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Nitrogen-reducing Green Infrastructure in Environmental Justice Communities

Barnstable/Yarmouth—Cape Cod, Massachusetts

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About the Green Infrastructure Technical Assistance Program

Stormwater runoff is a major cause of water pollution in urban areas. When rain falls in undeveloped areas, soil and plants absorb and filter the water. When rain falls on our roofs, streets, and parking lots, however, the water cannot soak into the ground. In most urban areas, stormwater is drained through engineered collection systems and discharged into nearby water bodies. The stormwater carries trash, bacteria, heavy metals, and other pollutants from the urban landscape, polluting the receiving waters. Higher flows also can cause erosion and flooding in urban streams, damaging habitat, property, and infrastructure.

Green infrastructure uses vegetation, soils, and natural processes to manage water and create healthier urban environments. At the scale of a city or county, green infrastructure refers to the patchwork of natural areas that provides habitat, flood protection, cleaner air, and cleaner water. At the scale of a neighborhood or site, green infrastructure refers to stormwater management systems that mimic nature by soaking up and storing water. These neighborhood or site-scale green infrastructure approaches are often referred to as *low impact development*.

The U.S. Environmental Protection Agency (EPA) encourages using green infrastructure to help manage stormwater runoff. In April 2011, EPA renewed its commitment to green infrastructure with the release of the *Strategic Agenda to Protect Waters and Build More Livable Communities through Green Infrastructure*. The agenda identifies technical assistance as a key activity that EPA will pursue to accelerate the implementation of green infrastructure. In October 2013, EPA released a new Strategic Agenda renewing the Agency's support for green infrastructure and outlining the actions the Agency intends to take to promote its effective implementation. The agenda is the product of a cross-EPA effort and builds upon both the 2011 Strategic Agenda and the 2008 Action Strategy.

EPA is continuing to provide technical assistance to communities working to overcome common barriers to green infrastructure. Selected communities received assistance with a range of projects aimed at addressing common barriers to green infrastructure, including code review, green infrastructure design, and cost-benefit assessments.

For more information, visit *http://water.epa.gov/infrastructure/greeninfrastructure/gi_support.cfm*.

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Executive Summary

In many ways, Cape Cod, Massachusetts is already an example of low impact development. Very little hardened stormwater infrastructure is present on the Cape, and stormwater runoff is often directed to natural depression areas where it infiltrates rapidly into the sandy soils present throughout the area. Historically, the natural infiltration capabilities of the soils also led to the installation of septic systems to easily treat wastewater across the Cape. Unfortunately, many embayments around the Cape are now becoming eutrophic due to the high nutrient loadings from both surface water and groundwater sources.

Nitrogen is one of the primary pollutants impacting these embayments. Although wastewater from septic systems represents a significant nitrogen load within impacted watersheds, the cost and logistics of eliminating septic systems makes reducing nitrogen from wastewater difficult. As an alternative, green infrastructure is proposed to address surface sources of nitrogen. A variety of green infrastructure techniques are evaluated based on their efficiency in removing nitrogen and their effectiveness in the sandy soils present on the Cape. A screening process is developed and applied to watersheds within the communities of Yarmouth and Barnstable (two areas where environmental justice issues are also prevalent) to identify potential sites that are most suitable for implementation of green infrastructure techniques.

Working with a diverse group of stakeholders including consultants, staff from the Cape Cod Commission, and local officials and community members, potential green infrastructure sites identified through the screening process are evaluated in more depth through field visits resulting in the development of conceptual designs on two selected sites. Conceptual green infrastructure designs at these two sites focus on innovative practices, including enhanced bioretention and phytoremediation, to increase nitrogen removal. Conceptual designs are also tailored to the land use and configuration of the two sites (one site is an existing elementary school, while the other site is a proposed marina redevelopment) to showcase additional benefits of utilizing green infrastructure for water quality treatment.

Conceptual designs are modeled using EPA's SUSTAIN to evaluate the effectiveness of the proposed systems in reducing stormwater runoff and total nitrogen. Modeling the proposed concepts indicates a small reduction in runoff volume (approximately 5%) but a significant reduction in total nitrogen (approximately 60%), based on the configuration of the techniques and the specific site conditions. An assessment of the regulatory requirements and cost estimates of the two sites indicate few barriers to implementation of the proposed concepts, which can serve as examples of how to effectively address surface water sources of nitrogen. Although wastewater on the Cape represents a significant source of pollution to local embayments, appropriate siting and use of innovative green infrastructure techniques gives Cape Cod an alternative solution to help quickly reduce nitrogen loading within impacted watersheds.

I. Introduction

Cape Cod, Massachusetts is a peninsula located in the southeast portion of the Commonwealth and is defined by water. The Cape includes 560 miles of coastline and numerous lakes, ponds, bays and inlets that draw an estimated four million visitors to the region each year. Cape Cod is home to almost 220,000 year-round residents; the summertime population grows to an estimated 750,000 people. With bountiful water resources and proximity to major northeast urban areas, Cape Cod has seen rapid population growth over the last half century. Development on Cape Cod has been primarily residential with associated commercial, industrial and tourism-based land uses.

Cape Cod geology consists primarily of sandy well-drained soils formed as a result of glacial deposits. Cape Cod relies on a sole source aquifer (groundwater) for most of its drinking water and on its ponds, bays, and coastal zone for much of its economy. The region also relies heavily on septic systems to manage wastewater. Groundwater carries and ultimately discharges nitrogen from wastewater to the coast. Of the region's 57 coastal embayments, 46 are eutrophic due to excessive nutrients and pollutants. The watersheds of these eutrophic embayments encompass 69% of Cape Cod's land area and 2/3 of them cross town boundaries, making the restoration and management of their water quality a regional issue.

Nitrogen is perhaps the most significant pollutant with the highest percentage resulting from the multitude of septic systems present throughout Cape Cod. Studies from the Massachusetts Estuaries Project (MEP) indicate that nutrients, primarily from traditional on-site septic systems and cesspools, are seriously impairing water quality in most of the Cape Cod's estuaries studied to date. To meet the established Total Maximum Daily Loads (TMDLs) approved by the Massachusetts Department of Environmental Protection (MassDEP) and the United States Environmental Protection Agency (EPA), a significant reduction of nitrogen is necessary. Although wastewater is the main source of nitrogen on Cape Cod, eliminating excessive nutrient loading from embayments will need to address both groundwater and stormwater through a mix of traditional and innovative wastewater management systems, alternative nitrogen reducing options (such as aquaculture and permeable reactive barriers), and green infrastructure. While the focus of this report is on impairments from nitrogen, it is worth noting that many of the Cape's freshwater ponds and lakes are also impaired by phosphorous, another nutrient, which comes from sources such as rainfall runoff, septic systems and fertilizers.

The Cape Cod Commission (CCC) is developing a Regional Wastewater Management Plan (RWMP) to identify the best combination of watershed approaches to manage nitrogen to restore the quality of the region's coastal waters in a ways that consider costs to homeowners to the best extent feasible. The goal of the RWMP is to develop and implement nitrogen reducing approaches and strategies that integrate water quality restoration with affordability, appropriate infrastructure, and growth management. Much of the implementation will be the responsibility of the communities of Cape Cod under their local Comprehensive Wastewater Management Plans, while the RWMP will be implemented by the CCC with the approval of MassDEP.

The dispersed pattern of development, relatively low incomes and aging population on Cape Cod, and its fragile natural environment, make the cost of constructing sewer systems throughout the entire region both impractical and unsustainable, particularly for the most vulnerable populations. To achieve TMDLs at affordable rates, the communities and the CCC will consider installing sewers in more densely populated areas while also capitalizing on advanced decentralized wastewater systems, natural attenuation, and green infrastructure methods to remove nitrogen and other pollutants from the Cape's watersheds.

As part of the RWMP, CCC staff has examined opportunities including dredging, inlet widening, and aquaculture. However, additional data are needed to establish the percent nitrogen removal that can be attained using green infrastructure solutions. This EPA technical assistance focused on the use of constructed wetlands and green infrastructure stormwater management practices to reduce nitrogen within Environmental Justice (EJ) communities.

The overall intention of this project is to identify areas within EJ communities where pollutants from stormwater may be addressed closer to the source at a reasonable scale and cost. It also offers greater opportunities for creating access to green open space, providing air quality benefits, recreational opportunities, and re-establishing the human-environment connection. Many of the green infrastructure options discussed in this report are transferable among similar communities and can provide EJ community youth with construction and landscaping skills and improved job opportunities for building and maintaining these practices. Such projects are needed throughout the region and could help provide sustainable solutions for community resiliency.

Technical assistance was provided through EPA's 2012 Green Infrastructure Technical Assistance Program to develop conceptual designs for green infrastructure projects in the Lewis Bay/Parkers River watersheds. These concepts are specifically targeted and designed to remove nitrogen from groundwater and stormwater sources.

As part of the project, a screening process was refined to utilize a siting criteria matrix to identify areas of opportunity for green infrastructure practices. The green infrastructure practices identified and assessed as part of the screening process were specifically selected for nitrogen reduction capabilities and included constructed wetlands, phytoremediation, enhanced bioretention and many others. Application of the screening process resulted in the selection of eight high opportunity sites for green infrastructure placement. These sites were investigated in more detail through a field site assessment that evaluated physical, public outreach, economic, water quality, and constructability considerations.

The project team presented the screening process and the site opportunities to a group of local stakeholders from the towns of Barnstable and Yarmouth. This group of stakeholders, Commission staff, and consultants collectively selected two sites to advance to conceptual designs. An advanced bioretention system was designed for an elementary school in Barnstable and a bioretention/phytoremediation area was designed for a proposed marina site in Yarmouth. In addition, conceptual plans and details, an analysis of the regulatory pathway, and cost estimates for the two sites were also developed.

2. Screening Process

The project team collaborated to develop a screening process to identify site opportunities for green infrastructure and LID practices throughout the Lewis Bay and Parkers River watersheds. The screening process began with a desktop investigation of potential sites by utilizing a siting criteria matrix developed by CCC. This matrix tool was applied to parcels within the Lewis Bay and Parkers River watersheds. Field assessments of the highest scoring parcels were performed by CCC resulting in eight potential sites for the development of conceptual green infrastructure designs; four sites were identified in Barnstable and four in Yarmouth.

2.1. Siting Criteria Matrix

2.1.1. Green Infrastructure/LID Practices

The siting criteria matrix consists of multiple GIS-based data layers (termed "siting criteria") along the vertical axis and a collection of potential green infrastructure and LID practices on the horizontal axis (See Figure 1 below). The practices identified have been selected based on their high nitrogen removal efficiencies and represent a range of practices that are applicable in a wide variety of conditions.

Since the proposed green infrastructure and LID practices are applicable in a variety of settings, one can expect a range of performance from any given practice, depending on how appropriate it is for the selected location. "A variety of site criteria should be evaluated to determine if a specific practice is suitable for a given site; an 'x' in the matrix below indicates siting criteria that are used to help identify appropriate sites for different practices. Alternatively, some practices may not be appropriate for a location when evaluated with some siting criteria; these are designated in the matrix with a 'c' (for constrained). Blanks in the matrix indicate that the specific practice is not impacted either positively or negatively by the siting criteria – the siting criteria has no real influence on whether the site is appropriate for implementation of the green infrastructure or LID practice. As an example of how this matrix is used, sites with well drained soils are appropriate for most of the techniques evaluated, including infiltration and phytoremediation. But if a high groundwater table is also present, this constraint can make the site infeasible for infiltration practices while phytoremediation is not significantly limited by this condition. Utilization of the siting criteria matrix is necessary to identify appropriate, technique-specific sites for potential implementation.

Siting Criteria	Constructed Wetlands	Permeable Reactive Barriers	Stormwater Treatment Wetlands	Phytoremediation	Biofiltration Strips	Bioretention/Advanced Bioretention	Infiltration	Green Roof[1]	Permeable Pavement	Bioswales[2]	Stormwater Disconnection	Gravel Wetland
Floodplain: V zone	c		x	c	x	c			c			c
Floodplain: A zone	c		x	c	x				c			c
SLOSH	c		x	c	x				c			c
350 ft buffer to vernal pool	c	x	c	c	c							
100 ft buffer to wetland	x	x	c		c	c			c			c
USGS zone of contribution		x	x		x							
Zone II's	c	x	x		x		c					
Soils: disturbed	x	x		x		x						x
Soils: well drained	x	x	x	x	x	x	x		x		x	
Within open space: agricultural			x		x							
Within open space: protected	c	c	c	c	c							
Within open space: recreation	x	x	x	x	x							
Within open space: government	x		x	x	x							
Adjacent to open space: agricultural			x		x							
Adjacent to open space: protected	x		c		c							
Adjacent to open space: recreation			x		x							
Adjacent to open space: government	x		x		x							
Wellhead Protection Areas (i.e. Zone I)	c		c				c					
DEP wetlands	c	c	c			c			c	c		c
Endangered species habitat	c		c									
Depth to groundwater > 4'	c		c		x	x	x		x		x	
Depth to groundwater < 4'	x	x	x			c	c		c			
Proximity to golf courses, athletic fields	x		x									
Impervious areas	x		x		x	x	x		x	x	x	x
Proximity to schools, etc.	x		x			x	x		x	x	x	

[1] Green roofs have a significantly different set of siting criteria from other stormwater LID techniques
[2] Although bioswales can be designed to function as infiltration BMPs, those mentioned here are designed as water quality BMPs
[3] An "x" indicates that a practice is appropriate for a site, based on the evaluation criterion, while a "c" indicates that a practice may have significant constraints at a site.

Figure 1. Siting criteria matrix

Larger practices such as permeable reactive barriers have a large number of siting criteria and site constraints that are necessary to evaluate to determine appropriate locations because these practices are highly dependent on specific site conditions. This limits the areas where placement of these techniques is feasible and beneficial. Alternatively, practices such as bioretention or pervious pavement can be applied to a wide variety of sites and conditions and have fewer siting criteria or constraints.

A detailed understanding of the characteristics of each practice is important to determine optimal sites. Several of the potential techniques to be evaluated for this project are described in Section 2 below. Siting criteria and constraints used in the screening process to identify appropriate sites are discussed; variations of these techniques could be proposed as part of the concept plan development.

2.2. Green Infrastructure/LID Practice Technical Specifications

2.2.1. Constructed Wetlands/Stormwater Treatment Wetlands

Description: Constructed wetlands are intended to simulate the functions of natural wetlands by utilizing vegetation, soils, and microbial activity (MassDEP 2003). Constructed wetlands are typically separated into surface flow wetlands and subsurface flow wetlands (which will be discussed in a following section).

Surface flow wetlands (often called stormwater treatment wetlands) treat surface water runoff from storm events. Constructed wetlands are generally implemented in upland areas, as placement in or near natural wetlands and streams require a Section 404 permit, and care should be taken in regards to the constructed wetland discharge, which can impact the water temperature of fisheries or the hydroperiod of downstream wetlands (VADCR 2011).

Constructed wetlands can be built in areas of high groundwater, which can be used to maintain the hydrology. Designs should create a long flowpath and a footprint equal to approximately 3% of the contributing drainage area (VADCR 2011). An example of a constructed wetland is shown in Figure 2 below and a typical plan view is shown in Figure 3.

Figure 2. Example of a constructed wetland system (CRWA 2008)

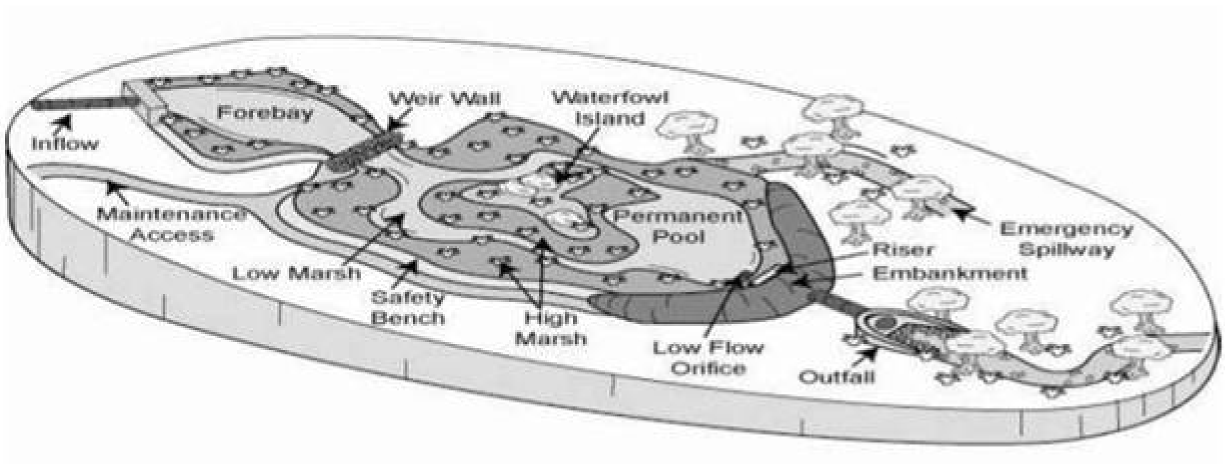


Figure 3. Typical plan view of a constructed wetland system (VADCR 2011)

Nitrogen Removal Process and Efficiency: Nitrogen (N) removal occurs through physicochemical and biological processes, with the main nitrogen removal process being nitrification followed by denitrification (Lee et al. 2009). Connection to the groundwater table can result in treatment of nitrogen from septic system discharges but can also reduce the pollutant removal efficiency of the system, since constructed wetlands require a long residence time for pollutant removal. Total nitrogen (TN) removal for constructed wetlands can reach a maximum of 55% (CRWA 2008). If properly designed and constructed, constructed wetlands can achieve high pollutant removal for a period of 10 years with minimal maintenance.

Effectiveness in the sandy soils such as on Cape Cod: 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 which would increase the cost and eliminate the ability to treat septic system discharges.

2.2.2. Permeable Reactive Barriers

Description: A Permeable Reactive Barrier (PRB) is a stratified multi-media biofilter containing sand, expanded clay and lignocellulosics (plant dry matter), and/or elemental sulfur (Figure 4). PRBs are trenches, or trench-like features, filled with organic materials such as sawdust and/or wood chips that serve as energy sources – food – for microbes/bacteria for removal by denitrification (Ecosite 2011). To be effective, PRBs must be able to intercept the flow of groundwater containing nitrogen without getting bypassed either below or around the barrier (ITRC 2011). This requirement results in placement of PRBs where the groundwater is typically 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 are highly effective in treating groundwater nitrogen, particularly due to the low nitrogen concentrations (often 1.0 mg/L – 5.0 mg/L) found in contaminated groundwater. PRB's should be placed only into freshwater groundwater -because coastal salt water can rot saw dust or wood chips. PRBs placed in tidal zones can also be affected by density driven circulation which can result in the nitrate plume undercutting the PRB (Vallino et al. 2008).

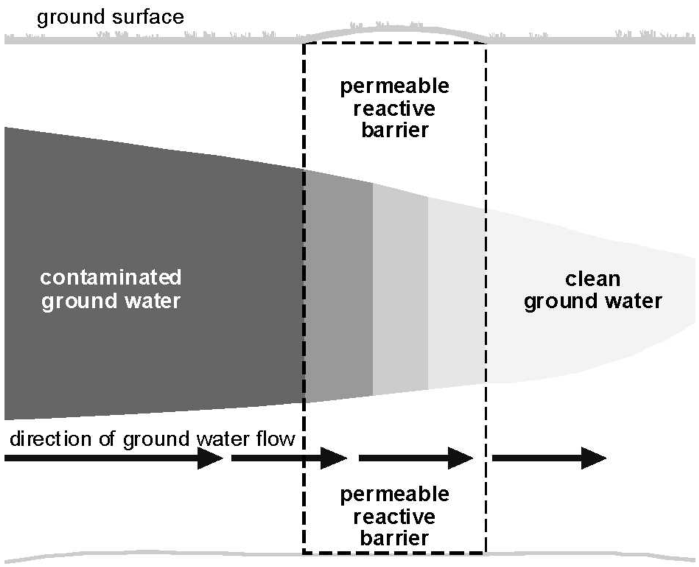


Figure 4. Permeable reactive barrier (EPA 1999)

Nitrogen removal process and efficiency: This technology can provide effective removal at runoff concentrations, and remains effective after 15 years. TN reductions of greater than 95% can be achieved at retention times less than 10 hours (Ecosite 2011). NITREX™ PRBs are proprietary practices that have been installed in locations on Cape Cod that have a specific media mix to remove nitrogen. Studies have shown that these systems can remove 99% of groundwater nitrate concentrations. Other non-proprietary practices are currently being developed and tested for efficiency in groundwater nitrate removal.

Effectiveness in the sandy soils such as on Cape Cod: 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.

2.2.3. Phytoremediation

Description: Phytoremediation utilizes specific plant communities (Figure 5) 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.

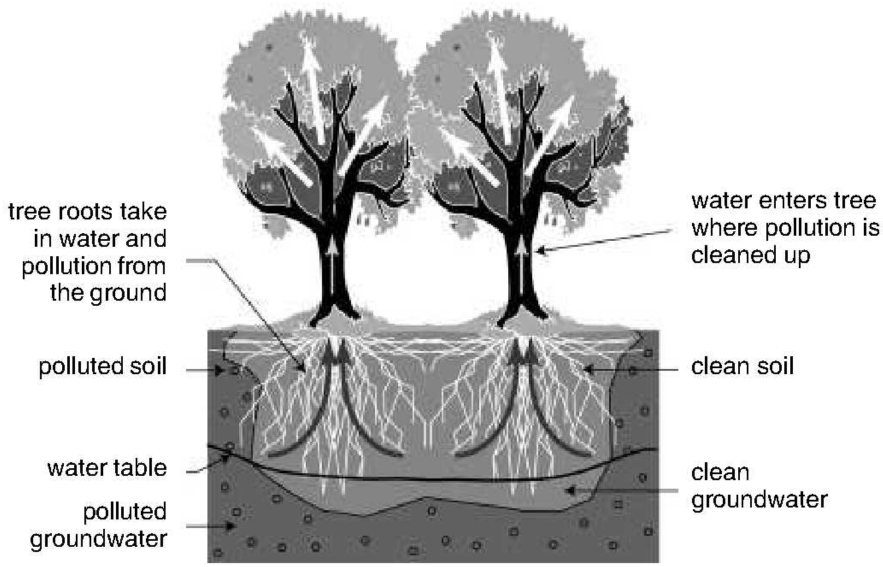


Figure 5. Typical phytoremediation process (EPA 2012)

Nitrogen removal process and efficiency: 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.

Effectiveness in the sandy soils such as on 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. Property owners, developers, landscape architects, and site engineers should consult with soils maps, town/USGS hydrogeologic GIS data layers, or conduct at least a minimal hydrogeologic assessment to determine groundwater depths suitable to the region's vegetation used in this technique.

2.2.4. Biofiltration Strips (Vegetative Buffer Strips)

Description: 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) (Figure 6). Biofiltration strips are often used to treat runoff from roads, parking lots, rooftops, and other impervious surfaces or are used as pretreatment.

Biofiltration strips require sheet flow to be effective; if runoff concentrates before reaching the biofiltration then a level spreader can be used to distribute the flow. Large runoff flows should be avoided to prevent concentrated flow, limiting the size and treatment area of the biofiltration strip. The contributing drainage area should be kept to a maximum of 5 acres to prevent concentrated flows (Clar et al. 2004).

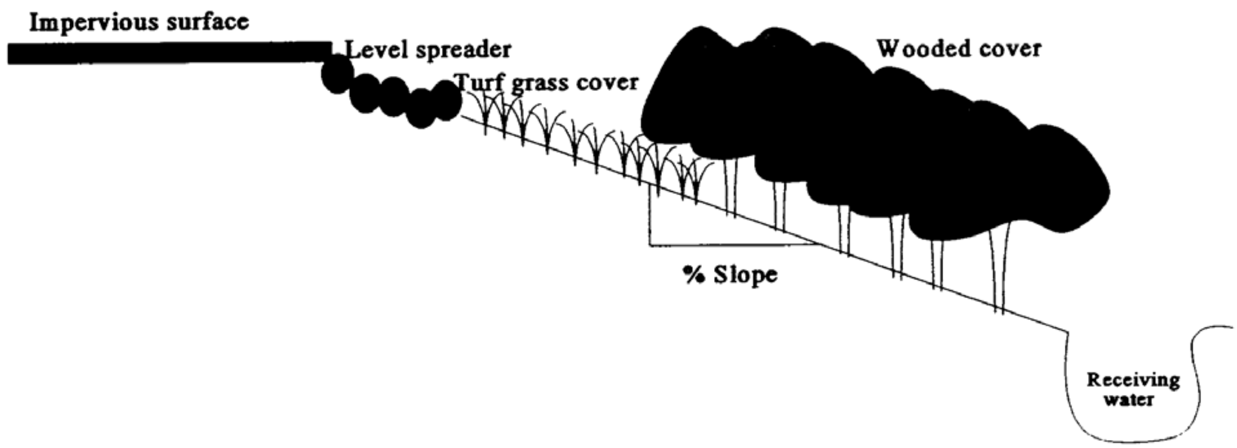


Figure 6. Diagram of a typical biofiltration strip (Clar et al. 2004)

Nitrogen removal process and efficiency: If flow rates are kept low, biofiltration strips are effective at removing sediment and phosphorus (P). Nitrogen removal rates are significantly lower with only 10% removal of nitrate/nitrite. The best performance for this type of nitrogen removal are in areas of high infiltration.

