Technical Support for Performance Assessment Monitoring of Stormwater Best Management Practices

RFQ-MA-17-00014, University of New Hampshire Stormwater Center

10/18/18

Final Report:

Subtask 1 a Kickoff Meeting

Deliverables:

Kick-off meeting within one (1) month of order issuance.

Kick-off meeting summary (including action items, scheduling adjustments, etc.) within one (1) week of kickoff meeting.

Status: Complete

Subtask 1b Conference Calls, Meetings and project Team Support

Deliverables:

Monthly conference calls (as needed; assume one per month)

Monthly conference call summaries including progress reports (assume one per month)

Project Team support for stakeholder outreach (assume formal comments will be needed three times over the 12 month POP)

Status Complete

Task 2 Review of QAPP

Deliverables:
Review of QAPP (1 month after kick-off meeting)
Incorporation of modifications to QAPP to support re-approval/iterative approval of QAPP by QAU (assume three modifications)

Status: Complete (see attachment A)

Task 3

Note on task 3: In light of the difficulties with the two monitoring sites UNHSC staff and EPA administrators have agreed that measures should be taken to get the monitoring locations up and running to the maximum extent and commence preliminary data collection. This may entail equipment set up, diagnostics, troubleshooting, calibration and other means necessary to get monitoring location up and running.

Task 3a Monitoring Program Overview

Chatham and Barnstable:

Unfortunately, there was no existing data to review. The reasons differed across each location. For the Barnstable location, the equipment was in good condition as much of it was kept indoors with a constant power supply. In-Situ probes including the area velocity flow meters and Aqua TROLL real-time sondes were installed but had never been cleaned or calibrated. Most were covered in grime and were not in an operable condition. For the Barnstable location, there was no advantage to collecting data as the system was completely offline. The system itself had a clogged or non-functioning vertical flow path and as a result was flooded with a constant elevated water level in the basin and had been colonized by cattails (typha).

For the Chatham location, despite the equipment being new and unused, it was generally in poor condition. This was in part due to the fact that there was no outside power to the site. There were batteries but the equipment had never been routinely operated, cleaned or calibrated. In-situ probes including the area velocity flow meters and Aqua TROLL real-time sondes were installed but fell into disrepair having simply been left unattended. The stormwater system also appeared to be in a state of failure. Wetland vegetation was not thriving and it appeared as though the system was experiencing long periods of inundation. Residents claimed that the system would pond after rain events for multiple days. This, of course, does not comply with the design standards which call for outlet controls to drain the system within a 24-hour period.

Upon further inspection of the system, it was discovered that the hydraulic inlet which should be perforated or slotted was obstructed by a solid pipe that extended to an elevation roughly 6 inches below the high flow bypass. This would mean that water would have to pond 3-4 ft within the system before accessing the hydraulic inlet, thus the only functional inflet for stormwater to get into the stone layer below was effectively the saturated hydraulic conductivity of the surface materials. Since the surface material possesses a low permeability, this could explain the extended ponding that residents had noticed. This ponding was remedied by perforating the solid, external standpipe at 12, 3, 6 and 9'oclock with 3/8" holes for the entire above-ground length of the standpipe.

Task 3b MP and BMP troubleshooting and optimization

As previously mentioned, there was no existing monitoring data. Each of the systems was in a different state of dysfunction that resulted with the inability of the installed equipment to collect data. The Chatham site was fixed and a post-construction operation and maintenance plan was developed for the Barnstable site: both of these remedies allowed water level performance monitoring in each system. Each site had a different monitoring objective. This said, the primary objective of the post-construction monitoring that UNHSC conducted was to determine system function and overall system hydraulics.

Barnstable:

The major research questions with respect to the Barnstable facility were two-fold:

1.) What are the diurnal patterns with respect to backwater caused in the system by tidal fluxes?

2.) What is the groundwater pattern within the system location and if the system is intersecting groundwater, is the cause of the permanent in-system ponding?

To answer these questions instrumentation was installed within the system consisting of an Aqua TROLL 200 probe measuring depth and specific conductivity. In addition, two groundwater monitoring wells were hand augured and installed on either side of the system and outfitted with HOBO level loggers. Additional HOBO level loggers were installed above ground in the local atmosphere measure and compensate for barometric pressure fluctuations. Measurement of water level and conductivity within the inlet structure would be able to pick up flow and chloride concentrations and be used to evaluate the potential incidence of tidal backwater intrusion and subsurface water levels, which in turn provide information on long-term groundwater elevations and determine if the system can maintain enough driving head to reestablish the vertical flow path necessary for proper system function.

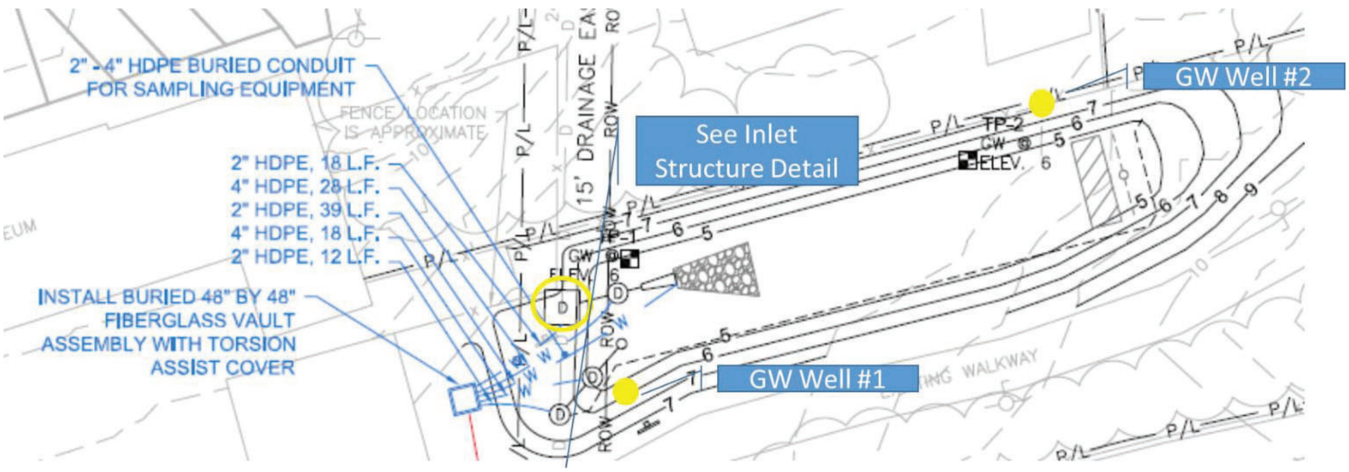


Figure 1: Barnstable instrumentation placement of groundwater wells.

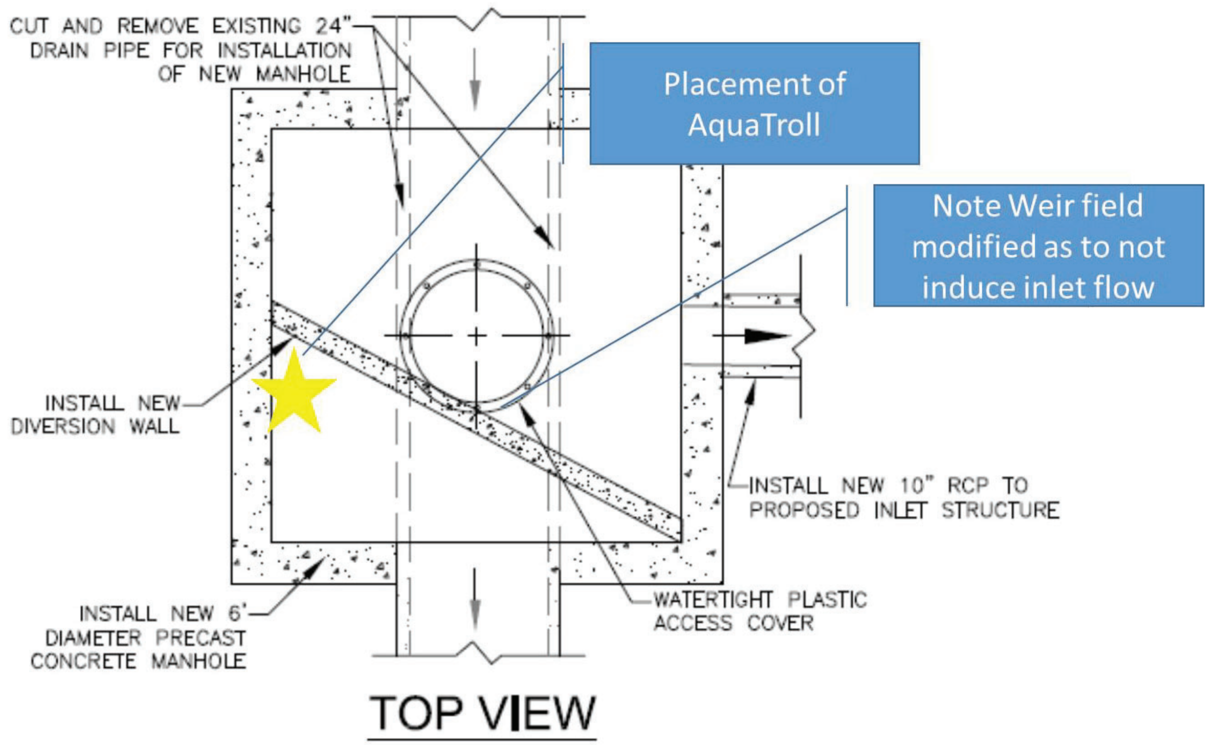


Figure 2: Barnstable instrumentation placement Aqua TROLL.

Table 1 shows the surveyed elevation data for the installed HOBO and Aqua TROLL instruments as well as points of interest in the system such as the system surface, weir, and system outlet invert.

Table 1: Barnstable surveyed elevations (Mean Sea Level) of instrumentation or points of interest. These are ranked from highest to lowest elevations.

Location / Instrument Description	Elevation MSL (ft)
Well 2: HOBO U20L	5.583
System surface	5.451
Inlet: top of weir	4.780
Well 1: HOBO U20L	4.366
Inlet: Aqua TROLL 200 (upstream of weir)	4.276
Outlet: system invert	3.602
Outlet: invert at sea	0.867
Mean Sea Level (MSL)	0.000

Chatham:

The major research questions with respect to the Chatham facility was characterization of system hydraulics, including:

- Is the system under or over capacity?
- What does the inlet hydrograph look like with respect to ponding? Do inlet flows create backwater conditions that would make inlet monitoring difficult?
- If operational, what are the peak flow reduction and volume reduction statistics?
- And finally, can future monitoring be performed at the inlet and outlet locations or does the system experience a backwater that would drive monitoring further up gradient?

To answer these questions instrumentation was installed within the system inlet and outlet structures consisting of a HOBO level loggers. An additional HOBO level logger was installed above ground in the local atmosphere to address for barometric pressure fluctuations. The barometric compensation was performed using HOBOware Pro's Barometric Compensation Assistant (BCA). The BCA adjusts the level logger's pressure data according to the temperature-based water density as measured, and the barometric pressure time series is then subtracted from the density adjusted pressure data using an interpolation if needed according to the two loggers' timestamp intervals. The resulting data represents the barometric and water density-adjusted water level from the level logger. The resulting water levels were plotted as relative elevations and used to estimate discharge using Manning's equation in the respective HDPE inlet and outlet pipes.

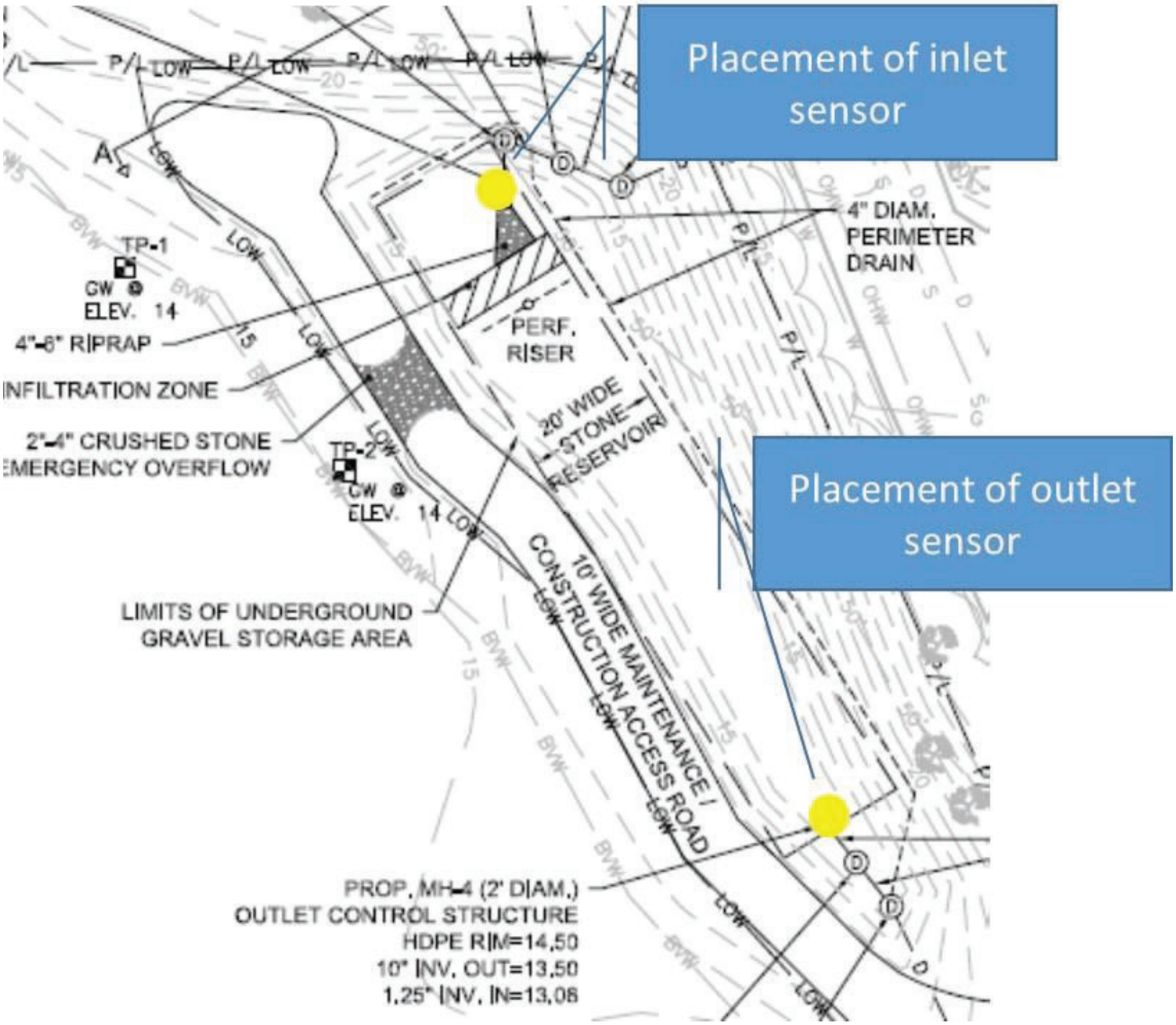


Figure 3: Chatham instrumentation placement

Table 2 shows the surveyed elevation data for the installed HOBO level loggers as well as points of interest in the system such as the inverts of the inlet and outlet, system surface, stand pipe, and high flow bypass. Note that these elevations are relative with the datum at the system surface.

Table 2: Chatham surveyed elevations (relative to system surface) of instrumentation or points of interest. These are ranked from highest to lowest elevations.

Location / Instrument Description	Relative Elevation to Surface (ft)
Bypass: high flow bypass	2.728
Top of stand pipe	2.489
Inlet: pipe invert	0.280
System surface	0.000
Outlet: pipe invert	-1.316

Results:

Barnstable

To answer the first question: what are the diurnal patterns with respect to backwater caused in the system by tidal fluxes, conductivity was measured in the inlet structure. Typical ocean conductivity is >30,000 uS/cm. Figure 4 documents measurements alongside with rainfall depths. Conductivity largely trends with precipitation events and never exceeds 1,100 uS/cm. This monitoring clearly indicates no strong seawater influence in the inlet structure.

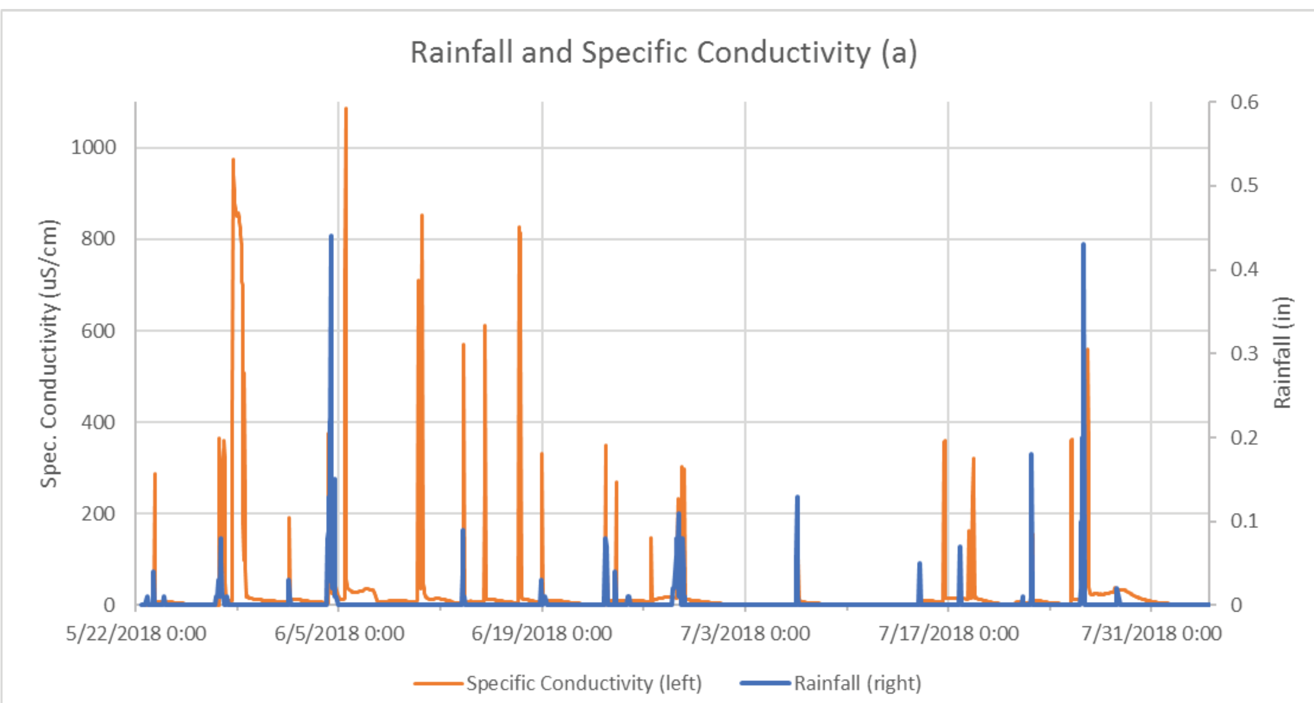


Figure 4: Conductivity and rainfall for the Barnstable inlet structure.

To answer the second question: what is the groundwater pattern within the system, levels were measured in two wells upstream and downstream of the system. Elevations were also surveyed and related back to means sea level. Figure 5 shows a strong hydraulic gradient across the system. Figure 5 illustrates a strong groundwater influence regardless of rainfall patterns. Well 2 groundwater elevations always exceed those of well 1 indicating groundwater flows from 2 to 1 or from upgradient to downgradient across the system. This figure also indicates that the upgradient groundwater elevations exceeds the water level in the inlet most of the time, indicating that even during precipitation and runoff events, groundwater has the ability to enter the system from below.

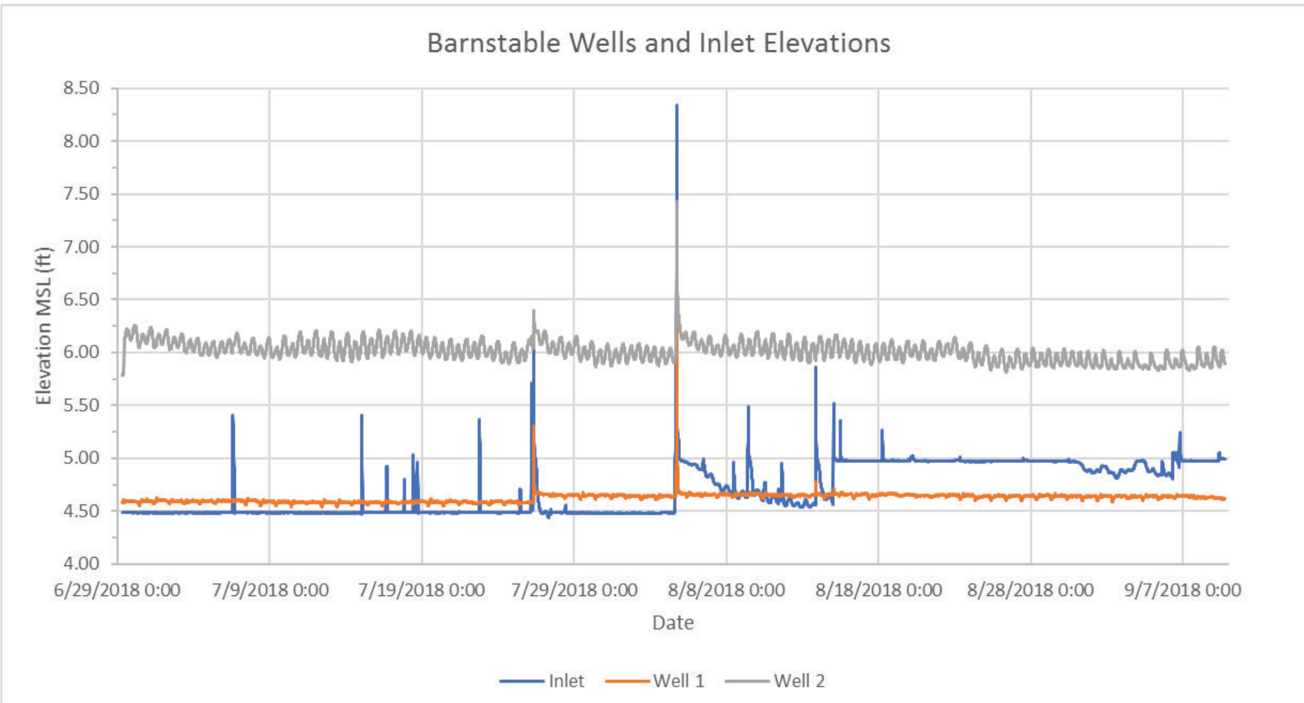


Figure 5: Water elevations related to mean sea level for the upgradient and downgradient wells and inlet structure over the monitoring period.

Figures 6-7 show the hydraulic groundwater gradient across the system in relation to the system surface elevation. Of specific note is the nearly 1-inch differential between the horizontal groundwater head and the system surface elevation. The groundwater elevation is likely artificially lowered by the installation of the 4-inch perforated perimeter drain, however it is unclear whether as constructed, that the system will generate sufficient driving head to hydraulically route stormwater through the system. If the system is to be maintained, we would recommend raising the surface as high as possible and creating an offline flow through elevation of the weir wall in the inlet structure coupled with a low flow orifice for non-stormwater flows.

Figures 6 and 7 show the hydraulic gradient plotted across the system by taking the elevation differential between the two wells and dividing by the horizontal distance between the wells. A groundwater head gradient of 0.01 ft/ft is a common value in natural settings. The gradient of this system is high, between 0.06 and 0.07, indicating that there is high driving head. In very permeable sediments such as on the Cape, the head gradient indicates the potential for significant groundwater flux into the system that may be sufficient to impair the management of surface stormwater flows by preventing the stormwater from infiltrating the system media due to hydraul;ic resistance, and instead bypassing the system through the surface bypass structure.

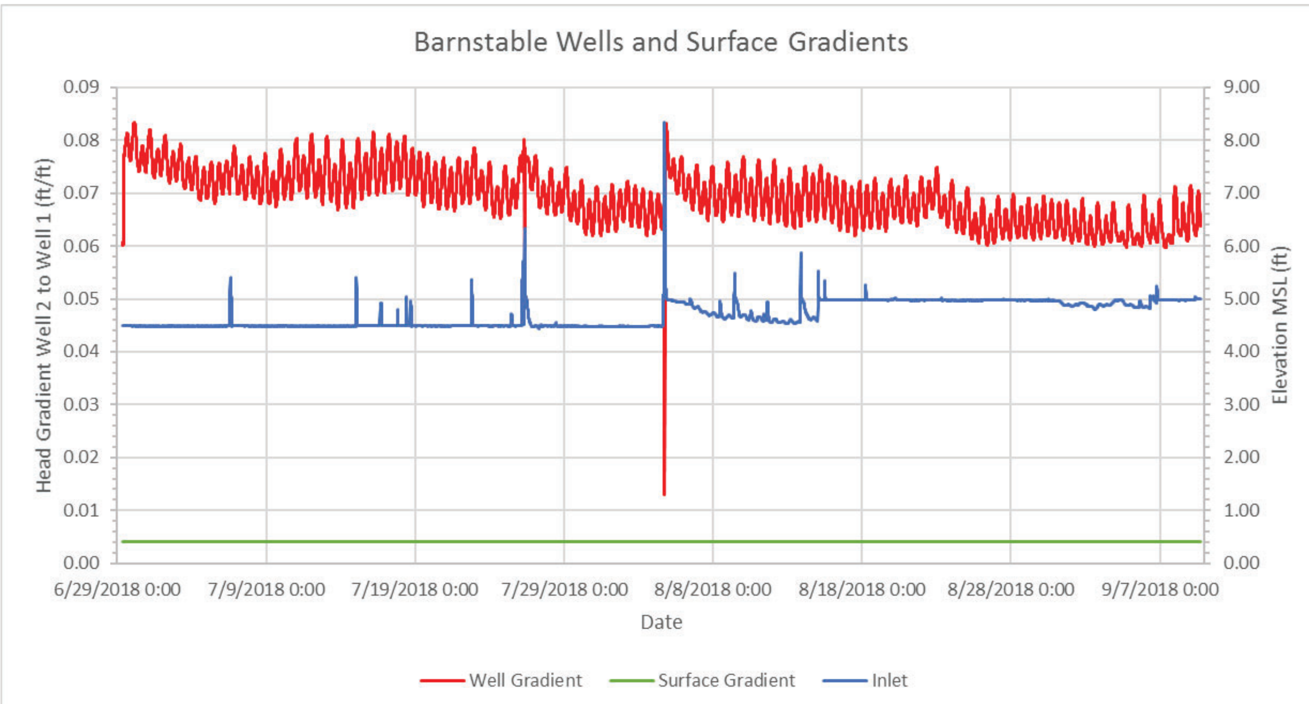


Figure 6: Hydraulic gradient across the system in relation to system surface elevation over the monitoring period.

Figure 7 is simply a shorter time period cropped from Figure 6 to demonstrate the effect of the tide. Of note is the fluctuating gradient largely dictated by diurnal tidal pressure. While tidal flux (salt water) is not flowing into the system it is clear that the tidal flux is regulating the groundwater gradient.

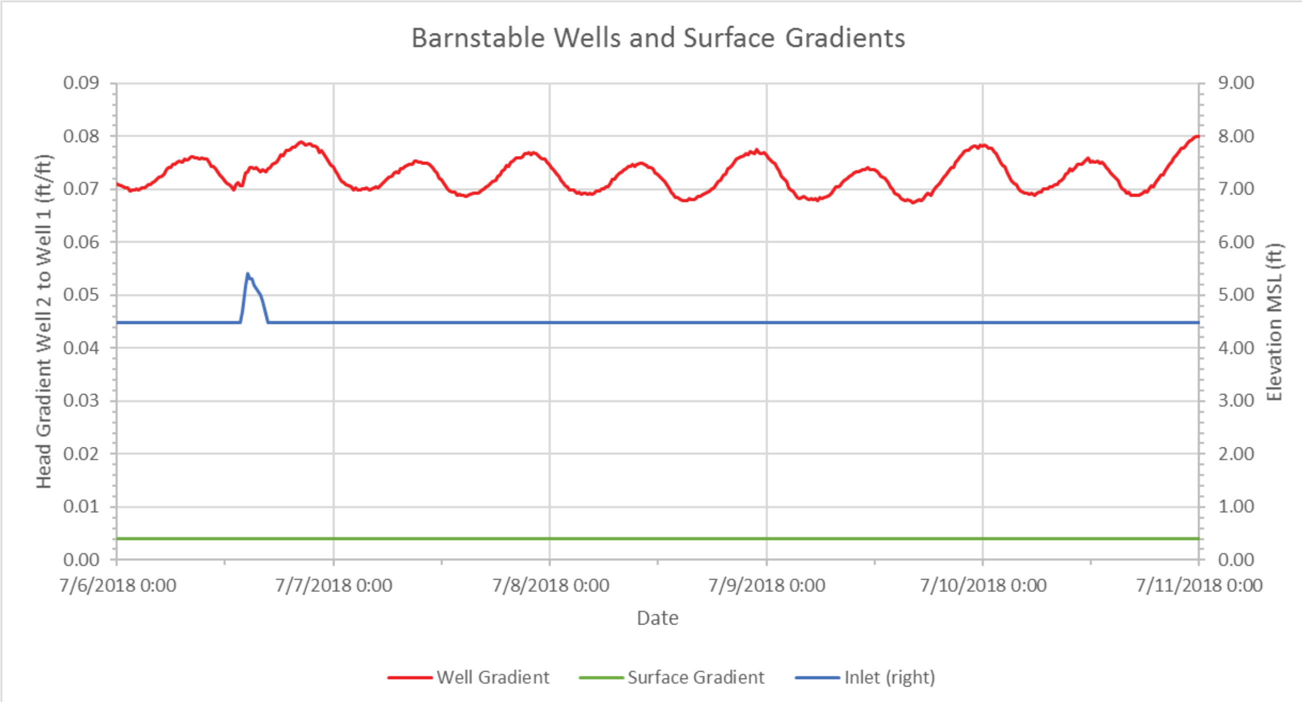


Figure 7: Hydraulic gradient across the system in relation to system surface elevation over a four day period to show diurnal patterns.

