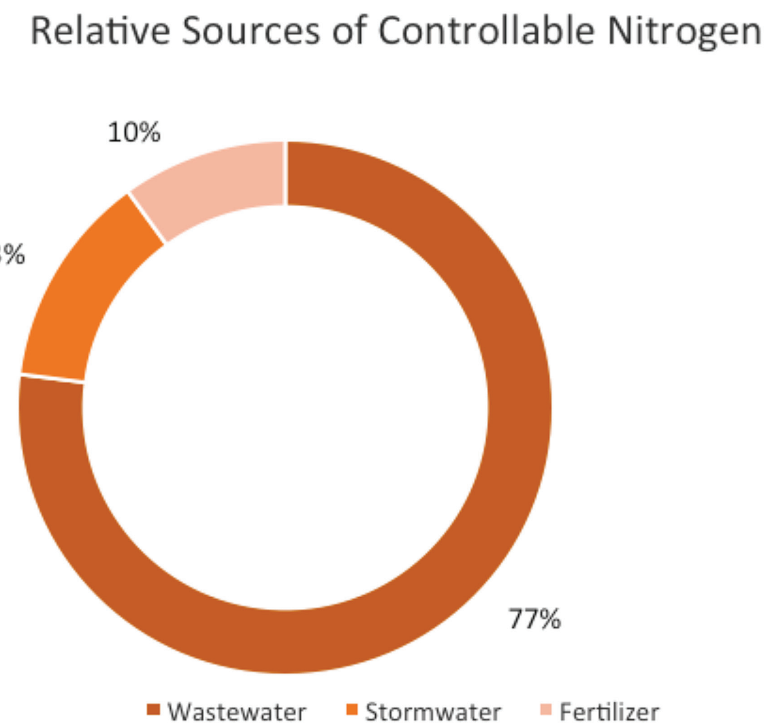
FIGURE 4: Relative sources of controllable nitrogen in Three Bays.



disposal of wastewater. The non-traditional approach considers a wide array of technologies and approaches to reduce nitrogen from both septic and non-septic nitrogen sources.

Subsequent to the completion of the 208 Plan the Three Bays Preservation, Inc. engaged the services of the Cape Cod Commission to prepare a targeted watershed plan for the Three Bays area. This targeted plan builds upon the 208 Plan Update, identifies priority projects within the watershed and provides more detailed assessments of each. This project seeks to begin implementing the 208 Plan Update by developing more specific designs for recommended strategies and discussing them with local stakeholders. It identifies pilot projects where the technologies can be implemented on a small scale and then monitored to determine their effectiveness.

NON-TRADITIONAL/GREEN INFRASTRUCTURE APPROACH

A watershed scenario was developed using a broad range of non-traditional or green infrastructure technologies. This plan was prepared utilizing information from the Cape Cod Water Quality and Technologies Matrix (http://www.cch2o.org/Matrix/), along with a GIS-based site screening analysis. The latter was developed to identify potential locations for technologies based upon position within the watershed, depth to groundwater, availability of public rights-of-way (such as roads), parcel size and ownership. A Watershed Calculator that cumulatively applies the nitrogen removal benefits of selected technologies to the target nitrogen reduction load was developed.

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A watershed management strategy, utilizing non-traditional technologies and approaches, was developed for the Three Bays watershed to achieve the nitrogen loading targets identified in the MEP technical report and TMDL. It is comprised of source reductions, remediation, and restoration practices. Source reduction includes a urine diversion and re-use demonstration project at Cape Cod Academy, ecotoilets (urine diversion or composting) at 458 homes (representing 5% of the households distributed evenly throughout the watershed), and fertilizer reductions. Remediation strategies designed to attenuate nitrogen along its flow path through the watershed include stormwater retrofits, dredging of Mill Pond in Marstons Mills, installation of fertigation wells at several golf courses and cemeteries and 5 permeable reactive barriers. The plan also includes 26 acres of aquaculture (some of which has already been implemented since the MEP report was completed) and 2200 square feet of floating constructed wetlands. The following figure and table summarizes the approximate locations of potential non-traditional technologies and approaches in the watershed and provides a calculator that accounts for proposed nitrogen reductions and the associated cost estimates for this Three Bays scenario. The calculator incorporates capital costs, operation and maintenance,

FIGURE 5: Non-traditional watershed plan.