Effectiveness in the sandy soils such as on Cape Cod: The best pollutant reduction for biofiltration strips are attained in highly permeable soils making this technique widely useable in many areas of Cape Cod, especially as a pretreatment technique for other green infrastructure features.

2.2.5. Bioretention

Description: Bioretention is a method of treating stormwater by ponding water in shallow depressions underlain by a sandy engineered soil media (Figure 7 and Figure 8), through which most of the runoff passes and includes common practices like rain gardens (Clar 1993). Bioretention can easily be incorporated into the landscape to address and maintain any or all of the essential hydrologic functions including: canopy interception, evapotranspiration, groundwater recharge, water quality control, runoff volume and peak discharge control. Pollutants in runoff are then settled, filtered, adsorbed, taken up, immobilized, and/or transformed. This extensive array of pollutant retention mechanisms makes bioretention one of the most effective practices in the designer's toolbox.

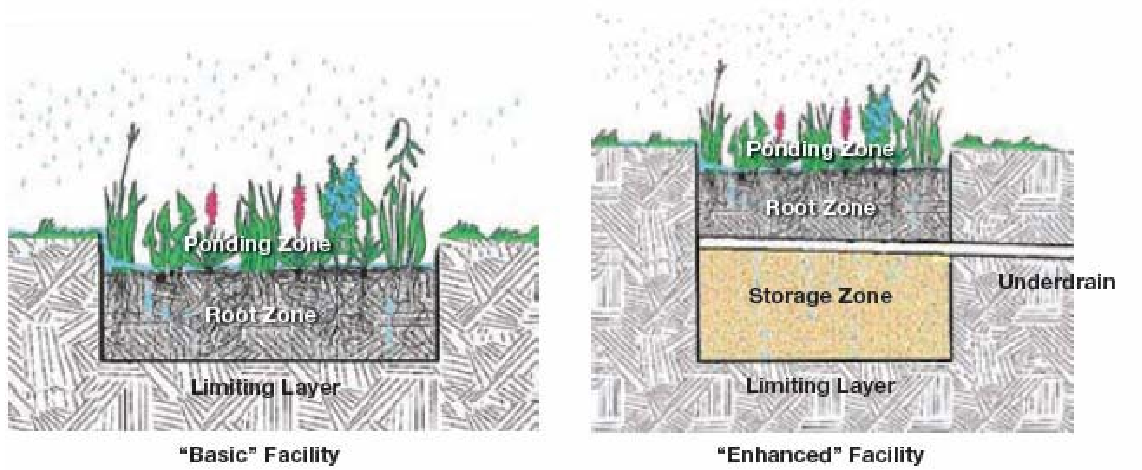


Figure 7. Basic bioretention models (Atchison et al. 2006)

Figure 8. Bioretention island (Tetra Tech)

Nitrogen removal process and efficiency: Table 1 presents a generalized summary of bioretention performance for a variety of stressors. Numerous studies (as cited in Davis et al. 2009) document that bioretention performs well for total suspended solids (TSS) and associated particulate stressors, as well as metals and hydrocarbons. This is due to the effectiveness of bioretention at filtering solids while the negatively charged organic amendments have a very high affinity for positively charged metals. Biological activity also effectively removes biochemical oxygen demand (BOD) and hydrocarbons.

However, many properties of typical bioretention systems also impede effective nutrient retention. Negatively charged dissolved P and N 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 N and P is much less effective.

Table 1. Typical range of retention performance of bioretention systems expressed in terms of concentration as opposed to mass load reduction (Lucas and Greenway 2011a).

Runoff Stressor	Typical Inflow (mg/l)	Range of Reduction
Total Suspended Solids (TSS)	15-350	90-99%
Biological Oxygen Demand (BOD)	1.50-22.0	80-90%
Total Copper	0.01-0.28	60-90%
Total Zinc	0.03-0.35	85-95%
Oil and Grease	0.40-20.0	95-99%
Particulate Phosphorus	0.10-2.20	95-99%
Dissolved Phosphorus	0.05-1.50	10-30%
Dissolved Nitrogen	0.10-3.70	***-40-40%***
Particulate Nitrogen	0.50-3.50	***25-50%***

As P is often the 'limiting' nutrient (the principal controlling factor) for freshwater impoundments, such as lakes and reservoirs, excess P increases eutrophication by stimulating the growth of plankton and larger aquatic plants. On the other hand, as N is often the 'limiting' nutrient for salty-mixed estuarine waters, excess nitrogen causes eutrophication – excessive plant growth and low dissolved oxygen – in these ecosystems, although P at times can also be implicated (Correll 1999). N is the second most common element in living cells and P is a fundamental component of cellular metabolism. N is the fundamental element in all amino acids that make up proteins, and is also a basic component of DNA. N and P are typically found at an N:P ratio of approximately 16:1 in plankton.

Effectiveness in the sandy soils such as on Cape Cod: Bioretention tends to work best in sandy soils such as those present in many areas of Cape Cod. Sandy soils allow bioretention systems to be designed as infiltration systems, which provide better performance than filter designs. In addition, sandy soils are well suited for the use of in-situ design and construction techniques for bioretention systems (Clar 2010) that can reduce construction costs to 25% of traditional systems.

2.2.6. Enhanced Bioretention

Description: Specialty media can be combined with outlet controls to improve nutrient retention performance of bioretention systems. Media can be amended with materials with a high P sorption capacity to improve P retention. The enhanced (or advanced) bioretention system (ABS) contains high amounts of alum from water treatment residuals (WTRs). Adding WTR amendments to media greatly improves P retention (Lucas and Greenway 2011).

Increasing hydraulic retention time also increases N retention. The outlet used in the ABS provides a novel approach to resolve the conflicting goals of restricting flows to extend retention time for N retention, while minimizing bypass flows (Figure 9). This is accomplished by a dual stage outlet (Lucas and Greenway 2011a). The lower outlet is elevated above the stone layer so as to provide a saturated zone and regulated to provide a flow rate of approximately 8 cm-h^{-1} when the media begins to pond.

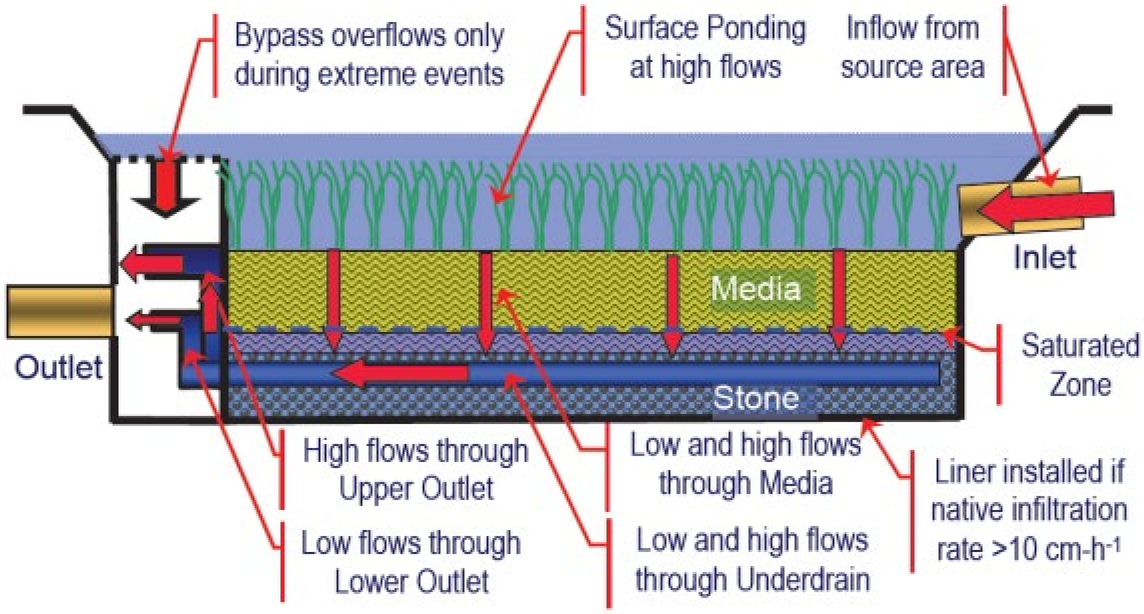


Figure 9. Advanced Bioretention adapted from Lucas & Greenway (2011a)

It is supplemented by an upper outlet that flows when ponding occurs, with its flow rate determined by media saturated hydraulic conductivity (K_{sat}) and relative head. Due to high K_{sat} in the media, this arrangement allows for substantial flows to pass through the media. With such an outlet, the plug flow retention through rapidly infiltrating media time increases to 150 minutes compared to the free discharge retention time less than 20 minutes (Lucas and Greenway 2011b). This results in greatly improved N retention compared to free discharge bioretention systems typically used (Lucas and Greenway 2011c).

Nitrogen removal process and efficiency: The initial N and P retention performance of the ABS presented in Lucas and Greenway (2011a) showed that Total Dissolved Phosphorus (TDP) retention from stormwater after over 30 years of urban runoff was 93%, with 99% retention of PO_4-P.

Lucas and Greenway (2011a) present results from large events (approximately 6 month recurrence interval for Brisbane, Australia) that show TN retention of 66%, with NO_x retention of 62%. The corresponding retention in typical bioretention systems was 27% and 19% respectively, documenting the benefits of the dual outlet of the ABS in increasing N retention. When subjected to a smaller dose representative of a more typical event, TN retention increased to as high as 78%, while NOx retention was as high as 94%. The ABS was able to provide a significant increase in N retention compared to the corresponding free discharge treatment.

Effectiveness in the sandy soils such as on Cape Cod: The advanced bioretention system is more effective than typical retention techniques in sandy soils. It does not require liners and can work in any soil.

2.2.7. Infiltration

Description: Infiltration is used to both describe a process whereby stormwater is infiltrated into the soil, and also a series of storm water practices whose primary function is to infiltrate storm water runoff. These stormwater practices include infiltration trenches (Figure 10), infiltration basins, landscape infiltration (Figure 11), and dry wells. In addition, a number of practices also use infiltration as part of the design when suitable soils are present. These practices include bioretention, bioswales, and filter strips.

Figure 10. Infiltration trench (*http://ian.umces.edu/imagelibrary/*)

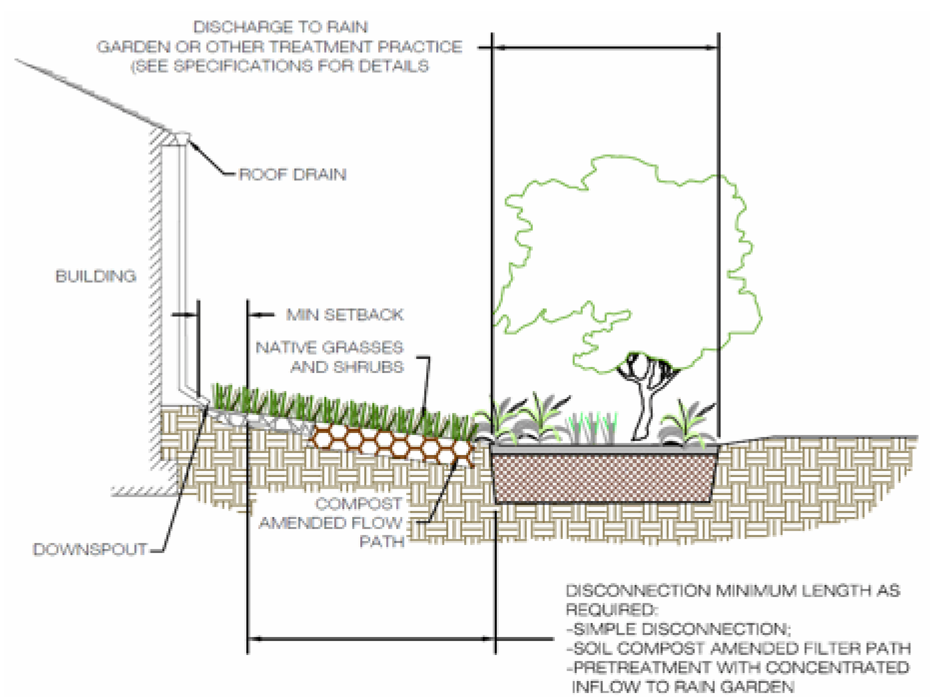


Figure 11. Landscape infiltration (VADCR 2011)

Nitrogen removal process and efficiency: EPA's Chesapeake Bay Program (CBP) and the Maryland Department of the Environment (2009) report total nitrogen (TN) removal rates as high as 80% for stormwater infiltration practices as shown in Table 2 below. However in the same table, they report that landscape infiltration practices have a nitrogen removal rate of 50%. Removal efficiencies for total phosphorous (TP) and total suspended solids (TSS) are shown a well. Both of the rates appear rather high compared to the reported removal rates for bioretention practices shown in Table 1. The bioretention removal rates from Table 1 represent a conservative assessment of infiltration removal rates.

Effectiveness in the sandy soils such as on Cape Cod: 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.

Table 2. Urban Best Management Practice (BMP) Efficiencies (MDE 2011)

BMP Practice	TN	TP	TSS
CBP Structural BMPs			
Dry Detention Ponds	5%	10%	10%
Hydrodynamic Structures	5%	10%	10%
Dry Extended Detention Ponds	20%	20%	60%
Wet Ponds and Wetlands	20%	45%	60%
Infiltration Practices	80%	85%	95%
Filtering Practices	40%	60%	80%
Vegetated Open Channels	45%	45%	70%
Erosion and Sediment Control	25%	40%	40%
Stormwater Management by Era			
Development Between 1985 - 2002	17%	30%	40%
Urban BMP Retrofit	25%	35%	65%
Development Between 2002 and 2010	30%	40%	80%
Development After 2010	50%	60%	90%
ESD to the MEP from the *Manual*			
Green Roofs	50%	60%	90%
Permeable Pavements	50%	60%	90%
Reinforced Turf	50%	60%	90%
Disconnection of Rooftop Runoff	50%	60%	90%
Disconnection of Non-Rooftop Runoff	50%	60%	90%
Sheetflow to Conservation Areas	50%	60%	90%
Rainwater Harvesting	50%	60%	90%
Submerged Gravel Wetlands	50%	60%	90%
Landscape Infiltration	50%	60%	90%
Infiltration Berms	50%	60%	90%
Dry Wells	50%	60%	90%
Micro-Bioretention	50%	60%	90%
Rain Gardens	50%	60%	90%
Grass, Wet, or Bio-Swale	50%	60%	90%
Enhanced Filters	50%	60%	90%
Additional Structural BMP Guidance			
Redevelopment (MDE)	50%	60%	90%
Existing Roadway Disconnect (MDE)	50%	60%	90%
Step Pool Storm Conveyance (MDE)	50%	60%	90%

(Adapted from CBP Urban BMP Efficiencies, and Stormwater Management by Era, MDE 2009)

2.2.8. Green Roofs

Description: Green roofs are alternative roofing systems that replace conventional construction materials or retrofit existing roofs and include a protective covering of planting media and vegetation. Also known as vegetated roofs 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 to help mitigate stormwater impacts. The vegetative cover of green roofs can also lower ambient air temperatures in the summer and provide insulation in the winter, therefore reducing cooling and heating demands for buildings.

There are two basic green roof designs that are distinguished by media thickness and the plant varieties that are used. The more common or "extensive" green roof (Figure 12) is a lightweight system where the media layer is between two and six inches thick. This limits plants to low-growing, hardy herbaceous varieties. An extensive green roof may be constructed off-site as a modular system with drainage layers, growing media, and plants installed in interlocking grids. Conventional construction methods may also be used to install each component separately.

"Intensive" green roofs have thicker soil layers (eight inches or greater) and are capable of supporting more diverse plant communities including trees and shrubs. A more robust structural loading capacity is needed to support the additional weight of the media and plants. Intensive green roofs are more complex and expensive to design, construct, maintain, and therefore are less commonly used.

Figure 12. Chicago City Hall Urban Heat Island Initiative project (Source: Roofscapes, Inc.)

Nitrogen removal process and efficiency: EPA's Chesapeake Bay Program and the Maryland Department of the Environment (Table 2) report that green roofs have a nitrogen removal rate of 50% (MDE 2011).

Effectiveness in the sandy soils such as on Cape Cod: The soil type is not a factor in green roof selection or design.

2.2.9. Permeable Pavement

Description: Permeable pavements are alternatives to traditional pavements or concrete that may be used to reduce imperviousness (Figure 13). While there are many different materials commercially available, 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.

Figure 13. Permeable pavement in parking lot (Tetra Tech)

Nitrogen removal process and efficiency: In a review of stormwater control measures used to manage nitrogen, Collins et. al (2010) indicated that, "several studies have suggested that aerobic conditions, which typically occur as runoff drains through permeable pavements, can result in nitrification of NH_4^+ to NO_3^-." Substantially lower NH_4-N and total Kjeldhal nitrogen (TKN) concentrations and higher NO_3-N concentrations have been measured in permeable pavement drainage as compared to asphalt runoff in multiple experiments. A few studies have shown a decrease in concentrations of all measured nitrogen species (NH_4-N, TKN, and NO_3-N) (EWRI 2012).

EPA's Chesapeake Bay Program and the Maryland Department of the Environment recommend using a 50% nitrogen removal rate for permeable pavements (Table 2) (MDE 2011).

Effectiveness in the sandy soils such as on Cape Cod: Permeable pavement stormwater practices are essentially infiltration techniques and, as such, work best with well drained sandy soils such as are present in many areas of Cape Cod. The presence of high water tables will limit the use of this practice.

2.2.10. Bioswales

Description: Bioswales are channels that provide conveyance, water quality treatment, and flow attenuation of stormwater runoff (Figure 14). 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.

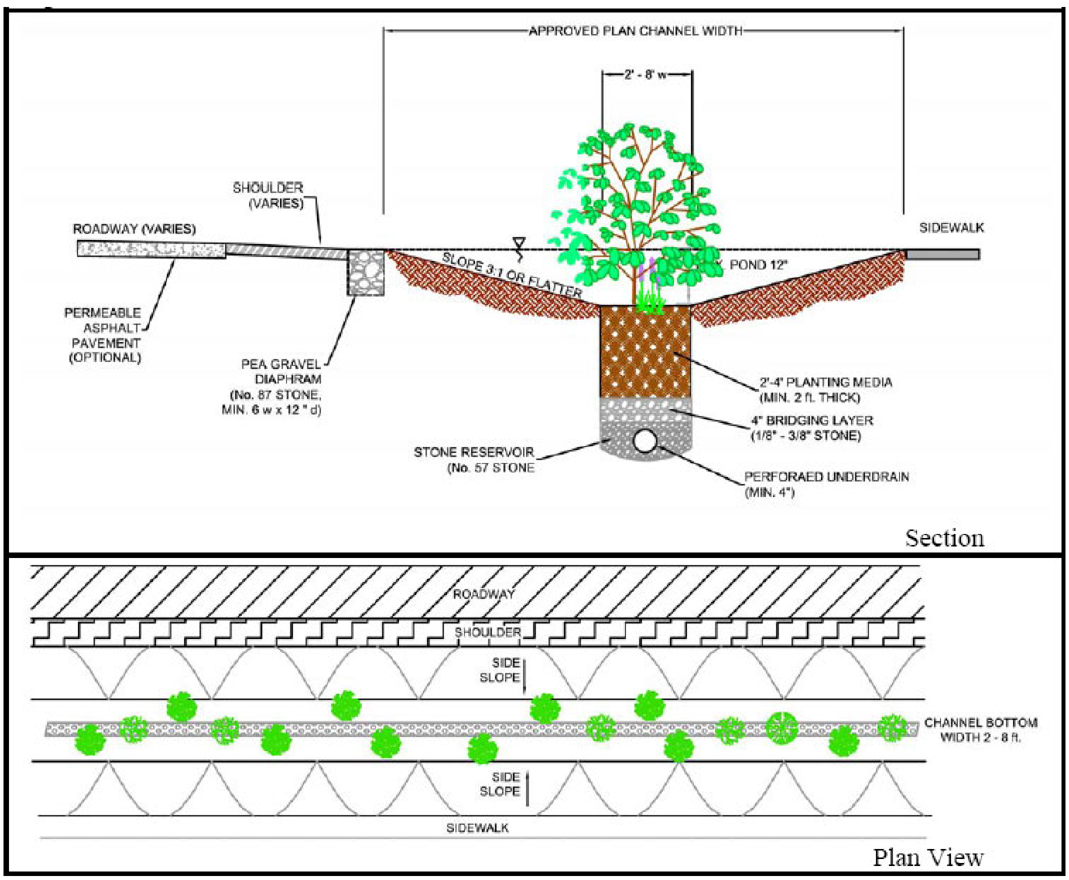


Figure 14. Bioswale (MDE 2009)

Nitrogen removal process and efficiency: EPA's Chesapeake Bay Program and the Maryland Department of the Environmental recommend using a 50% removal rate for bioswales (Table 2) (MDE 2011).

Effectiveness in the sandy soils such as on Cape Cod: 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.

2.2.11. Stormwater Disconnection

Description: Stormwater disconnection is used to describe a process whereby stormwater from impervious surfaces is directed to pervious areas such as lawns, where the runoff has an opportunity to be filtered and infiltrated into the soil. Stormwater disconnection can also refer to a series of stormwater practices conceived to achieve this objective. Commonly used practices include rooftop downspout disconnection, impervious non-rooftop area disconnection, and discharge to conservation areas (MDE 2009). A number of practices can be used to achieve the disconnection including rain gardens, dry wells, and stone diaphragms, such as the one shown in Figure 15.

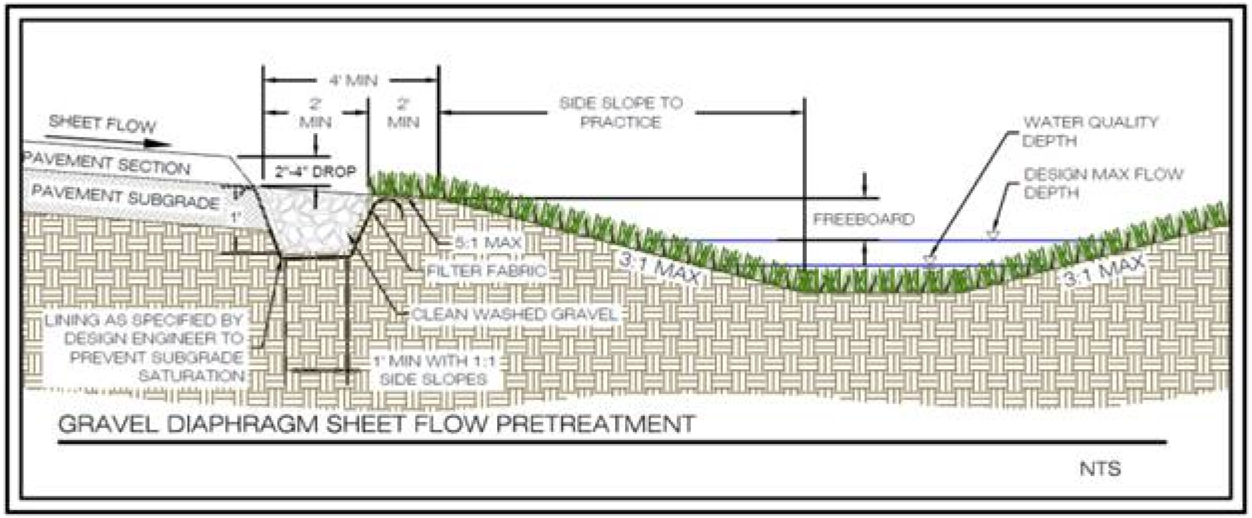


Figure 15. Stone diaphragm (VADCR 2011)

Nitrogen removal process and efficiency: EPA's Chesapeake Bay Program and the Maryland Department of the Environment recommend using a 50% removal rate for stormwater disconnection (Table 2) (MDE 2011).

Effectiveness in the sandy soils such as on Cape Cod: Stormwater disconnection practices work best with well drained sandy soils, which are present in many areas of Cape Cod.

2.2.12. Gravel Wetland

Description: The gravel wetland is designed as a series of flow-through treatment cells, preceded by a sedimentation basin (Figure 16 and Figure 17). It is designed to attenuate peak flows and provide subsurface anaerobic treatment. The subdrains distribute the incoming flow, which then passes through the gravel substrate, and then 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.