Because of groundwater controls it is difficult for this system as constructed to properly manage stormwater, our recommendation is to keep the system offline, elevate the surface, and restore the surface soils and replant with desired native vegetation or preferably with a wetland seed mix: basically rebuild the system at a higher elevation. The system serves as a fantastic visual educational feature. It was noted throughout our site visits that people frequently stopped and read the signs and learned about the importance of stormwater management and water quality.

Chatham

Table 1 illustrates the hydrologic properties of the Chatham system. Over seven rainfall events, the system achieved an average peak flow reduction of 74% and average volume reduction of 42%. This is significant as five out of the seven rainfall events exceeded the modeled system design capacity of 0.3 inch rainfall. The largest was a 4.94-inch rainfall event where the system ponding depth did not exceed 1.3 ft, which is about half full. This is even more remarkable considering the fact that the system was reportedly lined with an impermeable liner, which should minimize volume losses (infiltration). It is unknown whether the liner extended up the system sidewalls and/or completely surrounded the system, or was only on the bottom or on some of the sides. Horizontal flow patterns may dominate volume reductions as evidenced in other systems not designed for infiltration (UNHSC, 2016). Figures 8through10 show graphical results over the monitoring period. While no water quality data was collected, the resulting system hydrologic performance is quite remarkable.

Table 3: Tabular results for the seven storms monitored for the system.

	DATE	Event Rainfall (in)	Antecedent (day)	Peak Flow Reduction	Volume Reduction
	5/27/2018	0.15	3.6	88%	94%
	6/1/2018	0.27	4.3	95%	59%
	6/4/2018	4.94	2.7	72%	28%
	6/23/2018	0.92	4.1	76%	48%
	7/25/2018	1.50	3.1	73%	34%
	8/4/2018	0.97	6.8	42%	-31%
	8/9/2018	2.46	4.5	76%	62%
Statistics:	**min**	**0.15**	**2.67**	**0.42**	**-0.31**
	med	**0.97**	**4.13**	**0.76**	**0.48**
	mean	**1.60**	**4.18**	**0.74**	**0.42**
	max	**4.94**	**6.83**	**0.95**	**0.94**
	std	**1.67**	**1.35**	**0.17**	**0.39**
	n	**7**	**7**	**7**	**7**

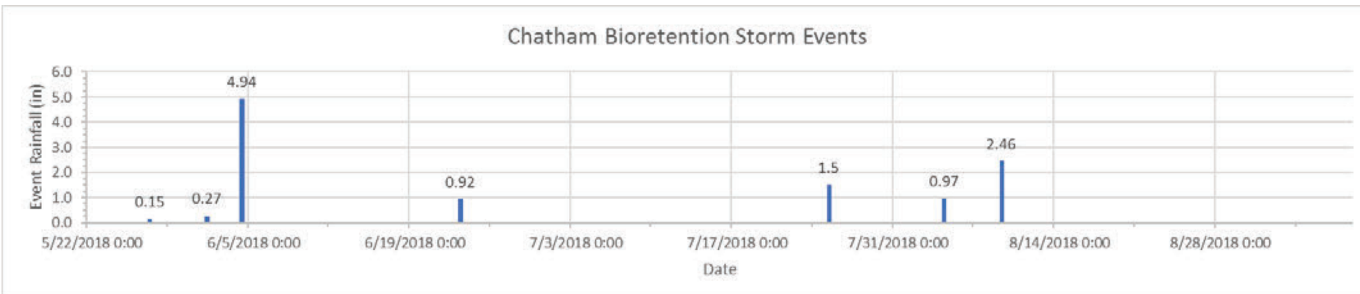


Figure 8: Rainfall depths monitored over the course of the study.

Figure 9: Relative elevations plotted in relation to influent and effluent depths over the monitoring period.

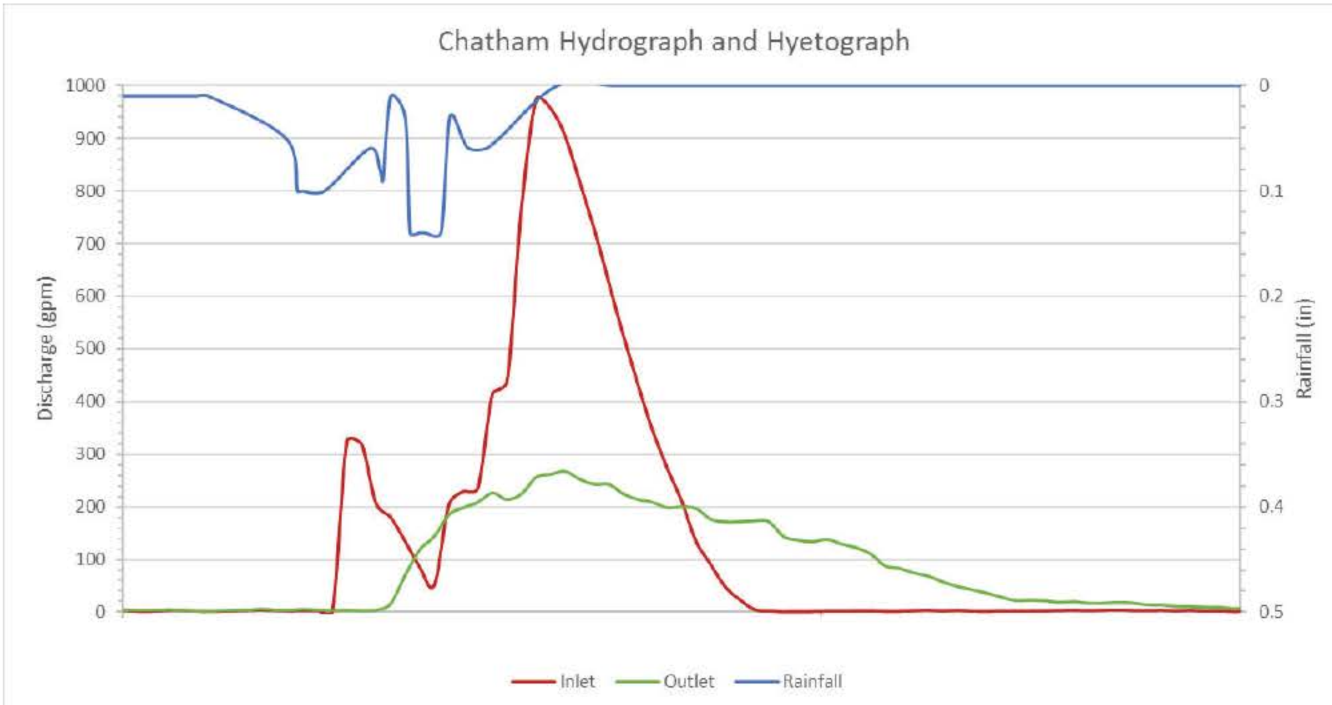


Figure 10: Event-based comparison of influent and effluent flows and rainfall depths for the 7/25 1.5 inch storm event.

For water quality treatment calculations, which were beyond the scope of this effort, the EPA Region I performance curves may be used. According to the system type, design characteristics and local hydrology total phosphorus, total nitrogen, total suspended solids and total zinc removal efficiencies can be reported as 34%, 66%, 72%, and 76% respectively.

Table 4: Subsurface Gravel Wetland Performance Data EPA Region 1 curves (appendix F, NH MS4 Permit, 2017)

Gravel Wetland BMP Performance Table				
BMP Capacity: Depth of Runoff Treated from Impervious Area (inches)	0.1	0.2	0.3	0.4
Cumulative Phosphorus Load Reduction	19%	26%	34%	41%
Cumulative Nitrogen Load Reduction	55%	60%	66%	71%
Cumulative TSS Phosphorus Load Reduction	48%	61%	72%	82%
Cumulative Zinc Phosphorus Load Reduction	57%	68%	76%	83%

Final System Conclusions:

The Barnstable requires significant modification and maintenance prior to undertaking any water quality monitoring. Additional hydrological monitoring could inform maintenance and redesign efforts. Capping and monitoring the 4" perforated perimeter drain could identify the limit of groundwater depth and help determine future surface elevation details that should be addressed during system rehabilitation. A scope of work for the minimum maintenance details is provided in the appendices.

The Chatham system is operating well. System hydrology could continue to be collected and water quality parameters could be monitored for the majority of annual storm events. Automatic samplers take significant time and personnel to manage properly and develop defensible data. It is unclear as to whether this capacity exists at the present time. The site has no consistent power and thus instrumentation is unused and exposed to harsh elements with no management. We recommend absent a funded monitoring approach that the equipment be removed and stored outside of the elements for future long term function.

Task 4a BMP Performance Monitoring Design Support

Deliverables:
Written overview identifying key elements of a successful monitoring project, including lessons learned (challenges and recommendations for avoiding mistakes)

Status: First draft included as an appendix. Note it is anticipated that this white paper will be reviewed by EPA Region 1 program officer. UNHSC staff is committed to collaboratively complete this white paper in close coordination with relevant EPA staff so as to best address and inform identified monitoring questions.

Task 4b Implementation Science for Water Resource Optimization

Participation in the Mystic River Watershed Nutrient Management

Phase 1: Develop and Pilot Effective Communication and Technical Support Strategies for Watershed MS4 Municipalities

PROJECT OBJECTIVES:

Work with ready to adopt municipal officials in 3-6 MS4 communities within the Mystic River Watershed to collaboratively develop effective strategic approaches, communication products and technical support to effectively advance restoration efforts and inform municipal governments on:

1) Watershed stormwater (SW) management needs for addressing existing water resource impacts caused by uncontrolled stormwater (SW) runoff;

2) Opportunities for readily implementing efficient SW control retrofits and every-day-counts improvements in municipal stormwater operations and planning.

3)Quantifiable benefits for beginning long-term SW control retrofit programs that will address multiple issues related to increased peak flows, runoff volumes, water quality and health and safety issues related to urban drainage.; and

4) Approaches for developing long-term comprehensive and affordable SW management strategies for achieving water resource goals.

Through a series of working meetings, the Project Team will collaborate to develop streamlined informational materials designed to effectively communicate important scientific and technical information needed by communities to develop technically sound and affordable SW management programs. This will be contrasted by pragmatic point of use approaches from infrastructure owners and personnel that have the authority and responsibility to act. Together the information generated will help facilitate local ownership and transferability for use in other developed watersheds throughout New England where municipalities face similar water resource management challenges. During this first phase (year 1), the Project Team will share experiential information and data on cutting edge SW management approaches that focus on developing co-production of solutions and communication strategies that meet both regulatory and practitioner needs. Throughout this experiential approach, information also will be collected to develop a scope of work for a next phase (e.g., year 2) that will include comprehensive end user input and focus on developing similar supporting scientific, technical and quality of life information deliverables designed to inform next to adopt communities and the general public. This project has been developed on the shoulders of a decade and a half of experience and implementation efforts in New England including regulators, practitioners and academic researchers and is founded in the development of local implementation champions that adapt approaches to fit local municipal management cultures. This strategic approach starts and ends with the essentials of a sustainable stormwater management program, good regulations and custom GI approaches that can be easily implemented and maintained.

Status: complete

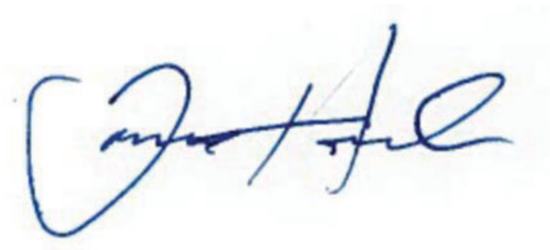
Task 4c Implementation Science for Nutrient Pollution Control Optimization

Deliverables:
Crosswalk for P-Curves; and technical summary worksheets for all BMPs included in the MS4 permit and Opti-Tool.

Status: Complete

Please let me know if you have any questions or need additional details and or documentation

Sincerely,



James Houle, PhD., CPSWQ, CPESC
Program Manager
The UNH Stormwater Center
Dept of Civil and Environmental Engineering
35 Colovos Road
University of New Hampshire
Durham, NH 03824
Phone: 603-862-1445 Fax: 603-862-3957
web: http://www.unh.edu/unhsc/

APPENDIX A: QAPP REVIEW

FINAL

QUALITY ASSURANCE PROJECT PLAN (QAPP)

for

Performance Assessment Monitoring of Green Infrastructure Stormwater Best Management Practice Retrofits Constructed on Cape Cod for the Control and Treatment of Nitrogen – A Demonstration, Education, and Outreach Project

July 12, 2017; Updated Oct 04, 2017 (Rev. 02)

A Joint Collaboration Between:
Region I U.S. Environmental Protection Agency
Office of Ecosystem Protection (OEP),
Office of Environmental Measurement & Evaluation (OEME) and
The Towns of Barnstable and Chatham, MA

EPA Project Manager: ________________________________ Date: ________________
Ray Cody

OEP Technical Advisor: ________________________________ Date: ________________
Mark Voorhees

EMT Technical Advisor: ________________________________ Date: ________________
Tim Bridges

EPA Chemistry Lab Lead: ________________________________ Date: ________________
Dan Boudreau

EPA QA Officer: ____Date: ________________
Nora Conlon

EMT Team Leader: ____________________________________ Date: _________________
Diane Switzer

Town of Chatham Lead: ________________________________ Date: ________________
Robert Duncanson

Town of Barnstable Lead: ________________________________ Date: ________________
Dale Saad

EXECUTIVE SUMMARY

The monitoring program design in this Quality Assurance Project Plan (QAPP) is for performance monitoring of two (2) subsurface gravel wetlands (SGW) best management practice (BMP) retrofits for the control and treatment of nitrogen (N) in stormwater discharges. The BMP retrofits were constructed on Cape Cod in the Towns of Barnstable and Chatham in spring, summer and fall of 2015. The BMP retrofits are based on a smaller prototype design from the University of New Hampshire Stormwater Center.

Because the performance of SGW BMPs for control of nitrogen is still unclear, the BMPs will be monitored for a period of two or three years to assess the overall cumulative performances of the BMPs for treatment of nitrogen. This QAPP sets forth the experimental foundation and mechanics for the design of the monitoring program. The Monitoring Plans, which translate the requirements of the QAPP into field sampling protocols and procedures, are based on the QAPP.

The monitoring program design set forth in this QAPP is predicated largely on the BMP constructed at the Town of Barnstable because of: (a) base flow observed in the municipal separate storm sewer system (MS4) at Barnstable; (b) the dynamics associated with runoff volume and velocity from the Barnstable sub-catchment impervious cover; and (c) the high anticipated wash off and solubility characteristics of nitrogen (particularly dissolved inorganic nitrogen (DIN)).

Collectively, these factors, and others, have necessitated a carefully considered approach for designing the monitoring program for Barnstable. Even though the Chatham sub-catchment and BMP are larger than Barnstable, Chatham does not appear to be complicated by base flow or unusually high runoff velocity and volume. Nevertheless, much of the Barnstable design approach and its elements can be readily applied to Chatham, if not by direct application then by iterative empirical extrapolation based on this QAPP and as reasonable and appropriate under the circumstances.

I. INTRODUCTION

EPA has retrofitted existing stormwater discharges in the Towns of Barnstable and Chatham, MA, by constructing innovative green infrastructure (**GI**) subsurface gravel wetland BMP retrofits as a demonstration for control of nitrogen pollution in stormwater discharges. EPA is coordinating with the Towns of Barnstable and Chatham to conduct monitoring of the BMPs to assess their overall performance for treating nitrogen. The work conducted as part of this project may have broad applicability throughout New England.

A project for design and construction of a stormwater BMP to control and treat nitrogen aligns with EPA priorities, including selecting sites that are consistent with TMDLs and the Section 208 Water Quality Plan Update; promoting the appropriate application of GI; using technologies that improve stormwater infiltration and lead to reductions in runoff volume and peak volume discharge; improving water quality; and potentially reducing combined sewer overflow (CSO) events (if locations are in a CSO area). Other important objectives include engaging local departments of public works personnel in GI installation techniques, operation and maintenance practices, and for assistance in monitoring the physical and water quality parameters that help determine BMP performance.

This plan describes the field and QA program for assessing the overall performance of the BMPs for treating nitrogen, including the objectives, responsibilities, and the field and laboratory tasks for this phase of the Project.

II. PROJECT DESCRIPTION

A. Background and Objective

The specific objective of this GI implementation demonstration and education and outreach project was to design and construct two GI stormwater BMP retrofits for control and treatment of nitrogen on Cape Cod, Massachusetts. An additional objective is to assess and determine the performance of the BMPs, in part to help develop and/or refine performance curves for the BMPs.

Construction of the BMPs occurred in spring, summer and fall of 2015. The retrofits have been provisioned for monitoring the BMP inflow and outflow. Discharge of stormwater to the BMPs did not begin until early spring of 2016, in part to allow BMP plantings to establish. Moreover, once discharge to the BMPs occurs, additional time is required to establish a robust anaerobic microbe population within the BMP. Consequently, BMP monitoring is expected to occur in the fall of 2016 at the earliest.

The goal is to monitor the BMPs for approximately 20 or more rain events of various intensities and depths over the course of two to five years. Core monitoring for performance sampling will consist of flow-weighted composite (FWC) and discrete-time interval (DTI) sampling; the samples will be collected using automatic samplers for laboratory analysis of total nitrogen (TN), total phosphorus (TP), and total suspended solids (TSS).

1. Monitoring Equipment and Configuration

Each BMP has 3 sample locations (see Figure II.A.1), including sample locations at the main trunk line, BMP influent, and BMP effluent. [1]

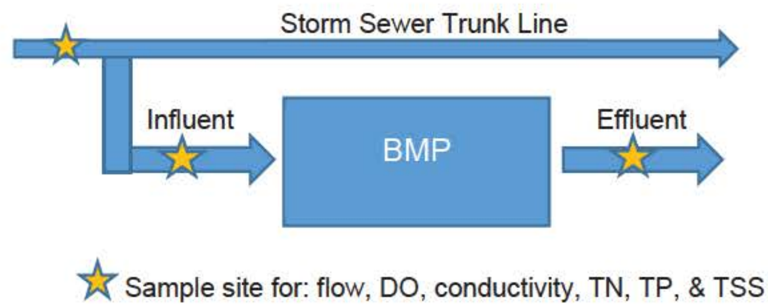


Figure II.A.1: Sample site locations in BMP schematic

Based on monitoring equipment recommendations made for the project by EPA's contractor, WaterVision LLC, EPA has acquired monitoring equipment to provision each BMP site with its own suite of monitoring equipment. Refer to the July 24, 2015 Technical Memorandum developed by WaterVision for the project entitled, *Monitoring System for Barnstable and Chatham BMPs (revised).* This technical memorandum is attached to this document as **Appendix A** (cost information redacted). Supplemental and supporting equipment specification information is provided as a standalone *.pdf, **Appendix A2.**

The Monitoring Plans for Barnstable and Chatham (attached as **Appendix B1/B2 and C**, respectively; provided as standalone *.pdf) will provide instructions for necessary equipment and supplies, calibration of meters and auto-samplers, and other items necessary for conducting the monitoring including regular inspections and maintenance of diversion structures and monitoring equipment. The Monitoring Plans are similar to Field Sampling Plans and provide protocols for conducting sampling based on this QAPP.

2. Flow Rate Monitoring

Because of the likely severe turbulence of the stormwater flow into the BMP as well as the comparatively low-flow laminar characteristics of flow at the BMP outlet, stormwater flow volume will be measured using two different methods: area-velocity sensors and calibrated flumes. Flumes measure water level and convert water level readings to volumetric flowrates based on the physical configuration of the flume. The use of two different methods for measuring flow is recommended to manage the severe difference in flow regimes between BMP inlet and outlet and because low flows at the BMP outlet are expected to be near the lower-limit of resolution for the area-velocity sensors.

[1] Note: water quality characteristics at the main trunk line and BMP input (i.e., influent) are presumed to be identical; both do not need to be sampled for water quality parameters - but flow measurement in the main trunk line (e.g., to determine high-flow bypass) is required to measure total flow.

Increases in measured flowrate at the BMP inlet will be used to trigger stormwater sampling events. Based on personal correspondence with New England Environmental Equipment (NE3), EPA's equipment vendor, the Teledyne Signature® Flow Meter can be programmed to trigger storm-sampling events on the basis of increases in volumetric level using either the flume and/or area-velocity flow sensors. Because the input flow regime of the BMPs could be particularly turbulent, as an extra precaution, data from rain gauges will be used as a secondary determinative factor for storm-sample event triggering. That is, both water level and rain gauge data values must be 'positive' for a storm-sample event to be triggered. This means that changes in base flow need not interfere with storm event triggering. Refer to Section II.F.3 below for specific details on storm event triggering using the Teledyne Signature® Flow Meter as configured for this Project.

3. Water Quality Parameter Monitoring

Prior to initiation of formal monitoring activities, a few grab samples for each type of analysis may be collected from one or more storm events to estimate expected concentrations of inflows to the BMPs. This will be particularly important in the event base flow is observed in the municipal separate storm sewer system (MS4) trunk lines that tie to the BMPs. The special problem of base flow at the Barnstable site is discussed in Section II.B below.

Initial 'first flush' stormwater event volumes are expected to contain higher nitrogen concentration because of the buildup / wash off characteristics of nitrogen coupled with the high solubility of nitrogen. Consequently, automated samplers will be programmed to collect samples to characterize first flush wash off as part of total mass performance assessment of storm events. Hydrodynamic modeling was used to help identify timing and frequency of inlet and outlet grab samples. Refer to Section II.C.

Grab samples of in-situ water quality parameters (temperature, pH, conductivity and dissolved oxygen (DO)) will be measured / collected manually by field sampling staff (or autonomously via Sondes) at least at the beginning of a storm event and then at regular intervals throughout storm events (depending upon field personnel availability).

Grab samples for bacteria (*E. coli*) may also be collected for analysis by the Towns. The Towns of Barnstable and Chatham have requisite laboratory facilities and conduct bacteria analyses routinely according to Standard Operating Procedures (SOP) that are <u>common to both Towns</u>. These SOPs are provided as **Appendices D1 thru D3** (provided as standalone *.doc).

4. Monitoring Program Management, Generally

EPA's contractor for the project, WaterVision and/or Comprehensive Environmental Inc. (CEI), will work with the project team to setup the monitoring system equipment. WaterVision is responsible for finalizing the Monitoring Plans based in large part on the information provided in this QAPP. Once the monitoring equipment install is complete, CEI will train municipal personnel which may include conducting "dry" runs prior to the start of the first rainfall event. Once trained, municipal personnel will be primarily responsible for operation and maintenance of the BMPs, for calibration and maintenance of onsite meters, and for carrying out most field activities.

EPA's Office of Ecosystem Protection (**OEP**) will be reviewing available data (esp., flow data) following sampling events to, among other things, troubleshoot system anomalies and determine how water quality samples are to be composited for analysis. Water quality samples will be shipped via FedEx (using EPA Region 1's FedEx account) to EPA's Office of Environmental Measurement and Evaluation's (OEME) New England Regional Lab (**NERL**) in North Chelmsford, MA for analysis by NERL.

OEP requested assistance from NERL with planning for the Cape Cod Stormwater BMP Demonstration Project. This included providing technical assistance developing this Project Plan; provision and setup of some monitoring equipment; providing some oversight during initial stormwater sampling events; and providing laboratory analysis of total nitrogen (TN), total phosphorus (TP), and total suspended solids (TSS) samples that are collected during rain events.

Additional details, such as processing, preservation, proper labelling and chain of custody forms for samples and proper shipment of samples to the analytical lab are described below and will be reproduced in more detail (incl. data collection sheets) within the Monitoring Plans.

Table II.A.4 Project Personnel

Name, Organization	Project Role	Email Address	Phone #
Ray Cody, EPA	EPA Project Manager	cody.ray@epa.gov	617-918-1366
Mark Voorhees, EPA	EPA/OEP Technical Advisor	voorhees.mark@epa.gov	617-918-1537
Tim Bridges, EPA	EPA/EMT Technical Advisor	bridges.tim@epa.gov	617-918-8603
Tom Faber, EPA	EPA/EMT Technical Advisor	faber.tom@epa.gov	617-918-8672
Diane Switzer, EPA	EPA/EMT Team leader	switzer.diane@epa.gov	617-918-8377
Dan Boudreau, EPA	EPA Chemistry Leader	boudreau.dan@epa.gov	617-918-8340
Bob Duncanson, Ph.D., Town of Chatham	Director of Health & Natural Resources	rduncanson@chatham-ma.gov	(508) 945-5165
Dale Saad, Ph.D., Town of Barnstable	Senior Project Manager, Barnstable DPW	dale.Saad@town.barnstable.ma.us	508-790-6400 X4941

B. Observance of Base Flow at Barnstable

At Barnstable, base flow has been observed in the MS4 trunk line that feeds the BMP. During BMP construction in the spring of 2015, base flow was measured at 17.5 gal/min on April 29, 2015 at 2:31 PM and 11.6 gal/min on May 5, 2016 at 4:10 PM. Base flow was measured using a 5 gallon bucket and stop watch. The observed decrease in base flow over time suggests it was a spring season-related phenomena, perhaps largely influenced by snow melt. However, base flow could also be associated with changes in groundwater generally, and influenced by precipitation events.

Prior to April 29, 2015, the base flow was sampled for total nitrogen by EPA's contractor, CEI, and it was determined that the base flow contained some 3.3 mg/l TN. As a general rule, the event mean concentration of TN in stormwater are typically between 0.8 to 3.0 mg/L.

Ideally, a minimum 24 hours of residence time for stored runoff volume within the internal storage reservoir (ISR) is needed to accomplish significant denitrification and nitrogen removal. The hydraulics of the subsurface gravel wetland is controlled by the outlet orifice diameter according to the following equations:

$$Q = C_d \ \ 1/4\ \pi\ D^2)(\sqrt{2}gh) \qquad (1)$$

and

$$Q = V / t \qquad (2)$$

where,

Q	is the outlet drainage flow rate (ft^3/s), where Q = V / t
V	is static ponding storage volume of the BMP (ft^3)
t	is the residence time to achieve denitrification (hrs), where t >= 24 hrs
C_d	is the coefficient of discharge (unitless) (typ., 0.60)
D	is the outlet orifice diameter (ft)
g	is acceleration due to gravity (32.2 ft/s)
h	is the hydraulic head at the average (i.e., centerline) of static ponding depth (ft)

The outlet orifice diameter (OD) was calculated for a minimum residence time of 24 hours, correlating to an OD of approximately 1.25 inches. To be conservative, the actual OD was set at 1 inch, corresponding to commercial PVC pipe diameter availability, resulting in a more conservative residence time (34 hours).

The outlet orifice controls the residence time of any quantity of water contained within the BMP, up to the static ponding level, which provides a storage volume within the BMP that is equal to 0.3 inches of runoff depth from the contributing impervious drainage area. Any storm volume greater than the static ponding level (0.3 in runoff depth) will bypass the BMP at the diversion weir upgradient in the MS4 storm drain. In brief, therefore, the base flow volume, when present, simply reduces the available ponding storage which effectively correlates to a smaller design capacity.

Considering: (a) the measured concentration of total nitrogen in the base flow is on the high end of typical stormwater,(b) sixty-one percent (61%) of New England storms are less than 0.2 inches, (c) nitrogen, particularly dissolved inorganic nitrogen (DIN), is expected to runoff within the early part of storm events and be preferentially captured by the BMP, (d) bypassing the base flow using weep holes (orifice weirs) installed within the inlet diversion structure would mean non-treatment of base flow nitrogen and likely also result in bypass of stormwater runoff from the early portion of storm events, and (e) the base flow is likely a limited transient seasonal phenomena, then it makes sense to capture and treat the base flow even if it means effectively reducing the design capacity of the BMP during periods of base flow. Such loss of BMP capacity is likely to be a temporary condition as the base flow is anticipated to be a transient phenomenon.

