CAPE COD COMMISSION

2024 REGIONAL TRANSPORTATION PLAN

Technical Appendix I: Stormwater Management

FINAL JULY 2023

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

Technical Appendix I: Stormwater Management

Stormwater runoff is caused by precipitation from rain and snowmelt events which flow over land or impervious surfaces and is unable to percolate into the ground. In natural systems, precipitation may be directly infiltrated subsurface, stored in natural depressions, or reintroduced to the atmosphere through evapotranspiration. However, development such as buildings, roads, sidewalks, and paved driveways increases impervious surface area and alters natural hydrology. The increase in impervious cover that accompanies development results in two main issues related to stormwater: 1) greater volume and peak flows of runoff and 2) transportation of contaminants into water bodies.

In natural ecosystems, runoff is infiltrated through the ground into groundwater and discharged to freshwater streams, ponds, lakes, rivers and marine estuaries. Flooding is less significant in natural systems because greater volumes of stormwater are able to infiltrate through the soil, passing it from the surface to the groundwater. In urbanized areas, dense impervious cover reduces the amount of infiltration that can occur. The increase in stormwater runoff volume results in increased ponding, flooding, and hydroplaning potential on roadways, which makes roadways unsafe for travel.

Stormwater runoff flushes pollutants and debris from impervious surfaces and discharges them to local waterways. Common pollutants found in stormwater runoff include oil; grease and metals from vehicular traffic; salts and other deicing agents used to maintain safe roadway operation under winter weather conditions; pesticides and fertilizers from landscaping activities; sediments from various activities; altered water temperatures and litter. When conveyed by stormwater runoff these pollutants impair waterways, degrade natural habitat, pollute groundwater, increase flooding, cause erosion of streambeds or siltation of waterways, and decrease the amount of water recharged to aquifers. Transported by stormwater runoff, pollutants find their way into the ground and surface waters throughout Cape Cod. These waters with increased pollutant loads ultimately discharge to coastal embayments.

STORMWATER MANAGEMENT CHALLENGES ON CAPE COD

What makes Cape Cod a unique area for stormwater management is the combination of highly porous native soils left by the retreating glaciers and shallow groundwater levels, which are especially prevalent in coastal communities. Well-drained soils readily infiltrate runoff, providing excellent volume reduction of stormwater. However, the combination of highly permeable soils and a high water table results in rapid infiltration of contaminated stormwater runoff in to the groundwater. Because groundwater on Cape Cod travels towards nutrient-sensitive coastal embayments, the quality of stormwater runoff is a concern.

Where most efforts to manage stormwater focus on moving the volume of water off roadways, stormwater management on Cape Cod also requires addressing the quality of stormwater that infiltrates to the Cape's groundwater (drinking water) resources and the Cape's coastal estuaries.

Stormwater and Drinking Water Protection

Drinking water on Cape Cod is provided by the groundwater, a sole source aquifer, and because of the hydrogeology of Cape Cod, the aquifer is sensitive to stormwater runoff. Areas of land that receive precipitation to recharge drinking water wells are called Wellhead Protection Areas (WPAs). Stormwater management is particularly important in these areas because contaminated stormwater runoff can potentially contaminate drinking water supply. Because of this threat, WPAs have specific regulations in place to protect the Cape's drinking water supply. Potential Water Supply Areas (PWSAs) have also been identified on Cape Cod to ensure consideration and possible protection of suitable land for drinking water wells. WPAs and PWSAs are mapped water resources areas in the Cape Cod Commission's Regional Policy Plan (RPP) and have specific regulatory review standards.

TMDLS and Impaired Watersheds on Cape Cod

The allowable load of a particular contaminant that changes a healthy system to a deteriorating system is defined as a critical threshold, which under the federal Clean Water Act is referred to as a Total Maximum Daily Load (TMDL). TMDLs determine the maximum allowable load of a pollutant to a water body that still enables that water body to meet state water quality standards. Establishing a TMDL includes identifying and quantifying sources of the pollutant of concern (from both point and non-point sources), taking into consideration a margin of safety, seasonal variations, and several other factors. Communities are required to restore impaired surface water bodies where a TMDL is determined. TMDLs are determined for specific pollutants such as nitrogen, phosphorous, and pathogens.

NITROGEN

In marine and coastal embayments, nitrogen generally acts as the limiting nutrient. Due to the Cape's unique geology, very little nitrogen is removed from groundwater by natural processes, so increased nitrogen loading from development has a particularly significant effect on the nitrogen-limited coastal embayments of Cape Cod. When an excess of nitrogen is introduced to an embayment, changes in the natural ecology will occur. A common result from excess nitrogen loading is eutrophication, which is the overgrowth of certain plant species (e.g. algae), often leading to the loss of species diversity and community richness, and overall habitat degradation. In some severe cases eutrophication creates anoxic environments resulting in fish kills, loss of eel grass, and aesthetically unpleasant conditions.

Nitrogen sources include septic systems and other water treatment facilities, fertilizer, stormwater, atmospheric nitrogen, sediment nitrogen, and natural background.

As of 2022, the Massachusetts Estuaries Project has studied 40 Cape Cod embayments. Of the 40 studied embayments, 36 are considered “impaired” and have a nitrogen TMDL that have been approved by the Massachusetts Department of Environmental Protection (MassDEP) and the U.S. Environmental Protection Agency (EPA). Though the majority of nitrogen reaching the coastal embayments originates from septic systems, a reasonable percentage of all controllable nitrogen sources originate from impervious surfaces (i.e., stormwater). The Waste Load Allocation (WLA) calculations in the Nitrogen TMDLs consider runoff from the entire impervious area within a 200-foot buffer zone around all waterbodies.

PHOSPHORUS

There are other nutrients that have detrimental effects on water resources besides nitrogen. Phosphorus is generally the limiting nutrient in fresh bodies of water. Phosphorus does not travel as readily through soils as nitrogen, because it binds to iron or aluminum oxides and hydroxides present in soil. However, once these binding sites are full, phosphorus will travel through the soil and into groundwater and freshwater ponds. Although there aren’t any TMDLs on Cape Cod for phosphorus, excess amounts of phosphorus are entering freshwater bodies and causing impairment. Like nitrogen, excess amounts of phosphorus loading causes eutrophication in ponds and lakes. Leading to impaired water quality, fish kills, and loss of habitat.

FIGURE 1. Stormwater Runoff Nitrogen Load to Impaired Embayments

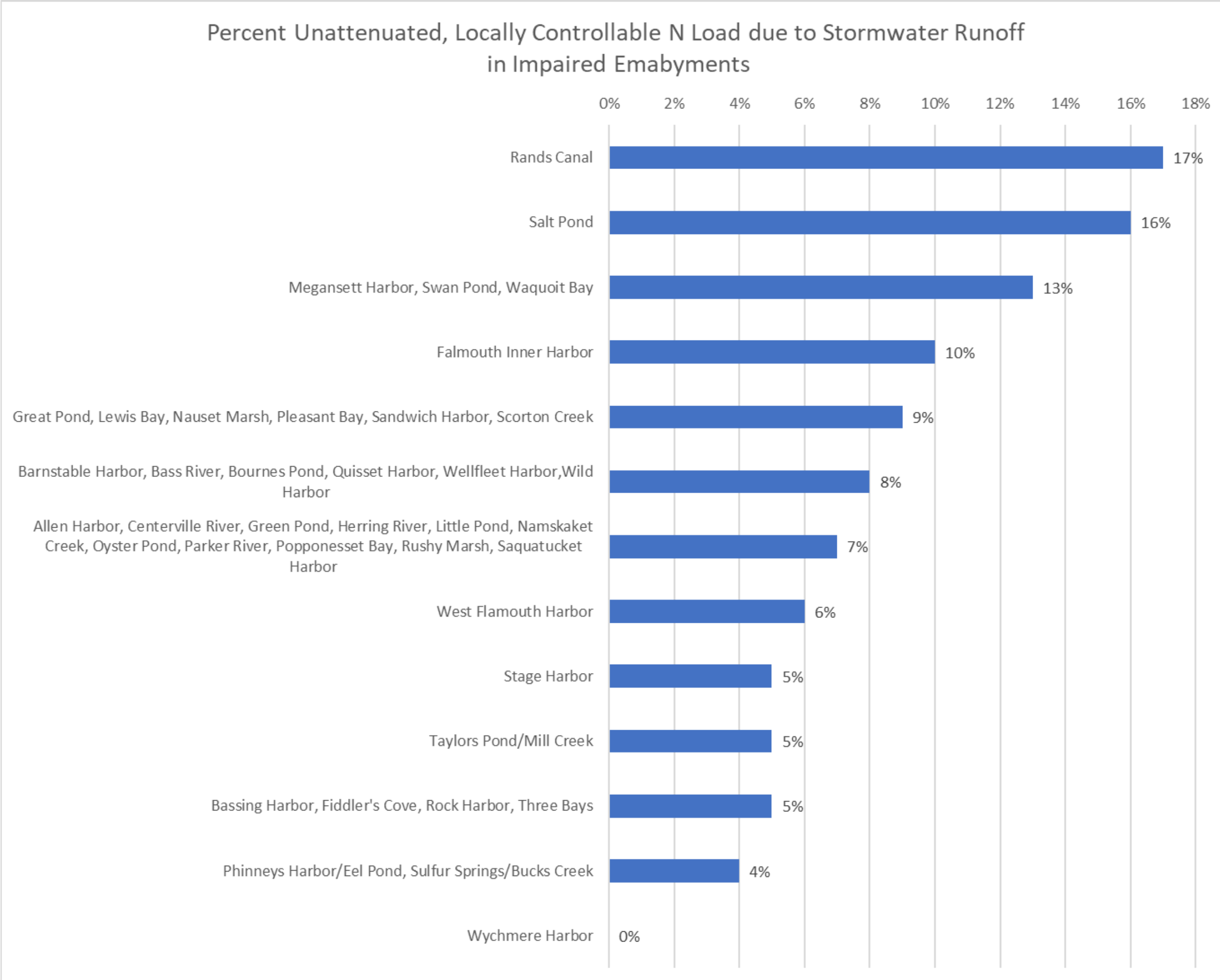
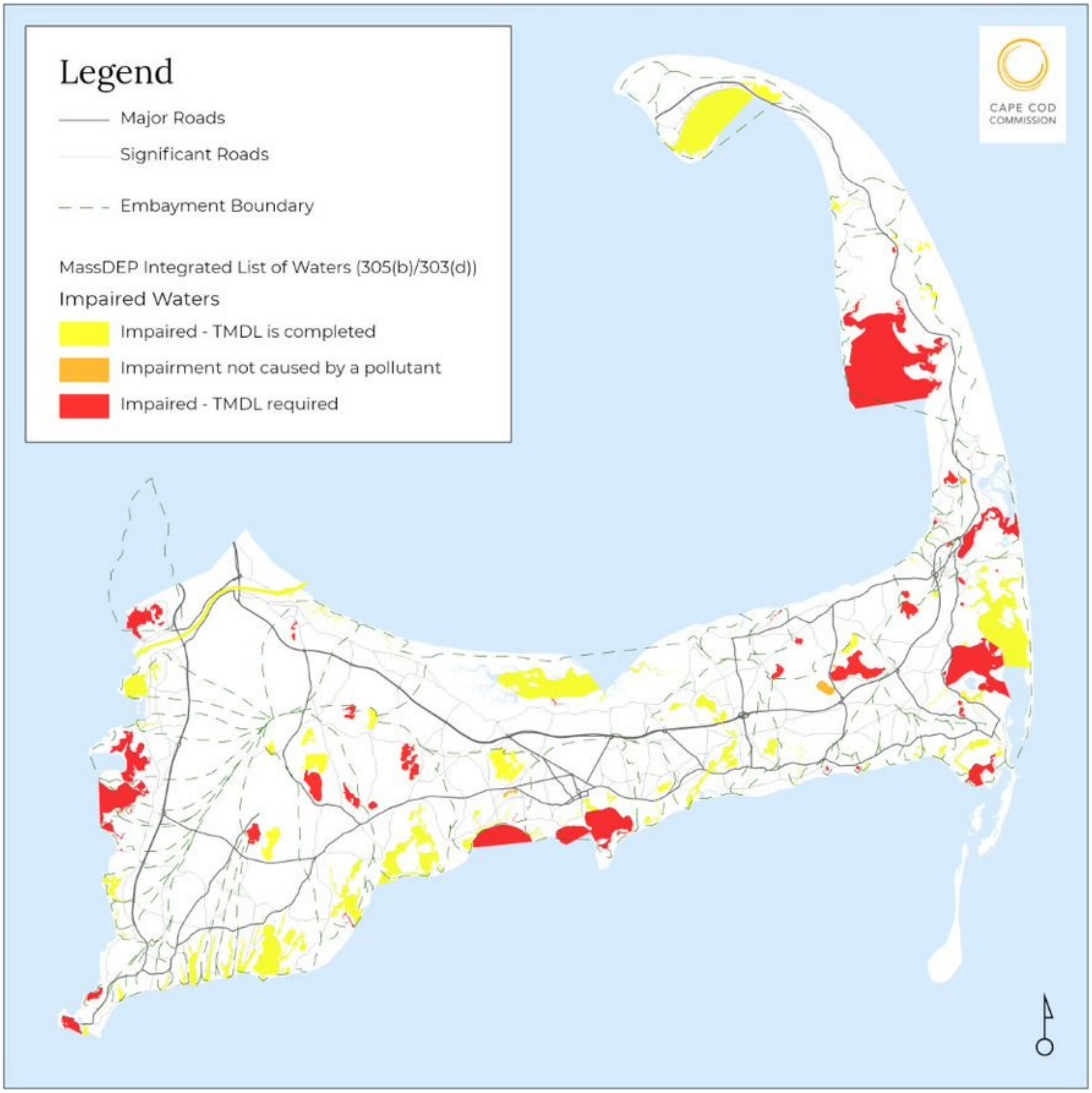


FIGURE 2. Impaired Waters (DRAFT)



BACTERIA

Pathogens can pose a risk to human health by causing gastrointestinal illness through exposure via ingestion, contact with recreational waters, and consumption of filter-feeding shellfish. Waterborne pathogens enter surface waters from a variety of sources including sewage, the feces of warm-blooded wildlife, pets, geese, gulls, and illicit discharges of boat wastes. Areas of elevated bacteria levels in Cape Cod watersheds are believed to be primarily from boat wastes, pets, wildlife, birds, stormwater, and failing septic systems. Eighty Five percent of Cape Cod's watershed populations (residences and businesses) have individual septic systems for disposal of human waste. Septic system failures or poorly performing systems play an important part in the bacterial contamination throughout the Cape.

Pathogen TMDLs were developed for all Cape Cod Watersheds using fecal coliform as an indicator bacterium for shellfish areas, enterococci for bathing in marine waters, and E. *coli* for fresh waters. Understanding sources of bacteria is essential when selecting appropriate stormwater management strategies.