Figure 16. Gravel wetland (Ballestero et al. 2011)

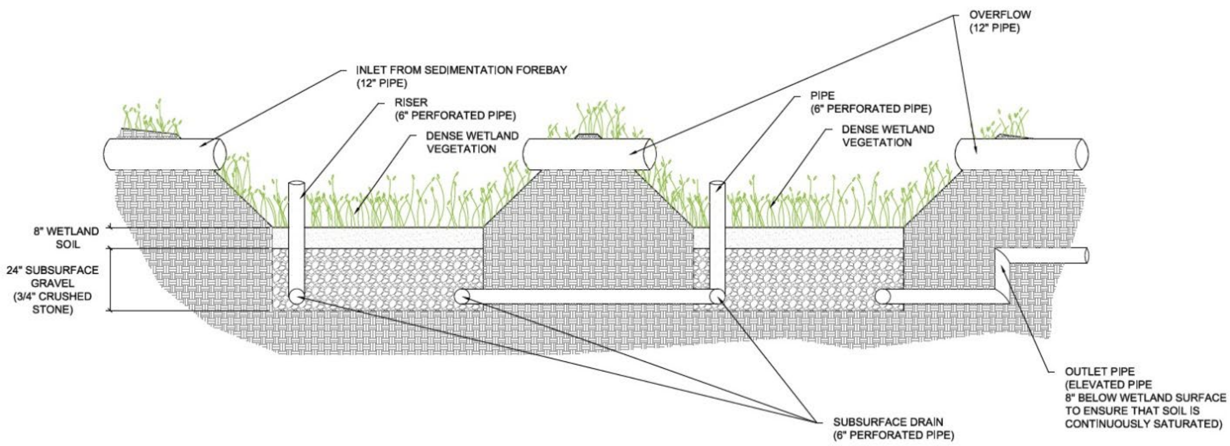


Figure 17. Gravel wetland schematic (CRWA 2009)

Nitrogen removal process and efficiency: UNH Stormwater Center provides the following guidance and nitrogen removal efficiencies (Figure 18) (Ballestero et al. 2011):

- Systems must be vegetated, sedimentation plays a minor role;
- Biologically-mediated conversion processes, whether aerobic or anaerobic;
- Microbial decomposition of organic matter produces reduced NH3 which is treated commonly through biological oxidation (nitrified) to NO2/NO3 and then treated by biological reduction anaerobically to N2.

Organic N= TKN

TN = Organic N+NH3+NH4+NO2+NO3

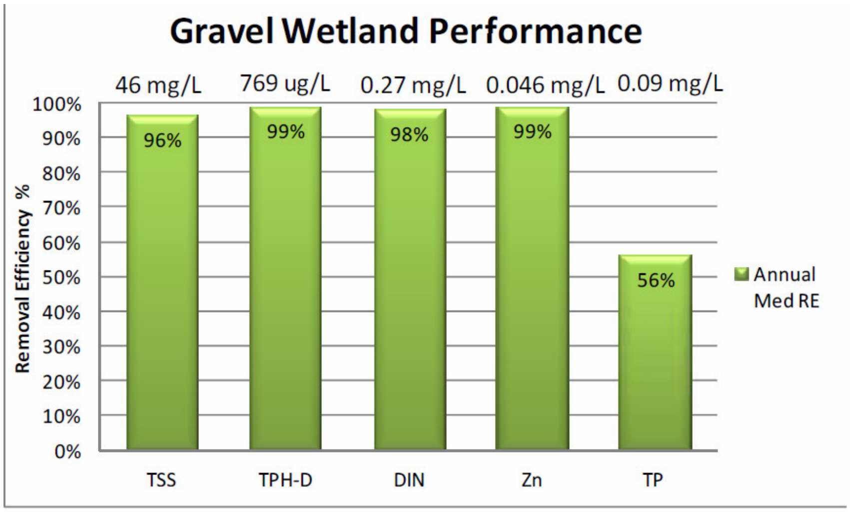


Figure 18. Nitrogen removal (Ballestero et al. 2011)

Effectiveness in the sandy soils such as on Cape Cod: The gravel wetland must be lined at the bottom to maintain anaerobic conditions and is not dependent on soil type.

2.3. Siting Criteria

Siting criteria can consist of both positive criteria and constraints. To identify locations for potential green infrastructure practices, siting criteria have been selected that focus on significant sources of nitrogen, high public exposure, favorable site conditions, and ease of implementation. Siting criteria that focus on public exposure and ease of implementation can be applied universally and tend to identify publicly owned land or community amenities in high-density areas. Other criteria are highly dependent on the practice evaluated. Impervious area represents a significant source of nitrogen and serves as a siting criteria for green infrastructure. These same sites would not necessarily favor groundwater-intercepting techniques, as wastewater in high-density areas is often collected and treated for nitrogen removal at a central location. In other cases, siting criteria that indicate an appropriate location for one practice could be a constraint for another. For example, infiltration-based practices require well-draining soils while constructed wetlands are not feasible in well-draining soils unless a high groundwater table is present. The screening process utilizes the siting criteria matrix to differentiate parcels based on these green infrastructure and LID practices.

2.4. Matrix Tool Application

2.4.1. Generic Application

Once the practices were identified and the siting criteria matrix developed, the CCC (GIS program) applied the siting criteria to each parcel within the two target watersheds in Yarmouth and Barnstable. The siting criteria matrix was initially applied generically. The green infrastructure practices were not evaluated separately; instead, parcels were assessed using a combination of all siting parameters for both wastewater and stormwater applications. A total of 14 siting parameters were assessed for each site and weighted equally, giving potential sites a maximum score of 14. CCC 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, CCC evaluated site constraints during the field assessments of the selected parcels.

The initial generic application of the matrix as part of the screening process resulted in 14 parcels that received a score of eight or more. A few of these initial 14 were eliminated based on review of aerial photos indicating that they were highly developed sites and/or privately owned. The remaining eight parcels were selected for further investigation through field assessments. Characteristics such as topography, development condition, neighboring uses, etc. were evaluated on the site, and presence/absence of wetlands, known location of Zone II and floodplains, and other constraints were discussed in the field and noted on site assessment forms.

Following analysis of these initial field results, CCC revised the criteria over the course of two more iterations to include the following resources, addressing both stormwater and wastewater siting interests: Environmental Justice communities, well drained soils, within recreation and/or government open space, adjacent to protected and/or government open space, proximity to golf courses, and impervious surfaces. In total, there were eight potential siting criteria (see Figure 19 below); when the GIS had run these criteria within the impaired watersheds within Barnstable and Yarmouth, the highest possible score was five. CCC filtered the results to show all parcels with a score of four or above that were coded as publicly owned. This exercise confirmed the sites previously visited and added 14 more parcels that CCC staff thought should be evaluated. Additional field visits were made, noting constraints in the field on site assessment forms.

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

Figure 19. Revised Screening Process Matrix

During the course of the field visits and the intervening time, CCC staff had opportunities to speak with a few abutters and potential project partners, which assisted in the decision to move forward or drop sites from consideration. Sites such as 122 Camp Street, a privately owned condominium/affordable housing project, initially seemed an unlikely candidate until a conversation with a resident indicated the potential for innovative solutions on the site.

2.4.2. Stormwater- and Wastewater-Specific Application

The initial, generic application of the siting criteria matrix resulted in 14 parcels that ranked highly for all siting criteria. These parcels contain a mix of parameters that favor techniques to address groundwater sources, stormwater sources, or both. In the end, the CCC settled on a refined set of siting criteria to identify potential sites, as discussed above. However, during the course of examining appropriate criteria to identify viable sites, the CCC ran separate screening processes to address green infrastructure practices that favor groundwater sources and LID practices that favor stormwater sources, independently. This iteration, separating the screening approaches, resulted in fewer siting criteria to evaluate but more technique-specific sites. CCC applied the siting criteria matrix to parcels utilizing this specific approach, which confirmed sites previously selected, and identified additional high opportunity areas for green infrastructure and LID practices.

2.5. Screening Process Results

A desktop-based application of the different iterations of the siting criteria matrix identified more than 15 total high opportunity areas for the placement of green infrastructure and LID practices. Subsequent field assessments identified six potential sites from the original generic matrix application and an additional two (2) sites from the specific matrix application. These sites were equally distributed between the communities of Barnstable and Yarmouth. Maps of these sites, along with a further suitability analysis examining possible constraints based on the field assessments, is included in the assessment of potential sites. These eight sites will be evaluated in more detail with input from other community stakeholders to identify two sites for green infrastructure conceptual designs.

3. Site Assessments

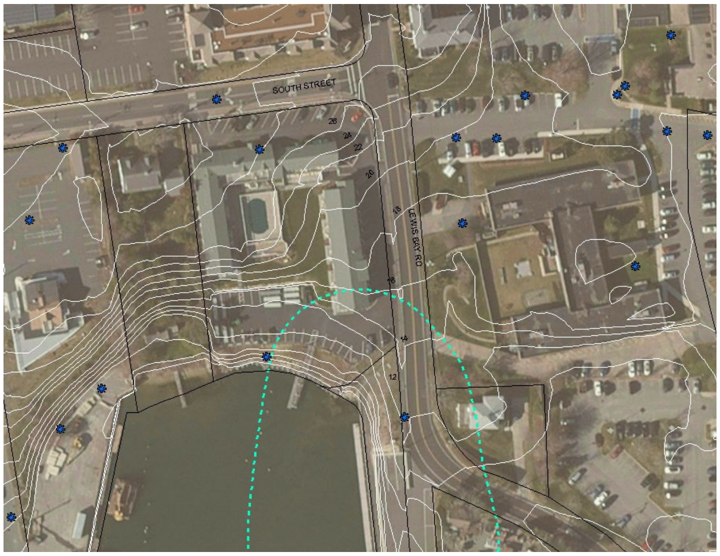
The CCC utilized the previously developed siting criteria matrix tool to identify potential sites for application of green infrastructure or LID. A total of 17 parameters were used as siting criteria within the tool and several sites were identified that contained eight or more of these parameters. After careful analysis of the tool results, 14 sites were selected for further feasibility assessment within the field. These 14 sites were located in environmental justice communities in both Barnstable and Yarmouth. Potential siting constraints were evaluated during the field assessment rather than in the tool.

Following the field assessment, the project team collectively reviewed the 14 tool-identified sites to select six potential green infrastructure or LID sites. These sites were split evenly between Barnstable and Yarmouth. Two additional sites were identified by CCC staff in the field and added to the list of potential sites. Based on GIS data of the sites and information provided by CCC from field assessments, a constructability assessment of the eight total potential sites was performed to evaluate a variety of physical, social, and economic factors. The constructability assessment of each of the eight potential sites is presented below in Sections 3.1 - 3.8. Pictures from the field assessments are presented along with aerial imagery for each of the sites (All images courtesy of Tetra Tech). Discussions of the physical, social, economic, and water quality considerations are included based on an evaluation of factors by the project team. Water Quality Volumes were calculated by siting a potential practice, delineating the total drainage area treated by the technique, assessing the amount of impervious surface within the treatment area, then applying a 1-inch storm event over the impervious area. This follows the process established in the Massachusetts Stormwater Handbook found here: *http://www.mass.gov/eea/agencies/massdep/water/regulations/massachusetts-stormwater-handbook.html*. This evaluation leads to a constructability assessment to determine the feasibility of implementing green infrastructure practices on each site.

This assessment offers limited guidance on potential techniques to be implemented, focusing primarily on the potential for implementation and any possible barriers to be resolved. A 'map' of suggested practices and their estimated treatment area is shown as part of the constructability assessment. These practices and their associated treatment areas have not been completely field-verified for feasibility. They serve primarily as an indication of a practice that might be feasible on the site.

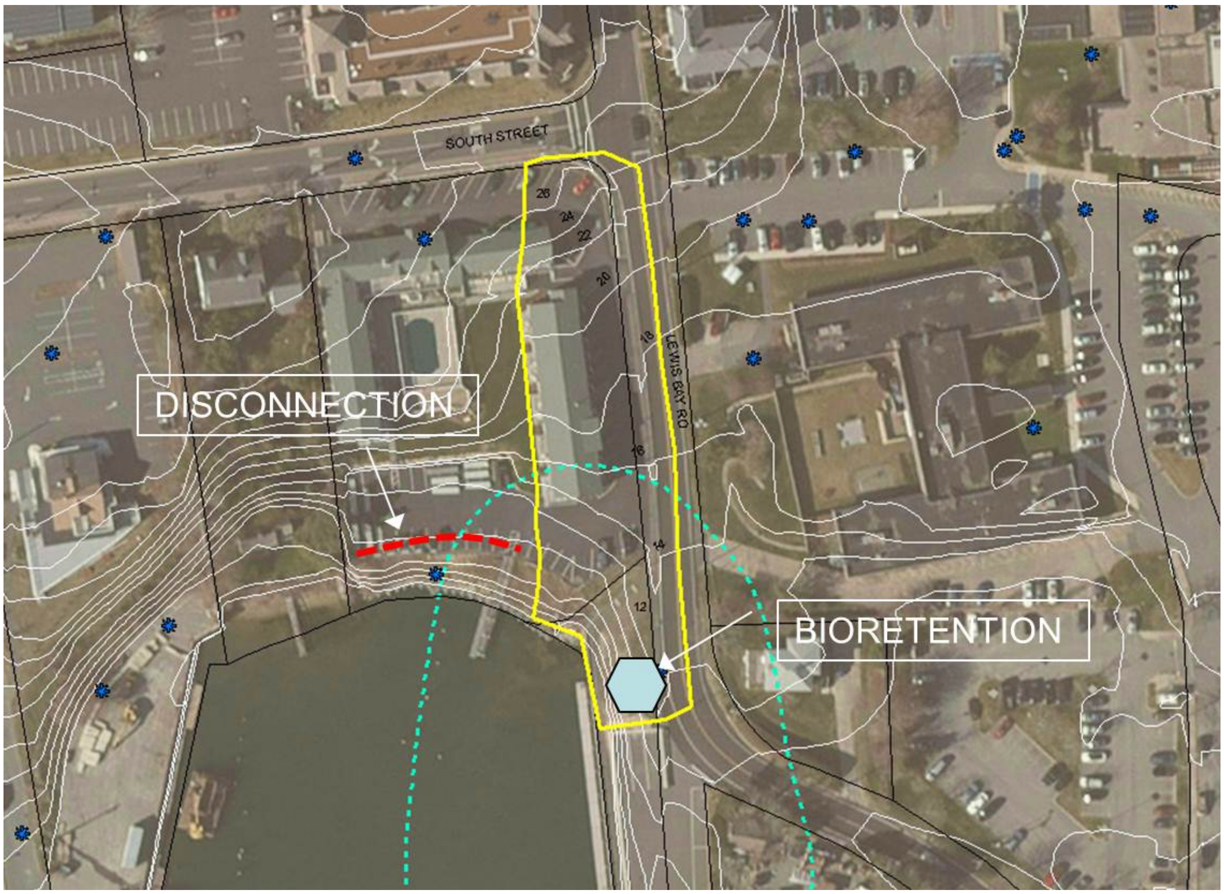
3.1. 1 South Street – Barnstable

Both the Anchor-In Hotel (at 1 South Street) and an adjacent public boat ramp appear to be suitable for small scale LID techniques.



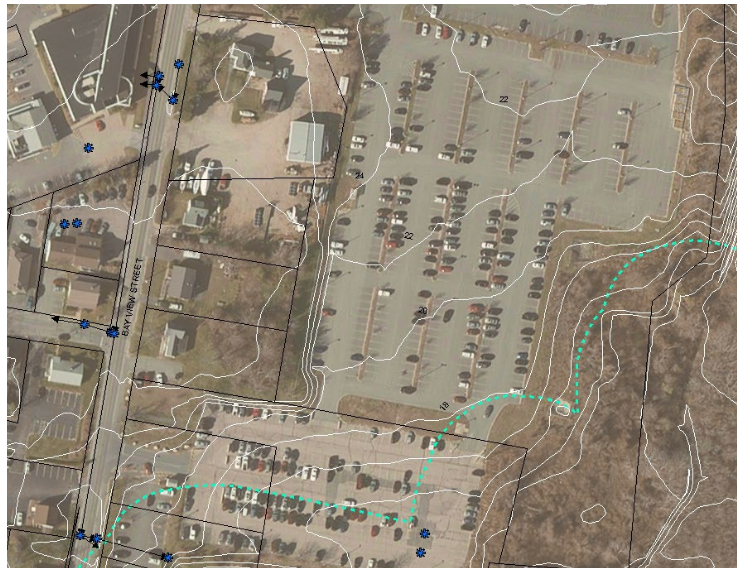
Physical Considerations	This site is located within a highly urban area and is bounded by the Hyannis Harbor. Although this results in potentially greater treatment it limits the size of the practice. The Anchor-In Hotel has a high percentage of impervious area and a minimal amount of available open space, limiting the options to small scale practices. There is an open, unused parcel as part of the public boat ramp but it has a small footprint, considerable land slope, and is contained by a bulkhead. The drainage area for this site is currently unknown but the field visit identified a ~24" stormwater outfall within the bulkhead.
Public Outreach and Education Considerations	The location of the boat ramp on the Hyannis Harbor, near both the Hyannis-Nantucket Ferry and the Hyannis Marina, results in high visibility and an opportunity to provide public exposure to green infrastructure practices.
Economic Considerations	Anchor Inn is privately owned; any proposed techniques would require support from the landowner which could be difficult at this site. The boat ramp is publicly owned and although property is highly valued in this area, the site identified is small and would not impact other uses.
Water Quality Considerations	Drainage flows south along the roadway towards the open area. If drainage is redirected away from the existing stormwater inlets and channels, nearly 0.75 acres could be collected, nearly all of which would be impervious area. This would result in an estimated Water Quality Volume of nearly 2,300 cubic feet.

Constructability Assessment	This site has a high potential for small scale LID techniques to treat stormwater runoff from the surrounding parcels. A bioretention area could be placed in the small open area of the public boat ramp to collect impervious area runoff from the roadway and adjacent hotel, as shown below.



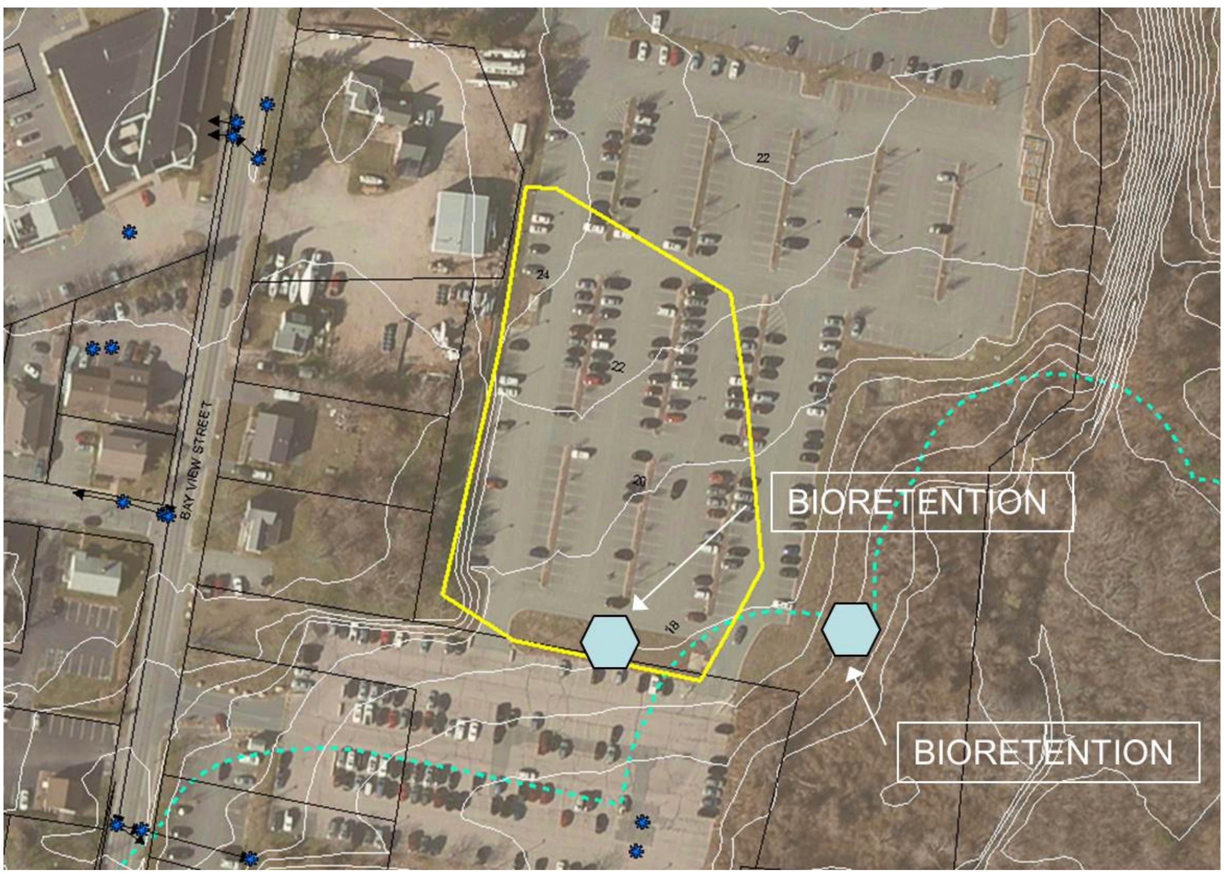
3.2. 4 Bay View Street – Barnstable

The Cape Cod Hospital employee parking area contains an extensive impervious area along with a large, mounded, unused median.



Physical Considerations	At approximately 6,500 SF, the grassy median area is large enough to support green infrastructure practices to address stormwater runoff from the parking area. A further examination of the site topography and stormwater infrastructure is needed to determine the potential treatment area available. As shown in the aerial photography, the southern parking area appears to be in need of repair; future rehabilitation of the parking area could help direct more runoff to the median. The Zone II boundary and cranberry bogs in the SE corner of the site would need to be delineated to ensure that any potential practices proposed in the open area south of the parking area would avoid these areas.
Public Outreach and Education Considerations	The Cape Cod Hospital is a single entity with a large amount of impervious area. Treating this impervious area with green infrastructure would serve as a model of community responsibility.
Economic Considerations	By utilizing unused areas of a parking lot, it is assumed that land costs would be negligible. Tying into an already existing stormwater network or re-grading/re-paving areas to expand the treatment area could lead to increased retrofit costs. These potential costs can be minimized by using in-situ design methods.
Water Quality Considerations	Drainage flows south over the parking lot, collected in stormwater inlets, and discharged to an infiltration basin near the cranberry bogs. If drainage is redirected away from the existing stormwater inlets and a curb cut is added to the median, nearly 1.9 acres of stormwater could be collected, mostly from impervious areas. This would result in an estimated Water Quality Volume of nearly 6,000 cubic feet.

Constructability Assessment	This site has a high potential for a small scale practice to treat stormwater runoff from the employee parking area, assuming runoff could be directed to the median area. A bioretention area would be ideal within the median, otherwise the existing infiltration basin could be possibly converted to a bioretention area to increase pollutant removal. Although there is significant impervious area treated, infiltration is already proposed so additional treatment would require an advanced practice. Constructed wetlands are also a possibility to provide additional treatment, although there is limited available space between the existing paved parking lot and the cranberry bogs. A concept plan has been previously proposed to reintroduce treated wastewater into this area to replenish the public water supply. It is suggested that any large scale projects outside of the parking lot boundaries should consider this proposed plan.

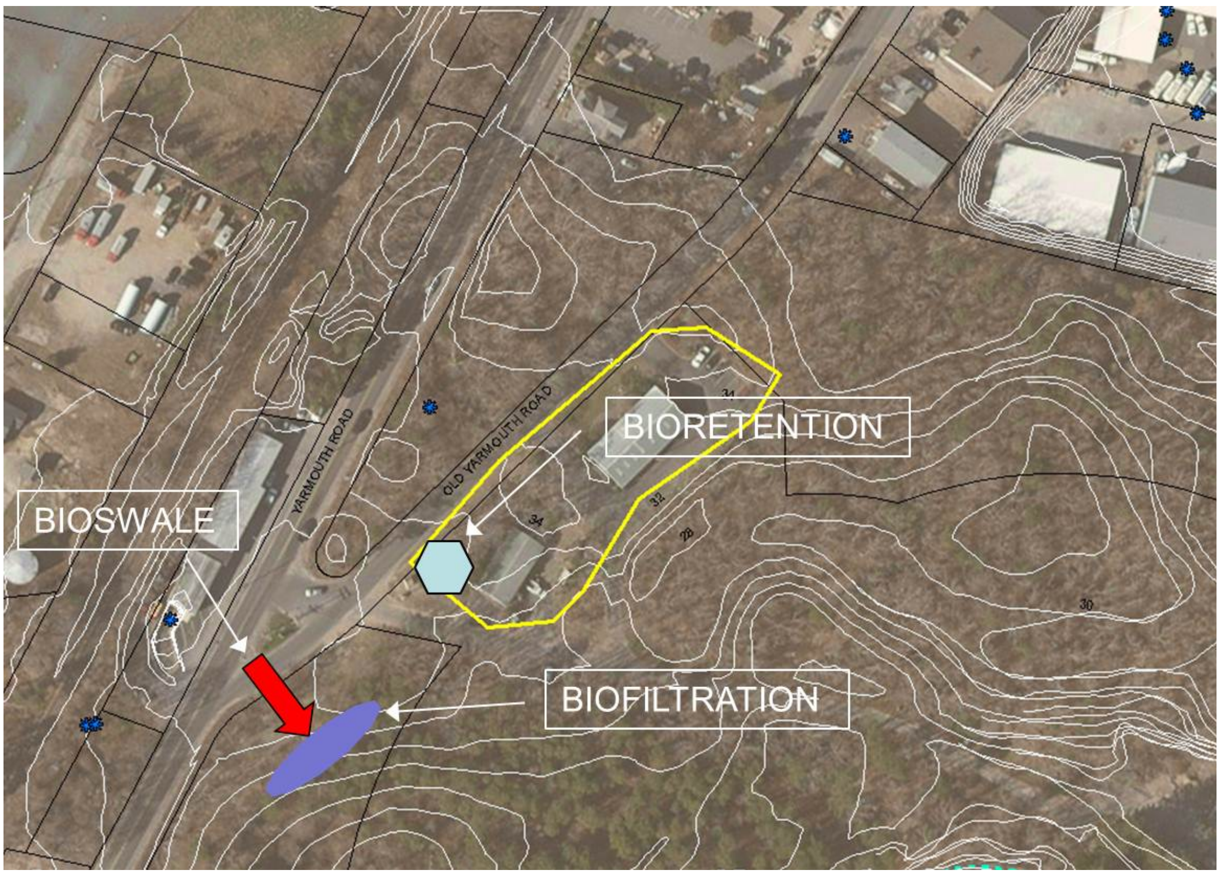


3.3. 0 and 47 Old Yarmouth Road – Barnstable

Both 0 and 47 Old Yarmouth Road are fairly open parcels located near a major arterial roadway and large impervious areas.

