Evaluating BMP Designs for Phosphorus Removal in Cambridge

A Major Qualifying Project Submitted By:

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Abstract

This Major Qualifying Project (MQP) reviewed the Best Management Practices (BMP) Accounting and Tracking Tool (BATT) for Cambridge to reduce its phosphorus loading to the Charles River. The study, in collaboration with Stantec, involved: calculation comparisons between BATT and regulations, sensitivity analysis of inputs, model validation, and application of the model to BMP design. Using findings from the sensitivity analysis, including input of infiltrating BMPs and ideal acreage distributions, the team redesigned Cambridge stormwater projects to produce optimal phosphorus reductions.

Authorship

Section	Primary Author
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Capstone Design

The Accreditation Board for Engineering and Technology (ABET) requires that students demonstrate knowledge and skills they acquire throughout their coursework and studies through a capstone design experience. The capstone design experience must incorporate engineering principles that are applied to realistic design constraints. In this project, the team analyzed and validated calculations in the Best Management Practice (BMP) Accounting and Tracking Tool (BATT) software using data provided by the City of Cambridge. With this knowledge, the team created alternative designs for stormwater projects implemented in Cambridge with the goal of increasing BATT phosphorus credits. Additionally, the team designed a template for developers to easily categorize designed BMPs into BATT and organize necessary BATT inputs. The goal of creating the developer template was ultimately to help developers use BATT, following Municipal Separate Storm Sewer System (MS4) Permit requirements. The project met the ABET realistic constraints as follows:

Environmental:

A major piece of this project was to decrease Cambridge's phosphorus output into the Charles River. When considering redesign of Cambridge stormwater improvement projects, the team was aware of the site characteristics of each project, and worked to optimize the design for each site. Site aspects were important to effectively select BMPs that would ultimately have the greatest decrease in stormwater runoff. This involved being mindful of the impervious and pervious land compositions and Hydrologic Soil Group (HSG), as each characteristic has the potential to infiltrate stormwater. The team also explored BMP options with various storage volumes for this site optimization.

Health & Safety:

The Charles River has had problems handling ample phosphorus loads, which cause the water to be dangerous for swimming and other recreational activities. According to the Massachusetts Department of Environmental Protection (MassDEP) Integrated List of Waters, the Charles River experiences the highest level of impairment, a category five. To improve water quality, and thus health and safety, stormwater must be treated effectively to decrease phosphorus runoff concentrations. Therefore, the team created alternative designs for sites using BATT to improve BMP phosphorus removal rates. Also, the template allows developers to claim the correct phosphorus reduction for a site. Both designs sought to decrease phosphorus runoff, reducing the potential of this hazard to both the environment and public surrounding the waterbody.

Ethical:

The team adhered to the American Society of Civil Engineers Code of Ethics. Following these principles, the team was unbiased in decision making for this project between Stantec and Cambridge. The team tried to provide the best recommendations for Cambridge to utilize BATT in a manner that helped it calculate phosphorus removal for its specific land characteristics.

Political:

To ensure that developers can utilize BATT effectively and understand MS4 Permit requirements, the team designed the template with ease of use and interpretation in mind. The template not only was designed for usability for the developer, but also for the municipality official who would receive the completed template. The design had to incorporate a layout style that reduced interpretation of data and was simple to fill out. Also, the template had a two-fold purpose of facilitating the input of data and informing the developer of BATT BMP compatibility. Therefore, a flow chart that categorizes BMPs was designed for users to easily read and learn how to categorize their BMPs in BATT.

Constructability:

When considering designs based on credits in BATT, the team was aware of site characteristics that could not be feasibly altered. The team did not change inherent site elements such as land use group that was based on zoning regulations. The team also chose not only BMPs with the highest phosphorus reductions, but also the highest redesign potential. For example, BMPs were chosen that could meet the size constraints of that subcatchment area and had similar characteristics to the previous site BMP. A detention pond could be changed to an infiltration trench because of the size and water release characteristics, whereas porous asphalt could be changed into an infiltration trench because of that size and media characteristics. In the other design element of the project, the template, the team also contemplated constructability elements of each BMP in order to create distinguishing characteristics between the BMP options in BATT. For example, the decision flowchart considered design characteristics such as infiltration potential and mechanisms for phosphorus filtration to select a BMP. Construction elements were key for the development of a decision flowchart and table of similar BMPs in BATT.

Professional Licensure Statement

In order to ensure that a project has been properly designed, engineering firms are required to have a Professional Engineer (PE) sign off on the project. Being a PE indicates that one has developed strong capabilities in engineering design. This role is quite important, since a PE takes responsibility for a project in its entirety by signing off on it.

To become a PE, one must first graduate from an accredited engineering program. The individual also has to have taken and passed the Fundamentals of Engineering (FE) Exam to become an Engineer in Training (EIT). After working in professional practice for four years as an EIT, the individual must pass the Principles and Practices of Engineering (PE) exam to receive professional licensure in his or her given state.

Professional licensure is important on both an individual and community-wide basis. Individually, passing the PE is an important step in one's engineering career. It signifies that one has reached a high level of expertise in engineer design. Communities that hire engineering firms benefit from having a professional engineer sign off on the finished project as it signifies that the project has reached high levels of health and safety standards through the design, review, and supervision of professional practice.

The proposed alternative stormwater management designs and developer template would require a stamp of a licensed PE in order to be implemented. These deliverables are preliminary and would require further review by a PE in order to ensure that they comply with state engineering standards.

Executive Summary

The amount of nutrients such as phosphorus that enter a watershed through stormwater can severely impair its water bodies. The impaired watershed focused for this project was the Charles River, narrowing on the municipality of Cambridge. Cambridge faces many challenges as a City to reducing its phosphorus runoff resulting from a high percentage of impervious surfaces in the City and a high water table. These specific difficulties made the municipality of Cambridge ideal for the team's case study on phosphorus reduction.

For municipalities such as Cambridge along impaired waters, requirements for phosphorus limits are put in place as a mandate for change. The Municipal Separate Storm Sewer System (MS4) Permit is the primary permit setting phosphorus reduction requirements for municipalities in the form of Total Maximum Daily Loads (TMDLs). Cambridge's requirement specifically mandates that it reduce its phosphorus load to the Charles River by 604 lb/yr. To meet this requirement Cambridge must implement Best Management Practices (BMPs) that capture and treat stormwater specifically designed for highly developed project sites.

Because Cambridge officials must work to meet this TMDL, one of the team's objectives was to help them incorporate the BMP Accounting and Tracking Tool (BATT), software developed to employ the MS4 Permit crediting protocols, into their strategy. The goal of the project was to work with Stantec to help Cambridge effectively use BATT to analyze site design improvements that will reduce phosphorus loading in the Charles River. The focus of the analysis was centered on BATT crediting processes for phosphorus. To develop the case study for Cambridge, the team first had to understand the methodologies associated with BATT.

Because the BATT was devised in order to track credits to meet MS4 Permit requirements, it was essential that it emulate exactly the MS4 Permit Appendix F methodology for calculating phosphorus removals. The team constructed Appendix F spreadsheets that followed each input and calculation to compare how closely BATT followed the permit methodology. When similar inputs were entered into both, several discrepancies were identified. The nonstructural, "No Application of Fertilizer with Phosphorus," the frequency function for Sweeping Technologies, and the calculation for conversion of impervious to pervious area each did not follow the MS4 Permit methodology in BATT. An interview conducted with EPA official working closely with BATT, Suzanne Warner, provided explanations on these differences.

Cumulatively, the team's experience working with BATT and identification of differences with Appendix F allowed the creation of a comprehensive user guide for the tool. Since the EPA has a user guide in place for BATT showing simply how to input information, the team's guide covered additional topics. These included instruction on setting up computers and on accessing hidden reference tables containing Appendix F performance curves. Municipalities such as Cambridge can use this guide to enhance the usability of BATT.

The team, having a grasp on the functionality of the BATT tool, conducted sensitivity tests to identify which inputs to BATT had the greatest impact on the BATT reduction. By changing one BATT input and maintaining constant the other BATT inputs, the team found

which characteristics are best to change within a project site. Results were graphed across a range of BATT input variables such as storage volume to observe trends in phosphorus reduction.

After gaining a grasp of the BATT methodology for producing phosphorus reductions, the team also studied how several organizations monitor BMPs to obtain real world removal efficiencies. Two of these organizations were the University of New Hampshire Stormwater Center (UNHSC) and the Charles River Watershed Association (CRWA). Comparing these organizations' monitoring results to BATT outputs for validation, the team found a correlation between the CRWA and BATT. However, most UNHSC monitoring removals were significantly higher than the BATT removals. The team hypothesized that this may be due to different assumptions made by the UNHSC on baseline loading and BATT being a conservative model.

Stantec also provided the team with 44 projects within Cambridge that contained BMPs for analysis. Utilizing the HydroCAD reports within the projects, the team was able to organize the BATT inputs for each. Additionally, the team sorted these projects based on presence within the Charles River Watershed, simplicity of design, and type of structural BMP, in order to decide which would be best for the design component of the project.

There were two design components for this project: redesigns of Cambridge sites and a developer template. The redesigns attempted to increase the predicted phosphorus reductions from BATT based on the in-depth understanding the team gained from this project. The team also took into account site inherent parameters, such as land use group, that were not manipulated in the redesign. Subcatchment permeability ratio, BMP choice, and BMP storage volume were the only parameters deemed acceptable for investigation. Sites for redesign were chosen based on prior analysis of the phosphorus loading and BMP removal efficiencies. The team selected three sites for redesign, employing the tactics above for site optimization. This led to potential BMP removal efficiencies increasing from around 30% to 90% for the projects.

The developer template was the other major design component. The template included inputs for BATT, BMP decision flowchart, and list of distinguishing characteristics for BATT BMPs. There are only a select number of BMPs in BATT, making new and creative BMP innovations up for interpretation by the BATT user. The team tried to filter these interpretations into the appropriate BMP through this template. This allows the greatest phosphorus reduction to be reported by the developer and credited for the municipality of Cambridge.

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List of Acronyms

AF - Annual Frequency
BATT - BMP Accounting and Tracking Tool
BMP - Best Management Practice
CRWA - Charles River Watershed Association
DSV - Design Storage Volume
EIT – Engineer in Training
EPA - Environmental Protection Agency
FE – Fundamentals of Engineering
GIS - Geographic Information Systems
HDR - High Density Residential
HRU - Hydrologic Response Unit
HSG - Hydrologic Soil Group
IA - Impervious Area
ISR - Internal Storage Ratio
MassDEP - Massachusetts Department of Environmental Protection
MCMs - Minimum Control Measures
MDR - Medium Density Residential
MQP - Major Qualifying Project
MS4 - Municipal Separate Storm Sewer System
NOAA - National Oceanic and Atmospheric Administration
NOI - Notice of Intent
NOI - Notice of Intent
NPDES Permit - National Pollutant Discharge Elimination System Permit
NRCS - National Resource Conservation Service
NSQD - National Stormwater Quality Data
PE – Professional Engineer
P8 - Program for Predicting Polluting Particle Passage Through Pits, Puddles, and Ponds
PCP - Phosphorus Control Plan
PLER - Phosphorus Load Export Rate
SWIP - Stormwater and Wastewater Infrastructure Permits
SWMM - Storm Water Management Model
SWMP - Stormwater Management Plan
TMDL - Total Maximum Daily Load
TN - Total Nitrogen
TP - Total Phosphorus
TSS - Total Suspended Solids
UNHSC - University of New Hampshire Stormwater Center
USGS - United States Geological Survey
WPI - Worcester Polytechnic Institute
WPLER - Weighted Phosphorus Load Export Rate
WQV - Water Quality Volume

1.0: Introduction

The Charles River has experienced issues regarding nutrient loading, particularly phosphorus. High concentrations of phosphorus can be detrimental to the health of the waterbody and the people living around it[1]. Nutrient loading causes the occurrence of harmful cyanobacteria, a primary health concern. In the summer of 2015 alone, the Charles River was required to fly a yellow flag, indicating caution due to cyanobacteria in the water, for 65 days[2]. According to the Massachusetts Department of Environmental Protection (MassDEP) Integrated List of Waters, the Charles River experiences a category five impairment, the highest level[3]. Municipalities near the Charles River have been making efforts to reduce their phosphorus loading through stormwater management designs.

To address the negative effect of phosphorus on water bodies, the United States Environmental Protection Agency (EPA) created Total Maximum Daily Loads (TMDLs) specific for each municipality that surrounds an impaired watershed. TMDLs provide the maximum amount of nutrients, such as phosphorus, that a municipality can discharge to a water body. These can be found in the Municipal Separate Storm Sewer System (MS4) Permit, which was created to provide standards that municipalities must follow to meet their TMDL requirements. Appendix F of the MS4 Permit contains calculations specific to phosphorus credits for stormwater management through implementation of Best Management Practices (BMPs) and land use conversions that municipalities can utilize to determine if they are meeting TMDL requirements. To ensure that municipalities are making efforts to meet TMDLs, they are required to file a Notice of Intent (NOI) to obtain authorization to discharge stormwater containing pollutants[4]. Additionally, municipalities must formulate a Stormwater Management Plan (SWMP) containing planned measures to reduce their phosphorus loading, including sections like public outreach[5].

Because BMPs are essential in meeting phosphorus reduction requirements, it is important to know their optimal design specifications that lead to high removal efficiencies. Organizations such as the University of New Hampshire Stormwater Center (UNHSC) and the Charles River Watershed Association (CRWA) closely monitor BMP efficiencies in phosphorus removal. They have collected data on various BMPs that are essential to contaminant removal in stormwater. These field examples are important for developers to learn from so they can

[1] USEPA. (2017). *Environmental challenges for the Charles River*. Retrieved from: https://www.epa.gov/charlesriver/environmental-challenges-charles-river

[2] Abel, D. (2016). "EPA forcing towns to clean up Charles River". *Boston Globe*. Retrieved from: https://www.bostonglobe.com/metro/2016/02/21/epa-moves-require-municipalities-curb-charles-river-pollution/nCgaDyYEQOhBKRo8wBVXmI/story.html

[3] MassDEP. (2014). 2014 Integrated List of Waters Map. [Interactive Map of Massachusetts Integrated Waters]. Retrieved from: http://maps.massgis.state.ma.us/images/dep/omv/il2014viewer.htm

[4] USEPA. (2017). *Massachusetts Small MS4 General Permit History*. Retrieved from https://www.epa.gov/npdes-permits/massachusetts-small-ms4-general-permit.

[5] USEPA. (2017). "Appendix F: Requirements for Discharges to Impaired Waters with an Approved TMDL" Massachusetts MS4 General Permit. Boston, MA

implement BMPs that will effectively reduce contaminant levels from stormwater. Analytically, these BMP monitoring efficiencies can be used on a higher scale to create or compare stormwater quality models and software.

The BMP Accounting and Tracking Tool (BATT) is software that predicts stormwater quality. It is used by the EPA to credit municipalities with TMDL reductions per MS4 requirements. TMDL parameters include Total Phosphorus (TP), Total Nitrogen (TN), and Total Suspended Solids (TSS). For this project, the team focused on phosphorus. When calculating these credits for a permittee, BATT has three major options: structural BMPs, non-structural BMPs, and land use conversion. Structural BMPs are most commonly utilized, and were the focus of the team's research. BATT is a rather new program, as it became public in 2016[6]. Questions have surfaced around the usability of the interface and how BATT calculates the reductions. Currently, phosphorus reduction results from BATT and other methods have concluded that municipalities such as Cambridge are far from meeting the permit goals[7].

Cambridge's current phosphorus load is 1,153 lb/yr, and the City faces an MS4 phosphorus limit of 505 lb/yr. To achieve this, Cambridge must decrease its loading by 604 lb/yr[8]. Because of the magnitude of this requirement, Cambridge was the specific focus for this project in assisting with stormwater regulation compliance and phosphorus reduction. The team worked in collaboration with Stantec, a contractor hired by Cambridge to aid the municipality in minimizing phosphorus loading through site redevelopments. One of the challenges that Cambridge has in meeting its MS4 Permit requirement is its high percentage of impervious or paved surfaces, which do not allow stormwater to infiltrate. Cambridge also lacks land area containing Hydrologic Soil Group (HSG) A, a highly pervious type of soil, and has a seasonably high water table that prevents infiltration in many sites around the City[9,10]. These aspects of the municipality are important factors to consider in Cambridge's efforts to reduce runoff to the Charles River.

The goal of the project was to work with Stantec to help Cambridge effectively use BATT to analyze site design improvements that will reduce phosphorus loading in the Charles River. To work toward this goal, the team devised several objectives. First, the team worked to understand existing conditions of BATT by analyzing the usability of the interface. A comparison between BATT calculations and the calculation requirements presented in Appendix F of the MS4 Permit was conducted to verify correlations between the two methods. Then, the team evaluated BATT performances efficiencies through a sensitivity analysis and data validation. Using sample engineering reports, the team performed a sensitivity analysis by changing certain inputs to determine which produce the largest changes in BATT outputs. BATT

[6] Tetra Tech. (2016). *BMP Accounting and Tracking Tool (BATT): User's Guide*. Retrieved from: https://www3.epa.gov/region1/npdes/stormwater/ma/batt-users-guide.pdf
[7] D. Duhamel, Personal Interview, November, 27, 2017

[8] (USEPA, 2017, Appendix F)
[9] United States Department of Agriculture (2017). *Web Soil Survey.* Retrieved from https://websoilsurvey.sc.egov.usda.gov/App/HomePage.htm.
[10] City of Cambridge. (2017). "Appendix B: Green Infrastructure Analysis & Urban Heat Island Modeling." Climate Change Preparedness & Resilience. [PDF]

calculations were validated by comparing BATT outputs to BMP monitoring data collected by the CRWA and UNHSC. Finally, the team analyzed Cambridge projects for design recommendations. The team assessed completed stormwater projects in Cambridge using BATT. Taking three of these assessments, the team created alternative designs for these sites to increase the phosphorus credit reported by BATT.

One of the deliverables was to create an in-depth user guide for BATT to clarify any initial issues that one may encounter with the software. Some key findings were placed into this user guide to help developers navigate BATT and categorize BMPs into the software. The other key deliverable was a developer template, where developers would input site details to be reviewed by municipality officials. This was a fillable PDF document that also included a decision flowchart for categorizing BMPs in BATT and distinguishing characteristics between these BMPs.

2.0: Background

This chapter provides an overview of information that closely relates to the team's objectives. The Municipal Separate Storm Sewer System (MS4) Permit provides important equations for calculating phosphorus load reductions for Best Management Practices (BMPs) and land use changes. The BMP Accounting and Tracking Tool (BATT) is meant to help municipalities calculate their phosphorus credits while adhering to the MS4 Permit calculation methods. Also, information is provided for organizations that monitor BMPs: the Charles River Watershed Association (CRWA) and the University of New Hampshire Stormwater Center (UNHSC).

2.1: Overview of the Municipal Separate Storm Sewer System Permit & Cambridge Regulations

A driving force behind the team's project for Stantec was the MS4 Permit and its restrictions set for nutrient loading in each municipality. This permit is under the National Pollutant Discharge Elimination System Permit (NPDES) required by the Clean Water Act and regulates discharges of pollutants through point sources[11]. Cambridge is specifically incorporated into Phase II of the NPDES permit for separate storm drainage systems in high-density urban areas. Appendix F of the MS4 permit outlines the requirements for discharges to impaired waters, including specific Total Maximum Daily Loads (TMDL) for the Charles River. For example, Cambridge's TMDL requirement for phosphorus is to reduce loading to the Charles River by 604 lb/yr[12].

The City of Cambridge developed minimum control measures (MCMs) to comply with the permit in its required Stormwater Management Plan (SWMP) established in 2006. The developed MCMs are evaluated each year by the City with progress reported in an annual report to the EPA and Massachusetts Department of Environmental Protection (MassDEP). Each summary of MCMs has six required sections including public education and outreach, illicit discharge detection and elimination, and construction site runoff control. For instance, Cambridge's 2016 MS4 Permit Annual Report specifies updates in stormwater drainage systems, outfalls, and receiving waters in Geographic Information Systems (GIS) which could help identify where phosphorus-heavy discharges are occurring[13]. Cambridge is also responsible for developing a Phosphorous Control Plan (PCP) as a part of its SWMP to demonstrate that the City intends to comply with the MS4 permit. The PCP has four phases that span roughly 20 years from the permit effective date. Each of these phases has several requirements for the municipalities to complete in order to demonstrate their phosphorus removal efforts[14].

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[11] USEPA. (2017). *Massachusetts Small MS4 General Permit History*. Retrieved from https://www.epa.gov/npdes-permits/massachusetts-small-ms4-general-permit.
[12] (USEPA, 2017, Appendix F)
[13] City of Cambridge, MA. (2006). *NPDES Phase II Final Rule Notice of Intent and Stormwater Management Plan*. 11 December 2017. Retrieved from http://www2.cambridgema.gov/TheWorks/stormwater/pdffiles/SECONDDraftCambridgeStormwaterManagementPlanandNOI_April%202006.pdf.
[14] (USEPA, 2017, Appendix F)

Additionally, Cambridge's stormwater regulations are primarily in the form of municipality ordinances for the Cambridge Sewer Use Regulations. The regulations focus on addressing stormwater in construction development and redevelopment projects that disturb at least one acre of land. Cambridge requires its own Stormwater and Wastewater Infrastructure Permits (SWIP) for various inputs such as construction site dewatering, demolitions, and fats, oils, and grease. The various tiers of stormwater regulations, local, state, and federal, have assured that cities like Cambridge have careful oversight in developments for phosphorus loading[15]. Cumulatively, the SWMP, PCP, and other local regulations detail measures that account for MS4 phosphorus reduction credits for a municipality.

2.2: BMP Accounting and Tracking Tool (BATT) Functions

2.2.1: Introduction to BATT

The Environmental Protection Agency (EPA) issued the BATT to help municipalities calculate reductions of phosphorus, nitrogen, and sediments by BMPs that have been implemented in new developments or retrofits. Municipalities can use BATT to guide adherence to the TMDL and nutrient reduction requirements outlined in the MS4 permit. The software was created by Tetra Tech and is a spreadsheet-based tool that runs on Microsoft Excel. To effectively use BATT, the EPA recommends that Microsoft Excel and Word 2013 are used, along with the Microsoft Word 15.0 Object Library[16,17].

There are three main functions available in BATT:

1. Accounting and Tracking of BMP Implementation;
2. Accounting and Tracking Changes in Land Use;
3. Reporting for nutrient load reduction

The Accounting and Tracking of BMP Implementation function is used to evaluate nutrient load reductions when considering current nutrient control methods. Both structural and non-structural BMPs are an option within this function. The Accounting and Tracking Changes in Land Use function helps users account for nutrient loading changes that may occur in bodies of water as a result of a change in land use group or distribution of impervious versus pervious area. The Reporting portion of BATT generates reports summarizing the data that has been input into the program. For each function of BATT, results are categorized into the three different

[15] City of Cambridge Public Works (2008). *Wastewater and Stormwater Drainage Use Regulations*. 11 December 2017. Retrieved from https://www.cambridgema.gov/~/media/Files/publicworksdepartment/Engineering/Regulations/WastewaterStormwaterUseRegulations.pdf?la=en

[16] Tetra Tech. (2016). *BMP Accounting and Tracking Tool (BATT): User's Guide*. Retrieved from: https://www3.epa.gov/region1/npdes/stormwater/ma/batt-users-guide.pdf

[17] Tetra Tech. (2016). *BMP Accounting & Tracking Tool (BATT).* [Excel].

types of BMPs: structural, non-structural, and land use changes. Results are also provided in a percentage reduction and mass flow rate reduction[18].

There is a "References" section in BATT that provides an overview of how the stormwater control design storage volume (DSV) of several BMPs is determined. The calculations for DSVs are different for each BMP and provide a theoretical size of the void space available for different BMPs. If the void space is increased, then there is a greater volume of stormwater that can be treated, making phosphorus removal more effective. The void spaces are also used to capture and store runoff before it can be treated. Another important portion of the "References" section is the descriptions of the BMPs in BATT. This informs the user how to categorize the BMPs when inputting them to BATT[19].

One of the first steps to entering a project to BATT for structural and non-structural BMPs is to insert the land use information. This includes inputting the land use groups and acreage of pervious and impervious area of the subcatchment that the user is analyzing. An example is shown below in Figure 1.

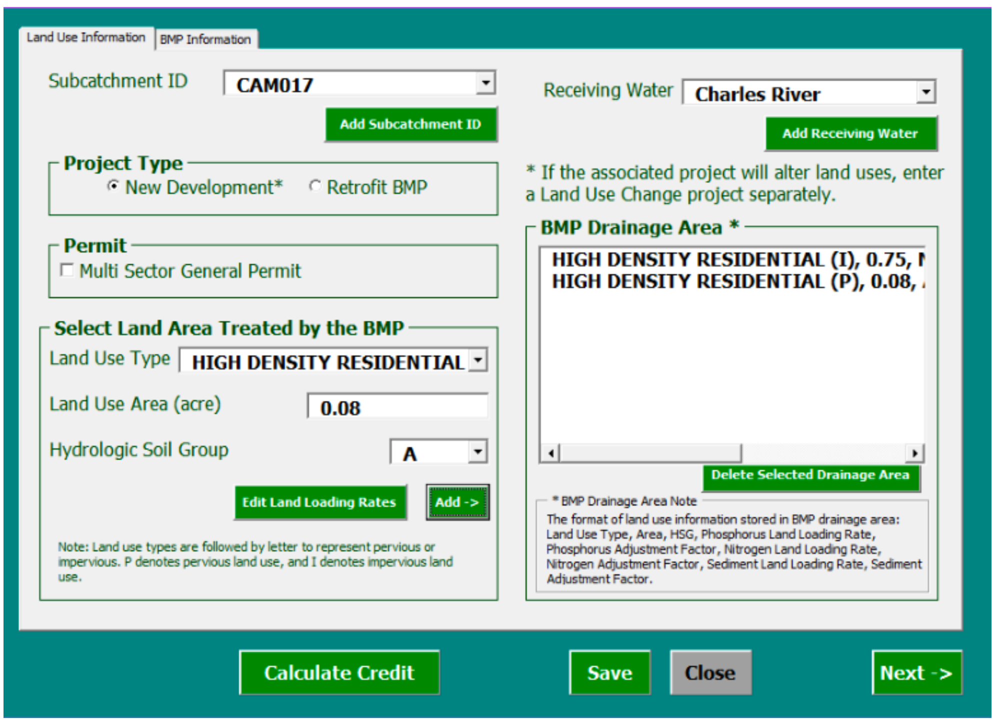

Figure 1: BATT Land Use Inputs for Structural BMPs Tab

After entering the land use information, the user must specify which BMP he or she has designed, along with the BMP specifications. These specifications are the BMP storage volume and, if applicable, the infiltration rate. Once BATT has received this information, the user can

[18] (Tetra Tech, 2016, User's Guide)
[19] (Tetra Tech, 2016, Excel)

select "calculate credit" to get a nutrient reduction in lb/yr. Figure 2 provides a visual of this BATT section.

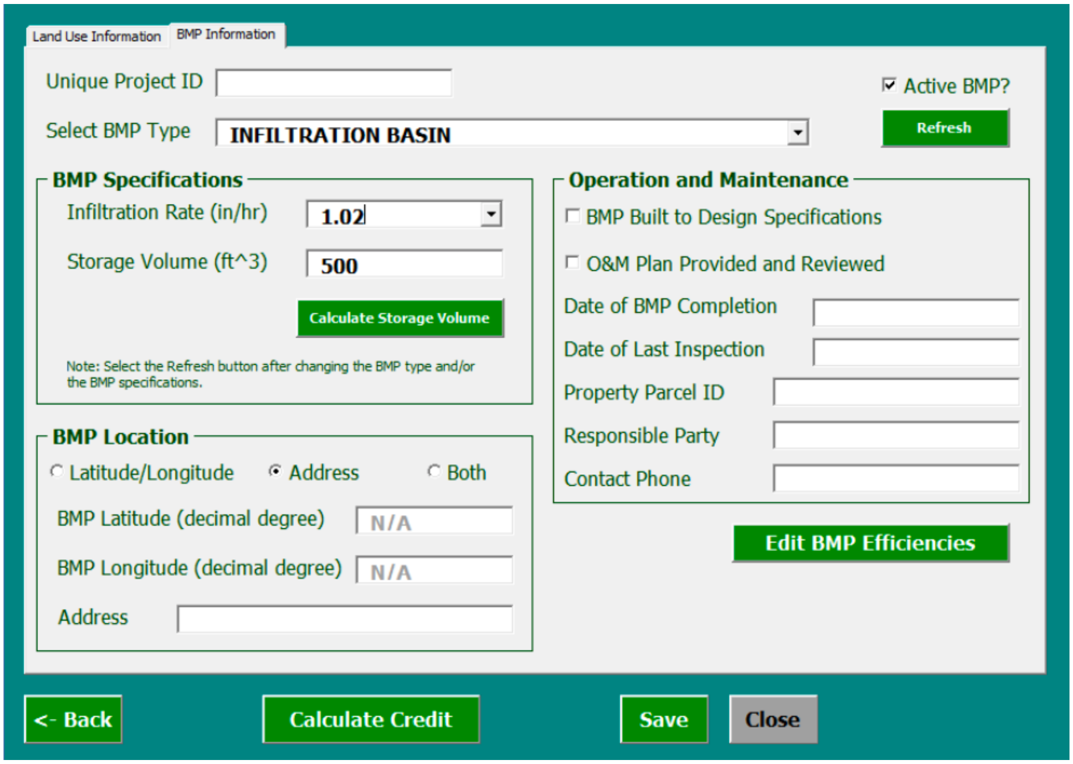

Figure 2: BMP Information Inputs for Structural BMPs Tab

2.2.2: Creation of BATT

BATT was created as a crediting tool so that the MS4 permit could be better utilized by communities, particularly for smaller municipalities that may not be able to easily access modeling software. It is based upon the Total Maximum Daily Load (TMDL) for Massachusetts to account for each municipality's particular credit requirements. The major modeling platform that goes along with the MS4 permit is the Opti-Tool. This software was also developed by Tetra Tech as part of a contract with the EPA, and is the separate design element related to BATT. The Opti-Tool provides a Storm Water Management Model (SWMM) model where a municipality can plan at a community basis and obtain design insights, while BATT provides the credits for such planning on a simpler platform[20].

Many datasets came together to model qualitative nutrient data that became the underlying mechanisms in BATT. The most important concepts in BATT that drive the model are nutrient load export rates and nutrient removal efficiency curves. Understanding this data as it relates to phosphorus gives great insight into how BATT operates.

The phosphorus load export rate (PLER) is used to determine the baseline phosphorus load coming from various land types in an input area. This is the amount of phosphorus going

[20] S. Warner, Personal Interview, January, 19, 2018.

into the BMP which will then be decreased through unit processes of the BMP. Therefore, the PLER number is very important to determine how much phosphorus is entering the BMP. The values for PLER were determined through many different datasets. A literature review of various studies was conducted from past modeling studies as well as academic journals and government documents. These literature values were then weighed with other studies including United States Geological Survey (USGS) data, National Stormwater Quality Data (NSQD), and Hydrologic Response Unit (HRU) Modeling. The HRU Model was a 5-year study conducted by the EPA using both the SWMM and Program for Predicting Polluting Particle Passage Through Pits, Puddles, and Ponds (P8) modeling techniques. These two modeling approaches differ in the way they represent hydrology: SWMM considers hydrologic processes such as infiltration and evapotranspiration, while P8 modeling considers the National Resource Conservation Service (NRCS) Method of simulating runoff coming off of surfaces[21]. In creating the PLER numbers presented in BATT, the EPA used a plethora of resources, datasets, and modeling styles that gives the most realistic parameters.

The phosphorus removal efficiency curves are BMP specific and influence the effectiveness of the desired BMP on any project. Their main purpose is to affect sizing decisions by looking at the efficiency of treatments. These curves were created by Tetra Tech through their contract with the EPA. Data inherent in this process were SWMM modeling and BMP simulations. The intent for these performance curves was for urban site specific treatment of highly impervious area. Therefore, only impervious area was used to generate pollutant concentration times. The SWMM model used Boston precipitation data to create curves based on 1-acre project areas. To further calibrate the curves for New England-specific conditions during the simulation phase, UNHSC data was used. Data was taken from the center between 2004 and 2014 for bioretention, grass swale, gravel wetland, infiltration system, porous pavement, and wet pond[22]. Tetra Tech decided that six to eight calibration attempts were needed to create the final performance curve[23].

2.3: BMP Removal Efficiency from Monitoring Data

When evaluating data generated by a model, it is important to note instances of research monitoring data that may explain the assumptions of both datasets. For stormwater quality research, complexities in BMP removal efficiencies add to the nuances needed for accurate model portrayals. The UNHSC and Charles River Watershed Association (CRWA) are both conducting BMP field research to find BMP nutrient removal efficiencies. Data obtained from their research may be used to calibrate and validate models, such as BATT, and elevate understanding of unit-processes in this developing field (UNH interview). Therefore, it is vital to understand these monitoring sets in order to grasp how closely models, such as BATT, accurately reflect real-world scenarios.

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[21] USEPA. (2017). "Response to Comments". *Massachusetts MS4 General Permit*. Boston, MA.
[22] Tetra Tech. (2010). *Stormwater Best Management Practices (BMP) Performance Analysis*. [PDF]. Retrieved from: https://www3.epa.gov/region1/npdes/stormwater/assets/pdfs/BMP-Performance-Analysis-Report.pdf
[23] Tetra Tech. (2015). *Technical Memos*. Obtained from Personal Communication with UNHSC.

2.3.1: Charles River Watershed Association (CRWA) Monitoring Program

The Charles River Watershed Association (CRWA) was formed in 1965 in response to the declining condition of the Charles River. Since then, it has worked closely with various citizen groups and government officials in efforts to cleanup and protect the Charles River[24]. The CRWA has implemented several BMPs into communities to treat stormwater that would otherwise carry pollutants to the local watershed. In order to measure the effectiveness of these BMPs, the stormwater is monitored before and after it is treated for parameters such as phosphorus content.

One of the BMPs installed by the CRWA, jointly with the Chelsea Creek Blue Cities Group, was a bioretention system in Chelsea, MA. It should be noted that this BMP was installed outside the Charles River Watershed. The system was composed of three bio-filters that were implemented to handle runoff from the Chelsea Housing Authority's Mace Apartment Complex[25]. This prevented runoff from flowing into the Chelsea Creek. To determine the effectiveness of the bioretention system in reducing pollutants, post-construction monitoring was conducted to detect mean concentrations of pollutants by fixing weirs to outflow pipes and using instruments such as the ISCO 6712 and YSI 600R, two data-logging, multiparameter meters, for automated readings[26,27]. Sampling was conducted primarily during wet weather conditions of greater than 0.2 inches of rain and when the influence of tidewater was not present[28].

From October 2014 to September 2015, the CRWA monitored stormwater from the biofilters on sixteen occasions and was able to capture three pre-construction and seven post-construction storm events. The biofilter achieved a Total Suspended Solids (TSS) removal of approximately 66%, but the phosphorus levels increased by approximately 31% with soil acting as a source of phosphorus, based on the CRWA report. Another possible reason for this high phosphorus level could be that plant decomposition added nutrients. Dissolved phosphorus in the stormwater was problematic as it does not settle out and is taken in by nuisance vegetation. Additionally, the phosphorus concentration in the beginning stages of construction of the soil medium was 20.6 mg/L with the standard amount needed in a soil medium being 10 to 14 mg/L[29,30]. The breakthrough of phosphorus through the soil is a good example of an external factor that may hinder the effectiveness of BMPs.

Another BMP project that the CRWA directed was the installation of porous pavement in Boston's South End coordinated with the Blue Cities Initiative, Boston Groundwater Trust, and

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[24] CRWA. (2014). *Charles River History*. Retrieved from: https://www.crwa.org/charles-river-history

[25] CRWA. (2014). *Mace Apartments*. Retrieved from: https://www.crwa.org/blue-cities/demonstration-projects/mace-apartments

[26] Horsley Witten Group, Inc. (2011, June 24). *Stormwater System Retrofits Mace Public Housing Chelsea, Massachusetts*. [PDF]. Obtained from Charles River Watershed Association.

[27] CRWA. (2015) Blue Cities *Stormwater Improvements Project for Chelsea Creek Post-Construction Sampling Report*. [PDF]. Obtained from CRWA.

[28] (CRWA, 2015)

[29] CRWA. (2015). *CRWA Bioretention Physical-Chemical Template*. [Excel]. Obtained from Personal Communication with CRWA.

[30] (CRWA, 2015, Blue Cities Report)

several other organizations[31]. This pavement, constructed in 2014 to be 66 ft long by 10 ft wide, lies in Alley 543 between West Canton and Holyoke Street. The design contains quite an extensive depth of 3 to 5 ft composed primarily of coarse gravel. Monitoring of the infiltration of the BMP was conducted through installing a six-inch diameter well in the storage area to measure the buildup of water. Additionally, two groundwater elevation wells collected information on phosphorus loading during five storm events[32]. In the storm event of 2015, approximately 0.71 mg/L of phosphorus were removed whereas in 2016 the removal was said to be 0.173 mg/L[33,34]. Data was only publicly available for two storm events, so the team had to work with an average of these two different values. Because the porous pavement allowed all of the water to infiltrate in the ground instead of overflowing to the storm drain, the CRWA report stated that the BMP effectively removed 100% of the phosphorus[35]. Therefore, the CRWA's monitoring indicated that this BMP was more successful in phosphorus reduction.

2.3.2: University of New Hampshire Stormwater Center Monitoring Program

The UNHSC was developed in 2004. For its first ten years, the UNHSC was operated by volunteers and funded by the National Oceanic and Atmospheric Administration (NOAA). The UNHSC initially decided which BMPs to research by identifying the top nonproprietary systems, which were: permeable pavements, bioretention systems, sand filters, surface sand filters, swales, retention ponds, detention ponds and hydrodynamic separators[36]. The BMPs that the center chooses to study are still based on funding from outside organizations. The UNHSC continues to be funded today by the Cooperative Institute for Coastal and Estuarine Environmental Technology and the NOAA, along with funding from organizations such as the EPA, the New Hampshire Estuaries Project, and manufacturers interested in testing the efficiency of products[37].

Over time, the UNHSC has gone through several iterations of its BMPs. Members have striven, through changes in conditions and sizing, to develop BMPs that will result in the greatest nutrient reductions. An important breakthrough that the UNHSC had was discovering that soil used in bioretention systems should not contain compost. Soil mixes that contained compost leached phosphorus, making the bioretention systems into sources of pollution. Furthermore, the UNHSC discovered that using amendment from water treatment residuals results in a high level of phosphorus absorbance. Media amendments, particularly those from alum, have been identified as "acceptable organic soil amendments" by the UNHSC.

The UNHSC designs its BMPs to handle the first inch of a rainfall event. This comes from the concept of the "first flush" or that the first inch of rainfall will have the highest concentration of pollutants in its runoff. The UNHSC uses stormwater runoff from a parking lot

[31] CRWA. (2014). *Porous Alley*. Retrieved from: https://www.crwa.org/blue-cities/demonstration-projects/porous-alley
[32] City of Boston, CRWA, The Boston Groundwater Trust, & VHB. (2016). *Boston's Porous Alley Demonstration Project: Summary Report*. [PDF].
[33] CRWA. (2014). *Porous Alley Monitoring Data*. Retrieved from: https://www.crwa.org/blue-cities/demonstration-projects/porous-alley/data
[34] CRWA. (2015). *Sampling Results Table*. [Excel]. Obtained from Personal Communication with CRWA.
[35] (City of Boston, CRWA, BGT, & VHB, 2016)
[36] J. Houle, Personal Interview, February 9, 2018.
[37] The University of New Hampshire. (2011). *About Us*. Retrieved from https://www.unh.edu/unhsc/about

on the UNHSC campus to test the efficiency of its BMPs. The stormwater flows from the parking lot to a collection box, which equally distributes the stormwater to the various BMPs at the Center. Both the flow and the pollutant composition of the stormwater are then assumed to be equal entering each BMP. The BMP effluents are captured in underdrains, and sent to an EPA accredited lab to test pollutant concentrations. In doing so, the UNHSC can test the efficiency of pollutant removal from its BMPs.

When analyzing UNH Data, it is important to note two attributes of their methodology for monitoring BMPs. To begin, the water quality is not monitored before entering the BMPs. It is evenly distributed in the collection box but an assumption is made about how much phosphorus is entering the BMP. This assumption is based on the land use group and the inch of rainfall. From monitoring the quality of water that exits the BMP, phosphorus removals are back calculated from this assumed loading. Another important attribute is that the stormwater does not undergo any pretreatment before it is distributed to the BMPs[38]. Some solids may settle in the box and not be distributed to the BMPs, but that is the only form of "pretreatment."

Many researchers and organizations highly respect the testing and sampling efforts of the UNHSC. In fact, the EPA utilized UNHSC data to calibrate BATT[39]. This calibration is outlined in Section 2.2.2 of the Background.

[38] (Houle, 2018)
[39] (Warner, 2018)

3.0: Methods

The purpose of this project was to work with Stantec to help Cambridge effectively use Best Management Practices (BMPs) Accounting and Tracking Tool (BATT) to analyze site design improvements that will reduce phosphorus loading to the Charles River. In order to meet this goal, the team outlined a proposed plan for the project.

The project methodology began with developing an understanding of BATT, where the team clarified initial issues with the software to develop a user guide and compared BATT calculations to Appendix F requirements. The team then analyzed data with BATT by comparing its outputs to actual data collected from the Charles River Watershed Association (CRWA) and University of New Hampshire Stormwater Center (UNHSC), as well as performing a sensitivity analysis. Lastly, Cambridge projects were evaluated for alternative designs using BATT. The team accomplished these tasks through the following objectives:

1. Assessed the Foundation and Usability of BATT
2. Evaluated BATT Performance Efficiencies
3. Analyzed Cambridge Stormwater Projects for Redesign Recommendations

This chapter describes the approach to the research, analysis of methods, and implementation steps of each objective. These objectives were intended to be applied to not only Stantec's work with Cambridge, but also any future projects requiring phosphorus treatment or stormwater management.

3.1: Assessed Foundation and Usability of BATT

3.1.1: Compared Calculations between those in BATT & Appendix F of MS4 Permit

To better analyze the formulas and concepts found in BATT, the team tried to confirm that the calculations presented in Appendix F of the Municipal Separate Storm Sewer System (MS4) Permit were identical to those used in BATT. In doing so, the team analyzed the phosphorus equations for land use change, non-structural BMPs, and structural BMPs present in both document and program. The formulas in the permit were entered into spreadsheets, and then tested against the same parameters in BATT for accuracy of results. This showed the team any inconsistencies within the permit and BATT that needed to be explored, since both calculations should be yielding similar phosphorus credits. To further gain insight into the relationship of Appendix F and BATT, the team also interviewed Suzanne Warner, an EPA official specializing in stormwater and construction National Pollutant Discharge Elimination System (NPDES) permitting. In doing so, the team hoped to gain more intimate knowledge regarding the correlation of the MS4 Permit with BATT and the logic behind calculations in BATT. The interview questions and transcript may be found in Appendix B. The team notes that all statements from Suzanne Warner were her own and not reflective of EPA views.

3.1.1.1: Calculating Phosphorus Load Increases Due to Development

Attachment 1 of Appendix F in the MS4 Permit details the necessary calculations for phosphorus load increases due to land use change. There were several steps involved in calculating phosphorus load increases due to development (P_{DEVinc}). The first step to calculating P_{DEVinc} was to obtain the baseline load from pre-development, as seen in Equation 1. This was calculated using Table 1 shown below for phosphorus load export rates (PLER) and the areas of land in question. When reading Table 1, entries that refer to 'See DevPerv' are for Developed Pervious areas that are broken up by Hydrologic Soil Group (HSG) at the bottom of the table.