Pathogen TMDLs exist for 86 pathogen-impaired water body segments on Cape Cod, defined through the following TMDL documents:

- Final Pathogen TMDL Report for the Cape Cod Watershed (49 segments) - 2009
- Addendum to Final Cape Cod Pathogen TMDL Report (17 segments) – 2012
- Final Pathogen TMDL for Buzzards Bay Watershed (14 segments) - 2009
- Final Pathogen TMDL for Three Bays Watershed, Barnstable, MA (4 segments) - 2009
- Bacteria TMDL for Muddy Creek - 2005
- Bacteria TMDL for Frost Fish Creek, Chatham, MA – 2005

The WLA calculation for the pathogen TMDL assumes a 200-ft buffer zone around embayments as the contributing area for stormwater. According to the Cape Cod Watershed TMDL, data indicate that in general, two to three orders of magnitude (i.e., greater than 90%) reductions in stormwater fecal coliform loading will be necessary, especially in developed areas.

HYDROLOGIC RESPONSE UNITS

To analyze the runoff potential, and specifically the amount of phosphorus load from stormwater runoff, Commission staff utilized work done to develop the EPA Opti-Tool (Tool). The Tool is designed to assist in the planning and optimizing of stormwater management practices to provide the greatest benefit for achieving water resource goals, while balancing costs. Output from the Tool helps users determine the best stormwater management practices across changing and developing landscapes. The Tool is based on extensive research and modeling and incorporates inputs that are regionally representative of stormwater data, precipitation data from Boston Logan Airport, and annual average load export rates from major land uses.

One of the main inputs to the Tool is hydrologic response units (HRUs). HRUs represent areas in our communities of similar physical characteristics that respond similarly to precipitation and weather events. The units in the hydrologic response units are newly defined categories comprised of land use, land cover, and soil type. These characteristics assess the potential of an area to generate stormwater runoff and estimate potential pollutant loading. Land use plays a lesser role in terms of generating runoff but is necessary for determining the amount and type of pollutants likely to be present in the runoff. When considered together in newly categorized HRUs, runoff, phosphorus, and nitrogen load values can be calculated.

Calculating runoff impacts consistently across towns or regions is important for monitoring current and potential impacts from stormwater and pollutant loads. Commission staff developed a standard for HRUs to ensure that each town in Barnstable County will have the same data and comparable stormwater impact calculations.

Hydrologic Response Unit data inputs for this analysis include:

- Land use describes how people modify land, representing the economic and cultural activities and the built environment in a given place. Land use definitions or districts divide properties into different categories (residential, commercial, agricultural). This information was obtained from MassGIS 2016 Land Use. Classifying land use within an area is an important step in identifying areas that are more vulnerable to stormwater runoff and pollution.

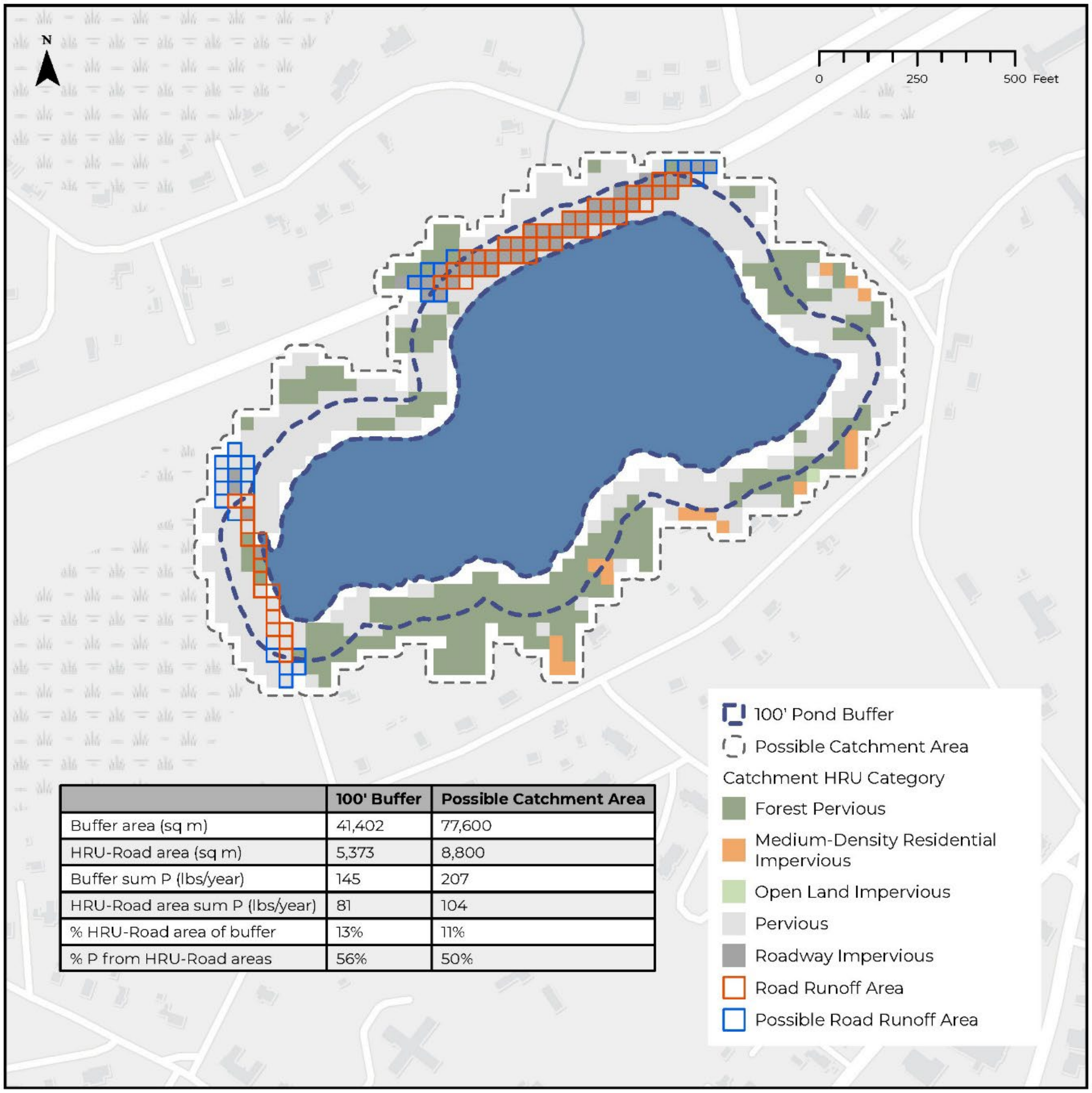
- Land cover indicates the physical land type (grass, bare ground, asphalt) and was also obtained from MassGIS 2016 Land Use.

- Soil type refers to the makeup and characteristics of the soil, and specifically for this purpose, the hydrologic soil group. The soil data were obtained from USDA NRCS Soil Survey Geographic (SSURGO) Database.

An adjustment made by Commission staff to the HRU was a designation of an area as impervious or pervious. Impervious and pervious surfaces have a large impact on rain and runoff infiltration. Nonporous materials, such as roads, roofs, and parking lots, significantly obstruct infiltration of water. The impervious or pervious designations were determined using a 30% threshold. In a 10x10 meter grid cell, if more than 30% of the cell's area was impervious, then the entire cell was determined to be impervious. If 70% or more of the grid cell has pervious surfaces, the entire cell was designated to be pervious. For reference, a 10x10 meter grid cell is about the size of a two-car garage.

To estimate which road segments may contribute runoff into a 100-foot pond buffer, a possible catchment area was delineated. Elevation information was used to define a contribution area to a pond buffer which included distance traveled on downhill slopes (-90° to 0° movement allowed) and forward aspects (180° movement allowed). The same parameters were used to calculate distance traveled from roads. Areas where travel distance "from" roads and "to" ponds intersected indicated possible road runoff areas that were not already captured within a 100-foot pond buffer. Surface water flow characteristics were not included in the catchment delineation.

Figure 3 illustrates the analysis described above and includes a pond, its 100-foot buffer, and a "possible catchment area" that includes the area that is connected by slope and direction to the pond buffer. The various HRU categories within the 100-foot buffer and catchment area are shown. HRUs that overlap roads in the 100-foot buffer are highlighted as "road runoff" areas, with "possible road runoff" areas additionally included where travel distance from roads falls within the catchment area.



	100' Buffer	Possible Catchment Area
Buffer area (sq m)	41,402	77,600
HRU-Road area (sq m)	5,373	8,800
Buffer sum P (lbs/year)	145	207
HRU-Road area sum P (lbs/year)	81	104
% HRU-Road area of buffer	13%	11%
% P from HRU-Road areas	56%	50%

FIGURE 3. Example pond and 100-foot buffer showing HRUs and phosphorus contribution to the pond from roads and other land use acivities.

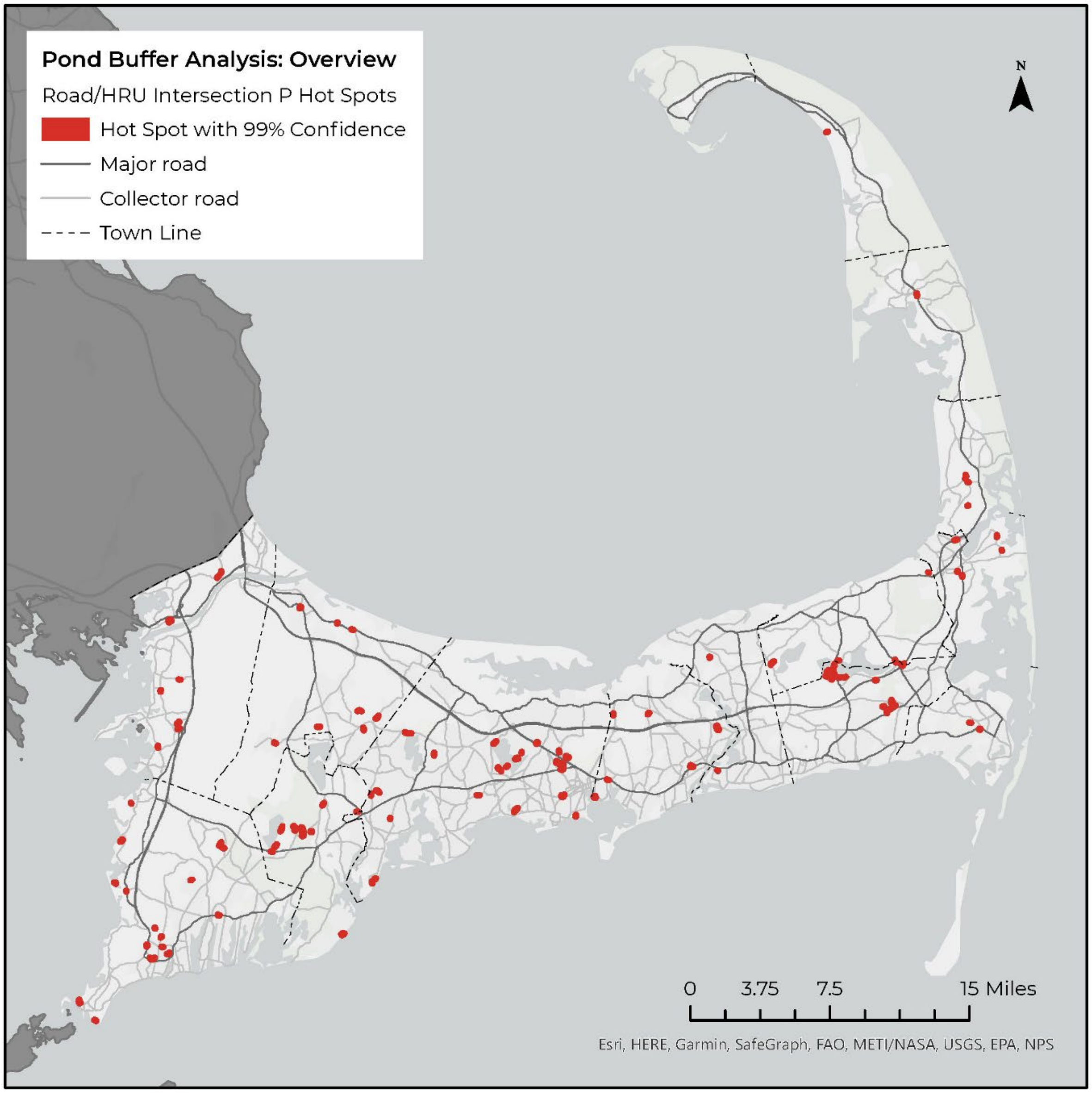


FIGURE 4. Cape-wide pond buffer analysis of road and HRU intersection indicating phosphorus loading hotspots.

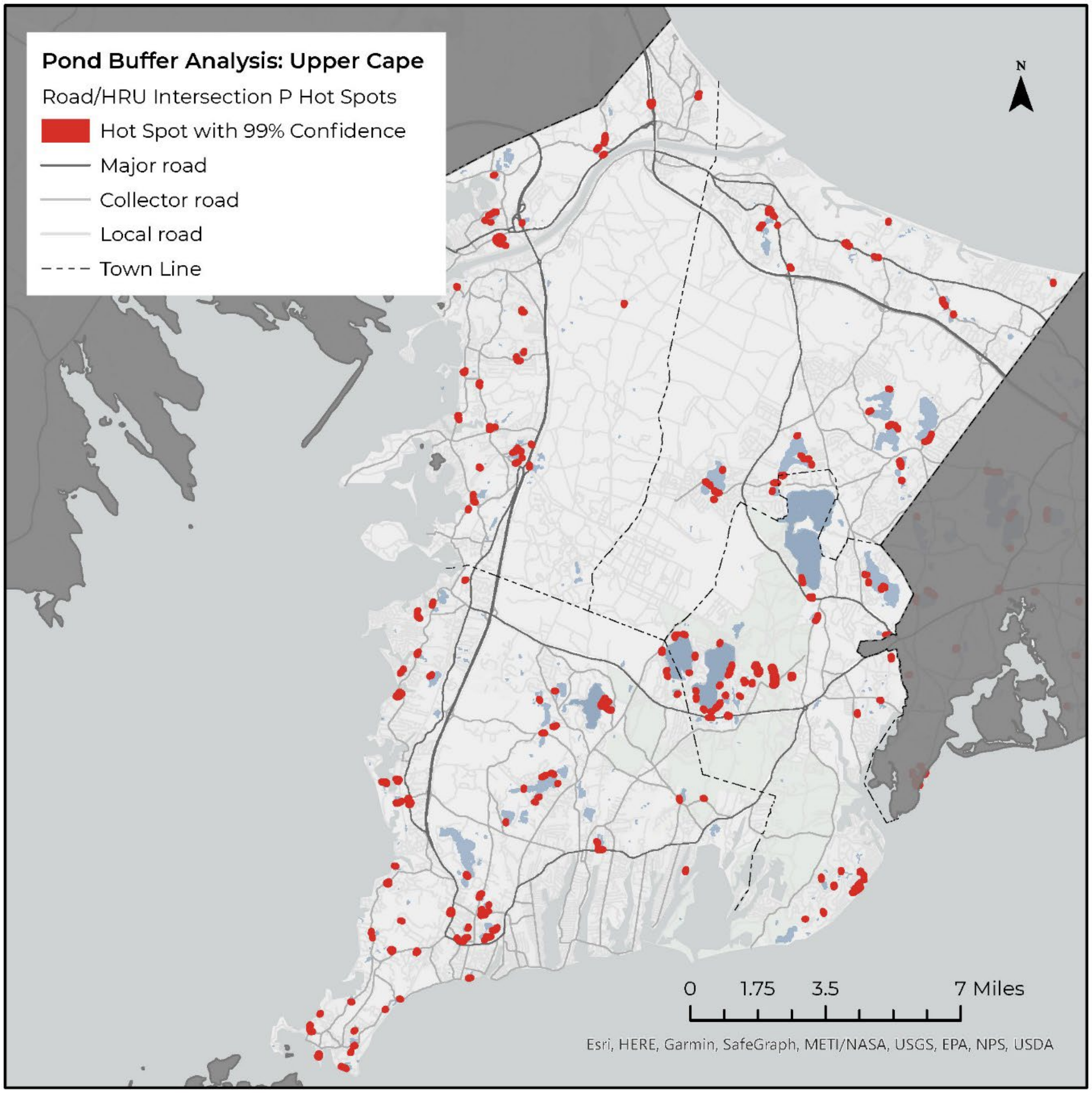


FIGURE 5. Pond buffer analysis of road and HRU intersection for upper Cape indicating phosphorus loading hotspots.