Recommended Approach for Managing Base Flow

Although the residence time for denitrification is not impacted by the observed base flow, the base flow implicates some additional monitoring requirements. The following are recommended management approaches to take into account the presence of base flow on BMP performance assessment.

1. Base Flow Measurements

In part because it is not clear whether the observed base flow at Barnstable is limited to spring snow melt and is indeed not associated with the impact of storm events on the ground water table, the MS4 trunk line at the BMP inlet should be monitored routinely (weekly or bi-weekly) over the course of at least one full year (preferably, two years). This may be accomplished using the Teledyne system, or it can be accomplished by accessing the MS4 trunk line at the BMP inlet and using a 5-gallon bucket and stopwatch to measure and record any flow observed.

2. Base Flow Water Quality

For any observed base flow, grab samples for TN, TP, TSS and DO should be collected at the BMP inlet and outlet. Confirmation sampling of the outlet is recommended only to confirm calculations of hydraulic performance assumptions and to obtain synoptic measurements for calculating denitrification performance. Once performance has been reasonably established, synoptic sampling of outlet flow for TN, TP and TSS may be discontinued.

It is recommended that grab samples of base flow for bacteria also be collected for analysis by the Town. This baseline data will be used to compare water quality parameters (WQP) under base flow conditions to WQP where the storm event threshold has been triggered, and to more generally assist in data interpretation.

Note: the data requirements of II.B.1 and 2 represent supplemental data collection efforts unrelated to storm events. The Project Team will want to discuss how the additional data requirements are most conveniently addressed. See also, Section II.F.4 below.

3. Calculation of Storm Event Concentration

Because of mixing of base flow with storm event flow, the actual concentration of nitrogen in the storm event flow volume cannot be determined except by calculation. The mixing problem is conceptualized below with Equation (3) providing the solution for calculating any instantaneous storm event concentration:

where, Q_b is the flowrate (gal/min) of base flow at total nitrogen (TN) concentration C_b (mg/gal) at time t_0, Q_{sw} is the incremental volume (gal/min) of storm event flow (gal/min) at unknown TN concentration C_{sw} (mg/gal) at time t, and C_{mix} is the mixed TN concentration of the base and storm event flow at time t (mg/gal). Therefore,

$$C_{sw} = C_{mix} (1 + Q_b / Q_{sw}) - (Q_b * C_b)/Q_{sw} \qquad (3)$$

C. Factors Influencing Performance Monitoring

1. Storm Event Size

Evaluation of the size and size distribution of New England storm events has been provided in earlier publications. Refer to Event Frequency analysis in Section 2.2 of U.S.EPA, Stormwater Best Management Practices (BMP) Performance Analysis (December 2008). Figure 3-1 of this Dec 2008 report (reproduced below as Figure II.C.1a) summarizes precipitation data for Boston, Massachusetts for the period of 1948-2004: 61% of all storm events are between 0.05 and 0.2 inches and 83% of storms are less than 0.6 inches.

A more recent analysis of data (Figure II.C.1b) from the period 1992 through 2014 indicates 39% of all storm events are between 0.05 and 0.2 inches and 66% of storms are less than 0.5 inches. This data may more accurately reflect current rainfall trends (e.g., climate change).

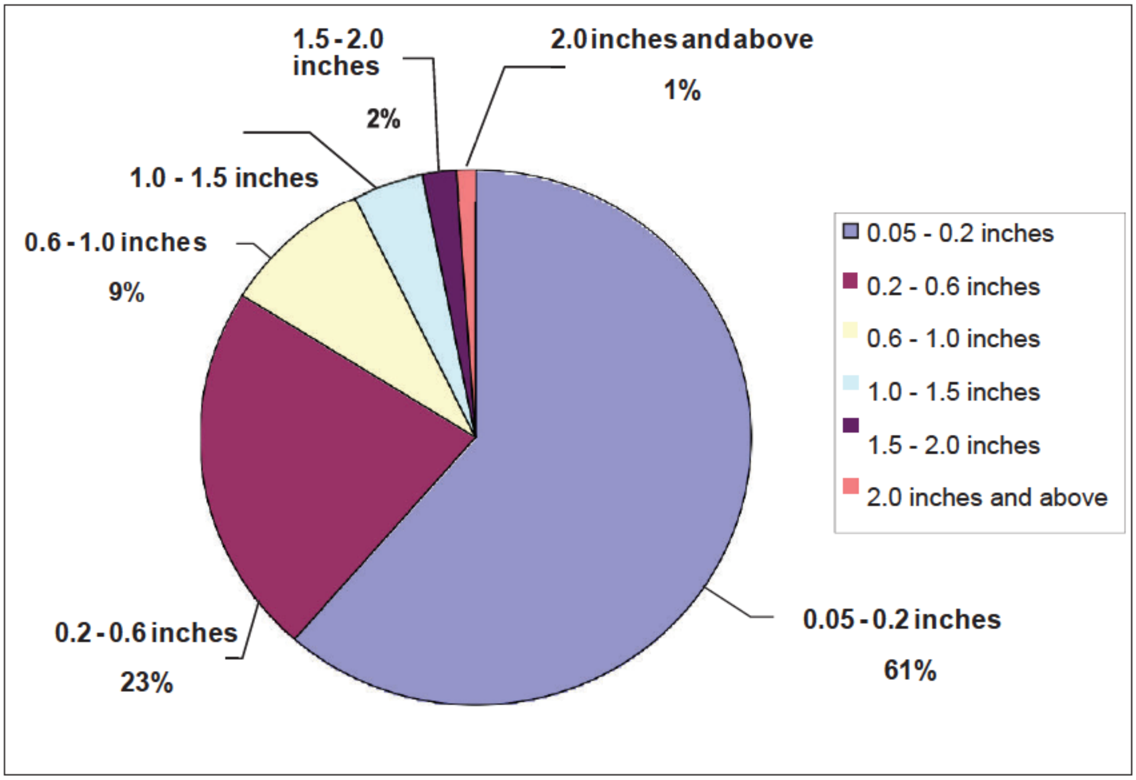


Figure II.C.1a

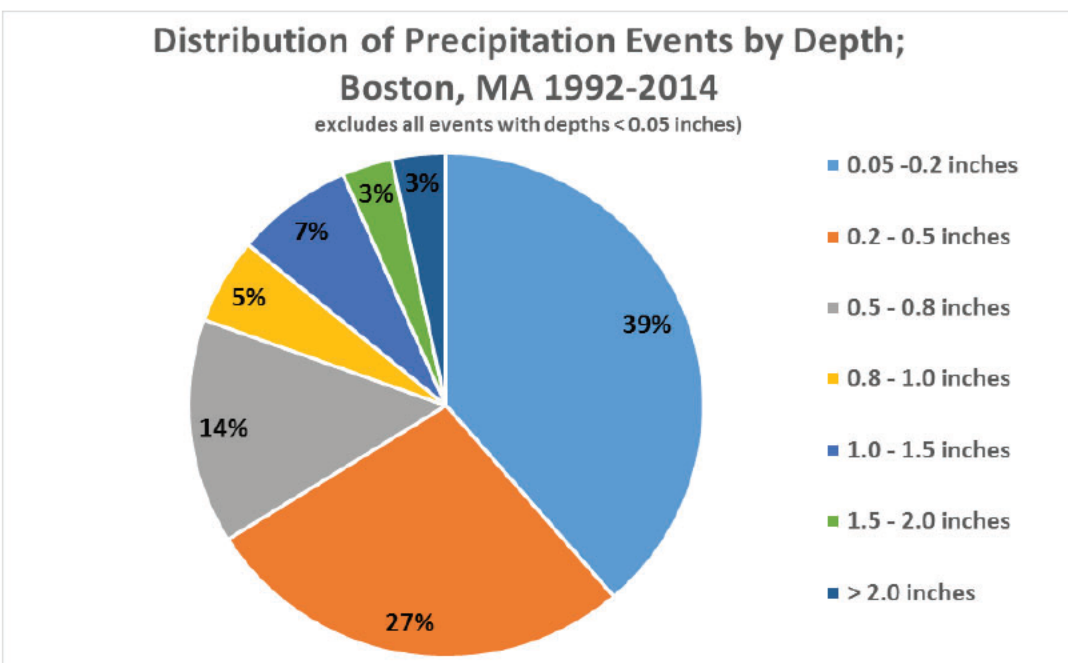


Figure II.C.1b

2. Nitrogen Loading from Impervious Surfaces

Figure II.C.2a was developed to estimate cumulative TN load delivery from impervious area.

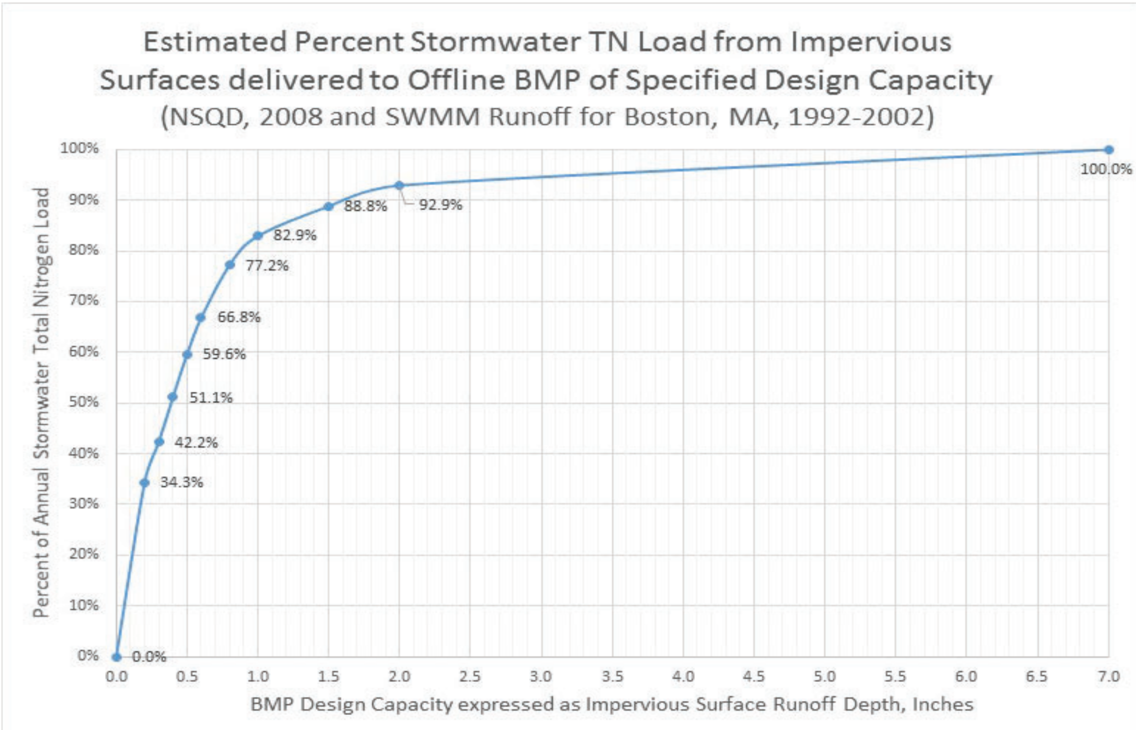


Figure II.C.2a

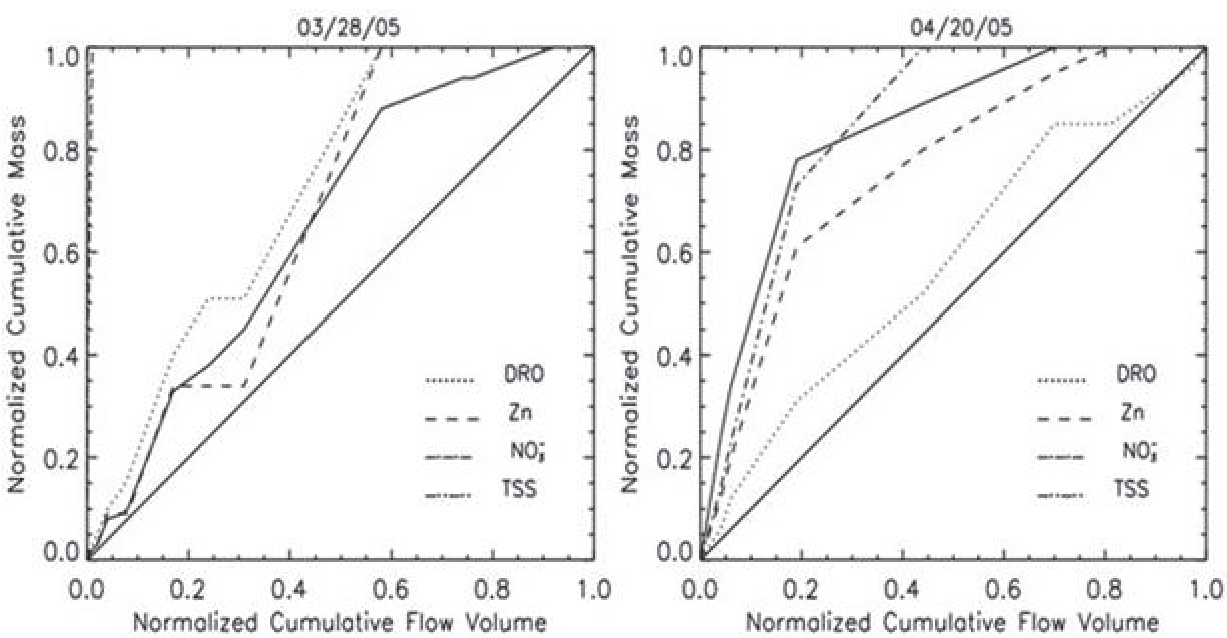


Figure II.C.2b

Figure II.C.2b, from the University of New Hampshire Stormwater Center (UNHSC), evidences more recent data on mass loading for diesel range organics (DRO), zinc (Zn), nitrate (NO_3), and total suspended solids (TSS) as a function of normalized storm volume for two storms: (a) a large 2.3 in rainfall over 1685 minutes; and (b) a smaller 0.6 in storm depth over 490 minute.[2] It may be difficult to view from the size and quality of the chart presented, but in the chart on the left for 03/28/05, approximately 100% of NO_3 washes off almost instantaneously in a 2.3 in storm. In the chart on the right for 04/20/05, approximately 80% of NO_3 washes off within the first 0.12 inches of the 0.6 inch storm (0.6 in x 0.2 = 0.12 in).

Figures II.C.2a indicates that BMP retrofits designed for smaller-scale storm sizes may capture a disproportionately higher nitrogen load from impervious surfaces (e.g., BMP designed for 0.3 inches would treat 42.2% of the total annual nitrogen load) and Figure II.C.2b indicates soluble nitrogen (NO_3) readily washes off of IC. Collectively, Figures II.C.1a, 1b, 2a and 2b suggest small-scale BMP retrofits may perform exceedingly well for capturing available nitrogen from IC in part because most storm events in New England are small and in part because small systems are likely to capture disproportionately higher nitrogen loads from IC. This is an important observation for geographically-constrained environs, such as urban environs within New England - and may suggest that BMP retrofits, although typically more costly compared to other BMPs, may indeed be cost competitive with larger systems, such as those required to meet a minimum of one (1) or more inches of water quality volume (e.g., new development or redevelopment projects that trigger stormwater requirements).

3. Storm Event Duration and Continuity

To assist in both modeling calibration and interpretation of results, precipitation data available for New England for the years 2000 thru 2014 was statistically evaluated. New England precipitation data was available for the period of 1992 thru 2014. The data sets are quite large and it was necessary to consider a representative portion of the data. The more recent data was chosen in part because it may more likely reflect changes in climate. Indeed, a higher frequency of very short duration storms (i.e., 1 to 2 to 4 hrs) was generally observed within the 2011-2014 period vis-à-vis data from 1992-1994.

There were 1,462 storm events over the eleven-year period, where an inter-storm duration period (**IDP**) of six (6) hours or greater was used to determine the end of one storm event and the beginning of another. The 6-hr IDP is an experience-based practitioner rule-of-thumb and is based in part upon agreement between stormwater professionals.

The metrics generated from the evaluation are provided below in Table II.C.3.

---

2 Source of Figure II.C.2b: James Houle, UNHSC.

Table II.C.3

Storm Event Duration (hours)	
New England, 2000-2014	
Average (mean)	9.87
Median	7.00
Max	72
Min	1
Std. Dev.	9.3
25% Quartile	3
75% Quartile	13
skew	2.04

The metrics indicate the mean is likely the best measure of the typical values within the data set because the quartile and skew metrics evidence a tendency for the data to concentrate to the right of the probability distribution. If the 25% Quartile is considered, this would place the storm duration within the range of 4 to 10 hrs, with the skewness suggesting the majority of the storm duration values may likely fall between 7 and 10 hrs.

The metrics suggest that storms having durations of about 4 to 10 hours may be more probable events. This may assist the field team in estimating time and resources for the more probable storm event durations. The metrics may also assist in programming the Teledyne Signature® Flow Meters (base system), in part because the base system can be programmed to disregard lack of storm event continuity below six hours. Storm continuity/non-continuity (i.e., IDP) therefore, can be an additional factor in determining bona fide storm events for the monitoring program. It is recommended that storm events for the monitoring program be confirmed by timely and accurate forecast information available to the field team; e.g., www.wunderground.com., which can include graphical forecasts of IDP. IDP will be particularly relevant for longer storm durations as the data generally indicated good to excellent continuity for storms with durations less than about 10 to 11 hours with lack of continuity increasing with an increase in storm duration.

4. Hydrodynamic Modeling

EPA's contractor, Comprehensive Environmental Inc. (CEI), conducted hydrodynamic modeling using Autodesk® Storm and Sanitary Analysis (SSA) to help inform the timing and frequency of water quality sampling, in part because the front end of the storm event is likely to contain higher concentrations of dissolved inorganic nitrogen (DIN) (often referred to as "first flush" analysis). The SSA is used for analyzing and designing urban drainage systems, stormwater sewers, and sanitary sewers and can be used to simultaneously model complex hydrology, hydraulics, and water quality. The SSA uses TR-55 as the computational engine. [3]

SSA was calibrated to incorporate the physical characteristics of the Barnstable sub-catchment draining to the BMP, including extent of impervious cover, and geometry and slope of the sub-catchment. Because the model relies on the Soil Conservation Service (SCS) runoff equation to predict time to concentration (i.e., peak rate of runoff) and total volume, the model was calibrated for impervious cover only. The modeling was conducted for the Barnstable BMP because of the observed base flow, the high percentage of impervious cover for the sub-catchment, and the geometry and slope of the sub-catchment. In general, these characteristics have tended to demonstrate the sub-catchment is perhaps uniquely 'fast' (i.e., volume and velocity as a function of time) in response to storm events. Modeling results including hydrographs are provided in **Appendix E** (provided as standalone *.pdf w/ attachments).

Based in part on the metrics provided in Section II.C.1 above, the model was used to simulate hydrographs and time to concentration (t_c) for various representative storm sizes and durations. Results of the modeling indicate that reasonable preliminary settings for TN grab sampling should likely be between 5 minutes to 3-4 hours. This range should likely capture first flush flows for a wide variety of potential storm events. The longer end of the range may provide useful information for some of the longer-duration slow-producing storms. The range can be shortened to 5 minutes to 2 hours if the Project Team wishes to concentrate more on the shorter duration smaller flow storms. It may be possible to pre-program the controller for two different sampling scenarios based on storm type which field personnel may then choose based on storm forecasting.

The recommended sampling regimen for each BMP is provided in Section II.F below.

D. Scoping Meetings

For EPA's initial discussion of technical details for the sampling and analysis portion of the project, a set of kick-off conference calls were held. Participants included Ray Cody, Marcel Belaval, Mark Voorhees, Lynne Hamjian, Katrina Kipp, Tim Bridges, Ernest Waterman, and Diane Switzer.

[3] "Technical Release 55 (TR-55) presents simplified procedures to calculate storm runoff volume, peak rate of discharge, hydrographs, and storage volumes required for floodwater reservoirs. These procedures are applicable to small watersheds, especially urbanizing watersheds, in the United States." TR-55 is perhaps the most widely used approach to hydrology in the US. Originally released in 1975, TR-55 provides a number of techniques that are useful for modeling small watersheds. Since the initial publication predated the widespread use of computers, TR-55 was designed primarily as a set of manual worksheets. A TR-55 computer program is now available, based closely on the manual calculations of TR-55. TR-55 utilizes the SCS runoff equation to predict the peak rate of runoff as well as the total volume. TR-55 also provides a simplified "tabular method" for the generation of complete runoff hydrographs. The tabular method is a simplified technique based on calculations performed with TR-20. TR-55 specifically recommends the use of more precise tools, such as TR-20, if the assumptions of TR-55 are not met." Refer to http://www.hydrocad.net/tr-55.htm.

Communications continue as the details of the overall project are worked out with EPA, WaterVision/CEI, the Towns of Barnstable and Chatham, EPA's NERL Quality Assurance Unit (QAU), and other partners.

E. Data Usage

For assessing BMP performance, the most important parameters are Total Nitrogen (TN), Total Phosphorus (TP) and TSS measured during storm events at BMP Inlets and outlets.

Note: grab samples for any parameter are not required to be collected at the BMP bypass. This is because each parameter is presumed to be completely mixed such that there is no difference between the BMP inlet and the bypass.

1. Total Nitrogen

The overall objective of the monitoring program is to assess the performance of these subsurface gravel wetland BMPs for capturing and treating nitrogen.

All usable data will be evaluated by EPA's Office of Ecosystem Protection (OEP) to determine the level of success of the demonstration project, and possibly to generate nitrogen reduction performance curves by way of developing and calibrating representative models of the BMPs. The influent data from the BMP inlet (assumed identical to the MS4 trunk line) will also be used to characterize the quality of the runoff from the contributing drainage areas, including characterization of the buildup and wash-off of nitrogen for the sub-catchment IC. If successful, information about the BMPs can serve as a basis for the transfer of subsurface gravel wetland technology across New England and the nation.

Note: because earlier discussions concluded project logistics would simplify if chemical analysis for nitrogen was limited to TN, it will not be possible to differentiate between the runoff profiles of DIN and Total Organic Nitrogen even though the lower relative solubility of Total Organic Nitrogen (TON) suggests the distribution of TON in stormwater runoff will likely differ from DIN; that is, TON is expected to have a tendency to correlate more closely with time to concentration (t_c) reflecting both (a) a more physical rather than chemically-influenced mobility pattern and (b) suggesting a more normally distributed profile consistent with the storm profile / hydrograph. Depending on initial monitoring results, it may prove helpful to expand analysis of the water quality samples for, at a minimum, nitrate (NO_3).

2. Total Phosphorus (TP) and Total Suspended Solids (TSS)

Grab and composite sampling for TP and TSS should be consistent with TN sampling efforts.

3. Bacteria

EPA does not require bacteria data to demonstrate BMP effectiveness for nitrogen, so the collection and analysis of samples for bacteria would represent supplemental information. In addition, were EPA to sample for bacteria, the relatively short hold times required for bacteria samples present a logistical problem: samples would need to be shipped overnight likely resulting in exceedance of hold time requirements.

Because of the logistics associated with monitoring BMPs on Cape Cod, the project has presumed to rely on a partnership between interested stakeholders, including each municipality (Barnstable, Chatham) as well as the Cape Cod Commission (CCC) and interested non-profit organizations such as the Association to Preserve Cape Cod (APCC). If project stakeholders are interested in bacteria data, EPA's preference is for the Towns to conduct bacteria sampling.

Grab samples for bacteria (*E. coli*) may be collected for analysis by the Towns. The Towns of Barnstable and Chatham have requisite laboratory facilities and conduct bacteria analyses routinely according to Standard Operating Procedures (SOP) that are common to both Towns. These SOPs are provided as **Appendices D1 thru D3** (provided as standalone *.doc).

At Barnstable, and because base flow has been observed in the MS4 trunk line that feeds the BMP, grab samples would need to be collected to account for the base flow as a 'background' or baseline condition. Consequently, it is recommended that base flow bacteria grabs be collected periodically for analysis by the Town if meaningful conclusions about bacteria in stormwater is to be possible. These grabs represent additional non-storm event sampling requirements not initially anticipated. During storm events, grab samples may be collected by the Town at a time after storm event initiation that the Town believes would be appropriate. The Towns may wish to mirror the interval frequency of the TN/TP and TSS sampling for the first few storm events and then reduce sampling over time. To evaluate BMP performance for bacteria, grab samples should be collected at both BMP inlet and outlet.

<u>4. Dissolved oxygen (DO), temperature, conductivity and pH</u>

Very early project scoping and planning discussions between OEP and NERL suggested that NERL would be able to provide Sondes for measuring DO, temperature, conductivity and pH. As these discussions matured, the project incorporated the Sondes into a specific project scope task, Task 4. Task 4 was generally provisioned for the development of the QAPP and Monitoring Plans. At that time, it was anticipated that development of the QAPP and MPs would require ongoing input and confirmation of prior OEP/NERL discussions, in part b/c the BMP inlet and outlet flow regimes were so drastically different and monitoring of the BMPs could become quite complex.

EPA and its contractor, WaterVision, held at least one meeting at EPA's offices to discuss the likely monitoring program which culminated in the July 24, 2015 Technical Memorandum entitled, *Monitoring System for Barnstable and Chatham BMPs (revised)* (Appendix A). The memorandum specified certain equipment that would be required for the monitoring program including Teledyne Instruments, Inc. flow controllers and Teledyne ISCO auto-samplers. Although the base equipment may incorporate DO, temp, conductivity and pH probes, this equipment was not specified, indicating the assumption incorporated into the Monitoring Program that NERL could provide equipment for DO, temperature, conductivity and pH. Again, if it turns out that NERL cannot provide this equipment, the base equipment platform

EPA purchased can readily incorporate equipment for these parameters. This may take some time, however, as it would require funding for a direct-purchase requisition.

At Barnstable, and for the same reason specified above to account for base flow, grab samples / measurements for DO, temp., conductivity and pH would need to be collected to adequately characterize base flow at the inlet with synoptic collection of grabs at the outlet. Grab sample measurements would then occur at storm event initiation and routinely throughout a storm event, for each storm event.

F. Sampling Event Design – Stormwater Monitoring and Sample Collection

Based on the information provided above, sampling is currently anticipated to incorporate two water quality sampling design methods: flow-weighted composite (**FWC**) and discrete time interval (**DTI**) grab sampling.

FWC is the preferred approach for overall BMP assessment in part because, all factors considered (incl., equipment capabilities and capacities), it is logistically straightforward and requires only one FWC sample per storm event at the BMP inlet and outlets for obtaining event mean concentrations (EMC) for a mass-balanced assessment of TN in and out of the BMP.

An additional ISCO will be used for DTI sampling - at the BMP inlet only - to characterize the wash off of nitrogen and phosphorus. Both approaches are described in more detail below in Sections II.F.4 and II.F.5.

1. Equipment

As described above in Section II(A), EPA has acquired monitoring equipment from Teledyne Instruments Inc. via NE3, Teledyne's New England representative. This equipment was direct-purchased by EPA based on monitoring equipment recommendations made for the project by WaterVision. Refer to the July 24, 2015 Technical Memorandum developed by WaterVision for the project entitled, *Monitoring System for Barnstable and Chatham BMPs (revised)* (Appendix A**)**. The equipment includes:

- **Signature® Flow Meters**.[4] These meters function as 'base controllers' for all the equipment, including flow devices, ISCOs, rain gauges and probes;

- flow measuring devices:
    - TIENet® Model 350 Area Velocity Sensor (**AV sensor**),[5] and
    - TRACOM Large 60° V Trapezoidal Flumes (**flume**) [6] retrofit with the TIENet® 330 Bubbler Module (**bubbler**);[7]

---

4 Refer to http://www.isco.com/products/products3.asp?PL=2022510
5 Ibid.
6 Refer to http://tracomfrp.com/wastewater_applications/flumes/trapezoidal-flumes/
7 Refer to footnote 4.

At each BMP, there are four AV sensors located at (a) the BMP Bypass (in the MS4 line), (b) the BMP inlet, (c) the BMP outlet and (d) in the BMP basin. The AV sensor in the BMP basin is to enable calculation of the transient storage of water during flow events. The AV sensors have a level measurement range of 0.01 to 3.05 m (0.033 to 10 ft; 0.4 to 120 in.) and a minimum depth of 0.08 ft (0.96 in.) with a Level Accuracy of ± 0.10% Full Scale.

At each BMP, there are also two (2) calibrated flumes located at the BMP inlet and outlet. The flumes are retrofitted with the bubbler which has a level measurement range of 0.003 to 3.05m (0.01 to 10 ft; 0.12 to 120 in.) and a Level Measurement Accuracy of +/-0.002m @ 22 °C (0.007 ft (0.084 in.) @ 72 °F) suggesting a sensitivity to water level rise on the order of less than 1/10th of an inch above 0.12 in.