Equation 1: Baseline Phosphorus Load Calculation

$$P_{Baseline} = \sum (A\ x\ PLER)$$

Where:

$P_{Baaseline}$ = Baseline Phosphorus Load

A = Predevelopment Area based on land use group

$PLER$ = Pre-development PLER based on land use group

Table 1: Proposed Average Annual Distinct Phosphorus Load Export Rates (PLER)[40]

Phosphorus Source Category Land Use	Land Surface Cover	P Load Export Rate (lb/acre/yr)	P Load Export Rate (kg/ha/yr)
Commercial (Com) and Industrial (Ind)	Directly Connected Impervious	1.78	2.0
	Pervious	See DevPerv	See DevPerv
Multi-Family Residential (MFR) and High-Density Residential (HDR)	Directly Connected Impervious	2.32	2.6
	Pervious	See DevPerv	See DevPerv
Medium-Density Residential (MDR)	Directly Connected Impervious	1.96	2.2
	Pervious	See DevPerv	See DevPerv
Low-Density Residential (LDR)	Directly Connected Impervious	1.52	1.7
	Pervious	See DevPerv	See DevPerv
Highway (HWY)	Directly Connected Impervious	1.34	1.5
	Pervious	See DevPerv	See DevPerv
Forest (FOR)	Directly Connected Impervious	1.52	1.7
	Pervious	0.13	0.13
Open Land (Open)	Directly Connected Impervious	1.52	1.7
	Pervious	See DevPerv	See DevPerv
Agriculture (AG)	Directly Connected Impervious	1.52	1.7
	Pervious	0.5	0.5
Developed Land Pervious (DevPERV) – HSG A	Pervious	0.03	0.03
Developed Land Pervious (DevPERV) – HSG B	Pervious	0.12	0.13
Developed Land Pervious (DevPERV) – HSG C	Pervious	0.21	0.24
Developed Land Pervious (DevPERV) – HSG C/D	Pervious	0.29	0.33
Developed Land Pervious (DevPERV) – HSG D	Pervious	0.37	0.41
Note: If HSG is unknown, use HSG C			

[40] (USEPA, 2017, Attachment 1 of Appendix F, pg 5)

It was necessary to then determine how each sub-area within a larger development should be categorized in terms of land use and pervious or impervious soil. The phosphorus load due to development (PDEV) was then calculated for each sub-area as presented in Equation 2. The phosphorus load increase was then calculated by subtracting the baseline load from P_{DEV}[41]. For example, if there was a development broken up into several categories, such as industrial, highway, and commercial, P_{DEV} would be calculated by:

Equation 2: P_{DEV} Calculation

$$P_{DEV} = (TA_{indust} \times PLER_{indus}) + (TA_{high} \times PLER_{high}) + (TA_{com} \times PLER_{com})$$

Leaving P_{DEVinc} to be:

$$P_{DEVinc} = P_{DEV} - \text{Baseline Load}$$

Where:
TA_i = Total Area (acres) of particular land use group 'i'
$PLER_i$ = Phosphorus Load Export Rate (lb/acre/yr) of particular land use group 'i'

3.1.1.2: Non-structural Calculations

Attachment 2 of Appendix F details the necessary calculations for determining phosphorus reduction credits for non-structural BMPs. The non-structural BMPs include enhanced sweeping programs, catch basin cleanings, eliminating use of fertilizers that contain phosphorus, and organic waste and leaf litter collection programs. Each BMP has specific formulas and tables for calculating yearly phosphorus reduction credits.

3.1.1.2.1: Enhanced Sweeping Programs

Calculations in Appendix F for enhanced sweeping are based on the phosphorus export rate for impervious area, a table for a phosphorus reduction factor, and the calculated annual frequency. Equation 3 represents this calculation:

Equation 3: Credit Calculation for Enhanced Sweeper

$$Credit_{Sweeping} = IA_{Swept} \times PLER \times PRF_{Sweeping} \times AF$$

Where:
$Credit_{Sweeping}$ = Amount of phosphorus load removed by enhanced sweeping (lb/yr)
IA_{Swept} = Impervious Area swept (acres)
$PLER$ = PLER from Table 1 based on land use (lb/acre/yr)
$PRF_{Sweeping}$ = Phosphorus Reduction Factor (PRF) for sweeping based on sweeper type and frequency as seen in Table 2
AF = Annual frequency of sweeping or months per year streets are swept

[41] USEPA. (2017). "Attachment 1 to Appendix F: Method to Calculate Baseline Phosphorus Load (Baseline), Phosphorus Reduction Requirements and Phosphorus load increases due to development." *Massachusetts MS4 General Permit.* Boston, MA.

An example of an annual frequency would be for a nine-month program, where streets are not swept during the winter, the AF would be:

Equation 4: Example Annual Frequency Calculation

$$AF = \frac{9\ months}{12\ months} = 0.75$$

The PRF value can be found using Table 2 below[42]:

Table 2: Phosphorus Reduction Efficiency Factors for Sweeping Impervious Areas[43]

Frequency	**Sweeper Technology**	**PRF**
Twice per year (Spring and Fall)	Mechanical Broom	0.01
	Vacuum Assisted	0.02
	High-Efficiency Regenerative Air-Vacuum	0.02
Monthly	Mechanical Broom	0.03
	Vacuum Assisted	0.04
	High-Efficiency Regenerative Air-Vacuum	0.08
Weekly	Mechanical Broom	0.05
	Vacuum Assisted	0.08
	High-Efficiency Regenerative Air-Vacuum	0.10

3.1.1.2.2: Catch Basin Cleaning

The Appendix F calculation for catch basin cleaning is based on the phosphorus export rate for impervious area and a constant value for the phosphorus reduction factor. This non-structural BMP calculation assumes a semi-annual rate for cleaning during the year. For example, the formula for calculating phosphorus credits for catch basin cleaning is provided in Equation 5[44]:

[42] USEPA. (2017). "Attachment 2 to Appendix F: Phosphorus Reduction Credits for Selected Enhanced Non-Structural BMPs in the watershed." *Massachusetts MS4 General Permit*. Boston, MA.
[43] (USEPA, 2017, Attachment 2 of Appendix F, pg. 4)
[44] (USEPA, 2017, Attachment 2 to Appendix F)

Equation 5: Credit Calculation for Catch Basin Cleaning

$$Credit_{CB} = IA_{CB}\ x\ PLER_{IC\text{-}and\ use}\ x\ PRF_{CB}$$

Where:

CB = Amount of phosphorus load removed by cleaning the catch basin (lb/yr)
IA_{CB} = Impervious drainage area to catch basin (acres)
$PLER_{IC\text{-}and\ use}$ = Phosphorus load export rate for impervious cover and land use (lb/acre/yr), values obtained from Table 1
PRF_{CB} = Phosphorus reduction factor for catch basin cleaning, which equals 0.02 for a semi-annual cleaning

3.1.1.2.3: Eliminating Use of Fertilizers that Contain Phosphorus

The Appendix F calculation for Eliminating Use of Phosphorus-rich Fertilizers contains several previously calibrated constant values such as the weighted phosphorus load export rate (WPLER), phosphorus reduction credit, and fertilizer factor. The total acreage to which the fertilizer is applied and the lawn percent are the only varying inputs to this formula, shown in Equation 6.

Equation 6: Credit Calculation for Eliminating Use of Fertilizers that Contain Phosphorus

$$Credit_{Fertilizer} = WPLER\ x\ PRF_{Fertilizer}\ x \sum (Area_{LU} * Lawn\%_{LU} * FF)$$

Where:
$Credit_{Fertilizer}$ = Amount of phosphorus load removed from eliminating the use of fertilizers that contain phosphorus from a site (lb/yr)
$WPLER$ = Weighted Phosphorus Load Export Rate (lb/ac/yr) for the municipality based on distribution of HSG. Cambridge has a WPLER of 0.290 lb/ac/yr
$PRF_{Fertilizer}$ = Phosphorus reduction credit, given as 0.5
$Area_{LU}$ = Total area (acres) based on land use group
$Lawn\%_{LU}$ = Lawn percentage in decimal format
FF = Fertilizer Factor, given as 0.5

3.1.1.2.4: Organic Waste/Leaf Litter Collection

The final non-structural BMP in Attachment 2 was an organic waste and leaf litter collection program. The calculation, as represented in Equation 7, was based on the PLER for impervious area and a constant phosphorus reduction factor[45].

Equation 7: Credit Calculation for Organic Waste and Leaf Litter Collection

$$Credit_{Leaf\ Litter} = IA * PLER * PRF$$

[45] (USEPA, 2017, Attachment 2 of Appendix F)

Where:
Credit = Amount of phosphorus load removed from administering an organic waste and leaf litter collection program
IA = Impervious area (acre) in watershed addressed by program
PLER = Phosphorus load export rate based on land use group as seen in Table 1
PRF = Phosphorus reduction factor, given as 0.05

3.1.1.3: Structural BMP Calculations

There are eight structural BMP categories listed in Attachment 3 of Appendix F: infiltration trench, surface infiltration or infiltration basin, biofiltration, gravel wetland, porous pavement, extended dry detention pond, wet detention pond, and water quality swale. Phosphorus credits for the structural BMPs are based on structural performance curves and design storage capacity (DSV) of the BMPs.

Appendix F in the MS4 Permit provides some general steps to solve for the phosphorus credit when the BMP, design storage volume, and land characteristics are known. The flowchart below in Figure 3 demonstrates the overall steps needed for this process when the land includes both impervious and pervious area:

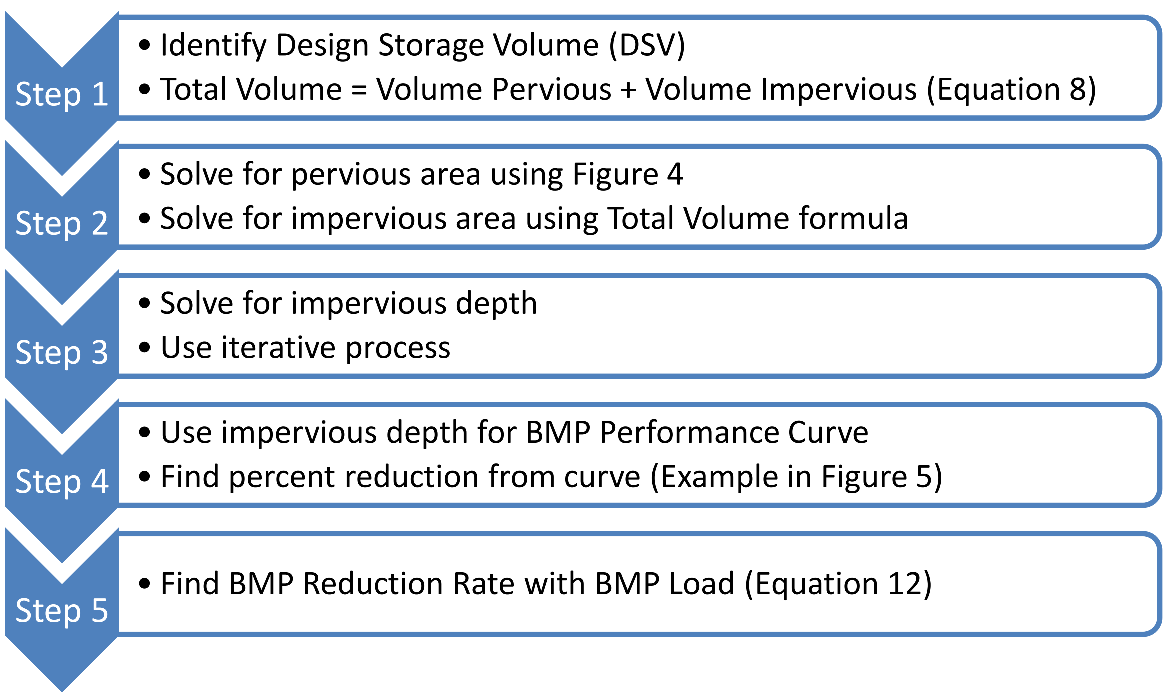

Figure 3: Flow Chart for Calculation of Structural BMP Phosphorus Credit

First, one must identify the drainage area of the BMP. Then, the land use type and soil groups can be identified for that area. Next, the storage volume should be determined for the

BMP based on the design specifications. This volume can also be broken down into two types of land use runoff as shown in the following equation:

Equation 8: Storage Volume Calculation

$$Storage\ Volume\ of\ BMP = BMP\ Volume\ from\ Impervious\ Area + BMP\ Volume\ from\ Pervious\ Area$$

The BMP volume from pervious area can then be solved for in the following equation:

Equation 9: BMP Volume for Pervious Area

$$BMP\ Volume\ from\ Pervious\ Area\ (ft^3) = \sum_{n=1}^{n} PA_n D_n\ x\ (3{,}630\ \frac{ft^3}{acre - in})$$

Where:
PA_n = Pervious Area (acre)
D_n = Runoff Depth for each Pervious Area (in)

Runoff depth information can be found in Table 3-3 from Attachment 3, Appendix F of the MS4 permit. Figure 4 below presents a copy of Table 3-3:

Rainfall Depth, inches	Runoff Depth, inches				
	Pervious HSG A	Pervious HSG B	Pervious HSG C	Pervious HSG C/D	Pervious HSG D
0.10	0.00	0.00	0.00	0.00	0.00
0.20	0.00	0.00	0.01	0.02	0.02
0.40	0.00	0.00	0.03	0.05	0.06
0.50	0.00	0.01	0.05	0.07	0.09
0.60	0.01	0.02	0.06	0.09	0.11
0.80	0.02	0.03	0.09	0.13	0.16
1.00	0.03	0.04	0.12	0.17	0.21
1.20	0.04	0.05	0.14	0.27	0.39
1.50	0.08	0.11	0.39	0.55	0.72
2.00	0.14	0.22	0.69	0.89	1.08
Note: Runoff depths derived from combination of volumetric runoff coefficients from Table 5 of *Small Strom Hydrology and Why it is Important for the Design of Stormwater Control Practices*, (Pitt, 1999), and using the Stormwater Management Model (SWMM) in continuous mode for hourly precipitation data for Boston, MA. 1998-2002					

Figure 4: Developed Land Pervious Area Runoff Depths[46]

Since rainfall depth is not known, iterations must be performed for the next set of calculations, BMP volume from impervious area (IA). The BMP volume for impervious area can be determined through the use of Equations 8 and 9. This then must be converted to Impervious Area Depth as shown in Equation 10, used in the iterative process.

[46] (USEPA, 2017, Attachment 3 of Appendix F, pg 20)

Equation 10: BMP Impervious Area Depth using BMP Impervious Area Volume

$$Impervious\ Area\ Depth\ (in) = \frac{BMP\ Volume\ for\ IA\ (ft^3)}{IA\ (acre)}\ x\ \frac{12\,\frac{in}{ft}}{43{,}560\,\frac{ft^2}{acre}}$$

Equation 11 displays the formula for when Storage Volume is converted to Impervious Area Depth. The value from Equation 11 is always compared to the iterations from Equation 10 until the values are within 5% of each other. Only then can the Impervious Area Depth be deemed acceptable:

Equation 11: BMP Impervious Area Depth using BMP Storage Volume

$$Impervious\ Area\ Depth\ (in) = \frac{BMP\ Storage\ Volume\ (ft^3)}{IA\ (acre)}\ x\ \frac{12\,\frac{in}{ft}}{43{,}560\,\frac{ft^2}{acre}}$$

Once the iterations are in an acceptable error range, the percent phosphorus load reduction can be evaluated using the performance curve for the BMP, as shown in Figure 5. The final iteration within the correct error range for Impervious Area Depth should be used when consulting the curve.

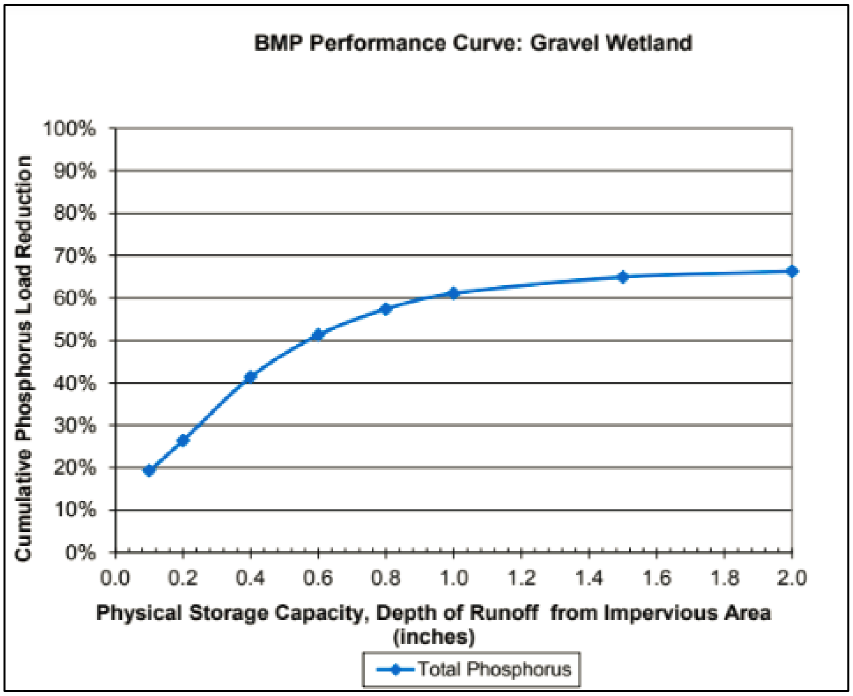

Figure 5: BMP Performance Curve Example for Gravel Wetland[47]

When the phosphorus load reduction percent from the curve is taken, the final formula can be used to get the reduction of phosphorus in pounds per year. The BMP Load is also needed using Equation 1 and Table 1 of this report. The formula for the final reduction is below:

Equation 12: BMP lb/yr Reduction

$$BMP\ Reduction\ (lb\ P/yr) = \ BMP\ Load\ x\ (BMP\ Reduction\ \%P/\ 100)$$

If the design area in question is completely impervious, the calculation becomes much simpler. The pervious calculations and iterations drop out, so the total storage volume is represented by the impervious runoff volume. The impervious runoff depth can then be calculated, and the rest of the process is the same to find the final phosphorus reduction[48].

3.1.1.4: Semi-Structural BMP Calculations

Also outlined in Attachment 3 of Appendix F are four semi-structural BMPs. These include disconnection of impervious area with and without storage, conversion of impervious area to permeable pervious area, and soil amendments to increase permeability of pervious areas. Similar to the other BMPs mentioned these also have specific formulas and tables to determine the phosphorus reduction.

[47] (USEPA, 2017, Attachment 3 of Appendix F, pg 47)

[48] USEPA. (2017). “Attachment 3 to Appendix F: Methods to calculate phosphorus load reductions for structural stormwater best management practices in the watershed.” *Massachusetts MS4 General Permit*. Boston, MA.

3.1.1.4.1: Impervious Area Disconnection through Storage

Impervious area disconnection through storage is a semi-structural BMP that takes rooftop stormwater into a storage container such as a cistern or rain barrel. It then releases this water over a permeable area after a certain retention time. Figure 6 below represents the steps for this calculation[49].

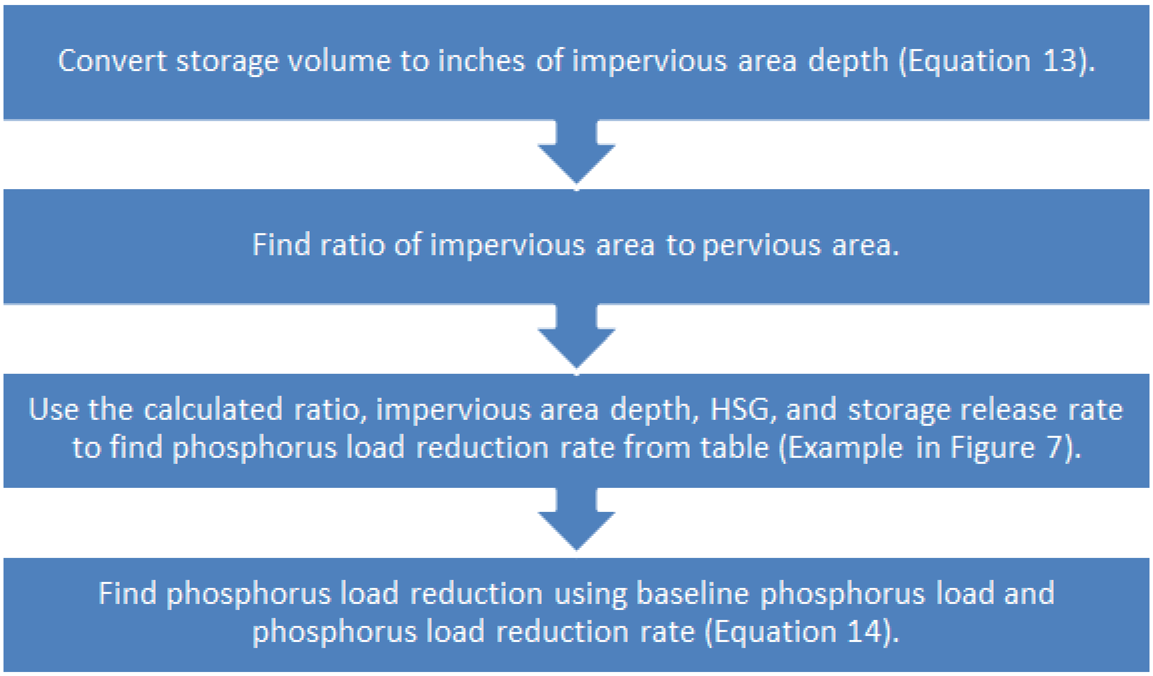

Figure 6: Flow Chart for Impervious Area Disconnection through Storage Calculation

From Figure 6 above, the first step for this calculation is converting storage volume to inches of impervious area depth. This may be calculated using Equation 13 below.

Equation 13: Calculation for Impervious Area Depth based on Storage Volume

$$IA\ Depth = \frac{Storage\ Volume}{IA}\ x\ (\frac{12\ in/ft}{43560\ ft^2/acre})$$

Where:

IA Depth = Impervious Area Runoff Depth (in.)

Storage Volume = Volume BMP can hold (ft^3)

IA = Impervious Area (acre)

Another value needed is the ratio of impervious area to pervious area. Once this value is obtained along with the impervious area depth calculated previously, the total runoff volume and

[49] (USEPA, 2017, Attachment 3 of Appendix F)

phosphorus load reduction percentages can be obtained from a table. An example table is shown as Figure 7. The HSG of the pervious land and release rate for the system must also be known.

Impervious Area Disconnection through Storage: Impervious Area to Pervious Area Ratio = 6:1												
Rain barrel volume to impervious area ratio	Total Runoff Volume and Phosphorus Load (TP) Reduction Percentages											
	HSG A			HSG B			HSG C			HSG D		
	1-day	2-day	3-day	1-day	2-day	3-day	1-day	2-day	3-day	1-day	2-day	3-day
0.1 in	24%	23%	22%	24%	23%	22%	24%	23%	22%	23%	23%	22%
0.2 in	40%	38%	37%	40%	38%	37%	40%	38%	37%	28%	30%	33%
0.3 in	52%	50%	49%	52%	50%	49%	47%	50%	49%	29%	31%	34%
0.4 in	61%	59%	58%	61%	59%	58%	48%	55%	58%	29%	31%	34%
0.5 in	67%	66%	64%	67%	66%	64%	48%	57%	63%	29%	31%	34%
0.6 in	73%	71%	70%	70%	71%	70%	48%	57%	65%	29%	31%	34%
0.8 in	78%	78%	77%	71%	78%	77%	48%	57%	66%	29%	31%	34%
1.0 in	79%	81%	80%	71%	79%	80%	48%	57%	66%	29%	31%	34%
1.5 in	79%	87%	88%	71%	80%	87%	48%	57%	66%	29%	31%	34%
2.0 in	79%	87%	91%	71%	80%	87%	48%	57%	66%	29%	31%	34%

Figure 7: IA Disconnection through Storage with Impervious to Pervious Ratio of 6:1[50]

Finally, the BMP Reduction can be calculated using Equation 14. This uses the percentage found from the table such as in Figure 7 and the BMP Load, calculated in the process described using Table 1 and Equation 1 of this report.

Equation 14: Calculation for Phosphorus Load Reduction

$$BMP\ Reduction\ (lb\ P/yr) = \ BMP\ Load\ x\ (BMP\ Reduction\ \%P/\ 100)$$

Where:
BMP Reduction = Phosphorus load reduction (lb P/yr)
BMP Load = Baseline phosphorus load using Table 1 values and site areas
BMP Reduction %P = Total runoff volume and phosphorus load reduction percentage from correct ratio table. An example table may be seen in Figure 7.

3.1.1.4.2: Impervious Area Disconnection

When storage is not designed, the calculations are slightly different from those of impervious area disconnect with storage. Only the impervious to pervious area ratio and soil group are needed from Table 3 and retention time is excluded.

[50] (USEPA, Attachment 3 of Appendix F, 2017, pg 53)

Table 3: Impervious Area Disconnection Performance Table[51]

IA:PA	HSG A (%)	HSG B (%)	HSG C (%)	HSG D (%)
8:1	30	14	7	3
6:1	37	18	11	5
4:1	48	27	17	9
2:1	64	45	33	21
1:1	74	59	49	36
1:2	82	67	60	49
1:4	85	72	67	57

Then the phosphorus reduction can be calculated using the phosphorus performance percentage and baseline phosphorus load, as seen in Equation 14. It is important to note that only pervious area should be used when calculating the baseline phosphorus load[52].

3.1.1.4.3: Soil Amendments

When soil amendments are used in a design, the HSG can be changed to represent a better quality soil. The example calculations given in Attachment 3 to Appendix F in the MS4 Permit make a C quality soil have the same infiltration qualities as a B quality soil. Within any pervious area, the final credit is calculated utilizing the superior soil group[53].

3.1.1.4.4: Impervious Area Changed Into Pervious Area

The final semi-structural BMP in Attachment 3 is impervious area changed into pervious area. This calculation follows a similar format as land use change in Section 3.1.1.1, with the addition of an impervious to pervious area conversion table. The steps for this calculation are laid out in Figure 8[54].

[51] (USEPA, Attachment 3 of Appendix F, 2017, pg. 63)
[52] (USEPA, 2017, Attachment 3 of Appendix F)
[53] (USEPA, 2017, Attachment 3 of Appendix F)
[54] (USEPA, 2017, Attachment 3 of Appendix F)

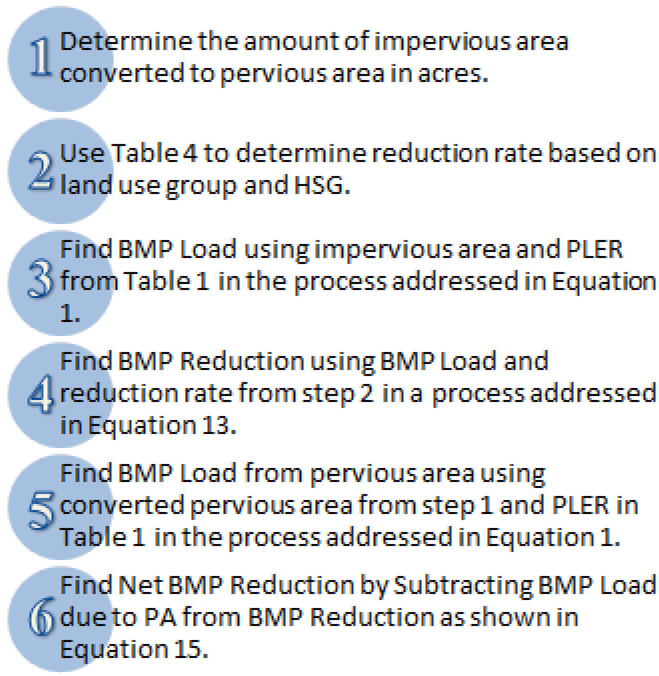

Figure 8: Flow Chart for Impervious Area Changed Into Pervious Area

The first step is determining the area that is being converted in acres. Then, Table 4 may be used to find the performance rate for that particular land use group and HSG.

Table 4: Performance Table for Conversion of Impervious Area to Pervious Area[55]

Land Use Group	IA to HSG A (%)	IA to HSG B (%)	IA to HSG C (%)	IA to HSG C/D (%)	IA to HSG D (%)
Commercial and Industrial	98.5	93.5	88	83.5	79.5
High-Density Residential	98.8	95	90.8	87.3	84.2
Medium-Density Residential	98.6	94.1	89.1	85	81.4
Low-Density Residential	98.2	92.4	85.9	80.6	75.9
Highway	98	91.3	84	78	72.7
Forest	98.2	92.4	85.9	80.6	75.9
Open Land	98.2	92.4	85.9	80.6	75.9
Agriculture	70.6	70.6	70.6	70.6	70.6

The BMP Load for the impervious area may be found using Equation 1 and Table 1 from this report. This BMP Load is used in conjunction with Equation 14 and the reduction factor from Table 4 to obtain the BMP Reduction. BMP Load for the pervious area must then be found by using Equation 1 and Table 1 from this report. Finally, Equation 15 may be used to find Net BMP Reduction.

[55] (USEPA, Attachment 3 of Appendix F, 2017, pg. 64)

Equation 15: Credit Calculation for Conversion of Impervious Area to Pervious Area

$$Net\ BMP\ Reduction = BMP\ Reduction - BMP\ Load_{PA}$$

Where:
Net BMP Reduction = Net reduction of phosphorus from converting impervious area to pervious area (lb/yr)
BMP Reduction = Cumulative phosphorus load reduction from impervious area used in the land conversion (lb/yr)
BMP $Load_{PA}$ = Phosphorus load reduction from the restoration of pervious area (lb/yr)

3.1.1.5: Data Analysis

Once the team had all of the equations aforementioned in spreadsheets, comparisons were made between BATT outputs and Appendix F outputs from spreadsheet analysis. The team first tested the spreadsheets created with examples provided in the MS4 Permit to ensure that the entered equations were correct. Then, the same parameters from the permit were used in BATT to compare the results of BATT to Appendix F. Examples of the spreadsheets used in these calculations for land use conversions, non-structural BMPs, structural BMPs, and semi-structural BMPs may be found in a separate file submitted with this report.

3.1.2: Developed User Guide

The team created a user guide based on its experience with BATT. The user guide has tips for those who have never used the software before. It is meant to complement the user guide that the EPA released for BATT, which is more tutorial based[56]. A major component of the team's user guide is to address how to run the software on computers that do not have the 2013 versions of Microsoft Excel or Word. The user guide also covers specific issues users may encounter while utilizing BATT, involving how to ensure it is properly calculating credits and understanding the values that BATT utilizes in its calculations. Additionally included in the user guide were instructions on how to "unhide" reference tables in BATT that contain performance curves and other useful information taken from the MS4 Permit Appendix F. This allowed the user a better grasp on not only the usability and set up of BATT but also the foundation behind BATT.

3.2: Evaluated BATT Performance Efficiencies

The team evaluated BATT performance efficiencies to determine how accurate the software is compared to BMPs that have been implemented and monitored in real projects. This included conducting a sensitivity analysis to analyze where BATT outputs change the most for each input. The team also used data from CRWA and UNHSC to validate BATT BMP performance curves.

[56] (Tetra Tech, 2016, User's Guide)

3.2.1: Sensitivity Analysis Methods

When developing the methodology for the sensitivity analysis, structural BMPs, non-structural BMPs, and land use change were tested separately. The strategy for approaching structural BMPs was first devised through maintaining controls for most BATT inputs while isolating a tested input. The team's objective was to observe the trend in phosphorus credits based on changes in each variable. Combinations for BMP conditions were exponential given eighteen options for land use group, nine options for BMP type, six options for infiltration rate, four hydrologic soil groups (HSG), and countless possibilities for BMP storage volume and acreage. Therefore, for these six different BATT inputs, the team decided to select a certain number of variables based on what was typically seen throughout Cambridge projects. The methodology for selection of variables is described in separate sections below, starting with structural BMPs, as the team devised an individual methodology and spreadsheet for each.

3.2.1.2: Land Use Group

The team tested all eighteen land use groups to perform the sensitivity analysis for this BATT input. In order to see the effect of impervious versus pervious surfaces on phosphorus loading, the team had two repetitions for each land use group. Within each, the first repetition involved one acre of impervious land and the second repetition was half an acre of impervious and half an acre of pervious land. To decide the control land use group, the team utilized the 2005 Massachusetts Geographic Information System (GIS) Land Use Map to determine which land use groups were the most common groups in the municipality of Cambridge, displayed in Figure 9. The map indicated the three primary land use groups in Cambridge were commercial, high density residential (HDR), and medium density residential (MDR). These three were then used for the sensitivity analysis of every other BMP input.

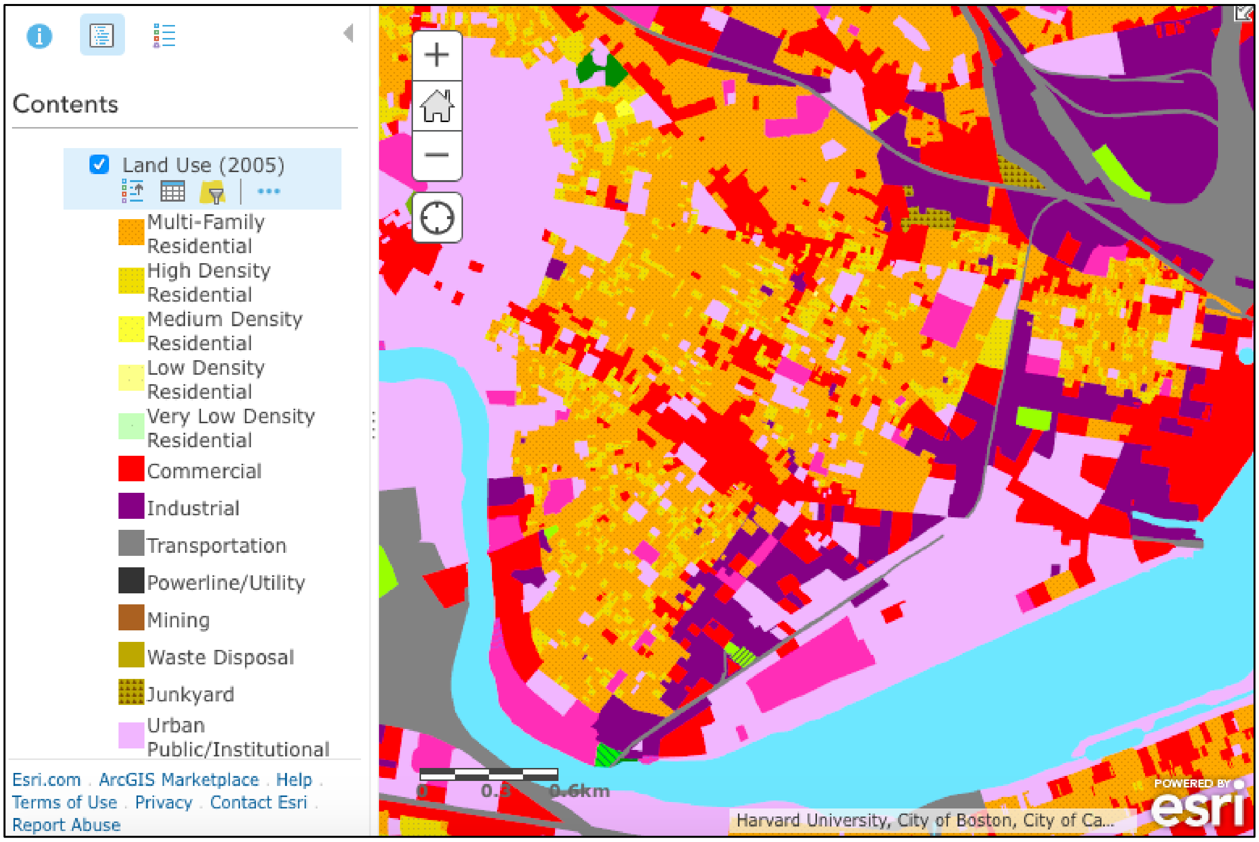

Figure 9: MassGIS Land Use Map 2005 of Cambridge[57]

3.2.1.3: Hydrologic Soil Group

The HSG section of the sensitivity analysis simply tests phosphorus credit trends for each of the soil groups: A, B, C, D, and C/D. For other sections of the sensitivity analysis, soil group C was chosen as a control. The team used USGS Soil Maps to determine the most common soil group in Cambridge. Below, Figure 10 provides a visual of the different soil groups in Cambridge. Based on Table 5, 'unknown' soil group comprised most of Cambridge at 47.5%[58]. Therefore, the team used HSG C, because it is the designated 'unknown' soil group based on the EPA Appendix F Response to Comments[59].

[57] QGIS Development Team. QGIS Geographic Information System. Open Source Geospatial Foundation Project. [Interactive map]. MassGIS Online Layer Land Use Group 2005.

[58] USGS. (n.d.). *Soil Survey Map HSG*. [Interactive Map]

[59] (USEPA, 2017, Response to Comments)

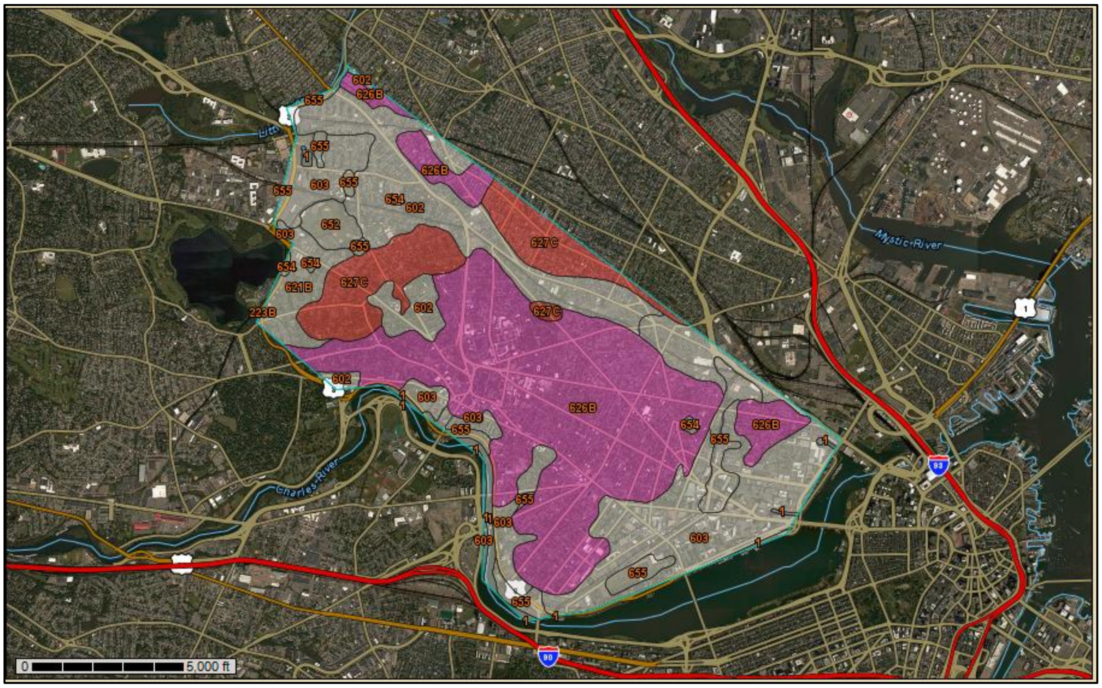

Figure 10: USGS Soil Survey Map of Cambridge[60]

Table 5: Distribution of Soil Groups Based on Figure 10[61]

Symbol	Unit Name	Assigned HSG	Acres	Percent
1	Water		63.6	1.6
223B	Scio very fine sandy loam, 3-8% slopes	B/D	0.7	0.0
602	Urban land		577.2	14.9
603	Urban land, wet substratum		878.6	22.7
621B	Scio-Urban land complex, 0-8% slopes		123.9	3.2
626B	Merrimac-Urban land complex, 3-15% slopes	A	1569.7	40.5
627C	Newport-Urban land complex, 3-15% slopes	D	397.5	10.3
652	Udorthents, refuse substratum		54.6	1.4
654	Udorthents, loamy		15.7	0.4
655	Udorthents, wet substratum		190.9	4.9

[60] (USGS, n.d.)
[61] (USGS, n.d.)

3.2.1.4: Acreage

The acreage section of the sensitivity analysis had the most repetitions to represent a low, medium, and high range of acreages including a varied impervious versus pervious land distribution within each. The low acreage value was 0.5 acres based on the smaller end of what was seen in Cambridge projects. One repetition was simply 0.5 acres of impervious land, while the other three followed a pattern: 50% pervious, 50% impervious; 25% pervious, 75% impervious; and 75% pervious, 25% impervious. This pattern was repeated for the medium, 1 acre, and high, 3 acre, ranges. Therefore, in this total of 12 repetitions, the effect of pervious and impervious land could be seen for greater or smaller acreages. The control acreage for other sensitivity sections, as mentioned above, is 1 acre of impervious and then a 50%:50% distribution of pervious and impervious.

3.2.1.5: BMP

The BMP sensitivity analysis section simply tested the nine different types of structural BMPs that are options in BATT. The team selected two different BMPs to be controls for the other sensitivity analyses. The infiltration trench and dry pond were chosen because they are different in the way they handle water and were commonly seen in the Cambridge projects.

3.2.1.6: Storage Volume

For the storage volume sensitivity analysis section, a range of nine different volumes in cubic feet were chosen for testing from 10 ft^3 to 5,000 ft^3. Both the low and high ranges of the chosen volumes were outside of what the team had seen in Cambridge projects but were useful in analyzing phosphorus credits from a theoretical standpoint. For the control storage volume for the other sensitivity analyses, 500 ft^3 was chosen as a medium level close to what was commonly seen in Cambridge projects.

3.2.1.7: Infiltration Rate

The infiltration rate sensitivity analysis section tested the six different infiltration rates provided in the BATT tool. The infiltration rate of 2.41 in/hr was chosen as the control rate for other sensitivity analysis based on what was commonly seen in the Cambridge projects. Instead of using dry pond as a control BMP for this section, the team used infiltration basin and trench as they are the only two BMPs with an infiltration rate.

3.2.1.8: Structural Sensitivity Data Analysis

When analyzing the outputs from each sensitivity analysis, many factors were considered. It was first important to organize each Excel sheet so that the team could test one parameter at a time. Therefore, the team set up each sheet changing one parameter, while keeping the others constant throughout all other tests. Table 6 below represents the variables chosen for each BATT input to use in sensitivity testing for the structural BMPs. The boxes highlighted in yellow show the variables that were held constant when testing other BATT inputs. The variables for each input section were chosen to represent a diverse range of projects while the variables held constant were typically seen in Cambridge.

Table 6: Structural BMP Sensitivity Analysis Parameters

Land Use Group	**Hydrologic Soil Group**	**Acreage**	**BMP Type**	**Storage Volume (ft^3)**	**Infiltration rate (in/hr)**
Commercial	A	0.5 (I)	Dry Pond	10	0.17
High Density Residential	B	0.25 (I) + 0.25 (P)	Infiltration Trench	25	0.27
Industrial	C	0.375 (I) + 0125 (P)	Bioretention	50	0.52
Medium Density Residential	C/D	0.125 (I) + 0.375 (P)	Enhanced Bioretention	100	1.02
Low Density Residential	D	1 (I)	Grass Swale	500	2.41
Open Land		0.5 (I) + 0.5 (P)	Gravel Wetland	750	8.27
Forest		0.75 (I) + 0.25 (P)	Infiltration Basin	1000	
Agriculture		0.25 (I) + 0.75 (P)	Porous Pavement	2500	
Highway		3 (I)	Wet Pond/ Created Wetland	5000	
		1.5 (I) + 1.5 (P)			
		2.25 (I) + 0.75 (P)			
		0.75 (I) + 2.25 (P)			

The team then wanted to test the sensitivity of each of these parameters to the reduction of phosphorus output through BATT. To do this analysis clearly, graphs showcasing the tested parameter on the x-axis and phosphorus reduction on the y-axis were created.

3.2.1.9: Non-Structural Sensitivity Analysis

A similar system for graphical analysis was used when analyzing the sensitivities for non-structural BMPs. Table 7 shows a table for non-structural BMPs in a similar set-up to Table 6 above.