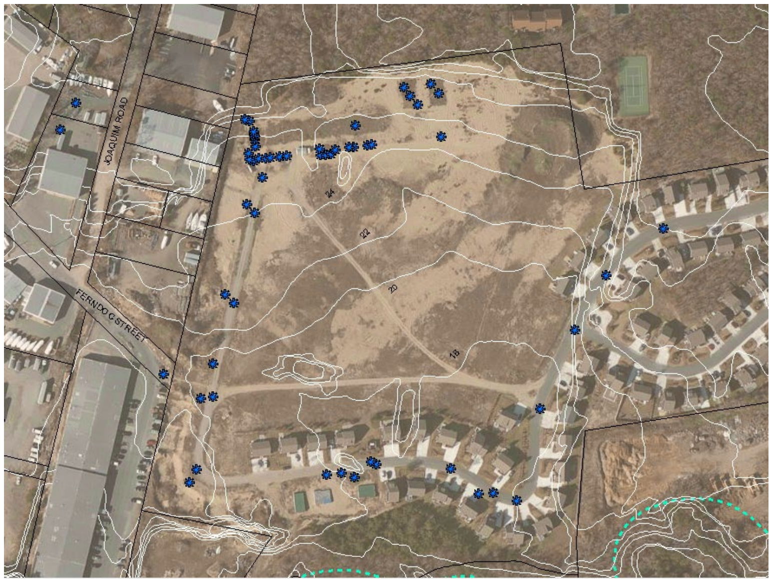
Physical Considerations	These sites are located within a drinking water supply area, limiting the suitability for infiltration. Significant open area is available surrounding the drinking water tower and a major arterial roadway and quasi-industrial area is located nearby, providing a potentially high source load. Further investigation of topography and any stormwater infrastructure is needed to determine if runoff could be directed to these sites. An investigation into groundwater flow would also help determine if green infrastructure could be implemented to intercept and treat groundwater before it reaches the drinking water wells.
Public Outreach and Education Considerations	These sites have very minimal public exposure.
Economic Considerations	There should be enough open area surrounding the drinking water tower to place a small practice without impacting land costs and to avoid major retrofit costs. Any larger facility would potential impact usable land. Significant costs could also be incurred to direct water to the practice.
Water Quality Considerations	Information by town officials indicated there is a flooding issue near the intersection of Yarmouth Road and Old Yarmouth Road. Originally, a bioretention area located near the buildings was anticipated to collect nearly 0.8 acres (resulting in 1,000 cubic feet of Water Quality Volume) but the site visit confirmed that collection in this area would be difficult.

Constructability Assessment	Although these sites have a large amount of open space and a potentially large treatment area, directing flows to the site could be difficult. Also, the location within a drinking water supply area significantly limits the type of suitable techniques. A better alternative than the bioretention area might be a bioswale/biofiltration located at the area that is prone to flooding. This would improve the safety and provide additional water quality treatment before the runoff enters the water supply area. Plans to redevelop the corridor could significantly reduce the flooding and water quality problems.



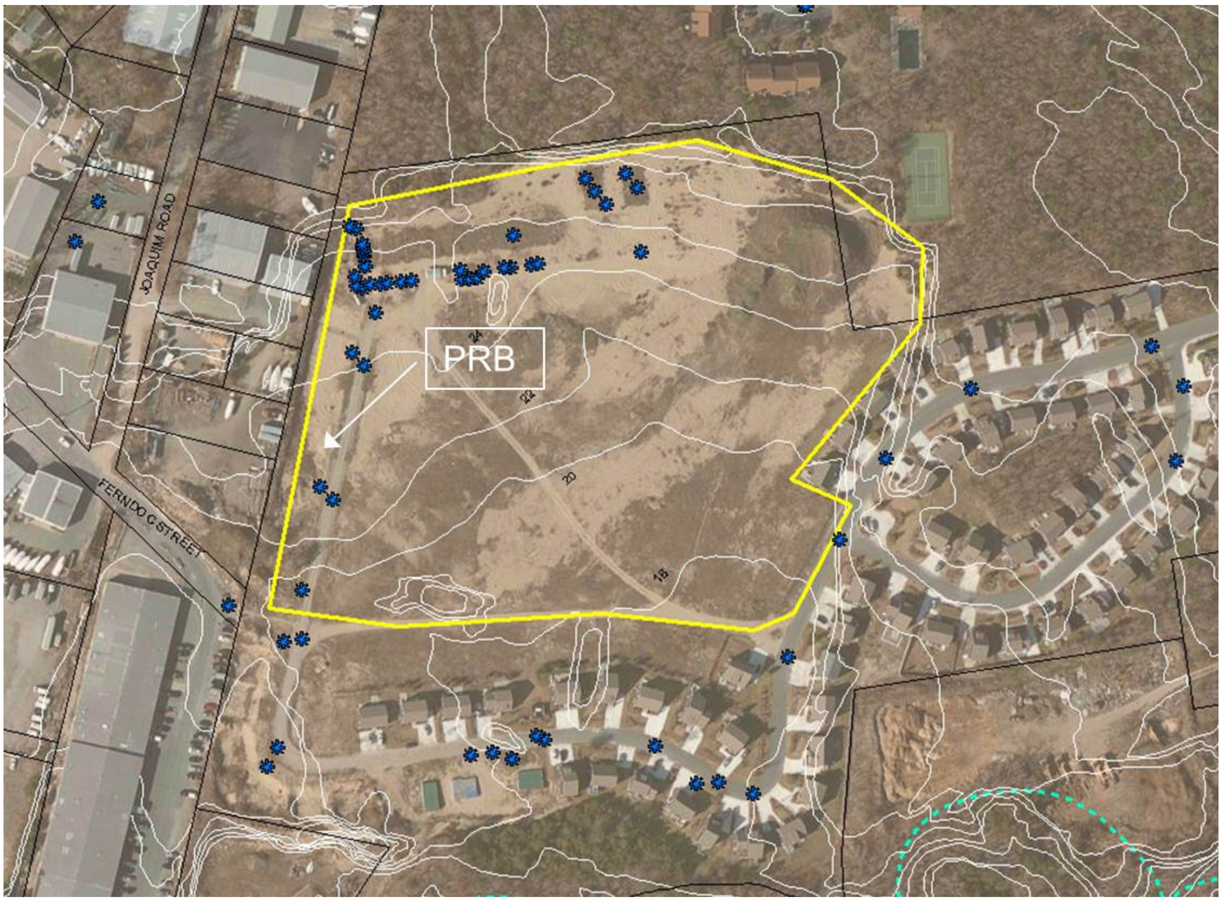
3.4. 122 Camp Street – Yarmouth

This site consists of condo units as part of an affordable housing project. The site is about 50% developed and includes a RUCK wastewater system with high operation and maintenance costs.



Physical Considerations	Since the majority of the site is not yet developed, there is significant opportunity to integrate green infrastructure and LID into the future development plans. An investigation of any stormwater infrastructure would be necessary to properly locate any treatment practices. This site is also adjacent to the 47 Old Yarmouth Road site, which contains several drinking water wells.
Public Outreach and Education Considerations	With more than 100 total housing units planned, this site represents a high exposure area within an environmental justice community.
Economic Considerations	Since this site is privately owned and yet to be fully developed, any potential practice will have to be sited with input from the developer. Although it is outside of the scope of this project, working with the developer to help address the high operation and maintenance costs associated with the existing RUCK system might provide a financial incentive to implement alternative treatment practices.
Water Quality Considerations	This site is fairly flat and there is no stormwater collection system. All impervious areas are already disconnected and infiltrate directly. Collecting stormwater doesn't seem necessary or possible, limiting the water quality analysis. Any additional water quality benefits would come from interaction with groundwater sources.

Constructability Assessment	Implementation in this area is dependent on buy-in from the developer. Currently, collection of stormwater doesn't seem feasible or necessary. But a discussion with residents during a site visit indicated that the existing RUCK system is both highly functioning and expensive. It might be possible to add a permeable reactive barrier (PRB) to help reduce the monitoring requirements of the RUCK system (and the operational costs).

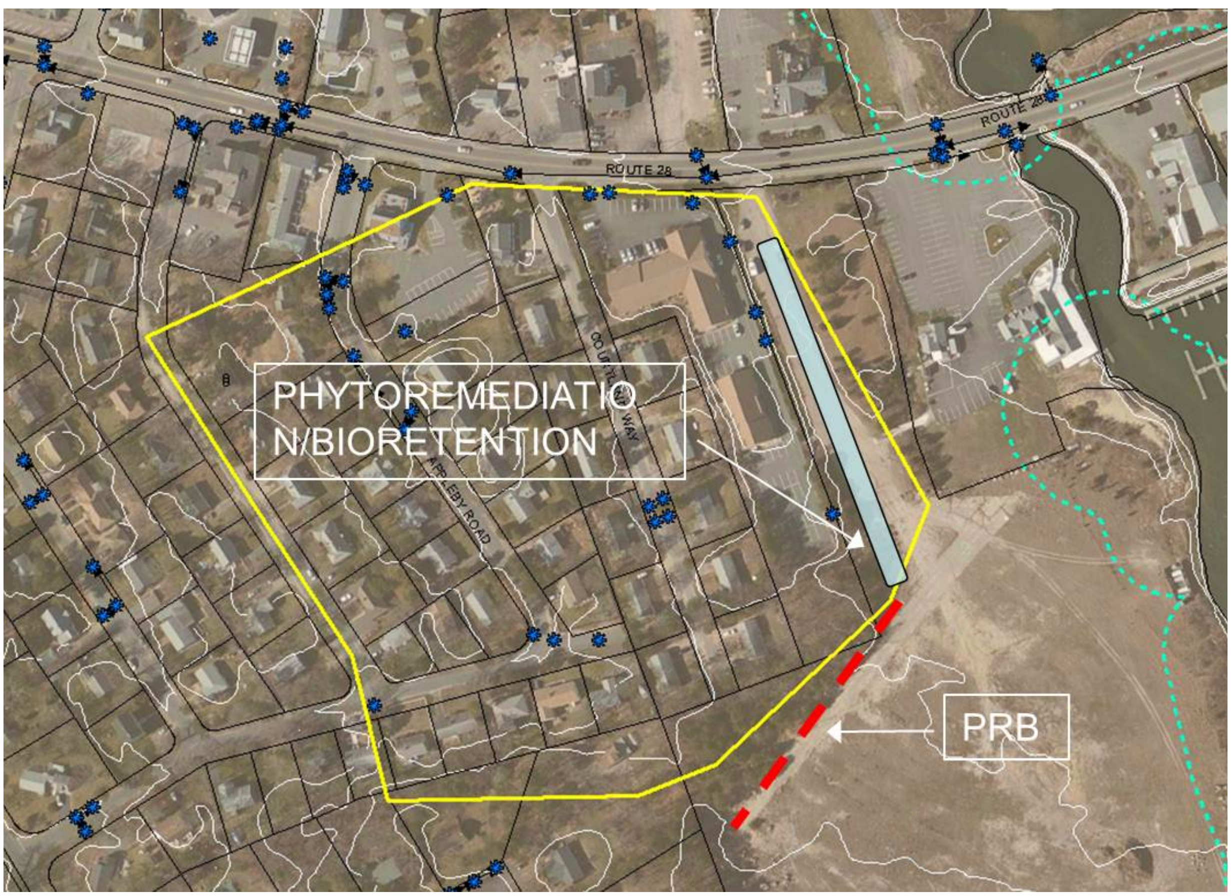


3.5. 669 Route 28 (Drive-In) – Yarmouth

This site is a former drive-in movie theater where historic wetlands were filled with poor-quality soil. The site is currently unused but redevelopment plans have been discussed.

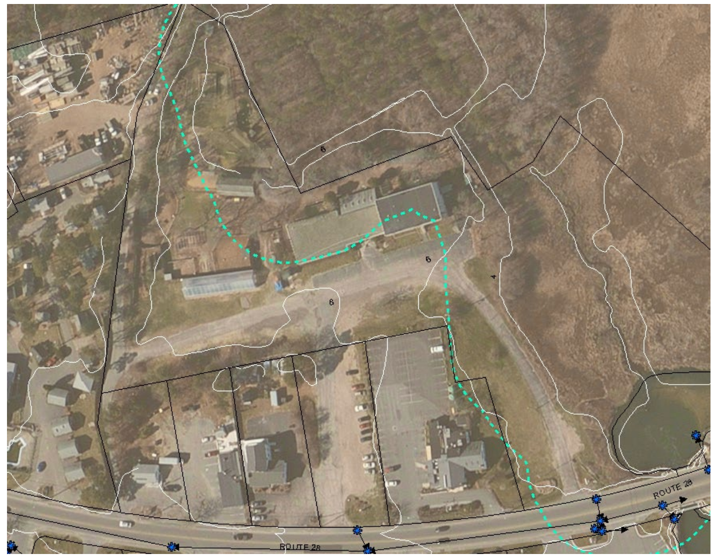
Physical Considerations	The former parking area represents ample open space to implement a green infrastructure or LID although this area is partially located within a hazardous floodplain. A potentially high groundwater table would limit the implementation of infiltration-based stormwater practices but is highly suitable for practices that intercept groundwater, such as constructed wetlands or permeable reactive barriers. The fact that historic wetlands were once present on the site makes this type of technique more desirable. The location along a channel running from Swan Pond to the coast makes this area a high priority for treatment.
Public Outreach and Education Considerations	The existing drive-in is a high exposure site that is currently being underutilized. Including innovative green infrastructure or LID into any potential redevelopment of the site would greatly expand the public perception of these types of practices.
Economic Considerations	Construction on this site could involve excavation and off-site removal due to the existing fill material but construction costs should remain fairly low due to the easy access and already cleared site. There are plans to convert this site into a future marina and other public uses, limiting the ability to place a large scale practice such as a constructed wetland. Implementing a LID facility (like a permeable reactive barrier with a small footprint) that would not impact future development plans would be important to reduce opportunity costs.

Water Quality Considerations	Although the site is fairly flat, initial estimates of the drainage area indicate nearly 14 acres of treatment is available (depending on the presence of a storm drain network). Even though only 5 acres of this is impervious area, it still results in a potential Water Quality Volume of 18,000 cu. ft. The opportunity is high to treat a considerable amount of runoff.
Constructability Assessment	This site has high potential to install for a practice that both treats stormwater runoff, as well as intercepting and treating groundwater flows. If the necessary space is not available as part of the redevelopment, a smaller LID facility to treat stormwater only could be implemented. A possible opportunity might be a phytoremediation/bioretention facility with an adjacent permeable reactive barrier to increase nitrogen removal.



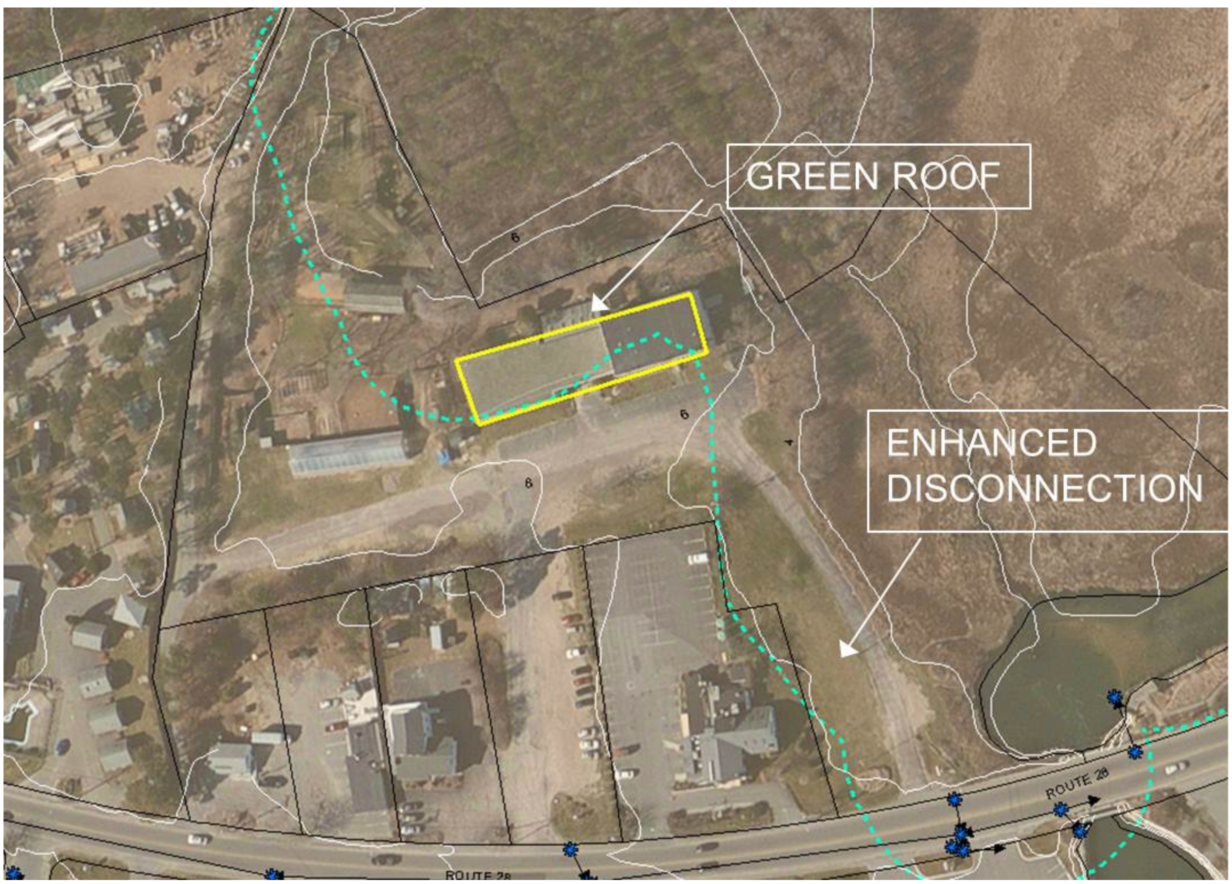
3.6. 674 Route 28 (Zooquarium) – Yarmouth

This privately owned site has been a popular marine tourist attraction for over 40 years. Water quality research is currently being performed at an on-site greenhouse.



Physical Considerations	The buildings, driveway, and parking area represent a significant amount of impervious area that can be treated. Open space is available but potential placement is limited by impervious and wetland areas on site. There is evidence of a high groundwater table on the site, limiting the use of infiltration practices. In-situ design techniques for LID can help address high groundwater concerns and the large amount of open space available might be more suitable for vegetative buffers. No stormwater infrastructure appears to be present although a further investigation into the topography and groundwater table will be necessary to determine possible locations.
Public Outreach and Education Considerations	Green Infrastructure and LID associated with popular tourist attractions have high visibility within the community to both residents and visitors.
Economic Considerations	This site is privately owned so any proposed technique would need approval from the property owner. Since a research greenhouse is located on site, the property owner seems committed to environmental causes and could be a strong partner. Access to the site and possible facility locations are fairly open, reducing the cost to retrofit the site. Long term maintenance responsibility should be addressed; green infrastructure practices with low maintenance costs might provide additional motivation to the property owner.

Water Quality Considerations	This site is also fairly flat and is partially located with the buffer area of wetlands associated with the river. There is minimal space to install on-ground techniques and minimal drainage area that can be easily collected and treated. There is approximately 0.25 acres of roof area which can be easily collected and treated, resulting in a Water Quality Volume of nearly 1,000 cu. ft.
Constructability Assessment	Assuming the property owner buys into the project, this site represents a good opportunity for green infrastructure or LID. The high groundwater table and the presence of wetlands significantly limits both the type and location of practices but does not exclude the implementation of a treatment practices on this site. One potential opportunity that would not affect any additional space would be the design of a green roof on top of the existing zooquarium building.



3.7. 165 Bearses Way – Barnstable

This elementary school has significant open space and impervious area, along with high public exposure.

Physical Considerations	This is the only school located within the two targeted watersheds in these communities. Considerable impervious cover is present on the school site and the area is surrounded by medium density residential land, resulting in significant nitrogen sources within the treatment area. Open areas are present on the site but large green infrastructure practices could potentially impact the usability of the site. Undisturbed forested area in the NW portion of the site and potential wetlands in the southern portion should be avoided. Several practices could be implemented throughout the site without greatly impacting the existing use. A recently redeveloped community center south of the school has already implemented bioretention and permeable pavement, and additional practices on the school site would be a natural extension.
Public Outreach and Education Considerations	Schools have very high visibility and represent excellent opportunities to promote green infrastructure throughout the community. In addition, on-site practices can be integrated into environmental education curriculum for the students.
Economic Considerations	The school is publicly-owned, reducing any land costs associated with the site. Economic considerations should include any potential redevelopment or expansion planned for the site. Larger scale practices such as constructed wetlands could incur significant construction costs due to excavation and off-site removal.

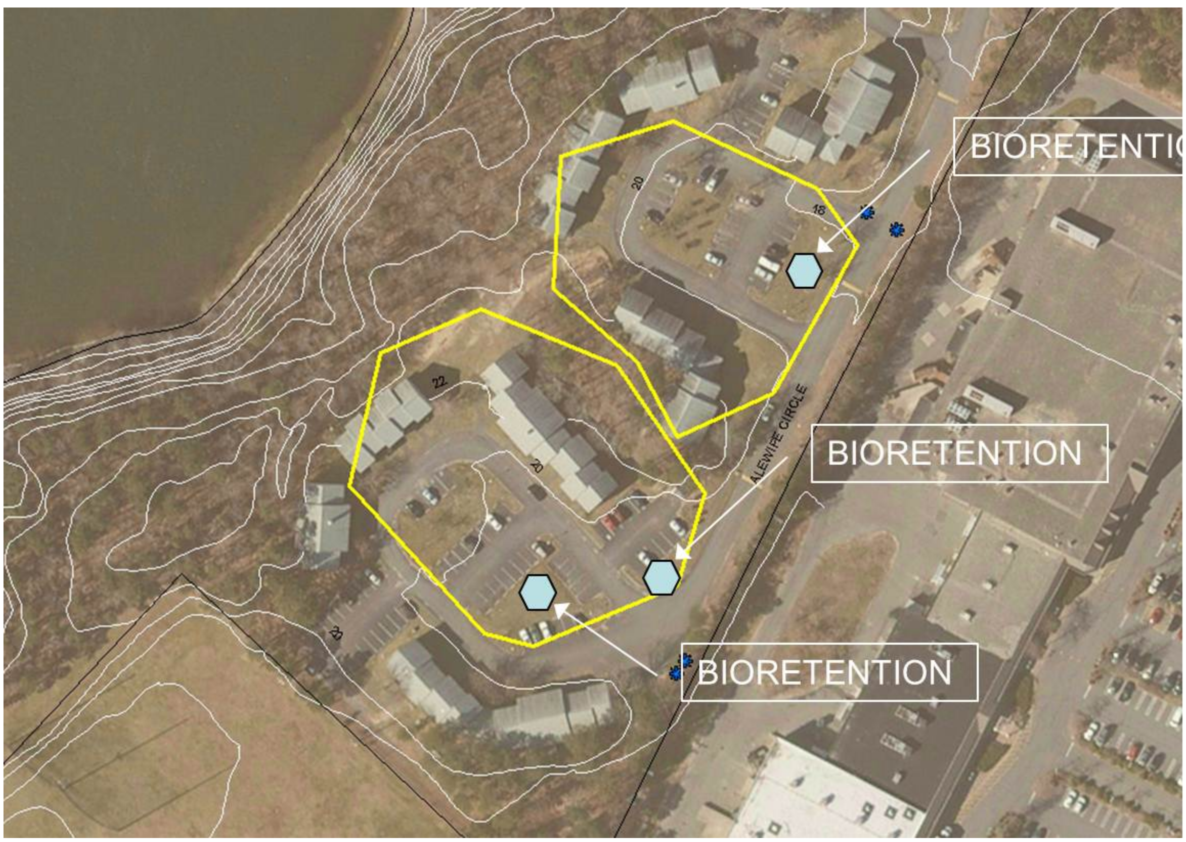
Water Quality Considerations	The total treatment area available is dependent upon the location of the green infrastructure practice on the site. A bioretention facility located where runoff enters the recreational fields would collect much of the school and surrounding paved areas, resulting in a treatment area of more than 1.5 acres, resulting in a Water Quality Volume of 3,700 cu. ft. A constructed wetland in the southern portion of the site near the pond could collect a treatment area of nearly 10 acres, resulting in a Water Quality Volume of 13,400 cu. ft.
Constructability Assessment	This site is an excellent opportunity for bioretention or permeable pavement. As determined during a site visit, runoff from the school and surrounding paved areas is concentrated into a single asphalt-lined drainage swale and directed into the recreational fields, which act like a large infiltration basin. This area would be a great opportunity for a green infrastructure practice to provide additional water quality treatment. Larger practices such as constructed wetlands will require a greater amount of open space and will incur significant construction costs.