- **ISCO samplers**. Model 6712 Full Size Portable Samplers.[8] At both Barnstable and Chatham, there is one ISCO for each BMP inlet and outlet (2 ISCO's per BMP) for FWC sampling. At Barnstable, there is an additional ISCO for BMP inlet DTI sampling; after DTI sampling is completed at Barnstable, this ISCO can be moved and retrofitted for DTI sampling at Chatham.

  The ISCOs are provisioned to use 1-liter **ProPak**® sample bags [9] and each ISCO has a capacity of twenty-four (24) 1-L ProPak® bags. Based on conversation with NE3, the equipment can be configured to collect more than one sample in any one bag (e.g., four (4) 200 ml samples in one bag). This *may* be useful for sampling to the extent that it can significantly extend the capacity of the ISCOs for longer duration storms but may complicate post-storm event compositing of grabs.

- Model 674 **Rain Gauges**. [10] There is one rain gauge per ISCO.

- **(Updated Oct 2017) Four (4) In-Situ Aqua TROLL 600 Multiparameter Sondes.** The original work assignment for this project speculated that EPA's NERL might be able to provide Sondes for measuring dissolved oxygen (DO) and other related parameters. As of summer of 2017, the Project had not been able to obtain these Sondes from NERL. As a result, EPA's equipment provider, New England Environmental Equipment (NE3), has specified In-Situ Aqua TROLL 600 Multiparameter Sondes as compatible with the Project's equipment configuration, including the Teledyne Flow Controller. The base sensor configuration of the Sondes includes EPA-approved optical RDO, pH/ORP, turbidity, conductivity, temperature, and pressure. Turbidity is a particularly useful parameter insofar as it relates to total organic nitrogen.

---

8 Refer to http://www.isco.com/products/products3.asp?PL=201101010
9 Refer to http://www.isco.com/products/products3.asp?PL=2017010
10 Refer to http://www.isco.com/products/products3.asp?PL=202803010

Information on the Aqual Troll 600 Multiparameter Sonde is available at: https://in-situ.com/products/water-quality-testing-equipment/aqua-troll-600-multiparameter-sonde/

At Barnstable, the equipment will be housed inside the Cape Cod Maritime Museum (**CCMM**) and powered using 120V service provided by the CCMM. There are multiple advantages for using the CCMM for the equipment, including among other things, dedicated and heated space. However, this caused the ISCO sample lines to be longer than anticipated, requiring acquisition of additional tubing. The sample line run length increased to about fifty (50) feet. Although the specifications providing in the ISCO manuals provides flowrate and transport velocities for suction heads under twenty-five (25) feet, personal correspondence with NE3 confirmed that the suction head would be adequate for the 50 ft run, and the flowrate and velocity can be calibrated during test runs (to be conducted in fall of 2016). The Chatham equipment will be housed in subsurface sampling vaults (SSV) (4' square x 3'D) and powered by marine batteries. There is an SSV at Barnstable currently used as a junction box for equipment lines and which could be used for NERL Sondes.

Operational information for the Teledyne base controller, flow measuring devices, ISCO auto-samplers and rain gauge is provided in the manuals accompanying this equipment and will be stored on-site at each BMP site for reference. Equipment specification information is provided as **Appendix A2**.

2. Monitoring Program Objectives; Qualifying Rain Events for Sample Collection

The goal of the project is to collect information from approximately twenty (20) storm events over a two (2) to three (3) year period. These events should characterize a wide range of rain events of varying intensities and with varying IDPs to generate a set of event mean concentrations that are representative of varying intensities, depths and IDPs.[11] Ideally, the resultant EMCs would statistically tend toward the distribution of all storm events (e.g., many small with some larger events including the varying IDPs).

"Event mean concentration (**EMC**) is a parameter used to represent the flow-proportional average concentration of a given parameter during a storm event. It is defined as the total constituent mass divided by the total runoff volume. When combined with flow measurement data, the EMC can be used to estimate the pollutant loading from a given storm. Flow weighted composite samples produce EMCs by design by taking subsamples based on a predetermined flow value (flow weighting is determined prior to event based on anticipated storm duration and intensities)."[12] EMC is defined generally as:

---

[11] **Note:** For purposes of sampling, the duration of a storm event is defined to include the 24 hour period following cessation of storm event precipitation where outlet flow continues as the static ponding level drains down through the ISR.

[12] UNH et al., *Quality Assurance Project Plan Berry Brook Watershed Assessment*, March 2011, p. 25

EMC = Change in volume x concentration / Change in Volume.

Specifically:

$$EMC_i = \frac{\sum_{t=1}^{t=T} Q_t C_t}{\sum Q_t} \qquad (4)$$

where:

EMC$_i$ is the event mean concentration of a given water constituent *i* (mg/L),
Q_t is the discrete run-off flow rate discharged at time *t* (L/min),
C_t is the corresponding concentration at time *t* (mg/L).

As the monitoring program matures, it may be desirable to target certain storm sizes and IDPs. It is expected and desirable that sampling will occur during all seasons as long as snow/ice events are not present or otherwise prohibit monitoring. The Project Team will want to continually review the data collected in part to ensure that the storm events reflect the objectives of the monitoring program.

It is recommended that pending weather forecast information be reviewed, and a determination made by the Project Team as to whether a given storm event is to be sampled. The determination of whether or not to initiate a sampling event will be informed by data usability generally, weather forecasts (e.g., www.wunderground.com), and may also be dependent upon resources and the availability of field personnel.

Lastly, any given storm sampling event will require communication and coordination with NERL.

3. Signals for a Sample Event

As described above in Section II.A.2, the Teledyne Signature® Flow Meter can be programmed to trigger storm-sampling events on the basis of increases in volumetric level using either the flume and/or area-velocity flow sensors.[13] Because the input flow regime of

[13] As provided in the July 24, 2015 WaterVision Technical Memorandum:

> Each flume will be instrumented with a water-level sensor while the adjacent upstream 10-inch-diameter outflow pipe will be equipped with a velocity-area sensor. Water-level readings in the calibrated flume will be convertible to flow, providing a redundant flow reading to the velocity-area sensor. This redundancy is recommended to provide a cross-check and because low flows are expected to be near the lower-limit resolution of the velocity-area sensor. In addition, the above-ground basin will also be equipped with a water-level sensor to enable calculation of the transient storage of water during flow events. (The vendor specified a velocity-area meter for the water-level sensor since it includes an accurate water-level sensor, is comparable in cost to a water-level sensor alone, and provides compatibility with the other components of the system.) The system will provide redundant measures of the inflow to

the BMPs could be particularly turbulent, as an extra precaution, data from rain gauges will be used as a secondary determinative factor for storm-sample event triggering. That is, **both water level and rain gauge data values must be 'positive' for a storm-sample event to be triggered**. This means that changes in base flow need not interfere with storm event triggering.

Although the AV sensor is likely to provide better overall BMP inlet flow data, because the flume/bubbler is more sensitive for lower flows than the AV sensors, use of the flume at the BMP inlet may be best for storm event triggering.

> *Re: Special Note on Measuring Base Flow*. During a test of the Signature® Flow Meter (**SFM**), it was determined that actual flow levels were detected by the flow sensors on powering up the SFM. It is not clear, however, whether the SFM records data unless or until a storm event is triggered. Therefore, it will be important to review the earliest flow level data recorded immediately after storm event triggering to determine the base flow level. If possible, field personnel should check for observance of base flow before a storm event.

4. Water Quality Sampling Approaches

As a general rule, sampling for BMP performance assessment will accord with the objectives stated above in Section II.F.2 to attain EMCs using FWC sampling. A supplemental objective, based on the information provided above in Section II.C, will be to characterize the buildup and wash off of nitrogen. An additional ISCO is available for DTI sampling, and if space is available may be retrofitted into the BMP inlet to characterize the wash off of nitrogen and phosphorus. Otherwise, once adequate EMC data has been obtained, the ISCO may be reprogrammed for DTI sampling.

> **Note on base flow.** Barnstable sampling will need to consider base flow which should be characterized using non-storm event base flow grab. Once base flow is observed, it is recommended that characterization of base flow water quality occur at initial observance and then periodically (e.g., every two weeks) for the duration of observed base flow. Grab samples for base flow water quality would likely be most conveniently collected immediately before a storm event, but not necessary. For determination of TN, TP and TSS in stormwater, the flow rate / level and concentration of TN, TP and TSS in base flow samples will need to considered as per equation (3) provided in Section II.B.3
>
> The Teledyne ISCOs can be directed to collect 'manual' grab samples by the push of a button. Because the current plan is to treat the base flow in the BMP, base flow samples should be collected at the BMP inlet and labeled as "base flow" along with

---

and outflow from the BMP as well as the storage within the BMP, thus enabling construction and checking of a complete water balance over the BMP.

the date and time of collection. Each base flow sample will require two (2) 1-Liter ProPaks® or glass bottles: 1 L for TN/TP and 1 L for TSS.

i. Flow-weighted Composite (FWC) Sampling

Based on conversation with UNH's Stormwater Center and the hydrodynamic modeling described above in Section II.C.4, the Signature® Flow Meter will be initially and generally programmed to provide preferential weight to ISCO grab samples collected prior to time to concentration (t_c). Flow weighting will be refined, if possible, prior to qualifying storm events based on anticipated storm durations and intensities. Such weighting will help ensure that the average concentration of nitrogen developed from grab sample compositing will most accurately reflect the total nitrogen into and out of the BMP.

Initially, for the first one or more storm events, FWC grab samples will be collected at both the BMP inlet and outlet. Once it is confirmed, as expected, that the concentrations of target parameters do not appreciably change at the outlet, the frequency of BMP outlet grab sampling may be reduced to ease project resources and administration.

ii. Discrete Time Interval (DTI) Sampling

There is an additional ISCO that may be used as a backup/spare, or may be used for DTI sampling. This ISCO would be used at the BMP inlet (only) at Barnstable to characterize the first flush wash off of TN, TP and TSS. After DTI sampling is completed at Barnstable, this ISCO could be moved and retrofitted for DTI sampling at Chatham.

The discrete time intervals for DTI sampling will be based on the Hydrodynamic Modeling described above in Section II.C.4 and is provided below.

Re: DTI logistics. Each DTI grab for TN/TP and TSS requires two (2) Propak® bags (back-to-back sequential grab samples). This means the bag capacity of the ISCOs effectively represents twelve (12) discrete grab samples. Considering the sampling regimen recommended by the Hydrodynamic Modeling presented in Section II.C.4 above, there should be adequate capacity, even for longer storm durations, so that mid-storm change-out and replacement of Propak® bags in the ISCO will not be necessary.

5. Sample Design: Recommended Initial FWC and DTI Sampling Regimen

Recommended time-discrete intervals for both FWC and DTI sampling is as follows:

i. Barnstable

Storm event 'first flush' grab samples collected by the Teledyne ISCOs for both FWC and DTI sampling for TN, TP and TSS should be collected at the BMP inlet and outlet at following intervals: 5, 15, 30, 60, 120 minutes after the Teledyne system is triggered

for a storm event.[14] After 120 minutes, DTI sampling may be discontinued.[15] After this time, grab samples collected for FWC may be evenly spaced on the half-hour or hour depending upon anticipated storm duration.

To compensate for the delay associated with sample flow and pre and post sample purge cycles, the sample line length should be minimized and care should be taken that the line is straight without slack or dips.

At least for the first few storm events, to ensure that outlet sampling is synoptically related to inlet sampling, BMP outlet sampling should take place at identical intervals as BMP inlet sampling. However, recall from above in Section II.F.2 that the duration of a storm is defined to include the 24 hour period following cessation of storm event precipitation. Therefore, **post-precipitation grabs over this 24 hour period occur at the BMP outlet only.**

FWC and DTI samples are to be packaged and shipped overnight using EPA's FedEx account and according to appropriate Chain-of-Custody procedures provided below in Section VI (generally) and the Monitoring Plans (specifically).

Lab analysis of the DTI samples may begin as soon as the samples arrive at NERL.

Lab analysis of the FWC samples must not occur until OEP has uploaded and evaluated the flow data in order to provide instructions to NERL on how to composite the FWC samples. Once composited, the samples will need to be split for TN, TP and TSS analysis.

> **Note on ISCO ProPak® capacity.** Although the system can be configured to collect more than one sample in any one bag, this would complicate flow-dependent compositing. Therefore, the suggested intervals above would correspond to 5 ProPak® bags (1 sample interval per bag), leaving nineteen (19) bags for the remainder of the storm event for the ISCOs dedicated to FWC sampling. Assuming FWC grabs are collected on the half-hour, this would represent an approximate twelve (12) hour storm; 1 hour grabs would represent an approximate 24 hour storm. However, recalling that the storm event includes the post-storm 24-hour period, it may be conservatively assumed the number of bags be halved, leaving less bags for post-first-flush-interval storm sampling. Because the flowrate at the BMP outlet should remain relatively constant, it may be possible to consolidate up to four (4) of these outlet grabs per bag thereby preserving bags for the actual storm event. These logistics can be worked out in the field during test runs and some of the initial storm events.[16]

[14] These intervals accord with the hydrodynamic modeling results for shorter storm durations. The Project will focus on these storms initially, in part b/c it simplifies Project logistics.

[15] For DTI sampling, this represents 5 grabs (10 ProPak® bags: one bag for TN/TP and one for TSS).

[16] Because of the capacity of the Teledyne ISCO auto-samplers, if a given rain event exceeds the 24 ProPak® bag capacity of the ISCO, FWC grab samples may need to be removed from the auto-sampler and set aside in order that additional ProPak® bags may be added to the ISCO. However, because this implicates field personnel time and availability, effort should be made to plan for and optimize ISCO bag capacity.

At Barnstable, lab analysis for FWC translates into a total of two (2) composite samples (1 sample per BMP inlet and outlet) split for TN, TP and TSS based on OEP flow calculations. A duplicate may be run on one or more of the composite splits.

DTI analysis represents five (5) near-simultaneous sequential grabs (BMP inlet only) where each "grab" is two (2) liters (1 L for both TN and TP, and 1 L for TSS).

For the Project's initial grab sample interval configuration, the FWC and DTI sampling represent a total of seven (7) WQ samples for lab analysis.

ii. Chatham

Considered with the overall characteristics for the Chatham BMP, the Barnstable modeling results likely suggest response time will be generally longer with longer grab intervals starting later after storm event initiation. It is recommended that grab sampling intervals be empirically adjusted based on data collected from the project.

At Chatham, storm event 'first flush' grab samples collected by the Teledyne ISCOs for FWC sampling of the BMP inlet and outlet flows are proposed for following intervals: 10, 30, 60, 90, 120, 180 minutes after storm event triggering. After 180 minutes, grab samples collected for FWC may be evenly spaced on the half-hour or hour (or longer) depending upon anticipated storm duration.

When the DTI-dedicated ISCO is available from Barnstable, then DTI sampling would accord with FWC intervals; and after the last first-flush interval, DTI sampling may be discontinued.

At Chatham, lab analysis for FWC translates into a total of two (2) composite samples (1 sample per BMP inlet and outlet) split for TN, TP and TSS based on OEP flow calculations. A duplicate may be run on one or more of the composite splits.

DTI analysis represents six (6) near-simultaneous sequential grabs (BMP inlet only) where each "grab" is two (2) liters (1 L for both TN and TP, and 1 L for TSS).

In all, the initial grab interval configuration represents a total of eight (8) WQ samples for lab analysis.

Sampling Regimen: Summary

Because the dedicated DTI ISCO will be used first at Barnstable and then at Chatham, then initially and for any storm event, there will be a total of four (4) FWC and 5-6 DTI grabs for laboratory analysis (1 L for TN/TP and 1 L for TSS), plus duplicates and blanks.

6. Sample Processing

a. Flow-Weighted Composite (FWC) Grab Samples (UPDATED Oct 2017)

Based on conversation with NERL over the summer of 2017, NERL does not composite samples. This means flow-weighted compositing must occur at the lab/offices of the municipalities.

EPA has developed a conceptual approach for preparing 1 Liter flow-weighted composite samples based on sample flow data from the Teledyne system.

EPA and the municipalities have agreed that the municipalities will email the flow data to EPA. EPA will import the data into an Excel spreadsheet and perform calculations on the data to determine the proper aliquots to be taken from each grab sample for preparing the 1L FWC samples. The municipalities will then make the 1L FWC samples and ship the samples to NERL. The composited samples will then be preserved and shipped overnight to NERL for analysis.

Although this approach requires the municipalities to prepare the FWC samples themselves, it simplifies and eliminates the need to ship all the grab samples collected by the ISCOs. Rather than ship some 92 grab samples per storm event, the muni's need ship only four (4) 1L composited samples per BMP storm event: one 1L sample for TN/TP and TSS for BMP inlet, and same for BMP outlet. This is a significant savings in shipping cost and coordination.

OEP recommends that one or more test storm events be used to refine the exact procedure for compositing. Although OEP has developed an approach and Excel spreadsheet for this purpose, as of October 2017, (a) uncertainties still exist insofar as how exactly storm event triggering will occur, (b) the exact relationship for collection of outlet samples based on inlet storm event triggering, (c) the data that is imported into Excel is parsed into columns, and these columns need to be confirmed for the source of the data (flume or AV Sensor, etc.) and (d) the recently procured In-Situ Aqua TROLL 600 Multiparameter Sondes have still to be incorporated into the BMPs and Teledyne system.

Splitting of the composite samples will be done manually until such time as a cone splitter may be procured.[17]

b. Discrete-Time Interval (DTI) Grab Samples

DTI grab samples will be processed separately to support characterization objectives in II.F.2 (EMC) and II.F.4.ii (first flush analysis); these samples will not be composited. Rather, these 1 L samples will be analyzed individually. If the 1 L ProPak® sample collection bags are not convenient for NERL, the 1 L samples can be transferred to poly-propylene or glass bottles.

---

[17] Cone splitter is recommended by UNHSC. Refer to http://www.rickly.com/sai/dekaport.htm.

Note: per Section II.G below, one (1) liter of sample is required for TN, 0.1 liter of sample is required for TP and one (1) additional liter is required for TSS. However, per Section V below, one liter has been determined to be sufficient for both TN and TP. If any DTI sample does not have sufficient volume for all planned analyses, priority will be given to analytes in the following order: total nitrogen, total phosphorus, and then TSS.

c. Continuous Monitoring

For each event, continuous or near-continuous monitoring of flow, DO, temperature, conductivity and pH will occur at sample locations as shown on Figure II.A.1. Flow monitoring will be automated and collected/recorded by the In-Situ Sondes and the Teledyne system. Note that although water quality sampling of the MS4 trunk line (i.e., bypass) will not be required, measurement of flow will be required.

DO, temp., conductivity and pH will occur using the recently procured In-Situ Sondes.

Continuous monitoring should be set to data collection intervals of 5 minutes.

d. Bacteria.

If bacteria samples are collected during a storm event by the Towns, they will be collected as grabs, separate from auto-sampler composites and processed according to the Town's SOPs (Appendix D1 thru D3). Bacteria samples will be collected from the same sample locations as shown in Figure II.A.1.

7. Sample Labeling (Updated Oct 2017)

Based upon conversation with Teledyne Instruments, the Teledyne system records / labels samples according to:

- time,
- date, and
- bottle (i.e., ProPak®) number.

Therefore, sample containers for TN/TP and TSS should be labeled according to the following schema:

B = Barnstable
C = Chatham
FWC = flow-weighted composite grab sample
DTI = discrete-time interval grab sample (from dedicated ISCO)
BMP Inlet = inlet
BMP Outlet = outlet
date; time = mm/dd/yy;

Therefore, the recommended sample format would appear as:

<site> <sample type> <analyte> <location> <date>

Ex.1. A TN FWC sample composited from grab samples collected from the BMP inlet at 7:57 PM on October 17, 2016 at Barnstable after storm initiation recorded as 6:10 PM**: "B FWC TN Inlet 10-17-16.**

Ex.2. A TN/TP DTI sample collected from the BMP outlet at 1:06 PM on November 21, 2016 at Chatham after storm initiation recorded as 12:15 PM: **"C DTI TN/TP Outlet 11-21-16.**

8. Chain-of-Custody

A chain-of-custody form will be completed, signed by the person processing and shipping the samples, placed into a gallon plastic bag and taped to the inside lid of the cooler. A protocol for this is in the Monitoring Plan.

9. Transportation of Samples to the EPA Laboratory

EPA's Chemistry Lab Lead or representative must be notified about the potential rain event as early as possible. TN, TP and TSS samples will be packaged and placed in a cooler with ice for transport by FedEx overnight shipping to the NERL Chemistry Lab using EPA's FedEx account number. Samples must be shipped for overnight delivery, only on Mondays through Thursdays. If samples are driven to the lab, they can be accepted Monday – Friday. The lab will also be contacted if there is a weekend event, to also see if alternative arrangements can be made for sample transport.

Bacteria samples will not be transported to the EPA laboratory. If these samples are collected, they will be analyzed by the Town's own laboratory or a local lab of the Town's designation; transportation to the lab will follow procedures established by that lab.

10. Quality Control Samples

There will be field quality control procedures, and quality control field samples will be collected. These include:

a. Calibration – All meters and auto-samplers will be calibrated prior to use according to the Monitoring Plan and manufacturers' manuals.

b. Sample container blanks – Distilled or deionized water may be placed in clean sample containers, labeled as a routine sample, and analyzed to determine whether container contributes to nitrogen, phosphorus or TSS results. Based on comments received from EPA QAU, sample container blanks are likely unnecessary as a matter of course / routine. Sample container blanks could be employed as necessary as part of a forensic regimen in the event such becomes necessary.

c. Duplicate composite samples – In addition to the initial sample from the compositor, a second sample from the composite will be submitted to determine if there is good representation of results by the initial sample.

d. QC Criteria – Data that does not meet laboratory QC criteria will be flagged by the laboratory and reviewed by the Project Manager, municipal leads, and technical assistance leads.

G. Monitoring Parameters

Parameter(s)	Sample Matrix	SOP/Protocol	Sample Container	Preservation	Holding Time
Flow	Water	1. AV Sensor 2. Flume/bubbler	In-situ	None	Immediate
DO, Cond., Temp, pH, TSS	Water	In Situ Multi-parameter Sonde Manual	In-situ	None	Immediate
Total Nitrogen	Water	EIASOP-INGNO3NO20	*1 Liter Precleaned PP	H_2SO_4 to pH<2, cool to 4°C	28 Days
Total Phosphorus		EIASOPINGTP11			
TSS	Water	EIASOP-INGTSS-TDS-VRES6	1 L, plastic	Cool to 4°C	7 Days
E. Coli	Water	Refer to Appendices D1-D3	Refer to Appendices D1-D3	Refer to Appendices D1-D3	Refer to Appendices D1-D3

* Note: the Teledyne equipment specifications included 1 liter ProPak® sample bags, and samples collected by the ISCOs will be collected in ProPak® bags. Based on conversation with Teledyne, samples collected in the ProPak® bags can be preserved with sulfuric acid. Alternatively, depending upon laboratory preference, samples collected in the ProPak® bags may be transferred to and adjusted for pH in one-liter poly-propylene (PP) or glass containers. Refer to http://www.isco.com/products/products3.asp?PL=2017010. In addition, although 2.1 L of sample is specified, NERL has indicated that the 1 L sample collected for TN can also be used for TP. This is particularly helpful because it saves one bag for each sample (multiple bags for each storm event), and simplifies timing and logistics for collecting the two (2) 1-liter samples required for each sample event (which will require near-simultaneous sequential sampling by the ISCO).

III. DATA QUALITY OBJECTIVES

Accuracy and precision values are for method internal QA/QC.

Parameter	Sample Matrix	Reporting Limit	Accuracy	Precision
Flow: AV Sensor	Water	0.4 inches	± 0.10% Full Scale	N/A
Flow: bubbler	Water	0.12 inches	0.084 in. @ 72 °F	
Dissolved Oxygen	Water	0 to 15.0 mg/L	± 0.2 mg/L	N/A
Conductivity	Water	0 to 4999 µS/cm	±0.1 ppt or ± 2%	N/A
Total Nitrogen	Water	0.04 mg/L	±20%	±20%
TSS	Water	5.0 mg/L	±25%	±25%

Total Phosphorus	Water	0.005 mg/L	±20%	±20%
E. coli	Water	Refer to Appendices D1-D3	Refer to Appendices D1-D3	Refer to Appendices D1-D3

IV. DATA REPRESENTATIVENESS/COMPARABILITY/COMPLETENESS

Samples must be representative of the BMP stormwater inflow and treated outflow. The outflow will be compared to the inflow to assess change in nitrogen, phosphorus and TSS concentrations. The target requirement of valid data for the total number of rain events, and operational BMP inflow and outflow sampled, is 80% completeness. However, an evaluation of critical samples may determine if data are complete or incomplete, and the Project Team will determine if additional rainfall events are needed.

V. SAMPLING PROCEDURES

Samples will be collected according to this QAPP and the Monitoring Plans (the Monitoring Plans translate the requirements of the QAPP into field sampling protocols and procedures). Nutrient and TSS samples will be collected as grabs for FWC and DTI sampling. On any occasion that the Project Team determines another procedure must be used to obtain samples, the procedure will be documented in the field log book with a description of the circumstances requiring its use. Sampling personnel must have qualifications as described in Section X.

Table V

Barnstable Sample Collection for Laboratory Analyses (per Storm Event)

<table>
<tr><th>PARAMETER</th><th>COLLECTION METHOD</th><th># SAMPLES</th><th>VOLUME/SAMPLE</th><th>ANALYTICAL LAB</th></tr>
<tr><td>Total Phosphorus</td><td>Grab or Composite</td><td rowspan="2">Per BMP sample event:

FWC: multiple grabs for two (2) lab composites

DTI Grabs: 5-6 1-liter ProPaks® *

plus
- 1 bottle blank (optional) ^
- 1 field duplicate **</td><td rowspan="2">1 Liter for both TN & TP</td><td>NERL</td></tr>
<tr><td>Total Nitrogen</td><td>Grab or Composite</td><td>NERL</td></tr>
</table>

TSS	Grab or Composite	Per BMP sample event: **FWC:** multiple grabs for two (2) lab composites **DTI** Grabs: 5-6 1-liter ProPaks® * plus - 1 bottle blank (optional) ^ - 1 field duplicate **	1 Liter	NERL
E.coli	Grab	Refer to Town SOPs (Appendix D)	100 ml	Town

Chatham Sample Collection for Laboratory Analyses (per Storm Event)

PARAMETER	COLLECTION METHOD	# SAMPLES	VOLUME/SAMPLE	ANALYTICAL LAB
Total Phosphorus	Grab or Composite	Per BMP sample event: FWC: multiple grabs for two (2) lab composites DTI Grabs: five to six 1-liter ProPaks® * plus - 1 bottle blank (optional) ^ - 1 field duplicate **	1 Liter for both TN & TP	NERL
Total Nitrogen	Grab or Composite			NERL
TSS	Grab or Composite	Per BMP sample event: FWC: multiple grabs for two (2) lab composites DTI Grabs: 5-6 1-liter ProPaks® * plus - 1 bottle blank (optional) ^	1 Liter	NERL

		- 1 field duplicate **		
E.coli	Grab	Refer to Town SOPs (Appendix D)	100 ml	Town

Notes for Table V

ProPak® bags will likely need to be transferred to 1 L glass bottles in the field. Field personnel will then package and ship bottles to NERL. Bottled samples received at NERL and labeled as FWC per Section F7 above, will then be composited for analysis by NERL based on post-storm event flow data provided to NERL by OEP.

* DTI Grabs. The dedicated DTI ISCO will be used first at Barnstable and then at Chatham. For any storm event where there will be DTI sampling, there will be a total of 5 to 6 DTI grabs (BMP inlet only).

** Field Duplicates. Based on comments from EPA's QAU, it will likely be adequate to have one field duplicate per parameter per storm event. The duplicate could be rotated between inlets, outlets and Barnstable and Chatham.

^ Bottle Blanks. Bottle blanks are intended to qualify absence of contamination in ProPaks® and glass bottles, and/or can be used to qualify absence / de-contamination of sample equipment / lines. These blanks may be employed at the discretion of EPA and/or field personnel, and/or be employed as part of a forensic evaluation in the event troubleshooting is recommended.

VI. SAMPLE CUSTODY PROCEDURES

Samples will be collected in accordance with this QAPP and the Monitoring Plan. Each Sample will be given a unique identification number which corresponds with the inflow and outflow locations, and rainfall event. Refer to Section II.F.7 above. Samples for chemical analysis will be handled according to EPA's OEME Lab SOP database.

VII. DOCUMENTATION, DATA REDUCTION, AND REPORTING

All information will be recorded in field log books or Cape Cod Stormwater BMP field data sheets, in addition to completion of all chain of custody forms, labels, etc. Any photographs taken will be documented in the field log book or field sheets. Analytical data will be tabulated by the laboratory and reported to the Project Manager in accordance with NERL procedures and the NERL Laboratory Quality Manual. The expected turnaround time for analytical results is approximately one month. Field reporting will be in accordance with the respective Monitoring Plans.