Table 7: Non-structural BMP Sensitivity Analysis Parameters

Land Use Group	Acreage	BMP Type	Sweeper Technology	Sweeper Frequency	Release Rate (days)	Storage Volume (ft^3)	Receiving Pervious Area (ft^2)	HSG
Commercial	1(I)	Catch Basin Cleaning	Mechanical	Weekly	1	1000	11000	A
High Density Residential	0.5(I) + 0.5(P)	Enhanced Sweeping	Vacuum Assisted	Monthly	2	2500	22000	B
Industrial		Impervious Area (IA) Disconnection	High Efficiency Regenerative Air Vacuum	Twice per Year	3	5000	33000	C
Medium Density Residential		IA Disconnection with Storage				7500		D
Low Density Residential		No Application of Fertilizer with Phosphorus						
Open Land		Leaf Litter and Organic Waste Collection						
Forest, Agriculture, Highway								

The non-structural sensitivity analysis was devised under the same type of methodology as the structural BMP analysis. Constants were maintained for all of the BATT inputs when varying one parameter. In Table 7 above, all of the variables tested for each input are laid out under the column for that input. The variables highlighted in yellow were held constant while other inputs were tested. Enhanced sweeping and IA disconnection were chosen as the constant BMPs during other tests because they contained a variety of inputs. Sweeper technology and sweeper frequency were only tested under the enhanced sweeping BMP. The vacuum assisted sweeper technology and monthly frequency were considered median choices and chosen as a constant. The storage volume, receiving pervious area, pervious area HSG, and release rate are only tested under the impervious area disconnection without storage. The storage area of 5,000 sq. ft. and receiving pervious area of 22,000 sq. ft. were commonly seen in Cambridge projects and were held constant. A release rate of two days was chosen because it was the medium range number. HSG C was used, similar to the structural BMP section, as explained in Section 3.2.1.3.

To analyze the parameters for non-structural BMPs, the team employed a similar methodology for graph creation as in the structural BMP section. Each graph displayed one varying parameter at a time, similar to the sensitivity analysis itself, to convey the strongest correlations for that specific input. Therefore, the team visually represented results for this section.

3.2.1.10: Land Use Conversion Analysis

The team tested the sensitivity of the land use conversion in BATT to determine how significant the changes were in phosphorus loading when different land conditions were altered. These tests were done differently than the structural and non-structural tests, since the only parameters analyzed were land use type, HSG, and the composition of pervious versus impervious land for "before" and "after" the conversions. The team focused on testing the "after" conditions for this test because the "after" results would be the opposite in terms of negative or positive as the "before" results.

3.2.1.10.1: Acreage "After"

Acreage "After" refers to the amount of impervious and pervious land after the land use conversion is completed on a site. The team tested the sensitivity of changing the acreage composition for three types of land use: HDR, MDR, and commercial. Within each land use, different acreage sizes were tested. For example, the team started with an initial "before" acreage of one acre, and converted it to 0.5 acres of pervious and 0.5 acres of impervious land. The team continued this pattern, changing the percent composition of impervious versus pervious land for the "after" land use conversion, while keeping the land use group constant in the "before" and "after" categories.

3.2.1.10.2: Hydrologic Soil Group (HSG) "After"

HSG "after" refers to the HSG after the land use conversion. The team tested the sensitivity of changing the HSG "after" using HDR as a constant, since a large majority of Cambridge land is classified as HDR. The acreage composition before and after was kept constant at 0.5 acres for both impervious and pervious land. The team did multiple tests for each HSG. For example, the team tested the sensitivity of using HSG A as the acreage "before", and changing the acreage "after" to each HSG class.

3.2.1.10.3: Land Use Group "After"

Land use group "after" refers to the type of land use after construction. The team tested the effects of changing land use after construction for HDR, MDR, and commercial land types. The "after" land use groups were HDR, MDR, and commercial. This analysis was done with two trials - one trial was done by keeping the acreage "before" and "after" as one acre, while the other trial had a "before" acreage of 0.5 pervious, 0.5 impervious, and an "after" acreage of one acre of pervious land.

3.2.1.10.4: Constant Parameters & Analysis

There were several parameters that were held constant during the land use conversion sensitivity analysis. Table 8 demonstrates which parameters were held constant for the different sensitivity analysis trials performed. The parameters that are highlighted in yellow are those that were kept constant for each analysis.

Table 8: Land Use Conversion Sensitivity Analysis Parameters

Land Use Group Before	Impervious Area Before	Pervious Acreage Before	HSG Before	Land Use Group After	Impervious Acreage After	Pervious Acreage After	HSG After
HDR	1	0.5	A	HDR	0.5	0.5	A
MDR	0.5		B	MDR	1	1	B
Commercial	5		C	Commercial	0.25	0.25	C
	10		C/D		0.75	0.75	C/D
			D		2.5	2.5	D
					5	5	

To analyze the data collected in the sensitivity analysis for land use conversion, the team created graphs similar to those for the structural and non-structural BMP sensitivity analysis. Graphs were created for each specific test type, with the testing parameter on the x-axis and the phosphorus reduction on the y-axis, and can be found in Appendix C.

3.2.2: Validated Using CRWA and UNHSC Data

3.2.2.1: CRWA Validation

To gain a better understanding of the Charles River Watershed Association (CRWA) monitoring protocols, the team met with Elisabeth Cianciola, a member of the field science group at the CRWA. The list of questions and transcript for this interview can be found in Appendix D. Specifically, the team wanted to discern if the volunteers of the monitoring program collected samples directly from stormwater outfalls. This information would determine if the CRWA monitoring data could be used to adequately establish the influence of BMPs on phosphorus levels in the Charles River. However, Ms. Cianciola stated that, to assure the consistency and ease of sampling, monitoring was done in the center of bridges[62]. Therefore, this monitoring data contains background river concentrations rendering it unusable for this project. The 'Find it and Fix it' program through the CRWA was taken more directly from outfalls. However, because of mixing from the combined sewer system, the team decided not to use this data as well[63,64]. The team did not want to disregard any possible data that could be a real-world validation for BATT, and therefore it was important to discuss in this meeting the details and usability of these numbers.

The team also met with Ms. Cianciola to learn more about the CRWA BMP monitoring programs. Ms. Cianciola stated that the CRWA has not yet implemented BMPs in Cambridge, but that there are plans for several future green infrastructure projects in the City. However, there

[62] E. Cianciola, Personal Interview, January 26, 2018

[63] (Cianciola, 2018)

[64] CRWA. (2017). *CRWA Cambridge Results 1995-2017 WPI*. [Excel]. Obtained from Personal Communication with CRWA.

were two BMPs close to Cambridge that did participate in the monitoring program, one in Chelsea and one in Boston[65].

The Chelsea bioretention system and Boston porous pavement that were discussed in the meeting are described more specifically in the background section based on reports that Ms. Cianciola sent the team. In the meeting, the team gained further explanations on the sampling methods utilized for inflow and outflow to these BMPs. After gaining the understanding of the sampling methods and obtaining the reports for the BMPs, the team was able to enter the BMP and site characteristics into BATT for validation analysis[66].

3.2.2.2: UNHSC Validation

The team used University of New Hampshire Stormwater Center (UNHSC) data to validate BATT further as the center is a leader in northeastern stormwater research and its data was used to calibrate the BMP performance curves inherent in BATT[67]. To learn more about the UNHSC, the team also interviewed Dr. James Houle, Program Director for the center. The list of questions and transcript for this interview can be seen in Appendix E. Within this interview, the team gained information about which UNHSC data should be used for inputs into BATT and to compare with the UNHSC monitoring results. From Dr. Houle's recommendation, the team used the latest iterations of BMPs at the UNHSC from a paper outlining operations and maintenance procedures, "Comparison of Maintenance Cost, Labor Demand, and System Performance for LID and Conventional Stormwater Management"[68,69]. The team took data from bioretention units, gravel wetland, dry pond, wet pond, vegetated swale, and porous asphalt outlined in the paper. Table 9 below shows the data for these BMPs[70].

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[65] (Cianciola, 2018)

[66] (Cianciola, 2018)

[67] (Tetra Tech, 2010)

[68] Houle, J. J., Roseen, R. M., Ballestero, T. P., Puls, T. A., Sherrard Jr., J. (2013). "Comparison of Maintenance Cost, Labor Demands, and System Performance for LID and Conventional Stormwater Management." *ASCE Journal of Environmental Engineering*. 139: 932-938.

[69] (Houle, 2018)

[70] (Houle, et. al., 2013)

Table 9: UNHSC Values used for BATT Inputs[71]

Parameter	Vegetated Swale	Wet Pond	Dry Pond	Gravel Wetland	Bioretention 1	Bioretention 2	Porous asphalt
Filter length (m)	85.3	21.3	21.3	15.8	20.4	10.4	26.8
Width (m)	3.0	14.0	14.0	11.3	10.7	2.4	19.5
Area (m^2)	260	299	299	179	218	25	523
Depth (ft)	0.0	0.5	0.0	0.6	1.1	0.8	1.3
Ponding Depth (ft)	0.6	0.5	0.9	0.4	0.2	0.2	0.0
Catchment Area (ha)	0.4	0.4	0.4	0.4	0.4	0.4	0.05

Then, the data was entered into spreadsheets and manipulated into the BATT format. Since singular dimensions were given in various units, design storage volume needed to be calculated and units had to be converted so that the data could be comparable in BATT. All land types were assumed to be impervious commercial based on previous UNHSC reports[72,73,74]. Each drainage or subcatchment area for BATT was assumed to be the UNHSC parking lot area of 0.4 ha[75]. Porosity was taken as a mean from Table 10 below for the various soils[76]:

Table 10: Porosity Values[77]

Description	Minimum	Maximum	Average Used
Gravel	0.23	0.38	0.305
Well-graded sands, gravelly sands, with little or no fines	0.22	0.42	0.32
Fine Sand	0.29	0.46	0.375
Uniform inorganic silt	0.29	0.52	0.405
Inorganic clays of high plasticity	0.39	0.59	0.49

[71] (Houle et. al., 2013, pg 934)
[72] UNHSC. (2010). *University of New Hampshire Stormwater Center 2009 Biannual Report*. [PDF].
[73] UNHSC. (2012). *University of New Hampshire Stormwater Center 2012 Biennial Report*.
[74] UNHSC. (2016). *Break Through University of New Hampshire Stormwater Center 2016 Report*.
[75] (Houle, et. al., 2013)
[76] Geotechdata.info (2013). *Soil Porosity*. Retrieved from: http://www.geotechdata.info/parameter/soil-porosity.html
[77] (Geotechdata.info, 2013, pg. 1)

These porosities were used for gravel wetland and bioretention. Gravel was used for the gravel wetland whereas the bioretention units used a special soil blend characteristic to and developed by UNHSC. The mixture given in percentage by dry weight may be seen in Table 11 below[78]. The percentage by dry weights was used with the porosities from Table 10 above to find the soil porosity of the mixture, a needed parameter in BATT. Sand was assumed to be 70% of the amendment for calculation purposes.

Table 11: UNHSC Soil Amendment Composition by Dry Weight[79]

Soil Amendment Composition	Percentage by Dry Weight
Very Coarse Sand/Gravel	5%
Sand	60-85%
Silt	20%
Clay	5%

Assumptions were also made for the internal storage ratio (ISR) surface area parameter needed in BATT for the gravel wetland. A specific design report produced by UNHSC showed the water quality volume (WQV) to ISR ratio in their designs was 4 to 1[80,81]. Since the BMP had a WQV of 97.7 cubic meters, the team was able to calculate the ISR surface area using this WQV and the filter length from Table 9[82].

This analysis culminated in determining the BATT inputs. Table 12 provides an example of BATT inputs for the porous asphalt. The rest of the BMP inputs may be found in Appendix F. It should be noted that the team used Cambridge as the input city in BATT. However, this should have no impact on the calculations for structural BMPs. The team then compared the BATT output to the UNHSC outputs for each BMP and produced graphical representations for the results.

Table 12: UNHSC Porous Asphalt Inputs for BATT

Land Use Group	Subcatchment Area (acre)	BMP Type	Depth of filter (in.)
Commercial (I)	0.124	Porous Pavement	15.6

[78] UNHSC. (2017). UNHSC Bioretention Soil Specifications. [PDF].
[79] (UNHSC, 2017, Soil Specs, pg. 3)
[80] UNHSC. (2015). Design and Maintenance of Subsurface Gravel Wetlands. [PDF].
[81] UNHSC. (2016). UNHSC Subsurface Gravel Wetland Design Specifications. [PDF].
[82] (Houle, et. al., 2013)

3.3: Analyzed Cambridge Projects for Design Recommendations

3.3.1: Calculated Phosphorus Credit from Cambridge Projects using BATT

To determine the phosphorus credits that Cambridge has earned from past stormwater management projects, the team inputted parameters from Cambridge projects into BATT. Stantec, the sponsor, gave the team 44 reports from various Cambridge stormwater projects. The team had to first become acquainted with the general layout of the reports. Key information the team extracted from the project reports included: descriptions of the site characteristics before and after the project, implemented BMPs, and stormwater calculations.

In several cases, the land use types were not directly stated, and the team had to decide which land use option in BATT would best match the project. This was accomplished by using the description of the project site and knowledge of land use groups in GIS, as seen in Table 13[83].

[83] (USEPA, 2017, Appendix F)

Table 13: Land Use Groups from GIS as BATT Inputs[84]

Mass GIS Land Use LU_CODE	Description	Land Use group for calculating P Load – 2013/14 MA MS4
1	Crop Land	Agriculture
2	Pasture (active)	Agriculture
3	Forest	Forest
4	Wetland	Forest
5	Mining	Industrial
6	Open Land includes inactive pasture	Open Land
7	Participation Recreation	Open Land
8	Spectator Recreation	Open Land
9	Water Based Recreation	Open Land
10	Multi-Family Residential	High Density Residential
11	High Density Residential	High Density Residential
12	Medium Density Residential	Medium Density Residential
13	Low Density Residential	Low Density Residential
14	Saltwater Wetland	Water
15	Commercial	Commercial
16	Industrial	Industrial
17	Urban Open	Open Land
18	Transportation	Highway
19	Waste Disposal	Industrial
20	Water	Water
23	Cranberry Bog	Agriculture
24	Powerline	Open Land
25	Saltwater Sandy Beach	Open Land
26	Golf Course	Agriculture
29	Marina	Commercial
31	Urban Public	Commercial
34	Cemetery	Open Land
35	Orchard	Forest
36	Nursery	Agriculture
37	Forested Wetland	Forest
38	Very Low Density Residential	Low Density Residential
39	Junkyards	Industrial
40	Brush Land/Successional	Forest

The team also encountered challenges with classifying the BMPs used in the projects. Due to the creativity of developers, there are a variety of ways BMPs can be uniquely designed and labeled. However, there are only nine BMP options to select in BATT. To help future

[84] (USEPA, 2017, Attachment 1 of Appendix F, pg 6)

BATT users, the team created a section in the User Guide that helps classify BMPs with the available options in BATT.

The team pulled information about storage volumes and infiltration rates from the stormwater calculation portions of the reports. In terms of different calculation methodologies seen in reports, some reports utilized HydroCAD, while others used the Rational Method. HydroCAD software was used more frequently in reports than the Rational Method to represent stormwater flow through BMPs. HydroCAD clearly provided information about the area of each subcatchment, a diagram of flow pathways between subcatchment areas and BMPs, infiltration rates of BMPs, as well the area that each soil type covered. The Rational Method also provided the BMP infiltration rates and subcatchment areas, but was harder for the team to become acquainted with since it was utilized less frequently.

The team obtained the necessary information from the reports and then used BATT to calculate the phosphorus credits for each project site in Cambridge. It is important to note that not all 44 reports were inputted into BATT. Some project sites were not associated with Cambridge or the Charles River, and the team wanted to primarily focus on these particular locations. Additionally, some projects contained BMP and subcatchment layouts that were far too simplistic or too complex to be considered feasible for input to BATT. The team created a master spreadsheet of all projects that was then used to filter out those that were not acceptable to put in BATT because of lack of information, location in the Mystic Watershed, and use of only proprietary BMPs. An example of this filtering method can be seen in Table 14 below. The rest of the projects may be seen in Appendix G of this report.

Table 14: Examples of Filtering Projects

Project Name	**Watershed**	**BMP Type**	**Land Use**	**HydroCAD or Rational Method?**	**Pursue for Alternative Analysis?**
58 Plympton Street	Charles River	Impervious area Disconnection with Storage	HDR	HydroCAD	Yes
10 Glassworks Avenue	Charles River	Jellyfish (proprietary)	HDR	HydroCAD	No
15-33 Richdale Avenue	Mystic River	Infiltration Trench, Drywell	HDR	HydroCAD	No
131 Harvard Street	Charles River	Dry Pond	HDR	HydroCAD	Yes

Once projects were filtered, 15 were selected to be entered into BATT. To organize information from each report, the team created a spreadsheet that contained the parameters inputted into BATT for each specific project, as well as the phosphorus reduction calculated by BATT. The parameters involved land use type, BMP storage volume and type, infiltration rate, soil group, and acreage.

Along with phosphorus reduction calculated by BATT, the team also calculated the baseline phosphorus load for each filtered project. By doing so, the team put low phosphorus reductions into perspective with baseline phosphorus loads to create BMP removal efficiencies at each site, seen in Equation 16 below. BMP removal efficiencies provided a sense of effectiveness of BMPs on sites rather than the reported low mass flow rate of phosphorus reduction. This analysis contributed to the next phase of evaluating projects for redesign to help remove more phosphorus by improving BMP efficiency.

Equation 16: BMP Removal Efficiency

$$\text{BMP removal efficiency} = \frac{\text{Structural BMP phosphorus load (lb/yr)}}{\text{Baseline phosphorus load (lb/yr)}} * 100$$

3.3.2: Proposed Alternative Design using BATT

The first part of the design component for the project was the creation and evaluation of alternative designs utilizing projects in Cambridge. For each alternative design, the team analyzed which conditions and characteristics of BMPs could be changed in a project to increase the phosphorus reduction in BATT. When examining ideal projects compiled in the master spreadsheet of projects, the team looked at various factors to decide which were the best to use for the alternative design. The simplicity of the design was considered since the group preferred to have multiple BMPs and subcatchments. Additionally, projects with proprietary BMPs were not considered since there is not a section within BATT to account for proprietary credits. The impervious versus pervious ratio for site areas was taken into consideration to determine where more infiltration could be allowed. Finally, the potential for improvements was considered when selecting a project. If one site was already designed with what proved to be a higher efficiency BMP utilizing mostly impervious subcatchment area, the BMP would be close to its maximum effectiveness. Therefore, ideal projects would have lower BMP efficiencies and high enough baseline loads that the team could still manipulate the site.

The basis of the alternative design methodology was to isolate one BATT input tested by keeping the remaining inputs constant in order to select the most ideal variable for that input. Then the BMP was tested using each ideal variable selected, changing multiple BATT inputs. The team had to first decide which BATT inputs to change within the project, based on what was most feasible for a developer. For instance, the BATT input ‘Land Use Group’ is not very manageable to change since these are based on the zoning ordinances for that area. The team also based the selection of inputs on the sensitivity analysis results, showing the influence of various inputs on phosphorus credit. Ultimately, the inputs of impervious to pervious area ratio, BMP type, and storage volume were chosen for alternative analysis.

Figure 11 below represents the three BATT inputs changed. As seen in the bottom box for Phosphorus Load Reduction Change, installed design phosphorus reduction was subtracted from the alternative design phosphorus reduction in order to observe changes in BMP effectiveness. Performing this subtraction, the greatest difference in removal was used to select the ideal variable per BATT input and ultimately the ideal design for that BMP.

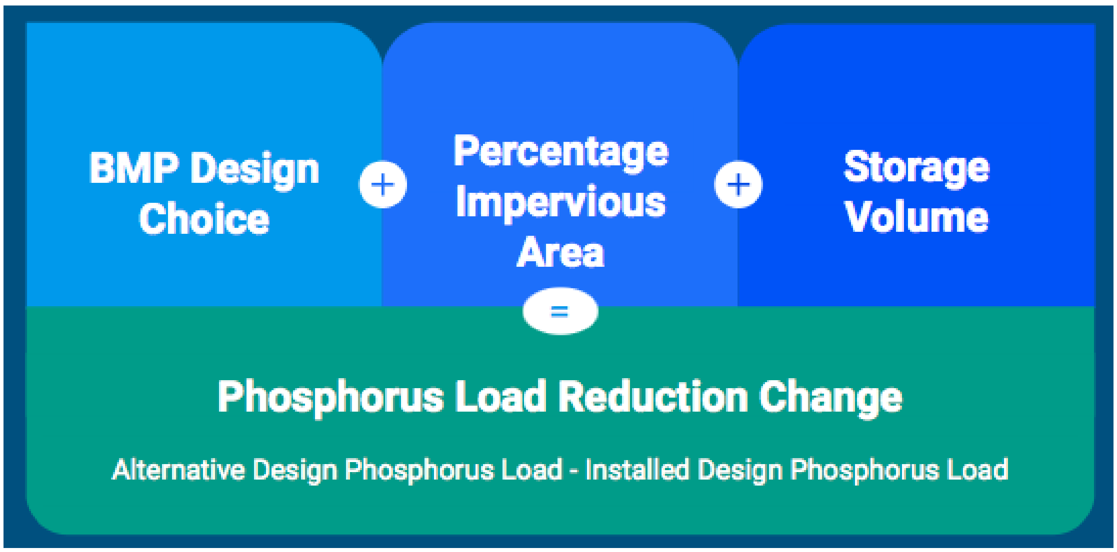

Figure 11: Diagram of Alternative Design Methodology

When changing the distribution of impervious versus pervious area within a project, it was necessary to obtain credits utilizing two sections of BATT. The first step was to enter the change in impervious versus pervious area into the 'Add Land Use Conversion' tab of the BMPs accounting for simply the change in the land. From the initial installed condition of the project, adding more impervious area decreased the credit attained. This is because less stormwater containing phosphorus is able to infiltrate into the ground with added impervious area. Additionally, the changed impervious versus pervious conditions must be inputted into 'Add BMP Structural' section in order to view how these changes affect the performance of the BMP. This section must be utilized even if no characteristics of the BMP are changed because the subcatchment area of the BMP is being altered. If more impervious area is added to this subcatchment area, the BMP will achieve more credit. This is because more water is able to run off of the impervious area and into the BMP. Table 15 below shows an example of how this relationship works when changing a site originally at 80% impervious area.

Table 15: Example of Alternative Methodology for Impervious to Pervious Area Distribution

% Impervious	Change in Structural BMP from Original Site	Change in Land Use Conversion from Original Site	Total Change in Credit (lb/yr)
0%	-0.105	+0.170	+0.065
50%	-0.041	+0.076	+0.035
100%	+0.026	-0.041	-0.015

3.3.3: Product to Enhance Usability of BATT

The second part of the design for this project was a fillable template to input BATT parameters. BATT and nutrient regulations are very new for municipalities and developers. Because of the team's intimate knowledge of the program and permit, the team was asked to create an easily usable template for a developer to easily organize site details that a municipality could then use to obtain a credit through BATT.

With this goal in mind, the team wanted to make the template easy to read, use, and integrate for the developer. This meant keeping in mind inputs needed for BATT while also thinking of how information was usually characterized in project reports for a fluid transition. The program used to create the template had to be universally usable on various software platforms so that this information could be transmitted easily between parties. The display had to be easily readable for the person filling out the template as well as the next person who would need to interpret that information. All of these factors were considered for the final design.

Moreover, for a new user, some elements of BATT can be difficult to interpret. One of the most challenging features is the narrow selection of BMP options. A variety of names can be assigned to unique BMP designs but the developer must ultimately choose one of the nine options available in BATT. Therefore, the team included the Guide to BMPs presented in the User Guide the team created. The User Guide can be found in Appendix H of this report. The team also developed a flowchart for choosing the appropriate BMP as defined in BATT.

4.0: Results

This chapter focuses on the team's results and analysis after completing the methodology. The main findings that are addressed include discrepancies between the Best Management Practices (BMP) Accounting and Tracking Tool (BATT) and Appendix F of the Municipal Separate Storm Sewer (MS4) Permit, BATT sensitivity and validation, and redesign of Cambridge stormwater projects using BATT.

4.1: Assessed Foundation and Usability of BATT

4.1.1: Compared BATT to Appendix F

The team created spreadsheets of the phosphorus removal calculations outlined in Appendix F of the Municipal Separate Storm Sewer (MS4) Permit to easily compare BATT results to those of Appendix F calculations. The team was able to input the exact land conditions and sizing of BMPs into both BATT and the spreadsheets to compare results from examples provided in Appendix F. Ultimately, this allowed the team to pinpoint discrepancies between BATT and Appendix F.

The team began with the simpler Appendix F calculations given for non-structural BMPs, comparing specifically how BATT correlated with equations in Attachment 2 of the MS4 Permit. By inputting examples provided in Appendix F into both BATT and the created spreadsheets, the team concluded that for catch basin cleaning and organic leaf litter collection BATT emulated Appendix F exactly. One small difference between BATT and Appendix F was within the enhanced sweeping program BMP. The Appendix F equation contained an Annual Frequency (AF) value allowing for a ratio of the exact amount of months in the year out of twelve in which the municipality swept. However, in BATT the only options are weekly, monthly, or twice per year, not accounting for a sweeping frequency outside of those values. In the case of Cambridge, which sweeps for nine months out of twelve, the BATT method may not provide full credits earned.

The most glaring difference between BATT and Appendix F occurred in the case of the 'No Application of Fertilizers Containing Phosphorus'. The method in Appendix F was fairly logical including a Weighted Phosphorus Load Export Rate (WPLER) (lb/acre/yr), a phosphorus reduction factor, total lawn area, and lawn percent, producing reasonable values. However, in BATT, the 'No Application of Fertilizers Containing Phosphorus' BMP only allowed for an input for land use. Also, looking through the BATT reference tabs, the team found the WPLER value was slightly different, in a factor of a hundredth, for Appendix F and BATT for Cambridge. The result for Cambridge was consistently 15.067 lb/yr, no matter what acreage or land use type was selected.

After discovering this discrepancy, the team gained insights into how the calculation changed from the interview with Suzanne Warner from the EPA. She stated that a fertilizer ban specifically targeting fertilizers with phosphorus was instated during the creation of the BATT. Therefore, instead of continuing with a calculation for this input in BATT, the EPA simply calculated for each municipality its credit if no fertilizers with phosphorus were allowed, appending the calculations from the original permit through an attachment in the "Response to Comments" section[85]. The 'No Application of Fertilizers Containing Phosphorus' section of Attachment 3 to Appendix F Response to Comments showed the fertilizer credit assigned to Cambridge was calculated to be 11.2 lb/yr[86]. However, Attachment 2 to Appendix F in the MS4 Permit gave Cambridge a credit of 9.0 lb/yr[87]. Further communication with Suzanne Warner clarified that the EPA has already credited Cambridge with 11.2 lb/yr and neither BATT nor Appendix F should be used to calculate phosphorus credits for 'No Application of Fertilizers Containing Phosphorus'[88].

When evaluating structural BMPs, two differences were found. First, BATT only references tables of the performance curve, whereas the specific methodology for Appendix F requires curve interpolation for a more specific credit. Second, Appendix F has eight structural BMPs, while BATT has nine. BATT adds enhanced bioretention that is not accounted for in the permit. Looking through the reference tabs, BATT also has performance tables for a sand filter, but does not have this selection option.

Finally for Land Use Conversion, BATT did match the calculation for land use change when Table 2-2 in the Appendix F was used, or Table 1 of this report. The team had initial confusion because two tables are presented in this section of the permit; however, as described in the methods chapter, the same table is used in the "before" and "after" land categories. This was confirmed by Suzanne Warner.

However, the question of keeping land use the same, but changing pervious area content, a common practice in projects, was less straightforward. This practice is explained in Attachment 3 of Appendix F as impervious area changed into pervious area. The only option to do this in BATT is to use the land use change section. However, as can be seen in the methodology, these two calculations are not the same and, in fact, the impervious to pervious area change includes an extra performance table. Therefore, the team found that BATT did not produce the same results as Appendix F. As seen in Table 16, BATT results were greater because land use conversion does not consider performance efficiency from changing permeability.

[85] (Warner, 2018)
[86] (USEPA, 2017, Response to Comments)
[87] (USEPA, 2017, Attachment 2 of Appendix F)
[88] (Warner, 2018)

Table 16: Results for Appendix F and BATT Comparison of Land Permeability Change

Land Conditions (HDR)	Appendix F Calculations (lb/yr)	BATT Calculations (lb/yr)
0.5 acres Impervious to 0.5 acres Pervious HSG A	1.131	1.145
0.5 acres Impervious to 0.5 Pervious HSG D	0.792	0.975

The EPA User Manual states users should use the Land Use Conversion option in BATT when calculating changes in site permeability[89]. Since this is in direct contradiction to the permit, the team recommends reaching out to the EPA for this calculation. If the EPA User Manual is correct, the team also recommends renaming the Land Use Conversion section in BATT in future iterations to lessen confusion. Since land use is associated directly to land use group, the team suggests using broader terms such as ‘site conditions’.

4.1.2: Developed User Guide

After becoming familiar with BATT and discovering differences between BATT and Appendix F, the team created a user guide for new users. This guide is meant to complement the user guide created by the EPA, which is more tutorial based for using BATT. The team’s user guide has three main sections: Computer Compatibility Issues Help, Tips and Tricks, and a Guide to BMPs. First, it provides detailed instructions for how to make BATT compatible with different versions of Microsoft Excel and Word. The guide also includes the necessary steps to unhide tables that BATT refers to for its calculations. This is important for the user to see in order to understand the inner workings of BATT. Then, findings from the Appendix F comparison section are included to give users the most up-to-date information on BATT. Finally, BMP distinguishing characteristics with a list of possible alternatives for that category are given, thereby allowing users to better enter designed BMPs into BATT. The user guide can be found in Appendix H of this report. Following are findings that were entered into the user guide.

The initial step to using BATT was to determine how to get the software to operate on computers that do not have the 2013 versions of Microsoft Excel and Word. BATT was programed to refer to specific reference libraries that are only available in the 2013 versions of Word and Excel. Through investigations into the team’s personal hardware issues, it was found that BATT is unable to function with a missing reference library. To solve this issue, the team determined how to uncheck missing libraries from the references that BATT requires. These references can be found in the “Editor” portion of BATT in the tools tab.

The team also discovered other important aspects involved with operating BATT that may not be apparent to a new user. After specific data about a project is entered it is important to

[89] (Tetra Tech, 2016, User’s Guide)

first check the “Active” box in BATT in order to calculate credits. If the “Active” box is not selected, the program will not calculate credits.

Another important aspect of BATT is that it must reference a variety of BMP performance tables to reach certain values in its calculations. These values may be found in hidden reference tabs in BATT. For the team, these hidden tabs provided insight into how BATT differentiated performance between various BMPs and land use types.

4.2: Evaluation of BATT Performance Efficiencies

4.2.1: Performed Sensitivity Analysis

The team conducted a sensitivity analysis of BATT to determine which parameters it is most sensitive to when calculating phosphorus reduction credits. The most significant results to this analysis for structural and nonstructural BMPs are presented in this segment of the paper. Refer to Appendix C for graphs of all sensitivity analysis results.

4.2.1.1: Analysis of BATT Sensitivity to Structural BMP Type

The team conducted the sensitivity analysis of BATT for different structural BMP types to determine which BMPs would receive the highest phosphorus credit in BATT. The analysis was done using land use types of high density residential (HDR), medium density residential (MDR), and commercial. Furthermore, the team chose to analyze the sensitivity when there was one acre of impervious land, and half an acre of both pervious and impervious land to determine if the acreage composition also had an effect on the phosphorus removal efficiency of each BMP. For the test results described below, Hydrologic Soil Group (HSG) C was utilized, along with a storage volume of 500 ft^3. Below, Figure 12 illustrates the phosphorus removal for each BMP type with a commercial land use.

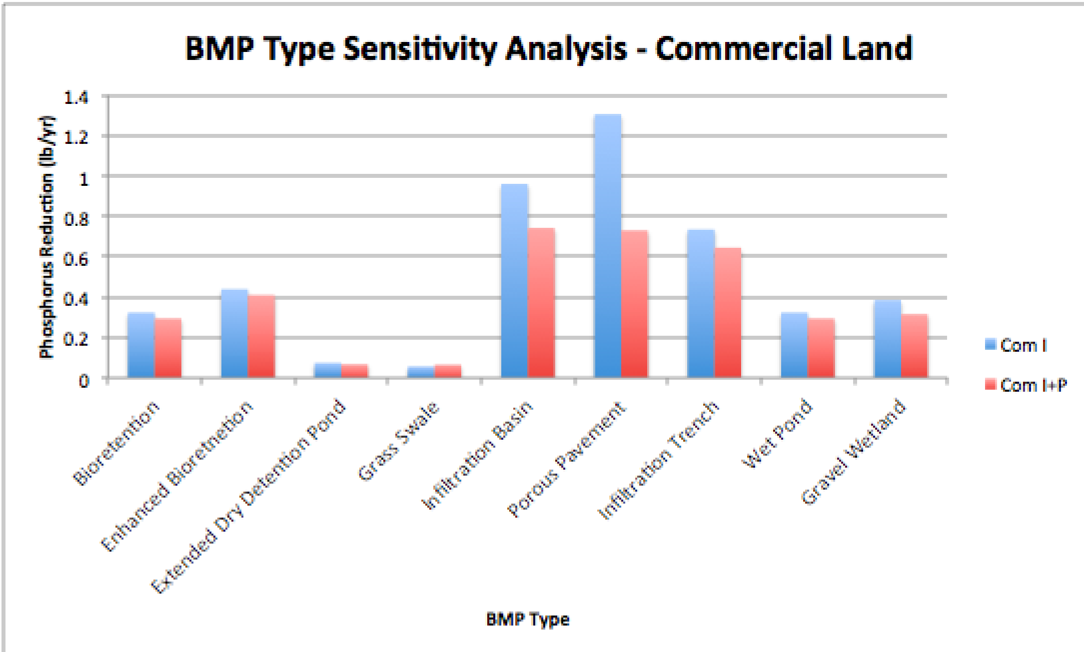

Figure 12: BMP Type Sensitivity Analysis in Commercial Land

The red bars in this graph indicate that the land use composition inputted to BATT was half an acre of impervious land and half an acre of pervious land. The blue bars indicate that one acre of impervious land was used. The x-axis includes all of the structural BMPs available in BATT, and the y-axis is the phosphorus reduction in lb/yr. It is important to note that the results found for commercial land use also correlate to those of the HDR and MDR land uses.

Most BMPs, except for the grass swale and dry detention pond, reduced a significantly higher amount of phosphorus with 100% impervious land compared to the 50% pervious, 50% impervious land combination. This is because BATT is assuming that with impervious land, all of the stormwater will runoff into the BMPs. If there is pervious land available, the stormwater will also be infiltrating into the ground, and less stormwater will reach the BMP. This results in a smaller amount of phosphorus reduction when pervious land is present in BATT. The results of this analysis also indicate that the most effective structural BMPs are infiltration basin, infiltration trench, and porous pavement.

As for porous pavement, BATT is assuming the impervious area entered is the surface area of the BMP, even though this is not always the case. The team also chose the average value for media depth of 22 inches to test for porous pavement. With the acreage being the same for each site and considering this depth, the porous pavement does not have the same storage volume as the others. The porous pavement results should not be viewed in comparison with the other BMPs, though it can be considered a medium range amount.

4.2.1.2: Analysis of BATT Sensitivity to Storage Volume Size

The team conducted a sensitivity analysis of BATT for storage volume size to determine how the storage volume size affects BMP efficiency. This analysis was done using MDR, HDR, and commercial land types. HSG C was kept as a constant. The test that will be discussed was done using an infiltration trench for the BMP, with an infiltration rate of 2.41 in./hr in commercial land. The team chose to test the sensitivity using acreage compositions of 100% impervious and 50% pervious, 50% impervious. Below, Figure 13 illustrates the phosphorus reductions when different storage volume sizes are utilized.

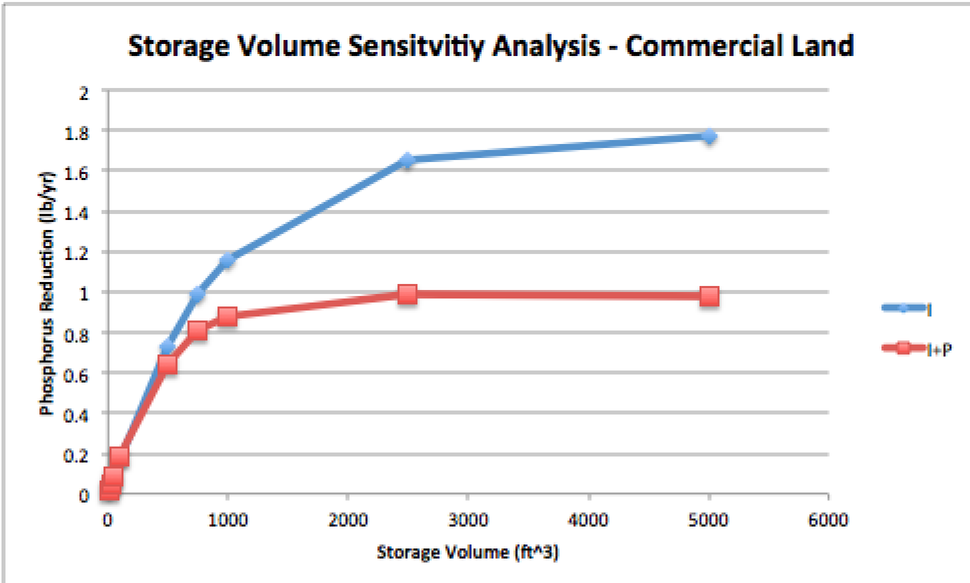

Figure 13: Storage Volume Sensitivity Analysis in Commercial Land

The red curves in this graph indicate that the land use composition inputted into BATT was 50% impervious, 50% pervious. The blue curves indicate that the land use composition was 100% impervious. The x-axis includes all of the storage volume sizes that the team tested in BATT for an infiltration trench, and the y-axis is the phosphorus reduction in lb/yr. The team found that the results for commercial land use are also consistent with those for MDR and HDR land use types.

BATT is more sensitive to storage volume sizes in lower ranges, between 10 to 750 ft^3. This is demonstrated by the steep slopes of both the red and blue lines. Past this steep point, both curves start to flatten out. Because the other parameters were held constant, the BMP may be overdesigned at the higher storage volumes. This indicates BATT has the sophistication to understand sizing restraints due to runoff.

It is also important to note that the trends of both impervious and impervious-pervious tests are similar, differing only in that the 100% impervious test resulted in a greater phosphorus reduction. This is because more stormwater can come to a BMP when there is increased impervious area coverage, thus allowing the size of the BMP to increase in compensation. However, the increased permeability that accompanies the impervious-pervious test makes the curve much shallower in mid to high range numbers than the curve for impervious land. This indicates that the amount of permeability matters less in lower storage volumes and much more in dealing with medium to larger storage volumes.

4.2.1.3: Analysis of BATT Sensitivity to Hydrologic Soil Group

The team performed a sensitivity analysis of BATT to HSG to determine if there are any correlations between HSG and the amount of phosphorus that is reduced. This analysis was done for HDR, MDR, and commercial land use groups; 0.5 acres of both pervious and impervious land; and a storage volume of 500 ft^3. Figure 14 illustrates the results for MDR. It is important to note that for this test, the results for commercial land differed slightly than those for MDR and HDR land.

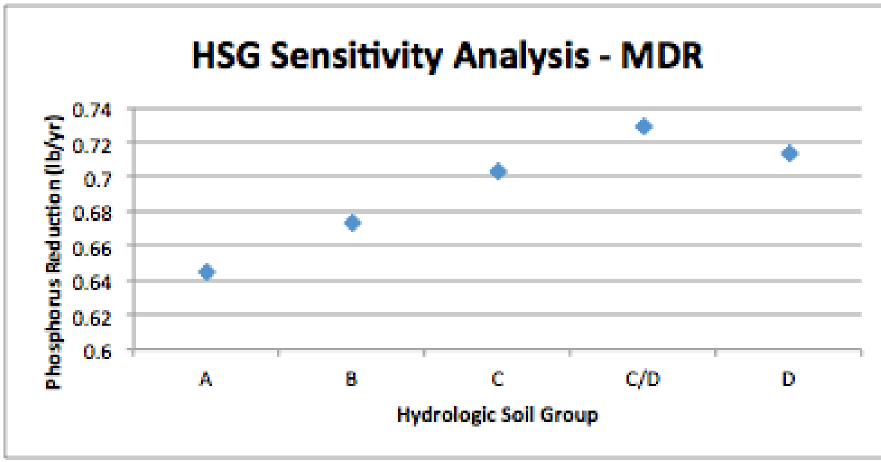

Figure 14: HSG Sensitivity Analysis for MDR

The blue markers above represent the phosphorus reduction for each HSG. The x-axis represents the HSG, and the y-axis is the phosphorus reduction in lb/yr. As shown above, there is a linear relationship between HSG and phosphorus reduction until HSG C/D is reached. The relationship for the MDR graph is linear from HSG A-C/D, but then drops off since the phosphorus reduction for HSG D is lower than that of C/D. For commercial and HDR land use groups, there is a linear relationship throughout, with the phosphorus reduction increasing for HSG A-D.

It is also important to note that HSG A is the least efficient. HSG A allows the stormwater to infiltrate at the highest rate of the HSGs. Therefore, less water is able to runoff HSG A soil to the infiltration trench, reducing the overall phosphorus reduction when HSG A is used. However when HSG C and D are present, there will be a greater phosphorus reduction since more runoff is reaching the BMP.

4.2.1.4: Non-structural BMP Sensitivity Analysis Results

4.2.1.4.1: Analysis of BATT Sensitivity to Sweeping Frequency

The team chose to conduct a sensitivity analysis for sweeper frequency to determine how significant the differences in phosphorus reduction are between sweepings that occur weekly, monthly, and twice a year. With this test, the team could also determine which sweeping technology is most effective. The test was done using HDR, MDR, and commercial land use types for completely impervious area, since the team was more interested in the effect of frequency than the acreage composition. Figure 15 below shows the results for the sweeping frequency test using commercial land. The results using commercial land are consistent with the tests of HDR and MDR as well.

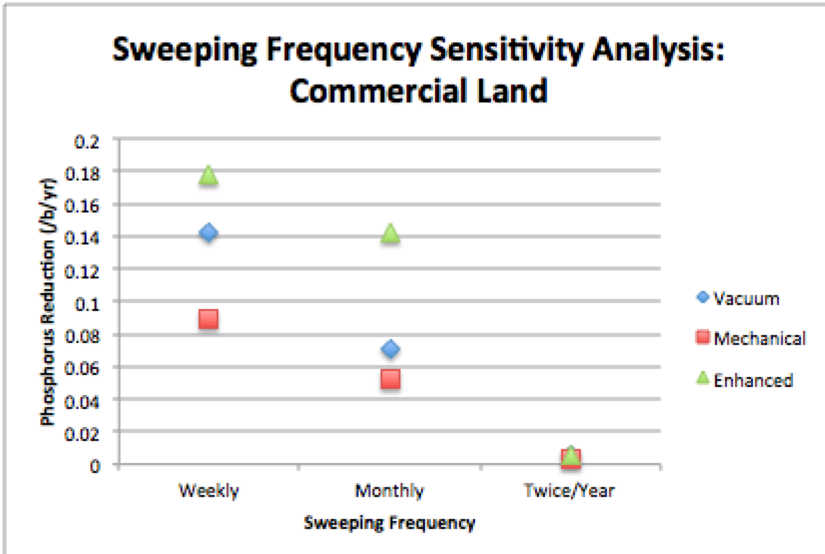

Figure 15: Sweeping Frequency Sensitivity Analysis in Commercial Land

On this graph, there is a marker for each sweeping type – vacuum assisted, mechanical, and 'enhanced' or high-efficiency regenerative air-vacuum. The x-axis is the sweeping frequency, and the y-axis is the phosphorus reduction. Based on these results, BATT does not give any credit for a sweeping frequency of twice a year. This is an important aspect of BATT for municipalities such as Cambridge to be aware of when determining if the credit received for sweeping twice per year is worth the effort. It is also important to point out that the 'enhanced' sweeping technology was consistently more effective than the other two types of technologies for this test, which is consistent with the team's analysis of sweeping technologies.