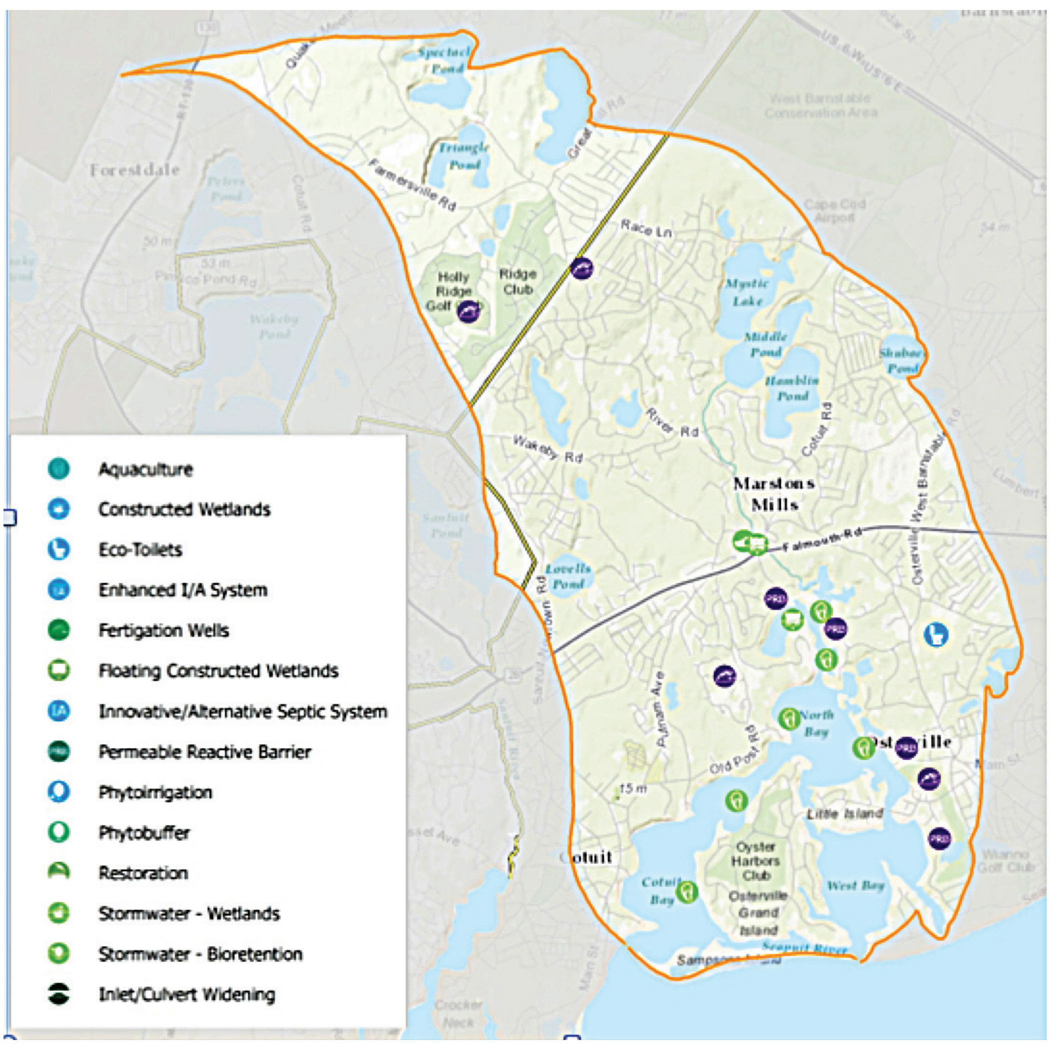

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FIGURE 6: Non-traditional calculator sheet.

NITROGEN REDUCTION CALCULATOR					
(MEP Watershed)		Name of Estuary	Three Bay		
MEP Targets and Goals			Attenuated Controllable Nitrogen Load kg/day	Attenuated Controllable Nitrogen Load kg/year	
Controllable Nitrogen Load	kg/year	kg/day	122.2	44,592	Present Total Watershed Load
Septic	34,387	94.2			
Fertilizer	4,470	12.2			
Stormwater	4,364	12.0			
Other	1,371	3.8	70.3	25,643	Threshold Load
			51.9	18,950	Load to be Removed
Total Number of Properties		9,153			

Community-Wide Projects	Percent of Total Removed	Reduction by Technology (Kg/yr)	Remaining to Meet Target (Kg/yr)	Average 20-Year Life Cycle Cost ($/kg N)	Amortized Annual Life Cycle Cost* ($/kg N)	Total 20-Year Cost (5% interest)
A) Fertilizer Management	25	1,118	17,832	$331	$27	$370,403
B) Stormwater Mitigation	25	1,091	16,741	$7,811	$627	$8,521,731

Watershed/Embayment Options	Quantity	Reduction by Technology (Kg/yr)	Remaining to Meet Target (Kg/yr)	Average 20-Year Life Cycle Cost ($/kg N)	Amortized Annual Life Cycle Cost* ($/kg N)	Total 20-Year Cost (5% interest)
A) Permeable Reactive Barrier (PRB)	3,000 linear feet	2,833	13,908	$4,659	$265	$13,200,000
F) Fertigation - Turf	188 acres	626	13,282	$1,853	$149	$1,160,317
I) Dredging - Mill Pond	50,000 cu. yard	1,590	11,692	$392	$31	$1,000,000
K) Aquaculture/Oyster Beds	42 acres	10,458	1,234	$329	$26	$3,440,096
M) Floating Constructed Wetlands	4,700 cu feet	1,472	-238	$101	$8	$148,563