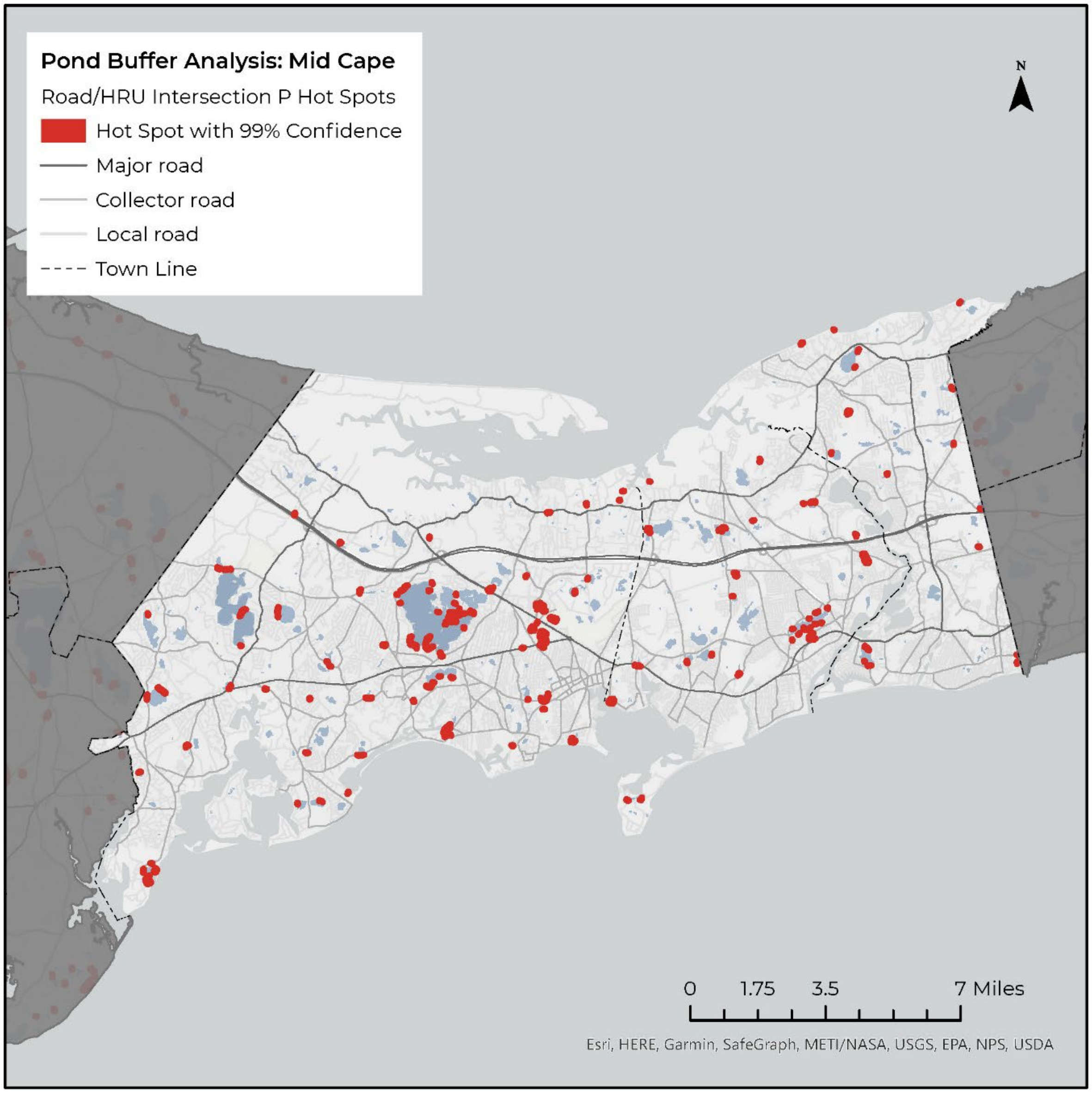


FIGURE 6. Pond buffer analysis of road and HRU intersection for mid Cape indicating phosphorus loading hotspots.

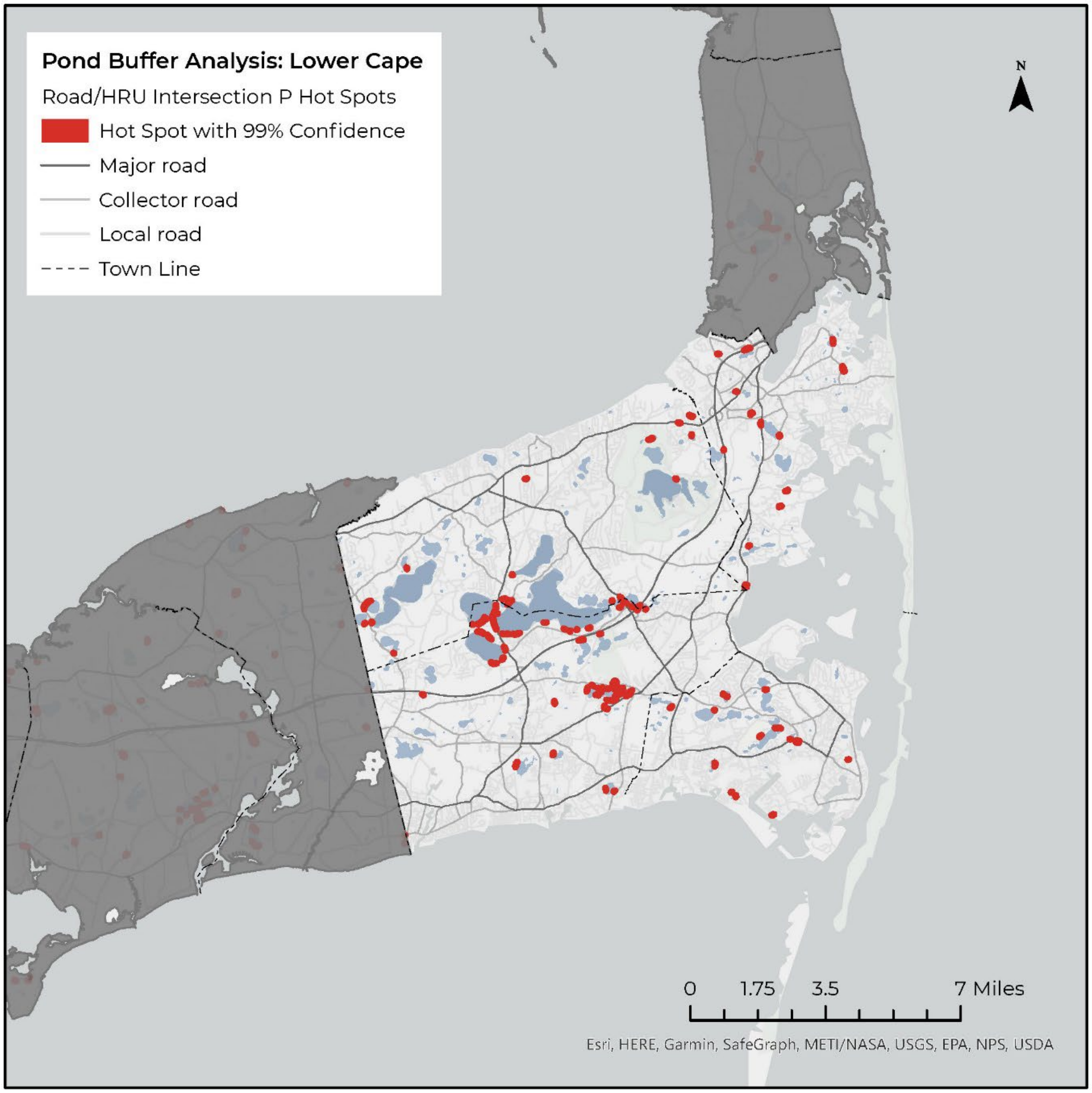


FIGURE 7. Pond buffer analysis of road and HRU intersection for lower Cape indicating phosphorus loading hotspots.

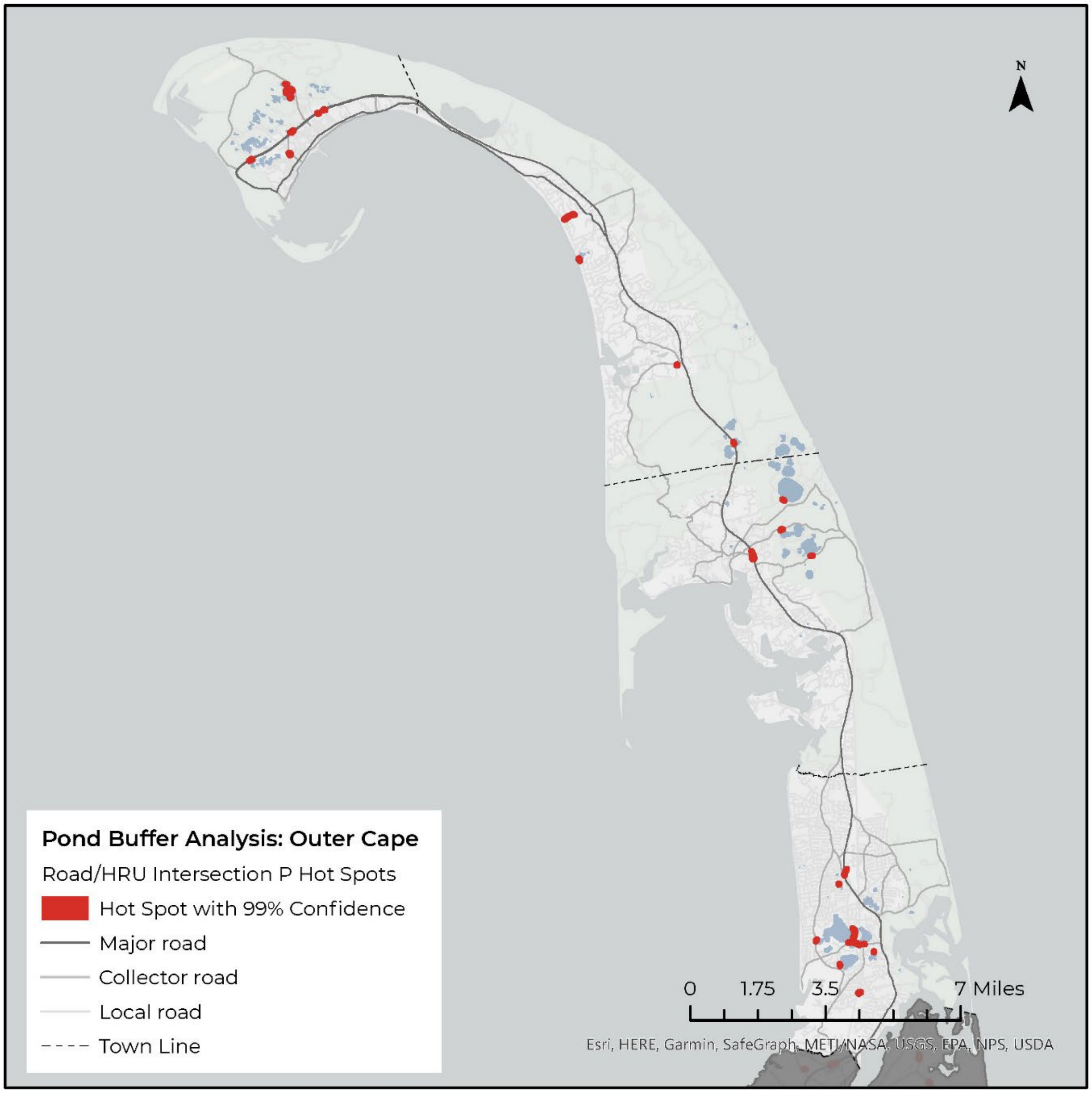


FIGURE 8. Pond buffer analysis of road and HRU intersection for outer Cape indicating phosphorus loading hotspots.

Stormwater Runoff and Sensitive Resource Areas

The map (Figure 9), below, identifies resource areas (and buffers around those areas) that can be sensitive to pollutants in stormwater runoff. These identified areas are where Nitrogen, Phosphorous, and/or Pathogens should be mitigated in stormwater runoff to protect sensitive resources areas on the Cape. Existing roadway retrofits and future roadway development should consider treatment of these pollutants in the identified areas.

Because different resource areas are sensitive to different kinds of pollutants, Table 1, below, outlines the resource areas mapped and their associated pollutants of concern. Buffer distances around resource areas were chosen by considering where stormwater runoff from roads may impact sensitive natural habitats and are derived from TMDL considerations and the RPP. In general, buffers are required to protect surface water bodies from sedimentation, erosion, and pollution; they are also needed to maintain wildlife habitat. In WLA calculations used for both the Nitrogen and Pathogen TMDLs on Cape Cod, a 200-foot buffer was considered as the contributing area for stormwater runoff. The RPP designates buffer distances around Sensitive Natural Resource Areas (SNRA), where development should be located outside of these buffer zones. Buffers include a 300-foot buffer around ponds, a 350-foot buffer around certified vernal pools, and a 200-foot buffer around rivers.