A laptop computer was provisioned for downloading flow measurement and ISCO sample data from the Teledyne equipment, including the Signature® Flow Meters. The laptops will likely be secured and stored at the respective offices of the Towns, although the laptop for Barnstable may be most conveniently stored at the Cape Cod Maritime Museum. Data uploaded to the laptops following storm events will be emailed or otherwise transmitted to EPA's Region 1 offices for analysis. Flow data will be important for informing NERL on how to composite FWC samples for analysis, so this data must be emailed to EPA as soon as possible following conclusion of storm event sampling.

VIII. DATA REVIEW

Analytical data will be reviewed by routine laboratory procedures specified in the NERL Laboratory Quality Manual. Data will be reviewed against the criteria presented in this QAPP. Any limitations on the use of data will be documented and explained. Field data will be compiled and reviewed by the Project Team and any corrective actions or issues that are needed will be brought to the Project Manager.

IX. CORRECTIVE ACTION

Any corrective action regarding field work, and onsite meters, will be determined by the Project Team, documented as necessary, and discussed with the Project Manager.

Any significant issue with laboratory performance identified by the Chemistry Laboratory will require that the Project Manager be notified immediately and appropriate corrective action taken.

Performance and systems audits may be performed by the EPA QA Office, or Chemistry and Field QA Officers, as requested by the Project Manager. Possible reasons for an audit may include: new field personnel, new sampling procedures and/or unusual field circumstances.

X. TRAINING

Field personnel are required to attend training and demonstrate proficiency in their duties. Performance competency will be determined by the Project Team. Field personnel are required to attest that they have read and understood all applicable protocols and this QAPP. NERL personnel undergo annual training in the area of data reporting and use.

One or more simulated storm events may be employed both to refine the data collection protocols and requirements, and to train municipal and volunteer personnel. In addition, one or more actual storm events may be required to fully refine and finalize sampling event design. As the first formal storm event approaches, the QAPP and Monitoring Plan(s) will be amended to incorporate any changes that are needed.

XI. TENTATIVE SAMPLING SCHEDULE

A period of one year may be required for newly constructed BMPs to establish themselves before performance monitoring begins. Once performance monitoring begins, specific sample dates depend on rainfall events. The goal is a total of twenty (20) storm events per BMP depending upon the objectives outlined generally above and more specifically in Sections II.E and II.F.nd 2. More storm events may be required based on project stakeholder interest.

Location	Lat/Long	Date	Number of Samples	Project Manager	Analysis Requested
Barnstable	41°39'5.43"N, 70°16'44.41"W	June 2016 – Oct. 2018	Per BMP, per sampling event, per sampling location (inlet, outlet): FWC - multiple DTI – 5 grabs - 1 composite - 1 field duplicate * - 1 blank	Cody, Voorhees	Total Nitrogen, Total phosphorus, TSS
Chatham	41°41'0.94"N, 69°58'8.63"W	June 2016 – Oct. 2018	Per BMP, per sampling event, per sampling location (inlet, outlet): FWC - multiple DTI – 6 grabs - 1 composite - 1 field duplicate * - 1 blank	Cody, Voorhees	Total Nitrogen, Total phosphorus, TSS

The total number of samples for laboratory analysis per BMP sampling event is: multiple FWC grabs for two (2) lab composites; 5 to 6 DTI grabs; 1 duplicate and 1 blank per sampling location. **Because the dedicated DTI ISCO will be used first at Barnstable and then at Chatham, then for any storm event, there will be a total # of four (4) FWCs, 5-6 DTI grabs, 1 duplicate and 1 blank per sample location (i.e., BMP inlet and outlet).** Sampling requirements may be reduced or otherwise adjusted as BMP performance is clarified.

* based on comments received from EPA's QAU, it should be adequate to have one field duplicate per parameter per storm event. The duplicate could be rotated between inlets, outlets and Barnstable and Chatham.

XII. ATTACHMENTS

Appendix A. July 24, 2015 Technical Memorandum, *Monitoring System for Barnstable and Chatham BMPs (revised)*(cost information redacted).

Appendix A2. Supplemental and supporting equipment specification information (provided as standalone *.pdf).

Appendix B. Barnstable Monitoring Plan (provided as standalone *.pdf).

Appendix C. Chatham Monitoring Plan (provided as standalone *.pdf).

Appendix A

TECHNICAL MEMORANDUM

To: Ray Cody, United States Environmental Protection Agency, Region 1

From: Peter Shanahan and Ken Hickey, WaterVision

Subject: **Monitoring system for Barnstable and Chatham BMPs (revised)**

Date: July 24, 2015

INTRODUCTION

This memorandum presents WaterVision's revised recommendation for hydrologic and water-quality monitoring at the Barnstable and Chatham bioretention best management practices. Our recommended system addresses the following two goals:

1. Evaluation of BMP performance. The primary goal of the monitoring program is to evaluate the performance of the bioretention cells for stormwater treatment. Achieving this goal requires the construction of accurate water and mass balances around each bioretention cell. The variability of quality and quantity of stormwater inflow creates challenges with respect to constructing mass balances, and thus we have recommended a system with redundant measurements of flow in order to assure accurate measurements of the inflows to and outflows from the bioretention cell.
2. Characterization of watershed loads. An additional goal of the monitoring is to measure the load of nutrients and other nonpoint-source pollutants from the watersheds served by the BMPs. The BMPs are designed to treat low to medium flows and it is expected that stormwater will bypass the cells during intense storms. Thus, measurements of the watershed load will put in context the contribution of the BMPs to addressing nonpoint-source pollution from the watershed. We view the monitoring requirements for this component to be less stringent than those for evaluating BMP performance—the goal here is to put bounds on the magnitude of the variable watershed load, which does not require the same accuracy as constructing water and mass balances over the bioretention cells.

The recommendations included in this memorandum have been revised to incorporate comments received from EPA following our prior memorandum dated June 22, 2015.

BARNSTABLE BMP

Figure 1 is a schematic of the proposed monitoring installation for the Barnstable BMP. Table 1 provides a list of recommended equipment for the installation. Both the inlet and outlet to the BMP pass through

4-foot-diameter sampling manholes that will be outfitted with calibrated flumes (TRACOM Large 60° V Trapezoidal Flume—see Attachment 1 for the cost quotation and Attachment 3 for specifications and other information). Each flume will be instrumented with a water-level sensor while the adjacent upstream 10-inch-diameter outflow pipe will be equipped with a velocity-area sensor. Water-level readings in the calibrated flume will be convertible to flow, providing a redundant flow reading to the velocity-area sensor. This redundancy is recommended to provide a cross-check and because low flows are expected to be near the lower-limit resolution of the velocity-area sensor. In addition, the above-ground basin will also be equipped with a water-level sensor to enable calculation of the transient storage of water during flow events. (The vendor specified a velocity-area meter for the water-level sensor since it includes an accurate water-level sensor, is comparable in cost to a water-level sensor alone, and provides compatibility with the other components of the system.) The system will provide redundant measures of the inflow to and outflow from the BMP as well as the storage within the BMP, thus enabling construction and checking of a complete water balance over the BMP.

Both the inlet and outlet flumes will also be equipped with a sampling suction line terminating at a sampling strainer and connecting to an automatic sampler with capacity for 24 separate samples. The automatic samplers will be located in a secured sampler box next to the Cape Cod Maritime Museum shed. A system controller/data logger will also be installed in the sampler box. It is anticipated that an electrical supply can be provided from the shed. The system controller will trigger the inlet and outlet samplers and operate the samplers so as to collect flow-weighted samples through storm events. Different sampling schedules are anticipated to be needed for the inlet and outlet flows. The inlet flow is expected to be flashy, with rapid increases and decreases in flow during storm events. The outlet flow is expected to be much more extended and steady due to the slow passage of water through the subsurface layers of the BMP. We have also included in Table 1 an on-site rain gauge as an optional equipment item.

The proposed autosampler model is non-refrigerated. The recommended sampler can be pre-loaded with ice to keep samples at proper temperature, but the considerable extra expense and power needs of a refrigerated sampler seems unnecessary in light of the anticipated sampling program. Rather than equipping the sampler with bottles, which would need to be washed prior to every use, we have incorporated a recommendation from Diane Switzer and Tim Bridges of the Region I Office of Environmental Measurement and Evaluation to use Propak sterile single-use sample bags with Teflon caps. The quoted cost is for the samplers equipped with a Propak holder rack with a second rack for each sampler to facilitate change-out of sets of samples.

Figure 1 and Table 1 also show the monitoring components for the storm drain that carries flow from the watershed. The flow from the watershed passes through a diversion manhole that will divert low flows through the BMP but allow flows in excess of the BMP's capacity to be bypassed. Flow diverted to the BMP will be measured at the BMP inflow manhole as described above. Bypassed flow is proposed to be measured by a velocity-area sensor installed in the pipe upstream of the bypass structure as shown in Figure 1. A sample suction line and strainer will also be installed at this location to enable characterization of the quality of water flowing from the watershed. The water quality of the bypassed flow should not differ significantly from the flow at the BMP inlet and therefore this sampler installation is shown in Table 1 as optional. If this sampler is not installed, we recommend that an occasional grab sample be collected during the startup of the monitoring system to check that the bypassed flow is indeed similar in quality to the flow diverted to the BMP.

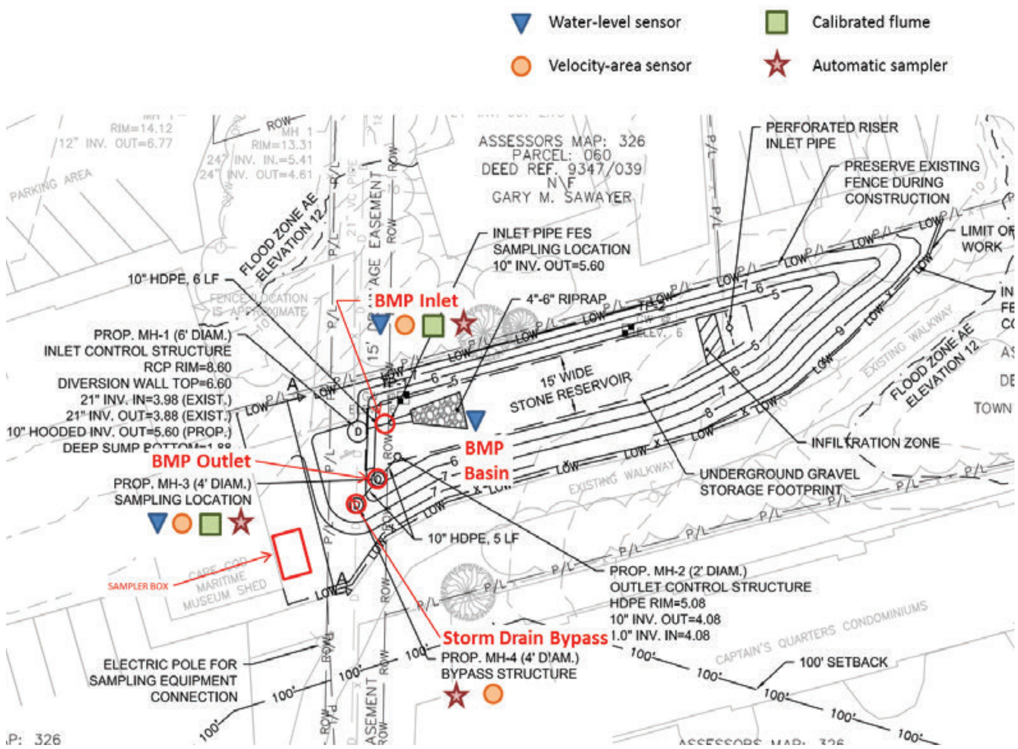


Figure 1. Recommended Monitoring Installation at Barnstable BMP

An important aspect of the system plan is its accessibility for maintenance and equipment change-out. All components are physically accessible in amply-sized manholes and installed with quick-connect connectors to enable ready access, removal, and re-installation.

Table 1 includes equipment only; additional costs for engineering and site contractor services to install the sampler boxes, flumes, conduit, etc., are not included. The vendor's quotation showing a system schematic and the detailed costs that are the basis for Table 1 is included as Attachment 2. Vendor information on the equipment is found in Attachment 4. Table 1 has been annotated to indicate the correspondence between the vendor's quote and the costs as aggregated in Table 1.

Table 1. Equipment Schedule for Barnstable BMP Monitoring System (with cross-reference to items identified in Attachment 2).

Quan.	Item	Unit price	Total
2	TRACOM Large 60° V Trapezoidal Flume (including $100 shipping)	$	$
2	Isco Signature Base Meter (data logger and controller) Package (Items 1 through 5)	$	$
1	Cable, expansion boxes, receptacles for system assembly (one half of Item 8, three of Item 9, five of Item 10)	$	$
1	Area-velocity sensor for basin water-level readings (Items 11, 12, and 14)	$	$
2	Area-velocity sensors at inlet and outlet flumes (Items 11, 12, and 15)	$	$
1	Area-velocity sensor for stormwater bypass (Items 11, 12, and 13)	$	$
2	Isco Model 6712 Portable Sampler packages for inlet and outlet (Items 16 through 20, 22, and 25 and one-third each of Items 21 and 24)	$	$
1	Software for Isco Signature System (provides licenses for two computers) (Item 26)	$	$
2	Start-up and training by vendor ($900 per day)	$	$
Total			$

Optional equipment:			
1	Isco Model 6712 Portable Sampler package for stormwater bypass (Items 16 through 20, 23, and 25 and one-third each of Items 21 and 24)	$	$
1	Cable, expansion boxes, receptacles for stormwater bypass sampler (Items 9 and 10, one half of Item 8)	$	$
1	Rain gauge installation (Items 6 and 7)	$	$
Total with optional equipment			$

CHATHAM BMP

Figure 2 depicts the recommended system for Chatham and Table 2 tallies the system components. The installation is nearly identical to that at Barnstable with the following exceptions:

1. There is no readily available power supply at Chatham and it will be necessary either to arrange for a power drop from the adjacent utility pole or to operate all equipment using battery power. If the latter, we recommend enlisting town personnel to charge and change out the batteries. The

cost quote below assumes the equipment will operate from battery power but also includes a power drop as an option with a rough cost estimate.

2. The inlet and outlet are separated by much greater distance at Chatham, necessitating two separate sampler boxes. Since this is a less developed site than Barnstable, we propose that the sampler boxes be buried, accessible via surface covers, to minimize visual impact and deter potential vandalism. We recommend a 4-foot-by-4-foot-by-3-foot-deep pre-fabricated vault with torsion-assist covers by Armorcast (Attachment 5).
3. The manhole with the diversion structure at the storm drain from the watershed is much deeper than at Barnstable and can only be serviced by personnel qualified for confined space entry. It is also located within a public road. We recommend sampling of this flow be delegated to the town if at all possible. We have included optional costing for a velocity-area sensor but have not included an automatic sampler in light of the logistical difficulties for its installation. We also presume that the water diverted to the BMP is likely to be of similar quality to any bypassed flow. This could be confirmed by a limited set of grab samples.

A conceptual plan showing the proposed equipment vaults, associated conduit for sampler tubes, and the optional power drop is included as Attachment 6.

Table 2. Equipment Schedule for Chatham BMP Monitoring System
(with cross-reference to items identified in Attachment 2).

Quan.	Item	Unit price	Total
2	TRACOM Large 60° V Trapezoidal Flume (including $100 shipping)	$	$
2	Isco Signature Base Meter (data logger and controller) Package (Items 1, 2 and 5)	$	$
1	Cable, expansion boxes, receptacles for system assembly (one half of Item 8, three of Item 9, five of Item 10)	$	$
1	Area-velocity sensor for basin water-level readings (Items 11, 12, and 14)	$	$
2	Area-velocity sensors at inlet and outlet flumes (Items 11, 12, and 15)	$	$
2	Isco Model 6712 Portable Sampler packages for inlet and outlet (Items 16 through 20, 22, and 25 and one-third each of Items 21 and 24)	$	$
4	Deep-cycle marine batteries (approximate cost)	$	$
2	Start-up and training by vendor ($900 per day)	$	$
Total			$

Optional equipment:			
1	Area-velocity sensor for stormwater bypass (Items 11, 12, and 13)	$	$
1	Rain gauge installation (Items 6 and 7)	$	$
Total with optional equipment			$

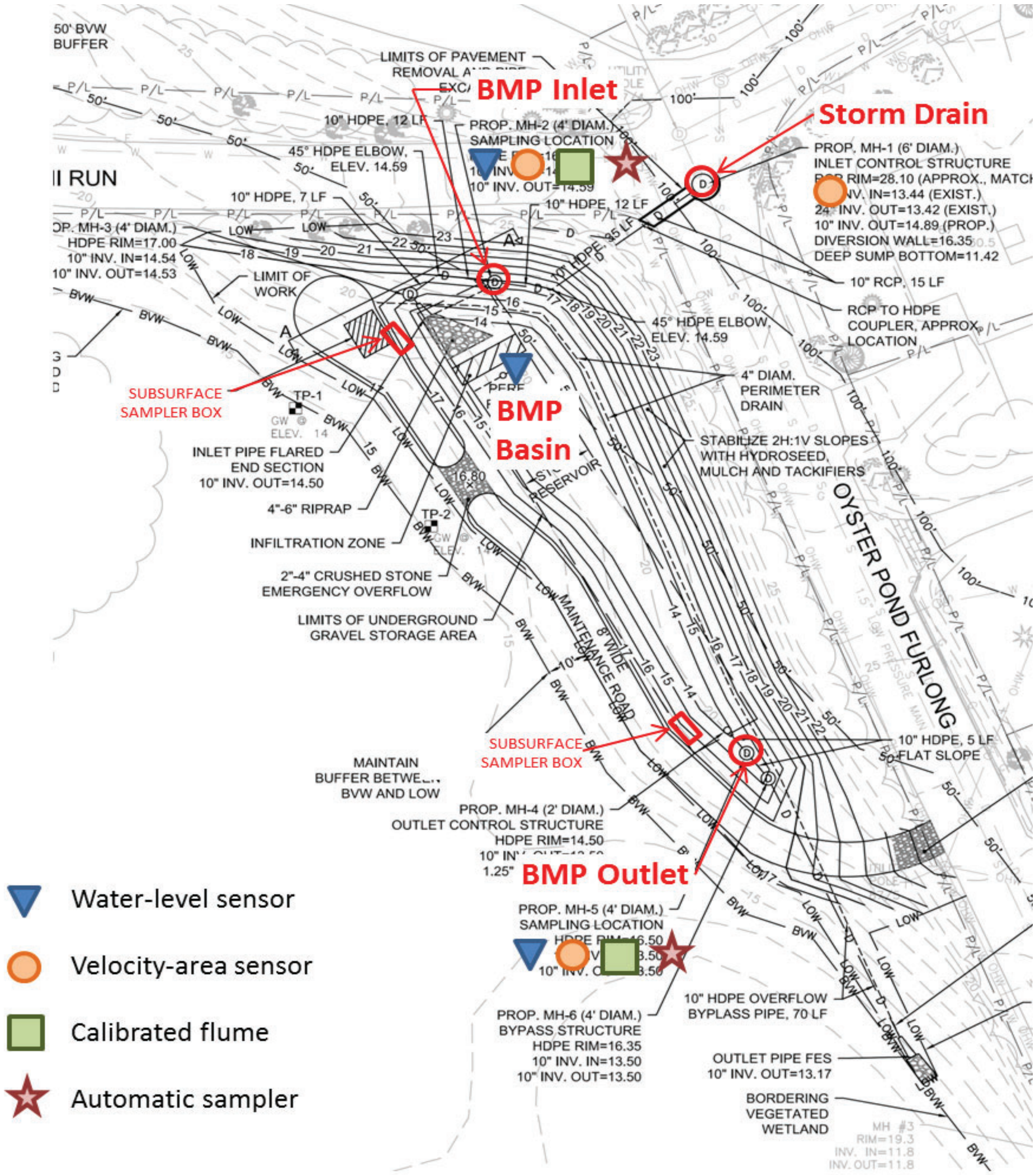


Figure 2. Recommended Monitoring Installation at Chatham BMP

SUMMARY

The set of recommended monitoring equipment provided above was selected through a collaborative process that featured several meetings and conference calls between staff from EPA, WaterVision, CEI, and monitoring equipment companies. We are confident that the recommended equipment will successfully support BMP performance monitoring.

Please note that the equipment costs provided in Tables 1 and 2 are not all-inclusive. There will be additional expenses associated with costs for engineering and site contractor services to install the equipment (e.g., the sampler boxes and flumes) and to dig shallow trenches for conduit between sampling locations and boxes. In addition, some relatively minor equipment, including sampling equipment boxes and spare parts, have not been included.

Please do not hesitate to contact us with any questions or additional requests.

APPENDIX B: BARNSTABLE SYSTEM MAINTENANCE SCOPE OF WORK AND BUDGET

SCOPE OF WORK

Barnstable Innovative Bioretention Project

The coastal embayments of Cape Cod have historically received excess nitrogen loadings, with a portion of nitrogen supplied by stormwater runoff. As a consequence of the excessive nitrogen, the Massachusetts Estuaries Project (MEP) developed total maximum daily load allocations (TMDLs) for many southern Massachusetts embayments including those in Cape Cod. To begin the process of reaching the TMDL goals, the City of Barnstable partnered with the United States Environmental Protection Agency (EPA), WaterVision, LLC, and Comprehensive Environmental Inc. (CEI) to initiate a pilot project in Cape Cod in 2014 and demonstrate the effectiveness of nitrogen load-reducing stormwater BMPs. This project was designed to monitor and quantify the BMP performance for nitrogen removal. Since the BMPs installation there has been significant surface clogging of the system such as to necessitate maintenance and system repair. There are numerous confounding issues that the University of New Hampshire Stormwater Center (UNHSC) has been requested to investigate. This project has three tasks:

Task 1: Contractor Selection and system maintenance and repair
Task 2: Preliminary Monitoring
Task 3: Initial System Monitoring

Task 1: Contractor Selection and system maintenance and repair

This part of the project includes the labor and materials necessary for the maintenance of the Barnstable Bioretention system. Work will include but may not be limited to: excavation of the first 4-6 inches of the existing bioretention area or until original engineered soils are exposed. This scope also includes the purchase and placement of all additional system materials necessary to rehabilitate and reestablish the originally designed hydraulic routing, hauling of cut soils, and seeding as necessary. UNHSC will be available to oversee maintenance and coordinate operations with the contractor such that site stabilization and safety considerations will be managed appropriately.

Construction will follow the previously developed scope of work (see attachment). Particular attention will be spent to ensure system resiliency across several variable climate conditions such as seasonally high water table elevations, sea level rise and storm surge.

Task 1 Deliverables:

- An online working innovative bioretention system
- Built in resiliency to variable climate conditions

Estimated expenses

Contractor subcontract and supplies: [redacted]

Project Management and Engineering Oversite: [redacted]

Task 2: Preliminary Monitoring

UNHSC will conduct field investigations to ensure proper system function. These will include depth to water measurements to understand ground water elevation, reinstrumentation of the facility to measure influent and effluent flows, investigation of tidal surge and other hydraulic factors that may influence system operation.

Task 2 Deliverables:
- Verification of functional system hydrology and hydraulics.
- Documentation of variable climate conditions

Estimated Expenses

Project Management and data collection: [redacted] (this assumes hand well installation).

Task 3: Initial System Monitoring

On successful reconstruction and reestablishment of the BMP a limited number of storms will be monitored. Depending on the acquisition of real-time probes the monitoring will either be conducted with existing equipment or with real time UV-sensors (see attached quote).

The purpose of the monitoring program for the Barnstable BMP is to quantify the nitrogen load-reduction performance of the innovative bioretention system. A confounding issue that has been historically raised for coastal systems is how they would operate under changing water elevations either due to rising sea levels or other natural phenomena. Until now there has been little other than speculation as to system performance under these variable conditions. This data will help answer in part the effect of these fluctuations on system performance. To quantify the effectiveness of the Barnstable BMP, parameters including flow, total nitrogen (TN), total phosphorus (TP), and total suspended solids (TSS) will be monitored at the inlet and outlet of the BMP. These measurements will be analyzed to compare the percentage of nutrients and sediment entering and leaving the treatment system.

Task 3a: Monitoring Program Overview
UNHSC will develop a sampling approach consistent with equipment availability and update or develop a Quality Assurance Project Protocol (QAPP) as necessary.

Task 3b: Monitoring Program Management:
Note: this requirement necessitates the contractor is able to travel on short notice to the BMPs in order to oversee execution of the MP during storm events.
UNHSC will collect data and assist with the administration of three to five (3-5) storm events. There is limited availability of local volunteers to assist with the project but UNHSC staff will provide guidance and direction as necessary to help enhance the amount of monitoring results collected.

Monitoring program protocols will be specifically outlined and detailed in the approved QAPP.

Task 3 Deliverables:
- An updated and approved QAPP
- Capture and collection of 3-5 storm events
- Analysis of all associated data
- Final report

Estimated Expenses:

Project Management and reporting: [redacted]

Total project expenses:

Task 1: Contractor Selection and system maintenance and repair: [redacted]
Task 2: Preliminary Monitoring: [redacted]
Task 3: Initial System Monitoring: [redacted]

Total: [redacted]

APPENDIX C: MONITORING WHITE PAPER DRAFT

Outline for monitoring white paper for EPA Region 1

Background:

For stormwater sampling historically there are two basic techniques: samples may be taken manually or captured using automatic samplers. Obtaining manual samples involves sending personnel to the sampling location before the rain event occurs and physically capturing samples as the stormwater effluent where it is accessible. This process is burdened with resource issues centering on moving personnel to the sampling locations before a rain event and capturing samples in potentially hazardous situations. This method also depends on accurate rainfall forecasts.

The use of automatic samplers provides an alternative solution. These samplers can be triggered remotely or be programmed with a sampling protocol to begin taking samples as soon as the rain event begins (flow trigger or precipitation trigger). The benefit of using automatic samplers is that many samplers may be placed concurrently in different locations to capture a rain event. The location of the sampling intake of the samplers can be secured to the bottom of the invert of a pipe, swale, or other location of interest ensuring the same cross sectional location of pipe is sampled. This is referred to as a point integrated sample (Lane S. et al. 2003).

That said automatic sampling is hardly easy. Personnel time and other manual burdens persist, and incidence of unrepresentative or unusable storms can border on 50% even if you are thorough and knowledgeable about the equipment.

Fundamental sampling methods

Stormwater samples and their analyses yield a description for the fundamental water quality characteristics (median, average, standard deviation, etc.). The data may also be used to assess removal efficiencies for stormwater management systems by synthesizing the water quality and flow data into total mass or event mean concentration. This of course assumes that flow monitoring is reliable and accurate. Grab samples are samples that are taken without interruption and represent the stormwater at that instant of time. Grab samples may be taken manually or by automatic samplers (US EPA 1992). “Composite samples are samples simply comprised of a series of individual aliquots that when combined, reflect the average pollutant concentration of the storm water discharge during the sampling period (US EPA 1992).” The spacing between when aliquots are taken is paced using either flow or time. The following two types of composite samples can be developed:

Constant Time-Constant Volume: A single composite average sample created from a set of samples having equal volumes which were taken at equal increments of time during an event. This will result in a sample that averages the individual concentrations, but fails to represent pollutant mass.

Constant Time-Volume Proportional to Flow Increment: A single or set of composite samples that were created by varying the volume being placed in them proportionally to the amount of flow that passed by during equal lengths of time. This method results in a sample that represents the event mean concentration.

Most stormwater sampling methods were adopted from the drinking water and wastewater settings. One could question the difficulty of ushering in a set of new sampling standards, but the reality is, there never really were many sampling standards to begin with.

Modern challenges with stormwater sampling.

Much of the data collected in the 1980's through the national urban runoff program (NURP) was collected using grab samples. Grab samples are exactly that, grabbing a sample sometime during a storm event. These older sampling approaches have largely been supplanted by auto samplers. Still much of the data, simple as it may be, has been aggregated into simple pollutant load export rates that are largely differentiated by a generic land use category. These pollutant load estimates have remained relevant and applicable largely due to the fact that collecting trustworthy input data is difficult. The NURP program was a large, well-funded, nationally - administered program, not simply a repository for any and all data. Today, many stormwater management systems are designed and installed yet monitoring was never included as an objective. Therefore monitoring such systems after they are constructed presents significant monitoring issues, including: access issues (equipment and personnel), flow pathways, lack of grade (hydraulic head sufficient to allow the monitoring method to be hydraulically invisible) and underdrain/outfall exposure.

Environmental data is variable by nature. For the most part stormwater sampling equipment was adapted from the wastewater industry. Without strict guidance and protocols, humans are traditionally unreliable, or at least inconsistent, when it comes to methods. With astormwater sampling it seems that everyone does things a little bit differently. This is part of the reason why environmental sampling is so hard to standardize. By nature, it is inconsistent and that is just the first part of the story.