4.2.1.4.2: Analysis of BATT Sensitivity to Storage Volume

The team conducted a sensitivity analysis for the storage volume to determine the magnitude of change in phosphorus reduction for a non-structural BMP as the storage volume is increased. This test was conducted using impervious area disconnection through storage, with a release rate of two days. The team also did the test using an acreage that was completely impervious, and an acreage that was 50% impervious, 50% pervious. Figure 16 below contains results using commercial land, and the results are also similar for HDR and MDR.

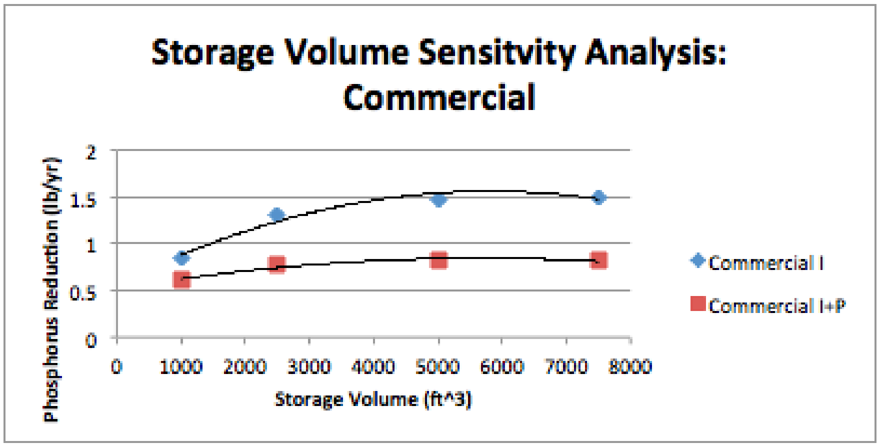

Figure 16: Storage Volume Sensitivity Analysis in Commercial

On this graph, the red markers represent the results of the test using impervious and pervious land. The blue markers represent results for completely impervious land. The x-axis is the storage volume, and the y-axis is the phosphorus reduction in lb/yr. The slopes for both curves increase more intensely for the lower storage volume sizes, until about 2500 ft^3. This is similar to the trend the team observed for the storage volume in structural BMPs. Initially, the phosphorus reduction increased greatly, but as the storage volume increased, the phosphorus reduction began to level out because the area of the subcatchment was not increased. The maximum phosphorus removal was reached for the given acreage size. This is important to know when designing a storage volume for BMPs – a larger storage volume does not automatically correlate to a greater phosphorus reduction. After a certain storage volume size has been reached for a subcatchment, there will not be a significant increase in phosphorus reduction unless the subcatchment area itself has also been increased.

4.1.2.4.3: Analysis of BATT Sensitivity to Bon-structural BMP Type

The team chose to perform a sensitivity analysis for nonstructural BMP type to determine which BMP is most efficient in phosphorus reduction. The test was conducted for HDR, MDR, and commercial land use types. When an HSG was needed, HSG C was utilized. The results for this test using commercial land are shown in Figure 17 below, and are also consistent with the HDR and MDR results.

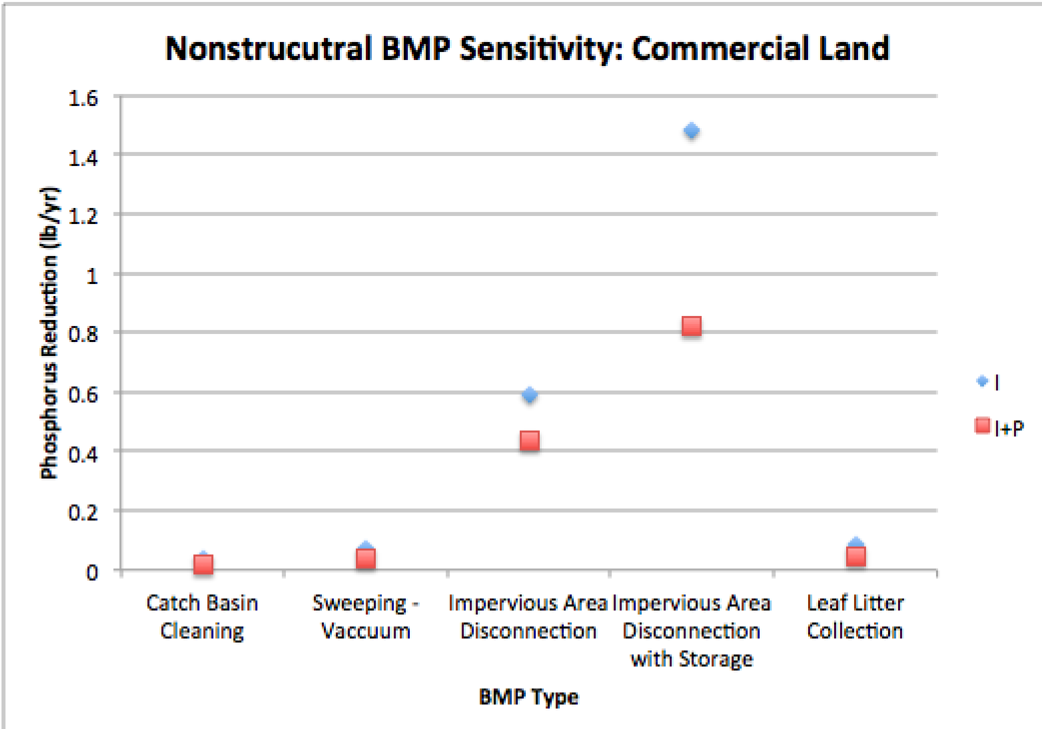

Figure 17: Non-structural BMP Sensitivity for Commercial Land

The blue markers on this graph represent the phosphorus reduction for completely impervious land. The red markers represent phosphorus reduction for 50% impervious, 50% pervious land. The most effective BMP was impervious area disconnection through storage. This BMP also had the greatest difference in phosphorus reduction between completely impervious area and the combination of impervious and pervious area. Because of the findings in the Appendix F comparison section, the team did not test "Removal of Phosphorus-rich Fertilizers" for this sensitivity. For some BMPs, there was barely a difference in the phosphorus reduction for impervious area versus the combination of pervious and impervious area. The team noticed that catch basin cleaning, sweeping, and leaf litter collection had phosphorus reductions proportional to impervious area; 50% impervious, 50% pervious compositions reduced the phosphorus credit by half. The nature of the calculations, as presented in the methodology, explains this phenomenon as only impervious area should be counted towards these credits. However, the other tested non-structural BMPs have more nuanced calculations, thereby explaining the large deviations from the pervious-impervious trial as well as from the other BMPs.

4.2.1.5: Summary of Key Findings

The team discovered several parameters of high sensitivity in BATT when calculating phosphorus reduction. For instance, in terms of BATT calculations, the most efficient structural BMPs are infiltration trench and infiltration basin. Impervious area disconnection with and without storage are the most effective non-structural BMPs. BATT calculates a greater phosphorus removal efficiency for BMPs when the land composition is 100% impervious. This is because more runoff is flowing from a subcatchment area into the BMPs instead of infiltrating through a pervious surface. This was similarly demonstrated in the HSG sensitivity analysis, where land compositions of HSG A resulted in less phosphorus removal than those involving HSG B-D. This is because more runoff can infiltrate in HSG A soil, meaning less runoff reaches the BMP for phosphorus reduction.

BATT is also more sensitive to storage volumes of lower sizes, specifically below 1000 ft^3 of volume. This was found in both structural and non-structural BMP analyses. The removal efficiency increases greatly when the size of smaller storage volumes is increased, and eventually levels out when the storage volume reaches a certain size. This sensitivity finding may stem from the relationship between storage volume and acreage. Since the acreage was held uniform in the storage volume sensitivity section, storage volumes above 1000 ft^3 may have been over designed for the acreage. The team also found that soil permeability influences BATT's calculations when the storage volumes are larger. With large storage volumes, the phosphorus reduction does not increase in the same trend that it does for 100% impervious land.

4.2.2: Validated with CRWA and UNHSC Data

4.2.2.1: Charles River Watershed Association Validation

Validation with monitoring data from the Charles River Watershed Association (CRWA) was conducted in order to investigate how closely the modeling of phosphorus reductions in BATT correlated with reductions occurring in real applications. Of the two BMPs that the CRWA constructed, the porous pavement, described as Public Alley 543 in the Background chapter of this MQP, was chosen by the team for validation because of the specificity of design information provided and positive phosphorus reductions from monitoring results. The team decided to not use the bioretention area, described as the Chelsea biofilters in the Background, in the validation step. Because of the breakthrough in phosphorus due to the soil amendment composition, the monitoring data had increases in phosphorus[90]. Public Alley 543 was a better example for the team's exploration into the accuracy of BATT. When validating the porous alley, the team was able to explore BATT BMP categorization as a tool for credit accuracy.

The first task in validating BATT results with the CRWA monitoring data was determining the BATT inputs for the porous alley. The BMP would, at first glance, be categorized as a porous pavement. However, the BATT description of porous pavement requires an impermeable liner and an underdrain emptying the storage area within the BMP. In the case of this porous alley BMP, the stormwater was allowed to infiltrate into the ground after passing through the porous media. Therefore, when entering the BMP into BATT, the team categorized this BMP as an infiltration trench, allowing an infiltration rate and increased removals.

Moving into BATT input categorization of land use conditions, the porous alley report stated that it was located in a primarily residential district "characterized by Victorian

[90] (CRWA, 2015, Blue Cities Report)

housing"[91]. Therefore, the land use group was categorized as high density residential (HDR). Extracted from the design drawing of the porous alley was a drainage area of 4,820 ft^2 or 0.111 acres of HDR[92]. The infiltration rate for the infiltration trench was assumed to be 8.27 in/hr, since the porous alley report states: "Confirmed very high levels of infiltration into the ground"[93]. The highest infiltration rate available from a drop-down menu in BATT is 8.27 in/hr. Storage volume in between the voids of coarse gravel was also explicitly stated in the report as 425 ft^3.[94]

Once all of the conditions present in the CRWA porous pavement report were entered into BATT, a phosphorus credit could be calculated for this BMP. When entered into BATT as an infiltration trench, the credit produced was 0.256 lb/yr reduction. Compared to the baseline load of 0.256 lb/yr, there was a 100% phosphorus reduction. Because all of the stormwater containing phosphorus was infiltrating into the ground, the BATT output stated that all of the phosphorus was removed by this BMP. Therefore, the reduction discovered by the CRWA Porous Alley 534 validated the BATT reduction[95].

However, the CRWA also monitored the effectiveness of flow and nutrient reduction through the porous media. The CRWA monitored water quality using a logger within a six-inch diameter well to obtain data on the levels of buildup in the temporary storage section of the BMP and to detect levels of phosphorus directly exiting the filter media layers. For the continuous readings of buildup of water in the storage area, the CRWA's objective was to detect any overflows of water and how quickly it infiltrated into the soils below[96]. It found that the "water level in the storage area rarely built up more than a few inches even after heavy rain events."[97] Therefore, the CRWA summary stated a 100% removal of phosphorus because all of the stormwater was infiltrating into the ground without any overflows. However, the monitoring of phosphorus exiting the filter media produced different results.

During the two storm events that levels of phosphorus were monitored directly entering and exiting the filter media, reductions were detected to be 64.54% and 38.58%[98]. Therefore, not all of the phosphorus was removed by the porous pavement filter media. Some phosphorus may have seeped into the ground, potentially entering the groundwater or remaining in the soil. This may eventually produce breakthroughs of phosphorus. The team decided to emulate the reduction just through the filter media layers by inputting this BMP as a porous pavement into BATT under the same land and sizing conditions. This reduction was 0.2 lb/year or a 77.84% reduction. This efficiency is comparable to what was detected in the CRWA monitoring of the

[91] (City of Boston, CRWA, BGT, & VHB, 2016, pg 2)
[92] Vanasse Hangen Brustin (VHB). (2013) "Public Alley #543". *Boston Porous Pavement*. [PDF]. Funded by MassDEP. Obtained through Boston Public Works Department, Charles Watershed Association, & Boston Groundwater Trust.
[93] (City of Boston, CRWA, BGT, & VHB, 2016, pg 7)
[94] (City of Boston, CRWA, BGT, & VHB, 2016, pg 4)
[95] (City of Boston, CRWA, BGT, & VHB, 2016)
[96] (City of Boston, CRWA, BGT, & VHB, 2016, pg 7)
[97] (City of Boston, CRWA, BGT, & VHB, 2016)
[98] CRWA. (2014). *Porous Alley Monitoring Data*. Retrieved from: https://www.crwa.org/blue-cities/demonstration-projects/porous-alley/data

media layers. The team believes maintenance assumptions and execution were a factor in the differing reduction percentages.

Based on these findings, the team emphasizes the effectiveness of infiltration BMPs in regards to BATT crediting. As seen in this validation, the infiltration trench both theoretically and in practice produced 100% removal. However, the effect of only the filter media of the porous pavement produced lower removal efficiencies. Though phosphorus may remain in the soil with an infiltration trench, it is theoretically a more practical approach according to BATT. The 100% removal calculated in BATT may not be representative of the phosphorus remaining in the soil system.

4.2.2.2: University of New Hampshire Stormwater Center Validation

This section of the results presents the team's findings from validating BATT using the University of New Hampshire Stormwater Center (UNHSC) monitoring results and BMP parameters. These findings were important for validating BATT because the UNHSC data was used by Tetra Tech to calibrate the tool[99]. Both the results in pounds per year and the BATT inputs for the UNHSC BMPs were obtained from the UNHSC Operation and Maintenance report[100]. The methodology section explains the process of utilizing BMP dimensions in this report to produce storage volumes. It additionally states how the team obtained information about land use group and drainage area to input into BATT.

Table 17 below contains credit amounts for the UNHSC monitoring data and BATT results. A consistent trend in the discrepancies between these results was that the UNHSC credit produced in the field was significantly higher than the BATT calculated credit. This was the case for bioretention 1, bioretention 2,3, gravel wetland, and porous asphalt, the latter two BMPs containing the most pronounced differences. Conversely, the vegetated swale, wet pond, and dry pond produced no phosphorus credit within the UNHSC monitoring but BATT calculated credits for each. When analyzing these differences, the team looked at various reasons behind them.

Table 17: UNHSC Validation Results

BMP Type	Gravel Wetland	Bioretention 1	Bioretention 2	Porous Asphalt	Vegetated Swale	Wet Pond	Dry Pond
Storage Volume (ft^3)	1,263	1,501	136.4	15.6" deep	238,731	1,609	2,896
UNHSC Monitoring Credit (lb/yr)	3.75	1.76	1.76	3.90	0	0	0
BATT Credit (lb/yr)	0.658	0.662	0.094	0.147	0.633	0.681	0.194

99 (Tetra Tech, 2010)
100 (Houle, et. al., 2013)

In the case of the four BMPs that contained much higher credits within the UNHSC monitoring than the BATT outputs, the team analyzed assumptions made by the UNHSC for land use conditions. As stated in the methodology, the UNHSC characterized its monitoring area as a commercial land use group. However, the UNHSC does not monitor the phosphorus in stormwater before entering a BMP but rather back calculates from volume reductions and final nutrient measurements. From that calculation, the UNHSC establishes a phosphorus loading rate for its parking lot, which is assumed to be equivalent to commercial land[101]. Since a commercial land use group in the fairly rural Durham, NH, where the UNHSC is located, is different than an urban environment, the UNHSC may have assumed high values for the baseline loading. A larger amount of initial phosphorus would explain the ultimately high credits for these BMPs.

Additional reasons behind the higher UNHSC monitoring results relate to the maintenance of these BMPs. When the UNHSC is monitoring in its site, the employees maintain these BMPs to a high standard to ensure optimum performance. However, the BATT assumption for maintenance of BMPs, although consistent with the New Hampshire State Stormwater Handbook, may be less than what UNHSC conducts. A lower assumption for maintenance would cause lower BMP credits. Additionally, the BATT tool may be a simply conservative model, drawing from conservative BMP performance curves.

Observing the differences in credit for the vegetated swale, wet pond, and dry pond, the phosphorus credit for UNHSC that was obtained from monitoring stormwater after flowing through the BMP was higher than the assumed baseline loading. Therefore, the credit was stated to be zero. Reasoning for this may be that the vegetation in these BMPs did not uptake the anticipated amount of phosphorus in the soil. Also, vegetation was allowed to decay over the winter for the dry pond, releasing phosphorus[102]. Therefore, breakthroughs of phosphorus occurred when stormwater flowed through the BMP. UNHSC monitoring of these BMPs is an example of how outside factors within the site can influence a theoretical reduction for a BMP in BATT.

4.3: Analyzed Cambridge Projects for Design Recommendations

4.3.1: Analyzed Cambridge Projects

The team sorted 44 Cambridge projects to 15 to pursue for further analysis in BATT. Those 15 projects were analyzed extensively for pertinent information of various BATT inputs and organized into spreadsheets. The team looked for structural, non-structural, and land use change inputs during this analysis. Total storage capacities for BMPs were used as design storage volumes from these reports. Based on the provided stormwater reports, the team was able to enter this information into BATT and determine the phosphorus load reductions.

After the phosphorus load reduction was found from BATT, the team also calculated the baseline phosphorus load using Excel spreadsheets setup during the Appendix F calculation

[101] (UNHSC, 2010)
[102] (UNHSC, 2012)

phase of the project. By doing so, the team found the removal efficiencies of the constructed BMPs and put the phosphorus reduction output from BATT into perspective.

An example project can be seen in Table 18 below. The data provided is for the installed project for 131 Harvard Street. The land use change here, depicted as increased pervious area change, only caused a minute increase in the phosphorus credit. Notice that the baseline phosphorus load is only at half a pound per year so any credits produced from BATT may seem small in the scheme of this load. However, there is very little phosphorus coming from this property, as built.

Table 18: Implemented Plan for 131 Harvard Street

Project Name	**131 Harvard Street**	
	Subcatchment 1	*Subcatchment 2*
Land Use Group	HDR	HDR
Acreage	0.195 I	0.034 P HSG A, 0.229 I
BMP Used	Dry Pond	*Increased Pervious Area
Storage Volume	534 ft^3	N/A
Phosphorus Reduction	0.048 lb/yr	N/A
Removal Efficiency of BMP	8.98%	N/A
Baseline Phosphorus Load	0.545 lb/yr	
Total Phosphorus Reduction, Including Land Use Change	0.066 lb/yr	

There were several challenges the team faced when entering projects into BATT. The limited number of structural BMPs made it difficult to determine the correct category for a specific BMP. For example, one project utilized a green roof design. The team chose to categorize this under the land use change option only. BATT also made it difficult to analyze projects with a treatment train of structural BMPs. For example, one project had a detention pond feeding into an infiltration basin. The team was unable to further analyze this project because BATT only models reductions from land, not other BMPs. Therefore, analysis would have to be done using the methodology outlined in Appendix F.

Analysis for fourteen projects analyzed containing structural BMPs may be seen in Table 19 below. All structural BMPs for that site are credited in the "Structural" heading of the table. Baseline phosphorus loads for the proposed or as-built site are provided to show the amount of phosphorus leaving the land. The structural BMP removal efficiency is shown to give perspective on how much the site BMPs removed from the baseline. Eight of the fourteen projects removed 75% or greater phosphorus from their site, and ten of the fourteen removed 50% or more. Without designing specifically for nutrient removal, there are still high efficiencies from these projects.

The impact of land use change, as it pertains to increasing permeable area, can also be seen in the table. If the land use change for the proposed site had more impervious area than the existing site, a negative credit is reported. Depending on the project, the credit from land use change can make a major impact on the total credit. For example, in 1066 Cambridge Street, land use change was only a minor factor for crediting, whereas in 130 Brookline Street more credit was received from land use change than from the structural BMPs. Therefore, land use change is an important element in calculating the holistic phosphorus credit.

Table 19: Structural BMP Analysis

Project	**Structural (lb/yr)**	**Land Use Change (lb/yr)**	**Baseline (lb/yr)**	**Structural Efficiency**
1066 Cambridge Street	0.465	0.029	0.629	78.5%
130 Brookline Street	0.161	0.183	0.596	27.0%
131 Harvard Street	0.048	0.018	0.535	9.0%
147 Prospect Street	0.108	-0.016	0.133	81.1%
168 Hampshire Street	0.310	0.084	0.310	100.0%
1-7 Brattle Street	0.441	0.066	0.510	86.5%
1801 Mass Avenue	1.031	-0.460	1.032	99.9%
219-221 Monsignor O'Brien Highway	0.952	-0.010	1.194	79.8%
240 Sidney Street	1.762	0.904	2.218	79.4%
262 McGrath O'Brien	0.194	0.292	0.563	34.5%
625 Putnam Street	0.673	0.053	0.979	68.8%
7 Cameron Avenue	0.178	0.007	1.049	17.0%
76 Prospect Street	0.201	-0.003	0.336	59.7%
88 Cambridge Park Drive	5.496	N/A	7.679	71.6%

Given all fifteen projects analyzed and including non-structural BMPs where appropriate, the team calculated their cumulative contribution to the phosphorus credit for Cambridge, seen in Table 20. Though many projects had high removal efficiencies, the baseline loading was low for the projects. Therefore, the team calculated a credit of 13.799 lb/yr from the projects, far from the goal of 604 lb/yr outlined in the MS4 permit. Many of these projects were small sites of less than two acres, making the baseline phosphorus small, and thus the phosphorus removal credit small. The team believes that many small projects could feasibly reach the goal.

Table 20: Cumulative Credits from 15 Projects Analyzed in Cambridge

Type	Phosphorus Credit (lb/yr)
Structural	12.020
Non-structural	0.593
Land Use Change	1.186
Total	**13.799**

4.3.2: Alternative Designs of Cambridge Projects

From the 15 projects identified in Table 19, twelve projects were organized by baseline phosphorus load and cumulative removal efficiencies of all structural BMPs present. This layout allowed the team to identify the projects with the most potential for redesign based on BATT phosphorus credits. Those with less efficiency and greater baseline loads would be ideal for a redesign. Figure 18 shows a plot of these twelve projects with baseline phosphorus load on the x-axis and structural removal efficiency on the y-axis.

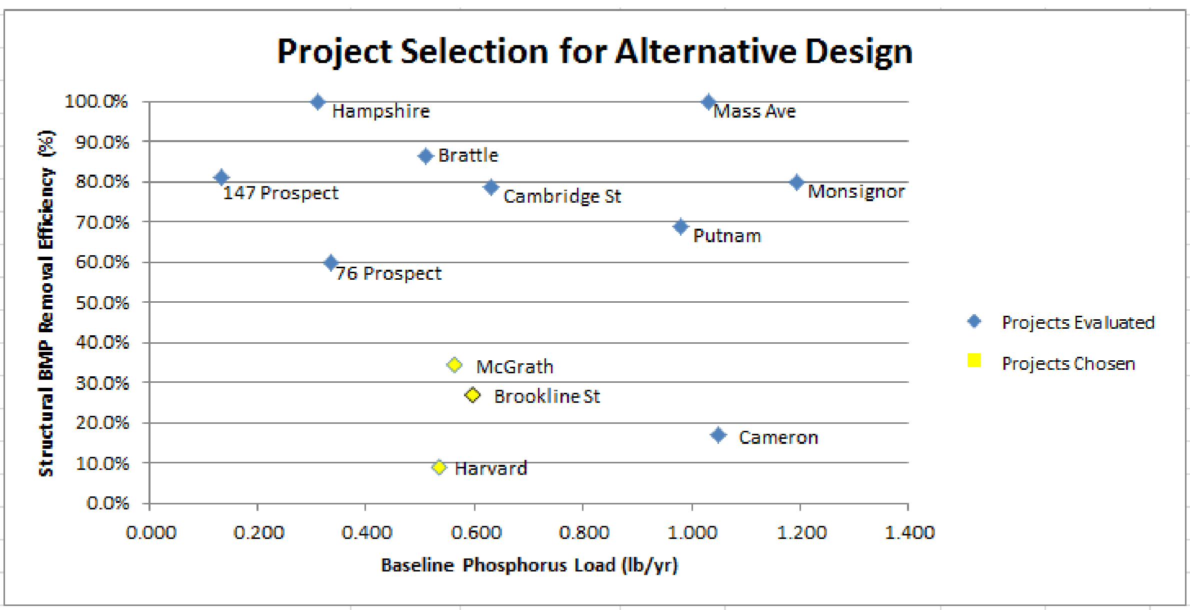

Figure 18: Project Selection for Alternative Design

From the Figure, Cameron Street, Harvard Street, McGrath (Monsignor O'Brien), and Brookline Street were explored for alternative redesigns. These projects had the most potential for redesign based on our criteria. In an investigation of Cameron Street, the team found a simplistic project with only one implemented BMP in one subcatchment area. Therefore, the team chose the three projects outlined in yellow, shown in Figure 18 above, for the alternative design.

4.3.2.1: Alternative Design of 130 Brookline Street

One of the projects chosen for alternative design was 130 Brookline Street, a redevelopment project located in Cambridge, MA. The project site consisted primarily of the land in between the two buildings of 17 Tudor Street and 130 Brookline Street where an abandoned building was demolished. The project contains four primary subcatchment areas: two consisting of completely pervious area and two consisting of primarily impervious area. This made the project an ideal choice for redesign since there are various ways these subcatchments can be changed in order to produce higher credits. Additionally, the project contains two porous pavements with reservoirs underneath instead of allowing for infiltration. Furthermore, there are two bioretention systems, a BMP with lower removal efficiency. One bioretention system and one porous pavement were designed for stormwater collection on each side of the site, before going offsite. Therefore, no BMPs on this site were designed to infiltrate. These BMPs allow for great flexibility in change from one BMP to another and potential for higher removals. Table 21 below provides a summary of the implemented site characteristics. The project is fairly complex in its direction of water from four sub-catchment areas to four BMPs. However, it is not so complicated that an understandable cumulative alternative design cannot be produced.

Table 21: Implemented Site Details for 130 Brookline Street

	Subcatchment 1	**Subcatchment 2**	**Subcatchment 3**	**Subcatchment 4**	**Total**
Land Use	HDR, HSG A	HDR, HSG A	HDR, HSG A	HDR, HSG A	
Impervious Acreage	0.084	0	0.129	0	0.213
Pervious Acreage	0.018	0.007	0.026	0.004	0.055
BMP	Porous Pavement	Bioretention	Porous Pavement	Bioretention	
BATT Phosphorus Credit (lb/yr)	0.121	0.002	0.186	0.002	0.311
Baseline Phosphorus Load	0.195	0.016	0.306	0.009	0.495

The two components of this alternative analysis are described in detail in the following section for the first Subcatchment 1 and for its BMP the Porous Pavement. Because much iteration went into deciding the ideal alternatives for just one BMP, it is more understandable to explain one at a time. As described in the methodology section of the alternative analysis, the change in impervious versus pervious area distribution was analyzed utilizing two sections of BATT, the "Add Structural BMP" and "Add Land Use Change" section. The balance of the credits altered just from the change in land use must be weighed against the credits altered from the change in BMP performance. As seen in Figure 19 below, the installed project impervious versus pervious distribution of 80:20 was changed to three distributions: all impervious, half pervious and half impervious, and all pervious land. It is important to keep in mind that each bar in the graph represents simply the change from the installed BMP conditions to the team's new BMP conditions. For instance, the first green bar under the "All Impervious" section represents that the porous pavement produced about 0.02 lb/yr more credit under the new impervious distribution compared to the installed distribution. However, when accounting for the changes in the land use, the orange bar represented an almost 0.05 lb/yr decrease in credit from the original installed distribution. Therefore, viewing the gray negative net credit bar, this would not be an ideal option for the alternative of impervious versus pervious area.

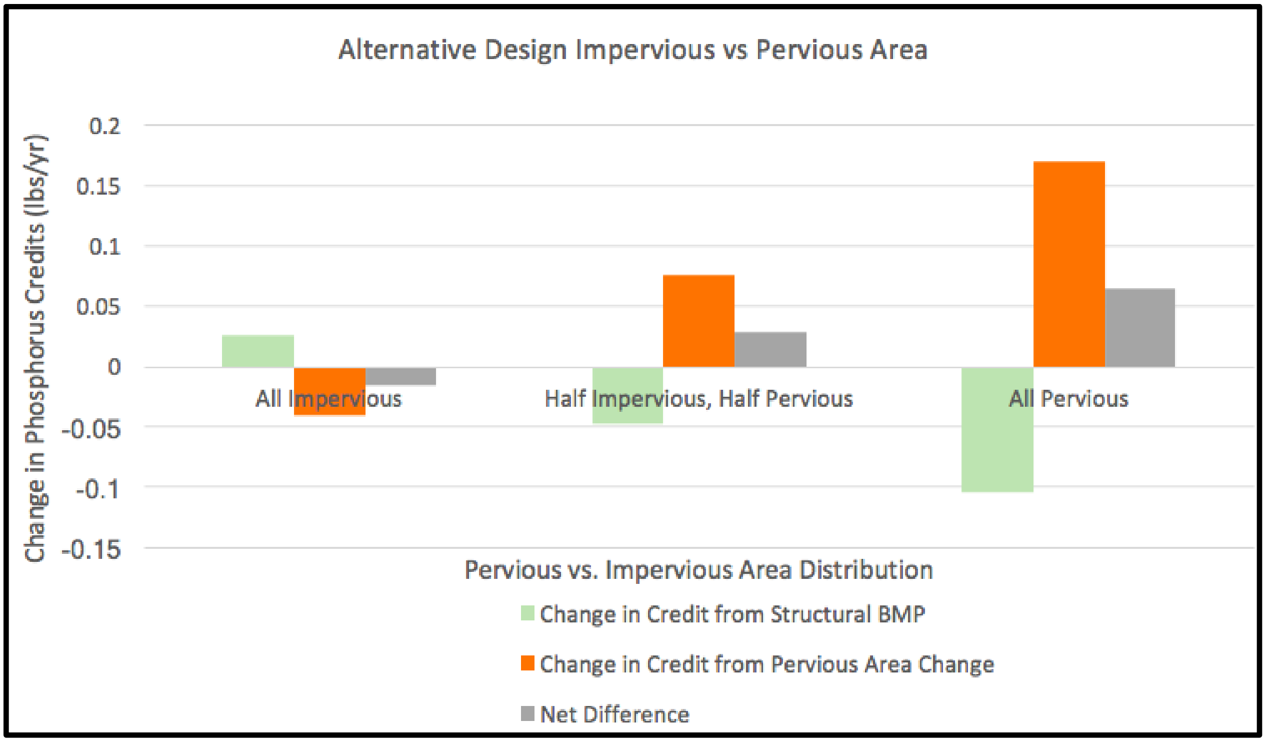

Figure 19: Alternative Design Impervious vs. Pervious Area

As seen in Figure 19, as more pervious area is added, more credit is obtained from the land use change section of BATT than is obtained from the Structural BMP section. The ideal impervious to pervious area distribution for this porous pavement subcatchment was the half impervious, half pervious area. There was still a positive net credit; however, the decrease in the credit from the structural BMP did not outweigh the cost of installing the BMP. The Subcatchment 3 for the second porous pavement was ideally impervious area when a similar analysis was conducted. Therefore, that porous pavement's sub-catchment was changed to all impervious area. More stormwater was then able to run off of the BMP and into the porous pavement. The increase in pervious area was not so great as to produce a detrimental land use change value.

In the next section of the alternative analysis for Subcatchment 1, the team changed the BMP type while maintaining the installed impervious to pervious area distribution of 80%:20%. The BMPs that were tested were chosen according to the results of the team's sensitivity analysis indicating the most effective BMPs for phosphorus removal. The team considered not only the most effective BMP for phosphorus removal, but also the ease of converting one BMP to another. As seen in Figure 20 below, the infiltration trench had the highest removal rate. Additionally the steps needed to convert a porous pavement to an infiltration trench were simply to remove the impervious layer on the bottom, in this case the reservoir. Therefore it was seen as the ideal alternative for the BMP.

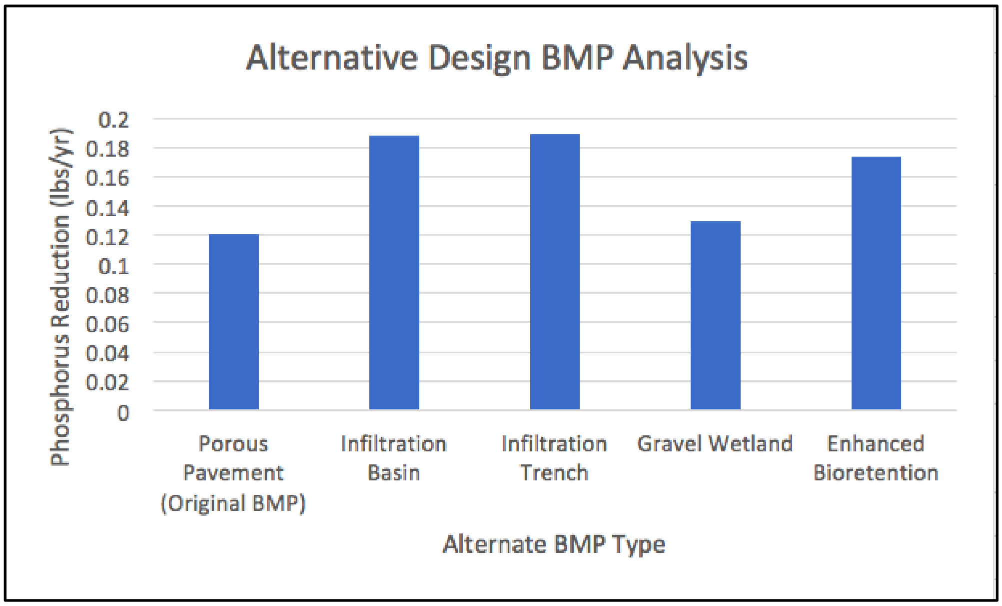

Figure 20: Alternative Design for BMP Analysis

Additionally, the alternative design was considered two-dimensionally. Therefore, when analyzing alternatives for BMPs, the ideal change in impervious versus pervious area distribution, the 50-50 split for Subcatchment 1, was also applied to ensure that this BMP was still the most effective. Within BATT, various BMPs have varying sensitivities to changes in impervious versus pervious area, as seen in the results of the sensitivity analysis. As seen in Figure 21 below, the orange bars represent the BMP removal under the ideal impervious versus pervious area. The infiltration trench still performed the best under the new conditions while considering the ease of the redesign.

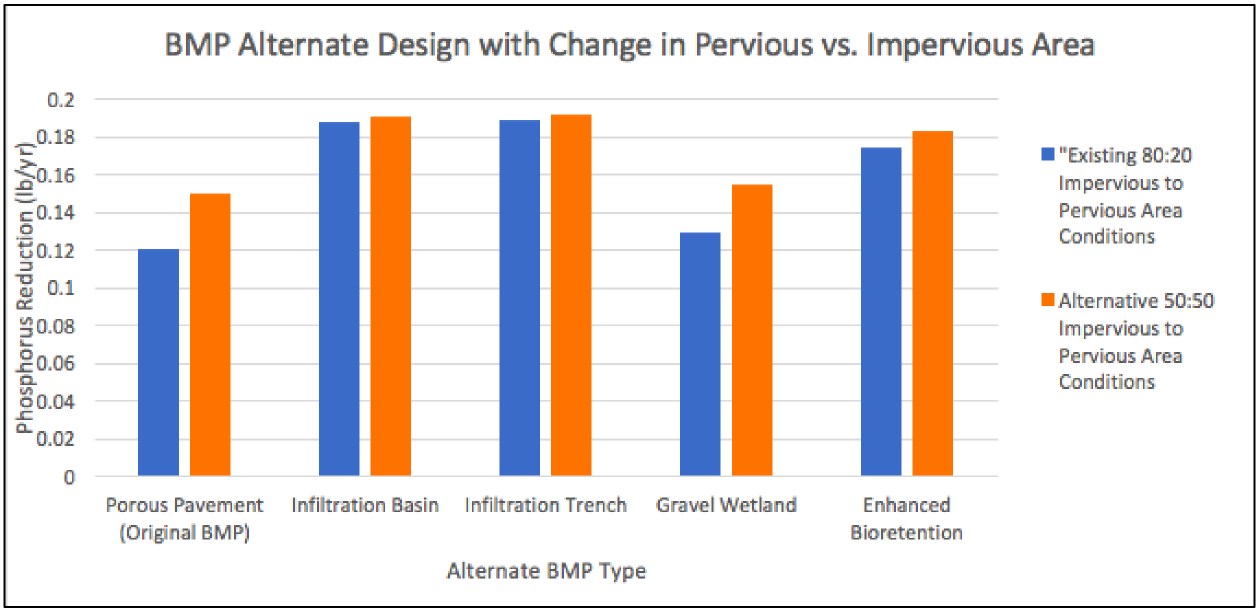

Figure 21: BMP Alternative Design with Change in Pervious vs. Impervious Area

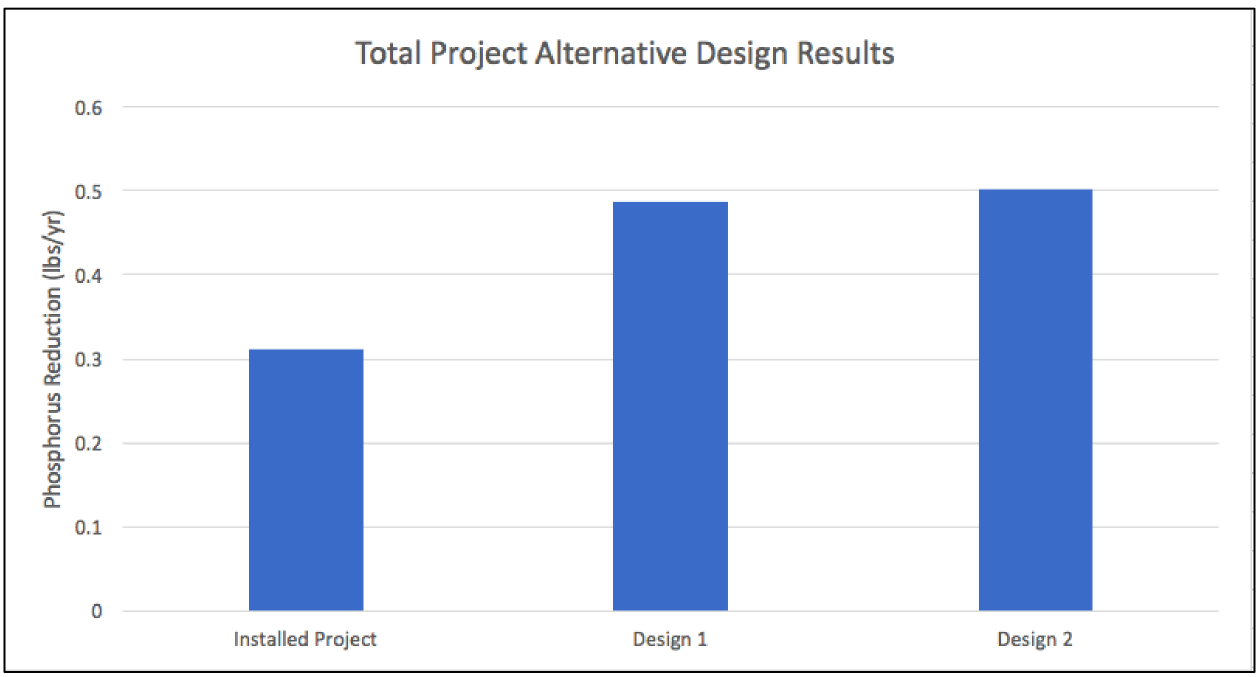

Figure 22: Total Project Alternative Design Results for 130 Brookline Street

The 130 Brookline street analysis contained four BMPs with four corresponding sub-catchment areas. Therefore, this process of interactions for impervious versus pervious area and BMP alternates was repeated four times over for various BMPs. Considering changes in impervious to pervious area ratio and BMP changes, the team produced two alternative designs as seen in Figure 22. The installed project conditions were utilizing 79.2% impervious area and 20.8% pervious area and two porous pavements and two bioretention systems. Phosphorus credit for this installed project was 0.311 lb/year. Two variations of the design were produced that significantly improved the phosphorus credit for the site.

The first alternative design utilized changes in BMP type only. Because the drainage area of 0.007 acres was so small for the bioretention system, any changes in BMP did not raise the credit. However, the two porous pavements were changed to infiltration trenches. This alteration, to meet the BATT criteria, would involve removing the reservoir underneath and underdrain within the porous pavement temporary storage system. The ease of change was present and the alternative design credit was 0.487 lb/yr of phosphorus removal. Considering a baseline load for the site of 0.495 lb/yr, the effect of simply allowing infiltration beneath the porous pavements was substantial.

The second alternative design incorporated changes in both the BMP and the distribution of impervious to pervious area within each sub-catchment. As discussed in the impervious versus pervious area distribution section, one porous pavement sub-catchment was altered to a distribution of half impervious, half pervious area. The porous pavement was also changed to an infiltration trench. The amount of pervious area allowing water to infiltrate raised the phosphorus credit from 0.121 lb/yr to 0.192 lb/yr just for this subcatchment. A similar process was repeated for the second porous pavement subcatchment, changing the distribution to all impervious area. In finality, the design changing area distributions and BMPs produced a 0.502 lb/yr phosphorus credit. Considering a baseline phosphorus load of 0.479 lb/yr, this was a complete removal.

Table 22 below contains information about each alternative design broken down by the increased credit from the structural BMP and the land use change. Taking into account the increase in phosphorus removal simply by changing the type of BMP, it may be advantageous for the developer to allow infiltration since the soil group of the land is HSG A. The increased credit from changing the ratio of impervious to pervious area may not be substantial enough to be worth the expense of altering the acreage of impervious area.

Table 22: 130 Brookline Street Alternative Design Breakdown

Design	Structural BMP (lb/yr)	Land Use Change (lb/yr)	Baseline Phosphorus Load (lb/yr)	BMP Removal Efficiency
Alternative 1	0.192	N/A	0.495	98.3%
Alternative 2	0.164	0.093	0.479	100%

4.3.2.2: Alternative Design for 131 Harvard Street

In the 131 Harvard Street project, the developer built a high density residential building that occupied the majority of the 0.263 acre site. The roof of this building was one subcatchment for this project, where stormwater was collected and brought to an underground detention tank on site. The other subcatchment for the project did not have any BMPs within it and consisted of a sidewalk and a landscaped area above the detention tank. Permeable soil on site was HSG A if uncovered and HSG C if paved over. Alternative designs for this subcatchment then involved changes in impervious versus pervious area and implementation of new BMPs. Table 23 shows as-built conditions for the site.

Table 23: Implemented Site Conditions for 131 Harvard Street

	Subcatchment 1	**Subcatchment 2**	**Total**
Land Use Group	HDR	HDR	
HSG	N/A	A	
Acreage (I)	0.195	0.034	0.229
Acreage (P)	0	0.034	0.034
BMP	Dry Pond	None	
Storage Volume (ft^3)	534	N/A	
BATT Phosphorus Reduction (lb/yr)	0.048	0	0.048
Baseline Phosphorus Load (lb/yr)	0.452	0.080	0.532

When starting the alternative design analysis, the team first analyzed the roof subcatchment area. Considering the installed 100% impervious roof design roof, the team decided the only applicable alternative option was 100% pervious roof. Therefore, 100% pervious options were tested to represent the implementation of a green roof. HSG was changed in these scenarios to account for various design choices present in green roofs. The team chose to use HSG B to represent a green roof as it would be a conservative approximation of a designed infiltration rate.