3.8. 65 Long Pond Drive – Yarmouth

This site consists of high-density residential bordered by open water, commercial area, and a driving range.

Physical Considerations	High density residential area is separated from Swan Pond by a forested buffer. Impervious areas such as roads and sidewalks within the residential area seem to discharge to grassy median areas, but drainage of the large commercial area to the SE is unknown. The high quality of the forested buffer and the limited amount of open space limits the suitability for large scale practices such as constructed wetlands. Smaller scale practices can help reduce nitrogen entering Swan Pond but a further investigation into stormwater infrastructure and drainage is needed. A large open area is located SW of the residential area but any green infrastructure or LID in this area could affect the existing use of the driving range. Still, if stormwater could be directed to this open area from the surrounding impervious areas, a significant amount of treatment is possible. A publicly owned parcel is located north of the residential area but this parcel is a well-established natural area and retrofits should be avoided.
Public Outreach and Education Considerations	Potential green infrastructure practices would be located away from community centers and major roadways and have limited visibility, reducing the public exposure.
Economic Considerations	The residential area and the driving range are both privately owned and any implemented green infrastructure practices could greatly impact opportunity costs, driving up the total cost of the project.

Water Quality Considerations	The high density residential, paved parking areas, and open medians make this site ideal for retrofits. A site visit, though, revealed that there is no storm drain network and that runoff is currently entering infiltration areas. Although nearly 2.5 acres of treatment area is available, resulting in a Water Quality Volume of more than 4,000 cu. ft., collecting this runoff and providing additional treatment would be difficult.
Constructability Assessment	The limited amount of open space prevents the implementation of large scale practices and encourages small-scale practices such as bioretention. Space constraints and private ownership make siting potential techniques difficult and potentially costly. In addition, runoff is already distributed and entering infiltration areas, preventing significant gains from additional water quality treatment.



3.9. Selection of Sites for Concept Plan Development

On November 15-16, 2012, the project team presented the results of the screening process and site assessments to a collection of local stakeholders from Yarmouth and Barnstable. The group assessed the sites collectively and selected two sites for advancement to conceptual designs – the 165 Bearses Way (School) site in Barnstable and the 669 Route 28 (Drive-In) site in Yarmouth. These two sites were selected after discussing the assessment metrics, site visits to the two locations, a discussion of the benefits and constraints present at each site, and the perceived likelihood of the projects to be implemented on the two sites. At these two sites, an enhanced bioretention facility is proposed at the School site while a bioretention/phytotechnology area is proposed at the Drive-In site. The concept plans developed for these two sites are included in the Appendix.

4. Model Process and Results

As part of this study, hydrologic modeling was performed to quantify the environmental benefits of the proposed concept designs. Hydrologic and water quality (i.e. TN) benefits were evaluated for the green infrastructure opportunities at each of the two sites using EPA's System for Urban Stormwater Analysis and Integration (SUSTAIN) model. In addition, a simplified cost-effective analysis was conducted at both sites to provide a more comprehensive basis for stormwater management decision-making. The SUSTAIN hydrologic simulation provided results for stormwater flows only but a discussion of additional water quality benefits from groundwater interaction is also included.

4.1. Overview of the Modeling Process

SUSTAIN incorporates water hydrologic and optimization algorithms to evaluate the impacts of BMPs on water quality and quantity (Tetra Tech 2009b). An overview of the modeling setup is shown in Figure 20. The SUSTAIN model is used to simulate the cumulative hydrologic and water quality benefits from the BMPs implemented at the two project sites by performing a water balance at each BMP site.

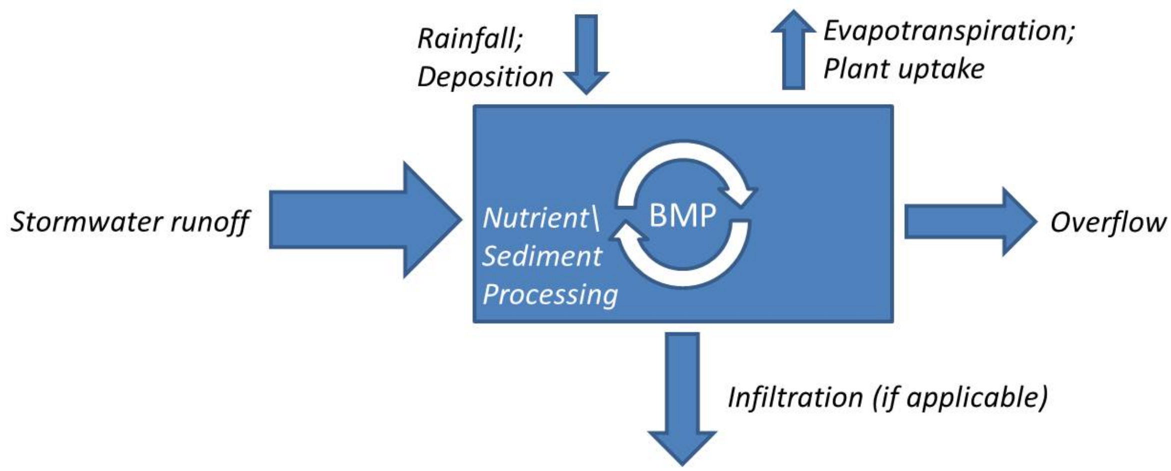


Figure 20. Overview of basic modeling analysis processes (Tetra Tech 2009b)

Long-term hydrologic and water quality time series are needed in the SUSTAIN model for evaluating cumulative BMP performances. The development of hydrologic/water quality performance curves is an intensive process and significant effort was saved on this project by using performance curves developed for a separate project for the Boston area. Continuous runoff time series based on the rainfall data from Boston Logan International Airport were obtained to run the simulations (Tetra Tech 2009a). The hourly time series cover the period of 1992/01/01 to 2002/12/31. Although these curves were not developed using precipitation data from Cape Cod, the general hydrologic regime is assumed to be consistent between the two sites over the performance period.

4.2. Evaluation of the 165 Bearses Way (School) Site

An innovative practice that has the combined features of both gravel wetland and bioretention is proposed at the School site. The innovative practice, referred to as enhanced bioretention, has been researched by the University of New Hampshire Stormwater Center (UNHSC). BMP monitoring data show that it has relatively high efficiencies for removing TN. CCC, in developing the 20% concept plans for the School site, proposed a facility that includes two enhanced bioretention cells and one conventional bioretention cell. The two enhanced bioretention cells are designed to capture all runoff from the site and overflow into the conventional bioretention cell. Since the exact configuration of the site is not yet finalized, the SUSTAIN model will evaluate the pollutant reduction potential of the enhanced bioretention cells as a conservative approach. The additional bioretention cell should provide additional water quality treatment beyond what is included in this modeling memo.

4.2.1. Site Conditions

The School site is located at a local school, with most of the stormwater runoff from the school site being routed to the BMP. Major land uses at the School site include buildings, transportation (road, parking lot, driveway, etc.), playground, and open space. A summary of the land uses is shown in Table 3. The School site has a total drainage area of 3.87 acres and the imperviousness percentage is 53%. The enhanced bioretention was originally sized to treat one inch of runoff from the impervious surfaces but the size of the facility was decreased by CCC during the iterative design process. The proposed 20% concept design includes two enhanced bioretention cells and one conventional bioretention cell, all with approximately equal footprints. The enhanced bioretention cells were reduced to focus on costs; with the current sizing these two cells treat approximately 0.55 inches of runoff from the treatment area. More discussion on the water quality treatment is included in Section 4.2.4 Model Results.

Table 3. Major land uses at the School Site

Land use type	Area (acre)
Building	0.49
Playground	0.01
Transport	1.57
Open space	1.80
Total	**3.87**

The site plan for implementing the enhanced bioretention at the School site is shown in Figure 21. The bioretention cell receives stormwater runoff from the nearby school buildings and parking lots and the outflow is routed through a conventional bioretention cell and onto an open recreational field where it is infiltrated.

Figure 21. Site Plan for bioretention implementation at the School site (Cape Cod Commission/Tetra Tech)

4.2.2. The Enhanced Bioretention for the School Site

A cross-section view of the enhanced bioretention proposed for the School site is shown in Figure 22. As shown in the figure, the profile of the enhanced bioretention includes an average of four inches of ponding depth, two feet of bioretention soil mix, six inches of gravel, and two and half feet of crushed stone layer. The design enhancement concept was introduced by UNHSC and this design was built at a Municipal Lot along Pettee Brook Lane in the City of Durham, NH. Monitoring data from the enhanced bioretention indicate that pollutant removal, TN in particular, is relatively high (i.e. 86% removal of TN when treating one inch of runoff from commercial land use) (Tetra Tech 2012). Stormwater runoff enters the enhanced bioretention through surface flow and filters through the bioretention soil mix, flows above the geomembrane when present, and enters into a permanent pool of water held within the crushed stone layer. The anaerobic environment (similar to a gravel wetland) is the key element for effective TN removal. The enhanced bioretention is lined in highly porous soils to maintain anaerobic conditions within the substrate.

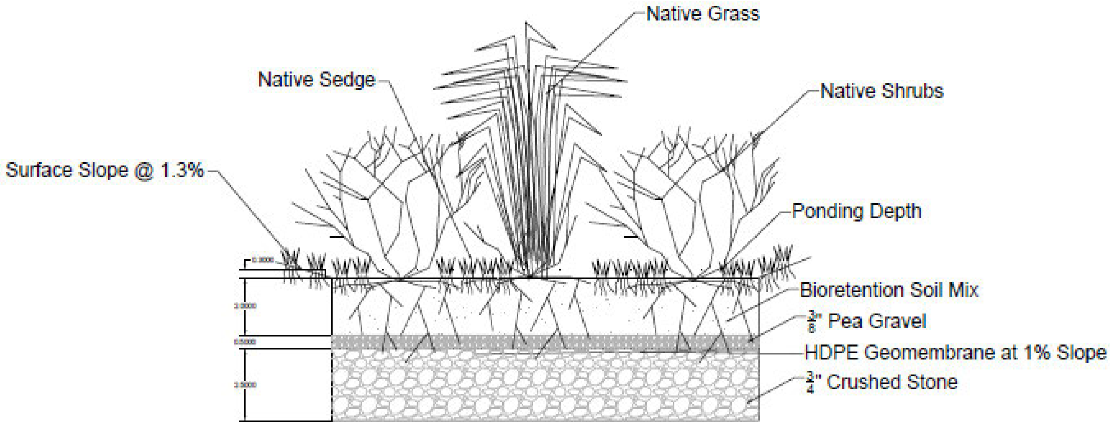


Figure 22. Cross-sectional view of the enhanced bioretention to be implemented at the School site (Cape Cod Commission/Tetra Tech)

A list of design parameters for the enhanced bioretention is summarized in Table 4 below.

Table 4. List of enhanced bioretention design parameters used in the SUSTAIN representation

Components	Parameters	Value
Ponding area	Depth (ft)	0.33
Planting soil mix	Depth (ft)	2
	Porosity	0.24
	Hydraulic conductivity (in/hr)	2.5
Stone reservoir	Depth (ft)	2.5
	Porosity	0.42
	Hydraulic conductivity (in/hr)	5000
Orifice	Diameter (in)	12
	Inlet offset from soil surface (ft)	2.5
Overflow weir	Length (ft)	3.14

The enhanced bioretention has been previously calibrated using observed data from the UNHSC (Tetra Tech 2012). The calibrated SUSTAIN model is used for carrying out the long-term simulations of hydrologic and water quality benefits at the site.

4.2.3. SUSTAIN Model Setup

The School Site is represented in the SUSTAIN model in the ArcGIS environment. The model setup is shown in Figure 23. Runoff from the watershed is routed to the enhanced bioretention and the assessment point is located downstream of the enhanced bioretention.

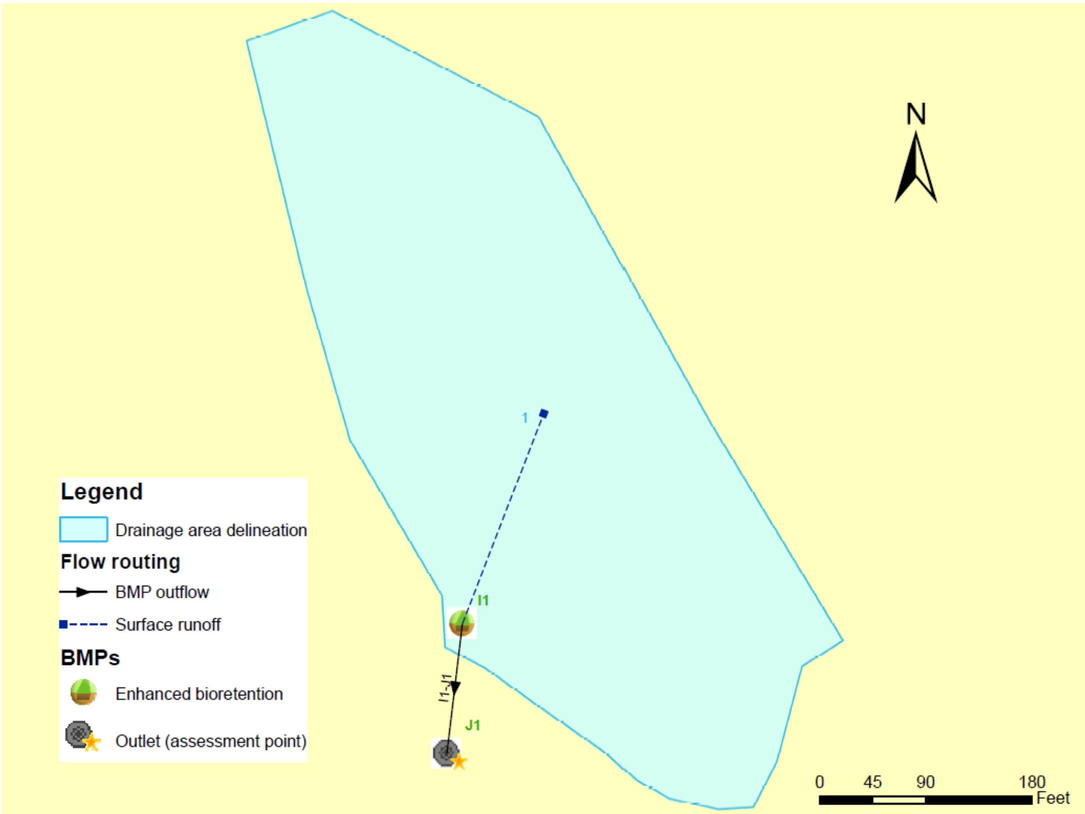


Figure 23. SUSTAIN model setup for the School site

A schematic drawing of the proposed representation scheme in SUSTAIN is shown in Figure 24 below. As shown, the representation consists of a ponding area on the top, a soil mix layer, a crush stone layer, an overflow weir (Weir #1) at the maximum depth of ponding area, and an overflow orifice (Orifice #1) for discharging water exceeding the maximum permanent pool depth. When stormwater enters into the BMP, the water will first infiltrate into the soil water mix, and the percolated water enters the crush stone layer to form a permanent subsurface pool of water. After the permanent pool of water exceeds a certain depth, overflow is discharged through Orifice #1. During this process, whenever the ponding depth is exceeded, overflow occurs through Weir #1. Flows from Weir #1 and Orifice #1 are combined to form the overflow routed to downstream. The proposed representation scheme captures major hydrological processes occurring in the enhanced bioretention.

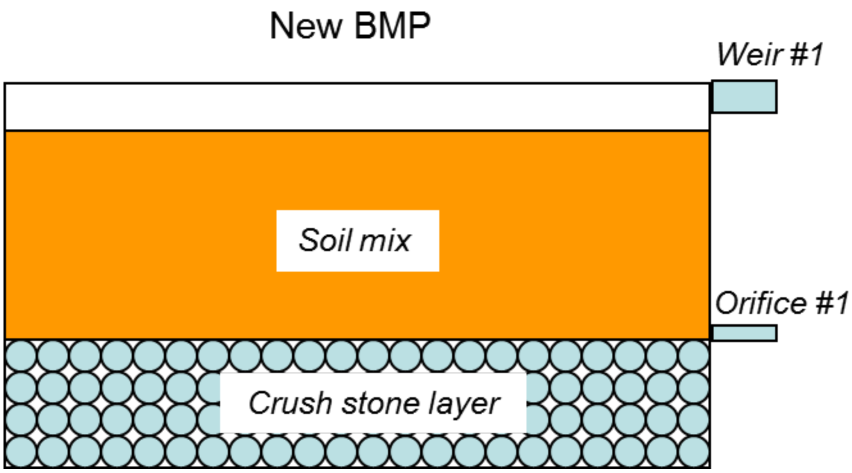


Figure 24. Schematic for representing the enhanced bioretention into SUSTAIN (not to scale)

SUSTAIN model parameters representing hydrological and water quality processes were calibrated based on monitoring data collected by UNHSC (Tetra Tech 2012) and the same model parameters were used in the analysis assuming that the proposed enhanced bioretention will have similar treatment capability to the one installed by UNHSC. The SUSTAIN model setup for the School site is evaluated through continuous simulation for the period of 1992/01/01 to 2002/12/31. The cumulative total runoff volume reduction, TN removal, and the water balance in the enhanced bioretention are summarized at the end of the simulation process.

4.2.4. Model Results

The SUSTAIN analysis for the School site is summarized in Table 5 below. As shown in the table, the overall runoff volume reduction from the enhanced bioretention is 4.1%, and the overall TN load removal from the site is 65%. Since the configuration of the enhanced bioretention requires a liner to create anaerobic conditions, no infiltration is possible and the only reduction in stormwater volume occurs through evapotranspiration. Although the enhanced bioretention system can treat the equivalent of the 0.55 inch runoff event within the two enhanced bioretention cells, most of this water flows through the system resulting in a small reduction in total runoff volume. Although the reduction in runoff volume is small, the enhanced bioretention system will adjust the hydrograph of storm events and impact the downstream hydrology and, as Table 5 shows, significantly reduce the total nitrogen load that is exported over the 10 year simulation period. These results are conservative, as it is expected that the additional bioretention cell will provide additional water quality treatment.

Table 5. Summary of SUSTAIN simulation results for the period of 1992/01/01 to 2002/12/31 at the School site

	Runoff volume (ft3)	Total Nitrogen (lbs)
Total inflow	5,953,767	416.6
Total outflow	5,709,634	144.52
Percentage of reduction	4.1%	65%

The overall water balance of outflow at the enhanced bioretention throughout the simulation period is presented in Figure 25. As shown, the only loss from the system is through the evapotranspiration (ET) process. No percolation occurs due to the lined bottom of the BMP.

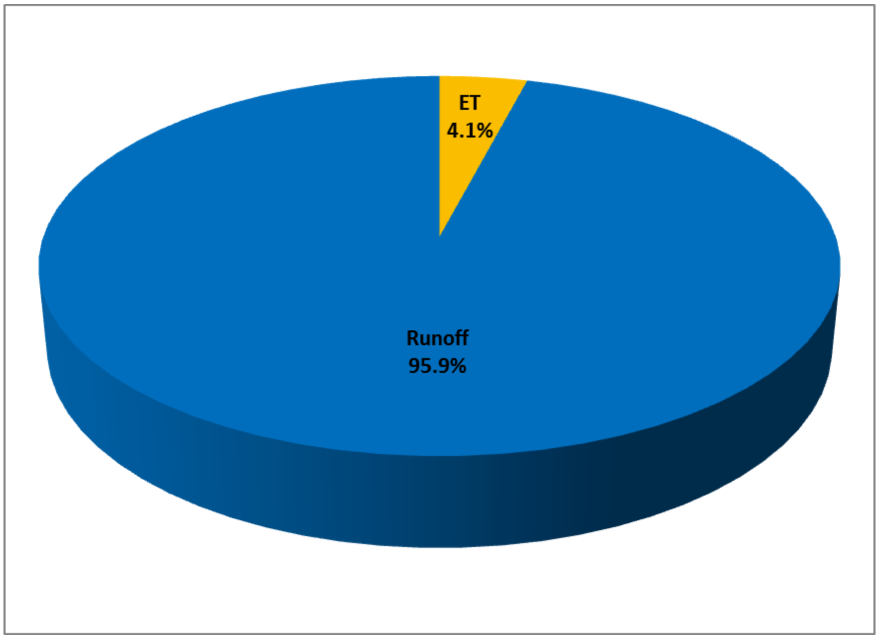


Figure 25. Overall water balance in the enhanced bioretention outflow at the School site

4.2.5. Simplified Cost-Effectiveness Analysis

While continuous simulations of the enhanced bioretention provides a solid assessment of cumulative hydrologic and water quality performances for the BMP, it is always in the best interest of the decision-makers to have a full understanding of the cost-effectiveness of a particular technique. To provide a comprehensive picture about the hydrologic and water quality performances of the enhanced bioretention, the SUSTAIN model is commissioned to simulate the BMP for sizes that treat impervious runoff depths for a range of runoff depths rather than just the one inch. This analysis results in simplified performance curves for the BMP.

The analysis results are presented in Figure 26 below. As the BMP size increases, the total runoff volume reduction percentage increases almost linearly (albeit at a relatively small rate). The TN removal percentages, meanwhile, increase dramatically when the BMP is sized to treat 0.1 to 0.6 inches of impervious runoff, and then tends to level off. This simplified analysis can greatly improve the decision-making for appropriately sizing BMPs, especially when either the site conditions or the budget become limiting factors and assuming there are no regulatory sizing requirements.

The trend of diminishing return in TN removal as the BMP sizes increase is more obvious when the BMP costs are also considered. In the absence of locally available BMP cost, it was assumed that the unit construction cost of enhanced bioretention volume is $5.00 per cubic feet. This information does not have any relation to actual construction costs associated with BMPs in the Cape Cod region, and should be limited to use for evaluating the relative differences of BMP cost for planning purposes only. The corresponding costs and the rates of TN removal percentage increase as the BMP volume increases are summarized in Table 6.

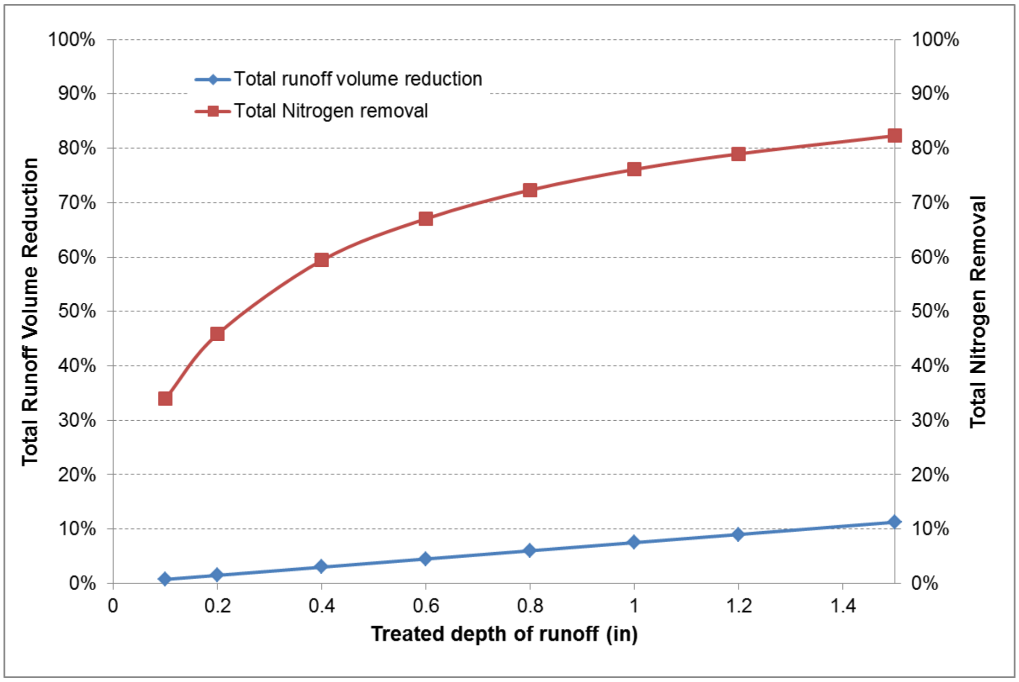


Figure 26. Simplified cost-effective analysis for sizing the enhanced bioretention at the School site

Table 6. Total cost for the enhanced bioretention at varying treatment depths

Treated depth of runoff	Total BMP volume (ft3)	Total cost ($)	TN removal	Increase in total cost ($)	Increase in TN removal
0.1 in	751	3,755	34%	-	-
0.2 in	1,502	7,510	46%	3,755	12%
0.4 in	3,005	15,025	59%	7,515	13%
0.6 in	4,508	22,540	67%	7,515	8%
0.8 in	6,011	30,055	72%	7,515	5%
1.0 in	7,514	37,570	76%	7,515	4%
1.2 in	9,017	45,085	79%	7,515	3%
1.5 in	11,271	56,355	82%	11,270	3%

As shown in Table 6, the greatest gains in TN removal per unit cost occur at lower runoff depths due to the effectiveness of treating the first flush of contaminants. This information will allow decision-makers to efficiently allocate the budget when faced with competing projects and ensure that the money spent will yield the most cost-effective results. In the case of the school site, doubling the size of the enhanced bioretention would only provide an additional 13% of TN removal at approximately double the cost. This validates the reduced-size design at the School site.