Alternative On-Site Options	Quantity	Reduction by Technology (Kg/yr)	Remaining to Meet Target (Kg/yr)	Average 20-Year Life Cycle Cost ($/kg N)	Amortized Annual Life Cycle Cost* ($/kg N)	Total 20-Year Cost (5% interest)
A) Ecotoilets (UD & Compost)	113 homes	680	-918	$2,037	$164	$1,385,303
B) UD School or Public Facility	69 people	100	-1,018	$249	$20	$24,920
C) I & A Systems	0 homes	0	-1,018	$5,461	$438	$0
D) Enhanced I & A Systems	0 homes	0	-1,018	$8,115	$651	$0

	Quantity	Reduction by Technology (Kg/yr)	Remaining to Meet Target (Kg/yr)	Average 20-Year Life Cycle Cost ($/kg N)	Amortized Annual Life Cycle Cost* ($/kg N)	Total 20-Year Cost (5% interest)
Attenuated Load Remainder***	0 homes	0	-1,018	12,460	1,000	$0
Costs Using Non-Traditional Method				$1,538	$123	$30,717,100

* Amortized at 5% annual interest over 20 years.

and monitoring over a 20-year lifecycle planning period. It shows that this non-traditional approach would cost approximately $31 million.

To estimate comparative costs using a traditional sewering approach, figures from the 2014 updated version of the Barnstable County Wastewater Cost report as summarized in the 208 Plan Update were used. This document estimates satellite sewage treatment systems at $858/kg of nitrogen removed. Applying this unit cost to the required 19,824 kg/year over a 20-year lifecycle planning period yields a cost estimate of $212.6 million – roughly six times the cost of the green infrastructure approach.

CASE STUDY – THREE BAYS

Three Bays was selected as a case study to test the implementation of a non-traditional watershed plan that focuses on green infrastructure. A series of five meetings with the Three Bays Preservation staff and board of directors were conducted to discuss the 208 Plan Update and to select priority projects to test the various green infrastructure technologies. Based upon those discussions the following priority projects were selected for more detailed evaluation and piloting:

- Mill Pond (dredging and wetland restoration)
- Cape Cod Academy (ecotoilets and fertigation)
- Town Dock, Cotuit (stormwater remediation)

Mill Pond has a rich and varied history, dating back to the 17th century and has served as a key landmark in the historic village center of Marstons Mills for the last 300 years. Mill Pond was created by a small dam, built to power the gristmill on its shore that dates back to a grant of the Barnstable Proprietors, who owned the land, to John Stacy in 1705 for the right

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FIGURE 7: Mill Pond view north from Route 149.

to place a grist mill dam on the Cotuit River. Later the stream was known as Goodspeed's River, named for the first white settler in 1653, and still later the waterway was called Marston's River after Benjamin Marston who inherited the Goodspeed rights. A hydroelectric plant was also temporarily operated immediately downstream of the pond by David Leland just before Word War II.

To this day, Mill Pond remains a scenic refuge for wildlife and is one of the most photographed locations in the Town of Barnstable. It serves as an active herring run and provides an intermediate resting place for the fish on their passage upstream to their spawning ground in Middle Pond. Herring have been observed during their migration starting in late March through early April throughout the pond's history. Three Bays Preservation, Inc. tracks the fish annually with a count of 87,308 herring in 2012.

Mill Pond receives water inputs from the Marstons Mills River that drains from the north. It also receives groundwater discharging subsurface from the north and by precipitation falling directly on the pond's surface. Water leaves the pond via two outlets that flow through culverts below Route 149 and then below Route 28. Water also leaves the pond subsurface as groundwater.

The western outlet has historically served as a herring run up the Marstons Mills River. Additionally, the pond plays a significant ecological role for the downstream bay waters since it has the potential to serve as a trap or "sink" for nitrogen loads by means of denitrification and retention within the pond's water column and sediments. However, this role has been significantly diminished due to significant eutrophication and sedimentation over the 300 years since the pond was created.

The nitrogen loads entering Mill Pond, attributed to surface water inflow from upstream via the Marstons Mills River, were measured and calculated at 12.85 kg-N/d or 4690 kg N/yr by the MEP (2006). This is the net input to the Pond from the associated watershed where a land use/nitrogen loading analysis was calculated at 31.94 kg N/d or 11,647 kg N/year. This suggests an attenuation rate of 60% of nitrogen in the upper watershed. This attenuation is believed to be a function of a series of ponds, streambeds, and associated vegetated wetlands that are upstream of Mill Pond.

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MEP estimated current nitrogen attenuation within Mill Pond is 22%. This is significantly less than the average default value of 50% used for ponds in the MEP model and the measured rates from the other fourteen ponds in the upper watershed (that averaged 73%). The report suggests that the reduced attenuation rate in Mill Pond is due to its shallow depth and limited residence time due to long term sedimentation that has filled the pond (MEP, 2006, p. 50). Longer residence time provides for more settling of solids and increased biological uptake and denitrification processes. Assuming that the nitrogen attenuation capacity of Mill Pond could be restored to 50% removal this would represent an increased attenuation rate of 2271 kg/year to the downstream Three Bays system. A restoration of the pond to reinstate this capacity would be one of the largest restoration/reduction functions at any single location in the watershed.