FIGURE 9. Stormwater Treatment Areas and the Pollutant(s) to be Treated (DRAFT)

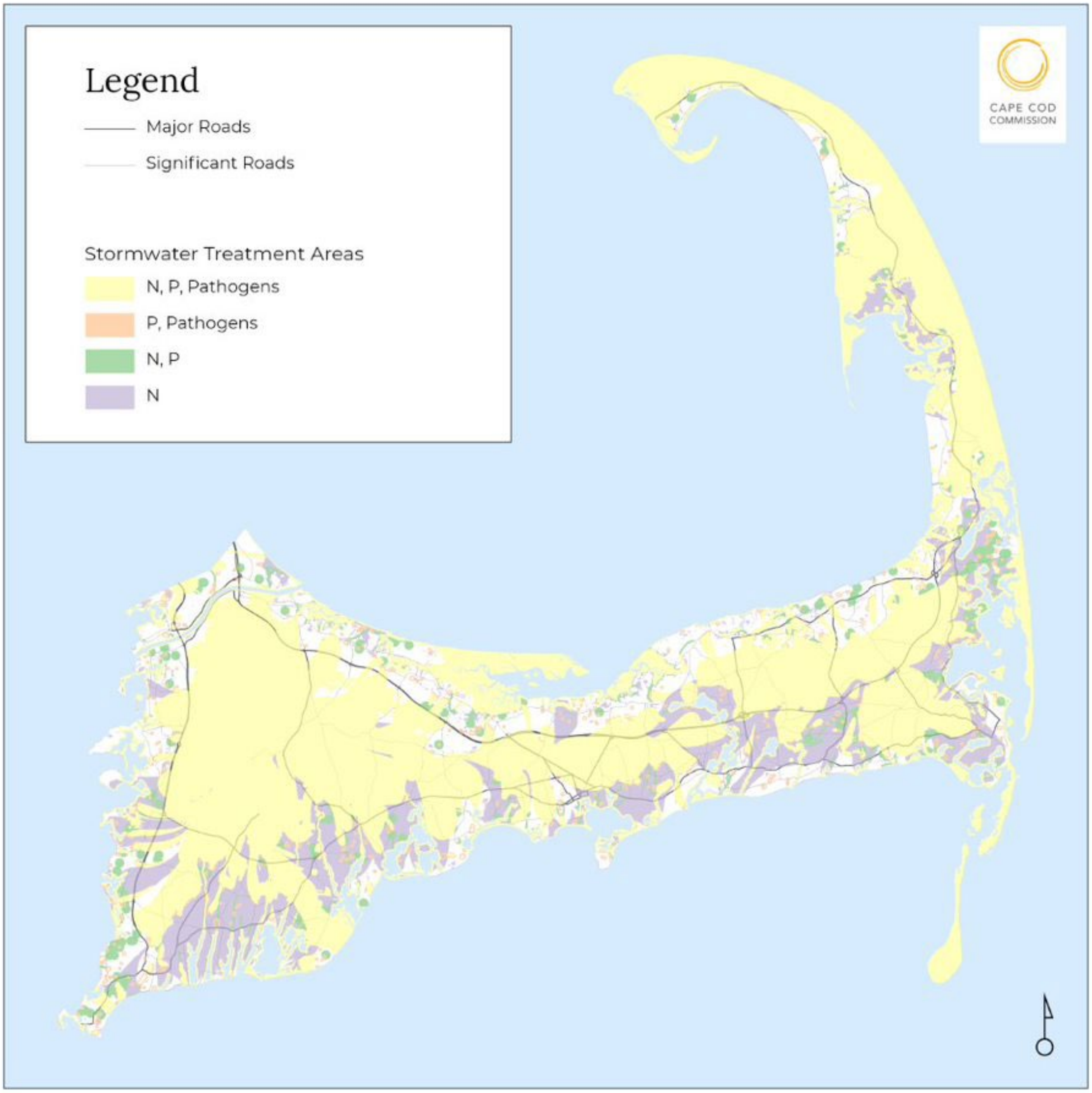


TABLE 1. Sensitive Resource Areas and Associated Pollutants of Concern

SENSITIVE RESOURCE AREA	NOTES	POLLUTANTS TO REDUCE
Watersheds requiring N removal	Indicates to what level watersheds must reduce current nitrogen loading	N
Impaired Waters	Impaired for pollutants (nutrients, metals, pesticides, solids, and pathogens) or impaired for pollution (e.g., low flow, habitat alteration, non-	P, N, Pathogens

	native species infestations). "Impaired" defined by Section 305 (b) and 303 (d) of the CWA.	
Impaired Waters Buffer	300-foot buffer around impaired waters	P, N, Pathogens
Outstanding Resource Waters	Considered a "Critical Area" according to MA Stormwater Standards. Stormwater discharges to Outstanding Resource Waters shall be removed (and set back from the receiving water or wetland) and receive the highest and best practical method of treatment	N, P, Pathogens
WPAs & IWPAs	Considered a: "Critical Area" according to MA Stormwater Standards. Water Resource Area in the RPP which have additional considerations for maintenance of water quality "Significant Natural Resource Area" according to RPP	N, P, Pathogens
Coldwater Fisheries	200 foot buffer. Overall sensitive habitat that requires maintenance of cold temps and high dissolved oxygen.	P, N, Pathogens
National Heritage and Endangered Species Program (NHESP) Certified Vernal Pool buffers	350 foot buffer required per RPP. Considered a SNRA (per RPP). EPA recommends managing a 1000 foot radius area beyond the edge of a vernal pool basin as vernal pool upland habitat.	P, N
Ponds Buffer	300 feet	P, Pathogens
River Buffer	200 feet	P, N
MassDEP Wetland Areas	Considered a SNRA (per RPP).	N
NHESP Priority Habitats	Considered a SNRA (per RPP).	P, N, Pathogens
Freshwater Recharge Area	Considered a Water Resource Area in the RPP with additional considerations related to phosphorus loading	P, N, Pathogens
Potential Public Water Supply Area	Considered a SNRA (per RPP).	P, N, Pathogens

Climate Change Considerations in Stormwater Management

Recent storm records and predictions for storm activity in the coming years suggest that roadways in New England will trend towards more extreme events. Accordingly, Massachusetts transportation infrastructure should be designed to accommodate higher intensity storm events. The Massachusetts Climate Change Adaptation Report also cites evidence that by 2050, annual precipitation in Massachusetts may increase by 8%, with a winter increase of 16% (accompanied by a decrease in snow days and an increase in winter rain precipitation). These climate predictions suggest that future planning for stormwater management should consider increased volumes of water (and stormwater runoff) on Massachusetts roadways.

Climate Change Consideration for Low Lying Roads

Low lying roads are areas prone to flooding from the combined effects of hazards such as sea level rise, storm surge, and erosion. Cape Cod is especially vulnerable to multiple hazards including erosion, coastal storm flooding, and sea level rise, because of its unique geography and roadways that travel through ever-changing environments. Flooding is currently a regular event on several road segments during extreme high tides and storm events. As seas rise and storms intensify the impact to our coastlines and flooding occurrences will increase in frequency and depth.

Roads are more or less likely to flood depending on a number of factors such as proximity to the coast and road elevation. Significant rain events may also result in inland road flooding but are not a focus of this project. The vulnerability of a road is determined by the probability or likelihood that it will flood on an annual basis. The probability of a road flooding annually is determined by the elevation of the road surface as compared to the elevation of the anticipated water surface during a storm event, under future time horizons.

Regionally available data was used to score roads and road segments according to their criticality within a community. Criticality is how important a road is to the community's transportation needs. The scoring framework used to determine road criticality includes variables such as:

1. Usage/Network function - the type of road and average daily traffic

2. Vulnerable populations - environmental justice or social vulnerability communities,

3. Emergency/Community Services - access to critical, emergency, or community facilities

4. Economy - business activity density

The roads in a community that are both highly critical and have a high probability of flooding are ranked as high-risk roads or road segments that may require adaptation alternatives, including elevation or relocation of a road segment. Relocation, also known as managed retreat, is the process of strategically relocating roads or a road segment out of the path of coastal hazards.

Cape Cod communities are identifying vulnerable roads utilizing the Massachusetts Coast Flood Risk Model (MC-FRM), a state-of-the-art model that projects flooding under future time horizons. The model includes the dynamic impacts of tides, waves, wave run-up and overtopping, storm surge, winds, and currents over a range of storm conditions to generate the probability of inundation. The MC-FRM generates hydrodynamically modeled projections for sea level rise and storm surge to determine projected changes in the likelihood of flooding under climate conditions for 2030, 2050, and 2070. The model uses inputs, such as sea level rise, tropical storms, landscape, elevation, and climate change, to create multiple outputs. Flood probability and flood depth are the primary outputs used in this assessment to evaluate roadways.

DESIGN CRITERIA FOR MANAGING STORMWATER VOLUME

First Flush

The Water Quality Volume (WQV) represents the runoff generated by a design depth of rainfall from a given drainage area. This provides a minimum quantity (ft^3) of water to capture and treat for the constituents of concern. To capture the full volume of each rain event would be costly and require large, dedicated portions of land. In its essence, the goal of stormwater management is twofold and includes treating contaminated runoff and minimizing flooding issues for the majority of storm events. The WQV calculation ensures that water quality treatment is provided for the most contaminated runoff, or the "first flush," of each event. The first flush typically includes the most polluted runoff of an event as it re-suspends contaminants that have been gathering on impervious surfaces during dry periods. Therefore, guaranteeing the capture and treatment of this initial runoff stream is the most important consideration from a water quality standpoint.

As defined by the Massachusetts Stormwater Design Handbook, the required WQV for the below land use types equals 1.0 inch of runoff times the total impervious area.

- from a land use with a higher potential pollutant load
- within an area with a rapid infiltration rate (greater than 2.4 inches per hour)
- within a Zone II or Interim Wellhead Protection Areas (IWPAs)
- near or to the following critical areas:
  - Outstanding Resource Waters
  - Special Resource Waters
  - bathing beaches

- shellfish growing areas
- cold-water fisheries.

The remaining land use types not listed here require a design depth of 0.5", but 1" is currently a recommended practice and will likely be the standard in the near future.

For the purposes of this report the WQV is calculated following Equation 1 and is defined below.

Equation 1: WQV Calculation

WQV = P * Rv * I * A

Where:

P = precipitation (in.)

Rv = unitless volumetric runoff coefficient

I = percent impervious cover draining to structure

A = contributing drainage area to BMP (acre)

Greater Design Flood Frequency

As discussed in the 2011 Massachusetts Climate Change Adaptation Report, addressing the resiliency and adaptability of infrastructure in the face of global climate change is of paramount concern. A 2010 study from the University of New Hampshire discussing trends in precipitation in the Northeastern United States indicates "that the occurrences of extreme precipitation events, and the intensity of rainfall, are increasing." The study shows that annual precipitation has increased since the late 1940's with the largest increases occurring in recent years. Researchers with the University of Massachusetts Boston Environmental, Earth and Ocean Science Department analyzed trends in precipitation from 1954 to 2008. Findings in the study strongly suggest the need for updating design storm estimates in Maine, New Hampshire and Massachusetts.

The table below, Figure 10, is an excerpt from Chapter 8 of the Mass Highway Design Manual, 2006 Edition and shows the recommended design flood frequencies for drainage systems by highway functional class. With trends showing an increase in event intensity and frequency, consideration should be taken to use greater design flood frequency values in areas of increased hydroplaning risk. It is becoming increasing common, and generally recommended, to the 2015 NOAA Atlas 14 or the regularly updated Northeast Regional Climate Center estimates.

FIGURE 10. Recommended Design Flood Frequency (excerpt from MassHighway Design Manual)

		Type of Installation		
Highway Functional Class	Urban/Rural	Cross Culverts	Storm Drain System[2]	Open Channels[3]
Interstate/Freeway/Expressway	Both	50-yr	10-yr[4]	50-yr
Arterial	Urban	50-yr	10-yr[4]	50-yr
	Rural	50-yr	10-yr[4]	50-yr
Collectors/Local	Urban	25-yr[5]	5-yr	25-yr[5]
	Rural	10 or 25-yr	2 or 5-yr	10 or 25-yr

1. The values in the table are typical ranges. The selected value for a project is based on an assessment of the likely damage of a given flow and the costs of the drainage facility.
2. This includes pavement drainage design.
3. This includes any culverts which pass under intersecting roads, driveways, or median crossings.
4. Use a 50-yr frequency at underpasses or depressed sections where ponded water can only be removed through the storm drain system.
5. The selected frequency depends on the anticipated watershed development and potential property damage.

Source: HEC #1, March, 1969. Design of Highway Pavements, pp. 12-5 to 12-6. Note: HEC #12 — Revised, March, 1984.

Note: 100-year requirements must be checked if the proposed highway is in an established regulatory floodway or floodplain, or resource area is defined by the April, 1983 revisions to Ch. 131 MGL, Section 40. See Section 10.1.2.

Pavement Cross Slope and Expanded Shoulder

Providing adequate cross slope on a roadway surface and expanding the road shoulder are effective ways to manage runoff. Assuming shoulders are properly sloped to drain away from pavement, both help convey (?) runoff from driving lanes. Because adjusting roadway cross slopes is expensive and results in significant disruption to vehicular travel, such an approach would be considered only if a segment of roadway was already slated for reconstruction and resources like historic character and critical vegetation would not be damaged with inclusion of an expanded shoulder.

Minimize Drainage Path Lengths

Long downhill grades where water is channelized through raised shoulders or berms increase stormwater velocity and quantity until release points are reached, such as a curb cut or a curve transition where concentrated flow turns to sheet flow across the roadway. As drainage path lengths increase, the effects of channelization are compounded. By minimizing drainage path lengths through frequent curb cuts; runoff velocity, volume, and associated ponding are minimized. Catch basins, while a useful management tool for overall runoff reduction, should not be relied upon to minimize drainage path lengths. Due to improper placement, clogging and infrequent maintenance, catch basins are often unable to capture design volumes on busy roadways.

Curbing and Berming

Curbing is primarily used at the outside edge of pavement to contain surface runoff within the roadway and away from adjacent properties. Secondary and tertiary benefits of curbing include the roadside delineation, prevention of slope erosion, , and pedestrian sidewalk protection.

In many instances, preventing runoff from exiting the road surface is an important goal when large quantities of runoff have the potential to affect adjacent property owners and protected natural resources. However, curbing and berming may be unnecessary in areas where there are sufficient median and adjacent rights of way to capture roadway runoff. Where there is sufficient land area to capture roadway runoff excess curbing and berming may be an unnecessary preventative measure and counterproductive when attempting to minimize the potential for hydroplaning. Intermittent or complete removal of curbing and berms in applicable areas will reduce runoff build up and minimize drainage path lengths.

When combined with a properly designed cross slope, the complete removal of curbing and berms will promote country drainage and have minimal risk for slope erosion. Where curbing and berming must remain, drainage pathways should still be minimized by frequent curb cuts. Curb cuts capturing runoff from large drainage areas and long drainage path lengths must account for the increased energy and velocity of runoff to prevent erosion. This may be accomplished through a variety of energy dissipaters such as vegetated filter strips, riprap aprons and riprap outlet basins. Curb cuts capturing runoff within nitrogen sensitive watersheds could utilize specific stormwater controls that address nutrient reduction. The targeted controls should be placed down gradient of energy dissipaters to accept a more controlled flow.