4.3. Evaluation of the 669 Route 28 (Drive-In) Site

A unique pilot project is proposed for the Drive-In site that combines traditional LID approaches to collect and treat stormwater runoff with innovative green infrastructure practices designed to provide additional treatment to the shallow groundwater located on site. The 20% concept design developed by CCC integrates the green infrastructure project into the town's proposed marina redevelopment plan. The design includes a bioretention area and phytotechnology plantings down-gradient of a proposed leach field associated with the new marina. The bioretention area is expected to provide TN removal benefits to stormwater inflows, with the bioretention TN removal efficiencies based on previous studies conducted at Anacostia River, Maryland (Tetra Tech 2008). The additional phytotechnology component will treat wastewater effluent from the leaching area reducing nitrogen within the shallow groundwater before it enters Parkers River. The phytotechnology component cannot be modeled as part of this analysis, as SUSTAIN only has the capability to model stormwater flows, so this analysis will only address the bioretention. Similar to the School site, the modeling results for the Drive-In site will be conservative with additional pollutant removal available from the complete green infrastructure project.

4.3.1. Site Conditions

The Drive-In site receives runoff from nearby residential and commercial areas. Major land uses in the site include commercial, residential, transport, and open space. A summary of the land use areas in the Drive-In site is shown in Table 7 below. As shown, the total drainage area is about 2.96 acres, and the aggregated imperviousness percentage is about 30%. The conventional BMP is sized to treat one inch of runoff from the impervious surfaces. The site plan for the Drive-In site is shown in Figure 27 below, with runoff from nearby residential, commercial, and transportation areas directed to the bioretention area.

Table 7. Major land uses in the Drive-In site

Land use type	Area (acre)
Commercial	0.17
Residential	0.09
Transport	0.64
Open space	2.06
Total	**2.96**

Figure 27. Site Plan for BMP implementation at the Drive-In site (Cape Cod Commission/Tetra Tech)

4.3.2. Bioretention/Phytotechnology for the Drive-In Site

An innovative bioretention area/phytotechnology treatment area is proposed at the Drive-In site. To the maximum extent practicable with a new and innovative approach, the bioretention area design will follow that specified in the *Massachusetts Stormwater Handbook* (MassDEP 2008). However, as this approach contains an integrated phytotechnology intercepting groundwater, a characteristic strictly avoided with stormwater controls, the project design will not be limited by current stormwater standards. A cross-sectional view for the phyto/bioretention area is shown in Figure 28 below.

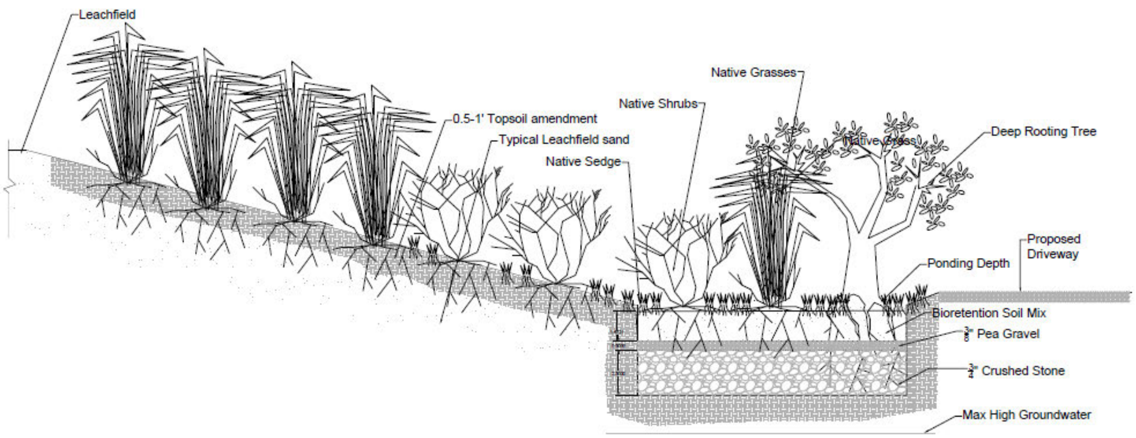


Figure 28. Cross-sectional view of the enhanced bioretention and phytotechnology area to be implemented at the Drive-In site (Cape Cod Commission/Tetra Tech)

Following the MassDEP design specifications, the design parameters for the bioretention are summarized in Table 8 below. As shown in the table, the bioretention has an effective depth of about 1.3 feet. Considering the fact that the Drive-In site has a relatively high groundwater table, the gravel layer is likely to be submerged in water when groundwater rises to seasonal high levels. Thus, the effective depth for the bioretention area is conservatively estimated as 1 foot.

Table 8. Bioretention design parameters following MassDEP design specifications

Components	Parameters	Value
Ponding area	Depth (in)	6
Planting soil mix	Depth (in)	21
	Porosity	0.3
	Hydraulic conductivity (in/hr)	2.5
Gravel layer	Depth (in)	8
	Porosity	0.4
	Hydraulic conductivity (in/hr)	14

4.3.3. SUSTAIN Model Setup

The Drive-In Site is represented in the SUSTAIN model in the ArcGIS environment. The model setup is shown in Figure 29. Runoff from contributing areas is routed to the bioretention unit and the assessment point is located downstream of the bioretention.

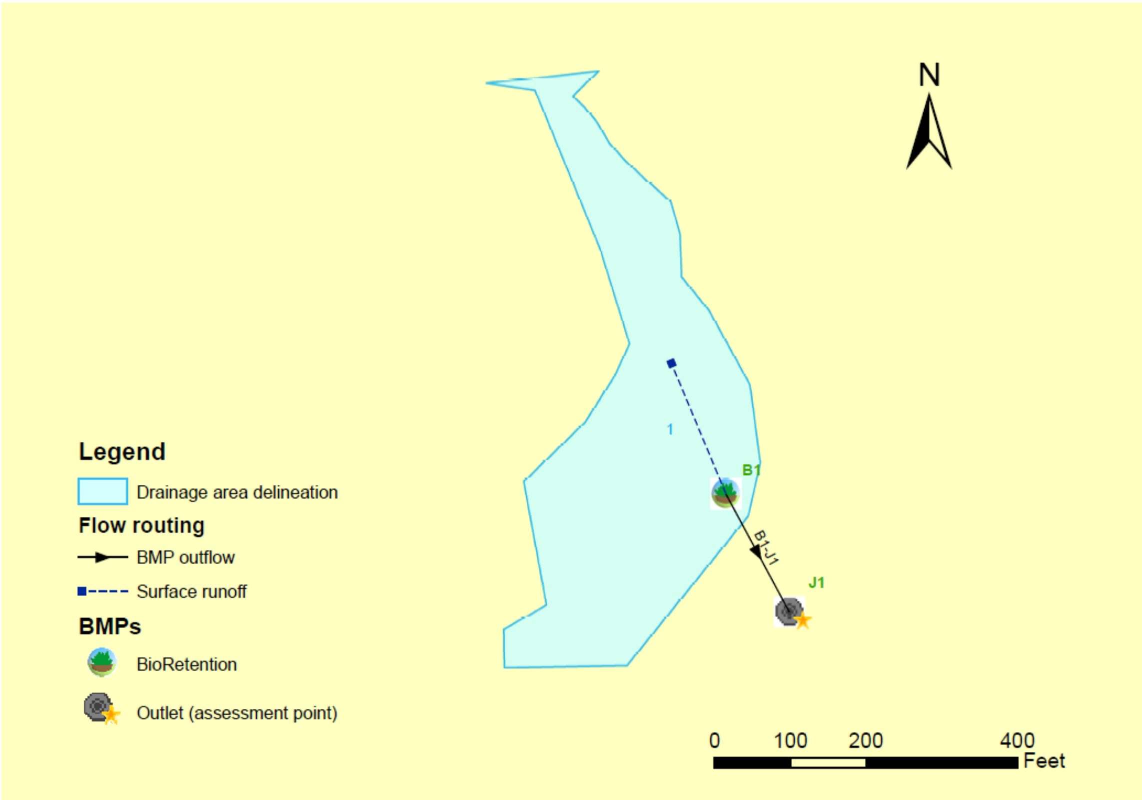


Figure 29. SUSTAIN model setup for the Drive-In site

A schematic drawing of the conventional bioretention representation scheme is illustrated in Figure 30 below. As shown in the figure, surface runoff entering the bioretention area first fills the ponding area, the water filters through the planting soil mix, and then enters the gravel layer. During this process, overflow is routed through the overflow weir to downstream when the inflow rate exceeds the infiltration rate into the planting soil mix.

The SUSTAIN model hydrologic and water quality parameters were previously calibrated in a study carried out at Anacostia River watershed, Prince George's County, Maryland (Tetra Tech 2008). Similar to the analysis carried out for the School site, the SUSTAIN model setup for the Drive-In site is also evaluated through continuous simulation for the period of 1992/01/01 to 2002/12/31. The cumulative total runoff volume reduction, TN removal, and the water balance in the conventional bioretention are summarized at the end of the simulation process.

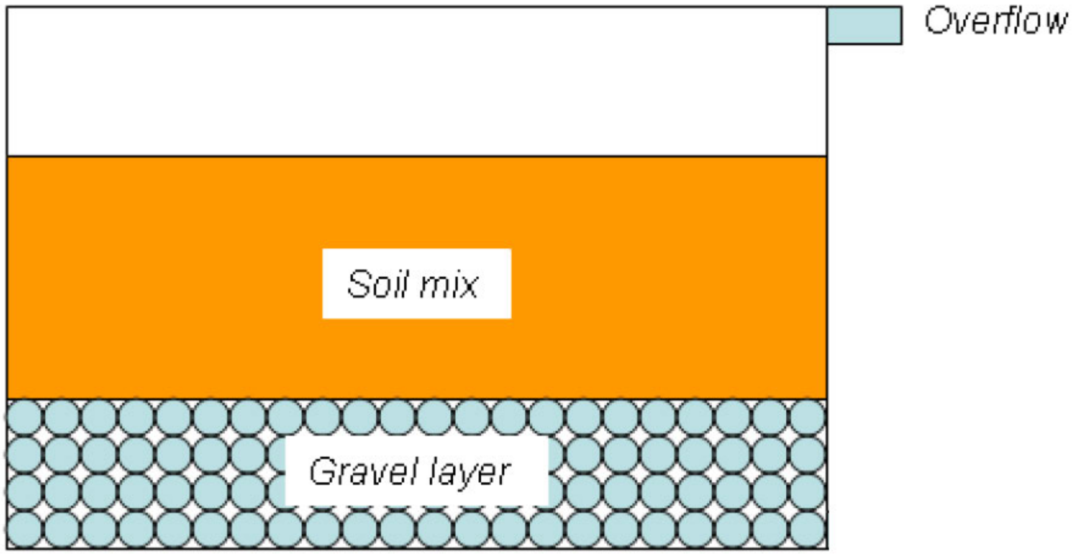


Figure 30. Schematic for representing the conventional bioretention into SUSTAIN (not to scale)

4.3.4. Model Results

The SUSTAIN analysis for the Drive-In site, representing the total runoff volume and nitrogen removed over the ten year simulation period, is summarized in Table 9 below. As shown in the table, the overall runoff volume reduction from the bioretention is 2.8%, and the overall TN load removal from the site is 60% assuming that the bioretention is sized to treat 1 inch of runoff from impervious surface.

Table 9. Summary of SUSTAIN simulation results for the period of 1992/01/01 to 2002/12/31 at the Drive-In site

	Runoff volume (ft3)	Total Nitrogen (lbs)
Total inflow	4,587,781	321.2
Total outflow	4,458,432	127.6
Percentage of reduction	2.8%	60%

The overall water balance of outflow at the conventional bioretention unit throughout the simulation period is presented in Figure 31. Similar to the School site, the only loss from the system is through the ET process. Although instead of an impermeable liner preventing infiltration, no deep percolation occurs at the Drive-In site since it is assumed that the gravel layer is already submerged by a high groundwater table. The bioretention/phytoremediation system functions primarily as flow through treatment for storm events.

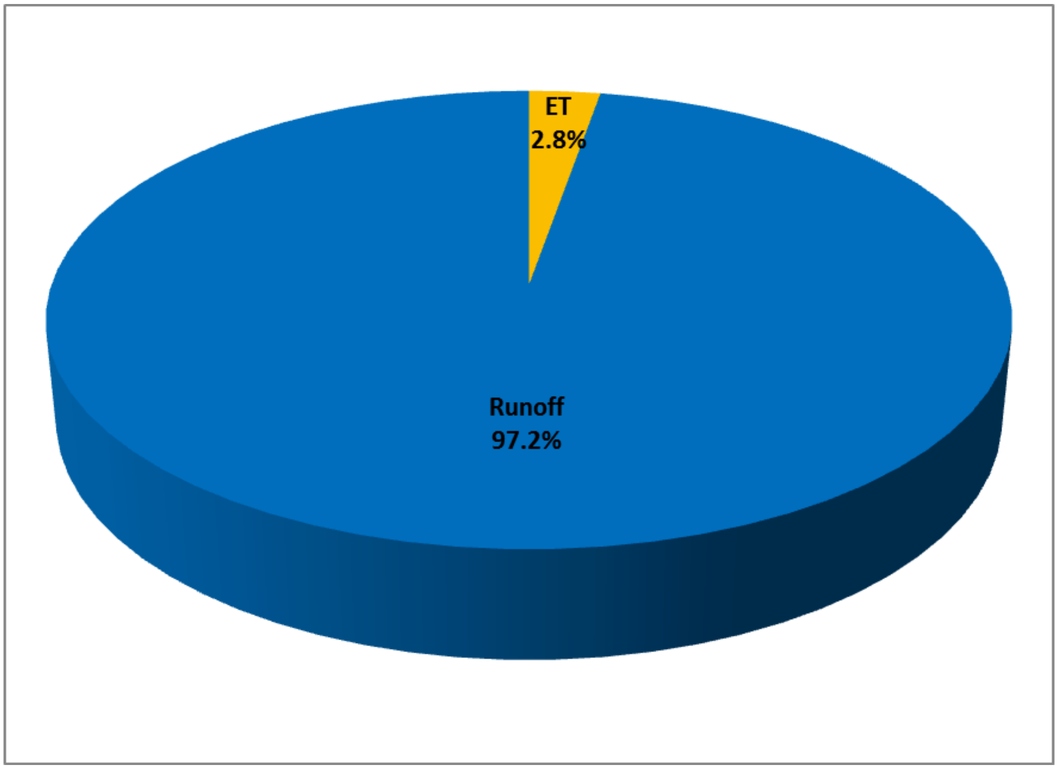


Figure 31. Overall water balance in the bioretention outflow at the Drive-In site

4.3.5. Simplified Cost-Effectiveness Analysis

A simplified cost-effectiveness analysis similar to the one conducted for the enhanced bioretention at the School site was also carried out for the conventional bioretention at the Drive-In site. The SUSTAIN model was set up to evaluate corresponding total runoff volume and TN removal percentages when the conventional bioretention is sized to treat impervious runoff depths other than one inch. A simplified performance curve was also generated for the conventional bioretention.

The simplified cost-effectiveness analysis results for the conventional bioretention are illustrated in Figure 32. As shown in the figure, overall the results demonstrate a pattern similar to that is previously observed for the enhanced bioretention. As the BMP sizes increase, the total runoff volume reduction percentages also increase almost linearly. The TN removal percentages increase more dramatically when the BMP is sized to treat 0.1 to 0.6 inches of impervious runoff, and the curve then tends to level off for treatment depths higher than 0.6 inches.

The pattern of diminishing return in TN removal as the BMP sizes increase is also analyzed for the conventional bioretention at the Drive-In site. For simplification purposes, the unit construction cost of the conventional bioretention is also assumed to be $5.00 per cubic feet[1]. Again this information does not have any relation to actual construction costs associated with BMPs in the Cape Cod region, and should be limited to use for evaluating the relative differences of BMP cost for planning purposes only.

The corresponding costs and the rates of TN removal percentage increase as the BMP volume increases are summarized in Table 10.

[1] This does not represent the actual construction cost, simply an arbitrary number used to illustrate the cost optimization.

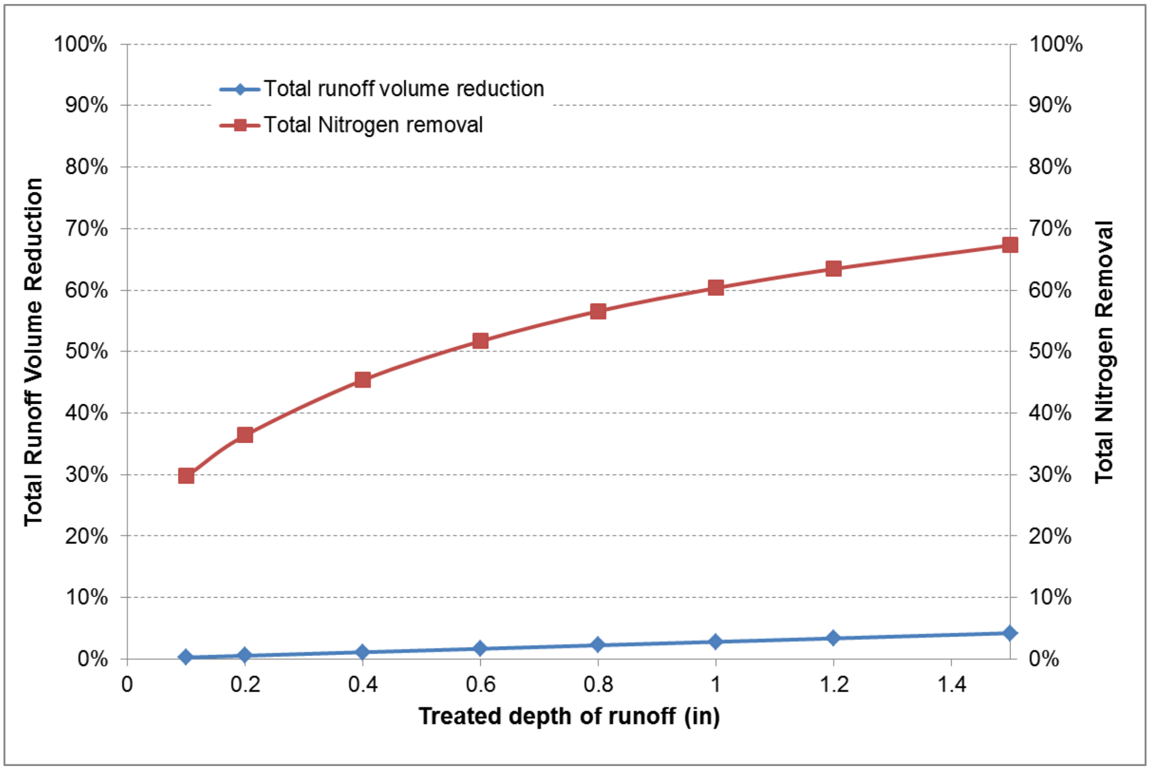


Figure 32. Simplified cost-effective analysis for sizing the enhanced bioretention at the Drive-In site

Table 10. Total cost for the conventional bioretention at varying treatment depths for the Drive-In site

Treated depth of runoff	Total BMP volume (ft3)	Total cost ($)	TN removal	Increase in total cost ($)	Increase in TN removal
0.1 in	327	1,634	30%	-	-
0.2 in	653	3,267	36%	1,634	7%
0.4 in	1,307	6,534	45%	3,267	9%
0.6 in	1,960	9,801	52%	3,267	6%
0.8 in	2,614	13,068	57%	3,267	5%
1.0 in	3,267	16,335	60%	3,267	4%
1.2 in	3,920	19,602	63%	3,267	3%
1.5 in	4,901	24,503	67%	4,901	4%

As shown in Table 10, the general pattern is similar to what was observed for the enhanced bioretention. That is, the rate of increase in TN percentage removal diminishes as the BMP sizes increase. This information is expected to help make cost-effective and defensible stormwater management decisions.

4.4. Groundwater Impact Analysis

The proposed green infrastructure plan for the Drive-In site represents a unique opportunity to integrate the treatment of wastewater in groundwater into a stormwater LID system. Typically, high groundwater is undesirable for bioretention facilities but at this site, the plan takes advantage of the high groundwater table to provide additional treatment through phytotechnology. Research by CCC has found that phytotechnology is capable of treating nitrogen in groundwater by using plants which draw in nutrients, creating an environment near the root zone that encourages nitrogen processing, and utilizing nitrogen to build plant material. The actual amount of removal is not well established and can be difficult to quantify, but a study of sewage treatment potential of water hyacinth resulted in upwards of 90% removal of TN from wastewater samples (USEPA 1988).

SUSTAIN is not capable of modeling nitrogen removal in groundwater as a result of phytotechnology. The modeled results from the conventional bioretention system represent a conservative reduction of nitrogen at this site. A thoughtful and detailed monitoring program, if added to this green infrastructure plan, could quantify the water volumes and nitrogen quantities at various points. This could lead to the future modification of BMP designs, the widespread implementation of phytotechnology for the treatment of wastewater, and the expansion of the SUSTAIN model. The close working relationship CCC has developed with the town increases the potential for this to be a successful and innovative green infrastructure project.

4.5. Summary

The SUSTAIN model is used to evaluate the hydrologic and water quality benefits from two proposed stormwater BMPs at the communities of Barnstable and Yarmouth. The two BMPs, one an innovative enhanced bioretention and the other a conventional bioretention, are first evaluated for treating one-inch of runoff from impervious surfaces. A simplified cost-effectiveness analysis is then carried out for each BMP, in which the BMPs are sized to treat impervious runoff depths varying from 0.1 inches to 1.5 inches. The analysis results demonstrate the general pattern of diminishing rate of increase in TN removal percentages as the BMP sizes increase due to the high concentration of pollutants included in the first flush of stormwater entering the BMP from the drainage area. While the analyses are conducted using assumed BMP construction cost values, the overall cost-effectiveness information of the two BMPs can greatly help stormwater decision-makers in making informed and defendable management decisions.

5. Regulatory Pathways

The project team conducted a review and evaluation of the regulatory requirements associated with the implementation of the proposed green infrastructure concept plans. The review includes local, Commonwealth, and federal requirements to implement the proposed projects in Barnstable and Yarmouth. A summary of required permits for these green infrastructure projects is included in Table 11 and a further discussion of the results of the review and recommendations is provided below. In general, very few permits are required to implement these two green infrastructure projects.

Table 11. Permit Requirements

Permit Level	Barnstable (School site)	Yarmouth (Drive-In site)
Local	No requirements[1]	No requirements[2]
Commonwealth	No requirements	Approval of Installation of an Alternate System for Piloting (BRP WP 64b) - monitoring required
Federal	No requirements	No requirements

[1] Personal communication with Dale Saad, Ph.D., Senior Project Manager, Water, Sewer and Green Energy Barnstable DPW, Tel: 508-790-6300

[2] Personal communication with George Allaire, Director of Public Works, Town of Yarmouth, Tel: 508-398-2231

5.1. Stormwater Discharges from Construction Activities (Construction General Permit)

Construction sites that disturb one or more acres and that discharge stormwater to a surface water of the United States, or to a municipal separate storm sewer system (MS4) that discharges to a surface water of the United States, are required to obtain coverage under the National Pollutant Discharge Elimination System (NPDES) General Permit for Storm Water Discharges from Construction Activities (also known as the "Construction General Permit" or "CGP") issued by the EPA. Although the Commonwealth has not joined with EPA in issuing the CGP, Massachusetts has issued a 401 Water Quality Certification for the permit. The Water Quality Certification requires compliance with certain Commonwealth regulations and policies, including the Massachusetts Clean Waters Act, Massachusetts Water Quality Standards, Surface Water Discharge Permit Program Regulations, Wetlands Protection Act, Wetlands Regulations, Final Orders of Conditions issued pursuant to the Wetlands Protection Act, Massachusetts Stormwater Management Policy, and the Massachusetts Endangered Species Act. If the requirements of the water quality certification are violated, MassDEP has the authority to require that the violations be corrected and to take any action authorized by the General Laws of the Commonwealth, the Massachusetts Clean Waters Act, and the regulations promulgated there under.