Sample programing

At this writing, the most reliable and reproducible sampling method is with automatic samplers. For the most part autosamplers were an advancement on grab sampling approaches. Autosamplers may be programmed in various ways. Time-based, volume-based, discrete, composite, single bottle, multiple bottle. Samples may be preserved at the time of sampling as well. Sample splitting may be a challenging step, however there is no difference with this process between grab and autosamples..

Unfortunately there appears to be the perception that anyone can perform sampling and that this will result with defensible research. This seems to be a consequence of more powerful and automated sampling equipment. Using modern equipment instills a belief that defensible data emerges just by turning on the power. The truth however is that these instruments require caretaking and constant program updating. In reality a few storms are required to "shake down" equipment, personnel, and software. That is assuming that the rainfall intensity, duration and frequencies do not change much with the season.

Composite sampling

Composite sampling is a much more economical approach to sampling with autosamplers. Storm capture and sample splitting are definite issues. If a single bottle is used for sample collection it often has to be split for different chemical analyses and for quality assurance protocols. Single bottle composites also limit the storm capture rates as anomalies such as short rain bursts may trigger the sampling program and intermingle non-events (rainfall < 0.1 inch).

Flow conversion is a major component of a sampling strategy. There are a number of ways to convert water depth to flow in open channels/pipes, but almost no proven methods to monitor direct flow in open drainage networks smaller with pipes/channels that are 12 inch in diameter or smaller. Manning's equation and volumetrically calibrated weirs are two of the most common methods. The presence of the automatic sampler sampling intakes, pressure transducer/bubbler tube and sample intake could all be creating an unusual amount of turbulence around the weir. The weir and associated level logger measures the level of water behind the weir and calculates a flow based on the depth vs discharge rating curve developed for the instrument in a laboratory under controlled laminar flow conditions. Turbulent flows however could be introducing different momentum forces at instrument interface not calculated in the lab. These anomalies would most certainly impact sampling programs and quality of the data collected. Inevitably the manufacturer's rating curve was not calibrated with probes near the point where stage was recorded, this is seldom ever addressed in modern stormwater monitoring QAPPs.

Storm characterization and troubleshooting.

Weather is variable. Rainfall characteristics change with the seasons, it is important that you adjust your sampling approach as well.

Modern Approaches

Most stormwater sampling approaches invite plentiful opportunities for error. From programming to flow depth to flow estimates to extend holding times (due to the fact that it always seems to rain at 2 am on Sunday morning). The errors that these methods impart on stormwater sampling data are largely undocumented. Adding sample splitting and issues related to representatives (just where was the sampler intake?) can make even the most seasoned researcher nervous. This is all prior to delivery to the lab. Laboratory analytics carry their own potential bias and often +/- 20% is the industry standard. In essence this acceptable deviation is at the very end of a long sampling and chain of custody process that may incur numerous other potential acceptable differences or acceptable protocol error. Table 1 is from a recently accepted QAPP for stormwater control measure verification.

Table 1: Relative percent difference (RPD) for common quality assurance project protocols for stormwater research.

Data Quality Indicators	Measurement Performance Criteria*	RPD Value
Precision-Overall	Relative Percent Difference (RPD)	RPD ≤ 20%
Precision-Lab	Relative Percent Difference (RPD)	RPD ≤ 20%
Accuracy / Bias	Relative Percent Difference (RPD)	RPD ≤ 20%

Data Evaluation

Data analyses typically cover a range of approaches including:

- assessment of storm characteristics
- estimation of event mean concentrations
- normalized performance efficiencies

Event mean concentrations (EMC's) are a parameter used to represent the flow-proportional average concentration of a given water quality parameter for a storm event. It is defined as the total constituent mass divided by the total runoff volume. When combined with flow measurement data, the EMC is used to estimate the pollutant mass loading. Most of the EMC data collected in stormwater studies are based on direct measurement from flow-weighted composite samples. Due to the variability of precipitation events and resultant runoff conditions, sample trigger conditions and flow-weighted sample pacing are highly variable and must be adjusted on a storm by storm basis according to the most up-to-date precipitation forecasts.

The range of analyses reveals a range of performance trends. Efficiency Ratio (ER) analysis may be performed with a final dataset. For many performance related datasets of stormwater treatment systems, the ER is a stable estimation of overall treatment performance as it minimizes the impact of low concentration values, or relatively clean storms with low influent EMCs. Whereas Removal Efficiencies (RE) reflect treatment unit performance on a storm by storm basis, ERs weight all storms equally and reflect overall influent and effluent averages across the entire data set. REs are presented as both an average and median of aggregate storm values. In general aggregate median RE values are more reliable in highly variable, non-normally distributed datasets such as those experienced in stormwater treatment unit performance studies.

When concentration results are below detection limit (BDL) a value of half the detection limit (DL) is commonly used for statistical purposes.

Innovations

Real-time sensing is an innovation to conventional stormwater monitoring efforts that often employs automated samplers, and flow-weighted composite sample splitting for laboratory produced pollutant export rates and associated stormwater control measure (SCM) removal performance. This groundbreaking approach holds promise to revolutionize field sampling methods and eliminate much of the potential error associated with automated samplers, long holding times, composite sampling approaches, and the time for wet chemistry analyses.

For example, real-time ultra-violet sensors technology is rapidly developing. UV-sensors convert spectral absorbance values to parameter concentrations based on the Beer-Lambert Law which states that light absorption is proportional to both the concentration of a material as well as the thickness of a material within a sample. UV-based measuring approaches have developed a wide range of global calibration curves for monitoring specific parameters in a variety of water compositions applicable to municipal and natural water systems. The global calibration curve employed should be indicative of the closest related water chemistry characteristics. Currently this is largely limited to the data and calibration curves available. Granted there are still unknowns with these newer instruments. Little is known with respect to adequate cleaning and calibration intervals, particularly in closed drainage networks. Still as sampling techniques evolve these approaches deserve attention as they have the potential to significantly increase monitoring sensitivity. Regardless the accepted sampling approach it is clear that any stormwater sampling is a complex and sensitive activity that it should be assumed can be completed with a vast range of accuracy and precision.

APPENDIX D: IMPLEMENTATION SCIENCE DELIVERABLES

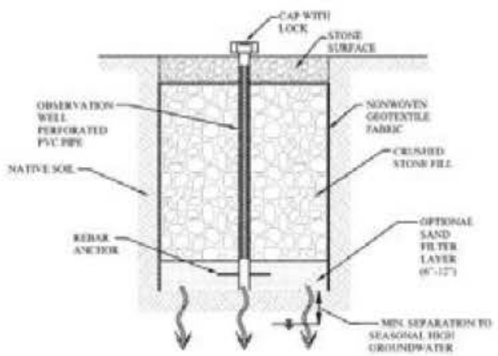
Massachusetts Stormwater Manual	New Hampshire Stormwater Manual	EPA Pollutant Curves	EPA Cost Estimates
Bioretention Areas & Rain Gardens (with infiltration)	Bioretention System (with infiltration)	Infiltration Basin	Bioretention
Bioretention Areas & Rain Gardens (underdrain, no infiltration)	Bioretention System (underdrain, no infiltration)	Biofiltration	Biofiltration
Proprietary Media Filters	Tree Box Filter	Biofiltration	Biofiltration
Extended Detention Wetlands	Extended Detention Wetlands	Dry Pond	Dry Pond
Extended Dry Detention Basins	Micropool Extended Detention Pond	Dry Pond	Dry Pond
Dry Detention Basins		Dry Pond	Dry Pond
Infiltration Basins	In-Ground Infiltration Basin	Infiltration Basin	Infiltration Basin
Wet Basins	Wet Pond	Wet Pond	Wet Pond
Wet Basins	Wet Extended Detention Pond	Wet Pond	Wet Pond
Wet Basins	Multiple Pond System	Wet Pond	Wet Pond
Wet Basins	Pocket Pond	Wet Pond	Wet Pond
Porous Pavement	Permeable Pavement	Porous Pavement	Porous Pavement
Water Quality Swale	Treatment Swales	Grass Swale	Grass Swale
Sand & Organic Filters	Surface Sand Filter	Sand Filter	Sand Filter
Infiltration Trenches	Infiltration Trench	Infiltration Trench	Infiltration Trench
Dry Wells	Dry Well	Infiltration Trench	NA
Leaching Catch Basin	Leaching Basin	Infiltration Trench	NA
Subsurface Structures	Underground (Subsurface) Infiltration Basin	Infiltration Trench	Infiltration Trench
Gravel Wetlands	Gravel Wetlands	Gravel Wetland	Gravel Wetland
Basin/Wetland System	Pond/Wetland Systems	Gravel Wetland	Gravel Wetland
Shallow Marsh System	Shallow Wetlands	Gravel Wetland	Gravel Wetland
Pocket Wetland		Gravel Wetland	Gravel Wetland
Systems that need additional description/credit details	**Systems that need additional description/credit details**		
	Residential or Small Pervious Area Buffer		
	Developed Area Buffer		
	Roadway Buffer		
Green Roofs	Green Roofs		
Rainbarrels & Cisterns	Rainbarrels/Cisterns		
	Underground Sand Filters		

Infiltration Trench Factsheet

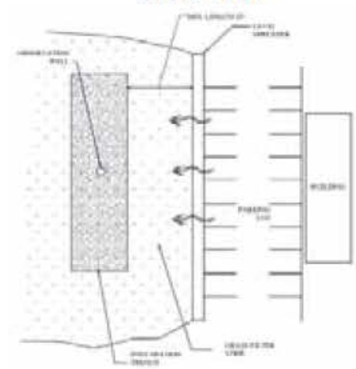
Infiltration Trench is a practice that provides temporary storage of runoff using the void spaces within the soil/sand/gravel mixture that is used to backfill the trench for subsequent infiltration into the surrounding sub-soils. Performance results for the infiltration trench can be used for all subsurface infiltration practices including systems that include pipes and/or chambers that provide temporary storage. Also, the results for this BMP type can be used for bio-retention systems that rely on infiltration when the majority of the temporary storage capacity is provided in the void spaces of the soil filter media and porous pavements that allow infiltration to occur. General design specifications for infiltration trench systems are provided in the most recent version of *The New Hampshire Stormwater Manual, Volume 2: Post-Construction Best Management Practices Selection and Design.*

Sample Design

Cross Section



Plan View



Examples images from the *New Hampshire Stormwater Manual, Volume 2,* p. 86

Pollutant Export Rate by Land Use[1]

Source Category by Land Use	Land Surface Cover	P Load Export Rate[1] (lbs./acre/year)	N Load Export Rate[2] (lbs./acre/year)
Commercial (COM) and Industrial (IND)	Directly connected impervious	1.78	15
Multi-Family (MFR) and High-Density Residential (HDR)	Directly connected impervious	2.32	14.1
Medium-Density Residential (MDR)	Directly connected impervious	1.96	14.1
Low-Density Residential (LDR) - "Rural"	Directly connected impervious	1.52	14.1

[1] From NH Small MS4 General Permit, Appendix F

General Equations

Physical Storage Capacity: Depth of Runoff * Drainage Area
Cost: Physical Storage Capacity * Cost Index * Adjustment Factor
Yearly Pollutant Removal: Pollutant Load Export Rate * Drainage Area * Efficiency

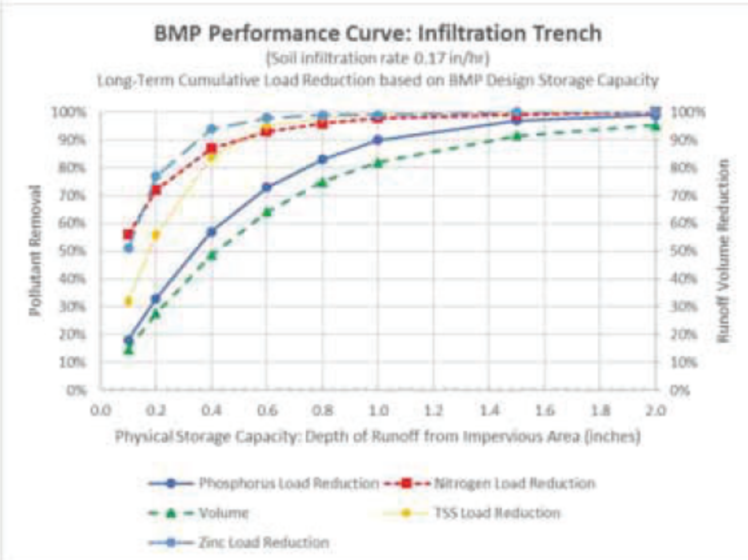
Cost

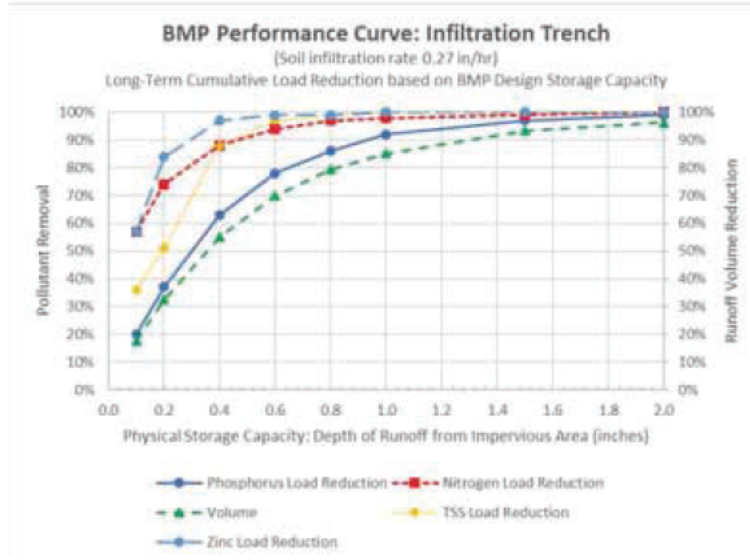
Infiltration Trench System	Materials and Installation Cost ($/ft^3) (2010)[2]	Design Cost ($/ft^3) (2010)	Materials and Installation Cost ($/ft^3) (2017)[3]	Design Cost ($/ft^3) (2017)
Rural	8	2.8	9.84	3.44
Mixed	16	5.6	19.68	6.88
Urban	24	8.4	29.52	10.32

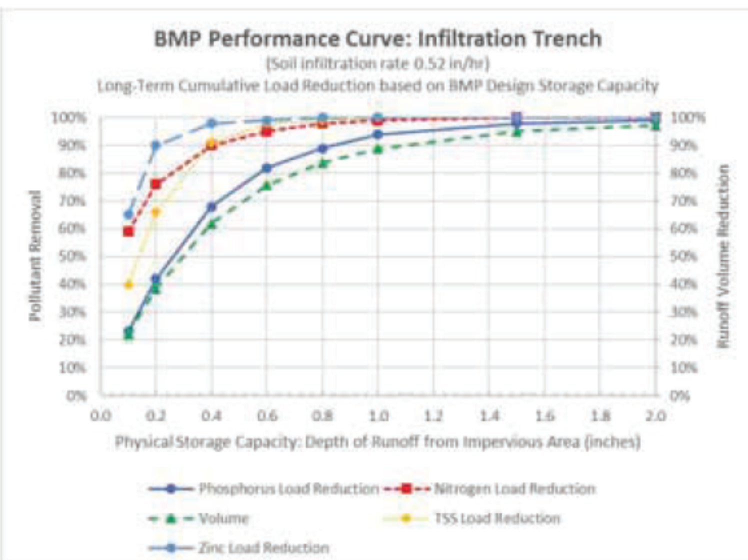
[2] From UNHSC Cost Estimates; converted from 2004 to 2010 dollars using U.S. Department of Labor (USDOL). (2012). Bureau of Labor Statistics consumer price index inflation calculator. http://www.bls.gov/data/inflation_calculator.htm
[3] Converted from 2010 costs using ENR Cost Index

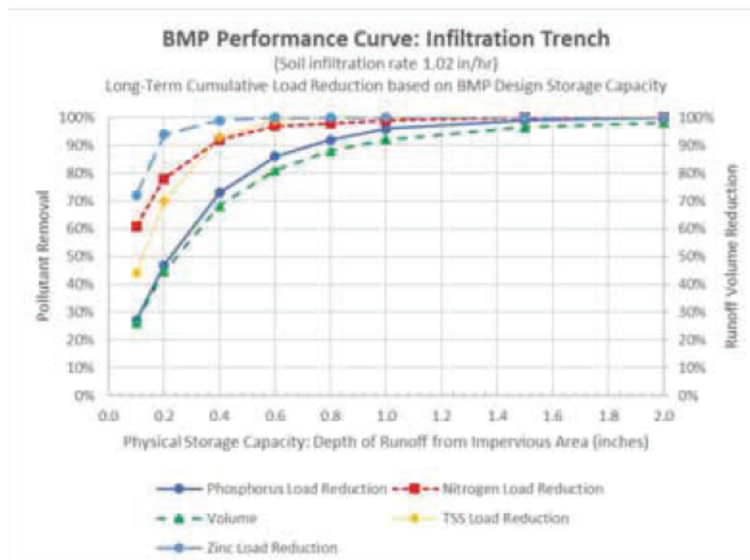
Prepared By:
University of New Hampshire
Stormwater Center
Durham, NH
www.unh.edu/unhsc
August 2017

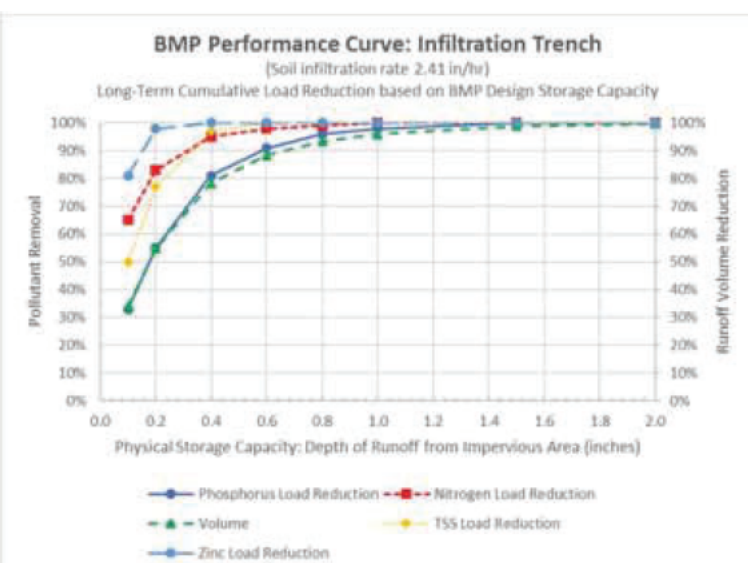
BMP Performance Curves for Soil Infiltration Rate: Infiltration Trench

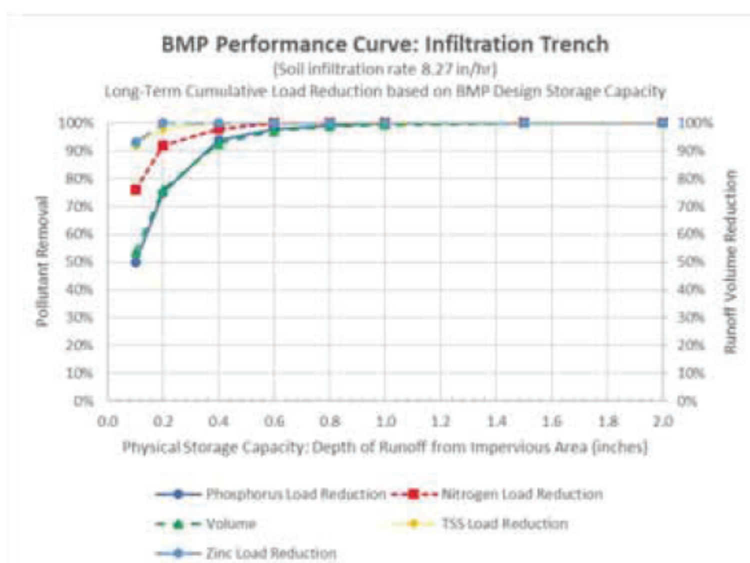










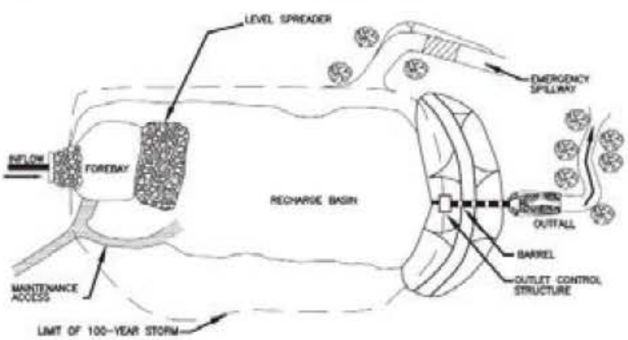


Infiltration Basin Factsheet

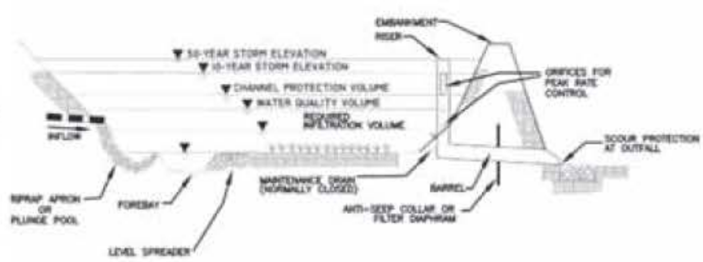
Infiltration Basin represents a practice that provides temporary surface storage of runoff (e.g. ponding) for subsequent infiltration into the ground. Appropriate practices for use of the surface infiltration performance estimates include infiltration basins, infiltration swales (not conveyance swales), rain gardens, and bio-retention systems that rely on infiltration and provide the majority of storage capacity through surface-ponding. If an infiltration system includes both surface storage through ponding and a lesser storage volume within the void spaces of a coarse filter media, then the physical storage volume capacity used to determine the long-term cumulative phosphorus removal efficiency from the infiltration basin performance curves would be equal to the sum of the surface storage volume and the void space storage volume. General design specifications for infiltration basin systems are provided in the most recent version of *The New Hampshire Stormwater Manual, Volume 2: Post-Construction Best Management Practices Selection and Design.*

Sample Design

Plan View



Profile View



Examples images from the *New Hampshire Stormwater Manual, Volume 2*, p. 90

Pollutant Export Rate by Land Use[1]

Source Category by Land Use	Land Surface Cover	P Load Export Rate[1] (lbs./acre/year)	N Load Export Rate[2] (lbs./acre/year)
Commercial (COM) and Industrial (IND)	Directly connected impervious	1.78	15
Multi-Family (MFR) and High-Density Residential (HDR)	Directly connected impervious	2.32	14.1
Medium-Density Residential (MDR)	Directly connected impervious	1.96	14.1
Low-Density Residential (LDR) - "Rural"	Directly connected impervious	1.52	14.1

[1] From NH Small MS4 General Permit, Appendix F

General Equations

Physical Storage Capacity: Depth of Runoff * Drainage Area
Cost: Physical Storage Capacity * Cost Index * Adjustment Factor
Yearly Pollutant Removal: Pollutant Load Export Rate * Drainage Area * Efficiency

Cost

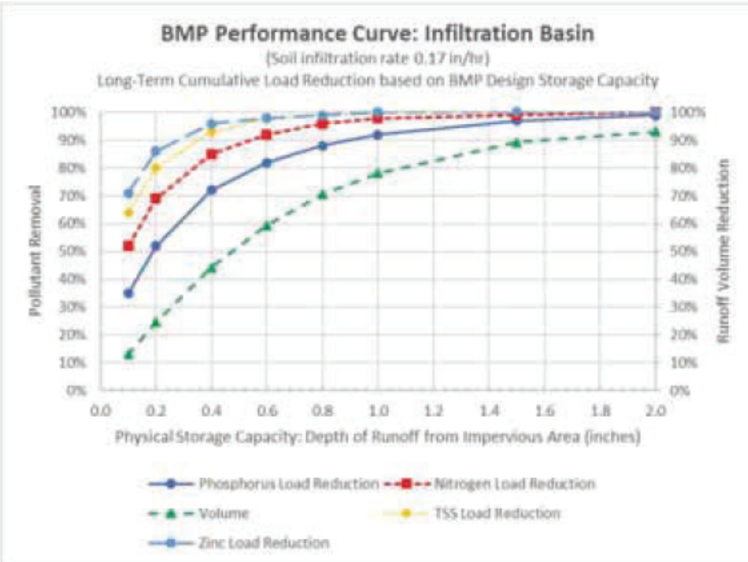
Infiltration Trench System	Materials and Installation Cost ($/ft³) (2010)[2]	Design Cost ($/ft³) (2010)	Materials and Installation Cost ($/ft³) (2017)[3]	Design Cost ($/ft³) (2017)
Rural	4	1.88	4.92	1.72
Mixed	8	3.76	9.84	3.44
Urban	12	5.64	14.76	5.16

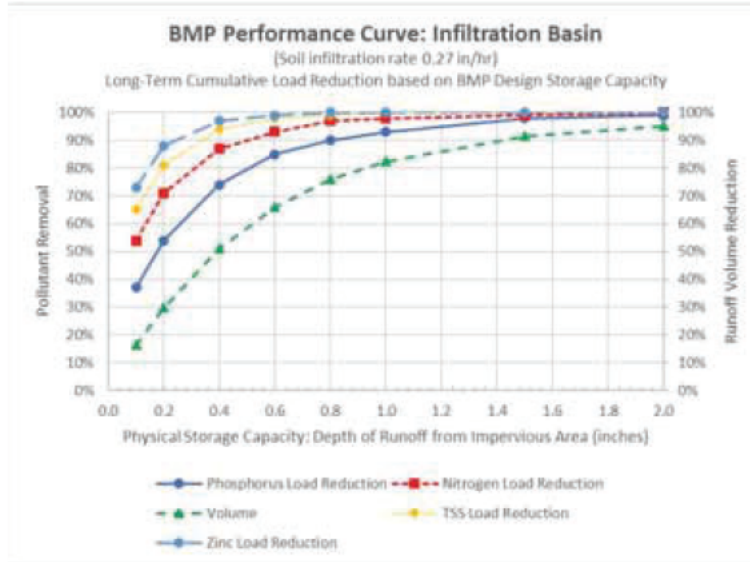
[2] From UNHSC Cost Estimates; converted from 2004 to 2010 dollars using U.S. Department of Labor (USDOL). (2012). Bureau of Labor Statistics consumer price index inflation calculator. http://www.bls.gov/data/inflation_calculator.htm

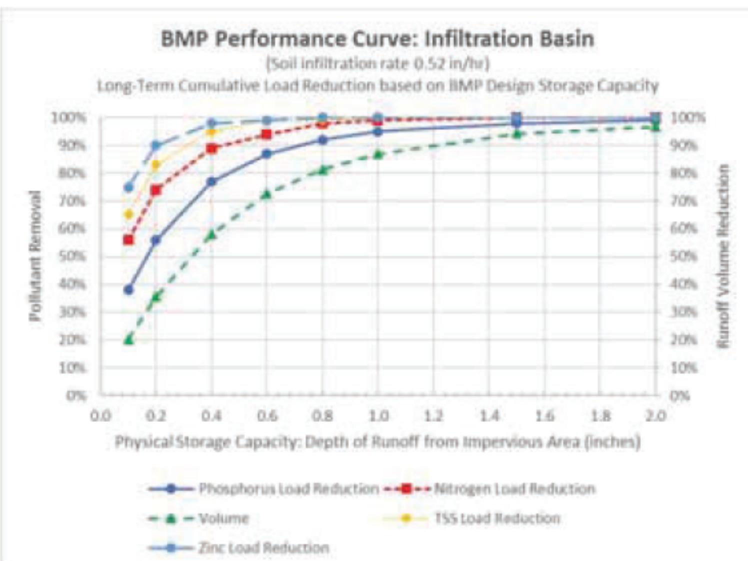
[3] Converted from 2010 costs using ENR Cost Index

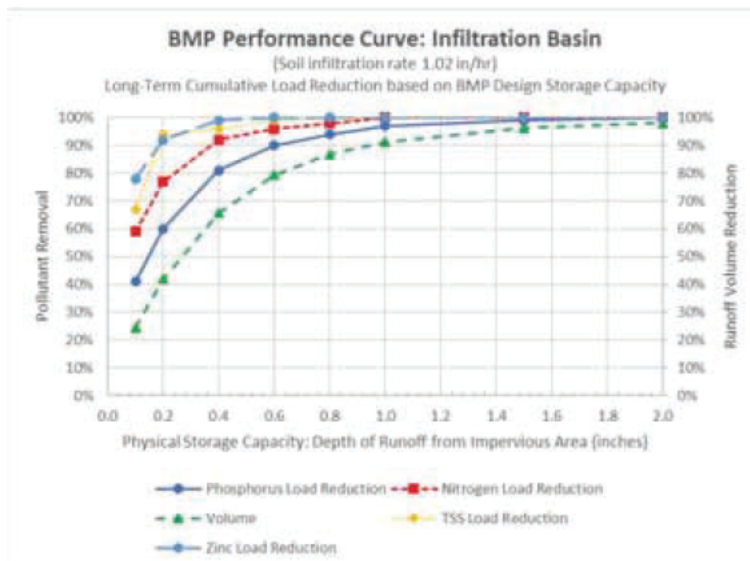
Prepared By:
University of New Hampshire
Stormwater Center
Durham, NH
www.unh.edu/unhsc
August 2017