DESIGN CRITERIA FOR WATER QUALITY

Pollutants in stormwater fall into two groups: suspended solids and dissolved pollutants. Particle sizes greater than 0.45 micron are considered suspended solids. Pretreatment devices, such as a sediment forebay or oil grit separator, are ordinarily designed to remove suspended solids that have larger particle sizes. Dissolved solids, however, are removed by treatment practices that rely on settling (e.g. extended dry detention basins and wet basins) or filtration (e.g. sand filters and filtering bioretention areas).

If stormwater runoff will affect surface water that is subject to a TMDL, proponents must design, construct, operate and maintain a stormwater management system that is consistent with the TMDL. Currently, there are TMDLs for both nitrogen and bacteria on Cape Cod.

Treating Nitrogen

There are a growing number of stormwater management technologies which effectively remove nitrogen from stormwater. Stormwater best management practices (BMPs) equipped with vegetation can remove nitrogen through nutrient uptake, while other BMPs create an anoxic, or oxygen free, environment for denitrifying bacteria to convert nitrogen in stormwater to inert nitrogen gas. BMPs that can effectively remove nitrogen include bioretention systems, tree box filters, sub-surface constructed wetlands and retention ponds. Nitrogen removal efficiencies of chosen BMPs can be found in Table 4 (page 31).

Treating Phosphorus

Although there are no TMDLs on Cape Cod for phosphorus, this nutrient impacts the water quality of fresh bodies of water, such as ponds and wetlands. In situations where the siting of a BMP is near a freshwater body, consider BMPs that capture and remove phosphorus, such as retention ponds or bioretention systems. Total phosphorus removal efficiencies for the listed BMPs can be found in Table 4.

Treating Bacteria

In shellfish growing areas and public swimming beaches, bacterial contamination is of concern. Therefore, designers should evaluate BMPs for their ability to capture bacteria or limit their growth. BMP technologies that retain water under conditions that promote bacteria growth (such as enclosed spaces that can become "septic" during extended no flow periods) should be avoided in these areas. For example, identification and remediation of dry weather bacteria sources is usually more straightforward and successful than tracking and eliminating wet weather sources. Only segments that remain impaired during wet weather should be evaluated for stormwater BMP implementation opportunities. Bacterial removal efficiencies for some chosen BMPs can be found in Table 4.

Environmentally Sensitive Roadway Design

Low impact development (LID) techniques are innovative stormwater management systems that are modeled after natural hydrologic features. Environmentally sensitive roadway design involves incorporating LID techniques to prevent the generation of stormwater and non-point source pollution by reducing impervious surfaces, disconnecting flow paths, treating stormwater at its source, maximizing open space, minimizing disturbance, protecting natural features and processes, and/or enhancing wildlife habitat.

BEST MANAGEMENT PRACTICES FOR ROADWAYS

Stormwater control measures (SCM) are best practies to limit untreated, polluted stormwater runoff from reaching waterbodies. SCMs can be categorized in to two categories: structural and non-structural SCMs. Structural SCMs are physical interventions in the landscape, while non-structural SCMs are administrative measures/requirements, such as trainings and operating procedures.

Structural SCMs

Structural SCMs are physical interventions for stormwater management that can be used alone or together to convey, treat, and/or infiltrate stormwater runoff. Structural SCMs can be classified in one or several of the following categories:

- Pretreatment
- Treatment
- Conveyance
- Infiltration
- Other

PRETREATMENT

Pretreatment SCMs are typically the first SCMs in a treatment train and typically remove coarse sediments that can clog other SCMs. The settling process generates sediment that must be routinely removed. Maintenance is especially critical for pretreatment SCMs, because they receive stormwater containing the greatest concentrations of suspended solids during the first flush. Pretreatment SCMs can be configured as on-line or off-line devices. On-line systems are designed to treat the entire WQV. Off-line practices are typically designed to receive a specified discharge rate or volume. A flow diversion structure or flow splitter is used to divert the design flow to the off-line practice. Examples of pretreatment SCMs include:

- Deep Sump Catch Basins
- Oil Grit Separators
- Proprietary Separators
- Sediment Forebays
- Vegetated Filter Strips

TREATMENT

Stormwater Treatment Basins provide peak rate attenuation by detaining stormwater and settling out suspended solids. The basins that are most effective at removing pollutants have either a permanent pool of water or a combination of a permanent pool and extended detention, and some elements of a shallow marsh. Stormwater basins include:

- Extended Dry Basins (Detention Ponds)
- Wet Basins (Retention Ponds)

Constructed stormwater wetlands are designed to maximize the removal of pollutants from stormwater runoff through wetland vegetation uptake, retention and settling. Gravel wetlands, however, remove pollutants by filtering stormwater through a gravel substrate.

- Constructed Stormwater Wetland
- Gravel Wetland

Other filtration SCMs include:

- Filtering Bioretention Areas and Rain Gardens
- Proprietary Media Filter
- Sand Filters/Organic Filters
- Tree box Filter

CONVEYANCE

These SCMs collect and transport stormwater, usually to other SCMs for treatment and/or infiltration. Conveyance SCMs may also treat runoff through infiltration, filtration, or temporary storage. For example, a vegetated swale functions both as a runoff conveyance channel and the vegetation prevents erosion, filters sediment, and provides some nutrient uptake benefits.

- Drainage Channels
- Grass Channels
- Water Quality Swales
    - Dry
    - Wet

INFILTRATION

Infiltration techniques reduce the amount of surface flow and direct the water back into the ground.

- Exfiltrating Bioretention Areas and Rain Gardens
- Dry Wells
- Infiltration Basins
- Infiltration Trenches
- Leaching Catch Basins

- Subsurface Structures

OTHER

- Dry Detention Basins
- Green Roofs
- Porous Pavement
- Rain Barrels and Cisterns

SCM accessories are devices that enable SCMs to operate as designed. SCM accessories include the following:

- Check Dams
- Level Spreaders
- Outlet Structures
- Catch Basin Inserts

TREATMENT TRAINS

A SCM "treatment train" incorporates several stormwater treatment mechanisms in sequence, like railcars in a train, to enhance the treatment of runoff. A series, rather than using a single method of treatment, improves the levels and reliability of pollutant removal. The effective life of a SCM can be extended by combining it with pretreatment SCMs, such as a vegetated filter strip or sediment forebay, to remove sediment prior to treatment in the downstream "units." Sequencing SCMs can also reduce the potential for re-suspension of settled sediments by reducing flow energy levels or providing longer flow paths for runoff.

Examples of treatment trains:

- A sediment forebay discharging to a wet basin flowing into a constructed stormwater wetland
- A water quality swale flowing into a wet basin or a constructed stormwater wetland
- An oil grit separator connected to a sand or organic filter
- A sediment forebay discharging to an extended dry detention basin connected to a sand filter
- A water quality swale discharging to a vegetated filter strip connected to an infiltration trench

Non-Structural SCMs

Non-structural SCMs are policies, educational approaches, and housekeeping efforts that can help mitigate stormwater runoff. Because nonstructural practices can reduce stormwater pollutant loads and quantities, the size and expense of structural SCMs can be reduced, thereby affording substantial cost savings. Below are two non-structural SCMs that can be used to reduce the amount of contaminants in roadway stormwater runoff.

STREET SWEEPING

Street sweeping programs have the capacity to be effective in removing pollutants, primarily total suspended solids (TSS), from stormwater.

Three factors that can have an influence on the effectiveness of a street sweeping program are:

(1) Access - Studies have shown that up to 95% of the solids on a paved surface accumulate within 40 inches of the curb, regardless of land use. Those responsible for stormwater maintenance have the ability to impose parking regulations during street sweeping occurrences so that sweepers can get as close to curbs as possible.

(2) Type of sweeper - There are three types of sweepers: Mechanical, Regenerative Air, and Vacuum Filter. Each has a different ability to remove TSS.

- Mechanical: use brooms or rotary brushes to scour the pavement. They are not effective at removing TSS (0% to 20% TSS removal).
- Regenerative Air: blow air from a closed-loop system onto the road or parking surface, causing debris, including fine particles, to rise and be vacuumed. Regenerative air sweepers may blow particulates off the vacuumed portion of the roadway or parking lot, where they can be collected by stormwater runoff when it rains.
- Vacuum filter: there are two types, wet and dry. The dry type uses a broom in combination with the vacuum. The wet type uses water for dust suppression. Research indicates vacuum sweepers are highly effective in removing TSS.

Regardless of the type chosen, the efficiency of street sweeping is increased when sweepers are operated in tandem.

(3) Frequency of sweeping - TSS removal efficiency is determined based on annual loading rates. If a road were swept only once a year with a sweeper that is 100% efficient, it would remove only a small fraction of the annual TSS load. Many studies and reports suggest that optimum pollutant removal occurs when surfaces are swept every two weeks.

TABLE 2. TSS Removal Credits for Street Sweeping

TSS REMOVAL RATE	HIGH EFFICIENCY VACUUM SWEEPER – FREQUENCY OF SWEEPING	REGENERATIVE AIR SWEEPER – FREQUENCY OF SWEEPING	MECHANICAL SWEEPER (ROTARY BROOM)
10%	Monthly Average, with	Every 2 Weeks Average, with	Weekly Average, with

	sweeping scheduled primarily in spring and fall.	sweeping scheduled primarily in spring and fall.	sweeping scheduled primarily in spring and fall.
5%	Quarterly Average, with sweeping scheduled primarily in spring and fall.	Quarterly Average, with sweeping scheduled primarily in spring and fall.	Monthly Average, with sweeping scheduled primarily in spring and fall.
0%	Less than above	Less than above	Less than above

It has been found that street sweeping programs may NOT be effective due to the following:

- The period immediately following winter snowmelt, when road sand and other accumulated sediment and debris is washed off, is frequently missed by street sweeping programs.
- Larger particles of street dirt may prevent smaller particles from being collected.
- The entire width of roadway may not be swept.
- Sweepers may be driven too quickly to achieve maximum efficiency.
- Land surfaces along the paved surfaces may not be entirely stabilized.

Successful street sweeping programs should consider factors such as whether road and parking lot shoulders are stabilized, the speed at which the sweepers will need to be driven (safety factor such as along a highway), whether access is available to the curb (whether vehicles parked along the curb line will preclude sweeping of the curb line), the type of sweepers, and whether the sweepers will be operated in tandem. Municipalities or private developers that are planning to purchase a new street sweeper should consider vacuum sweepers, because they are the most consistently effective.

ROAD SALTING

The application and storage of deicing materials, most commonly salts such as sodium chloride, can lead to water quality problems for surrounding areas. Salts, gravel, sand, and other materials are applied to highways and roads to reduce the amount of ice or to provide added traction during winter storm events. Salts lower the melting point of ice, allowing roadways to stay free of ice buildup during cold winters. Sand and gravel increase traction on the road, making travel safer.

As snow melts, road salt, sand, litter, and other pollutants are transported into surface water or through the soil where they may eventually reach the groundwater. Road salt and other pollutants can contaminate water supplies and may be toxic to aquatic life. Sand washed into waterbodies can create sand bars or fill in wetlands and ponds, impacting aquatic life, causing flooding, and affecting our use of these resources.

To prevent increased pollutant concentrations in stormwater discharges, the amount of road salt applied should be reduced. Calibration devices for spreaders in trucks aid maintenance workers in the proper application of road salts, so the amount of salt applied could be varied to reflect site-specific characteristics such as road width and design, traffic concentration, and proximity to surface waters. Alternative materials, such as sand or gravel, calcium chloride, and calcium magnesium acetate may be used in especially sensitive areas.

SCMs for Cape Roadways

The following SCMs are discussed in more detail, as they are suitable for construction on

the Cape considering the Cape's permeable soils and more rural, semi-urban landscape.

- Porous pavement (other)
- Leaching Catch Basins (infiltration)/ Infiltration Basins (infiltration)
- Sub-surface Sediment Chambers (pretreatment + infiltration)
- Retention Pond (treatment)
- Bioretention (treatment)
- Advanced Bioretention (treatment)
- Water Quality Swales (conveyance, treatment, infiltration)
- Constructed Stormwater Wetlands (treatment)

POROUS PAVEMENT

FIGURE 11. Porous Pavement adjacent to traditional impervious asphalt pavement (foreground)

(Source: Virginia Asphalt Association)

Porous pavement, also known as pervious, permeable, or open-graded asphalt, is a standard hot-mix asphalt with reduced sand or fines allowing stormwater to infiltrate through a permeable surface. The reduced fines provide air pockets in the pavement creating interconnected void space allowing stormwater to flow through the pavement and into a sand and crushed stone aggregate bedding layer base supporting the pavement. The sub-base provides storage and runoff treatment without requiring additional land area to do so. Porous pavement over an aggregate storage bed will reduce stormwater runoff volume, and pollutants. When properly constructed, porous pavement is a viable alternative to traditional pavement especially in areas where green space and/or additional land area to capture and treat stormwater is limited. Porous pavement may also be incorporated into sidewalks and bike lanes to further reduce site runoff.

Porous pavement has been shown to remove high levels of TSS and petroleum hydrocarbons. When designed correctly, porous pavements may also reduce bacteria contamination.