Since the scope of work at both proposed sites is less than one acre this CGP requirement will not apply.

5.2. Erosion and Sedimentation Control

The Wetlands Regulations also recognize that stormwater discharges may adversely impact wetland resource areas during construction. To prevent this impact, the Wetlands Regulations, 310 CMR 10.05(6)(b)(1), provide that the Order of Conditions shall impose conditions to control erosion and sedimentation within resource areas and the Buffer Zone. Erosion and sedimentation control is required, even if the project is a single-family house that is exempt from the requirement to comply with the Stormwater Management Standards. For projects subject to the Stormwater Management Standards, Standard 8, set forth in the Wetlands Regulations at 310 CMR 10.06(6)(k)(8), requires the development and implementation of a construction-period erosion, sedimentation and pollution prevention plan.

Erosion and sediment control plans will be developed as part of the construction plan set and included with the final construction plans. They will be prepared by a licensed professional engineer and submitted for review at the 70% plan stage.

5.3. Construction and Grading/Review/Approval

Construction and grading plans for each of the two green infrastructure projects will be prepared and submitted to the town's public works department for review and approval. These plans will also include the erosion and sediment control plans.

There are no review fees or other charge for these plans based on personal communication with Dale Saad, Ph.D. , Senior Project Manager, Water, Sewer and Green Energy Barnstable DPW, Tel: 508-790-6300, and Mr. George Allaire, Director of Public Works, Town of Yarmouth, Tel: 508-398-2231.

5.4. Special Conditions for Yarmouth Drive-In Site

Because the Yarmouth Drive-In site is proposed to provide treatment downfield of a Title V leaching field it is subject to certain special provisions. These requirements were identified, below, by Brian Dudley from MassDEP at a meeting with CCC staff to review 20% design plans for the Yarmouth drive-in site and discuss regulatory approaches incorporating a phytotechnology/bioretention system down gradient of a proposed Title V leaching field associated with the Town's marina project. The requirements are summarized below:

5.4.1. Monitoring

An extensive monitoring plan will be required for a piloting program. This plan is suggested to incorporate preconstruction information including groundwater flow paths and determinations of existing contaminants and plumes in the immediate area. A monitoring plan should include specifics such as the monitoring approach (i.e. mass balance or ground water concentration measurements), monitoring locations, sampling standards, sampling frequency and time frame. The time frame may be dictated by MassDEP staff.

MassDEP staff suggests monitoring wells up gradient of the leach field, down gradient of the leach field and up gradient of the phytotechnology/bioretention system and either monitoring wells or a monitoring fence down gradient of the phytotechnology/bioretention system. Mr. Dudley suggested that County Health Department lab may be able to assist with monitoring to reduce costs (contact George Heufelder, Director, Barnstable County Department of Health and Environment).

5.4.2. General Regulatory Notes

When installing a pilot program a site must also prove they have the ability to install a conventional system capable of meeting the loading requirements in the event the pilot does not perform as expected.

In addition to the BRP WP 64b form (attached), a Standard Transmittal Form will need to be filled out with the state when seeking piloting approval.

Consideration of the Wetland Protection Act and associated buffers will need to be taken into account when constructing any septic treatment system, Review of the project site indicates that the proposed phyto-bio system facility is outside the 100' wetland buffer.

5.4.3. Site Specific Considerations

An alternate leach field, such as a drip dispersal system that is approved by MassDEP for general use, may be utilized to lower the mounding requirements of the leaching area. A drip dispersal system requires a 3-foot high mound and then 6 to 9 inches of fill on top. This may facilitate ease of construction near the adjacent property boundary.

A design that captures leach field effluent and forces it horizontally towards the phytotechnology/ bioretention system above the high ground water level should not pose a problem for MassDEP as long as a 5-foot depth prior to any ponding above the liner is achieved. This will meet MassDEP standards for pathogen removal. If integrated into a pilot study no 50' setback from leach field to infiltration area is required. Although the site is located within a flood zone "A", "A" flood zones will not be an issue from a MassDEP standpoint.

Compliance with 310 CMR 15.214 (nitrogen sensitive areas) needs to be confirmed. Initial review and conversation with MassDEP staff indicates that the drive-in location is not located within a nitrogen sensitive area under MassDEP regulations, defined by location in Zone II, IWPA or specific nitrogen-sensitive designated area. However, site will be required to meet Developments of Regional Impact (DRI) Minimum Performance Standards as location is within a watershed with an interim TMDL established.

Since this location is not a nitrogen sensitive area CCC will not be held to the more stringent design flow of 440 gallons/acre/day. However, due to the overall acreage of the site it may still fall in compliance with this requirement.

5.5. Plan Development and Approval Process

The project team recommends the following procedures for plan development and seeking approval of the plans:

- 30% Stage - Submit the 30% concept plans to the respective towns and MassDEP (Yarmouth site only) to get the town representatives and MassDEP familiar with the concepts and to obtain comments and input to the plans.
- 70% Stage - Incorporate the town's input into a 70% stage construction plan set and resubmit these plans to the respective towns and MassDEP for a second review and comment period. These plans will consist of full scale construction plans showing the following elements:
    1. proposed limits of disturbance
    2. existing and propose grading
    3. erosion and sediment control plan
    4. all construction details
    5. additional requirements for Yarmouth drive-in site
        a. proposed monitoring plan
        b. preparation and submittal of BRP WP 64b form, and a Standard Transmittal Form to state
        c. show location of alternate leach field
    6. updated cost estimate for both sites

  These plans will prepared and sealed by a licensed professional engineer
- 100% (Final) Stage – Incorporate the 70% stage plan review comments into a 100% or final stage of plans and resubmit to the respective towns and MassDEP to obtain final approval for the plans. These plans will include:
    1. all the elements described in 70% submittal plans
    2. a complete set of bid document plans and specifications

6. Cost Estimates

A preliminary cost estimate has been developed for the proposed practices described in the 30% concept plans for both the School site and the Drive-In site in Barnstable and Yarmouth, respectively. This cost estimate is based on designs for an enhanced bioretention design concept (i.e., pioneered at the University of New Hampshire Stormwater Research Center) proposed at the Barnstable School site and a phytotechnology/bioretention concept proposed for the former Drive-In site and proposed marina facility in Yarmouth.

The cost breakdown for these two facilities is provided below. The costs were developed using the following approach:

- An estimate of quantities was developed for each facility based on the 30% concept plans. This estimate is summarized in Table 12 and Table 13, respectively.
- Unit cost estimates were applied to the estimated quantities to arrive at a preliminary cost. These unit costs are based on actual projects designed and built within the last 3 years in the northeastern U.S.
- A contingency factor of 20% was added to the cost estimate to reflect the degree of uncertainty and level of detail associated with a 30% concept plan.

The total estimated cost for each proposed facility is summarized in Table 14 and Table 15.

Table 12. Preliminary Estimate of Quantities: Barnstable School Site – Enhanced Bioretention System

ITEM	LENGTH	WIDTH	DEPTH	TOTAL	
	ft	ft	ft	cf	cy
Excavation -1*	200	25	5.5	27,500	1,019
Excavation -2*	75	25	4.8	9,000	333
Gravel/stone-1	200	25	3	5,625	208
Gravel/stone-2	75	25	3	13,000	481
Media - 1	200	25	2	10,000	370
Media - 2	75	25	1.7	3,188	188
Geotextile-HDPE	200	25	1	5,000	556

NOTES: Excavation-1* = excavation for enhanced bioretention area
Excavation -2* = excavation for traditional bioretention area
Gravel/stone -1 = enhanced bioretention area
Gravel/stone -2 = traditional bioretention area Media -1 = enhanced bioretention area
Media -2 = traditional bioretention area

Table 13. Preliminary Estimate of Quantities: Yarmouth Drive-In Site – Phytotechnology/Bioretention

ITEM	LENGTH	WIDTH	DEPTH	TOTAL	
	ft	ft	ft	cf	cy
Excavation-1*	200	25	4.8	24,000	889
Excavation-2*	100	25	2	5,000	185
Media	200	25	2	9,000	333
Gravel/stone	200	25	3	12,500	463
Topsoil Amend	700	30	1	21,000	778

Table 14. Preliminary Cost Estimate: Barnstable School Site – Enhanced Bioretention System

ITEM	Unit	Unit Cost	Qty	Total 1	Conting	TOTAL
					(20%)	
A. Design						
Surveys	EA	5,000	1	5,000		
Geotech	EA	3,000	1	3,000		
Design	LS	15,000	1	15,000		
		Subtotal 1		23,000	4,600	27,600
B. Construction						
Stakeout	LS	1	1,000	1,000		
E & S	LS	1	2,000	2,000		
Excavation*	CY	25	1352	33,800		
Media Mix	CY	35	488	17,080		
Gravel/stone	CY	25	690	17,250		
Geotex-HDPE	SY	20	556	11,120		
6" Underdrain	LF	15	60	900		
Access Pavers	SF	6	320	1920		
Trees	EA	2	100	200		
Shrubs	EA	40	30	1,200		
Grass	EA	25	30	750		
Sedges	EA	50	20	1,000		
Signage	EA	1,000	1	1,000		
As-builts	LS	1,000	1	1,000		
		Subtotal 2		90,220	18,044	108,264
		PROJECT TOTAL				135,864

Table 15. Preliminary Cost Estimate: Yarmouth Drive-In Site – Phytotechnology/Bioretention

ITEM	Unit	Unit Cost	Qty	Total 1	Conting	TOTAL
					(20%)	
A. Design						
Surveys	EA	5,000	1	5,000		
Geotech	EA	3,000	1	3,000		
Design	LS	15,000	1	15,000		
Permits	LS	2,000	1	2,000		
		Subtotal 1		25,000	5,000	30,000
B. Construction						
Stakeout	LS	1	1,000	1,000		
E & S	LS	1	2,000	2,000		
Excavation*	CY	25	1074	26,850		
Media Mix	CY	35	333	11,655		
Gravel/stone	CY	25	463	11,575		
Topsoil Amend	CY	25	778	19,450		
Trees	EA	27	100	2,700		
Shrubs	EA	109	30	3,270		
Grass	EA	57	30	1,710		
Sedges	EA	200	20	4,000		
Signage	EA	1,000	1	1,000		
As-builts	LS	1,000	1	1,000		
		SUBTOTAL 2		86,210	17,242	103,452
		PROJECT TOTAL				133,452

*Includes 6 in. ponding depth & disposal of soil onsite
(Note: If soil if taken offsite increase excavation cost by $ 95,000)
Cost / IA = $ 133,452 / 0.90 = $ 148,280

7. Conclusions

In a more traditional sense, Cape Cod is already implementing many LID/green infrastructure principles. The sandy, well-drained soils found on the Cape already promote high rates of stormwater infiltration, eliminating the need for considerable stormwater infrastructure in many areas. Permeable soils have reduced the need to treat stormwater quantity but have also removed the incentive to treat stormwater quality. Nitrogen can easily enter the groundwater table through surface runoff and septic systems and proceed untreated to local embayments, leading to eutrophication and subsequent loss of aquatic habitat.

Many coastal communities in the U.S. are facing similar nutrient pollution issues. Although groundwater sources of nitrogen from inefficient septic systems represent a significant pollutant load to local embayments, it is possible to reduce nitrogen loading through green infrastructure techniques that treat stormwater runoff. Use of innovative designs, thoughtful siting, and optimization of these techniques can make treating stormwater sources of nitrogen cost effective. In addition, green infrastructure can be easily placed throughout the watershed, resulting in multiple benefits for environmental justice communities on the Cape, while providing centralized wastewater treatment to take individual septic systems offline requires significant capital costs and a long timeframe.

The concepts presented in this study provide additional nitrogen removal options for both surface and groundwater sources; future monitoring efforts at the sites will establish the hydrologic and water quality effectiveness to guide future water quality projects on Cape Cod. The concepts have been located on public, highly visible land to promote the need for water quality treatment to protect the Cape's embayments and to reduce barriers to implementation such as land ownership. Tetra Tech and CCC have presented these concepts to the Towns of Barnstable and Yarmouth to begin to obtain public approval for the projects. CCC is currently pursuing funding opportunities to advance these projects to the final design and construction phase, using the modeling, costs, and design plans included in this report to prepare grant applications. Once implemented and established, the two projects will serve as educational and visual examples of future opportunities throughout Cape Cod. The lessons learned from this project will help Cape Cod and communities across the country better address coastal water quality issues.

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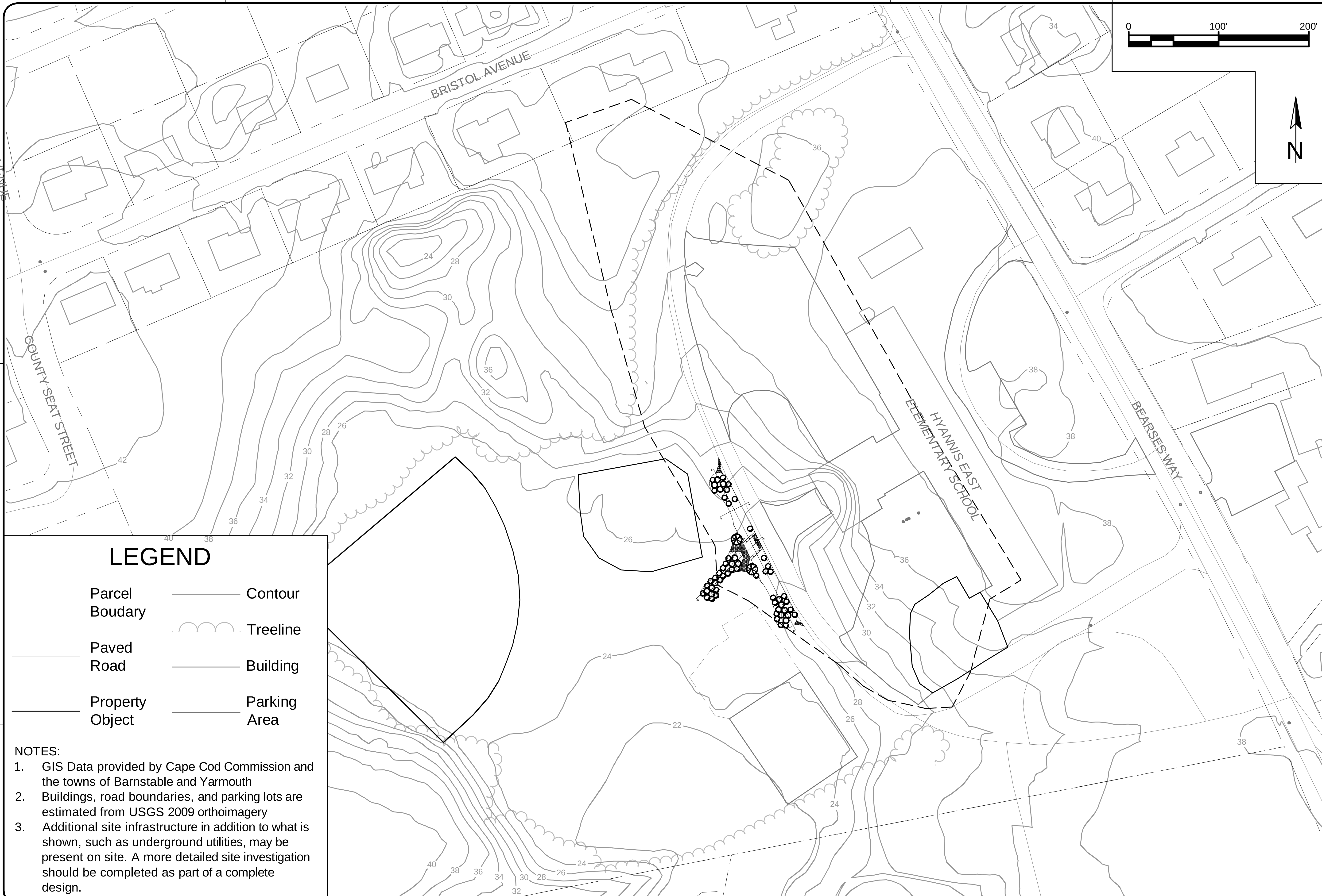

LEGEND

Parcel Boudary	Contour
Paved Road	Treeline
Property Object	Building
	Parking Area

NOTES:

1. GIS Data provided by Cape Cod Commission and the towns of Barnstable and Yarmouth
2. Buildings, road boundaries, and parking lots are estimated from USGS 2009 orthoimagery
3. Additional site infrastructure in addition to what is shown, such as underground utilities, may be present on site. A more detailed site investigation should be completed as part of a complete design.

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MARK	DATE	DESCRIPTION	BY

CAPE COD COMMISSION

EPA 2012 GREEN INFRASTRUCTURE
BARNSTABLE/YARMOUTH COMMUNITY PARTNERS PROJECT

165 BEARSES WAY (SCHOOL)
SITE OVERVIEW

Date: 03/11/2013
Designed By: RDD
Drawn By: RDD
Checked By:

S-1

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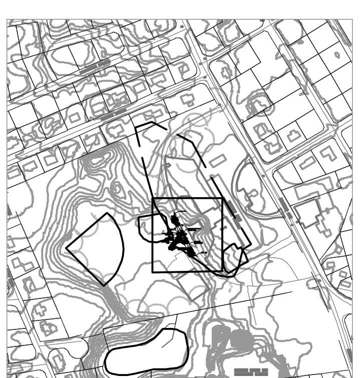
Watershed Characteristics		Retrofit Characteristics	
Watershed Area, acres	3.87	Proposed Retrofit	Bioretention (Enhanced and Traditional)
Town	Barnstable	Water Quality Volume, ft³	7,507
Street Address	165 Bearses Way	BMP footprint, ft²	3650
Total Impervious, %	53.5	Typ Ponding Depth, ft	0.33 (Enhanced) 0.50 (Traditional)
Design Storm Event, in	1"	Typ Media Depth, ft	2.0 (Enhanced) 1.7 (Traditional)

Proposed Retrofit Description: The proposed retrofit would utilize a portion of the school's recreational area. Flows from the impervious driving area would enter the enhanced bioretention cells through two curb cuts on either end and through a sediment forebay/seating area in the center. The seating area provides a focal point for the bioretention area that can be used for classroom exercises, while also providing a sediment forebay to reduce the amount of sediment that would impact treatment and maintenance. Flows would enter the enhanced bioretention through the gaps in the large structure rocks used for seating. After the enhanced bioretention cells are filled, water would spill over a grassed weir into the traditional bioretention cell where it would infiltrate into the existing soils.

NOTES:

1. The Enhanced Bioretention is to be completely lined with an HDPE liner.
2. Trees and deep rooting shrubs should not be planted in the Enhanced Bioretention to avoid puncturing the liner.
3. The outlet from the Enhanced Bioretention should be discharged into a perforated pipe that is sized to discharge outflows via infiltration to the in-situ soil.
4. Larger flow events are anticipated to overflow to the surrounding recreational area through the traditional bioretention area.
5. Curb cuts should be constructed of rock sized to resist the erosive entrance velocities.
6. The existing playground area is anticipated to be removed.
7. Pedestrian access to the recreational area is proposed through two mounded crushed rock access paths. A small fence should be placed around the cells to prevent pedestrian access.
8. This is a conceptual plan and is not to be used for construction.

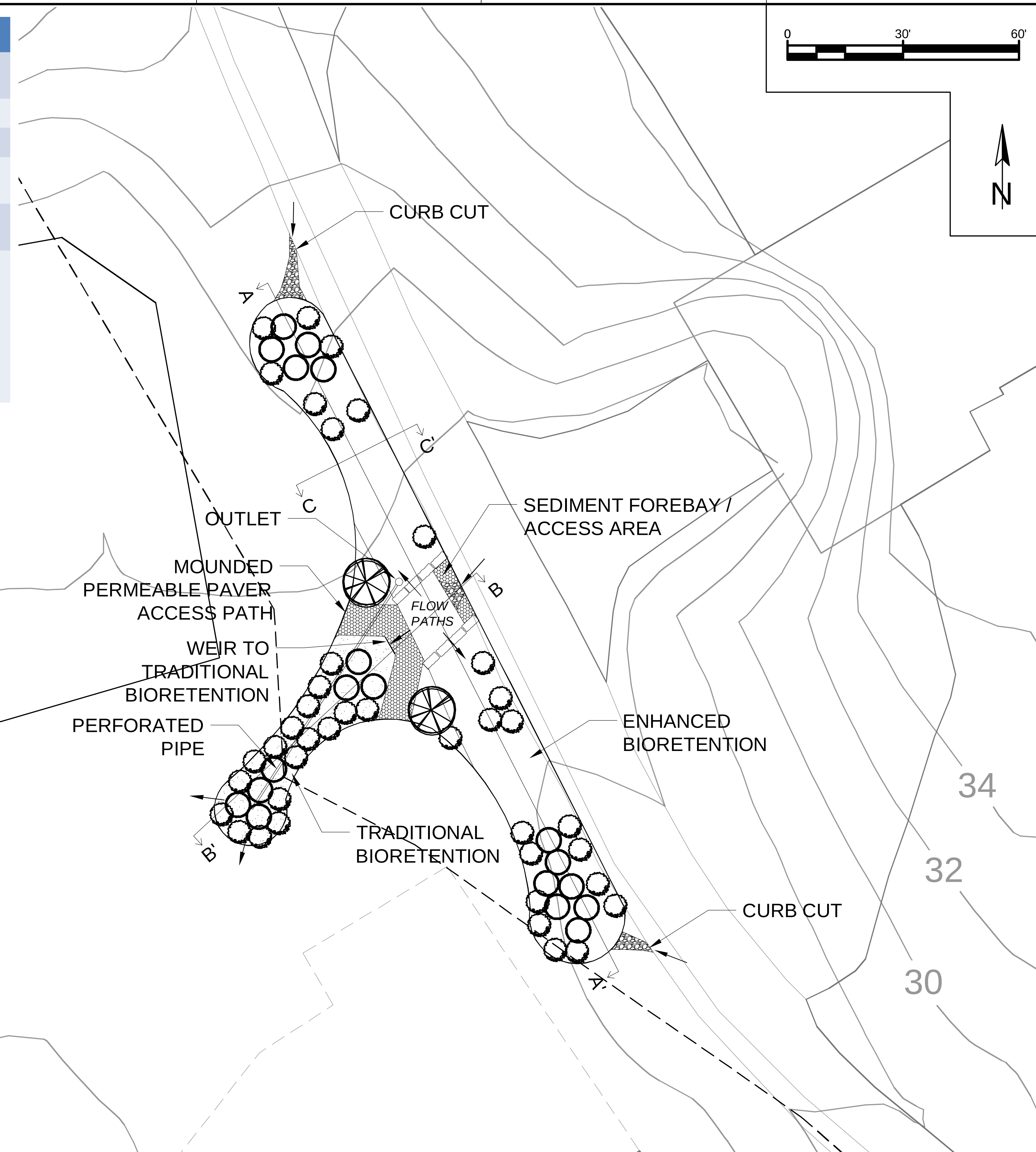


Plant Symbology

Tree

Shrub

Grass



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MARK	DATE	DESCRIPTION	BY

CAPE COD COMMISSION
EPA 2012 GREEN INFRASTRUCTURE
BARNSTABLE/YARMOUTH COMMUNITY PARTNERS PROJECT
165 BEARSES WAY (SCHOOL)
30% CONCEPT PLAN

Date: 03/11/2013
Designed By: CCC
Drawn By: RDD
Checked By:

S-2

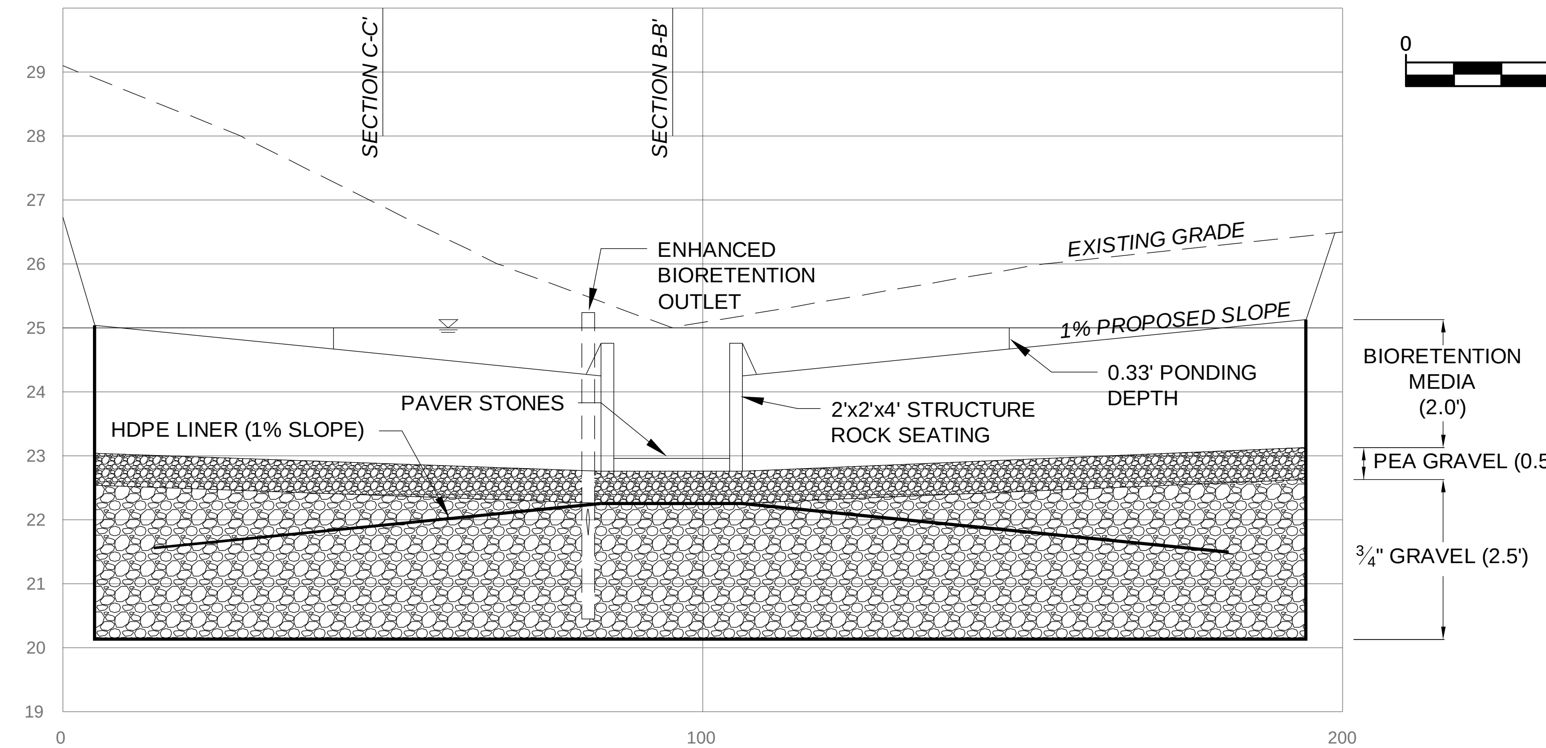
PLANT LIST

Key	Plant Type	Scientific Name	Common Name	Zone	Mature Height
G1	herbaceous	Andropogon gerardii	Big Bluestem	3 to 9	to 6'
G2	herbaceous	Calamagrostis canadensis	Blue Joint Grass, Reed G	3	2-4'
P2	herbaceous	Aster noviae angliae	New England Aster	3 to 9	2-6'
P3	herbaceous	Baptisia australis	Blue False Indigo	3 t 9	3-4'
P4	herbaceous	Geranium maculatum	Wild Geranium	3 t 8	to 2'
P5	herbaceous	Hemerocallis sp.	Daylily	4 to 9	to 3'
P6	herbaceous	Iris versicolor	Blue flag iris	3 to 9	2-2.5'
P7	herbaceous	Lobelia cardinalis	Cardinal flower	3 to 9	2-4'
S1	shrub	Amelanchier canadensis, Amelanchier arborea	Shadblow/ Serviceberry	4 to 9	18'+
S2	shrub	Aronia arbutifolia	Red Chokeberry	4 to 9	6-10'
S3	shrub	Clethra alnifolia	Sweet Pepperbush	3 to 9	3-8'
S4	shrub	Cornus amomum	Silky Dogwood	4	5-8'
S5	shrub	Ilex verticillata	Winterberry Holly	3 to 9	6-10'
S6	shrub	Itea virginica	Virginia Sweetspire	5	6-12'
S7	shrub	Vaccinium angustifolium	Lowbush Blueberry	2	2'
S8	shrub	Viburnum dentatum	Arrowwood Viburnum	3	6-12'
T1	tree	Acer rubrum	Red Maple	3 to 9	60-75'
T2	tree	Betula nigra	River Birch	4 to 9	50-70'
T3	tree	Chionanthus virginicus	White Fringetree	4 to 9	12-20'
T4	tree	Larix laricina	Eastern Larch/Tamara	2	40-80'
T5	tree	Salix discolor	Pussywillow		20-40'

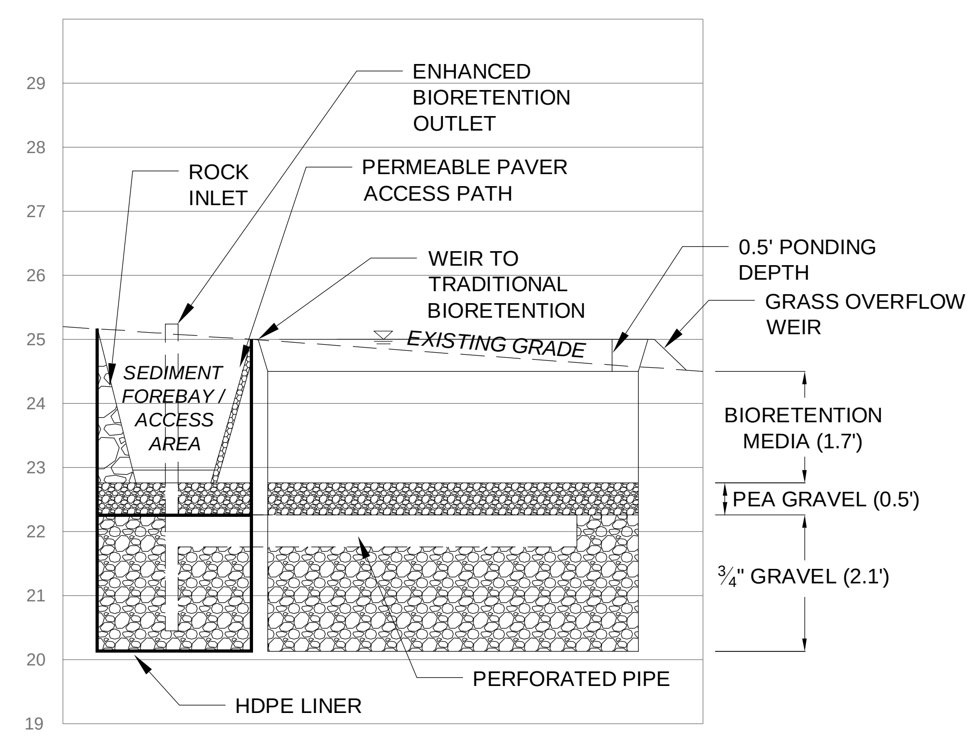
HORIZONTAL
0 30' 60'

VERTICAL
0 3' 6'

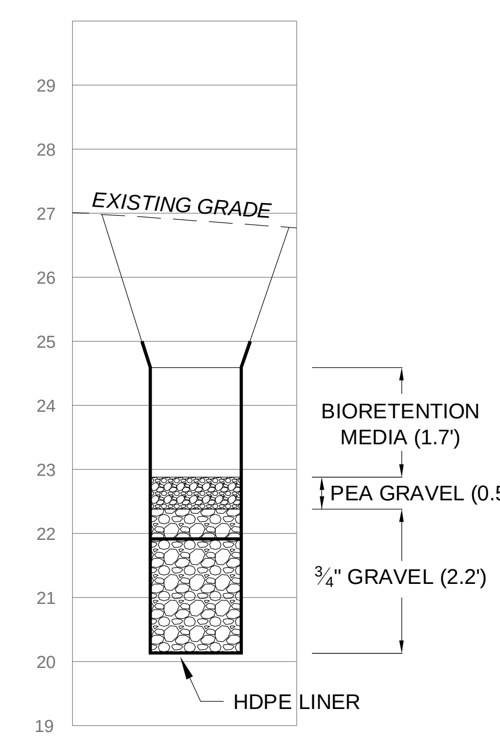
CROSS SECTION A-A'



CROSS SECTION B-B'



CROSS SECTION C-C'



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MARK	DATE	DESCRIPTION	BY

CAPE COD COMMISSION
EPA 2012 GREEN INFRASTRUCTURE
BARNSTABLE/YARMOUTH COMMUNITY PARTNERS PROJECT
165 BEARSES WAY (SCHOOL)
DETAILS

Date: 03/11/2013
Designed By: CCC
Drawn By: RDD
Checked By:

S-3

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LEGEND

Parcel Boudary	Contour
	Treeline
Paved Road	Building
Unpaved Road	Storm Sewer

NOTES:
1. GIS Data provided by Cape Cod Commission and the towns of Barnstable and Yarmouth
2. Buildings, road boundaries, and parking lots are estimated from USGS 2009 orthoimagery
3. Additional site infrastructure in addition to what is shown, such as underground utilities, may be present on site. A more detailed site investigation should be completed as part of a complete design.

MARK	DATE	DESCRIPTION	BY

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CAPE COD COMMISSION

EPA 2012 GREEN INFRASTRUCTURE
BARNSTABLE/YARMOUTH COMMUNITY PARTNERS PROJECT

669 ROUTE 28 (DRIVE-IN)
SITE OVERVIEW

Date: 03/11/2013
Designed By: RDD
Drawn By: RDD
Checked By:

DI-1

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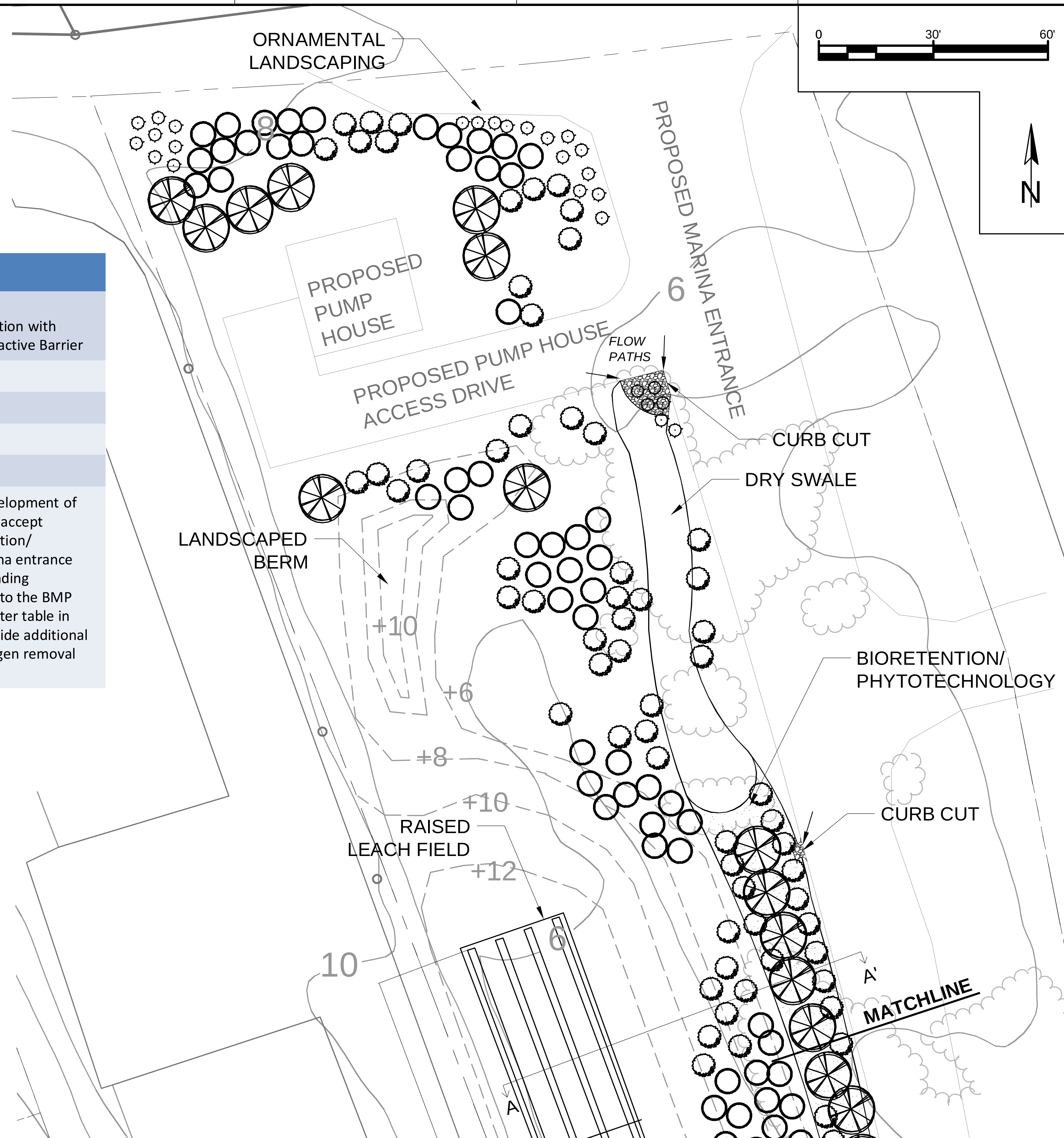

Watershed Characteristics		Retrofit Characteristics	
Watershed Area, acres	2.96	Proposed Retrofit	Bioretention/ Phytoremediation with Permeable Reactive Barrier
Town	Yarmouth	Water Quality Volume, ft^3	3,270
Street Address	Route 28	BMP footprint, ft^2	3,360
Total Impervious, %	30.4	Typ Ponding Depth, ft	0.5
Design Storm Event, in	1”	Typ Media Depth, ft	1.8

Proposed Retrofit Description: The proposed retrofit would be coordinated with the redevelopment of the site for use as a marina. A raised leach field is proposed near the entrance to the site to accept wastewater flows from the future marina facilities. A combined bioretention/phytoremediation/ permeable reactive barrier is designed between the proposed leach field and the new marina entrance road. This BMP facility will collect stormwater from the neighboring residences, the surrounding impervious area, the future entrance road, and any other stormwater that might be routed to the BMP from the redeveloped site. This BMP will be allowed to drain freely, although the groundwater table in this area is relatively shallow. To take advantage of the shallow groundwater table and provide additional treatment of nitrogen, the bioretention area will include deep rooting trees with high nitrogen removal capabilities as well as a permeable reactive barrier that contains organic material.

Plant Symbology

- Tree
- Shrub
- Grass
- Perennial
- Bioinfiltration/Phytoremediation

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CAPE COD COMMISSION
EPA 2012 GREEN INFRASTRUCTURE
BARNSTABLE/YARMOUTH COMMUNITY PARTNERS PROJECT
669 ROUTE 28 (DRIVE-IN)
30% CONCEPT PLAN

Date: 03/11/2013
Designed By: CCC
Drawn By: RDD
Checked By:

DI-2

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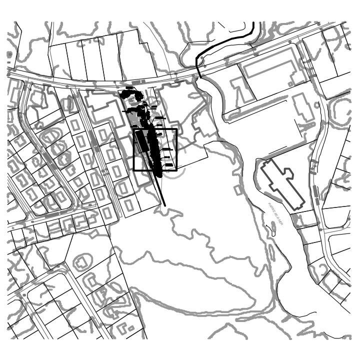
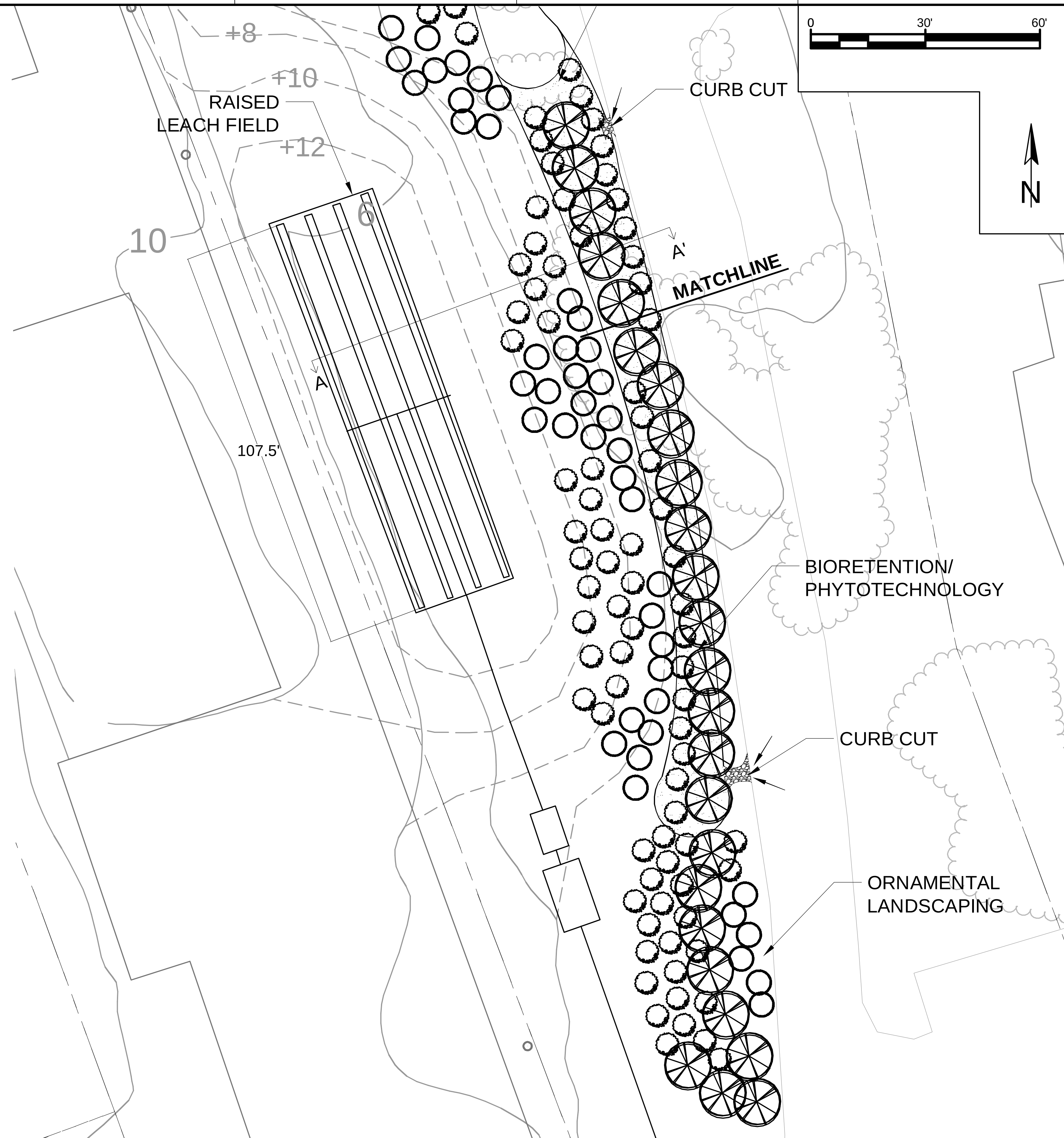
NOTES:

1. The dry swale should be sized to convey the storm events into the bioretention without erosive velocities.
2. Sampling wells are to be included in the final design. The locations are dependent on the final configuration of the bioretention area and the raised leach field.
3. An outlet is needed for the bioretention area for larger flows; this outlet should be included in the final design and coordinated with the proposed marina design.
4. Salix Discolor and/or Salix Nigra (both male species) should be used for the phytotechnology component due to the invasive tendencies of willows.
4. Long willow cuttings should be used for the phytotechnology component. These cuttings should be placed in the in-situ soil; the bioretention media layers should be carefully placed around the cuttings. These cuttings should be densely spaced (suggest 5 foot on center). More detailed planting plans will be included in the final design.
5. This is a conceptual plan and is not to be used for construction.





Plant Symbology

- Tree
- Shrub
- Grass
- Perennial
- Bioinfiltration/Phytoremediation

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CAPE COD COMMISSION
EPA 2012 GREEN INFRASTRUCTURE
BARNSTABLE/YARMOUTH COMMUNITY PARTNERS PROJECT
669 ROUTE 28 (DRIVE-IN)
30% CONCEPT PLAN

Date: 03/11/2013
Designed By: CCC
Drawn By: RDD
Checked By:

DI-3

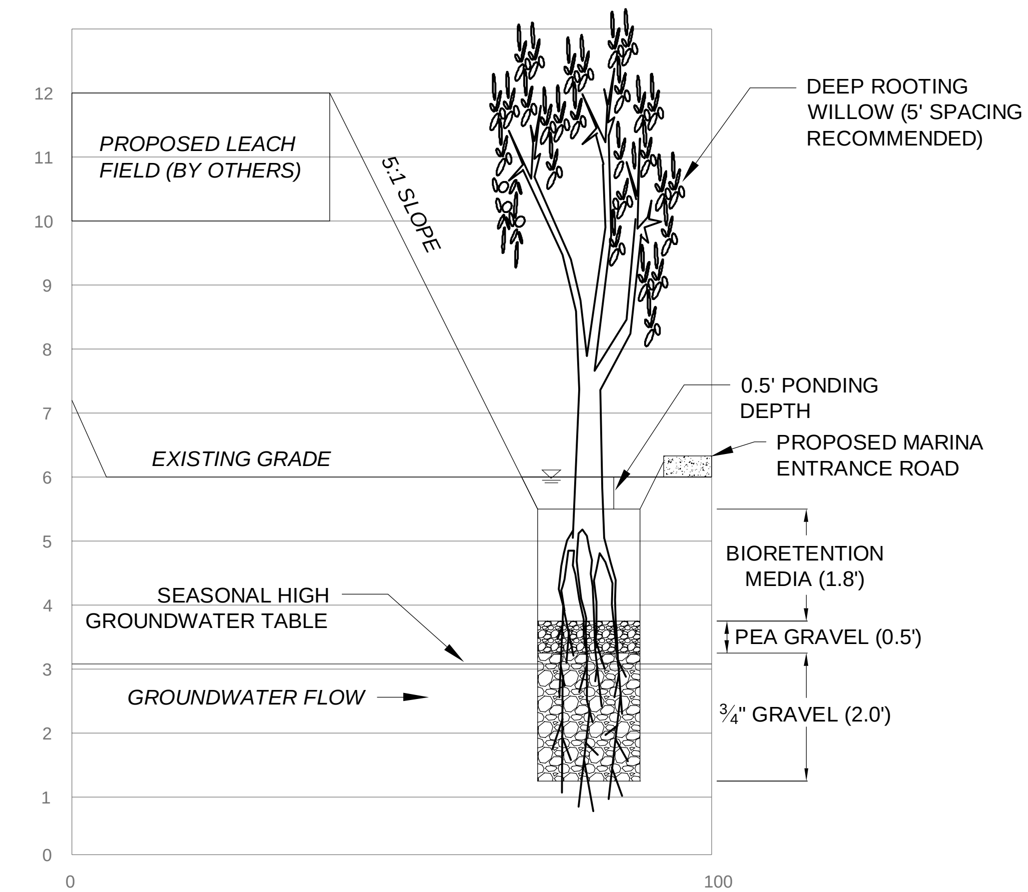
PLANT LIST

Key	Plant Type	Scientific Name	Common Name	Zone	Mature Height
G1	herbaceous	Andropogon gerardii	Big Bluestem	3 to 9	to 6'
G2	herbaceous	Calamagrostis canadensis	Blue Joint Grass, Reed Grass	3	2-4'
G3	herbaceous	Carex sp.	Various Sedge Species (check individual species and habitat types)		2-4'
P1	herbaceous	Baptisia australis	Blue False Indigo	3 t 9	3-4'
P2	herbaceous	Eupatorium purpureum subsp. maculatum 'Gateway'	Joe-Pye Weed	4 to 8	4-5'
P3	herbaceous	Iris versicolor	Blue flag iris	3 to 9	2-2.5'
P4	herbaceous	Liatris sp.	Blazing Star	5 to 9	to 5'
S1	shrub	Amelanchier canadensis, Amelanchier arborea	Shadblow/ Serviceberry	4 to 9	18'+
S2	shrub	Aronia arbutifolia	Red Chokeberry	4 to 9	6-10'
S3	shrub	Clethra alnifolia	Sweet Pepperbush	3 to 9	3-8'
S4	shrub	Cornus amomum	Silky Dogwood	4	5-8'
S5	shrub	Ilex verticillata	Winterberry Holly	3 to 9	6-10'
S6	shrub	Vaccinium corymbosum	Highbush Blueberry	3 to 8	6-12'
S7	shrub	Viburnum lentago	Nannyberry	2 t 8	14-16'
T1	tree	Acer rubrum	Red Maple	3 to 9	60-75'
T2	tree	Carpinus caroliniana	American Hornbeam	3 to 9	20-30'
T3	tree	Nyssa sylvatica	Black Gum/Tupelo	3 to 9	30-50'
T4	tree	Quercus alba	White Oak	3 to 9	50-80'

HORIZONTAL
0 30' 60'

VERTICAL
0 3' 6'

CROSS SECTION A-A'



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EPA 2012 GREEN INFRASTRUCTURE
BARNSTABLE/YARMOUTH COMMUNITY PARTNERS PROJECT
669 ROUTE 28 (DRIVE-IN)
DETAILS

Date: 03/11/2013
Designed By: CCC
Drawn By: RDD
Checked By:

DI-4