The team also looked into changes for the current structural BMP, which is only applicable when the roof is impervious. The team chose options such as infiltration basin, infiltration trench, and wet pond that produced higher credits and would be easier redesigns. When trying these other BMPs, the team used the same storage volume as the detention tank. For a conservative estimate on infiltration efficiency while also considering the performance of HSG A soils, the team used 2.41 in./hr for the infiltration rate. The group chose to pursue the infiltration basin for site analysis because it had the highest yield and only needed an infiltration mechanism in the redesign.

Then, the team looked at a similar process for the subcatchment around the building. This analysis was more complex for the redesign because two soil groups were considered when changing impervious area coverage and there was no structural BMP implemented in this area. Impervious area coverage was decreased in 5% increments because of the available space in the subcatchment. Increasing pervious area from the original 50-50 split introduced pervious area with HSG C, a soil group with low levels of infiltration. Therefore no benefits were obtained for increasing pervious area until 65% pervious area coverage, as seen in Figure 23 below. However, this would take away too much impervious area, in the form of pedestrian paths and other necessary spaces, to make this change worthwhile. In the other direction, increasing impervious area would create a negative land use change and cover the detention tank, making maintenance, and this option, impossible. Based on the findings, the team decided there could be no land use change in this area. The one condition that would reverse this decision would be a site design with no structural BMP from the roof.

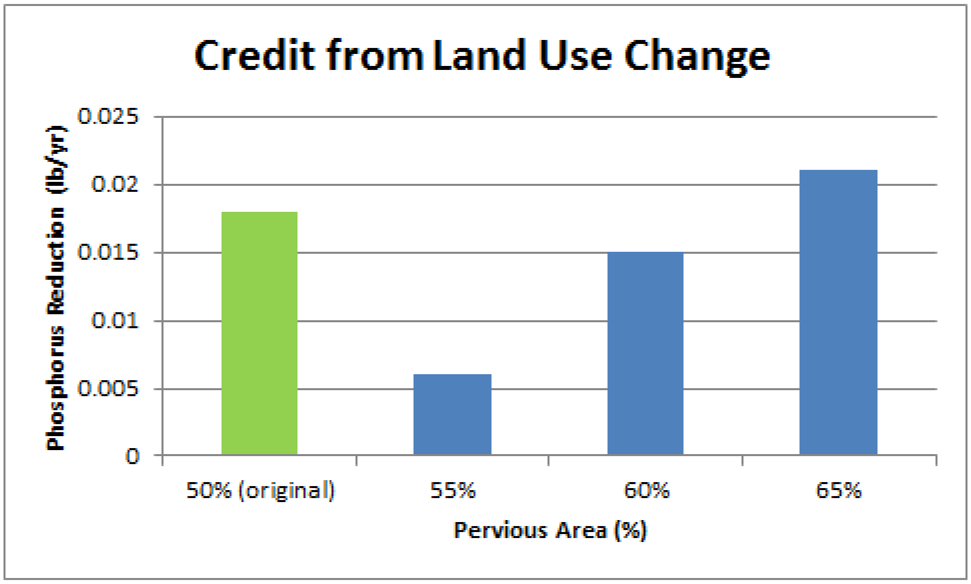

Figure 23: Alternative Design Credit from Land Use Change

Because of the small subcatchment areas in this site, only certain BMPs were explored. These were infiltration trench, porous pavement, bioretention, and enhanced bioretention. Porous pavement was explored for depths of 12 and 32 inches, with 32 inches producing the best results. Bioretention and enhanced bioretention were explored as options to replace the landscaping above the installed detention tank. Therefore, the area above the detention tank was used with conservative depths and average soil porosity. The infiltration trench was assumed to have a storage volume of 187 ft^3, proportional to the size of its subcatchment. However, this oversized the infiltration trench upon storage volume analysis. Rather, a storage volume of 100 ft^3 was used with 2.41 in/hr, creating the optimal BMP for the site, as seen in Figure 24.

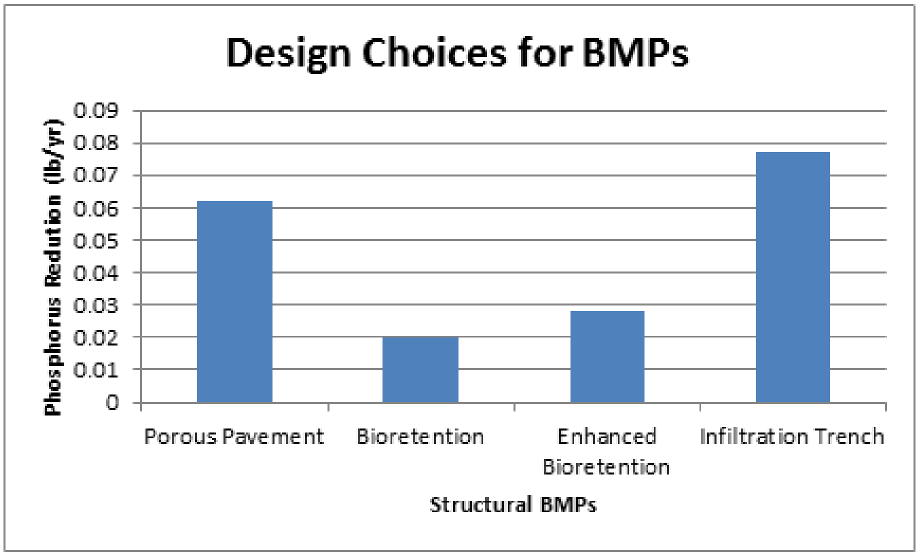

Figure 24: Alternative Design Choices for BMP Type

Four alternatives were chosen for the complete site design. Alternative 1 was the installed site design with the detention tank treating the roof runoff. Alternative 2 would be replacing the roof with a green roof and creating 100% porous pavement around the rest of the site. This would require major site modifications, but would reduce the baseline load and increase BMP removal efficiency without the need for infiltration. Alternative 3 changes the detention tank into an infiltration basin and implements infiltration trenches for the other subcatchment area. This may be the easiest to implement as it would require the addition of weeping holes in the detention tank and infiltration pipes or other mechanisms designed into other areas of the site. Alternative 4 changes the impervious roof to a green roof and also implements infiltration trenches for the other subcatchment area. This would also involve major modifications because of the addition of the green roof. Similar to Alternative 2, this design also greatly reduces the site's baseline phosphorus load. Table 24 and Figure 25 represent the credits from these alternatives.

Table 24: Alternative Site Designs for Harvard Street

Design	Impervious Acreage	Pervious Acreage	Structural BMP (lb/yr)	Land Use Change (lb/yr)	Total Credit (lb/yr)	Baseline phosphorus load (lb/yr)	BMP Removal Efficiency
Alternative 1	0.229	0.034	0.048	0	0.048	0.535	9.0%
Alternative 2	0.034	0.195	0.114	0.351	0.465	0.181	63.0%
Alternative 3	0.229	0.034	0.513	0	0.513	0.535	95.9%
Alternative 4	0.034	0.229	0.077	0.429	0.506	0.103	74.8%

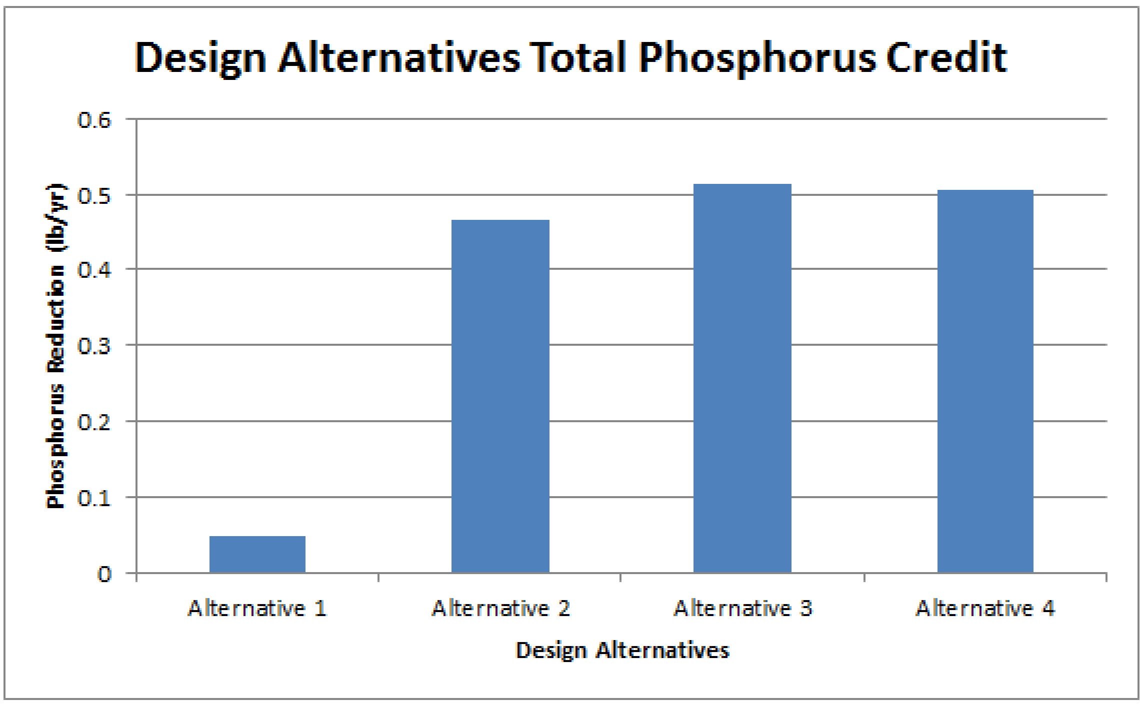

Figure 25: Design Alternatives Total Phosphorus Credit for Harvard Street

If a developer were to redesign the site, Alternative 3 should be chosen. This is because it receives the most credit and has the easiest redesign, as previously discussed. Since the water table for this project was seven to nine feet below grade, it may be possible for these infiltration BMPs to be implemented. However, more analysis should be completed regarding hazardous material in the soil and operation and maintenance needed for functionality.

If infiltration cannot be used on this site, the best design would then be Alternative 2. This would also increase the pavement around the building, potentially increasing walking and parking areas for residents. Though landscaping would decrease around the building, residents would enjoy a rooftop green space. These BMPs, if enacted, would need extensive operation and maintenance considerations.

4.3.2.3: Alternative Analysis for 262 Monsignor O'Brien Highway

This project was originally done to demolish an existing car wash and replace it with a seven-story apartment complex. The installed site had four subcatchments and three BMPs. There was one subcatchment that was designed to go directly to a reach instead of first being treated by a BMP. This was one of the reasons the team chose to evaluate the project for alternative design. The other three BMPs were an infiltration trench and two dry ponds. The team felt that with the aid of BATT, more efficient BMPs could be designed to replace the dry ponds. The conditions for the installed project site are described below in Table 25.

Table 25: Installed Site Conditions for 262 Monsignor O'Brien Highway

	Subcatchment 1	Subcatchment 2	Subcatchment 3	Subcatchment 4	Total
Land Use	HDR, HSG C	HDR, HSG C	HDR, HSG C	HDR, HSG C	
Impervious Acreage	0.001	0.001	0.088	0.131	0.221
Pervious Acreage	0.032	0.121	0	0.106	0.259
BMP	Dry Pond	Dry Pond	Infiltration Trench	None	
BATT Phosphorus Reduction (lb/yr)	0.001	0	0.194	0	0.195
Baseline Phosphorus Load (lb/yr)	0.009	0.0278	0.204	0.326	0.567

The team decided to focus on Subcatchments 1, 2, and 4 because they had the most potential to achieve a higher phosphorus reduction from BATT. Since subcatchment three is already an infiltration trench, and 100% impervious, it is already attaining the highest phosphorus reduction in BATT.

4.3.2.3.1: Design for Subcatchment 1

Since BATT calculates more phosphorus credit for structural BMPs when there is more impervious area, the team first evaluated the change in phosphorus reduction when the acreage composition was changed. Subcatchment 1 was originally composed of 97% pervious and 3% impervious land. The results shown in Figure 26 below demonstrate the changes in the phosphorus credit for the alterations that the team made. The original design created an almost completely pervious subcatchment; therefore, permeability was changed in 25% intervals. The blue bars represent the change in phosphorus credit from the installed structural BMP, and the red bars represent the change in phosphorus reduction from the installed land use composition. The green bars represent the net change from the installed design when taking the phosphorus credit from the structural BMP and subcatchment area into consideration.

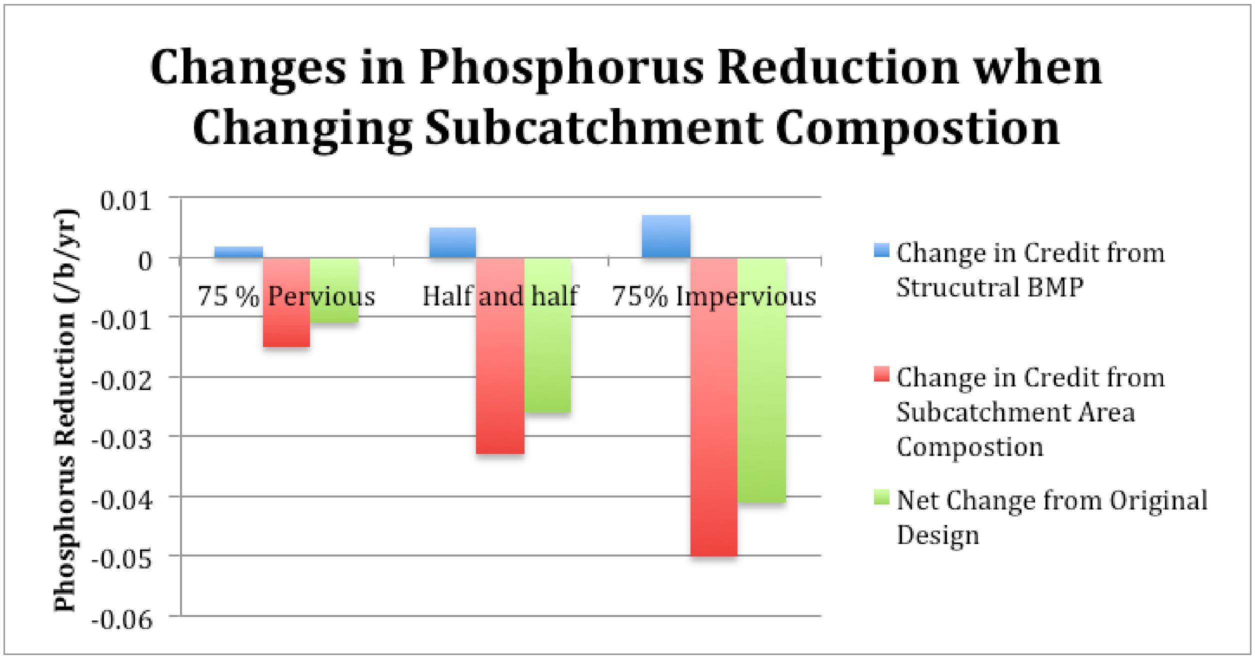

Figure 26: Changes in Phosphorus Reduction when Changing Subcatchment Composition

Based on Figure 26, it seems as though changing the land use only reduced the overall phosphorus reduction for this site. The team knew that dry ponds are not very efficient BMPs from the sensitivity analysis portion of the project, and that the phosphorus reduction of a different BMP would outweigh the negative phosphorus change from the land use conversion. From analyzing changes in distribution of pervious and impervious area, the team concluded that an ideal acreage distribution to move forward with would be 75% pervious area, because it results in the least net change in phosphorus reduction from the installed site design.

The team decided to next change the BMP type for this subcatchment, but kept the installed land use conditions the same – 0.032 acres pervious, 0.001 acres impervious – to solely focus on how the BMPs performed. The BMPs were chosen based on the team's findings of the most effective BMPs in the sensitivity analysis. Altering solely the BMP, the infiltration trench and infiltration basin performed the best. These results for the phosphorus reduction of each BMP are represented by the blue bars below in Figure 27.

To further analyze how the site would be affected by changing the BMP type, the team also decided to analyze these BMP options with the ideal change in impervious versus pervious area distribution of 75% pervious area. In Figure 27 below, the blue bars represent the BMP removal in the installed land conditions, and the red bars represent the BMP removal under the ideal impervious versus pervious area conditions.

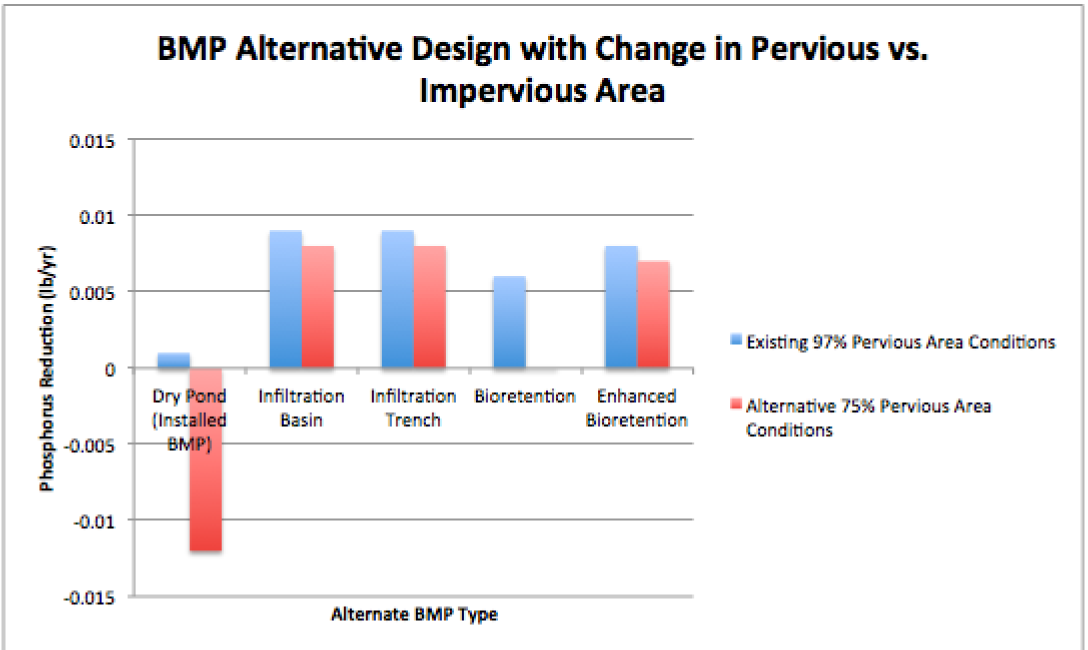

Figure 27: BMP Alternative Design with Change in Pervious vs. Impervious Area

It is clear that there are more efficient BMPs that could be installed in this subcatchment, which would also result in a greater phosphorus reduction under altered land use compositions.. The only BMPs that were not efficient enough to balance out the negative change in phosphorus reduction from changing the land composition were the bioretention and dry pond. This leaves the infiltration basin, infiltration trench, and enhanced bioretention as alternate options with 75% pervious area. Ultimately, the team felt that the infiltration basin would be the best choice for Subcatchment 1. Although the infiltration trench and infiltration basin have the same phosphorus reductions, it may be easier to convert the dry pond to an infiltration basin based on the available space of the site. Though this analysis only described Subcatchment 1 in detail, the other subcatchments chosen were analyzed in a similar thorough fashion.

4.3.2.3.2: Creating a BMP for Subcatchment 4

The main goal of this alternative design was to increase the phosphorus reduction for this site. Since subcatchment four does not have a BMP, the team chose to create one using various scenarios in BATT. This subcatchment currently has 0.131 acres of impervious area, and 0.106 acres of pervious area.

From the sensitivity analysis portion of the project, the team found that the infiltration trench and infiltration basin are generally the most effective BMPs. The team focused on these two BMP types, first with several different acreage compositions. The land use was kept as HDR, with an HSG C. A storage volume of 1050 ft^3 was used in this trial, and was chosen because this subcatchment area is nearly double that of Subcatchment 2 with a storage volume of 525 ft^3. The results using the infiltration basin and infiltration trench were quite similar, and the team decided to use the infiltration basin to be consistent with the designs for Subcatchments 1 and 3.

The team conducted a similar process to that of Subcatchment 1 when determining the best acreage composition for Subcatchment 4. Ultimately, the best option would be to have Subcatchment 4 be 75% pervious, as that resulted in a net phosphorus reduction of 0.316 lb/yr when considering the BMP performance and land use change.

After selecting an ideal BMP and land composition combination, the team started a process of fine-tuning the storage volume. The team was able to gradually increase and decrease the storage volume size to find the best size for the BMP and site conditions. The results are presented below in Figure 28.

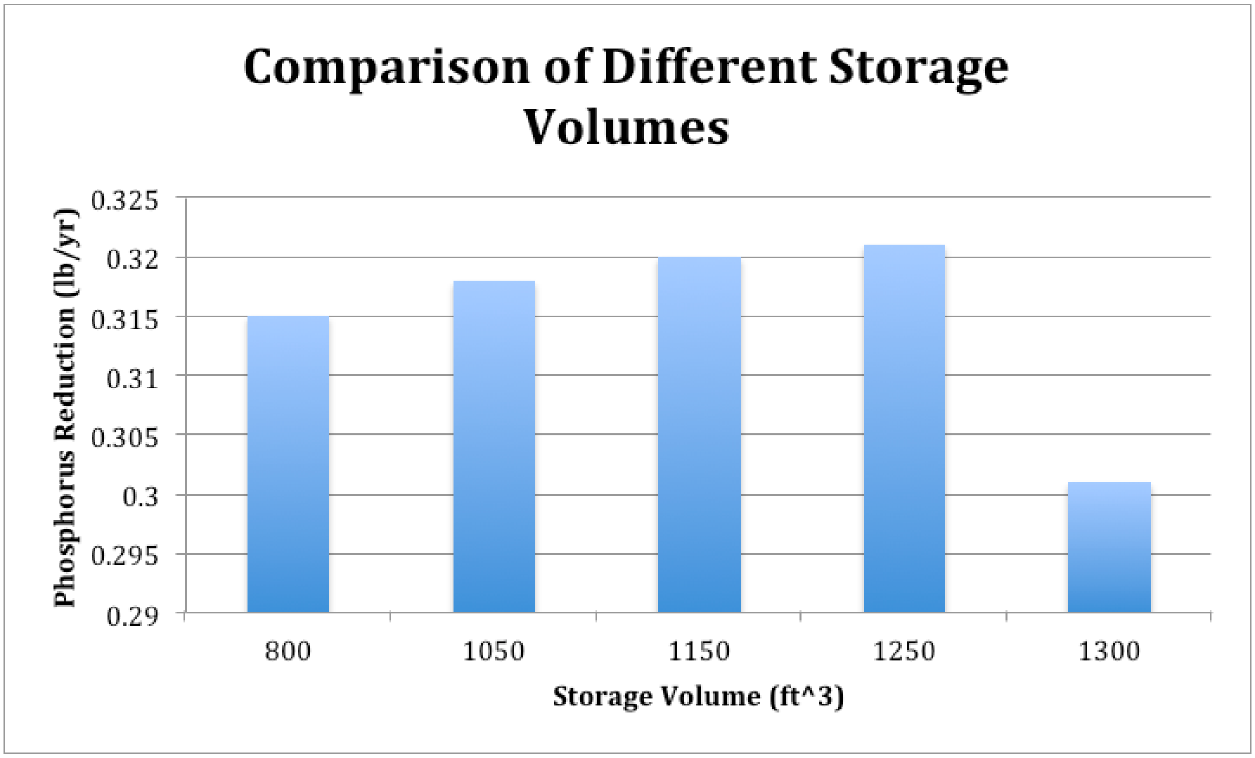

Figure 28: Comparison of Different Storage Volumes

Ultimately, the most effective storage volume was 1250 ft^3. This resulted in a phosphorus reduction of 0.321 lb/yr, the highest of all the design options.

4.3.2.3.3: Complete Site Design

This overall alternative design analysis involved creating different scenarios with ideal pervious versus impervious areas and BMPs. It also proposes a new BMP for a subcatchment with stormwater that is not currently being treated. The team composed four design alternatives to be considered. They are presented below in Table 26 and in Figure 29. Design 1 involves keeping the entire site as it is. Design 2 changes the two dry pond BMPs to infiltration basins, and keeps the other infiltration trench. The acreage composition was not altered. Design 3 becomes more complex, as both dry ponds are changed to infiltration basins, and the ratio of pervious to impervious area is altered. Design 4 has the greatest phosphorus reduction. However, it would be the most expensive of the alternatives, since it involves changing two dry ponds to infiltration basins, installing an infiltration basin, and altering the acreage composition.

If funding is available, Design 4 would be the best selection for a developer as the BMP removal efficiency would be 97%. Realistically, this redesign would be very intricate and require many changes to the site. Design 2 would be a more realistic selection, as it does not involve changing the acreage composition. The only changes would be transforming the dry ponds to infiltration basins. Design 2 is slightly less efficient than Design 3, but Design 3 would have a higher cost and be more difficult to execute than Design 2 due to all of the changes it would involve.

Table 26: Alternative Site Designs for 262 Monsignor O'Brien Highway

Design	Impervious Acres	Pervious Acres	Structural BMP Phosphorus Removal (lb/yr)	Land Use Change Phosphorus Removal (lb/yr)	Baseline Phosphorus Load (lb/yr)	BMP Removal Efficiency
1	0.221	0.259	0.199	0	0.567	35%
2	0.221	0.259	0.229	0	0.567	40%
3	0.258	0.222	0.302	-0.077	0.645	47%
4	0.305	0.176	0.722	-0.176	0.744	97%

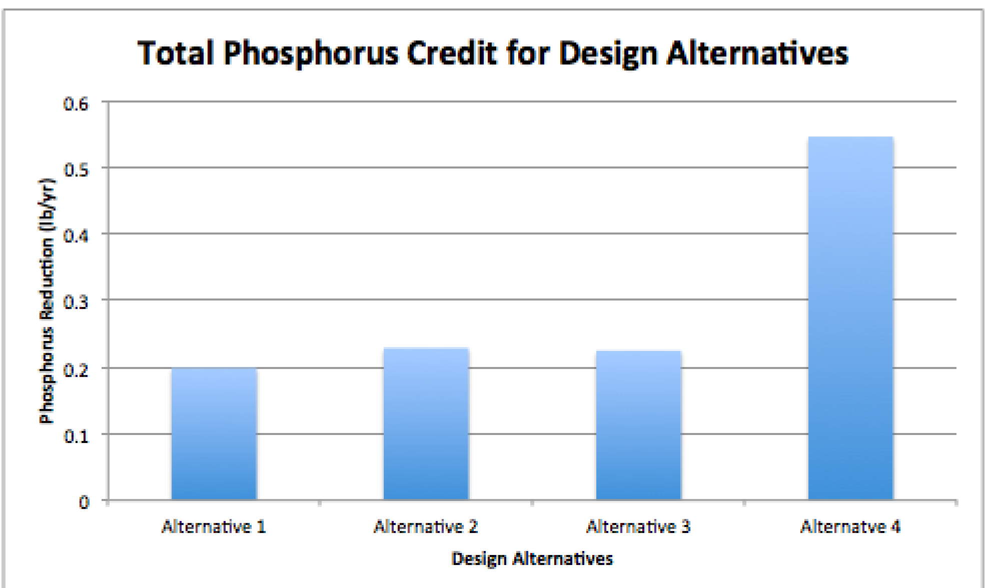

Figure 29: Total Phosphorus Credit for Design Alternatives for Monsignor O'Brien Highway

4.3.3: Product to Enhance the Usability of BATT

As a part of the design element for this project, the team created a template for Cambridge developers to use when they are inputting structural BMPs into BATT. The template has various components, one being a flowchart for categorizing structural BMPs. It also includes a list of characteristics of the structural BMPs available in BATT and other BMPs that may fall under BATT BMP options. To help developers organize their information, there is also a list of the necessary input parameters needed for each BMP in BATT. The flowchart is shown below in Figure 30, and is also available in Appendix I with the entire template.

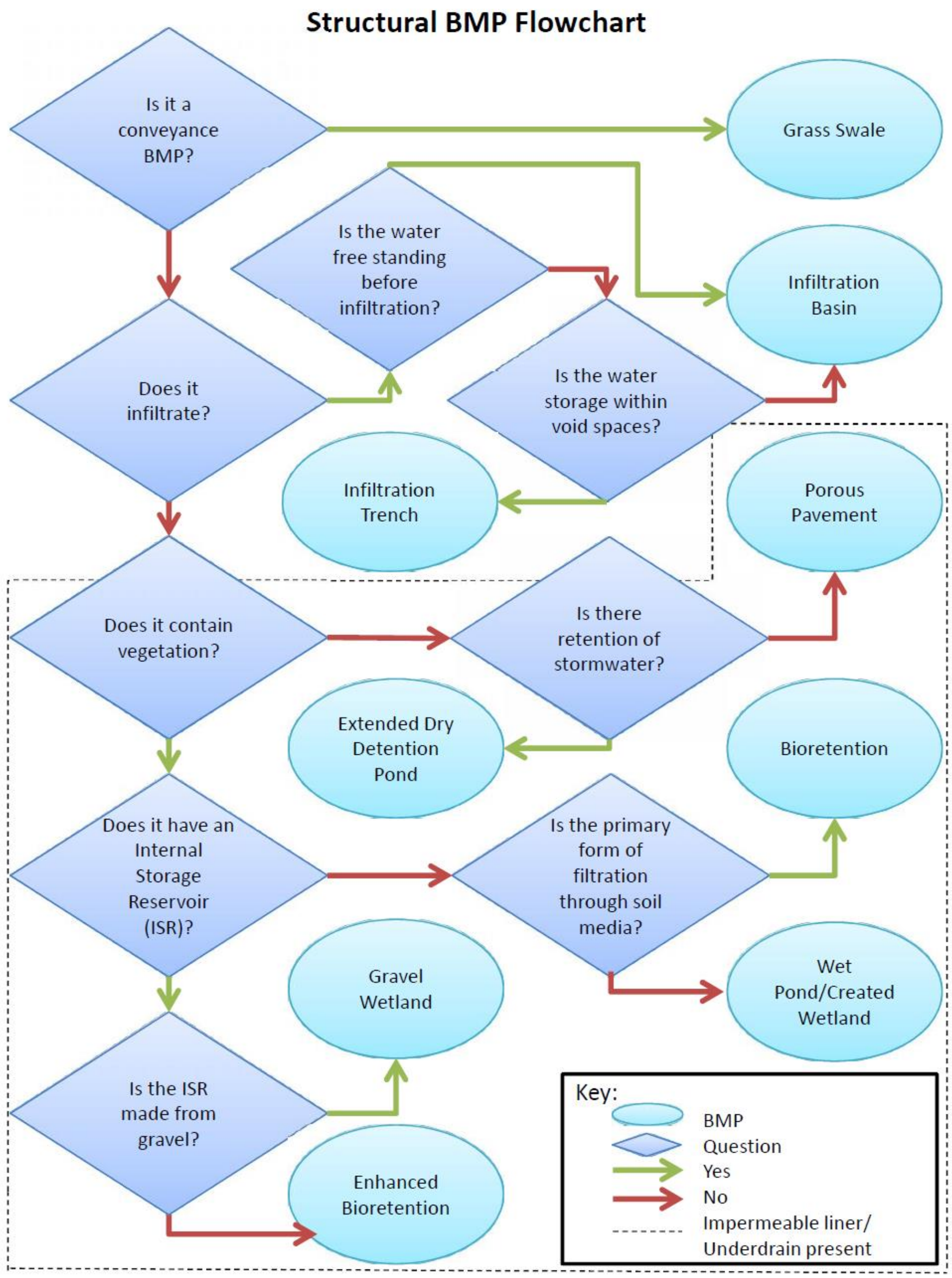

Figure 30: Structural BMP Flowchart from Template

To create the flow chart, the team referenced structural BMP descriptions in Volume 2 of the Massachusetts Stormwater Handbook, BATT, and the MS4 permit to design questions to help guide the user in categorizing his or her BMPs in BATT[103,104,105]. This is very important, as BATT has a limited amount of BMPs to choose from and developers will need to become accustomed to learning how to categorize their BMPs in BATT. For example, BATT only has two options for infiltrating BMPs: infiltration basin and infiltration trench. In some cases, the team recommends categorizing porous pavement as an infiltration trench in BATT if the runoff infiltrates directly into the ground rather than being directed to a storm-sewer. This is because BATT assumes that the porous pavement has an impermeable liner, and the water does not infiltrate - it is directed to the storm drain. Since the aspects of how the BMPs are designed are very important in categorizing the BMPs in BATT, most of the questions in the flowchart revolve around the workings of the BMP and components used to create it.

To create the list of BMPs that could be categorized as BMPs in BATT, the team also referred to work done by the UNHSC. The UNHSC developed a chart, titled "Crosswalk" that categorizes BMPs in the Massachusetts and New Hampshire Stormwater Manuals under BMP options from the EPA. This document was obtained during the team's interview with Dr. Houle, a professor at UNH, and served to be very useful to the team in making the developer template[106].

The developer template is meant to help streamline Cambridge's process for BATT entries. It is designed to be simple and comprehensive, so that users can easily categorize their BMPs in BATT and enter the necessary inputs into BATT to calculate phosphorus credits. Ultimately, the developer template can help Cambridge begin its process of using BATT to keep track of the phosphorus credits it receives for various retrofits and developments.

[103] MassDEP. (2008). "Volume 2 Chapter 2: Structural BMP Specifications for the Massachusetts Stormwater Handbook". *Massachusetts Stormwater Handbook and Stormwater Standards*. Boston, MA.
[104] (Tetra Tech, 2016, Excel)
[105] (USEPA, 2017, Attachment 3 of Appendix F)
[106] UNHSC. (2017). *BMP Definition Crosswalk Draft 3*. PDF from Personal Communication with [S. Cappelli, A. Locke, & J. Wey].

5.0: Conclusions

The goal of the project was to work with Stantec to help Cambridge effectively use the Best Management Practices (BMP) Accounting and Tracking Tool (BATT) to analyze site design improvements that will reduce phosphorus loading in the Charles River. The team met this goal by completing several objectives. After gaining an understanding of the interface and calculations of BATT, the team created a user guide that encompasses tips for effective use of the software. This includes how to operate BATT on computers that do not have the 2013 versions of Microsoft Word and Excel, discrepancies between BATT and Appendix F of the Municipal Separate Storm Sewer System (MS4) Permit, and main takeaways from the sensitivity analysis. The team also validated BATT using data from the University of New Hampshire Stormwater Center (UNHSC) and Charles River Watershed Association (CRWA) to determine how well the software emulates and agrees with real data. Lastly, the team analyzed three Cambridge stormwater redevelopment projects to propose alternative designs using BATT to predict phosphorus credits. To help Cambridge developers in their future efforts of reducing phosphorus loading to the Charles River, the team created a template in which developers can organize BMP and site characteristics to enter into BATT. The main conclusions from this project are presented below:

5.1: Assessed Foundation and Usability of BATT

The purpose of BATT is to emulate the phosphorus credit calculations outlined in Appendix F of the MS4 Permit. However, with close examination, the team found discrepancies between Appendix F and BATT. The "No Application of Fertilizer with Phosphorus" option in BATT does not have the correct phosphorus credits - these credits can be found in the Appendix F Response to Comments. BATT is also missing the "Annual Frequency Factor" used in Appendix F to calculate phosphorus credits for sweeper technologies. Lastly, BATT lacks a reference table that Appendix F utilizes for land use conversion calculations when there is a conversion from impervious to pervious area. It is important to keep all these differences between BATT and Appendix F in mind when calculating phosphorus credits, as BATT does not exactly follow all of the Appendix F equations.

5.2: Performed Sensitivity Analysis

From the sensitivity analysis of BATT, the team found that whenever it is possible in a site, infiltration BMPs should be used to treat the stormwater. Developers must be aware that if they have designed a BMP that infiltrates, it must be either categorized as an infiltration basin or an infiltration trench to receive proper credit for infiltration. Additionally, the sensitivity of storage volume indicated that the volume should be properly correlated with the acreage of drainage area. It was also discovered that BATT will produce less phosphorus credit for structural BMPs that have sub-catchment areas with Hydrologic Soil Group (HSG) A than HSG D. Less stormwater will reach a BMP when HSG A is present, since HSG A provides more infiltration than HSG D.

5.3: Validated with UNH and CRWA Data

The team conducted a model validation of BATT utilizing the monitoring data from the University of New Hampshire Stormwater Center (UNHSC) and Charles River Watershed Association (CRWA). Comparing monitoring results to BATT outputs, the CRWA porous pavement project had a fair correlation with BATT. However, UNHSC monitoring data indicated much higher phosphorus reductions than BATT produced for the same BMP inputs. Reasoning for this discrepancy included differences in the assumptions made for baseline phosphorus loading in the field data and BATT being a conservative model.

5.4: Analyzed Cambridge Projects for Design Recommendations

When engineers and developers are designing stormwater treatment for a given site, it is important to be aware of the baseline phosphorus load. In Cambridge, all of the sites that the team evaluated had low phosphorus baseline loads resulting in an even lower phosphorus reduction credit that developers can attain. Therefore, many of these small projects in Cambridge will be required to reach the phosphorus reduction requirement of 604 lb/yr.

Further developing the alternative designs using the structural BMP section of BATT to calculate phosphorus credit, phosphorus reduction is higher for a site when it has more impervious than pervious land. More impervious land produces higher reductions because more stormwater is reaching the BMP than infiltrating into the pervious soil. To account for changing the impervious versus pervious makeup of a site, the land use conversion section of BATT also must be used. This will balance out the higher phosphorus credit a developer may have received from having increased impervious area, decreasing the overall phosphorous credit for a site if the site has an increased impervious area.

While considering results for alternative design, it is important to note that the ideal choices were based solely on the credit calculated by BATT. When a developer decides on a design or retrofit, he or she should consider the site conditions and ability to maintain the BMP. For instance, a developer should determine the water table level before selecting a BMP that infiltrates to ensure that phosphorus does not seep into the groundwater. In addition, the developer may want to consider the hydrologic soil group when considering adding pervious area or an infiltration BMP. The most effective BMP that BATT predicts also may not be feasible to maintain and would therefore not be an ideal BMP in the long term.

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6.0: Appendices

Appendix A: Project Proposal

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Striving for Phosphorus Removal in Cambridge Using the BMP Accounting and Tracking Tool

A Major Qualifying Project Proposal Submitted By:

Stephanie Cappelli
April Locke
Jessica Wey

December 15, 2017

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Glossary of Terms

ABET - Accreditation Board for Engineering and Technology
BATT - Best Management Practices Accounting and Tracking Tool
BMP - Best Management Practices
CRWA - Charles River Watershed Association
DSV - Control Design Volume
EPA - Environmental Protection Agency
GIS - Geographic Information Systems
HSG - Hydrologic Soil Group
IA - Impervious Area
MQP - Major Qualifying Project
MS4 - Small Municipal Separate Storm Sewer System
NOI - Notice of Intent
NPDES - National Pollutant Discharge Elimination System
NRCS- National Resources Conservation Service
PA - Pervious Area
PCP - Phosphorus Control Plan
PLE - Phosphorus Load Export Rate
PRF - Phosphorus Reduction Factor
SWIP - Stormwater and Wastewater Infrastructure Permits
SWMP - Stormwater Management Plan
TA - Total Area
TMDL - Total Maximum Daily Load
TN - Total Nitrogen
TP - Total Phosphorus
TSS - Total Suspended Solids
UNH - University of New Hampshire
WPI - Worcester Polytechnic Institute

Capstone Design

The Accreditation Board for Engineering and Technology (ABET) requires that students demonstrate knowledge and skills they acquire throughout their coursework and studies through a capstone design experience. The capstone design experience must incorporate engineering principles that are applied to realistic design constraints. In this project, the team will analyze and validate calculations in the Best Management Practice (BMP) Accounting and Tracking Tool (BATT) software based on Cambridge data. With this knowledge, the team will design a template for developers to use that will pertain to Cambridge's unique conditions. The template will organize data about site conditions and other pertinent BATT inputs, allowing Cambridge officials to discern proposed projects that are effective in reducing phosphorus content in the Charles River. In doing so, the project will meet the ABET realistic constraints as follows:

Environmental:

A major piece of this project is to decrease Cambridge's phosphorous output into the Charles River. Overloading water systems with phosphorus can lead to environmental degradation, decreased dissolved oxygen concentration, and algae blooms that lead to formation of cyanobacteria. Environmental factors such as the Hydrologic Soil Group (HSG) inform the uptake of stormwater and effectiveness of BMPs. The team will work with Stantec to adapt BATT specifically for Cambridge's conditions, and design a template that will aid developers in making decisions for stormwater design, helping to reduce Cambridge's phosphorus loading.

Sustainability:

In order to be sustainable, the BMPs filtering stormwater runoff should be able to function with climatic changes and fluctuations in rainfall. When analyzing the design storage capacity of the BMPs calculated by BATT, the volume should be able to handle rainfalls in the 10- and 50-year flooding models. BMPs recommended for incorporation into redevelopments should also be built from low-impact and long-lasting materials. From this BATT analysis, the team can incorporate ideal BMP characteristics and sustainability goals into the final template design.

Ethical:

The team will adhere to the American Society of Civil Engineers Code of Ethics. Following these principles, the team will be unbiased in decision making for this project between Stantec and Cambridge. The team will try to provide the best recommendations for Cambridge to utilize BATT in a manner that will help it calculate phosphorus removal for its specific land characteristics. Furthermore, the team will hold itself to professional standards set by WPI and other agencies.

Health & Safety:

The Charles River has had problems handling ample phosphorus loads which cause the water to be dangerous for swimming and other recreational activities. The team hopes to improve the water quality of the Charles River. It will do so by working with Stantec to help Cambridge select designs to treat stormwater and decrease runoff phosphorus concentrations. This will primarily be done with the template so that developers can be more aware of site characteristics that contribute to phosphorus removal. The river will then experience less effects of contamination, reducing the potential of this hazard to both the environment and public surrounding the watershed.

Social:

The team is working closely with Stantec throughout this project experience. The team will mostly be in the Stantec office, where it will learn how to adapt to a professional environment and develop interpersonal skills with the Stantec employees. Respecting professional guidelines also includes ascertaining quality of the team's work from superiors to insure that it meets standards expected from Stantec work.

1.0: Introduction

The Charles River and its corresponding watershed have experienced issues regarding nutrient loading, particularly phosphorus. High concentrations of phosphorus can be detrimental to the health of a watershed and the people living in it[1]. Nutrient loading causes the occurrence of harmful cyanobacteria, a primary health concern. In the summer of 2015 alone, the Charles River was required to fly a yellow flag, indicating caution due to cyanobacteria in the water, for 65 days[2]. Cambridge, MA, a municipality near the Charles River, has been making efforts to reduce its phosphorus loading through stormwater management designs

Cambridge is the specific focus for this project in assisting with stormwater regulation compliance and phosphorus reduction for a number of reasons. To begin, the team is working for Stantec, a contractor hired by Cambridge to aid the city in minimizing phosphorus through site redevelopments. Additionally, Cambridge has a high percentage of impervious or paved surfaces, not allowing stormwater to infiltrate[2]. Another characteristic of Cambridge exacerbating the phosphorus loading issue is that Cambridge lacks land area containing hydrologic soil Group A, a highly pervious type of soil[3]. These aspects of the city are a factor in the daunting gap between Cambridge's current loading amount and the phosphorus loading requirement by the MS4 permit.

The Small Municipal Separate Storm Sewer System (MS4) Permit uses equations based on land use type to determine phosphorus loading requirements for each city. Cambridge's current baseline phosphorus load is 512 kg/yr, and the city faces an MS4 phosphorus restriction of 263 kg/yr[4]. To achieve this, Cambridge must cut its loading by 51% and implement strict restrictions on its developers. Small MS4 operators must file a Notice of Intent (NOI) to obtain authorization to discharge stormwater containing pollutants[5]. Additionally, Cambridge must formulate a Stormwater Management Plan (SWMP) containing planned measures to reduce its phosphorus loading, including sections like public outreach[4].