To address these challenges an integrated restoration plan has been prepared for Mill Pond. It includes dredging, stormwater management, and floating constructed wetlands.

Dredging & Re-Use: A bathymetric and sediment profile study was undertaken in 2015. This included 160 measurements and sediment probes along nine transects. This survey shows average water depths of approximately two feet throughout the pond with thick highly organic sediments averaging 5 feet in thickness.

FIGURE 8: Bathymetric transects and sediment photos.

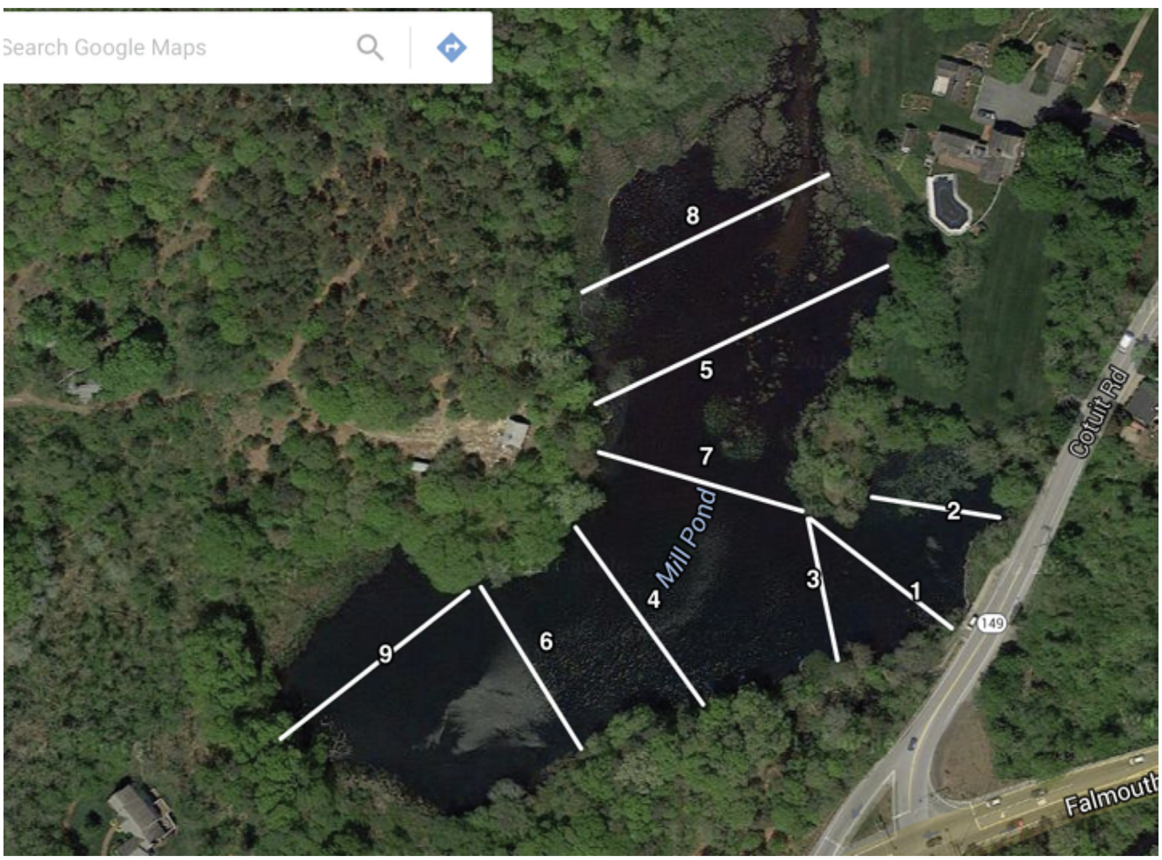

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FIGURE 9: Cross section of Mill Pond.