LEACHING CATCH BASINS/INFILTRATION BASINS

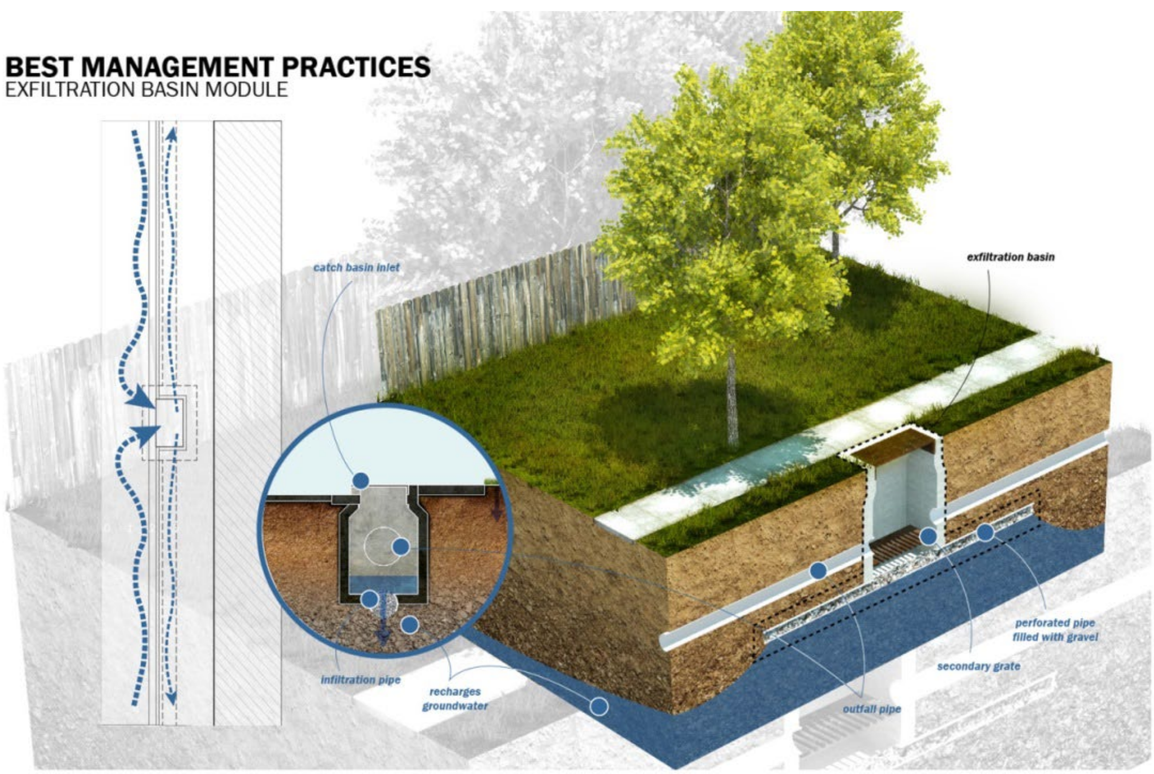


FIGURE 12. Leaching Catch Basin

(Source: Waggonner and Ball Architects)

A leaching catch basin is similar to a traditional catch basin with the added ability to permit the infiltration of captured runoff. Leaching basins are often installed in series with a deep sump catch basin that provides pretreatment. Because of this pretreatment, the catch basin/leaching basin combination is preferable to the leaching catch basin as a higher removal of TSS may be achieved while also extending the life and minimizing maintenance on the leaching catch basin. Leaching catch basins and leaching basins should only be used in areas with highly permeable soils, making these basins a popular stormwater control throughout the Cape.

Leaching catch basins, in series with pre-treatment catch basins, achieve excellent TSS removal in addition to constituents that sorb to fine particulates including petroleum hydrocarbons and metals.

SUB-SURFACE SEDIMENT CHAMBERS/UNDERGROUND SAND FILTERS

FIGURE 13. Sub-surface Treatment Chambers

(Source: Lindsay Cook, Cape Cod Conservation District Intern)

Sub-surface sediment chambers function similarly to surface sedimentation systems. Sediment trapping systems remove pollutants (mainly particulates) from stormwater runoff through a pretreatment sedimentation area followed by an outflow mechanism returning treated flow to a stormwater conveyance system.

In a treatment train, the outflow from the sedimentation area can be followed by an infiltration bed containing filter media (typically sand, soil, gravel or a combination of media).

This infiltration bed removes fines and the pollutants sorbed, or attached, to these particulates. Various contaminants including, but not limited to metals, petroleum hydrocarbons and bacteria may sorb to fines allowing infiltration systems to achieve removal efficiencies in these categories though the physical process of filtration.

WET BASINS

FIGURE 14. Wet Basin

(Source: U.S. EPA)

Wet Basins (formerly retention ponds), or "wet ponds," are a widely used conventional stormwater management tool. They are designed to retain a permanent pool of runoff allowing for continuous water quality treatment. Unlike detention basins, or dry basins, which detain runoff only for a limited period of time, retention ponds may be retrofitted from a flood control measure to a water quality treatment system through the installation of additional outlets. As retention ponds contain an active aquatic ecosystem frequent maintenance is required to prevent the buildup and export of contaminants.

Limitations include standing water increasing the risk of drowning and creating mosquito habitat. Retention ponds also may contain excess nutrients that, without proper maintenance, may lead to harmful algal blooms.

Retention ponds remove TSS, petroleum hydrocarbons, nitrogen (with proper maintenance), metals and in some cases bacteria.

BIORETENTION

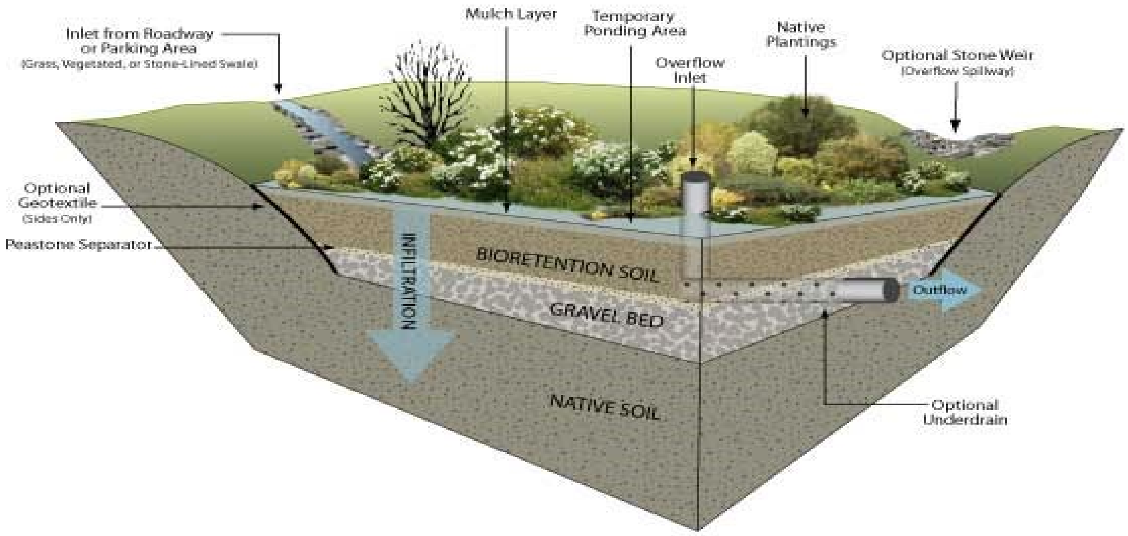


FIGURE 15. Bioretention

(Source: Douglas County Environmental Services)

Bioretention is a method that uses soils, plants, and microbes to treat stormwater before it is infiltrated and/or discharged. Stormwater ponds in shallow depressions underlain by a sandy engineered soil media through which most of the runoff passes.

Bioretention systems can easily be incorporated into the landscape to address and maintain many of the natural hydrologic functions. Pollutants within these systems are removed through both chemical and physical means within the bioretention soil mix. Bioretention systems also encourage biological treatment of nutrients, such as nitrogen, through nutrient uptake by vegetation within the system. Bioretention tends to work best in sandy soils, such as are present in many areas of Cape Cod.

Properly designed bioretention systems achieve excellent removal efficiencies for a wide range of pollutants including TSS, petroleum hydrocarbons, nitrogen, metals, phosphorus and bacteria. Typical removal efficiencies are shown in Table 4.

ADVANCED BIORETENTION

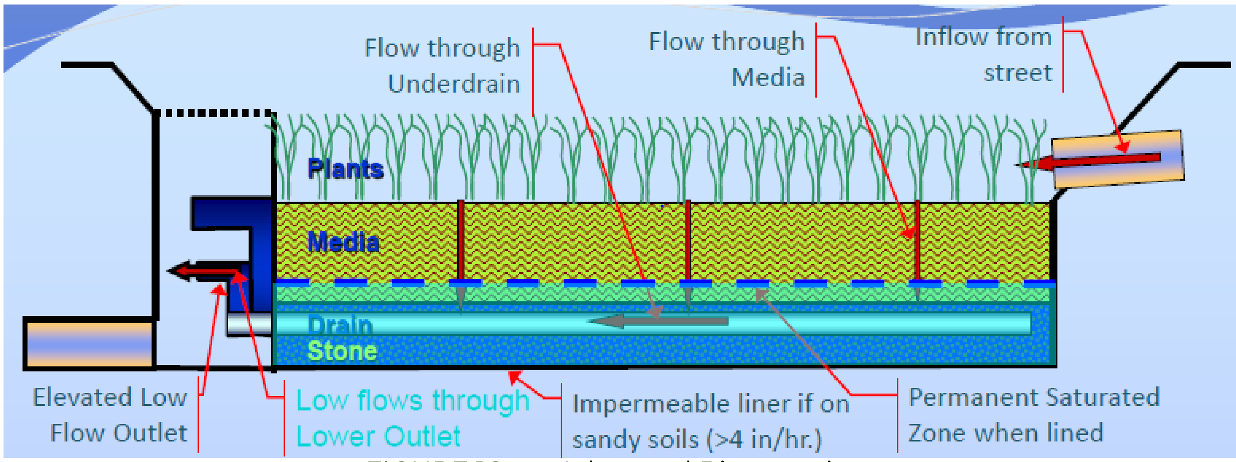


FIGURE 16. Advanced Bioretention

(Source: Washington Stormwater Center)

Advanced bioretention systems provide additional treatment through increased travel and residence time of stormwater. As runoff infiltrates vertically through the soil media, an impermeable liner intercepts and redirects the flow horizontally. This horizontal flow increases contact between runoff, bioretention soil media and root vegetation thereby attaining a reduction in nutrients and various other contaminants greater than traditional bioretention systems. Advanced systems are often lined at the bottom of excavation preventing infiltration and rerouting water once again on a horizontal flow path prior to discharge.

Other modifications to bioretention systems aimed at improving performance include adding supplements to the soil media. Additives such as activated charcoal, sawdust and shredded paper have been shown to improve removal of certain constituents from stormwater runoff. Another approach employs modifications to the configuration of the bioretention system to retain a portion of the accumulated stormwater. This internal water storage design has been shown to reduce soluble nitrogen levels by inducing an anaerobic condition within the bioretention facility itself. Research advances in bioretention system design are continuing to emerge, with promising new methods of increasing pollutant removal.

WATER QUALITY SWALES

FIGURE 17. Water Quality Swales

(Source: Washington Stormwater Center)

Water quality swales are vegetated channels providing conveyance, water quality treatment, and flow attenuation of stormwater runoff. Water Quality Swales provide pollutant removal through vegetative filtering, sedimentation, biological uptake, and infiltration into the underlying soil media. Both wet and dry water quality swales can be implemented with the appropriate type being dependent upon site soils, topography, and drainage characteristics. Water quality swale stormwater practices work best with well-drained soils that encourage infiltration as part of the water quality treatment approach. Recommended cross section of water quality swales includes a ¾ - 1" stone sub base covered with Type A native soils and vegetation.

A variety of shrubs, grasses, and ground covers are acceptable vegetation in both sun and shade conditions for the above mentioned stormwater technologies. Vegetation should be designed to maximize pollutant removal and contribute to native ecological systems and selected based on its tolerance to flooding and its ability to survive with little or no fertilizers and pesticides. This vegetation should be native, as it is adapted to the local climate and grows well without fertilizer..

Roadside water quality swales paired with country drainage provide increased water quality benefits, mimic the natural landscape, are highly compatible with LID design, have minimal impact on wildlife and reduce driving hazards by keeping stormwater flows off the roadway surface.

Water quality swales achieve adequate removal efficiencies for TSS, petroleum hydrocarbons, and metals. Typical removal efficiencies are shown in Table 4.

CONSTRUCTED STORMWATER WETLANDS

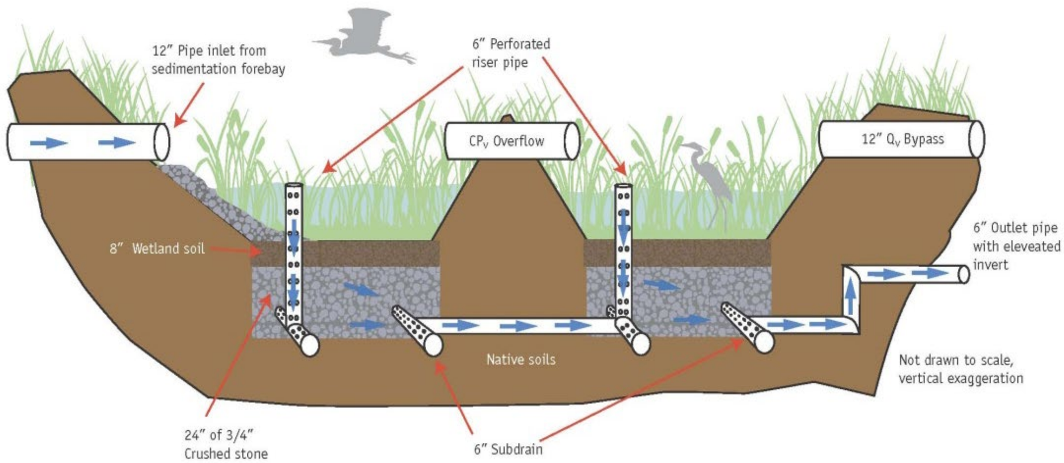


FIGURE 18. Constructed Stormwater Wetlands

(Source: University of New Hampshire Stormwater Center

Constructed wetlands are intended to simulate the functions of natural wetlands by utilizing vegetation, soils, and microbial activity. Constructed wetlands are typically separated into surface flow wetlands and subsurface flow wetlands (or gravel wetlands). These wetland systems have the ability to treat wastewater from a range of pollutant sources, utilize few to no chemicals, have a lower carbon footprint, and may be less expensive in both capital costs and operation and maintenance than conventional treatment options.

The subsurface gravel wetland is designed as a series of horizontal flow-through treatment cells, preceded by a sedimentation basin. It is designed to attenuate peak flows and provide subsurface anaerobic treatment. The subdrains distribute the incoming flow, which then passes through the gravel substrate, and then to the opposite subdrains, into the adjacent cell, and then exits the treatment system. In the event of a high intensity event, the WQV 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. Sub-surface gravel wetlands consistently achieve the highest removal efficiencies of any stormwater management system for a wide range of pollutants including TSS, petroleum hydrocarbons, nitrogen, metals, phosphorus, and bacteria. Typical removal efficiencies are shown in Table 4.

MAINTENANCE OF PREFERRED SCMS

It is important to note that these systems may require different maintenance and ongoing care regimes than what has been traditionally provided for stormwater management and landscape systems in the past. However, many of these systems do not require more time or cost intensive care than typical regimes; the care is just a different type of maintenance practice and these learning hurdles need to be overcome. For example, weekly mowing of traditional grass strips between roadways and sidewalks is both cost and time and fossil fuel resource intensive. In lieu of mown grass strips, Water Quality Swales could instead be constructed to provide contaminant removal benefits in addition to desired green aesthetics. Water Quality Swales may require less overall mowing than traditional grass strips, however, trash may need to be removed in monthly intervals. Overall, the amount of maintenance may be the same or less, but the ongoing care practices are different than what road maintenance crews may be used to. Introduction of preferred SCMs should be accompanied by an educational program that explains the necessary maintenance practices and educates maintenance personnel to ensure long-term maintenance adjustment to provide functional systems.