Environmental advocates such as the Charles River Watershed Association (CRWA) are collecting data and working with Cambridge officials to better strategize for stormwater management. The organization has various stormwater monitoring stations throughout the Charles River that report nutrient content in the water indicative of the city's progress[6]. The water is collected on a monthly basis for bacteria analysis and quarterly for phosphorus analysis[5]. Data from the CRWA will assist the team in performing a model validation of BATT results.

The Best Management Accounting and Tracking Tool (BATT) is a software used by the EPA to credit towns with Total Maximum Daily Load (TMDL) reductions per MS4

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[1] USEPA. (2017). *Environmental challenges for the Charles River*. Retrieved from: https://www.epa.gov/charlesriver/environmental-challenges-charles-river

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[4] USEPA. (2017). "Appendix F: Requirements for Discharges to Impaired Waters with an Approved TMDL" *Massachusetts MS4 General Permit*. Boston, MA

[5] USEPA. (2017). *Massachusetts Small MS4 General Permit History*. Retrieved from https://www.epa.gov/npdes-permits/massachusetts-small-ms4-general-permit.

[6] Charles River Watershed Association (2017). *Field Science.* Retrieved from http://www.crwa.org/field-science.

requirements. TMDL parameters include Total Phosphorus (TP), Total Nitrogen (TN), and Total Suspended Solids (TSS). When calculating these credits for a permittee, BATT has three major options: structural BMPs, non-structural BMPs, and land conversion. Structural BMPs are most commonly utilized, so they will be the focus for the team's research. BATT is a rather new program, as it became public in 2016[7]. Questions have surfaced around the usability of the interface and how BATT calculates the reductions. There also does not appear to be a way to incorporate proprietary BMPs into the system. Furthermore, reasonable phosphorus reduction results have not been achieved to match permit goals[8].

The goal of the project is to work with Stantec to help Cambridge effectively use BATT to analyze site design improvements that will reduce phosphorus loading in the Charles River. To work toward this goal, the team has devised several objectives. First, the team will work to understand existing conditions of BATT by analyzing the usability of the interface. A comparison between BATT calculations and the calculation requirements presented in Appendix F of the MS4 Permit will be conducted to verify correlations between the two methods. Using sample engineering reports, the team will also perform a sensitivity analysis by changing certain inputs to determine which produce the largest changes in BATT outputs. BATT calculations will then be validated by comparing BATT outputs to data collected by the CRWA and predictions of engineering reports for specific past site designs. Finally, the team will explore potential improvements to the BATT software. This involves assessing correlations of BATT calculations with other well-established methods, particularly the TR-55 method. The team anticipates developing a detailed user's guide to BATT as well as a template for developers to organize information about site conditions for BATT provided to Cambridge officials.

One of the anticipated deliverables is to create an in-depth user guide for BATT to clarify any initial issues that one may encounter with the software. The guide will explain the various inputs to BATT. To make it easier for Cambridge and developers to verify the accuracy of BATT inputs, the team will also design a template in the form of a spreadsheet or fillable PDF, thus meeting the design component for this project. This will help individuals organize their site condition data and other information before using BATT. Additionally, the team anticipates that a list of recommendations for any systematic adjustments to BATT and calculation explanations for phosphorus loading will be created. This project will also investigate alternative management strategies, such as proprietary BMPs implemented in Cambridge. Proprietary BMPs include settling or filtration mechanisms which capture pollutants, like phosphorus, before entering the sewer system[9]. Since these BMPs are not incorporated in the MS4 Permit for phosphorus reduction credits, the project will investigate how these BMPs can help Cambridge meet its requirement and count for credit in BATT.

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[7] Tetra Tech. (2016). *BMP Accounting and Tracking Tool (BATT): User's Guide*. Retrieved from: https://www3.epa.gov/region1/npdes/stormwater/ma/batt-users-guide.pdf

[8] D. Duhamel, Personal Interview, November, 27,2017

[9] Metropolitan St. Louis Sewer District. Proprietary BMPs. Retrieved from https://www.stlmsd.com/what-we-do/stormwater-management/bmp-toolbox/technology-matrix/proprietary-bmps.

2.0: Background

This chapter provides the reader with the necessary foundation to understand the scope of this project, as well as reasoning for the methodology. This portion of the report provides the following information: an overview of the Small Municipal Separate Storm Sewer System (MS4) Permit, a discussion of calculations outlined in Appendix F of the MS4 permit to determine phosphorus loading, the basics of the BMP Accounting and Tracking Tool (BATT), and a brief examination of the processes used to create a model.

2.1: MS4 Permit

A driving force behind the team's project for Stantec is the Small Municipal Separate Storm Sewer System (MS4) Permit and its restrictions set for nutrient loading in each city. This permit is under the National Pollutant Discharge Elimination System Permit (NPDES) required by the Clean Water Act and regulating discharges of pollutants through point sources. Cambridge is specifically incorporated into Phase II of the NPDES permit for separate storm drainage systems in high density urban areas.

Measures to comply with this permit are within the MS4 required general Stormwater Management Plan (SWMP) established in 2006 and then updated each year in the Small MS4 Permit Annual Report. Each summary of minimal control measures has six required sections including public education and outreach, illicit discharge detection and elimination, and construction site runoff control[11]. For instance, Cambridge's 2016 MS4 Permit Annual Report specifies updates in stormwater drainage systems, outfalls, and receiving waters in Geographic Information Systems (GIS) which could help identify where the phosphorus-heavy discharges were occurring[11].

Additionally, Cambridge's stormwater regulations are primarily in the form of city ordinances for the Cambridge Sewer Use Regulations. The regulations focus on addressing stormwater in construction development and redevelopment projects that disturb at least one acre of sewer system[12]. Cambridge requires its own Stormwater and Wastewater Infrastructure Permits (SWIP) for various inputs such as construction site dewatering, demolitions, and fats, oils, and grease[12]. The various tiers of stormwater regulations, local, state, and federal, have assured that cities like Cambridge have careful oversight in developments for phosphorus loading.

Appendix F of the MS4 permit outlines the requirements for discharges to impaired waters including specific Total Maximum Daily Loads (TMDL). There is a section that pertains specifically to the Charles River, with requirements for communities surrounding it. These communities are responsible for developing a Phosphorous Control Plan (PCP) as a part of their SWMP to demonstrate that they intend to comply with the MS4 permit. The PCP has four phases that span roughly 20 years from the permit effective date[4]. Each of these phases has several requirements for the municipalities to complete in order to demonstrate their phosphorus removal efforts. Cumulatively, the SWMP, PCP, and other local regulations detail measures that can account for MS4 phosphorus reduction credits in a city.

2.1.1: Structural BMP Calculations

There are eight structural BMP categories listed in Appendix F: Infiltration Trench, Surface Infiltration, Bio-filtration, Gravel Wetland, Porous Pavement, Extended Dry Detention Pond, Water Quality, and Wet Swale. The percent reduction of phosphorus for the structural BMPs is provided in the form of structural performance curves based on design storage capacity (DSV) of the BMPs. The data for these curves comes from a long-term study of performance. Performance also depends on infiltration rates. Infiltration was only modeled for the infiltration trench and surface infiltration, as all other structural BMPs would contain either an under-drain or impermeable liner. The six infiltration options are representative of saturated hydraulic soil conductivity[10]. Saturated hydraulic soil conductivity is a constant ratio between the hydraulic flux and the hydraulic gradient according to the National Resources Conservation Service (NRCS)[11].

Appendix F in the MS4 Permit provides some general steps to solve for percent reduction of phosphorus when the BMP, design storage volume, and land characteristics are known. The flowchart below in Figure 1 demonstrates the overall steps needed for this process:

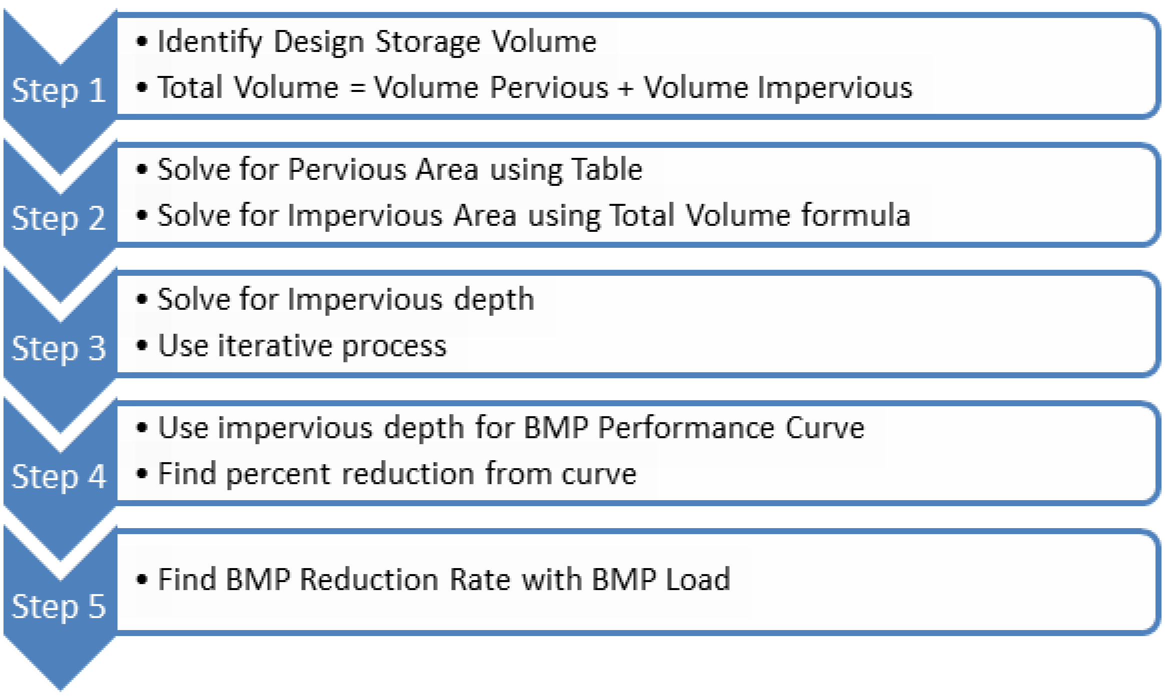

Figure 1: Flow Chart for Calculation of Structural BMP Phosphorus Credit

First, one must identify the drainage area of the BMP. Then, the land use type and soil groups can be identified for that area. Next, the storage volume should be determined for the BMP based

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[10] USEPA. (2017). "Attachment 3 to Appendix F: Methods to calculate phosphorus load reductions for structural stormwater best management practices in the watershed." *Massachusetts MS4 General Permit*. Boston, MA.

[11] US Department of Agriculture. (n.d.). "Soil Survey Technical Note 6." *NRCS: Soils*. (The contact for this technical note is the National Leader for Soil Classification and Standards, National Soil Survey Center, Lincoln, NE.) Retrieved from: https://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/ref/?cid=nrcs142p2_053573

on the design specifications[13]. This volume can also be broken down into two types of land use runoff as shown in the following equation[12]:

Equation 1: Storage Volume Calculation

$$Storage\ Volume\ of\ BMP = BMP\ Volume\ from\ Impervious\ Area + BMP\ Volume\ from\ Pervious\ Area$$

The BMP Volume from Pervious Area can then be solved for in the following equation[13]:

Equation 2: BMP Volume from PA

$$BMP\ Volume\ from\ Pervious\ Area\ (ft^3) = \sum_{n=1}^{n} PA_n D_n\ x\ (3{,}630 \frac{ft^3}{acre - in})$$

Where:
PA_n = Pervious Area (acre)
D_n = Runoff Depth for each Pervious Area (in)

Runoff depth information can be found in Table 3-3 from Attachment 3, Appendix F of the MS4 permit. Table 3-3 is shown below[14]:

Table 1: Developed Land Pervious Area Runoff Depths based on Precipitation Depth and HSGs

Rainfall Depth, inches	Runoff Depth, inches				
	Pervious HSG A	Pervious HSG B	Pervious HSG C	Pervious HSG C/D	Pervious HSG D
0.10	0.00	0.00	0.00	0.00	0.00
0.20	0.00	0.00	0.01	0.02	0.02
0.40	0.00	0.00	0.03	0.05	0.06
0.50	0.00	0.01	0.05	0.07	0.09
0.60	0.01	0.02	0.06	0.09	0.11
0.80	0.02	0.03	0.09	0.13	0.16
1.00	0.03	0.04	0.12	0.17	0.21
1.20	0.04	0.05	0.14	0.27	0.39
1.50	0.08	0.11	0.39	0.55	0.72
2.00	0.14	0.22	0.69	0.89	1.08
Note: Runoff depths derived from combination of volumetric runoff coefficients from Table 5 of *Small Strom Hydrology and Why it is Important for the Design of Stormwater Control Practices*, (Pitt, 1999), and using the Stormwater Management Model (SWMM) in continuous mode for hourly precipitation data for Boston, MA. 1998-2002					

Since rainfall depth is not known, iterations must be performed for the next set of calculations, BMP Volume from Impervious Area (IA). The BMP Volume for Impervious Area can be determined through the use of Equations 1 and 2. Then, two iterations of impervious area depth must be within 5% of each other for the volume obtained in Equation 2 to be considered

12 (Appendix F Attachment 3, 2017, pg 25)
13 (Appendix F Attachment 3, 2017, pg 26)
14 (Appendix F Attachment 3, 2017, pg 20)

acceptable[13]. Equation 3 displays the formula for impervious area depth used for the iterative process[15]:

Equation 3: BMP IA depth

$$Impervious\ Area\ Depth\ (in) = \frac{BMP\ Volume\ for\ IA\ (ft^3)}{IA\ (acre)}\ x\ \frac{12\frac{in}{ft}}{43{,}560\frac{ft^2}{acre}}$$

Once the iterations are in an acceptable error range, the percent phosphorus load reduction can be evaluated using the performance curve for the BMP, as shown in Figure 2. The last iteration for impervious area depth should be used when consulting the curve.

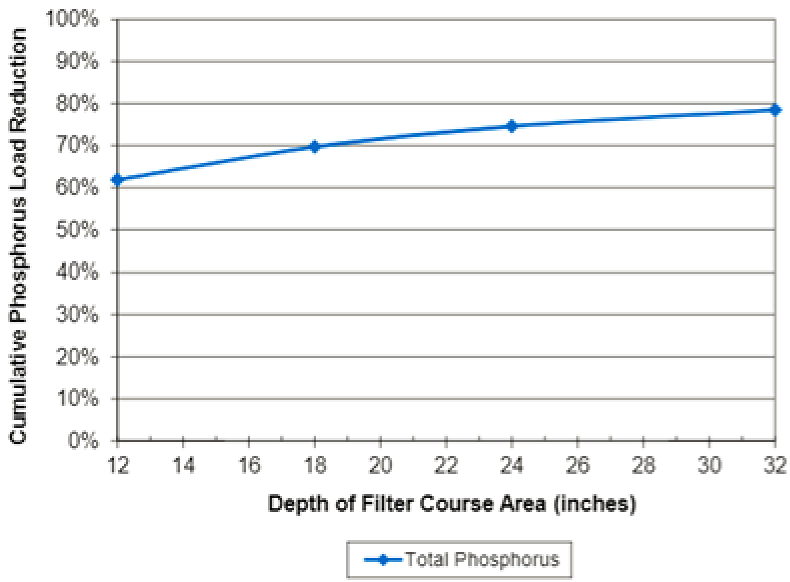

Figure 2: BMP Example Performance Curve for Porous Pavement[16]

When the phosphorus load reduction percent from the curve is taken, the final formula can be used to get the reduction of phosphorus in pounds per year. The BMP Load is also needed, which is either determined in calculations or from a value given in Table F-2 in Appendix F. The formula is below[17]:

Equation 4: BMP lb/yr reduction

$$BMP\ Reduction\ (lb\ P/yr) = \ BMP\ Load\ x\ (BMP\ Reduction\ \%P/\ 100)$$

If a town wants to use a different method for their calculations, there are several pieces of documentation that must be provided to the EPA. Calibration and calculations must be proven to be long-term and effective. Specifically, the model must simulate 10 years of data including climatic impact using hourly rainfall for the area. If the proposed method is not accepted, the permittee may receive only the minimal amount of credit for the area in question[13].

15 (Appendix F Attachment 3, 2017, pg 26)
16 (Appendix F Attachment 3, 2017, pg 48)
17 (Appendix F Attachment 3, 2017, pg 27)

2.1.2: Non-structural Calculations

Attachment 2 of Appendix F details the necessary calculations for determining phosphorus reduction credits for non-structural BMPs. This helps permittees measure compliance with phosphorus reduction requirements outlined in the MS4 permit utilizing more program and management-oriented strategies. The non-structural BMPs include enhanced sweeping programs, catch basin cleanings, eliminating use of fertilizers that contain phosphorus, and organic waste and leaf litter collection programs[18].

The provided formulas also incorporate various site conditions, such as pervious or impervious surfaces, and different land uses to make the calculated phosphorus credit more accurate to specific land areas. Below, Table 2 provides average phosphorus export load rates for different land use categories[19].

Table 2 - Proposed Average Annual Distinct Phosphorus Load Export Rates

Phosphorus Source Category by Land Use	Land Surface Cover	P Load Export Rate (lb/acre/yr)	P Load Export Rate (kg/ha/yr)
Commercial (Com) and Industrial (Ind)	Directly Connected Impervious	1.78	2.0
	Pervious	See DevPerv	See DevPerv
Multi-Family Residential (MFR) and High-Density Residential (HDR)	Directly Connected Impervious	2.32	2.6
	Pervious	See DevPerv	See DevPerv
Medium-Density Residential (MDR)	Directly Connected Impervious	1.96	2.2
	Pervious	See DevPerv	See DevPerv
Low-Density Residential (LDR)	Directly Connected Impervious	1.52	1.7
	Pervious	See DevPerv	See DevPerv
Highway (HWY)	Directly Connected Impervious	1.34	1.5
	Pervious	See DevPerv	See DevPerv
Forest (FOR)	Directly Connected Impervious	1.52	1.7
	Pervious	0.13	0.13
Open Land (Open)	Directly Connected Impervious	1.52	1.7
	Pervious	See DevPERV	See DevPERV
Agriculture (AG)	Directly Connected Impervious	1.52	1.7
	Pervious	0.5	0.5
Developed Land Pervious (DevPERV) – HSG A	Pervious	0.03	0.03
Developed Land Pervious (DevPERV) – HSG B	Pervious	0.12	0.13
Developed Land Pervious (DevPERV) – HSG C	Pervious	0.21	0.24
Developed Land Pervious (DevPERV) – HSG C/D	Pervious	0.29	0.33
Developed Land Pervious (DevPERV) – HSG A Developed Land Pervious (DevPERV) – HSG D	Pervious	0.37	0.41

Notes:

- For pervious area, if HSG is not known, assume HSG D conditions
- Agriculture pertains to row crops, hay fields, and pasture lands. Industrial land uses including government properties, hospitals, and schools are meant to be included in either commercial or industrial categories
- Impervious surfaces within the forest land use category are typically roadways adjacent to forested pervious areas

[18] USEPA. (2017). "Attachment 2 to Appendix F: Phosphorus Reduction Credits for Selected Enhanced Non-Structural BMPs in the watershed." *Massachusetts MS4 General Permit.* Boston, MA.

[19] (Appendix F Attachment 2, 2017, pg 2)

Each BMP has specific formulas for calculating yearly phosphorus reduction credits. There are also tables providing factors that pertain to each BMP, and are essential to properly calculate credits. For example, the formula for calculating phosphorus credits for catch basin cleaning is[20]:

Equation 5: Credit Calculation for Catch Basin

$$Credit_{CB} = IA_{CB} \ x \ PLER_{IC\text{-}and\ use} \ x \ PRF_{CB}$$

Where:

$Credit_{CB}$ = The amount of phosphorus load removed by cleaning the catch basin (lb/yr)

IA_{CB} = Impervious drainage area to catch basin (acres)

$PLER_{IC\text{-}and\ use}$ = Phosphorus load export rate for impervious cover and land use (lb/acre/yr), values obtained from Table 2

PRF_{CB} = Phosphorus reduction factor for catch basin cleaning, which equals 0.02 for a semi-annual cleaning

2.1.3: Calculating Phosphorus Load Increases Due to Development

When phosphorus loading from development increases (P_{DEVinc}), the baseline phosphorus load and reduction requirement will also increase. There are several steps involved to calculate phosphorus load increases due to development. Table 2 is necessary to perform these calculations, as it provides export rates[21].

The first step to calculating P_{DEVinc} is to obtain the baseline load. Calculations may be necessary for some regions, but for Cambridge, the baseline phosphorus load is set at 523 kg/yr[4].Then, one must determine where different parts of the development should be categorized into sub-areas in terms of land use and pervious or impervious soil. The phosphorus load due to development (PDEV) is then calculated for each land use category previously created by multiplying the subarea by the Phosphorus Load Export Rate (PLER) in Table 2. P_{DEVinc} is then calculated by subtracting the baseline load (523 kg/yr) from P_{DEV}[24].

For example, if there was a piece of land that was broken up into several categories, such as industrial, highway, and commercial, PDEV would be calculated by:

Equation 6: PDEV calculation

$$P_{DEV} = (TA_{indust} \ x \ PLER_{indus}) + (TA_{high} \ x \ PLER_{high}) + (TA_{com} \ x \ PLER_{com})$$

Leaving P_{DEVinc} to be:

$$P_{DEVinc} = P_{DEV} - Baseline\ Load$$

Where:

TA = total area (acres)

PLER = Phosphorus Load Export RATE (lb/acre/yr)

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[20] (Appendix F Attachment 2, 2017 pg 5)

[21] USEPA. (2017). “Attachment 1 to Appendix F: Method to Calculate Baseline Phosphorus Load (Baseline), Phosphorus Reduction Requirements and Phosphorus load increases due to development.” *Massachusetts MS4 General Permit*. Boston, MA.

2.1.4: Reporting

Six years after the permit effective date, permittees, in this case Cambridge, must submit an annual report. The report has several details, one of which includes all of the non-structural BMPs that have been implemented in the reporting year[4]. There should also be calculations consistent with those provided in Attachment 2 of Appendix F detailing the phosphorus reduction credits. The report also must include "structural controls implemented during the reporting year and all previous years"[22]. This involves the locations of the structural BMPs, either in the form of GPS coordinates or a street address. The phosphorus reductions from the structural BMPs also must be provided, and calculated based on requirements outlined in Attachment 3 of Appendix F. The date that each structural BMP was last maintained and inspected is also important to include in the report.

Permittees also need to include the amount of phosphorus loads that have increased due to development. Calculations for this are provided in Attachment 1 of Appendix F. The estimated amount of phosphorus that is expected yearly (P_{exp}) from the PCP location is also required in the report. This should be calculated using the equation below. By calculated P_{exp}, the municipality is "demonstrating compliance with the phosphorus reduction milestones required as part of each phase of the PCP"[25].

Equation 7: Calculation for Expected Phosphorus

$$P_{exp} = P_{base} - (P_{Sred} + P_{NSred}) + P_{DEVinc}$$

Where:

P_{exp} = Current phosphorous export rate from the chosen PCP area (mass/year)
P_{base} = Baseline phosphorous export rate from (Lake PCP) LPCP (mass/year)
P_{Sred} = Yearly phosphorus reduction from structural BMPs in the PCP (mass/year)
P_{NSred} = Yearly phosphorus reduction from non-structural BMPs in the PCP (mass/year)
P_{DEVinc} = Yearly phosphorus increase resulting from development since 2005 in the PCP (mass/year)

2.2: BATT

The EPA utilizes the Best Management Practices Accounting and Tracking Tool (BATT) to help municipalities keep track of credits earned for a BMP's reduction of phosphorus, nitrogen, and sediments. Municipalities can use BATT to make sure they are adhering to the MS4 permit and TMDL nutrient reduction requirements[7]. The software was created by Tetra Tech, and is intended to be used for US EPA Region 1. BATT is a spreadsheet-based tool that runs on Microsoft Excel. To effectively use BATT, the EPA recommends that Microsoft Excel and Word 2013 are used, along with the Microsoft Word 15.0 Object Library.

There are three main functions available in BATT[23]:

1. Accounting and Tracking of BMP Implementation;
2. Accounting and Tracking Changes in Land Use;
3. Reporting for nutrient load reduction

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[22] (Appendix F, 2017, pg 5)
[23] (Tetra Tech, 2016,pg. 5)

The Accounting and Tracking of BMP Implementation is used to evaluate nutrient load reductions of nutrient control methods that are currently being used. This part of the tool demonstrates compliance with MS4 Permit requirements[7].

The Accounting and Tracking Changes in Land Use helps to document changes in development and "impervious cover within a permitted area or watershed"[18]. This helps users to account for changes that may occur in nutrient loading to bodies of water as a result of a development or redevelopment. Even though there may be BMPs already in place, they may no longer be effective if pervious surfaces are covered during development. This portion of the BATT tool can help determine if an additional or alternate BMP should be established for a given piece of land.

The Reporting portion of BATT generates reports summarizing the data that has been input into the program. For each function of BATT, results are categorized into the three different types of BMPs, structural, non-structural, and land use changes. Results are also provided in a percentage reduction and lb/year reduced[7].

There is a "References" section in BATT that provides an overview of how the stormwater control design storage volume (DSV) of several BMPs is determined. The calculations for DSVs are different for each BMP and provide a theoretical size of the void space available for for different BMPs[8]. If the void space is increased, then there is a greater volume of stormwater that can be treated, making phosphorus removal more effective. The void spaces are also used to capture and store runoff before it can be treated.

When BATT is opened, the first inputs are the state and town. Then, the user must select if the project is a structural BMP, non-structural BMP, or a land use change. When adding a structural BMP to BATT, the user must first address the land use information. This includes "if the project is a new development or a retrofit BMP" and other pertinent data needed for BATT to calculate credits. Users also have the option to view and export their project, in the form of a summary report. BATT produces a summary report that includes a list of the BMP type and Land Use Conversion ID. It also identifies the total phosphorus, nitrogen, and sediment load reductions. The Project Summary Report provides information about how efficient the BMP is in removing nitrogen, phosphorous, and sediments, along with the BMP storage capacity. An image of this report is shown below in Figure 3[24].

[24] (Tetra Tech, 2016, pg 29)

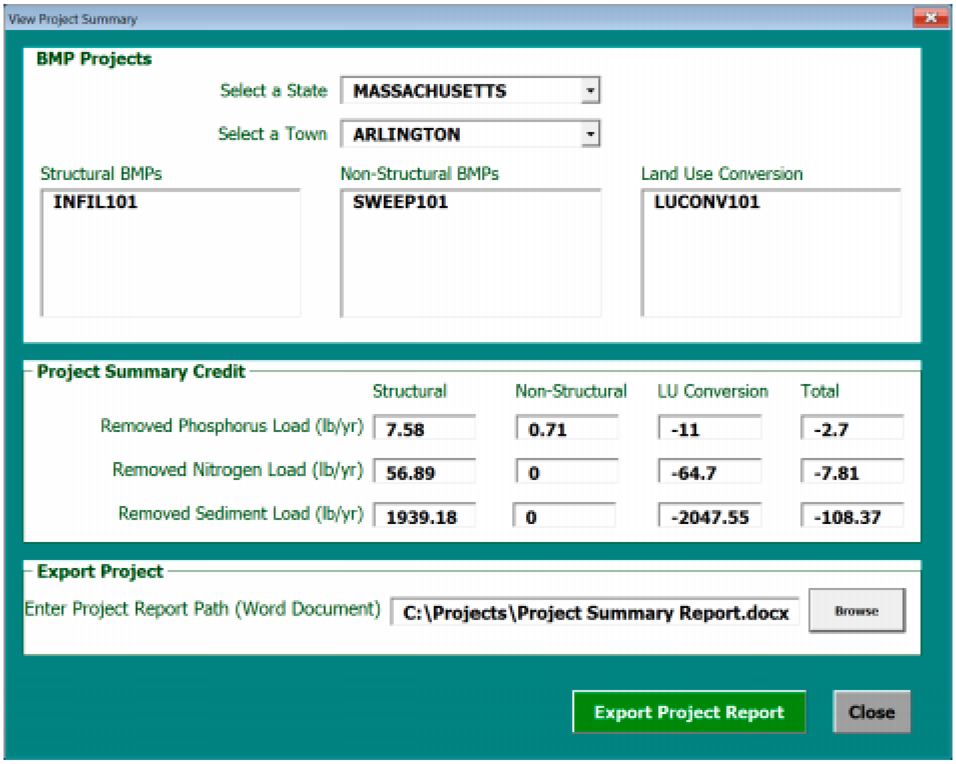

Figure 3: BATT Project Summary

2.3: Model Calibration

Conducting a model calibration involves several steps. It is important to first use available data of an area to define spatial patterns of parameter values. Once parameters are set, a conceptual model must be defined to include the parameters. Calibration involves comparing numerical values that are observed outside of the model to the values the model simulates[25]. Some parameters are immediately established from observations of the area in question, while others can be changed in the calibration process as they are not specific to the area that is being modeled. A sensitivity analysis can also be conducted to "investigate the sensitivity of the model, responses to its parameters, and to identify those which should be further refined via calibration"[26]. Experimental data must agree with model predictions in order to validate a model. Therefore, it is necessary to collect data that corresponds to the model predictions, and compare it to predictions of the model[27]. If the observed and collected data matches the model predictions, then the model is likely to be accurate and can be used for future tasks.

[25] Madsen, H. (2003). Parameter estimation in distributed hydrological catchment modelling using automatic calibration with multiple objectives. *Advances in Water Resources*, *26*(2), 205-216. doi:10.1016/s0309-1708(02)00092-1

[26] (Maidson, 2003, pg 207)

[27] Sankararaman, S., & Mahadevan, S. (2011). Model validation under epistemic uncertainty. *Reliability Engineering & System Safety*, *96*(9), 1232-1241. doi:10.1016/j.ress.2010.07.014

3.0: Methodology

The purpose of the project is to work with Stantec to help Cambridge effectively use the Best Management Practice (BMP) Accounting and Tracking Tool (BATT) when analyzing site design improvements for phosphorus load reductions in the Charles River. In order to meet this goal, the team has outlined a proposed plan for the project.

The project methodology begins with developing an understanding of BATT, where the team will clarify initial issues with the software, compare BATT calculations to Appendix F requirements, and perform a sensitivity analysis. The team will then validate BATT by comparing its outputs to actual data collected from the CRWA and expected outputs from engineering reports. Lastly, potential improvements to BATT will be explored involving a comparison of its calculation methods to other well-known methods, creation of a BATT user's guide, and production of a developer's template for organizational purposes. The team will accomplish these tasks through the following objectives:

1. Understand how the BATT software works
2. Validate BATT
3. Explore potential improvements to BATT software

This chapter will describe the approach to the research, analysis of methods, and implementation steps of each objective. These objectives are intended to be applied to not only Stantec's work with Cambridge, but also any future projects requiring phosphorus treatment or stormwater management.

3.1: Understand how the BATT software works

3.1.1: Clarify Initial Issues

The team will first determine the initial software tools and understanding level needed to run BATT. From the team's experience with BATT and the BATT User Manual, Microsoft Excel 2013 is needed as well as the Microsoft Word 2015 Library. Since BATT is a free downloadable program provided on the EPA website for a wide range of users, the team would like to explore how strictly these interfaces must be followed as well as the user roadblocks that may be encountered. The program will be tested on computers with different versions of Excel and different library availability. The Word Library's function will be analyzed in an Excel based program as well as any reasons to specify the 2015 version. Furthermore, BATT will be explored on Microsoft and Windows servers as these are common configurations.

The team will also note initial issues that are encountered with BATT. As the team begins to use BATT, it will record any specific inputs that produce a system error. If existing "holes" in the software can be recognized where BATT may not be functional, Stantec will be aware of them when helping Cambridge analyze its stormwater treatment processes.

There are also two necessary inputs into BATT -- the Subcatchment ID and Receiving Waters. The team will determine where these ID's are found in BATT. Then, it will be clear whether BATT recognizes these inputs geographically, or if they are more organizational for the user. To ensure that a strong foundation of BATT has been developed, the team will interview Suzanne Warner, an EPA official who has written articles and presented about BATT.

3.1.2: Compare BATT to Appendix F

While examining the methods of calculating loading reductions in BATT, the team will ascertain correlations between equations in Appendix F of the MS4 Permit and the calculations utilized by BATT. The method of determining loading rates of phosphorus will be explored by comparing how BATT calculates phosphorus reductions for structural and non-structural BMPs to the calculations outlined by the EPA in Appendix F. The structural stormwater control performance curves in Appendix F will be analyzed to verify if they are also applied to the structural BMPs available in BATT. For structural BMPs, the design storage capacity equations will be compared to what is specified in Appendix F utilizing depth and porosity as variables. The effect of storage capacity on flow rate will also be explored because of its importance in phosphorus reduction. Additionally, the storage capacity from manufacturing information of structural BMPs on the market can be compared to the result of BATT's storage capacity equations. Since soil group and land use type will be factors in the phosphorus reduction rates, their roles in the equations will also be analyzed.

3.1.3: Perform Sensitivity Analysis

Because the BATT was developed fairly recently, it is essential to determine what aspects of the tool contribute most to the final credits calculated. Therefore, a sensitivity analysis will be conducted to record the degree to which results in BATT are altered by changing a certain input. The team can take note of which theoretically impactful inputs are not having an effect on phosphorus reductions in BATT. Inputs which could influence a final reduction value would include hydraulic soil group or the land use type. This information could then be used to better inform those who are utilizing BATT to determine nutrient loading based on site conditions.

3.2: Validate BATT

3.2.1: Devise a model validation using CWRA and UNH data

Model validation, as discussed in the background, is an important step when testing data inputs. One method of data inputs the team will be testing will be real-world inputs from the Charles River Watershed Association (CRWA), taken from the Charles River, and University of New Hampshire (UNH) Stormwater Center, taken from real-time analysis of BMPs. As discussed in the background, the CRWA collects water samples from the Charles River and compiles phosphorus loading and bacteria levels. Before relating this data to BMP effectiveness, it will first be essential to assess the applicability of the CRWA data. It is preferential for monitoring sites to be located near outfalls to connect phosphorus loading to regions in Cambridge. If they are in the middle of the river, they will indicate phosphorus levels from upstream. Additionally, the team will verify timing of the data collection in relation to a storm event which causes phosphorus concentrations to fluctuate.

To complete this objective, the team will first determine which stormwater drainage areas are closest to the water monitors in the Charles River. This task is important to link certain BMPs near stormwater drainage areas to monitors analyzing phosphorus content in the river. The team will test the accuracy of BATT by using it to determine how much phosphorus is expected to enter the river after the BMP is applied. Then, comparisons will be made between the phosphorus loading by monitors in the river and the predicted loading rates in BATT. It is possible that multiple BATT tests will have to be executed if there are several BMPs contributing to the area where the monitoring station is located.

The UNH Stormwater Center provides multiple data points throughout the BMP process that can help determine efficiency. The team plans to visit and interview members of the UNH Stormwater Team to develop its understanding of stormwater design. The site conditions and dimensions of BMPs used at UNH will be entered into BATT. Then BATT calculations will be comparable real time data from UNH and the team can test the accuracy to validate BATT.

3.2.2: Validate using sample Cambridge projects

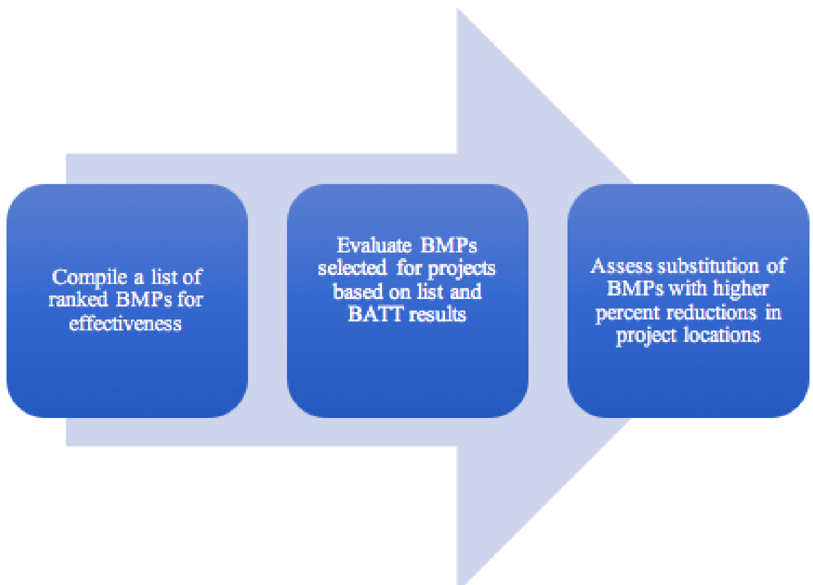

Figure 4: Objective 3.2.2 Flowchart

An alternate method for evaluating BATT will be utilizing Cambridge BMPs that have already been installed in the city. These BMPs will be compared to BMPs that effectively reduce phosphorus content found through research. The team will first create a list of effective phosphorus reducing BMPs, researching both structural and proprietary. BMPs will be ranked based on magnitude of percent reduction per implemented volume. Ideal Hydrologic Soil Groups (HSG) and land use types for each BMP will also be ranked. Proprietary and structural BMPs will also be organized in separate lists as proprietary are not available for selection in BATT.

Once the team has a foundational knowledge of efficient BMPs, sample projects will be used to test finished BMPs in Cambridge. The team will use project reports obtained through Stantec to better understand the developer's process of selecting BMPs. The BMPs suggested by these reports will be tested in BATT as well as any other alternatives proposed throughout the reports. The team can then compare the loading reduction from BATT with the predicted reduction from the project site reports.

Another comparison will then be made between the results from the previous analysis and the BMPs from the proposed list, keeping all other site conditions constant. The team will use BATT to incorporate BMPs with a higher percent reduction onto these test sites, and verify the anticipated phosphorus improvements. This will be completed using numerous sites in

Cambridge with varying characteristics including site size, BMP size, land use type, and soil type. The team will see if there are any trends in percentage phosphorus removal using spreadsheet analysis tools.

3.3: Explore potential improvements to the BATT software

3.3.1: Identify the logic of other methods

The team would like to address the accuracy of the methods chosen in BATT versus other well-established methods such as the TR-55 method. This method was created by National Resources Conservation Service (NRCS) and is a widely accepted method; therefore, the team will see how closely the equations relate to those used in BATT. Additionally, if there is a common hydrograph assumed for Massachusetts, this will provide insight into the calculations. From this information gathered through well-known methods, the team will create a list of recommendations for possible improvements to BATT. This will help Stantec and its clients be more aware of the relatability to these methods and the permit overall.

3.3.2: Develop a user's guide to BATT

Following comprehension of existing conditions in BATT, the team will develop a user guide to address any initial issues that may be encountered. Clarification is needed for software incompatibility and input specificity. Already, the team has noticed that adjustments are needed based on the user's version of Microsoft Excel. Additionally, the current user guide does not contain specificity in regards to inputs and precise labels needed for receiving water and subcatchment IDs. This minor deliverable should put Stantec and its clients at the advantage in the beginning stages of using the BATT tool.

Based on findings throughout the methodology section, a list of recommendations will be compiled for systematic adjustments to the tool. Possible beneficial adjustments to BATT are the software compatibility, clarity of the inputs with possible drop down sections, and improved organization of results. Recommendations for calculations will likely be broad to include results from the analyzing methods and sensitivity of inputs.

3.3.3: Design a template for easier usage of BATT

Finally, as the design component of the project, the team will develop a template for land developers to more easily organize site information. To develop a better understanding of what Cambridge could gain from BATT, the team will also interview Cambridge officials. This will provide insight into the challenges that Cambridge faces in both reducing phosphorus loading and receiving credits for its current BMPs.

The template will likely be in the form of either an Excel spreadsheet or fillable PDF which could be used by Cambridge and developers to easily verify the accuracy of inputs. To advance the deliverable beyond just a simple input template, the final template could contain an aggregation of results from previous methodology steps to advise developers about ideal site conditions and BMP type. In addition to addressing inputs like soil group or land use group, a short guide for soil type or land use per location in Cambridge could be provided.

Table 3: Gantt Chart

Timeline	First 3 Days	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7
	Jan. 10-11	Jan. 16-19	Jan. 22-26	Jan. 29-Feb.2	Feb. 5-9	Feb. 12-16	Feb. 19-22	Feb. 26-March 2
Contact Potential Interviewees*								
Meet with Potential Interviewees*								
Research & Categorize Effective Phosphorus Reucing BMPs (3.2.2)								
Understand BATT Conditions and Appendix F Correlation (3.1.1 & 3.1.2)								
Conduct Sensitivity Analysis (3.1.3)								
Validate CRWA Data (3.2.1)								
Complete User Guide (3.3.2)								
Input UNH Data to BATT (3.2.1)								
Evaluate BMPs in Selected Stantec Reports (3.2.2)								
Compare to other Methods (3.3.1)								
Assess Substitute BMPS for Stantec Reports and % Phosphorus Reduction (3.2.2)								
Input CRWA Data to BATT (3.2.1)								
Create Developer Template (3.3.3)								
Finish Paper and Present Findings								

*Potential Interviewees include Cambridge officials, CRWA, UNH Stormwater Center, and EPA officials such as Suzanne Warner

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Appendix B: EPA Official Questions & Transcript

The team would like the reiterate that these are thoughts of Suzanne Warner, and she is not representing the EPA in this interview.

Questions:

General Questions:

1. What is your position within the EPA and what role did you play in the creation or implementation of the BATT?
2. What was the EPA's goal in making the BATT?
3. What is the advantage of using the BATT as opposed to the method that municipalities and developers use currently to calculate credits?
4. What are the greatest challenges facing municipalities in reducing phosphorus loading to the Charles River?
5. What was your thought process for choosing certain BMPs to put in BATT?
6. How valuable do you think proprietary BMPs are for highly-urbanized municipalities that are having trouble reducing phosphorus loading?
7. Is there a way that they are accounted for in BATT?
8. We believe BATT is based on Appendix F of the General Massachusetts MS4 permit. How closely related are these?
9. What criteria are used to determine the phosphorus reduction requirements for municipalities?
10. What are your thoughts on a possibility of a system exchange of phosphorus credits if a municipality cannot meet its reduction requirement? In your opinion, is this system feasible?
11. Are there repercussions (fines, etc.) for municipalities that do not make their phosphorus reduction requirements?

BATT Specific Questions:

1. Non-Structural BMP: No Application of Fertilizers Containing Phosphorus (Attachment 2, Section 3, p.6)
    a. We noticed that the Weighted Phosphorus Load Export Rate (WPLER) values in Appendix F and BATT are slightly different, with Appendix F being 0.261, and BATT being 0.29.
    b. There is no table in BATT for Lawn percent, and there is a Lawn percent value used in the equations given in Appendix F.
    c. Land type does not affect the calculations - no matter what land type and area we put into BATT, we get a phosphorus reduction of 15.067 lb/yr.
2. Non-Structural BMP: Enhanced Sweeping Technologies (Attachment 2, Section 1, p.4)
    a. The factor specified in Appendix F for (months/year) to be multiplied in the equation does not have an entry in BATT
    b. BATT assumed the factor for each, weekly, monthly, and twice a year but does not account for if a municipality sweeps 9 months/year (Cambridge)

Transcript:

Jessica (J): So first we just want to ask a little about you and your experience. And what your position is within the EPA and what association you have with BATT, whether it be the creation or implementation of the tool.

W: OK. So, I work in the stormwater and construction permits section of our *(EPA)* NPDES water permits division, so the NPDES program is basically our implementation of the Clean Water Act. I don't know if this is all repetitive information for you guys. But we're charged with writing permits for point source discharges to waters of the United States. So I work with a team of people who are writing stormwater permits mostly. EPA directly writes the permits for Massachusetts and New Hampshire. So, that's what we do. We are writing MS4 permits, permits for construction sites, permits for industrial dischargers. But, the main thing is we really want permits to be implemented, so part of that is, was creating BATT to kind of just make that crediting process a little more accessible. I don't know if we envisioned like a larger firm or a larger city using it per say, but kind of just making that process more accessible to cities and towns that don't have a lot of modeling software or a lot of computer capabilities to calculate credits for any retrofits that are going to happen down the line for BMPs that are installed. So, basically BATT was kind of an add on to our whole process of developing this crediting system for the Charles River TMDLs and also the Lincoln Pond Phosphorus TMDLs of Massachusetts and New Hampshire. And our main kind of product out of that was the Opti-Tool. I don't know if you guys have…

April (A): We've heard of the Opti-Tool, yeah.