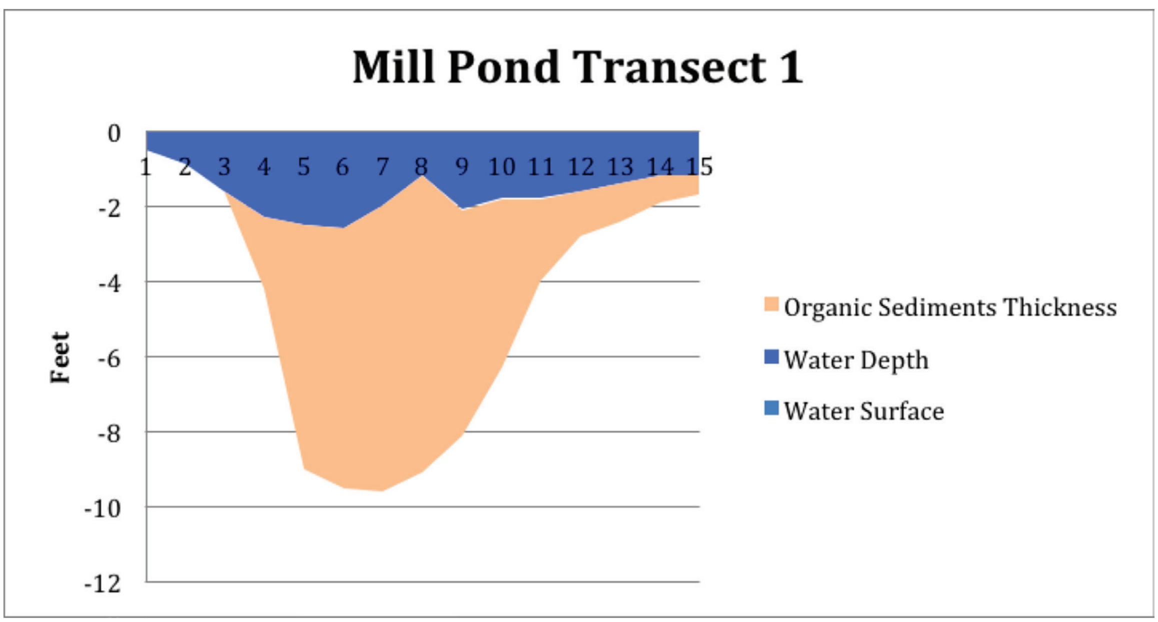

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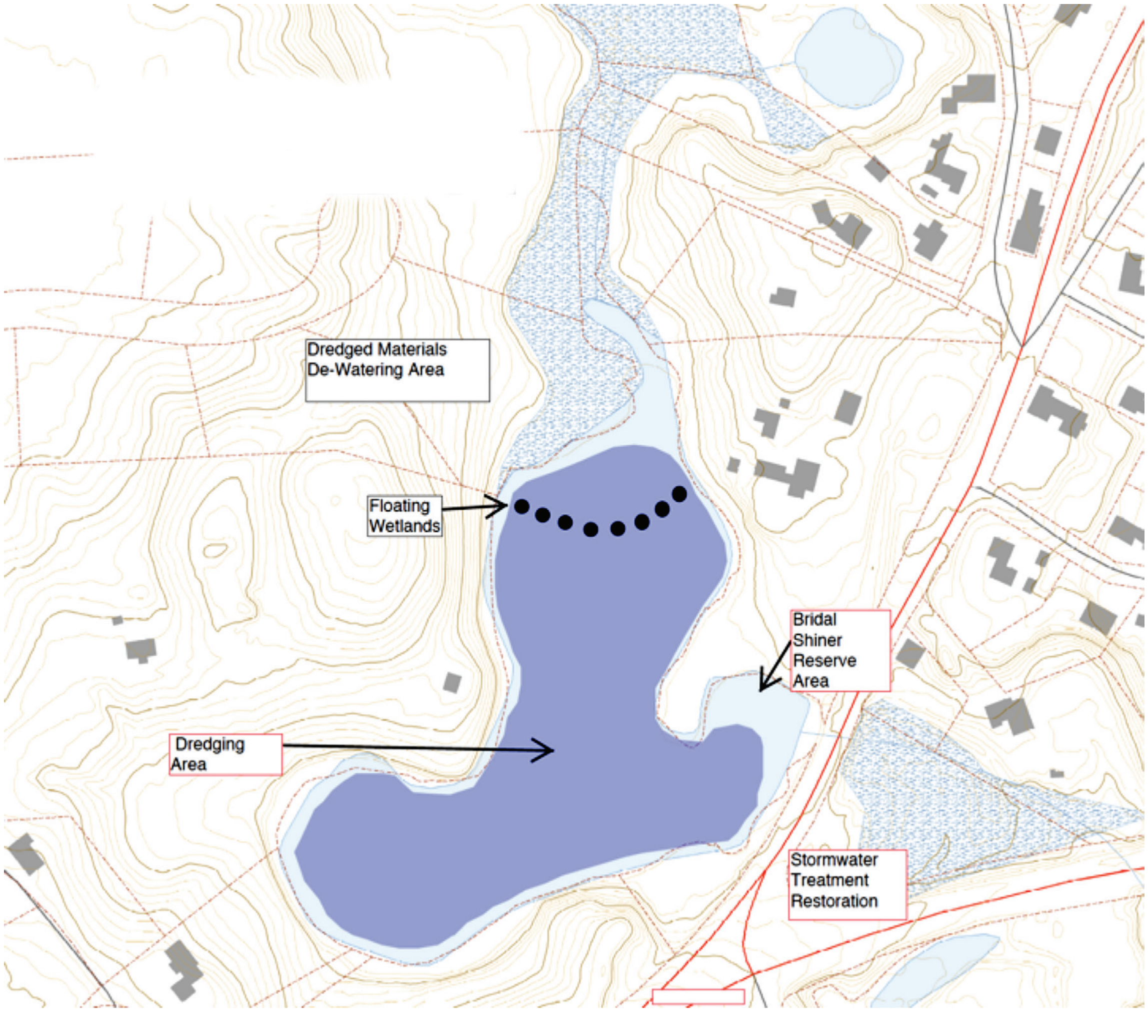
FIGURE 10: Conceptual management plan for Mill Pond.