Below, a typical maintenance summary is provided for the vegetated systems described in the previous section.

Year 1 & 2 - Establishment

Just like any landscape installation, correct moisture levels following construction are essential to plant survival. The first ninety (90) days after planting are the critical time for watering. Young plants require heavy watering to establish. This is the same maintenance as required for traditional roadway edges such as mown grass strips. It is recommended to plant native species as they are adapted to grow in our local climate and generally require less water and less fertilizer than non-native plants.

The plants in a vegetated stormwater system need to be monitored to make sure they become established. It is suggested that this be specified as part of the original construction contract. A two year maintenance period is suggested to be added onto the construction contract to ensure plant survival. Monitoring points should be set up to photograph and document progress of re-vegetation at 3 month intervals. The maintenance contractor would monitor and water the plants, be responsible for replacing any plants that have died, and would control weeds when needed.

Throughout the establishment phase it may be necessary to review individual species tolerance. Some planted species may need to be replaced with species that are performing well. A small allowance should be left in the project budget to adjust the species as needed during the 2 year establishment phase if needed.

During the 2 year establishment phase, it is suggested that the following maintenance procedures be put in place as part of the original construction contract:

First 90 days, Bi-Weekly:

1. Weed

2. Water as needed

3. Check for and fix erosion

4. Inspect for good general appearance of area/gardens, remove trash as needed

Rest of 2-year Establishment Period, Monthly:

1. Regularly inspect for signs of erosion, obstructions, and unhealthy vegetation.

2. Remove weeds and invasive plants.

3. Remove any trash that has washed into the vegetation areas or the inlet channels or pipes.

4. Check the facility within a few days after a rainstorm to observe drainage and infiltration.

Rest of 2-year Establishment Period Seasonally (Spring and Fall):

1. Replace mulch and finish surfaces where needed

2. Plant/replant as needed. Adjust replacement species if required.

3. Scratch surface to prevent "crust"

4. Check pH; adjust as needed (pH should be as close to neutral as possible)

Once the vegetated systems are established during the maintenance contract, the ongoing maintenance required can be less than a typical mown area. The key is that it is a different kind of maintenance that needs to be performed by trained personnel.

<u>Ongoing Maintenance After Establishment Phase</u>

The below seasonal maintenance schedule reflects the maintenance needed after the two year establishment period. Bi-weekly mowing would NOT be required unless grass species are specified as part of a mown Water Quality Swale. Water Quality Swales may require bi-weekly mowing (just like regular grass) in addition to the schedule noted below. Other than the necessary sediment and debris removal 4x per year, the maintenance required would be the same as a mown lawn strip.

TABLE 3. Recommended Time Frames for Typical Maintenance of Vegetated SCMs

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Post Establishment:												
Remove sediment, leaves, debris and weeds		X			X			X			X	
Pruning/Cutback		X									X	

Table 3. Typical Maintenance of Vegetated Stormwater SCMs

Activity	Time of Year	Frequency
Inspect & remove trash	Year round	Monthly
Mulch	Spring	Annually
Remove dead vegetation	Fall or Spring	Annually
Replace dead vegetation	Spring	Annually
Prune	Spring or Fall	Annually
Replace entire media & all vegetation	Late Spring / early Summer	As needed*

* Paying careful attention to pretreatment and operation & maintenance can extend the life of the soil media.

TABLE 4. Comparison of Selected SCMs

SCM	SOURCE	COST/METRIC*	% POLLUTANT REMOVAL						MAINTENANCE NOTES
			TSS	N	P	METALS	ORGANIC C	OTHER % REMOVAL	
Sub surface sediment chambers/Underground sand filters	The Water Research Foundation (2018)	$0.02 to $3,392.28 / sq. ft	70 %	46% (TKN)	33% (Total P)	45%	48%	76% Fecal Coliform	Routine inspections (after major storms) that include trash and debris removal. Lifespan 3-5 yrs. before corrective maintenance red: removal and replacement of top layers of sand, gravel, or filter fabric.
	NPREPD (2007)		86 %	32% (Total N)	59% (Total P)	37% Cu; 87% Zn		37% Bacteria	
Retention pond (Wet Detention Ponds)	The Water Research Foundation (2018)	$ 1.28-$42.0/cubic ft.	50-90 %	40-80% (soluble nutrients)	30-90% (Total P)	40-80%	20-40%	40-90% Pathogens (source: MA Stormwater Handbook)	Routine inspections (after major storms) that include trash and debris removal. Maintenance includes repairs to embankment, sediment removal, and control of algae, insects, and odors.
	NPREPD (2007)		80 %	31% (Total N)	52% (Total P)	57%(Cu); 64% (Zn)		70% Bacteria	
Bioretention	The Water Research Foundation (2018)	$1.26-$607.46/sq. ft. (capitol cost)	90 %	68-80% (TKN)	70-83% (Total P)	93-98%	90%	90% Bacteria	Biannual inspection of trees and shrubs, pruning and weeding, alkaline application.
	NPREPD (2007)		59 %	46% (Total N)	5% (Total P)	81%Cu;79%Zn			

Water Quality Swales	The Water Research Foundation (2018)	$30.86 - $1,537.77/ linear ft. (capital cost)	81%	38% (Nitrate)	9% (Total P)	42 - 71%	67%	62% Hydrocarbons	Periodic mowing, weed control, watering, reseeding of bare areas, mulch and fertilizer application, clearing of debris and sediment. Inspect four times per year. Indefinite lifespan, if properly maintained.
	NPREPD (2007)		81%	39% (Nitrate&Nitrite)	24% (Total P)	65% Cu; 71%Zn			
Porous Pavement	The Water Research Foundation (2018)	$2.07 to $40.28 / sq. ft. (capitol cost)	94%	43% (Nutrients)		76-93%	N/A	N/A	Vacuum sweeping and high-pressure hosing at least four times a year. Annual inspections. Longer lifespan than regular pavement: 30 yr. lifespan in Northern climates due to reduced freeze/thaw stress.
	NPREPD (2007)		89%	42% (Total N)	65% (Total P)	86% Cu; 66%Zn			
Constructed Stormwater Wetlands	EPA (1999)	$26,000 - $55,000 per acre (construction cost)	67%	28% (Total N)	49% (Total P)	36 - 62%	34%	77% Bacteria; 87% Hydrocarbons	Replanting, sediment removal, plant harvesting. Biannual inspections for first few years, annual inspections thereafter. >20 yr. lifespan
	NPREPD (2007)		72%	24% (Total N)	48% (Total P)	47% Cu; 42%Zn		78% Bacteria	

*The Water Research Foundation, International Stormwater BMP Database: 2020 Summary Statistics

REGULATIONS AND PERMIT CONDITIONS

Massachusetts Stormwater Management Standards

Many transportation projects in Massachusetts require adherence to MassDEP's Massachusetts Stormwater Management Standards. Specifically, the standards apply to transportation projects that require either a Massachusetts wetlands permit and/or require a Water Quality Certification. Through the State's Water Quality Certification, the general permit for municipal separate storm sewer systems (MS4) requires compliance with the Stormwater Management Standards. As an MS4 permit operator, the Massachusetts Department of Transportation (MassDOT) must abide by the Massachusetts Stormwater Management Standards.

The Massachusetts Stormwater Standards are comprised of 10 standards that:

1. Prohibit untreated stormwater discharges
2. Ensure peak discharge rates do not increase with development
3. Encourage infiltration by ensuring annual recharge does not decrease with development
4. Require stormwater management systems are designed to remove 80% of the average annual post-construction load of TSS.
    a. A long-term pollution prevention plan is implemented and maintained
    b. SCMs are sized to capture required volume (per Massachusetts Stormwater Handbook)
    c. Pretreatment is provided (per Massachusetts Stormwater Handbook)
5. Eliminate or reduce stormwater discharges to the maximum extent practicable (MEP) for land uses with higher potential pollutant loads.
6. Require the use of the specific source control and pollution prevention measures for discharges in Zone IIs, IWPAs, and near/to "critical areas" (defined below).
7. Require a redevelopment project to meet some of the Stormwater Management Standards and improve existing conditions. Existing stormwater discharges shall comply with Standard 1 only to the MEP.
8. Develop and implement a construction period erosion, sedimentation, and pollution prevention plan.

9. Develop and implement a long-term operation and maintenance to ensure that stormwater management systems function as designed.

10. Prohibit all illicit discharges to the stormwater management system.

Demonstrating compliance with the Stormwater Management Standards to the MEP requires:

1. Making all reasonable efforts to meet each of the Standards

2. Conducting a complete evaluation of possible stormwater management measures (e.g. LID techniques that minimize land disturbance and impervious surfaces, SCMs, pollution prevention, erosion and sedimentation control, and proper operation and maintenance of stormwater SCMs)

3. That if full compliance with the Standards cannot be achieved, they are implementing the highest practicable level of stormwater management.

CRITICAL AREAS

According to Standard 6, specific source controls and pollution prevention measures are required for "critical areas," as defined in MassDEP's Stormwater Management Handbook. MassDOT needs to identify discharges to the following resources areas as a priority and indicate in their stormwater management plan how stormwater controls will be implemented. The "Critical areas" defined in MassDEP's Stormwater Management Handbook, with associated references to the Code of Massachusetts Regulations (CMR), are as follows:

- Outstanding Resources Waters (314 CMR 4.00)
- Special Resources Waters (314 CMR 4.00)
- Recharge areas for public water supplies as defined in 310 CMR 22.02 (Zone Is, Zone IIs and IWPAs for groundwater sources and Zone As for surface water sources)
- Bathing beaches (105 CMR 445.000)
- Cold-water fisheries (310 CMR 10.04 and 314 CMR 9.02)
- Shellfish growing areas (310 CMR 10.04 and 314 CMR 9.02)

Designers of roadway improvements should recognize the special nature of "Critical Areas" (especially surface water drinking water reservoirs and other ORWs). In general, roadway improvements in these areas warrant additional efforts to protect water quality than may apply in other less sensitive areas.

Certain SCM design considerations are important to ensuring adequate performance in critical resource areas. The MassDEP Stormwater Management Policy uses TSS removal as an indicator for SCM performance. In some critical areas, however, TSS may not be the only parameter (or even the primary parameter) of concern. For example:

In shellfish growing areas and public swimming beaches, bacterial contamination is of concern. Therefore, designers should evaluate SCMs for their ability to capture bacteria or limit their growth. SCM technologies that retain water under conditions that promote bacteria growth (such as enclosed spaces that can become "septic" during extended no flow periods) should be avoided in these areas.

In cold water fisheries, water temperature is a critical parameter. Therefore, if a SCM discharges directly to temperature sensitive waters, the SCM should not retain water in such a manner that raises its temperature (as may occur in a shallow wet pond, for instance). Alternatively, SCMs can sometimes be designed to account for the temperature effects; for example, in a deeper wet pond, water can be discharged from lower levels of the pond or re-introduced to the downstream resource area through groundwater recharge.

MASSHIGHWAY STORMWATER HANDBOOK

MassDEP and MassHighway collaborated on the MassHighway Stormwater Handbook, which provides guidance on developing stormwater management strategies for highway projects in order to comply with the Massachusetts Stormwater Management Standards. The handbook describes how to determine whether the MassDEP Stormwater Management Policy applies to a particular project and how standards may apply to projects. The handbook also addresses design strategies that may facilitate compliance, and source control measures for controlling stormwater pollutant loads from stormwater runoff. Also provided is a process for screening and selecting SCMs for roadway improvement projects that meet the objectives of the MassDEP Stormwater Management Policy. The handbook is primarily intended for roadway designers, public works personnel, and other persons involved in the design, permitting, review, and implementation of highway and bridge improvement projects in Massachusetts.

MassDOT MS4 Permit

Phase II of EPA's National Pollutant Discharge Elimination System (NPDES) program applies to both roadway construction and existing roadways. Construction projects exceeding one acre of soil disturbance require filing a Notice of Intent with EPA under the NPDES Construction General Permit. NPDES Phase II Rule also applies to MassHighway, as it considers MassDOT to be an operator of an MS4. MassDOT currently holds an EPA NPDES Phase II Small MS4 General Permit (Permit #: MA043025), with a new MassDOT MS4 permit to be issued in the near future. The current MS4 general permit requires MassDOT to:

- Develop and implement a stormwater management program to reduce discharge of pollutants to the MEP.
- Develop measurable goals for the implementation of the stormwater management program and report on its progress on meeting those goals.
- Implement 6 "minimum control measures":
    - Public education and outreach

- Public involvement and education
- Illicit discharge detection and elimination
- Construction site runoff control program
- Post-Construction stormwater management
- Pollution prevention and good housekeeping in municipal operations.

MASSDOT'S STORMWATER MANAGEMENT PLAN

In MassDOT's *NPDES Stormwater Management Plan for MassHighway Owned and Operated Highways*, MassDOT explains how SCMs and associated goals are addressing each of the six minimum control measures laid forth in the MS4 permit. MassDOT's MS4 Permit also requires MassDOT to evaluate its discharges that fall within a watershed of a 303(d) listed water body. When a discharge drains to a listed waterbody for which a TMDL has been developed, the MS4 Permit requires MassDOT to comply with additional requirements. Discharges to impaired and TMDL watersheds are being addressed by MassDOT's Impaired Waters Program and MassDOT's TMDL Watershed Review Program, respectively.

IMPAIRED WATERS PROGRAM

MassDOT addresses stormwater runoff from its roadways draining to impaired water bodies as part of compliance with the NPDES Phase II Small MS4 General Permit. Starting in June 2010, MassDOT committed to assess all impaired water body segments that receive (or potentially receive) stormwater runoff from MassDOT roadways located in urban areas within five years. "Impaired" water body segments are those listed as Category 4a or 5 in MassDEP's Integrated List of Waters (referred to as the 303(d) list). MassDOT completed assessments of the 684 impaired water bodies identified including all 303(d) waters whose sub-basins contain some portion of MassDOT's urbanized area roadways. MassDOT expanded the water bodies list to encompass additional urban areas identified in the 2010 census, impaired waters listed on the 2012 final 303(d) list, and MassDOT property acquired (e.g., Mass Turnpike) since the enforcement as part of their good-faith commitment to improve stormwater runoff quality from their highways. In total, MassDOT assessed 826 waterbodies in five years, and continues to evolve the IWP as it moves towards a watershed-based approach for achieving water quality goals, Phase 2 of the IWP. To date, MassDOT has constructed 966 various treatment SCMs, addressing 103 waterbodies, and providing more than 626 acres of effective impervious cover reduction.

Phase 2 of the IWP, which is under development, will move away from tracking by impaired water to tracking by watershed. This approach will align with the water quality treatment goals of EPA as outlined in the 2016 MS4 Permit, which focus on stormwater improvements at the watershed scale and prioritizing TMDL watersheds. Additionally, the goal is to also align with anticipated changes to MassDEP's Stormwater Handbook, where offsite mitigation will be required to meet treatment goals for some projects. By tracking at a watershed-level, MassDOT can plan ahead for the anticipated TS4 Permit which is expected to resemble the 2016 MS4 Permit in terms of watershed improvement goals.