W: Yeah, so that was kind of the big effort to make accessible BMP modeling tool that would be consistent with the approach that we were taking in the permits to implement those TMDLs and the BATT was a little add on project to try to make the crediting system easier for somebody to keep track of BMP credits.

Stephanie (S): So, I don't really understand the difference between the Opti-tool and BATT. It seemed from our research that BATT was for the Phase II part of the permit while the Opti-tool was more for the bigger cities. Is that true or is that…

W: So the Opti-tool is … a more complicated piece of software. You can actually run SWMM model through that interface and its more for planning level or even more for a watershed level analysis at looking at BMPs from different areas. And then BATT is basically taking those credits from Appendix F and putting them into a spreadsheet, like you guys are doing.

J: So it's just meant to be a little more useful for developers and smaller cities?

W: Yeah, so the idea is if you had a small city with a pretty limited scope of projects you could be tracking that in a spreadsheet then input that into BATT or manually inputting projects through the planning process or something. And again we are still waiting for the permit to still go into effect so there is still always the opportunity to improve it. We were kind of guessing to what would be useful for communities which is hard to do until communities actually start using the tools, so we'll see.

A: So was the main goal of making BATT then just making it easier for communities to input their BMPs and calculate their credits. That was the main goal of making BATT?

W: Yes.

A: We got that question then. What's the advantage of using BATT as opposed to the methods municipalities and developers are currently using to calculate credits? So it's just a more uniform way to calculate credits so they're all on the same page with the equations their using?

W: Right.

A: Yeah.

W: Yes, and you know, eventually when the permits are put into effect we wanted have a system set up for communities to be able to take credit for projects and the BATT was just trying to make that process a little more automated for the communities.

J: I was reading Appendix F and there was a little section where it's like, Oh if you don't want to use this method it must be approved, like whatever alternate method must be approved by the EPA to earn credit, which seems kind of time consuming compared to just having this easy method.

W: Right and that. We are definitely open to that process, that process of gaining additional credits for additional BMPs, but for most common BMPs—I think this maybe goes into one of your other questions—but just for those common BMPs there's been a lot of work put in to creating those, those reduction calculations for, for those common BMPs. So yeah, that is not meant to, I don't know, replace other modeling efforts necessarily. It's definitely not a design tool for when you're designing a BMP or something. But mainly just to make those credits more accessible for the permitting process.

J: So next we just wanted to get a little of your opinion on just the different obstacles facing communities. So, what are the greatest challenges that municipalities are facing in reducing their phosphorus to comply with the permit?

W: That's a really good question. I think it's a very open ended process and it's a very daunting process for a lot of the communities. You know, you have your runoff from your entire city or portion of your city draining into the Charles River and then you're told to reduce that by some percentage based on the TMDL based on your permit requirements. So, our idea in the Charles River TMDL requirements was there would be a lot of planning up front to figure out how, what is the best way to go forward in reducing this phosphorus load. So, we all want communities to implement solutions to be the most efficient for their limited resources that will lead to better water quality in the river. So I think the challenge is that there's a million different ways they can do this. And figuring out what is going to be the best way for them is going to be a challenge and we are trying to provide resources, all the information we can for them to make the best decisions, but ultimately it has to happen at the community level. If that makes sense. So yeah, in terms of the permit requirements the first five years are kind of planning, looking, being really deliberate about how they are going to achieve these reductions so that we get effective solutions that will actually going to lead to results and then providing credits for that. The second part is kind of implementing the non-structural controls that hopefully are going to be a little more efficient then what we have data on right now. And then the third part is implementing retrofits where they need to continue to reduce the phosphorus loading to the Charles. So we've tried to build in that deliberate process in the permit in Appendix F for those requirements for the Charles TMDLs.

J: I guess each community would probably face a different challenges whether it be like their money constraints, or their space, or soil such as Cambridge.

W: Right, yeah. When you look across the watershed, there's a lot of, there's a wide range of communities in terms of their impervious cover and the open space they have available right now. And, yeah, obviously concerns about budgeting.

S: Our next question was just about your process for choosing the BMPs that went into the BATT tool?

W: So this kind of predates my involvement with this work actually. So the BATT is based off of a lot of effort that's been going on between EPA and the University of New Hampshire, a long contract with Tetra Tech to do modeling work for this. But, basically my understanding is that we were just looking at common BMPs, BMPs that UNH was building to study in New Hampshire in order to create a crediting system. So we just looking at the BMPs that are most commonly used and aren't proprietary.

J: Yeah, I think when we were looking at some of the projects we came upon some BMPs that were not within the BATT tool, so we were trying to find different ways it could be categorized under one of those or perhaps under a land use change.

W: Yeah, so we… That's definitely been a challenge. Is different ways that the states, the EPA, the individual consultants will define BMPs. We tried to provide description and it should be in the BATT, of what should go into that goes into that BMP and what that looks like and there's definitely flexibility to try to fit in BMPs into the categories.

J: We looked at the state handbook too to get the information about each BMP.

A: We were also wondering how valuable proprietary BMPs are for urbanized municipalities that are having trouble reducing their phosphorus loading.

W: So, I think proprietary BMPs are definitely, there's a lot of good solutions out there. We don't really get into the process of working with the vendors or working companies at that level, so that's why there's no proprietary BMPs kind of accounted for in our calculations and we're thinking that those companies, those vendors, should have the responsibility of doing the work and saying what kind of credit they want to get for proprietary BMPs, but I know in a lot of the really urbanized communities where there's not a lot of space for putting in infrastructure or for an underground or above ground system, the proprietary BMPs are a big part of that menu, so we don't want to discount that from the tool. It's just, it's not really in our wheelhouse to, to consider those.

A: So, it's like something that the vendor should be responsible for studying and knowing the phosphorus credits, and if a municipality is using those, you can add the credits on to your other BMPs that BATT has in it and it could help you in BATT too to help you keep track of that.

W: Right.

A: Oh, OK.

W: And, so BATT does not have that right now, but the idea would be if, if somebody went through a really robust effort to calculate removal percentages for their proprietary BMP that we would include that in all of our, kind of, literature and included into the opti-tool, and put it into the BATT. But that would be kind of a big process and would involve us, looking at it and then updating all of our software and stuff.

J: But that makes sense because I can see how those proprietary BMPs vary so much through different vendors it'd be hard to uniformly incorporate into BATT. Really something like the Jellyfish you need different types.

S: So at the moment it just can't be put into BATT in any way. You can't change the reduction factor, or whatever phosphorus, like you can't increase it or something right now. Or would you need to do anything for that and the city?

W: So for something like for a jellyfish or something like that we don't really know how you'd fit that into an existing BMP. If there was some kind of proprietary, like I know there's soil amendments for a biofiltration system, then you can talk about adjusting, like you said, the reduction percentages for that BMP. But yeah it would be a larger effort to add something like a jellyfish, or some a contained proprietary system.

S: So if they used some kind of specialized soil, they might be able to do something with the percentages, but if it's some new piece of technology, that has to go through the vendor. OK, just want to make sure it's clear. Then I think we just wanted to ask how closely related BATT is to Appendix F. While we were researching we weren't exactly sure at first, we thought it was very close, so we just wanted to confirm that, mostly.

W: Yep, so it's based off of all of the data in Appendix F. If you want more background on the things like the land use loading rates, the reduction percentages that are in Appendix F, the attachments to the "Permit Response to Comments" so that's at the end of that big long response to comments document, Attachment 1 is kind of the methodology that we took to incorporate those TMDL requirements into the permit. So that is a good resource.
Note here that along with Appendix F, Warner also brought in the Tetra Tech study we found

S: Yeah, that would be very helpful, thanks.

W: So, yeah, that kind of gets into the next question of what criteria are used to determine phosphorus reduction requirements for municipalities. So, yes, they are based off the upper and lower Charles River TMDLs. Not sure if you guys have dug into those. Again, I think the summary in attachment 1 is pretty good for our methodology there. A lot of folks at EPA that have worked on those TMDLs and who've worked on this, so we are trying to create consistency with that permitting process, with this, with that TMDL. So again, the TMDL specifies load reductions from certain types of land uses from the upper and lower watershed and then we just did a baseline calculation based on GIS data based on the land uses and soil types within the watershed of what each community would be responsible for reducing.

J: It was nice also that chart in the appendix that had all the GIS land uses and what you would categorize that in BATT. That's really helpful, so I think we'll come across all sorts of ones in the projects we're looking at.

W: Yeah, definitely. And there is that statewide database so we wanted to make sure that, which is available for everybody, could be translated into the required loadings for the permit.

J: Our next question, we wanted to get your thoughts or opinions about getting a system to exchange phosphorus credits if a municipality can't meet its requirements and how feasible you think that system would be?

W: I think it would be feasible, I don't see why it wouldn't be. I think it's really early in the process to talk about that. I was trying to think of examples of where it's been done before and I don't think anyone is quite there yet, in terms of a watershed trading program. There's been a lot of talk about it in different TMDLs around the country in different watersheds but I don't believe it's been implemented anywhere yet.

A: To kind of see what communities do themselves first with satisfying their own requirements…

W: Right.

A:... and then if they go beyond it they can like, "hey we can do some credit exchange, or something"

W: Right. So, yeah, we'll find out I think in the first permit term how feasible that is, if communities want to jump in a process like that.

J: I think we're thinking along the lines of carbon credits as well, but that process is so much further in than this.

W: So I don't… Yeah, we'd probably have to revise our permit a little bit to make sure that process is allowed under the permit conditions, but, again, I think it'll be down the line when we're thinking about revising the permit anyway.

A: We were also wondering if there were repercussions for municipalities that don't make their phosphorus reduction requirements, but that's still, I guess, early on because everyone's, kind of, still working on making plans for it.

W: Right, so, I think we're looking at, and I can't remember off the top of my head, so off the record: the reduction requirements, working towards those, don't start until maybe year 10 of the permit. And, so, there are fines associated with not meeting your NPDES permit conditions. Usually, in a case like, our enforcement office would get involved and they would try to work out an alternative schedule or some sort of consent decree with the permittee to try to work toward meeting their permit requirements. So, fines are a tool that we have to induce compliance but it's usually more effective to just try to work with the permittee to meet with their requirements at any point. So we do have that as kind of a stick to use for enforcement.

A: So, you'd rather work with them to find a different plan than just fine them, basically.

W: Yeah, well that's…

A:... Because you need to fix this.

J: I guess that could be money that could go into constructing BMPs, anything that could be fined.

W: Yeah, that will happen, where if we issue an enforcement order or something for a permittee that part of that, there's usually a negotiation of what happens if they are going to pay a fee, if they have to like an environmental project, which, yeah, spend a certain amount of money to put BMPs in the ground or something like that. So, it's definitely, usually, more complicated than sending a fine, than sending a bill to somebody. It's kind of a back and forth process, but yeah I don't work in enforcement, so I'm not the expert on that. If you guys want to talk to other folks too as part of your project, I don't know if you have to do lots of interviews or if you just are getting the one over with, but I can put you in touch with more of our experts on this too. Nobody's really around on Friday's or I would've invited them also, but…

J: Any contacts you have would be great. We could always email them too if they are pretty busy and can't meet with us. We don't really have a requirement for interviews. We just wanted to gain as much information as we could.

A: They kind of just let us go in whatever direction we wanted to go with the project. They've been very open to our ideas.

J: We are very excited to get interview here so early, especially we were like, "Oh my God, we are going to the EPA."

W: That's really funny. Well, yeah, I think the best way to figure it out is to figure it out in person, too.

W: And if you guys have follow up questions or anything, feel free, I'm much more articulate over email too, and, or, feel free to call me if you have any questions if you go back over the transcript or anything.

J: We have a couple of questions now that are very BATT specific with just some observations we've noticed.

A: We haven't gotten into the structural BMP calculations yet. We were a little overwhelmed by reading that and trying to put that into our Excel spreadsheet. We've done it for the non-structural ones so far, and we are looking at the no application of fertilizers containing phosphorus, and we noticed a couple of things. I guess a minor one was that the Weighted Phosphorus Load Export Rate Values in Appendix F and BATT were a little different for Cambridge, so we didn't know if they were supposed to be different or not I guess.

W: These are good questions. So I did look back in the tool. So where is the Weighted Phosphorus Load Export Rate in BATT.

A: There's…

S: It's all in the hidden tab's all in the bottom in the tables that they are using to look up. I think there was two different ones that said look up, so it was definitely one of those.

W: OK so if you look at Arlington, it says 0.261, but our Cambridge specific phosphorus export rate is 0.29. And there is some inconsistency, this is the one weird non-structural BMP because while we were drafting the final permit we, the state passed their fertilizer ban law for phosphorus fertilizers so we actually ended up rolling the fertilizer credit into the reduction requirements for the communities, so we just took that off the top for all of the communities. And so I believe the calculations that are in BATT are based off of those credits that we gave to the communities and took off of their reduction requirements. So, we haven't updated the fertilizer requirement in the BATT tool just because we're not really expecting people to use it. There's an appendix, Attachment 2 to the response to comments is kind of, goes through our fertilizer methodology. We got comments from the fertilizer industry about that, so that was fun (*sarcastic*). And that was something, that was a very small part of the permit that ended up being this huge effort that ended up calculating this non-structural control.

A: Yeah, we also noticed just comparing the equations from Appendix F and BATT for the fertilizer one that there's a lawn percent value in Appendix F but not in BATT, so…

W: Right.

A: Yeah.

W: So, there is this, this very detailed analysis you could do to figure out how much fertilizer is actually being applied throughout the town and how much is going to be reduced if you switch to a phosphorus free fertilizer application. But ultimately we ended up doing that calculation for the communities, kind of assuming all of those factors for them, figuring that somebody could go through the effort of customizing that calculation for their town if they wanted to, but because of the phosphorus fertilizer ban at the state, we figured we'd just add that calculation in for them. In BATT if you're looking up the fertilizer credit, I believe what happened is the credit is always going to be that pounds removal that we assigned for that town for the reduction requirements.

J: Yeah, we noticed that we always got 15.06 no matter how many acres or…

W: Right, so that is the…

J: ...land use types we put in.

W: ...that is the Cambridge reduction number.

A: Oh, OK.

W: So, when you're picking that drop down in the first part of the BATT of what town you're working in…

A: Yeah

W: ...that's gonna, that's what's going to pick the phosphorus reduction credit for fertilizer. And that's not really clear in the tool, obviously. So this is going to be a good exercise for us too.
S: In Appendix F right now they had a table on it too that said that the reduction requirement was 9 lb/yr calculated for Cambridge, I think it was table 2-5. But I guess when you were doing the calculations in this attachment, maybe it came out differently, so we'll just have to look at that and if we have any further questions afterwards we can contact you about it.

W: Yeah, definitely.

S: OK.

J: One other thing we noticed specific to the enhanced sweeping technologies section of the non-structural BMPs is that there was a factor for the weekly, monthly, and twice a year, but not-- in the Appendix F calculations there was a fraction of the months of the years to be multiplied. I know we assume weekly and in 12 months, and in twice a year, but in a case like Cambridge, they would sweep 9 months out of the year. So, I know that's just a small thing…

W: No, yeah.

J:... That's just a discrepancy we noticed.

W: That's something I brought up in one of our development meetings and it was not changed in the final one, so. I will follow up on that. So, yeah, there should be an annualizing factor that you could put in, a certain fraction of the year that you would get credit for that sweeping. Yeah, I think especially with the non-structural BMPs, we, a lot of it is based on weight of evidence just based on a literature review of information we could find and we're looking forward to more research that comes out about this technologies and hopefully being able to revise those credits as we go along.

J: Yeah. To me, it seemed like something where it was just a baseline one where BATT put out for every single thing, like a community would have to discuss and say "hey we swept for 9 months" so they can get more credit than what was originally calculated.

W: Right, or less credit I guess.

S: I think that was almost all of our observations.

A: Yeah.

S: so far.

A: This projects kind of cool because we don't have much stormwater background before doing this project so it's nice to get us into it before we enter the 'real world' of environmental engineering.

J: Yeah, a lot of our classes are centered around water, waste water, or just general environmental engineering, so this is a lot more specific and we get to look through a lot of permitting and a lot of project reports, and different hydrographs. Things that we are not used to yet.

Small talk at end. Incorporating most helpful portions
W: If you have any questions about that, I'm fluent in that (*Permit lingo*). But I'm really glad you're looking into the BATT and using it, and I hope it will be useful for communities or at least for students (*joke*)

Appendix C: CRWA Questions & Transcript

Questions:

General Questions:

1. What is your role within the CRWA and most important tasks?
2. What do you think is the greatest threat to the health of the Charles River?
3. We were reading about the history of the CRWA and how the water quality monitoring was established. We were wondering if the purpose of water quality monitoring is geared more towards detection of illegal dumping or just for the general monitoring of contaminant and bacteria levels?
    a. How does the CRWA pinpoint actual sources of illegal dumping?

Questions about Sampling Directly from the Charles River:

4. What kind of protocols are used to train the volunteers?
    a. How uniform are these sampling methods and have they changed over time?
5. How closely do you take samples in relation to outfalls?
    b. Is there a way that impacts from background river concentrations are avoided?
6. What parameters do you analyze water samples for?
7. Do you primarily analyze your samples in a lab or are they taken using a YSI?
    c. What is the average time between the sampling and when the samples are taken to the lab?
8. How do you take into consideration rain or other precipitation events for the timing of your samples?

Questions about BMPs:

9. What types of BMPs do you monitor inputs of inflow/outflows? Where are they located?
    a. Are these primarily projects just for the sake of monitoring or ones done for the communities?
    b. Are they mostly standard structural, or do you also monitor proprietary BMPs?
10. How is the water quality tested before and after it is treated by the BMPs?
11. Do you also consider timing of precipitation events when monitoring BMP outputs?
12. These are the BMPs that are currently in BATT. Are there any BMPs that you think are effective that are not on this list?

Stormwater Control Type	**Description**
Infiltration Trench	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.
Subsurface Infiltration	Provides temporary storage of runoff using the combination of storage structures (e.g., galleys, chambers, pipes, etc) and void spaces within the washed stone that is used to backfill the system for subsequent infiltration into the surrounding sub-soils.

Surface Infiltration	Provides temporary storage of runoff through surface ponding (e.g., basin or swale) for subsequent infiltration into the underlying soils.
Rain Garden/Bioretention (no underdrains)	Provides temporary storage of runoff through surface ponding and possibly void spaces within the soil/sand/washed stone mixture that is used to filter runoff prior to infiltration into underlying soils.
Tree Filter (no underdrain)	Provides temporary storage of runoff through surface ponding and void spaces within the soil/sand/washed stone mixture that is used to filter runoff prior to infiltration into underlying soils.
Bio-Filtration (w/underdrain)	Provides temporary storage of runoff for filtering through an engineered soil media. The storage capacity includes void spaces in the filter media and temporary ponding at the surface. After runoff has passed through the filter media it is collected by an under-drain pipe for discharge. Manufactured or packaged bio-filter systems such as tree box filters may be suitable for using the bio-filtration performance results.
Gravel Wetland	Based on design by the UNH Stormwater Center (UNHSC). Provides temporary surface ponding storage of runoff in a vegetated wetland cell that is eventually routed to an underlying saturated gravel internal storage reservoir (ISR) for nitrogen treatment. Outflow is controlled by an elevated orifice that has its invert elevation equal at the top of the ISR layer and provides a retention time of at least 24 hours.
Enhanced Bioretention	Based on design by the UNH Stormwater Center (UNHSC). Provides temporary surface ponding storage of runoff above a vegetated soil filter media cell that is filters runoff as it is routed to an underlying saturated washed stone internal storage reservoir (ISR) for nitrogen treatment. Outflow is controlled by an elevated orifice that has its invert elevation equal at the top of the ISR layer and provides a retention time of at least 24 hours.
Porous Pavement with subsurface infiltration	Provides filtering of runoff through a filter course and temporary storage of runoff within the void spaces of a subsurface gravel reservoir prior to infiltration into subsoils.
Porous pavement w/ impermeable underliner w/underdrain	Provides filtering of runoff through a filter course and temporary storage of runoff within the void spaces prior to discharge by way of an underdrain.

Sand Filter w/underdrain	Provides filtering of runoff through a sand filter course and temporary storage of runoff through surface ponding and within void spaces of the sand and washed stone layers prior to discharge by way of an underdrain.
Wet Pond	Provides treatment of runoff through routing through permanent pool.
Extended Dry Detention Basin	Provides temporary detention storage for the design storage volume to drain in 24 hours through multiple outlet controls.
Grass Conveyance Swale	Conveys runoff through an open channel vegetated with grass. Primary removal mechanism is infiltration as runoff flows are conveyed.

Transcript:
Not yet recording until second question

Q1: Role in CRWA and tasks
A: Elisabeth is an Aquatic Scientist who has been in the CRWA for 4 years now. Her role includes running the field science division, collecting data, coordinating the monthly volunteers that measure water quality of the Charles, and coordinating interns that measure water quality for public water quality notification services. Sample data is also collected. They have modeled *E. coli* bacteria in the river. There's also a volunteer program that identifies small invertebrates in the river to give a water quality score. There's also an invasive plant management program. Restoration programs including dam removals and stream day lighting happen. This is different from the restoration projects like the BMPs that are targeted at reducing the phosphorus loading.

Recording started
April (A): I guess another question we had is what you think is the greatest threat to the health of the Charles River?

Elisabeth (E): Yeah, so our focus recently, I was say at least the last 10 years, has been stormwater pollution and specifically nonpoint source pollution from impervious surfaces of the watershed. Phosphorus pollution is a problem throughout our watershed and, so that's why we went through the effort of coming out with the Total Maximum Daily Load Plan for Phosphorus for both the Upper Charles and Lower Charles. And so a lot of our restoration projects are related to trying to provide treatment to reduce that phosphorus loading.

Jessica (J): When we were reading about the history of the CRWA, one thing that was very interesting to me was the, it seemed that your monitoring program was brought up originally by your to detect illegal dumping within the river. I was wondering if that was still the goal of the monitoring program or if its been more for general information gathering now?

E: Yeah I would say the way we describe the program now is, we really refer to it as a baseline water quality monitoring program. There was a short period of time where we also ran a separate, what we called a “Find it and Fix it” program which was really very targeted at identifying illicit connections to the stormwater drainage system and other, kind of, illegal sources of bacteria pollution in the river. And the focus now has shifted a lot more to just providing a general picture of what’s happening in the watershed, what parts of the watershed need more attention for particular issues, and providing that information to the public and to decision makers at the local, state, and federal level.

J: My branch off question to that one was just how does the CRWA pinpoint sources of illegal dumping, I guess from the Find it and Fix it program. What goes into that?

E: Yeah, so, the area where we’ve had the most corrections, corrective actions, I would say, is around Boston. So a lot of times what we’ll do is if we see really high levels of *e. Coli* bacteria we’ll pass the data on to Boston Water and Sewer Commission directly or Massachusetts Water Resource Authority depending on whose drainage area is affected by the problem. And at this point we, kind of, really rely on them to actually figure out why the bacteria levels are actually very high. Boston Water and Sewer has a pretty detailed protocol, sort of like a decision tree, that identifies if this observation is made what kind of action do they need to take next to track exactly where sewage leaks are happening in their system. We don’t really have a good mechanism for identifying other types of illegal dumping, say if someone was storing salt improperly, or fertilizer, or other type of pollutant. We don’t really have a good way of tracking that.

J: So mainly reporting to the MWRA or the Boston Sewer.

E: Right. Mostly reporting back to the sewer utilities.

Stephanie (S): So now we wanted to go into your kind of protocols for sampling the Charles River. So our first question on that line was what kinds of protocols do you use to train volunteers?

E: Yeah, so, all volunteers are trained on a rolling basis. Essentially when we have an opening when we need another volunteer to help out at a site we train them as soon as someone expresses interest. And so they come to our office. We have another person on staff who will actually give them a presentation overview of the watershed and the monitoring program and then will take them out to the bridge right here outside our office to just practice the sampling techniques. We encourage the volunteers to use our online refresher training quiz just to make sure they’re aware of what the protocols are every year. There’s not really a good guarantee that everyone is doing that, but that resource is available if they have questions about the protocols. And all the training that happens in the field is documented in a quality assurance project plan and that’s approved by EPA and DEP.

S: And then looking at all of your historic data, because, has it been a uniform sampling method and has it changed over time, your protocol?

E: Yeah, so, the program is more than 20 years old now, so there’s been some things, some changes, and they’re really responses to available techniques and technology and trying to produce data that can be used in relation to regulations. So the program, as I think you guys kind of picked up, really started out as a way to track *e. Coli* bacteria, or basically sewage contamination in the river. So, originally we did have a lot more emphasis on *enterococcus* bacteria but when the state water quality standards for fresh water bodies shifted to be based on *e. Coli* concentrations, you know, we changed our sampling protocols, really that's on the lab side more so than on the field side for the volunteers. But we did still make that change, so we do still have a couple of sites that collect samples that are tested for *enterococcus*, but now really all of the samples are just being tested for *e. Coli* bacteria. And originally the volunteers just used what we called a bucket method to collect their water samples and transferred the water from the sampling container into a lab container, a sterile lab container. And so there had to be protocols for sterilizing the buckets and all the equipment that was used in the field, but we shifted in kind of the late 2000s to using what we now call a basket sampler. And we have them here if you would like to see what they look like, but essentially it's a shower caddy with some weights on the bottom and some clamps on top, so the volunteers are able to put the sterile lab containers right into the basket, clamp them in place, and collect the sample that way, so there eliminates the transfer between the different containers.

A: It'd be cool to see those after the…

E: Yeah…

A: Yeah, I'd like to see them.

E: Yeah. So, I guess most of the sites are on bridges, I don't know if you can really tell that from our website. There are a few volunteers that actually go out in canoes to collect their samples so they have a separate protocol for collecting samples with different equipment. And then there's one site where volunteers actually wade into the river, so they actually have a separate protocol for that.

A: Going along with that, we were wondering how closely you take samples in relation to outfalls. Like do you take any over there?

E: Yeah, so, most of the samples that are collected with this volunteer monthly water quality program are not in close proximity to outfalls. The thought process was back in the 90s we didn't really have good ways to share spatial information so using the center point of bridges made it really easy for volunteers to go to the same location to collect their samples. So that's why most of the sites are located near bridges. And, so bridges are not usually located near stormwater outfalls. Find it and fix it program that we ran for a few years would have been targeted at a lot of those outfalls.

A: OK, I guess our follow up question was is there a way that background river concentrations are avoided, but if you aren't taking samples near outfall I guess that kind of balances that a little maybe.

E: Yeah, so, I would say that we are not avoiding background concentrations, but we are kind of using data that we collect during dry weather conditions as a way to evaluate what the background level might have been on a wet weather sampling event.

A: OK
J: With the data from, that might be more closely related to outfalls through the Find it and Fix it program, is that publicly...available…

E: It should be on EPAs STORET the water quality exchange website, but it might be hard to find it that way, so we are happy to export from our database and just send you an Excel spreadsheet.

J: OK that'd be awesome.

A: That'd be great, yeah. Another question we had was what parameters do you analyze water samples for?

E: Yes. Yeah, so, the volunteer water quality monitoring program, all of the 35 sites collect one sample that gets tested for *e. Coli* bacteria on a monthly basis. And then once every quarter 12 of the sites collect an additional sample that gets tested for *enterococcus* and total phosphate, orthophosphate, total nitrogen, nitrates, nitrites, chlorophyll a, turbidity. I think I got them all, I might've missed one or two. Basically almost everything else we might want to know that a lab could test. We don't routinely measure dissolved oxygen and volunteers measure water temperature and depth in the field.

J: Last summer, I interned at the Martha's Vineyard Commission and we had some samples we put into acid washed bottles and sent into the Buzzards Bay lab and then other samples we got directly from a YSI. Do you use the YSI to get directly information or mostly your parameters sent to a lab to get your results?

E: Yeah, so, the volunteer monitoring program samples all go to the MWRA lab on Deer Island. The public water quality notification program samples that our interns collect go to GNL in Quincy to be tested for *e. Coli* bacteria. They do a one day turn around for us which is really nice. We used to have our own lab here, but we don't, well it wasn't in this location [*Weston office*] but at a different office space we had our own lab, but that is not the case anymore. We do use a YSI Sonde when we are doing summer monitoring to look for cyanobacteria blooms, but the YSI Sonde is kind of on a project by project basis and not one of our long term programs where we regularly use it.

J: Yeah, because I know we just got immediate data from that for like temperature, depth, and turbidity and dissolved oxygen…

E: Yeah, yep.

J:...and if you just have one it's hard to apply it, I'm sure, to all of the sites.

E: Yeah, it'd be hard to cover all of the sites the volunteers are using, but for our project-specific monitoring it's typically just our staff or our interns that are just going to you know one location or just a handful of locations, and so they are able to calibrate the instrument and take it out for the afternoon and come back.

J: Just a follow up question with that, we had noticed it was important the average time [between] when the sample was collected and when the samples got to the lab. Because we had to ship on the boat, we kept them on ice in a cooler, so I was just wondering on average, how long is there between when you sample and when they go to the lab?

E: Yeah, so the samples for the volunteer program, they're all collected at 6 AM. Or approximately 6 AM. And they come back here first for processing and then go to the Deer Island lab for 10, about 10 AM is when they'll make it to the lab. And when our interns are collecting samples they will drive samples from the field, they actually use a boat at the community rowing boathouse in Brighton, so they'll just drive the samples directly from the field to the lab and they'll collect the samples between maybe 8:30 and 10:30, so the samples will be at the lab by maybe about noon at the latest. And so our QAP [*Quality Assurance Plan??*] has protocols that samples are put on ice when they are collected in the field and stay on ice until they get to the lab and we do have kind of a maximum hold time, I think it may be something like 6 hours. But I can definitely find that out.

J: Yeah, that's really good, that's definitely a better turnaround time then we had, but obviously it's harder when you're on an island.

E: Yeah, we're lucky, kind of being in a densely populated area that is very prominent in the scientific fields where we have labs around us and it doesn't take much time to get from our watershed to the lab.

J: That definitely answered my question. The next one we were wondering how you take into consideration rain and precipitation events. I know we looked at some of your tables and you had the Logan airport rainfall amounts for the past three days and a lettering whether it rained after or during the sampling, so I guess from that, we were wondering is it more or less advantageous to sample during rain or during dry weather, and if you would change the time of the day for sampling if rain were to occur.

E: Yeah, so, for the volunteer program we actually have all the dates set at the beginning of the calendar year. And the idea is because we are using that as a baseline water quality monitoring program, we are just trying to catch random dry weather and wet weather events. So, the split between dry weather and wet weather events is a little different each year, but it usually does work out to be pretty close to 5 one way and 7 the other way, but it gives us a good mix and kind of also ensures that we don't have volunteers skipping out, just because they know it'll be rainy and cold. And, so that program is just kind of capturing random events. Our summer interns also will sample on fixed dates and so it may rain before their sampling event, it may not. For that program it might be useful to be a little more targeted about when we collect the samples, but we really focus more on consistency, and repeatability and honestly one of the more useful outcomes of that program in recent years is that we're able to pick up some of those dry weather pollution events and share those with other stakeholders. When we’re doing sort of restoration projects, if we are doing a monitoring component, that will be very strictly weather based, so we’ll establish how many wet weather and dry weather events we want to sample before and after the installation and then it’ll be someone’s responsibility to track the weather conditions before we send out a field team.

J: Yeah, I can see how it could be to your advantage to have that split of dry and storm event data.

E: Right, because I think we’re really using that dry weather as that baseline bacteria levels in the watershed.

J: Yep.

S: OK. So, now we’re going to go into the questions about specifically the BMPs that you mentioned in your email.

E: Sure.

S: So, we were just wondering what are the BMPs that you monitor and where are they located?
E: Yeah, so unfortunately none in Cambridge. But maybe in a few years, we are planning some green infrastructure projects for Cambridge. But a couple of years ago, I think it was 2014 or 2015, we had a project in Chelsea and one in Boston. The project in Chelsea was a bioretention system, so we sampled water coming into the drainage area kind of right before the catch basin that would’ve drained this sort of cul de sac. And so we sampled that condition before the BMP was installed and then once the bioretention was built we sampled the water coming out of the underdrain of the bioretention system, also through the storm sewer there. And in Boston we were collecting water samples only after the installation of a porous pavement system. And so I collected, originally the plan was just to collect samples from a well that we had kind of built into the design for the purpose of monitoring and it was a PVC pipe basically, and when we realized we had some extra budget available, we started collecting some samples at street level before water went into the system.

S: So, were all these projects mainly for monitoring or did they also help the community?
E: Yeah, so, I think the reason, one of the big reasons, we were doing some of that monitoring a few years ago was to just try to sell people on the fact that these best management practices are actually helping us meet our water quality goals. I think there’s less skepticism about that now. There’s kind of a growing universe of water quality data supporting the effectiveness of best management practices so we’ve actually seen lots of our state or federal funders are less interested in generating new data, and so we’ve backed away from doing that type of monitoring. But those were kind of our first projects where we used that type of technology and so we felt like it was important to demonstrate that it was working as we had expected.

S: So, did you just dabble into the structural BMPs, or did you ever look into proprietary BMPs as well?

E: We actually have never done any work with proprietary BMPs. You know we're not a public agency, so we probably could advocate for a particular proprietary BMPs if we knew that they were effective, but, yeah. So far all of our work has just been working with partnering engineering firms in our field who will design the structural BMPs.

A: We were also wondering how's the water quality tested before and after it's treated by the BMPs?

E: Yeah. The sampling approach for the bioretention system was to use an ISCO automated sampler, so essentially, what we had to do before each sampling event was sterilize some sample containers, set up a program on the sampler to tell it, you know, under what conditions it should sample, so our sampler was connected to a rain gauge that we had installed on site so we would sample after at least a quarter inch of rain, and we also had to calibrate the sensor to measure flow coming out of the underdrain. So then after the storm event, someone would go out and retrieve the sample bottles. Then, we'd kind of split them. We have a cone splitter that would help divide, that would help composite all of the samples that were collected and then divide them up equally into sterile bottles for the lab. Those samples, when we were monitoring structural BMPs are, the, you know, focus is very different from our baseline monitoring program. So they're only tested for phosphorus, orthophosphate, nitrogen, nitrates, and TSS. We don't bother with the bacteria samples for that. And then for this…. And then for the porous alley we actually tried to use like a plastic baler to basically vacuum water out of the monitoring well. Had a hard time getting suction, so sometimes we did just resort to using it more like a typical baler kind of scooping water out of the well. And that water was tested for the same parameters and for that particular project we usually had to go out to collect samples when it was raining or within maybe an hour of when it had rained because the water would drain pretty quickly.

J: Yeah, we thought with the BMPs it would be really different than like the sampling of the river in general. It kind of has to be more automated.

E: Yeah, yeah. We did not invite volunteers to come help with that.

J: It seems definitely more challenging.

E: It's kind of really on the fly, and sometimes it's kind of outside of standard business hours, and so yeah.

S: Is that data available on your website?

E: Yeah, so again I don't think it's on our website. We do have the data, well I take that back, the data might be on our website in a report format, but if you wanted it in a spreadsheet format we have that.

S: That'd be great, thank you.

A: Yeah, we were hoping to put it into BATT to see the phosphorus reduction BATT would give us, just to compare software to sampling.

J: Yeah, to real data. We were really excited when we discovered you also had BMP monitoring because we thought it was just the river.

E: Right, yeah. Yeah, and I think, I was hoping to get that data into, whatever it is, the National BMP Monitoring Database, but I think we got held up trying to enter cost information. We weren't, we didn't have, we kind of wanted to subtract some of the costs, the unrelated costs of the project like moving utilities and things like that, so.

S: So, our last question has to deal a little bit more with BATT in that we have a list of what BATT provides as BMPs. So, I don't know if you've had a chance to look at them.
E: I did. Kind of skimmed through it.

S: So, this is what BATT has as the BMPs listed and their descriptions, so if you thought of any BMPs that are effective but are not on this list, it would be really helpful for us going forward in our project.

E: Yeah, so this list is BMPs that provide nutrient pollution control, not just water volume control, right?

J: Yeah.

E: No, yeah, I think this hit all the types of BMPs we've used or recommended in the past, you know terminology is sometimes different, but I think they're all the same types of systems. We do have, I guess the infiltration trench could be a tree trench. So, we have had some communities refer to BMPs as tree trenches which are probably some sort of cross between a tree filter and an infiltration trench. Basically they have a series of trees in a trench. But otherwise, I think this is probably everything we would use.

J: Yeah, when we were looking at that. There's so many different terminologies of BMPs that we haven't had experience with like deep sump and dry well, so we gotta see where they would fit in the BATT tool under those categories. I think one that we really encountered that didn't seem to fit anywhere was the roof detention systems. But they may fall under a land use change category, we'll have to play around more with that.

E: Yeah, right. Oh, I guess there isn't a green or a blue roof on here, yeah. We haven't had anyone try to use a green roof with a project that we've been involved in. Yeah, that is definitely a category that doesn't really match what's on here. Yeah, and I'm sure you've seen the UNH Stormwater Center data. That's also what we've used as one of our reference for what we expect our BMPs to be able to do.

J: That's really impressive, the amount of information that they provide. We are also trying to get a visit there as well.

E: Oh, you should…

J: But they go to school so much later than us. Like we haven't gotten a response from any of our emails yet, but we'll see.

E: Yeah, yeah. I wonder, I think it's Jeff maybe who's the hands-on person now. He might have a slow response time too. I'm sure they get a lot of inquiries. But if you could tag along, I think the Fresh Water Resource Class, but some of the classes do tours and so you could just kind of say you would be happy to tag along when one of the classes does a tour and that might get you on the calendar faster than trying to set up your own.

J: Yeah, that's true.

E: Though, I don't know if that works for your timeline. They probably wait until late April, it's probably one of the last things they do because it's an outdoor activity.

A: Right before graduation, we'll get to go.

E: Well, I think if you go up there, you know, you can just walk around without a tour guide. So, if worse comes to worse.

J: We can always have a peak and see what BMP.

E: The UNH Stormwater Center is right near one of their visitor parking lots. Yeah, you can just kind of jump around.

J: That's good to know. So, we can just sneak around there. Yeah, it is hard because most senior capstones go three terms, so it's three fourths of the school year, and they'll do it with a professor on campus as a more research project, but since we're with a company, it's just in 7 weeks, so it's very overwhelming trying to finishing everything.

A: Yeah, fast turnaround.

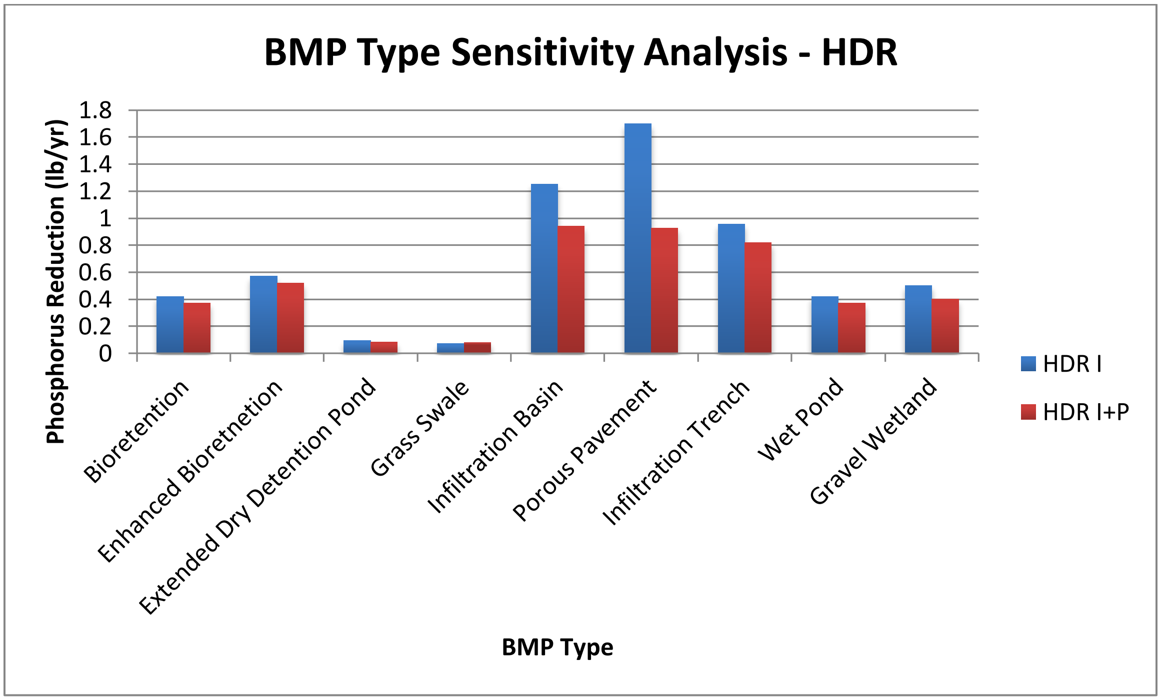
J: Yeah, we started a proposal, research part of the project last term, but this is primarily when we get the work done. We appreciate your responsiveness.