Based upon this information a project has been designed that includes a limited dredging area and a preserved shallow water habitat area for a locally rare fish, the Bridle Shiner. It also includes restoration of a stormwater treatment project and a pilot project for floating wetlands. Figure 10 provides a concept plan for the proposed project.

According to the Massachusetts Practical Guide to Lake Management, dredging costs range from \$8 – 25/cubic yard with an average of \$15/cubic yard. Assuming an estimate of 50,000 cubic yards, this represents an estimated average cost of nearly \$750,000. Assuming a 50-year life cycle and an average annual reduction of 2271 kg/year this represents a cost effectiveness of approximately \$9/kg of nitrogen removed.

The dredged materials are highly organic and nutrient rich and appear to be suitable for landscaping. Three sediment samples were collected in 2011 and analyzed by Groundwater Analytical. All samples were fine grained (86% or more silt and clay) and tested below detection limits for volatile organics and PCBs. Trace levels of some metals were detected and with the exception of one result for arsenic (historically used as a pesticide in the cranberry industry) are within the acceptable concentrations for re-use according to the Massachusetts Contingency Plan (MCP).

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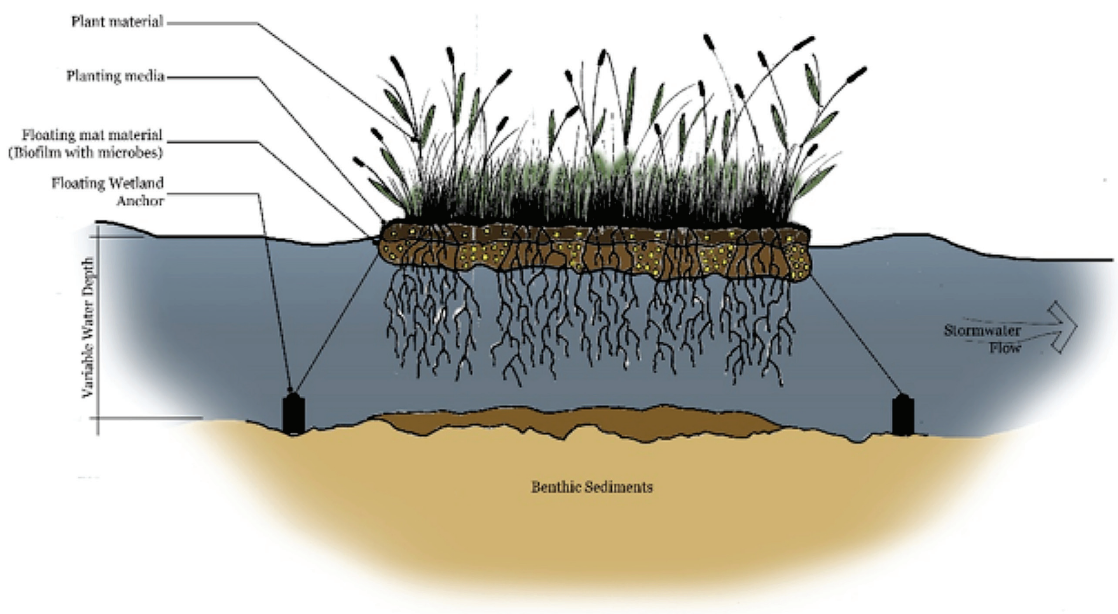
Floating Constructed Wetlands: The Mill Pond project also includes a pilot project for floating constructed wetlands. Floating constructed wetlands are an innovative technique to enhance nitrogen removal by utilizing the root zone of plants to uptake dissolved nutrients, physically trap suspended nutrients and metabolize them through a microbial nitrification-denitrification process.

FIGURE 11: Floating wetland technology.



This conceptual plan identifies an area in the northern reach of Mill Pond where a ring of floating constructed wetlands could provide a treatment barrier that would intercept and process in-coming waters from the Marstons Mills River. These wetlands could be anchored to the bottom using traditional ground tackle or could be supported by a floating dock system that could also be used to access the wetland systems for maintenance and monitoring. Maintenance would require the seasonal harvesting of plant material and possibly removal of the wetlands during the winter months.

According to the Water Quality Technologies Matrix, floating wetlands have the potential capacity to remove 0.4 kg/cubic foot-year. With a proposed project size of 2200 cubic feet of floating wetlands, the Three Bays calculator identifies a corresponding potential nitrogen reduction of 880 kg/yr.