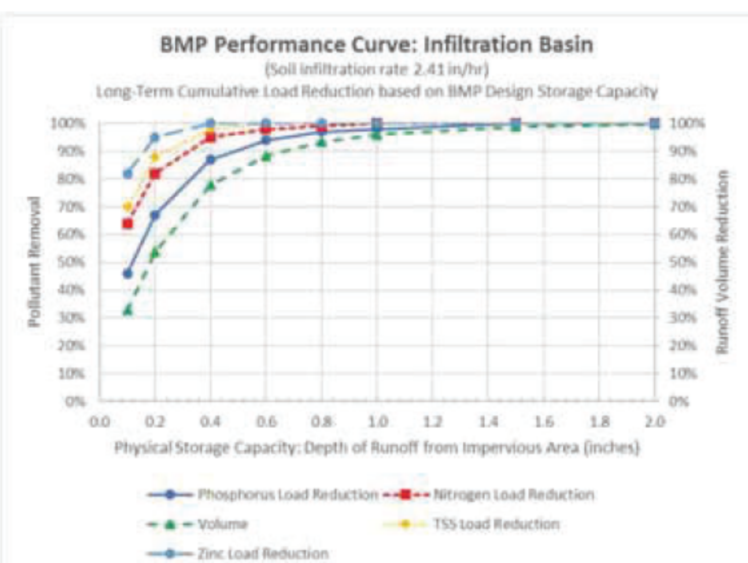
BMP Performance Curves for Soil Infiltration Rate: Infiltration Basin

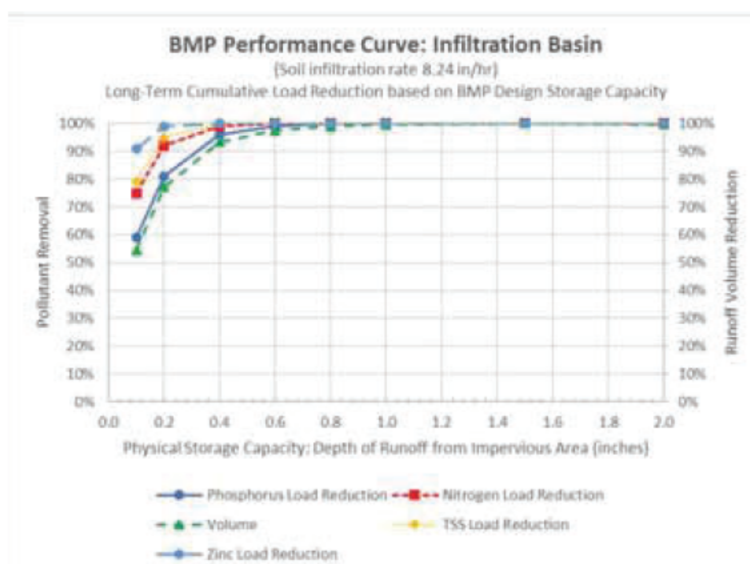










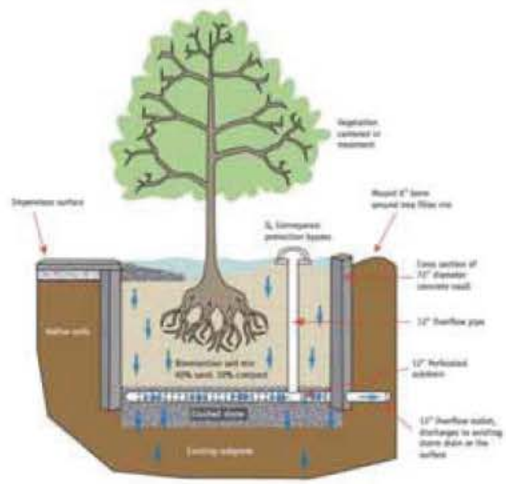


Biofiltration Factsheet

Biofiltration is a practice that provides temporary storage of runoff for filtering through an engineered soil media. The storage capacity is typically made of void spaces in the filter media and temporary ponding at the surface of the practice. Once the runoff has passed through the filter media it is collected by an under-drain pipe for discharge. The performance curve for this control practice assumes zero infiltration. If a filtration system has subsurface soils that are suitable for infiltration, then user should use either the performance curves for the infiltration trench or the infiltration basin depending on the predominance of storage volume made up by free standing storage or void space storage. Depending on the design of the manufactured or packaged bio-filter systems such as tree box filters may be suitable for using the bio-filtration performance results. Design specifications for biofiltration systems are provided in the most recent version of *The New Hampshire Stormwater Manual, Volume 2: Post-Construction Best Management Practices Selection and Design.*

Sample Design

Profile view of a Tree Box Filter. The underdrain makes the system one example of a biofiltration system.



Examples images from the *New Hampshire Stormwater Manual, Volume 2*, p. 116

Pollutant Export Rate by Land Use[1]

Source Category by Land Use	Land Surface Cover	P Load Export Rate[1] (lbs./acre/year)	N Load Export Rate[2] (lbs./acre/year)
Commercial (COM) and Industrial (IND)	Directly connected impervious	1.78	15
Multi-Family (MFR) and High-Density Residential (HDR)	Directly connected impervious	2.32	14.1
Medium-Density Residential (MDR)	Directly connected impervious	1.96	14.1
Low-Density Residential (LDR) - "Rural"	Directly connected impervious	1.52	14.1

[1] From NH Small MS4 General Permit, Appendix F

General Equations

Physical Storage Capacity: Depth of Runoff * Drainage Area
Cost: Physical Storage Capacity * Cost Index * Adjustment Factor
Yearly Pollutant Removal: Pollutant Load Export Rate * Drainage Area * Efficiency

Cost

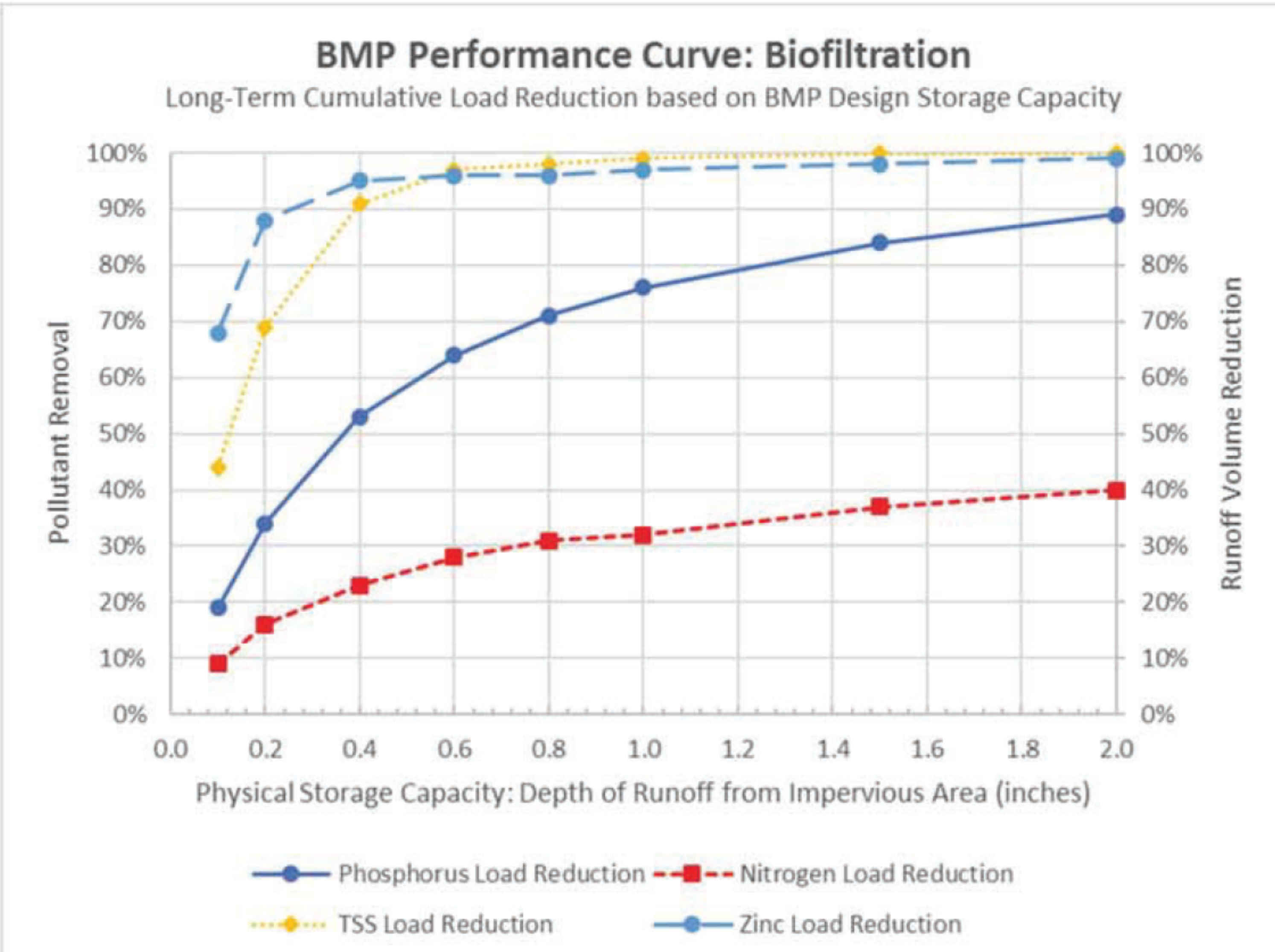
Infiltration Trench System	Materials and Installation Cost ($\$/\text{ft}^3$) (2010)[2]	Design Cost ($\$/\text{ft}^3$) (2010)	Materials and Installation Cost ($\$/\text{ft}^3$) (2017)[3]	Design Cost ($\$/\text{ft}^3$) (2017)
Rural	10	3.5	12.3	4.31
Mixed	20	7	24.6	8.62
Urban	30	10.5	36.9	12.93

[2] From UNHSC Cost Estimates; converted from 2004 to 2010 dollars using U.S. Department of Labor (USDOL). (2012). Bureau of Labor Statistics consumer price index inflation calculator. http://www.bls.gov/data/inflation_calculator.htm

[3] Converted from 2010 costs using ENR Cost Index

Prepared By:
University of New Hampshire
Stormwater Center
Durham, NH
www.unh.edu/unhsc
August 2017

BMP Performance Curve for Biofiltration

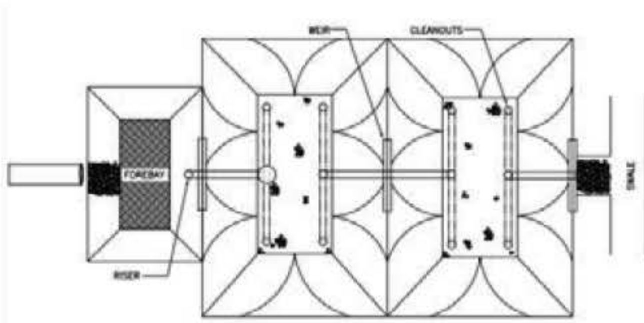


Gravel Wetlands Factsheet

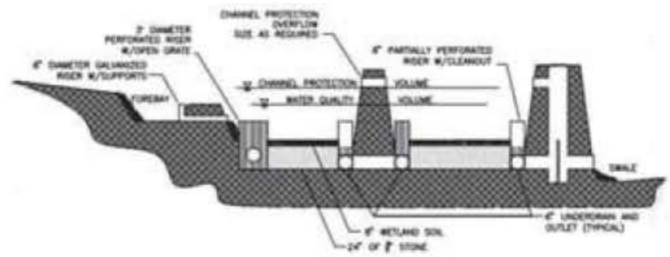
Gravel Wetlands consists of one or more flow-through constructed wetland cells, preceded by a forebay. The cells are filled with a gravel media, supporting an organic substrate that is planted with wetland vegetation. During low-flow storm events, the systems is designed to promote subsurface horizontal flow through the gravel media, allowing contact with the root zone of the wetland vegetation. The gravel and planting media support a community of soil microorganisms. Water quality treatment occurs through microbial, chemical, and physical processes within this media. Treatment may also be enhanced by vegetative uptake.. General design specifications for infiltration basin systems are provided in the most recent version of *The New Hampshire Stormwater Manual, Volume 2: Post-Construction Best Management Practices Selection and Design*.

Sample Design

Plan View



Profile View



Examples images from the *New Hampshire Stormwater Manual, Volume 2*, p. 80

Pollutant Export Rate by Land Use[1]

Source Category by Land Use	Land Surface Cover	P Load Export Rate[1] (lbs./acre/year)	N Load Export Rate[2] (lbs./acre/year)
Commercial (COM) and Industrial (IND)	Directly connected impervious	1.78	15
Multi-Family (MFR) and High-Density Residential (HDR)	Directly connected impervious	2.32	14.1
Medium-Density Residential (MDR)	Directly connected impervious	1.96	14.1
Low-Density Residential (LDR) - "Rural"	Directly connected impervious	1.52	14.1

[1] From NH Small MS4 General Permit, Appendix F

General Equations

Physical Storage Capacity: Depth of Runoff * Drainage Area
Cost: Physical Storage Capacity * Cost Index * Adjustment Factor
Yearly Pollutant Removal: Pollutant Load Export Rate * Drainage Area * Efficiency

Cost

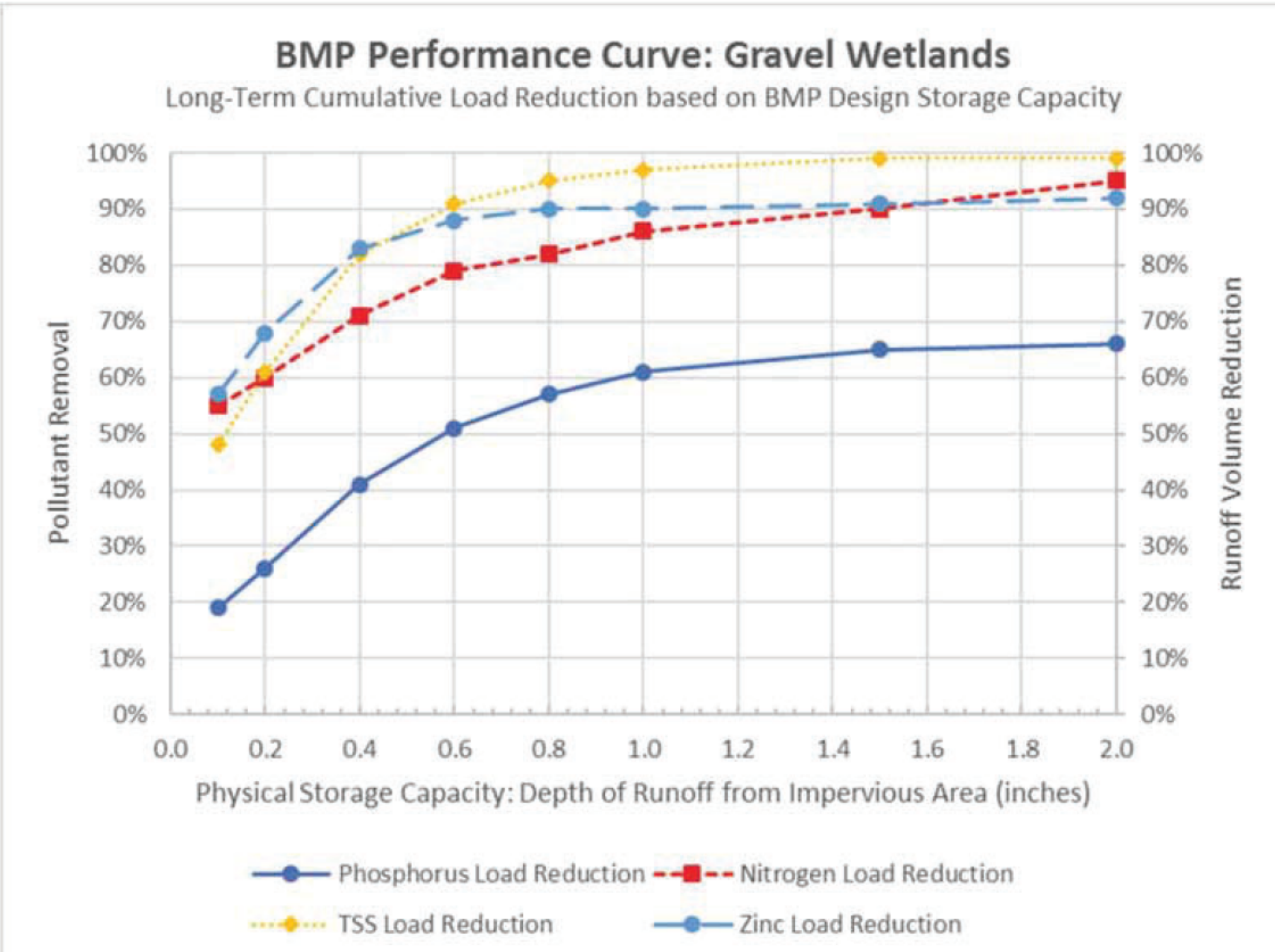
Infiltration Trench System	Materials and Installation Cost ($/ft³) (2010)[2]	Design Cost ($/ft³) (2010)	Materials and Installation Cost ($/ft³) (2017)[3]	Design Cost ($/ft³) (2017)
Rural	5.62	1.97	6.91	2.42
Mixed	11.24	3.94	13.82	4.84
Urban	16.86	5.91	20.73	7.26

[2] From UNHSC Cost Estimates; converted from 2004 to 2010 dollars using U.S. Department of Labor (USDOL). (2012). Bureau of Labor Statistics consumer price index inflation calculator. http://www.bls.gov/data/inflation_calculator.htm

[3] Converted from 2010 costs using ENR Cost Index

Prepared By:
University of New Hampshire
Stormwater Center
Durham, NH
www.unh.edu/unhsc
August 2017

BMP Performance Curve for Gravel Wetlands



Enhanced Biofiltration with Internal Storage Reservoir (ISR) Factsheet

Enhanced Biofiltration is a practice the provides temporary storage of runoff for filtering through an engineered soil media, augmented for enhanced phosphorus removal, followed by detention and denitrification in a subsurface internal storage reservoir (ISR) comprised of gravel. Runoff flows are routed through filter media and directed to the underlying ISR via an impermeable membrane for temporary storage. An elevated outlet control at the top of the ISR is designed to provide a retention time of at least 24 hours in the system to allow for sufficient time for denitrification and nitrogen reduction to occur prior to discharge. The design storage capacity for using the cumulative performance curves is comprised of void spaces in the filter media, temporary ponding at the surface of the practice and the void spaces in the gravel ISR. The cumulative phosphorus load reduction curve for this control is intended to be used for systems in which the filter media has been augmented with materials designed and/or known to be effective at capturing phosphorus. If the filter media is not augmented to enhance phosphorus capture, then the phosphorus performance curve for the Bio-Filter should be used for estimating phosphorus load reductions. The University of New Hampshire Stormwater Center (UNHSC) developed the design of this control practice and a design templated can be found at UNHSC's website.

Pollutant Export Rate by Land Use[1]

Source Category by Land Use	Land Surface Cover	P Load Export Rate[1] (lbs./acre/year)	N Load Export Rate[2] (lbs./acre/year)
Commercial (COM) and Industrial (IND)	Directly connected impervious	1.78	15
Multi-Family (MFR) and High-Density Residential (HDR)	Directly connected impervious	2.32	14.1
Medium-Density Residential (MDR)	Directly connected impervious	1.96	14.1
Low-Density Residential (LDR) - "Rural"	Directly connected impervious	1.52	14.1

[1] From NH Small MS4 General Permit, Appendix F

General Equations

Physical Storage Capacity: Depth of Runoff * Drainage Area
Cost: Physical Storage Capacity * Cost Index * Adjustment Factor
Yearly Pollutant Removal: Pollutant Load Export Rate * Drainage Area * Efficiency

Cost

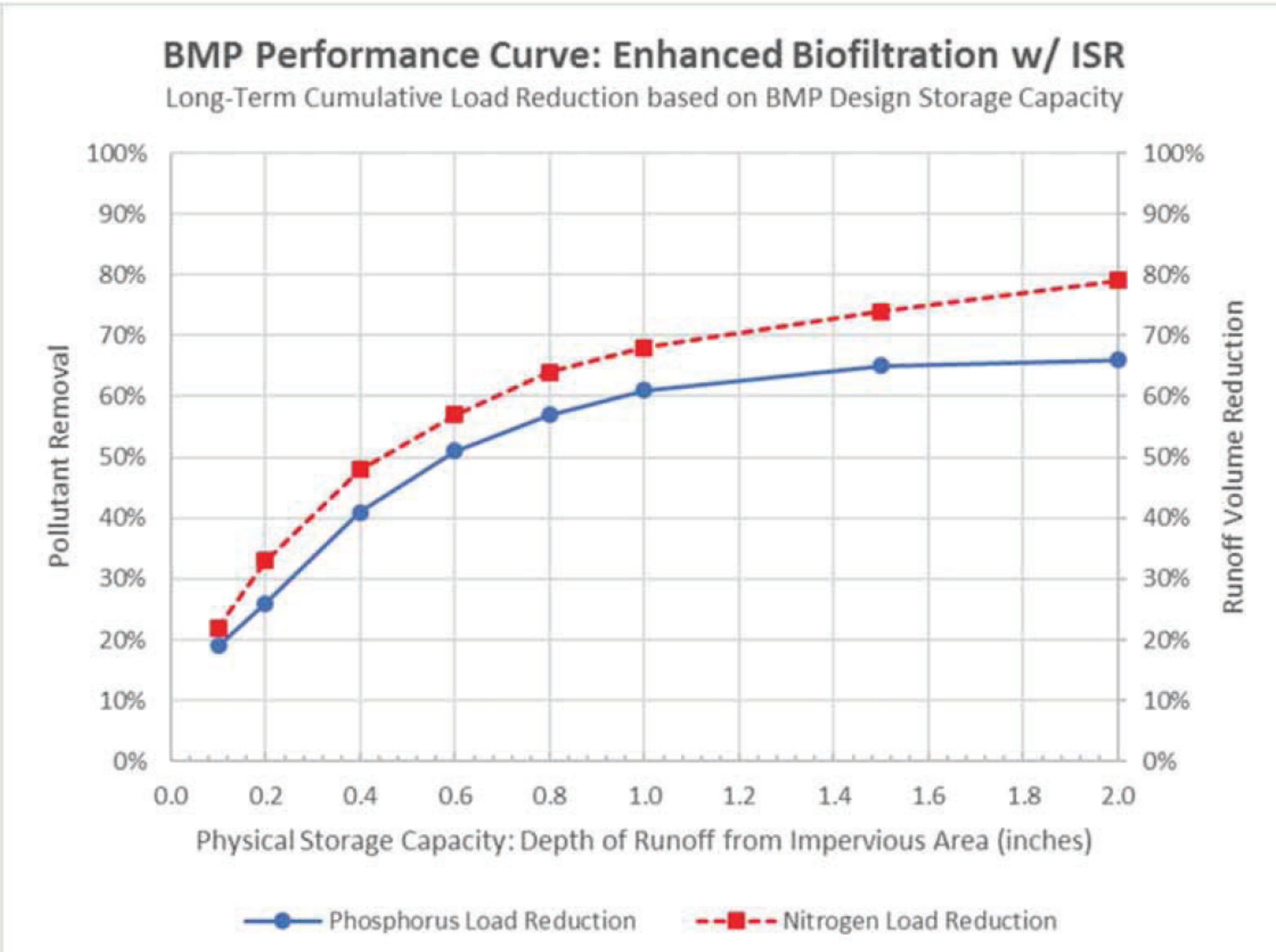
Infiltration Trench System	Materials and Installation Cost (\$/ft³) (2010)[2]	Design Cost (\$/ft³) (2010)	Materials and Installation Cost (\$/ft³) (2017)[3]	Design Cost (\$/ft³) (2017)
Rural	11.56	4.05	14.22	4.98
Mixed	23.12	8.10	28.44	9.95
Urban	34.68	12.15	42.66	14.93

[2] From UNHSC Cost Estimates; converted from 2004 to 2010 dollars using U.S. Department of Labor (USDOL). (2012). Bureau of Labor Statistics consumer price index inflation calculator. http://www.bls.gov/data/inflation_calculator.htm
[3] Converted from 2010 costs using ENR Cost Index

Prepared By:
University of New Hampshire
Stormwater Center
Durham, NH
www.unh.edu/unhsc
August 2017

BMP Performance Curve for Enhanced Biofiltration w/ ISR

This Graph is Incorrect: Pictured graph in Appendix F does not match the provided data, instead copy-pasted gravel wetlands data

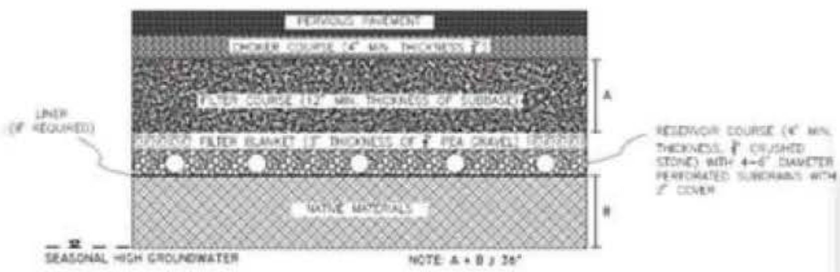


Porous Pavement Factsheet

Porous Pavement consists of a porous surface, base, and sub-base materials which allow penetration of runoff through the surface into underlying soils. The surface materials for porous pavements can consist of paving blocks or grids, pervious asphalt, or pervious concrete. These materials are installed on a base which serves as a filter course between the pavement surface and the underlying sub-base material. The sub-base material typically comprises a layer of crushed stone that not only supports the overlying pavement structure, but also serves as a reservoir to store runoff that penetrates the pavement surface until it can percolate into the ground. General design specifications for porous pavement systems are provided in the most recent version of *The New Hampshire Stormwater Manual, Volume 2: Post-Construction Best Management Practices Selection and Design*.