TMDL WATERSHED REVIEW

MassDOT will assess TMDL reports wherever a TMDL has been approved for a water body into which MassDOT's urbanized roadways discharges stormwater.

MassDOT has conducted an initial review of these 41 final TMDL reports to determine whether the TMDL WLA, SCM recommendations, or other performance requirements for stormwater discharges that are applicable to MassDOT.

The assessment includes identifying TMDL Waters to which MassDOT's urbanized roadways may potentially discharge stormwater, conducting a site survey of discharge points and drainage infrastructure, calculating loading from MassDOT Stormwater as it compares to the WLA, assessing whether the WLA is being met through existing stormwater control measures or if additional control measures may be necessary, and finally selecting, designing, and implementing SCMs.

PRIORITIZATION OF SCM INSTALLATION

MassDOT has developed a SCM Summary Matrix, comparing SCMs as they perform in regard to managing peak flows, recharge, TSS removal, pollutant loadings, and soil infiltration capacity, as well as other parameters such as drainage area, clearance to bedrock, clearance to high water table, setback requirements, land area, slope, and maintenance sensitivity.

MassHighway's policy is to give "critical" waters (which includes Class A waters and Zone I WPAs) higher priority in terms of implementing stormwater SCMs.

MASSDOT EFFORTS RELATED TO CAPE COD TMDLS

MassDOT reports on its stormwater related activities in annual reports under the 2003 NPDES Phase II Small MS4 General Permit (available at NPDES Phase II Small MS4 General Permit - EPA Permit Number MA043025 - MassDOT Permit Year 19 Annual Report). As of the most recent report (Permit Year 19, April 2021-March 2022) MassDOT advanced their stormwater program through continued implementation of the Impaired Waters Program (IWP), educating staff, conducting public outreach at seminars, performing good housekeeping measures including Stormwater Control Measure (SCM) inspections, and starting a pilot program to map MassDOT drainage infrastructure. Construction of a stormwater SCM to address the Herring River nitrogen TMDL was scheduled for Fall 2017 (couldn't find a date of completion), and other TMDL related projects may be planned in concert with future construction activities. Table 5, adapted from a table in the Permit Year 15 Annual Report (April 2017-March 2018), shows MassDOT stormwater work that has been completed or is planned in TMDL watersheds.

TABLE 5. MassDOT Actions in Cape Cod TMDL Watersheds

BASIN/ TMDL NAME	POLLUTANT	MASSDOT ACTIONS COMPLETED	TO DO
Buzzards Bay/Final TMDL of Total Phosphorus for White Island Pond	Phosphorus	MassDOT does not include any relevant BMP recommendations.	No action planned
Allen, Wychmere & Saquatucket Harbors	Nitrogen	TMDL states that runoff from impervious surfaces is a negligible source of nitrogen load to the embayments when compared to other sources. The TMDL suggests that compliance with MS4 permit requirements will contribute to the goal of reducing the nitrogen load for Allen, Wychmere, and Saquatucket Harbors watersheds	MassDOT will continue to comply with its Stormwater Management Plan under the NPDES MS4 Permit
Final Pathogen TMDL Report for the Cape Cod Watershed	Pathogens	.	
Final Pathogen TMDL for the Three Bays Watershed	Pathogens	MassDOT should determine the Route 28 roadway drainage area discharging to the Marstons Mills River and install best management structures and/or operational practices to the maximum extent practicable and at a minimum, be designed to meet the water quality standard for bacteria in SA waters. Given this is a waterway with an approved TMDL, the MHD must meet the requirements of EPA's NPDES General Permit for Stormwater Discharges from Small MS4s (Phase II0, Part ID(1-4), as it pertains to approved TMDLs. Infiltration structures and devices that have been	MassDOT has completed the statewide review of TMDL watersheds for the need for additional BMPs to meet the TMDL recommendations. If additional BMPs were identified, they have been or will be included in future construction projects. . MassDOT has completed the statewide review of TMDL watersheds for additional BMPs were identified, they have been or will be included in future construction projects

BASIN/ TMDL NAME	POLLUTANT	MASSDOT ACTIONS COMPLETED	TO DO
		installed to control the road runoff from Route 28 into the Martsons Mills River should be inspected to determine their performance and condition. MassDOT should also continue to identify and implement to the maximum extent practicable best management practices so that the water quality standard for bacteria in SA waters is met.	
Final TMDL Report of Bacteria for Frost Fish Creek, Chatham	Bacteria	MassDOT has completed the statewide review of TMDL watersheds for additional BMPs were identified, they have been or will be included in future construction projects.	Determine the Route 28 roadway drainage discharging to Frost Fish Creek and install best management structures and/or operational practices to the maximum extent practicable with a goal of meeting the water quality standard for bacteria in SA waters.
Final TMDL Report of Bacteria for Muddy Creek, Chatham	Bacteria	The Route 28 culvert, through which Muddy Creek flows has been replaced through a project funded by Massachusetts Department of Environmental Restoration. The new roadway crossing eliminated the tidal restriction and included leaching basins to treat stormwater discharge before entering Muddy Creek. This project has implemented all improvements feasible to improve water quality of Muddy Creek as it relates to Route 28.	Statewide review of TMDL watersheds for the need for additional BMPs to meet the TMDL recommendations has been completed. If additional BMPs were identified, they have been or will be included in future construction projects.
Herring River	Nitrogen	TMDL states that runoff from impervious surfaces is a negligible source of nitrogen load to the river when compared to other sources. The TMDL suggests that compliance with MS4 permit requirements will contribute to the goal of reducing the nitrogen load for the Herring River Estuarine System.	MassDOT will continue to comply with its Stormwater Management Plan under the NPDES MS4 Permit. MassDOT has designed and is planning to construct a stormwater BMP (water quality swale) to treat direct discharges to the Herring River from Route 6 at the Route 6 / Herring River crossing. Construction is scheduled to begin in the Fall of 2017.
Final Nutrient TMDL for	Total Nitrogen	No relevant BMP recommendation included	

BASIN/ TMDL NAME	POLLUTANT	MASSDOT ACTIONS COMPLETED	TO DO
Centerville River/East Bay			
Final Nitrogen TMDL for Little Pond	Total Nitrogen	No relevant BMP recommendation included	
Final Nitrogen TMDL for Oyster Pond	Total Nitrogen	No relevant BMP recommendation included	
Final Nitrogen TMDL for Phinneys Harbor	Total Nitrogen	No relevant BMP recommendation included	
Final Nitrogen TMDL for Pleasant Bay System	Total Nitrogen	No relevant BMP recommendation included	
Final Nitrogen TMDL Report for Five Sub-Embayments of Popponesset Bay	Total Nitrogen	No relevant BMP recommendation included	
Final Nitrogen TMDL Report for the Quashnet River, Hamblin Pond, Little River, Jehu Pond, and Great River in	Total Nitrogen	No relevant BMP recommendation included	

BASIN/ TMDL NAME	POLLUTANT	MASSDOT ACTIONS COMPLETED	TO DO
the Waquoit Bay System			
Final Nitrogen TMDL Report for the Three Bays System	Total Nitrogen		
Final Nitrogen TMDL for West Falmouth Harbor	Total Nitrogen		
Final Nitrogen TMDL Report for Five Chatham Embayments (Stage Harbor, Sulphur Springs, Taylors Pond, Bassing Harbor and Muddy Creek)	Total Nitrogen		
Final TMDLs of Nitrogen for Great, Green, and Bournes Pond Embayment Systems	Total Nitrogen		

BASIN/ TMDL NAME	POLLUTANT	MASSDOT ACTIONS COMPLETED	TO DO
Final Lagoon Pond TMDL	Total Nitrogen	No BMP recommendation included	

Coordinating Transportation Stormwater Infrastructure with the 208 Plan

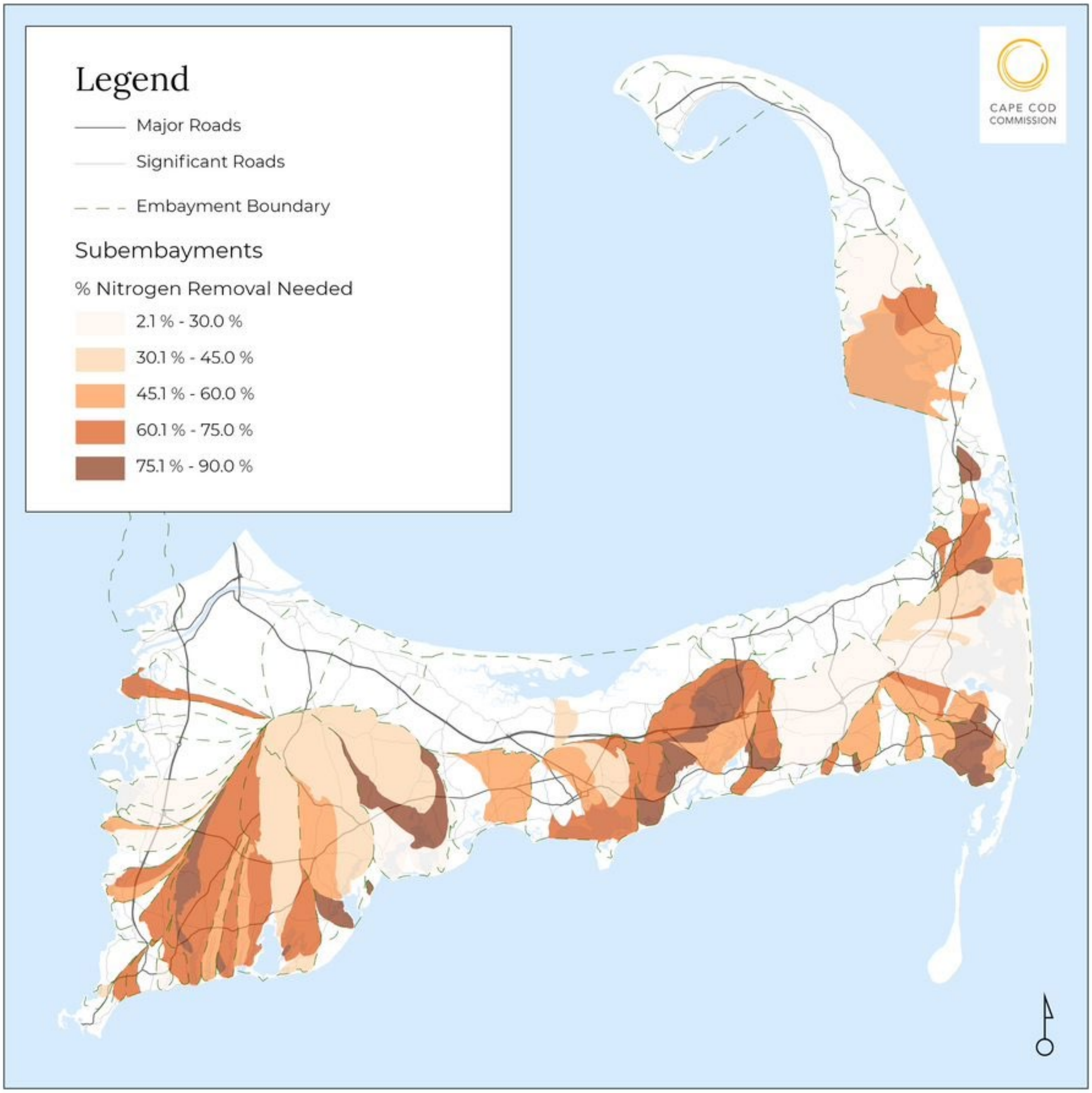
The Cape Cod Area Water Quality Management Plan Update, also known as the "208 Plan," addresses options for Cape Cod communities to address nitrogen loading from controllable sources in Cape Cod watersheds. The 208 Plan outlines many options for addressing nitrogen loading that include the traditional approach of sewering, as well as many alternative approaches such as installing permeable reactive barriers, constructed wetlands, ecotoilets, aquaculture and shellfish bed restoration. There are ample opportunities where stormwater management design on Cape Cod roadways should be coordinated with nitrogen reduction goals of the 208 Plan.

Cape Cod communities that consider constructing sewers as part of their nitrogen mitigation strategy can simultaneously incorporate stormwater management efforts on Cape Cod roadways. For example, as roads are repaved, communities can inspect water and sewer conduits, storm drains, remove illicit connections to sewers and storm drains, repair leaks, and make any other necessary repairs.

Some of the alternative technologies in consideration for nitrogen management on Cape Cod as part of the 208 Plan are actually stormwater treatment systems that also provide significant nutrient removal. Examples of stormwater BMPs proposed for nitrogen management are bioretention/soil media filters, phytobuffers, vegetated swales, and constructed stormwater wetlands. All of these technologies provide physical filtration, uptake of pollutants within plant tissue, nitrification and denitrification, and other microbial biochemical processes that effectively remove a broad range of pollutants from the water column. According to the2016 MS4 Permit, Cape Cod communities need to consider installing BMPs that significantly reduce nitrogen where discharges occur in nitrogen TMDL watersheds.

For optimal effectiveness, sewer infrastructure and alternative nitrogen reduction technologies should be located in areas that contribute the most nitrogen loading to impaired embayments. Roadway development or upgrades within watersheds that drain to subembayments that require a high amount of nitrogen removal should consider opportunities to (1) include sewer infrastructure alongside current roadway plans and (2) implement stormwater BMPs to remove nitrogen.

FIGURE 19. Nitrogen Removal Requirements in Subembayments (DRAFT)



Regional Policy Plan Considerations for Stormwater Management

Transportation infrastructure related to development or redevelopment may be subject to regional regulation by the Cape Cod Commission. If the development project meets a specific size or other threshold identified in the Cape Cod Commission's "Enabling Regulations for the Purpose of Reviewing Proposed Developments of Regional Impact (DRIs)," the project will be subject to review. In order for the project to be granted approval, the project must be consistent with the Goals and Objectives of the RPP (as well as local comprehensive plans, zoning, etc.). In its review, the Commission must also find that the probable benefits of the proposed project outweigh the probable detriments. The Commission may consider best practices and design elements that exceed minimum requirements in this analysis.

Design requirements related to Stormwater Quality are applicable to all DRI projects. Standards related to roadway runoff dictate on-site infiltration practices and devices, bioinfiltration practices, minimum of 2-foot separation to groundwater for infiltration basins or other stormwater leaching structures, and development of maintenance and operation plans. Additionally, the standards require limiting impervious surfaces by constructing overflow peak parking areas from pervious materials (porous pavement, permeable pavers, or grass pavers), and that bioremediation should be incorporated in to parking islands and roadway perimeters. Also, in the RPP is the recommended practice of reducing roadway widths and using permeable features to break up large impervious areas and to minimize runoff from impervious surfaces.

CAPE COD COMMISSION

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