Stormwater Management: A stormwater remediation project was installed in 1998 at the intersection of Routes 149 and 28. This project was designed by the Town of Barnstable to intercept stormwater runoff that discharged from Route 149 directly to Mill Pond. A series of four StormTreat Systems units were installed on land owned by the Barnstable Land Trust. This system is designed to capture and treat the "first flush" of stormwater runoff which is believed to contain the majority of stormwater pollutants.

The stormwater project was restored during the summer of 2016. This included hydraulic flushing of the inlet piping system and re-planting of the bioretention area.

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FIGURE 12: Floating wetlands – sample photograph.

CAPE COD ACADEMY – URINE DIVERSION AND FERTIGATION

Cape Cod Academy enrolls 240 students and employs 60 faculty on 46 acres in the Village of Osterville. The school has an active environmental education program and a strong commitment to environmental stewardship. Cape Cod Academy was identified during the 208 process as a potential site for a urine diversion demonstration/fertigation project. The purpose of this project is to pilot two non-traditional approaches (urine diversion and fertigation) and to develop an on-site learning laboratory for the faculty and students.

Cape Cod Academy generates two primary nitrogen loads that contribute to the Three Bays system – wastewater and fertilizer. The school relies upon on-site septic systems to dispose of their wastewater with an estimated design flow of 2400 gallons/day. Assuming an average nitrogen concentration of 35 mg/liter in the wastewater this represents a potential nitrogen discharge of 255 lbs (116 kg) per year. The Academy is beautifully landscaped with approximately 22 acres of athletic fields and lawn areas. According to staff that we interviewed fertilizers are applied at a rate of approximately 3 lbs (nitrogen) per 1000 square feet annually. This represents an annual nitrogen application of approximately 2400 lbs (1089 kg) per year. This comparison of wastewater-generated nitrogen and fertilizer applications suggests that if wastewater could be converted into fertilizer the turfgrass areas could easily assimilate the amount of nitrogen generated in wastewater.

Urine diversion technology is based upon the fact that 80 – 90 percent of the nitrogen contained in human wastewater is found in the urine. Urine diversion toilets (and urinals) provide possible means to separate urine at its source. Studies in Europe (and more recently

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FIGURE 13: Cape Cod Academy, Osterville, MA.

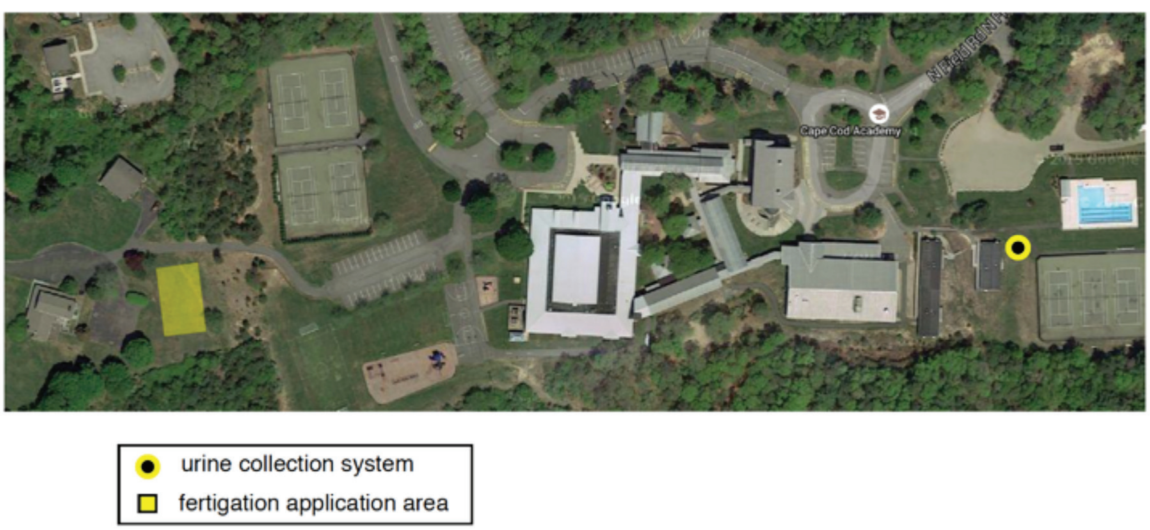
in the U.S. have demonstrated the potential use of urine as a fertilizer. The Rich Earth Institute in Vermont has been successful in developing a program collecting urine and applying it to hayfields as an alternative fertilizer source. Fertigation refers to the process of combining liquid fertilizers with irrigation water and applying the two simultaneously. This process is gaining in popularity in the turfgrass management field (including golf courses) as it achieves uniform applications in an efficient manner.

Properly fertilized turfgrass assimilates approximately 80% of the nitrogen that is applied. In this manner it functions as an efficient and inexpensive treatment system. Recycling diverted and sterilized urine as a turfgrass fertilizer significantly reduces the nitrogen impacts associated with wastewater discharges and the need for commercial fertilizers.

Urine is generally sterile and pathogen-free. Storing the collected urine for 30 days at 20 degrees C (or 68 degrees F) will sanitize the urine, disinfecting it in the event that some pathogens are present. The sanitized urine can then be diluted with water and applied as a fertilizer.