Sample Design

Profile View



Examples images from the *New Hampshire Stormwater Manual, Volume 2*, p. 120

Pollutant Export Rate by Land Use[1]

Source Category by Land Use	Land Surface Cover	P Load Export Rate[1] (lbs./acre/year)	N Load Export Rate[2] (lbs./acre/year)
Commercial (COM) and Industrial (IND)	Directly connected impervious	1.78	15
Multi-Family (MFR) and High-Density Residential (HDR)	Directly connected impervious	2.32	14.1
Medium-Density Residential (MDR)	Directly connected impervious	1.96	14.1
Low-Density Residential (LDR) - "Rural"	Directly connected impervious	1.52	14.1

[1] From NH Small MS4 General Permit, Appendix F

General Equations

Physical Storage Capacity: Depth of Runoff * Drainage Area
Cost: Physical Storage Capacity * Cost Index * Adjustment Factor
Yearly Pollutant Removal: Pollutant Load Export Rate * Drainage Area * Efficiency

Cost

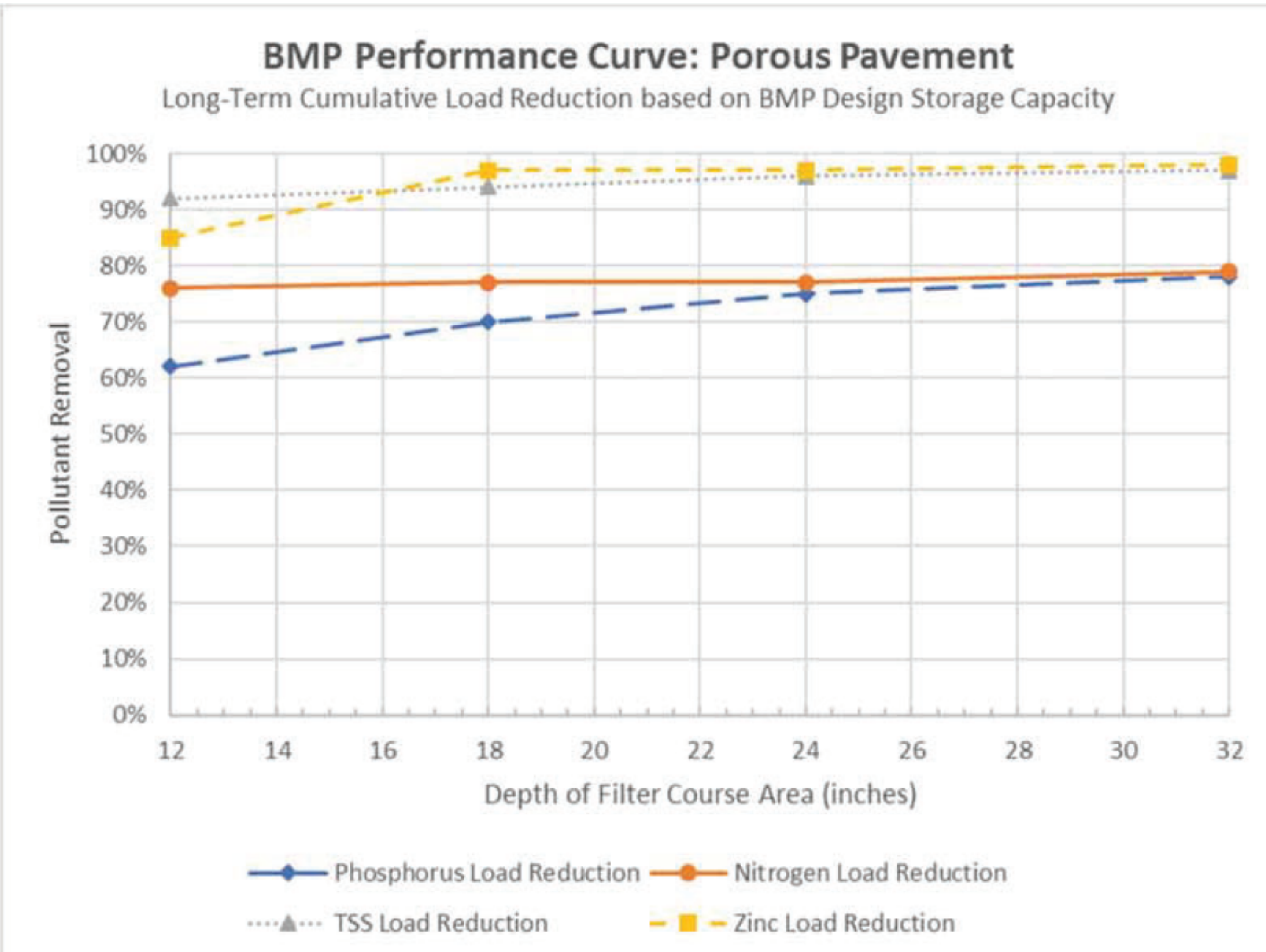
Infiltration Trench System	Materials and Installation Cost ($/ft³) (2010)[2]		Design Cost ($/ft³) (2010)		Materials and Installation Cost ($/ft³) (2017)[3]		Design Cost ($/ft³) (2017)	
	Porous Asphalt	Porous Concrete	Porous Asphalt	Porous Concrete	Porous Asphalt	Porous Concrete	Porous Asphalt	Porous Concrete
Rural	3.41	11.58	1.19	4.05	4.19	14.24	1.47	4.98
Mixed	6.8	23.16	2.38	8.10	8.38	28.48	2.94	9.96
Urban	10.23	34.74	3.57	12.15	12.57	42.72	4.41	14.94

[2] From UNHSC Cost Estimates; converted from 2004 to 2010 dollars using U.S. Department of Labor (USDOL). (2012). Bureau of Labor Statistics consumer price index inflation calculator. http://www.bls.gov/data/inflation_calculator.htm

[3] Converted from 2010 costs using ENR Cost Index

Prepared By:
University of New Hampshire Stormwater Center
Durham, NH
www.unh.edu/unhsc
August 2017

BMP Performance Curve for Porous Pavement

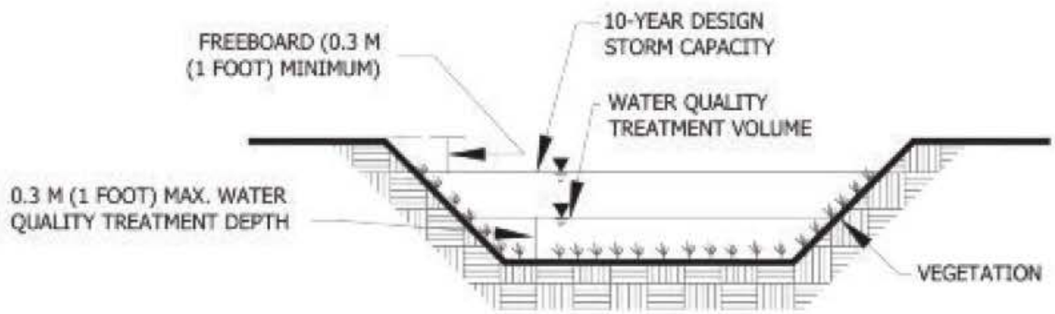


Grass Swale Factsheet

Grass Swale is a system which consists of a vegetated channel with check dams designed to convey and treat stormwater runoff. The design of allows filtration through the vegetation and check dams and infiltration through the subsurface soil media. Vegetation for the swale is selected based on mowing requirements, expected design flow, and site soil conditions. The channel should be designed to carry the max design flow within the design depth while preventing erosion within the channel. General design specifications for grass swale systems are provided in the most recent version of *The New Hampshire Stormwater Manual, Volume 2: Post-Construction Best Management Practices Selection and Design*.

Sample Design

Profile View



Examples images from the *New Hampshire Stormwater Manual, Volume 2*, p. 145

Pollutant Export Rate by Land Use[1]

Source Category by Land Use	Land Surface Cover	P Load Export Rate[1] (lbs./acre/year)	N Load Export Rate[2] (lbs./acre/year)
Commercial (COM) and Industrial (IND)	Directly connected impervious	1.78	15
Multi-Family (MFR) and High-Density Residential (HDR)	Directly connected impervious	2.32	14.1
Medium-Density Residential (MDR)	Directly connected impervious	1.96	14.1
Low-Density Residential (LDR) - "Rural"	Directly connected impervious	1.52	14.1

[1] From NH Small MS4 General Permit, Appendix F

General Equations

Physical Storage Capacity: Depth of Runoff * Drainage Area
Cost: Physical Storage Capacity * Cost Index * Adjustment Factor
Yearly Pollutant Removal: Pollutant Load Export Rate * Drainage Area * Efficiency

Cost

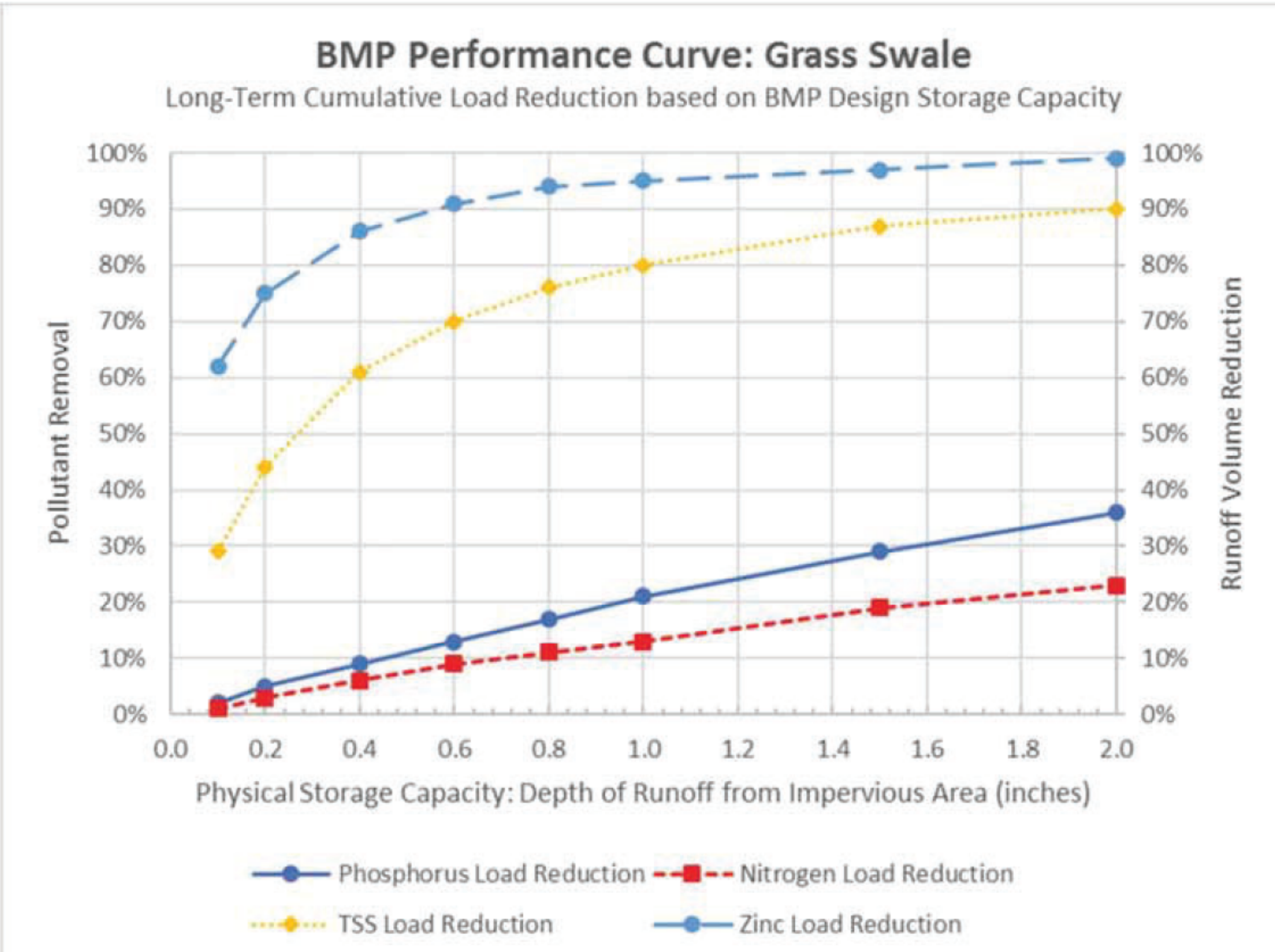
Infiltration Trench System	Materials and Installation Cost ($/ft³) (2010)[2]	Design Cost ($/ft³) (2010)	Materials and Installation Cost ($/ft³) (2017)[3]	Design Cost ($/ft³) (2017)
Rural				
Mixed				
Urban				

[2] From UNHSC Cost Estimates; converted from 2004 to 2010 dollars using U.S. Department of Labor (USDOL). (2012). Bureau of Labor Statistics consumer price index inflation calculator. http://www.bls.gov/data/inflation_calculator.htm

[3] Converted from 2010 costs using ENR Cost Index

Prepared By:
University of New Hampshire
Stormwater Center
Durham, NH
www.unh.edu/unhsc
August 2017

BMP Performance Curve for Grass Swale

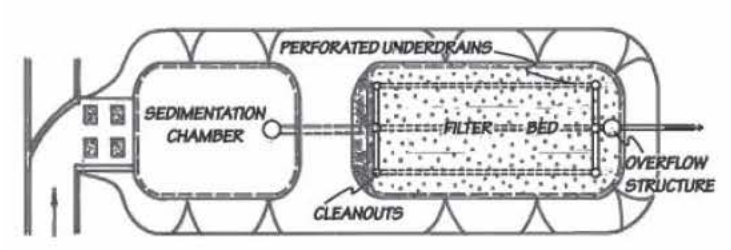


Sand Filter Factsheet

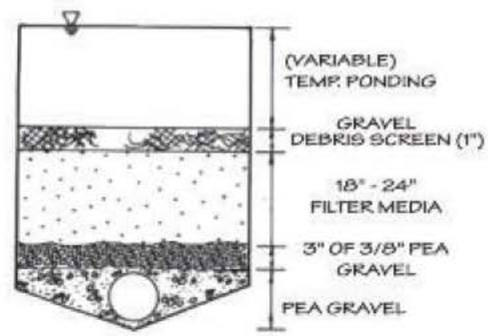
Sand Filter is a system which provides filtering of runoff through a sand filter media and temporary storage of runoff within the void spaces prior to discharge by way of an underdrain. Sand filters are generally used for overflow conditions of the primary BMP, and as such often include a pretreatment device to allow coarse settlements to settle out of the water. The top surface of the filter is kept clear of vegetation. General design specifications for sand filter systems are provided in the most recent version of *The New Hampshire Stormwater Manual, Volume 2: Post-Construction Best Management Practices Selection and Design.*

Sample Design

Plan View



Section View



Examples images from the *New Hampshire Stormwater Manual, Volume 2*, p. 104

Pollutant Export Rate by Land Use[1]

Source Category by Land Use	Land Surface Cover	P Load Export Rate[1] (lbs./acre/year)	N Load Export Rate[2] (lbs./acre/year)
Commercial (COM) and Industrial (IND)	Directly connected impervious	1.78	15
Multi-Family (MFR) and High-Density Residential (HDR)	Directly connected impervious	2.32	14.1
Medium-Density Residential (MDR)	Directly connected impervious	1.96	14.1
Low-Density Residential (LDR) - "Rural"	Directly connected impervious	1.52	14.1

[1] From NH Small MS4 General Permit, Appendix F

General Equations

Physical Storage Capacity: Depth of Runoff * Drainage Area
Cost: Physical Storage Capacity * Cost Index * Adjustment Factor
Yearly Pollutant Removal: Pollutant Load Export Rate * Drainage Area * Efficiency

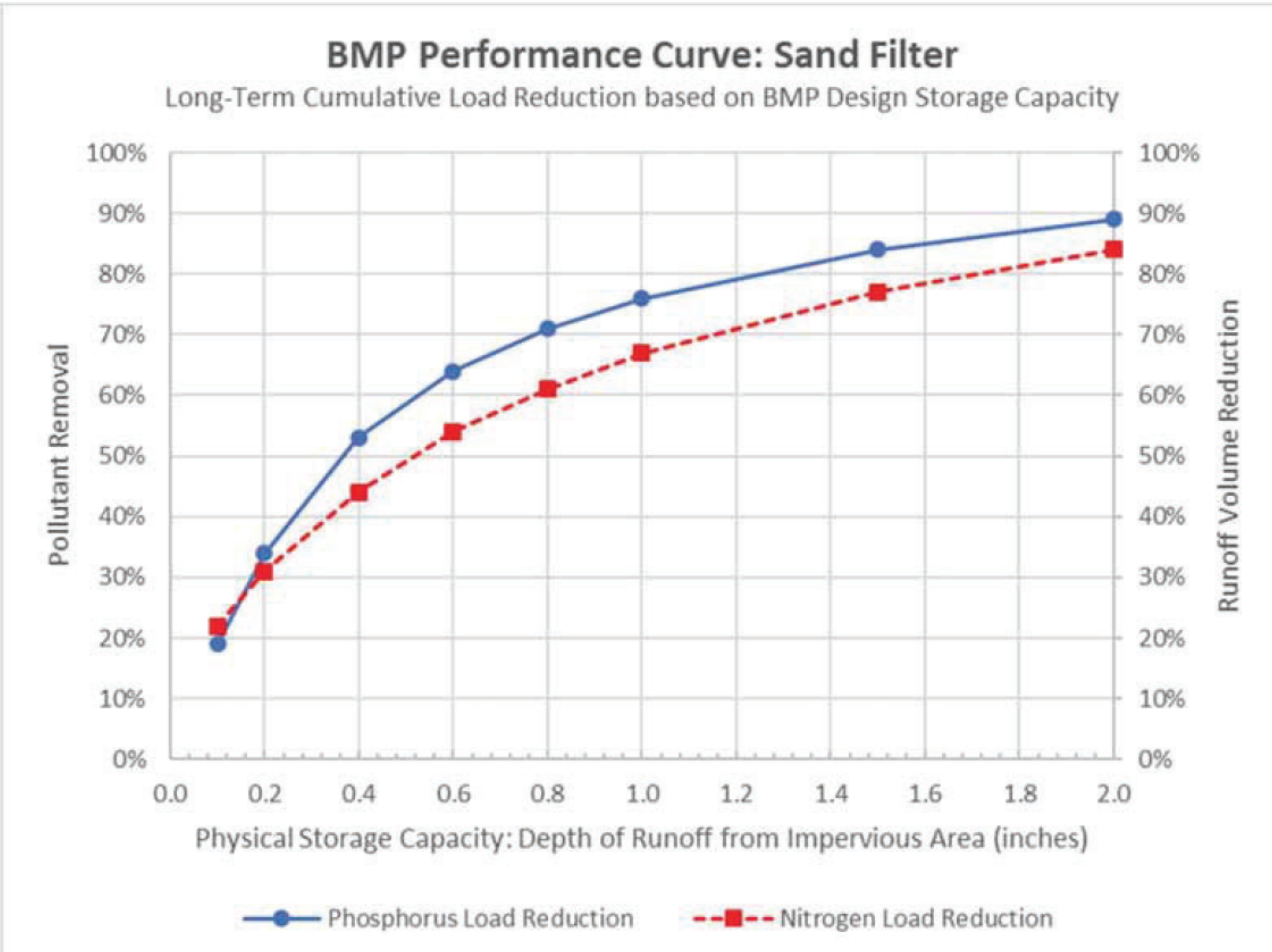
Cost

Infiltration Trench System	Materials and Installation Cost ($/ft^3) (2010)[2]	Design Cost ($/ft^3) (2010)	Materials and Installation Cost ($/ft^3) (2017)[3]	Design Cost ($/ft^3) (2017)
Rural	11.49	4.02	14.13	4.94
Mixed	22.98	8.04	28.26	9.88
Urban	34.47	12.06	42.39	14.82

[2] From UNHSC Cost Estimates; converted from 2004 to 2010 dollars using U.S. Department of Labor (USDOL). (2012). Bureau of Labor Statistics consumer price index inflation calculator. http://www.bls.gov/data/inflation_calculator.htm
[3] Converted from 2010 costs using ENR Cost Index

Prepared By:
University of New Hampshire Stormwater Center
Durham, NH
www.unh.edu/unhsc
August 2017

BMP Performance Curve for Sand Filter

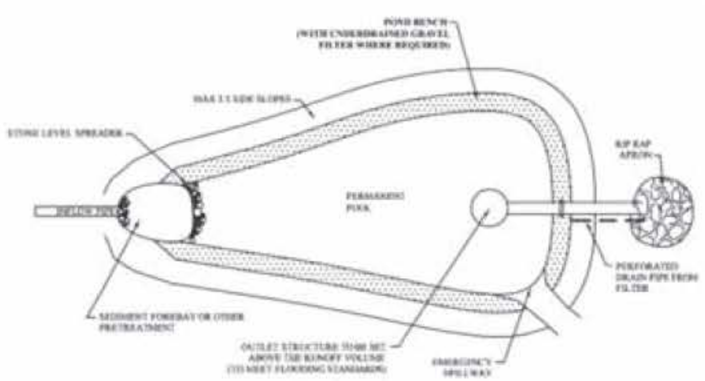


Wet Pond Factsheet

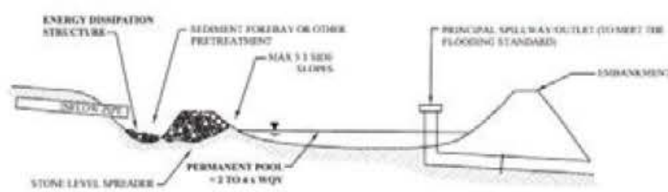
Wet Pond is a class of systems designed to maintain a permanent pool of water year-round. The pool allows for pollutant removal via settling, biological uptake, and decomposition. This allows the system to treat both sediment loads and its commonly associated pollutants along with treating dissolved nutrients through the pond's biological processes. For areas where water temperature is a concern, an underdrained gravel trench in the bench area around the permanent pool can allow for the extended release of stormwater, minimizing risk of clogging. General design specifications for wet pond systems are provided in the most recent version of *The New Hampshire Stormwater Manual, Volume 2: Post-Construction Best Management Practices Selection and Design*.

Sample Design

Plan View



Profile View



Examples images from the *New Hampshire Stormwater Manual, Volume 2,* p. 61

Pollutant Export Rate by Land Use[1]

Source Category by Land Use	Land Surface Cover	P Load Export Rate[1] (lbs./acre/year)	N Load Export Rate[2] (lbs./acre/year)
Commercial (COM) and Industrial (IND)	Directly connected impervious	1.78	15
Multi-Family (MFR) and High-Density Residential (HDR)	Directly connected impervious	2.32	14.1
Medium-Density Residential (MDR)	Directly connected impervious	1.96	14.1
Low-Density Residential (LDR) - "Rural"	Directly connected impervious	1.52	14.1

[1] From NH Small MS4 General Permit, Appendix F

General Equations

Physical Storage Capacity: Depth of Runoff * Drainage Area
Cost: Physical Storage Capacity * Cost Index * Adjustment Factor
Yearly Pollutant Removal: Pollutant Load Export Rate * Drainage Area * Efficiency

Cost

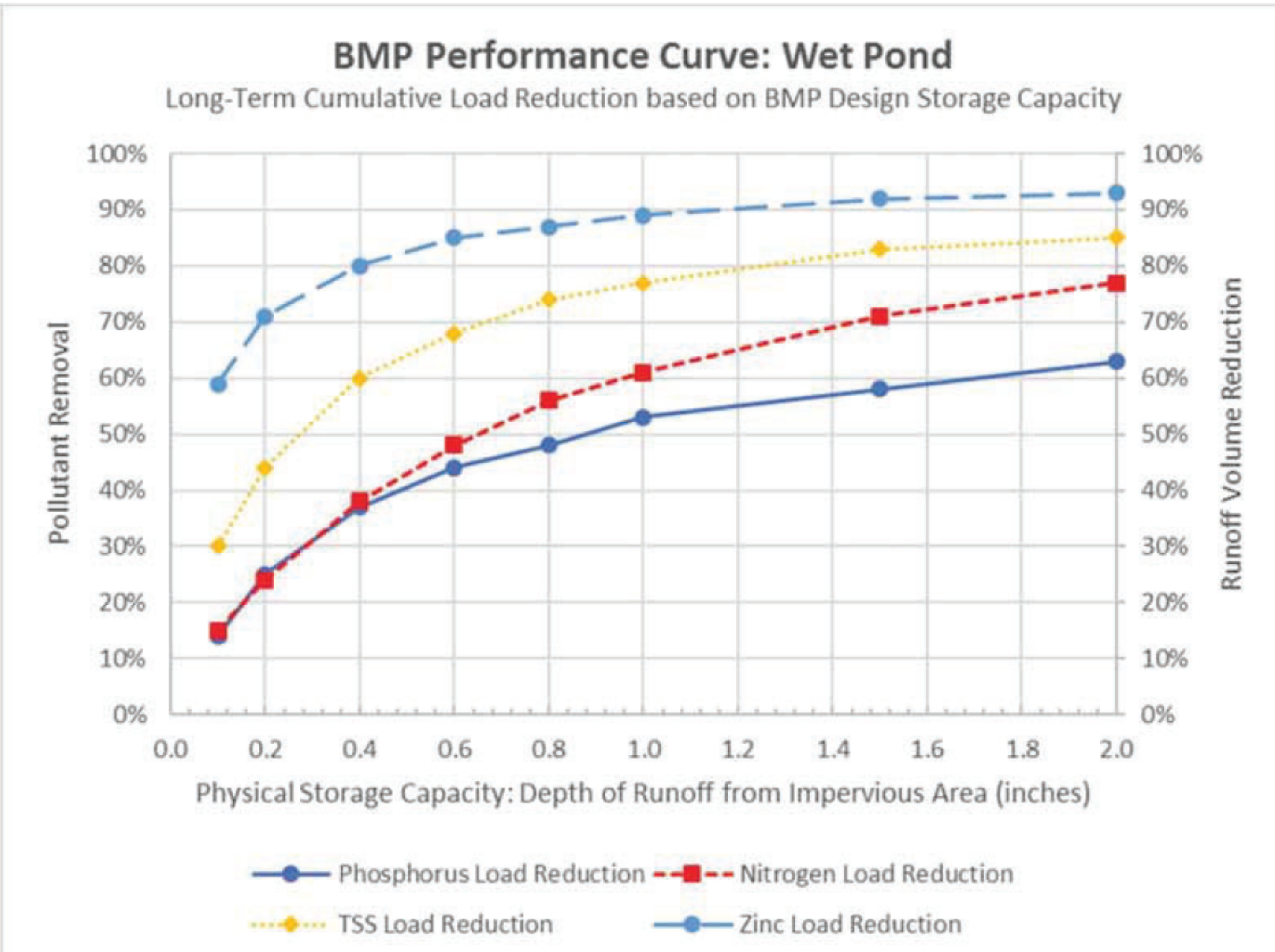
Infiltration Trench System	Materials and Installation Cost ($/ft³) (2010)[2]	Design Cost ($/ft³) (2010)	Materials and Installation Cost ($/ft³) (2017)[3]	Design Cost ($/ft³) (2017)
Rural	4.36	1.52	5.36	1.87
Mixed	8.72	3.04	10.72	3.74
Urban	13.08	4.56	16.08	5.61

[2] From UNHSC Cost Estimates; converted from 2004 to 2010 dollars using U.S. Department of Labor (USDOL). (2012). Bureau of Labor Statistics consumer price index inflation calculator. http://www.bls.gov/data/inflation_calculator.htm

[3] Converted from 2010 costs using ENR Cost Index

Prepared By:
University of New Hampshire
Stormwater Center
Durham, NH
www.unh.edu/unhsc
August 2017

BMP Performance Curve for Wet Pond

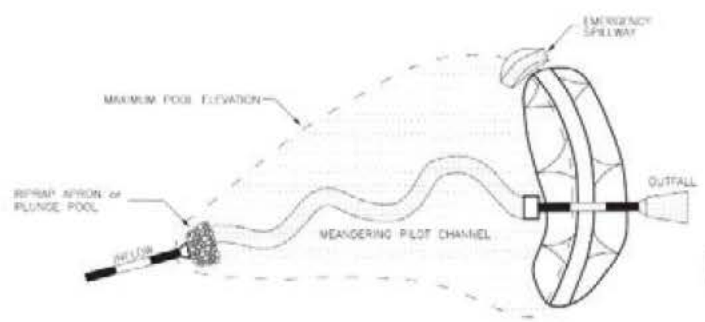


Extended Dry Detention Basin Factsheet

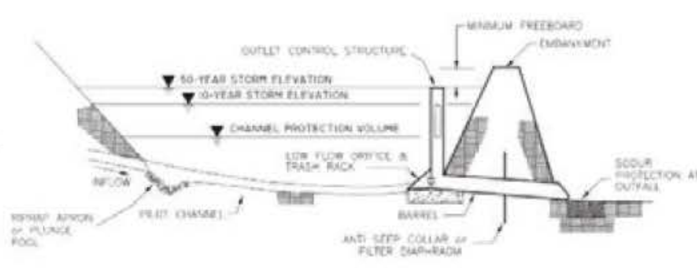
Detention Basin consists of a type of system which is primarily intended to provide flood protection by containing the flow within an excavated area and gradually releasing it over the course of a design length of time, with extended dry detention basins typically having a detention time of 24 hours. This reduces the intensity of peak flows, and the detention time allows the treatment of some pollutants, particularly those associated with suspended solids. A detention basin may be combined with other BPMs to combine detention with other treatment methods. Dry detention basins are often referred to as dry ponds, due to their similarity in design to wet ponds. General design specifications for detention basin systems are provided in the most recent version of *The New Hampshire Stormwater Manual, Volume 2: Post-Construction Best Management Practices Selection and Design*.

Sample Design

Plan View



Profile View



Examples images from the *New Hampshire Stormwater Manual, Volume 2*, p. 159

Pollutant Export Rate by Land Use[1]

Source Category by Land Use	Land Surface Cover	P Load Export Rate[1] (lbs./acre/year)	N Load Export Rate[2] (lbs./acre/year)
Commercial (COM) and Industrial (IND)	Directly connected impervious	1.78	15
Multi-Family (MFR) and High-Density Residential (HDR)	Directly connected impervious	2.32	14.1
Medium-Density Residential (MDR)	Directly connected impervious	1.96	14.1
Low-Density Residential (LDR) - "Rural"	Directly connected impervious	1.52	14.1

[1] From NH Small MS4 General Permit, Appendix F

General Equations

Physical Storage Capacity: Depth of Runoff * Drainage Area
Cost: Physical Storage Capacity * Cost Index * Adjustment Factor
Yearly Pollutant Removal: Pollutant Load Export Rate * Drainage Area * Efficiency

Cost

Infiltration Trench System	Materials and Installation Cost ($/ft³) (2010)[2]	Design Cost ($/ft³) (2010)	Materials and Installation Cost ($/ft³) (2017)[3]	Design Cost ($/ft³) (2017)
Rural	4.36	1.52	5.36	1.87
Mixed	8.72	3.04	10.72	3.74
Urban	13.08	4.56	16.08	5.61

[2] From UNHSC Cost Estimates; converted from 2004 to 2010 dollars using U.S. Department of Labor (USDOL). (2012). Bureau of Labor Statistics consumer price index inflation calculator. http://www.bls.gov/data/inflation_calculator.htm

[3] Converted from 2010 costs using ENR Cost Index

Prepared By:
University of New Hampshire
Stormwater Center
Durham, NH
www.unh.edu/unhsc
August 2017

BMP Performance Curve for Extended Dry Detention Basin