During the summer of 2016 a small-scale pilot project was conducted. Urine was collected at a portable toilet that was located near the tennis courts and swimming pool (see

FIGURE 14: Cape Cod Academy site plan.



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Figures 14 –16). Urine was then stored for 30 days to provide sterilization. It was then diluted (1 part urine/16 parts water) using an agricultural siphon mixer and applied to an 800-square foot test plot of turfgrass. The test plot was located immediately adjacent to lawn that was fertilized using conventional slow-release granular fertilizers. A urine application rate of approximately 5 gallons/week was designed to simulate the conventional fertilizer application rate of approximately 3 - 4 lbs of nitrogen/1000 square feet-year.

FIGURE 15: Urine diversion collection facility in portable toilet.

Cape Cod Academy is now considering scaling up the project. This could include installing waterless urinals in the men's/boy's restrooms and urine diversion toilets in the women's/girl's restrooms to collect urine year-round. Collected urine could be stored outside in subsurface tanks. Fertigation could then be conducted during the growing season using commercially-available liquid feed systems that could tie directly into the existing turf irrigation system.

FIGURE 16: Water-less toilets – future urine diversion installation.

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COTUIT TOWN DOCK – STORMWATER MANAGEMENT

Cotuit Town Dock is located at the end of Oyster Place, a paved, two-way street with forty-five parking spaces. The surface watershed includes approximately 35,000 square feet of impervious surfaces including Oyster Place and a contributing section of Main Street. Seven storm drain inlets were identified during field visits. Stormwater is currently collected from this area and discharged directly to Cotuit Bay via a large diameter pipe beneath the Town Dock.

Stormwater management was identified in the 208 Plan Update as one of the proposed management techniques in the watershed. The 208 Plan Update identifies the potential for up to a 25% reduction of stormwater loads. For the Three Bays watershed this translates to approximately 765 kg/year. This will require the implementation of numerous stormwater retrofit projects. The Town of Barnstable has been actively designing and installing several of these projects throughout the Three Bays watershed.

This project was designed and constructed by the Town of Barnstable, Department of Public Works in cooperation with Three Bays Preservation, Inc. The plantings were installed by students from the nearby Cape Cod Academy as part of their community service project (see Figure 17). It provides an excellent opportunity to mitigate direct discharges of pathogens and nutrients and for signage and public education.

The treatment system is comprised of two 50-foot long, 3-feet wide bioretention cells filled with permeable 3/8-inch stone and planted with eight species of native facultative wetland plants (see Figure 18). The first flush of stormwater is directed to the system and distributed laterally via a subsurface slotted pipe. The infiltrated stormwater then recharges

FIGURE 17: Construction of rain garden by Cape Cod Academy students.

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FIGURE 18: Rain garden at Cotuit Town Dock.

FIGURE 19: Completed rain garden showing solar panel and public education sign.

the underlying groundwater (approximately 2-3 below the lands surface). Groundwater flows towards the bay at an estimated rate of approximately 1 foot/day where it is intercepted by a shallow well that contains a solar-powered water pump. The pumped water is then recycled back throughout the bioretention system via a drip irrigation system that is powered by the solar panel and control box (see Figure 19). In this manner the stormwater is recycled through the treatment system several times to optimize treatment.

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Water quality sampling of this system has just begun. However, long-term studies conducted by the University of New Hampshire, Stormwater Center have demonstrated that these systems have the potential to remove 90% of the nitrogen.

SUMMARY

Green infrastructure provides an attractive opportunity for solving water quality problems associated with coastal waters on Cape Cod and elsewhere. An innovative watershed planning approach developed by the Cape Cod Commission as part of the 208 Plan Update allows for the comparison of traditional sewering to non-traditional solutions and ultimately for optimizing the use of both traditional and non-traditional infrastructure in each watershed on Cape Cod. Several tools were developed during the 208 process that could be transferred to other areas including a Technologies Matrix that provides in-depth information on over 40 technologies and a Watershed Calculator that quantifies the cumulative benefits of green infrastructure projects throughout a watershed and compares this to identified water quality goals and nutrient reduction targets.

The Three Bays watershed was evaluated for the application of both approaches to solve the water quality problems identified during the Massachusetts Estuaries Project study. An integrated watershed scenario was developed that includes a broad range of strategies including aquaculture, pond restoration, floating constructed wetlands, stormwater management, ecotoilets, fertigation, and permeable reactive barriers. This scenario demonstrates that water quality goals can potentially be met using non-traditional technologies at a significantly lower cost than traditional technologies including the construction of sewer collection systems and wastewater treatment plants.

Ongoing implementation of the conceptual plans identified through the work of Three Bays Preservation, Inc will include construction and monitoring of several pilot projects to fully evaluate the effectiveness of non-traditional technologies. The Watershed Calculator will be used to track the progress of these projects towards the identified nutrient reduction goals. It will also be used as an Adaptive Management tool to make adjustments to the plan throughout the implementation period.

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