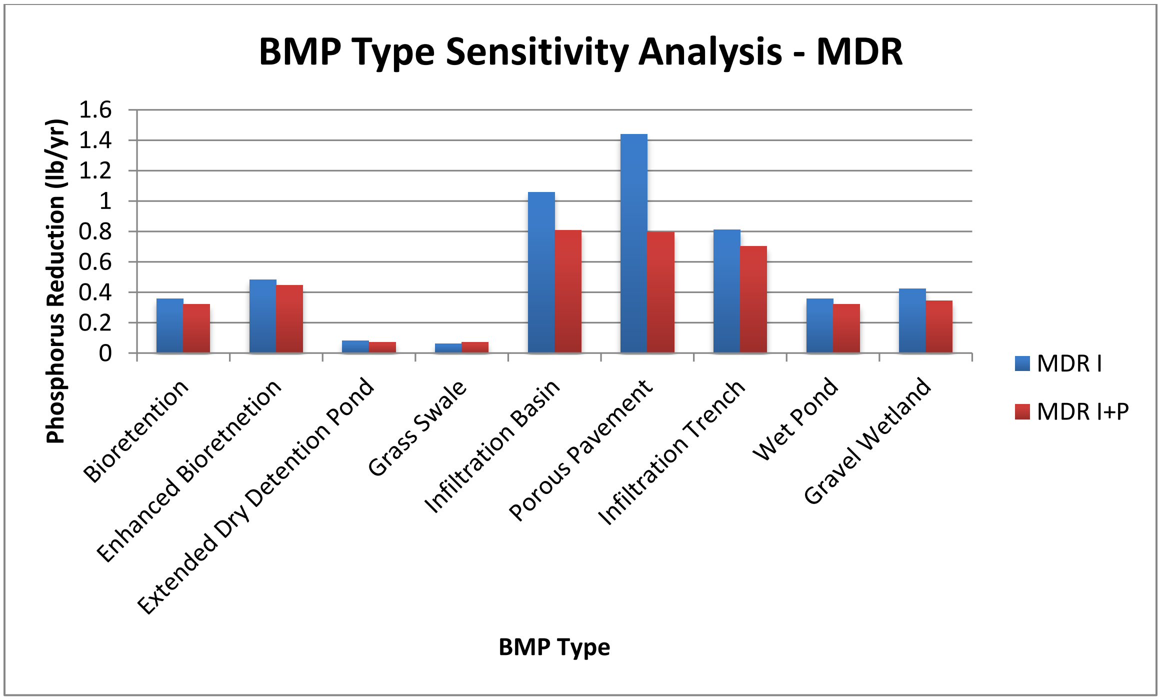
After the interview, Elisabeth Cianciola showed the team the tools the volunteers used to take samples from the bridges

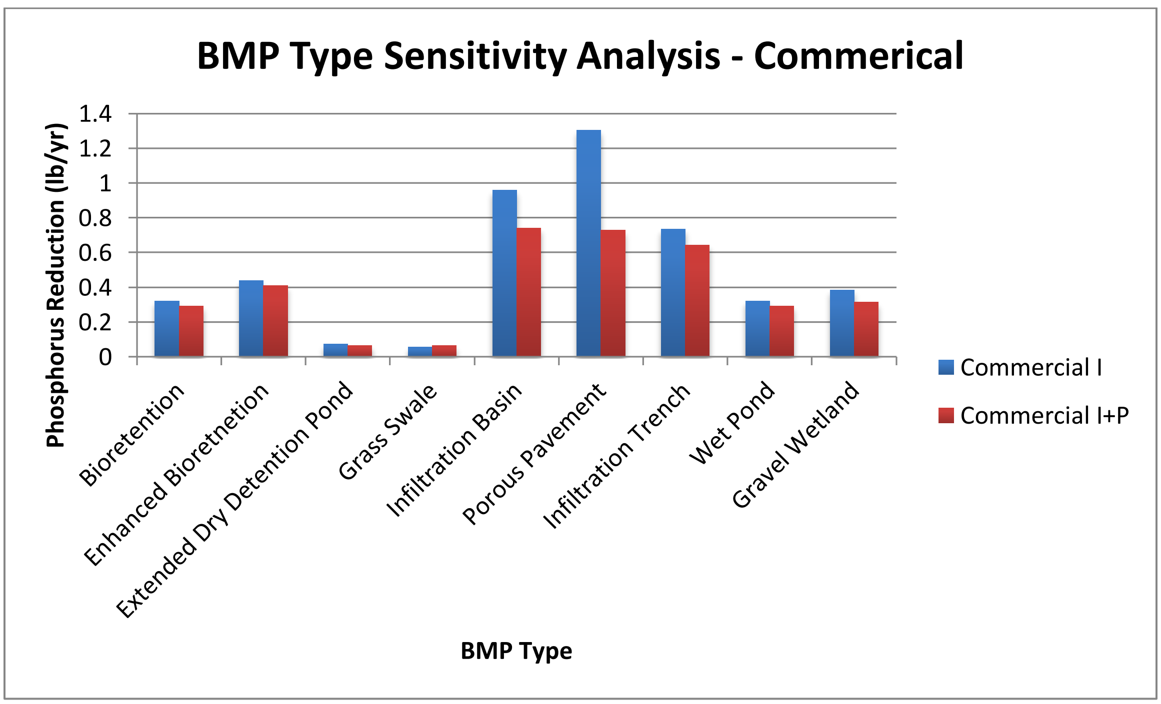
- *Takeaways from this extra part of our interview: Tools need to be cheap so that each volunteer can have their own, Creative solutions are needed*

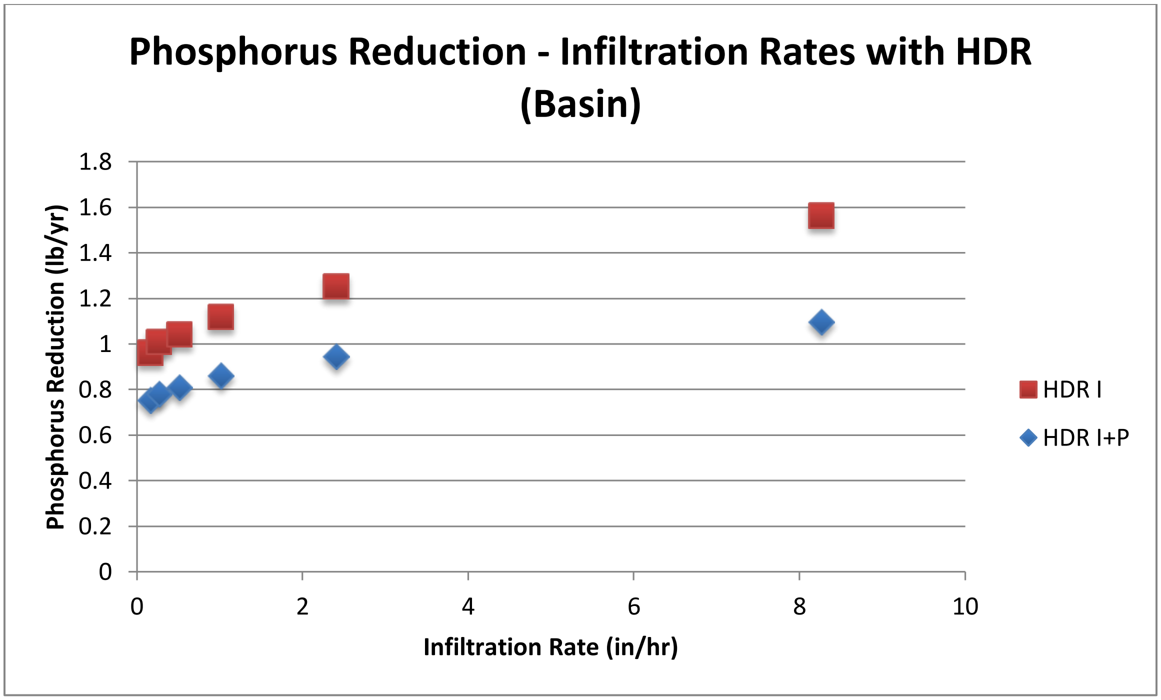
Appendix D: Sensitivity Analysis Graphs
MDR – Medium Density Residential
HDR – High Density Residential
I – Impervious
P – Pervious

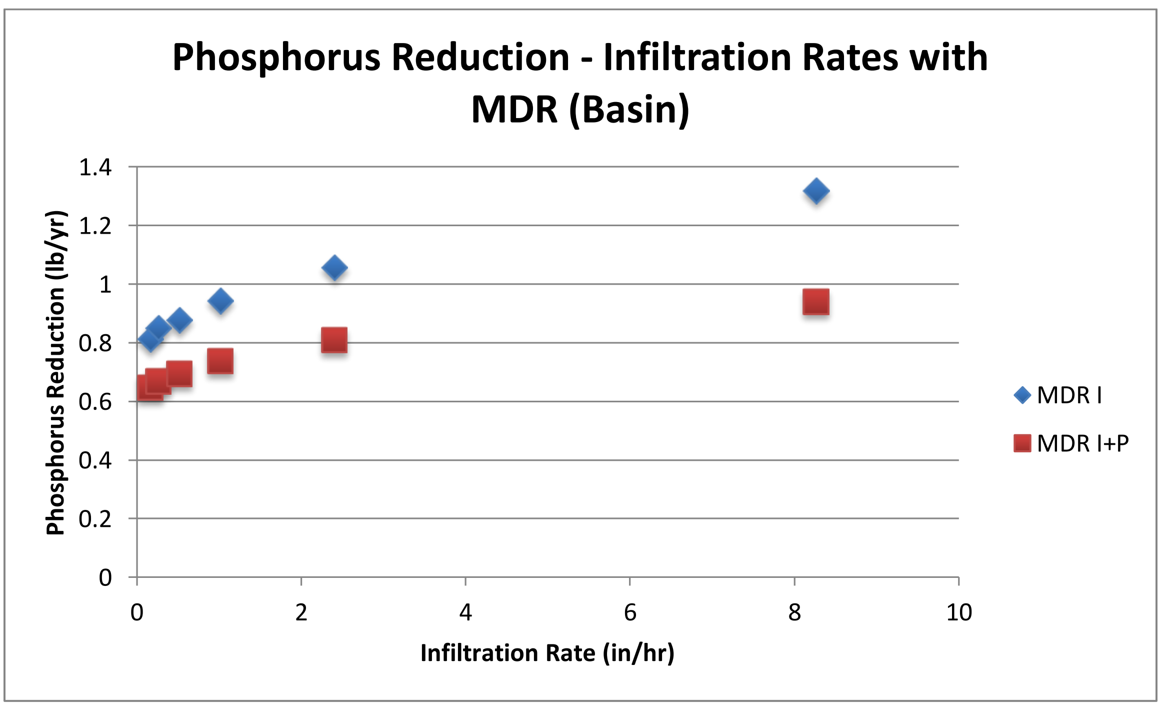
Structural Sensitivity Graphs

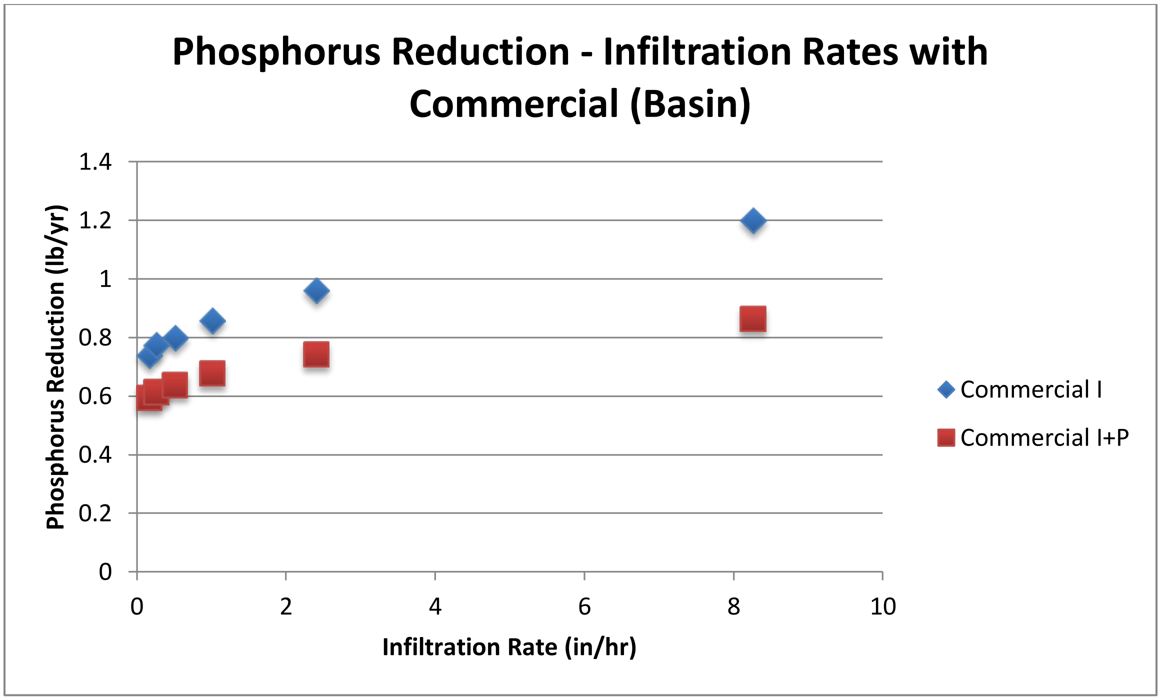


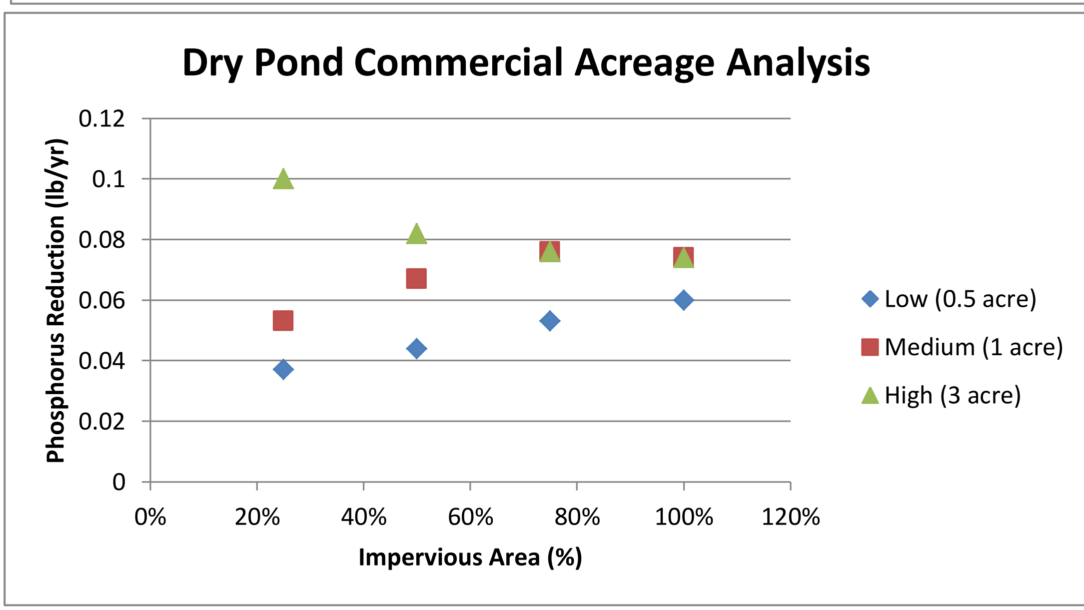

BMP Type Sensitivity Analysis - MDR
Phosphorus Reduction (lb/yr)
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
Bioretention
Enhanced Bioretnetion
Extended Dry Detention Pond
Grass Swale
Infiltration Basin
Porous Pavement
Infiltration Trench
Wet Pond
Gravel Wetland
BMP Type
MDR I
MDR I+P

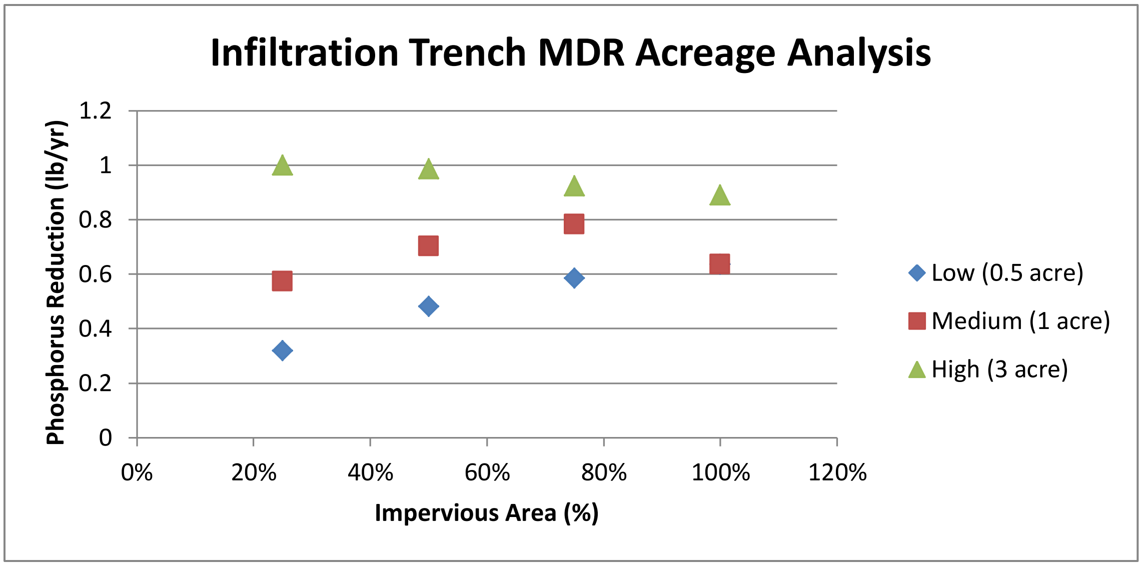

BMP Type Sensitivity Analysis - Commerical
Phosphorus Reduction (lb/yr)
1.4
1.2
1
0.8
0.6
0.4
0.2
0
Bioretention
Enhanced Bioretnetion
Extended Dry Detention Pond
Grass Swale
Infiltration Basin
Porous Pavement
Infiltration Trench
Wet Pond
Gravel Wetland
BMP Type
Commercial I
Commercial I+P

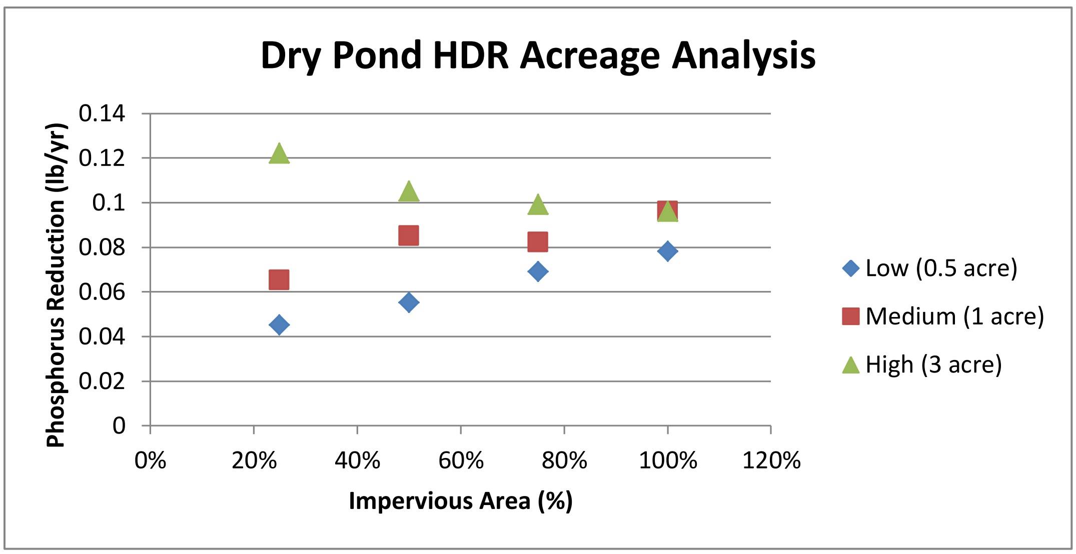

Phosphorus Reduction - Infiltration Rates with HDR (Basin)
Phosphorus Reduction (lb/yr)
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0
2
4
6
8
10
Infiltration Rate (in/hr)
HDR I
HDR I+P

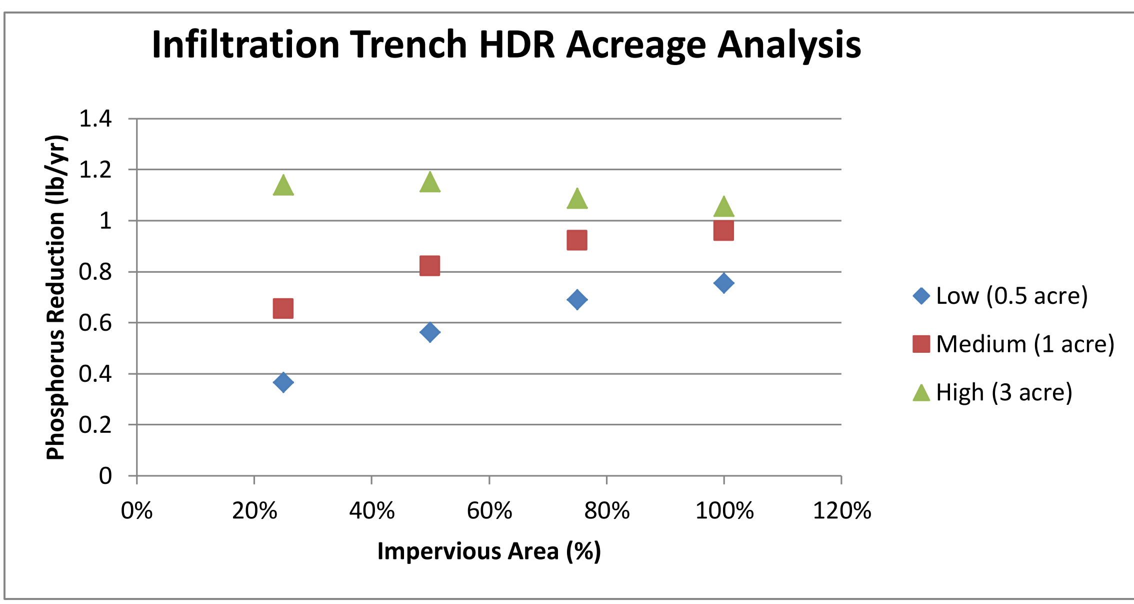

Phosphorus Reduction - Infiltration Rates with MDR (Basin)
Phosphorus Reduction (lb/yr)
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0
2
4
6
8
10
Infiltration Rate (in/hr)
MDR I
MDR I+P

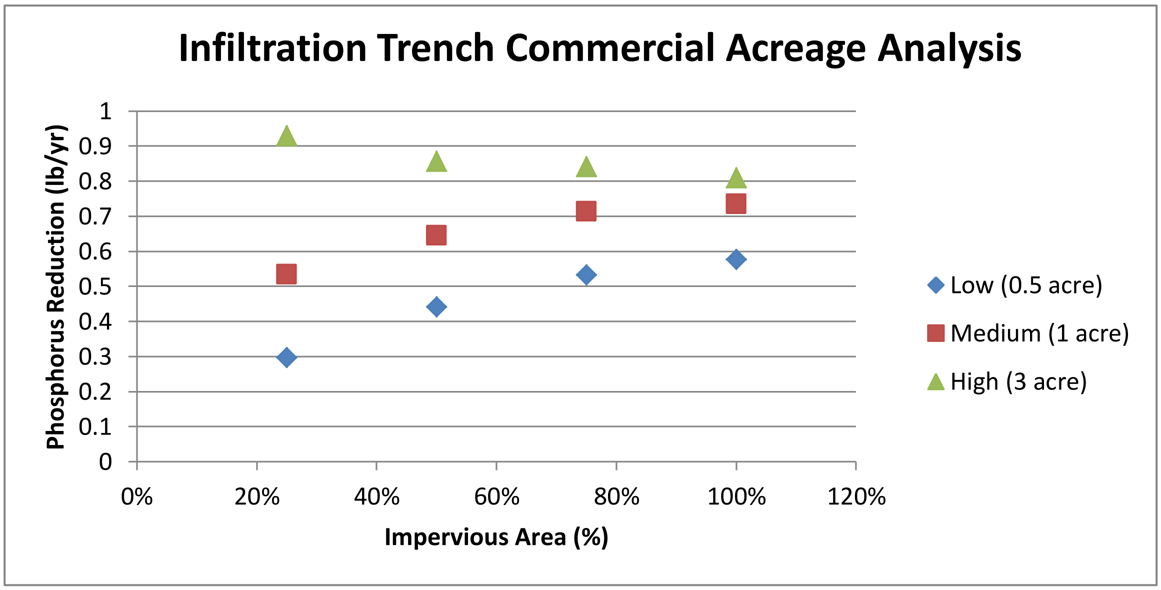

Phosphorus Reduction - Infiltration Rates with Commercial (Basin)
Phosphorus Reduction (lb/yr)
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0
2
4
6
8
10
Infiltration Rate (in/hr)
Commercial I
Commercial I+P

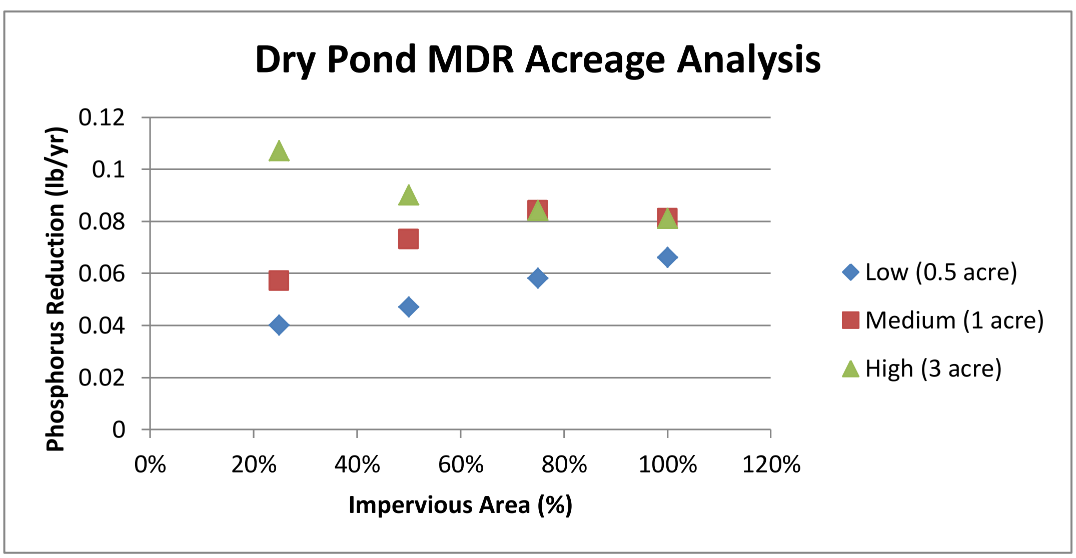

Dry Pond Commercial Acreage Analysis
Phosphorus Reduction (lb/yr)
0.12
0.1
0.08
0.06
0.04
0.02
0
0%
20%
40%
60%
80%
100%
120%
Impervious Area (%)
Low (0.5 acre)
Medium (1 acre)
High (3 acre)

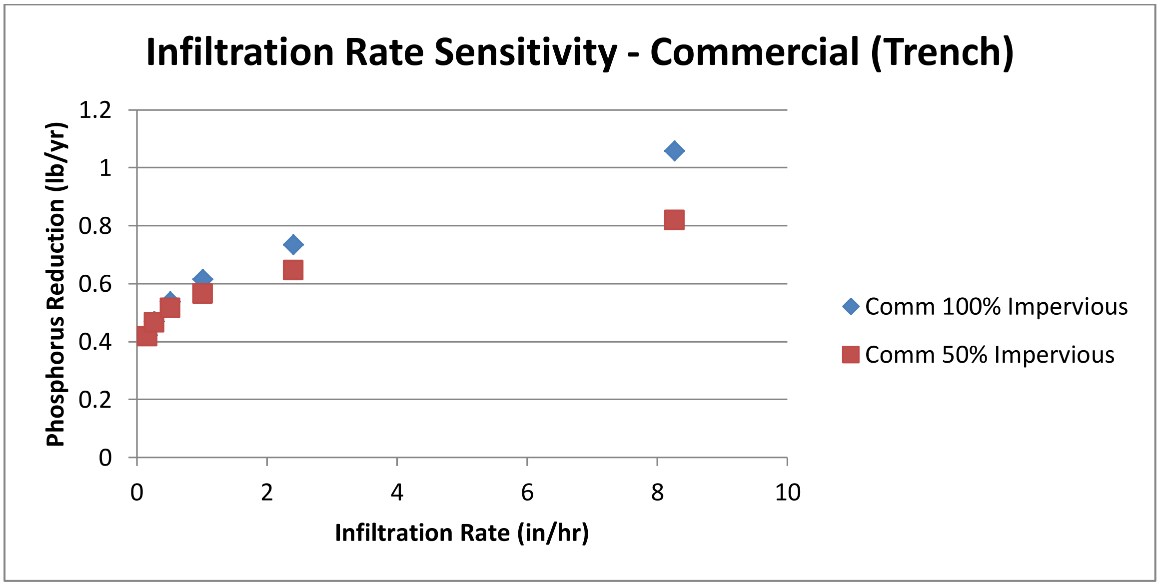

Infiltration Trench MDR Acreage Analysis
Phosphorus Reduction (lb/yr)
1.2
1
0.8
0.6
0.4
0.2
0
0%
20%
40%
60%
80%
100%
120%
Impervious Area (%)
Low (0.5 acre)
Medium (1 acre)
High (3 acre)

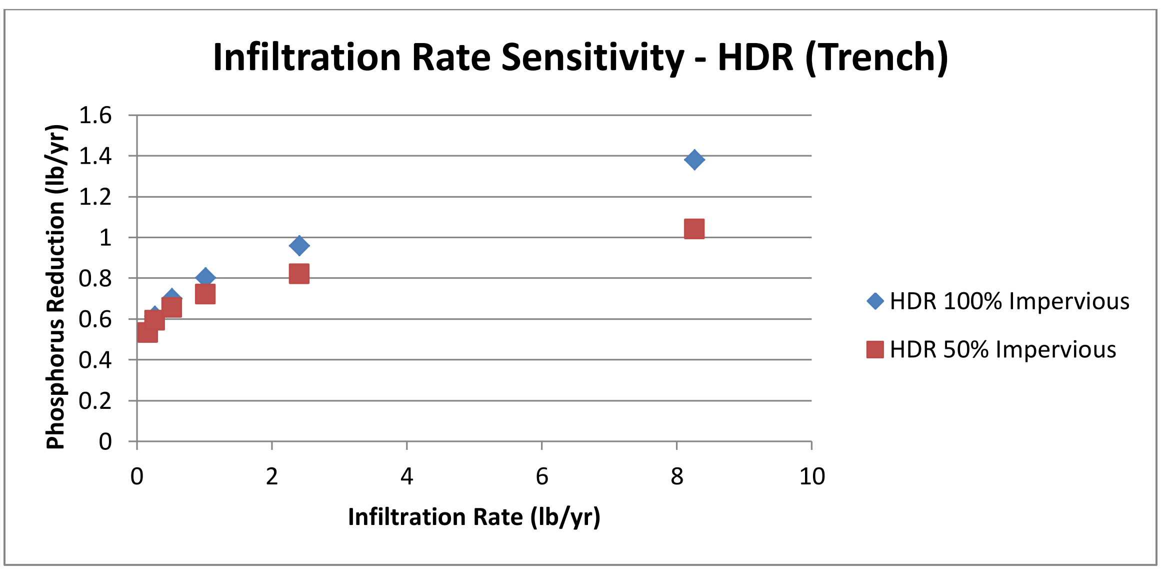

Dry Pond HDR Acreage Analysis
Phosphorus Reduction (lb/yr)
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
0%
20%
40%
60%
80%
100%
120%
Impervious Area (%)
Low (0.5 acre)
Medium (1 acre)
High (3 acre)

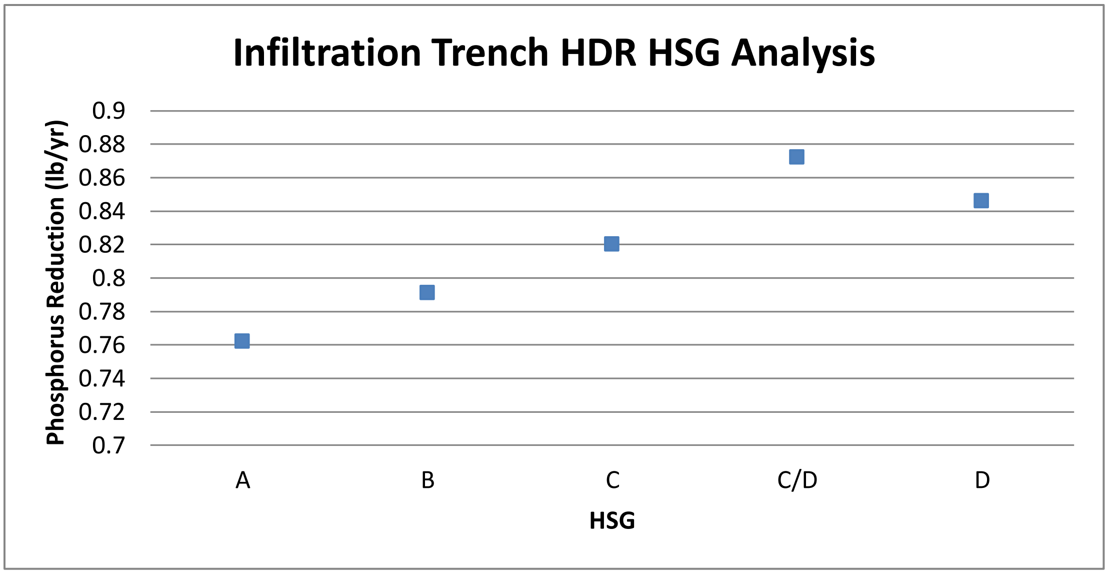

Infiltration Trench HDR Acreage Analysis
Phosphorus Reduction (lb/yr)
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0%
20%
40%
60%
80%
100%
120%
Impervious Area (%)
Low (0.5 acre)
Medium (1 acre)
High (3 acre)

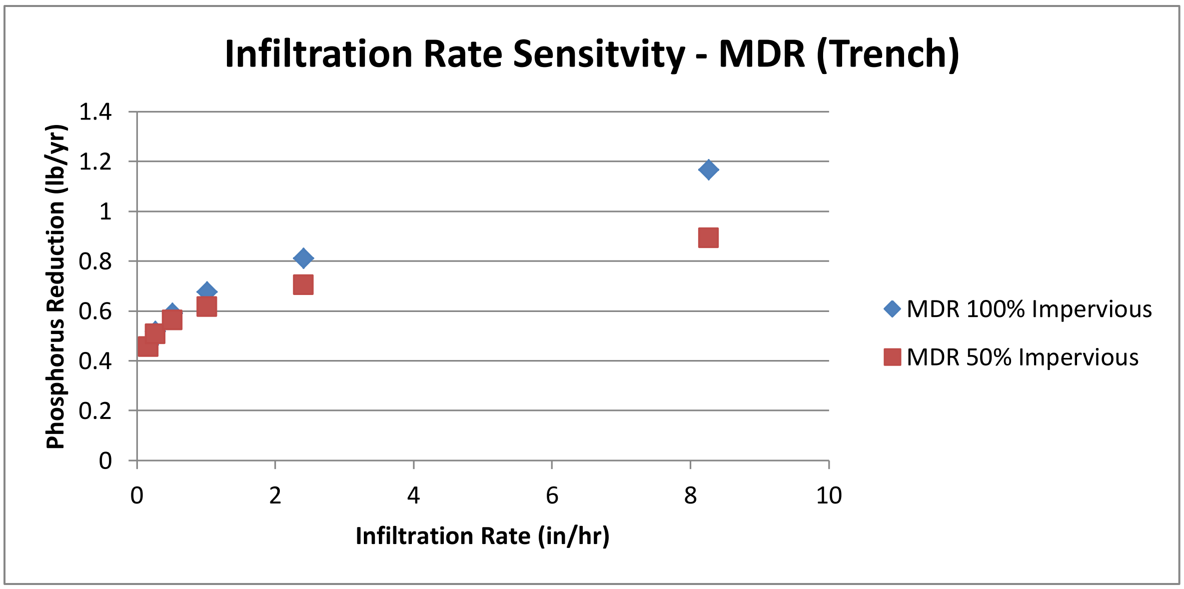

Infiltration Trench Commercial Acreage Analysis
Phosphorus Reduction (lb/yr)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0%
20%
40%
60%
80%
100%
120%
Impervious Area (%)
Low (0.5 acre)
Medium (1 acre)
High (3 acre)

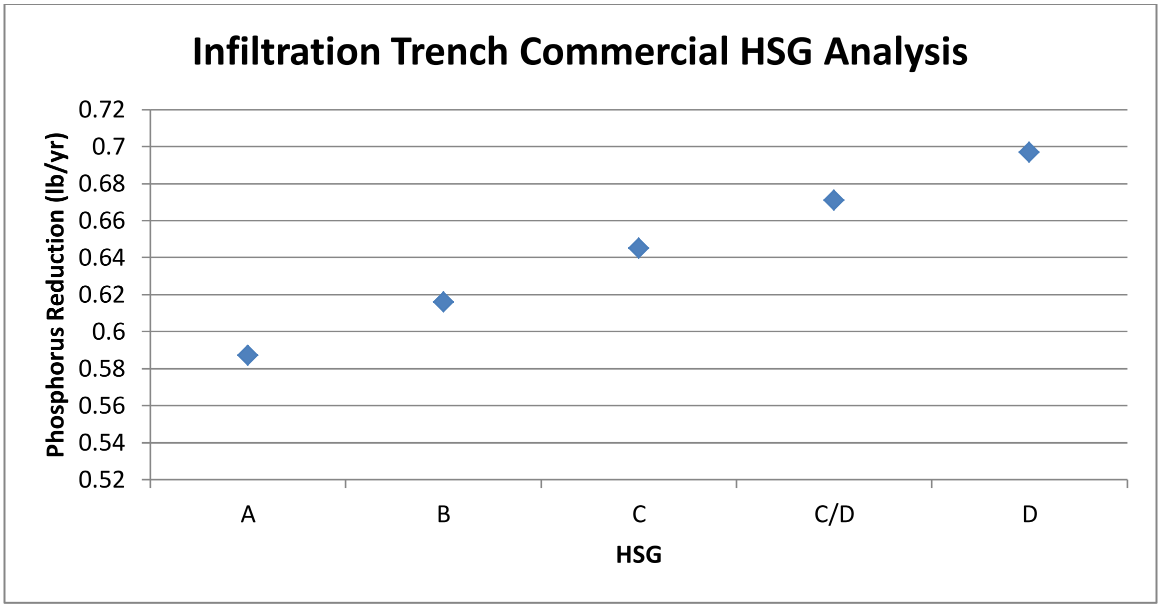

Dry Pond MDR Acreage Analysis
Phosphorus Reduction (lb/yr)
0.12
0.1
0.08
0.06
0.04
0.02
0
0%
20%
40%
60%
80%
100%
120%
Impervious Area (%)
Low (0.5 acre)
Medium (1 acre)
High (3 acre)

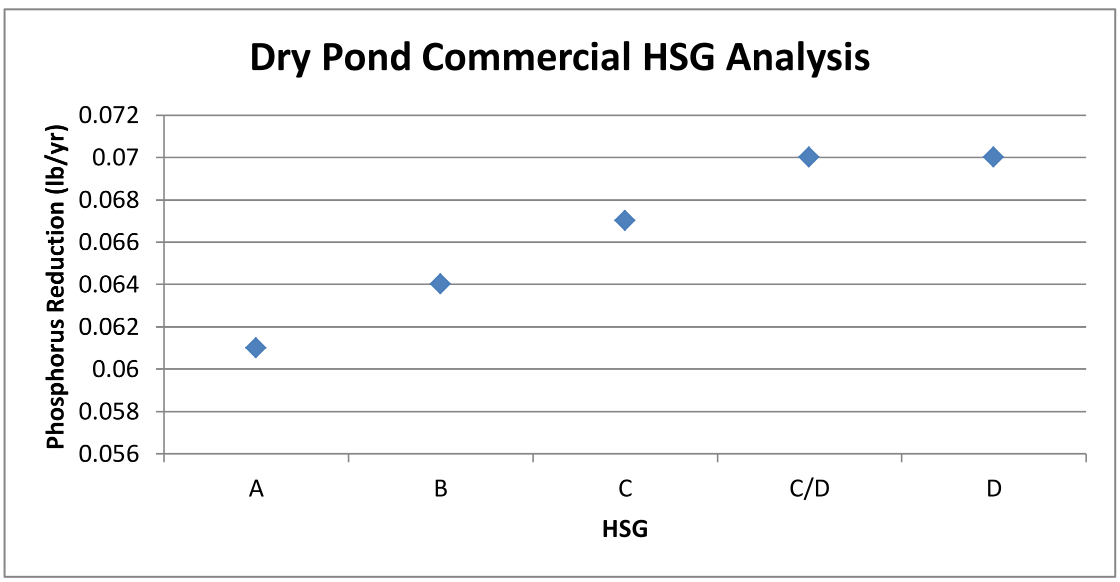

Infiltration Rate Sensitivity - Commercial (Trench)
Phosphorus Reduction (lb/yr)
1.2
1
0.8
0.6
0.4
0.2
0
0
2
4
6
8
10
Infiltration Rate (in/hr)
Comm 100% Impervious
Comm 50% Impervious

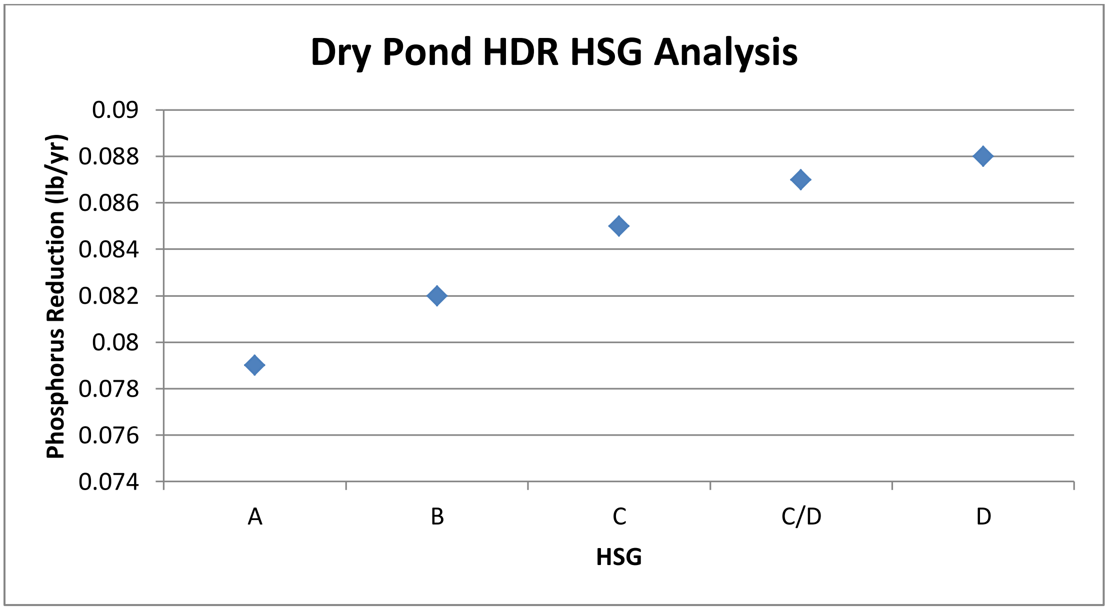

Infiltration Rate Sensitivity - HDR (Trench)
Phosphorus Reduction (lb/yr)
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0
2
4
6
8
10
Infiltration Rate (lb/yr)
HDR 100% Impervious
HDR 50% Impervious

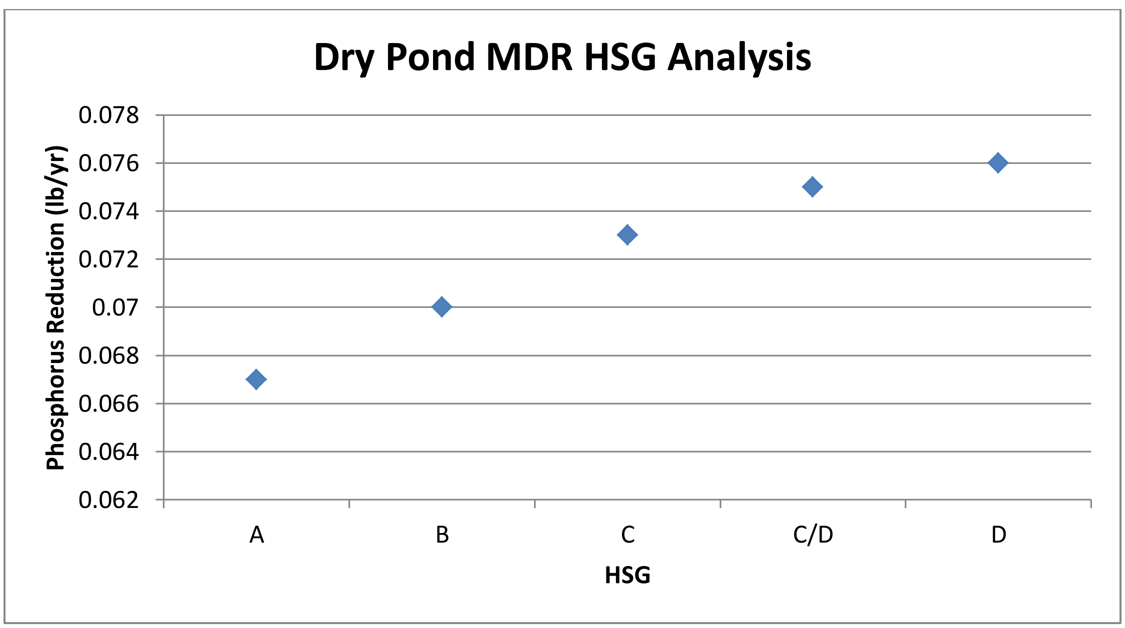

Infiltration Trench HDR HSG Analysis
Phosphorus Reduction (lb/yr)
0.9
0.88
0.86
0.84
0.82
0.8
0.78
0.76
0.74
0.72
0.7
A
B
C
C/D
D
HSG

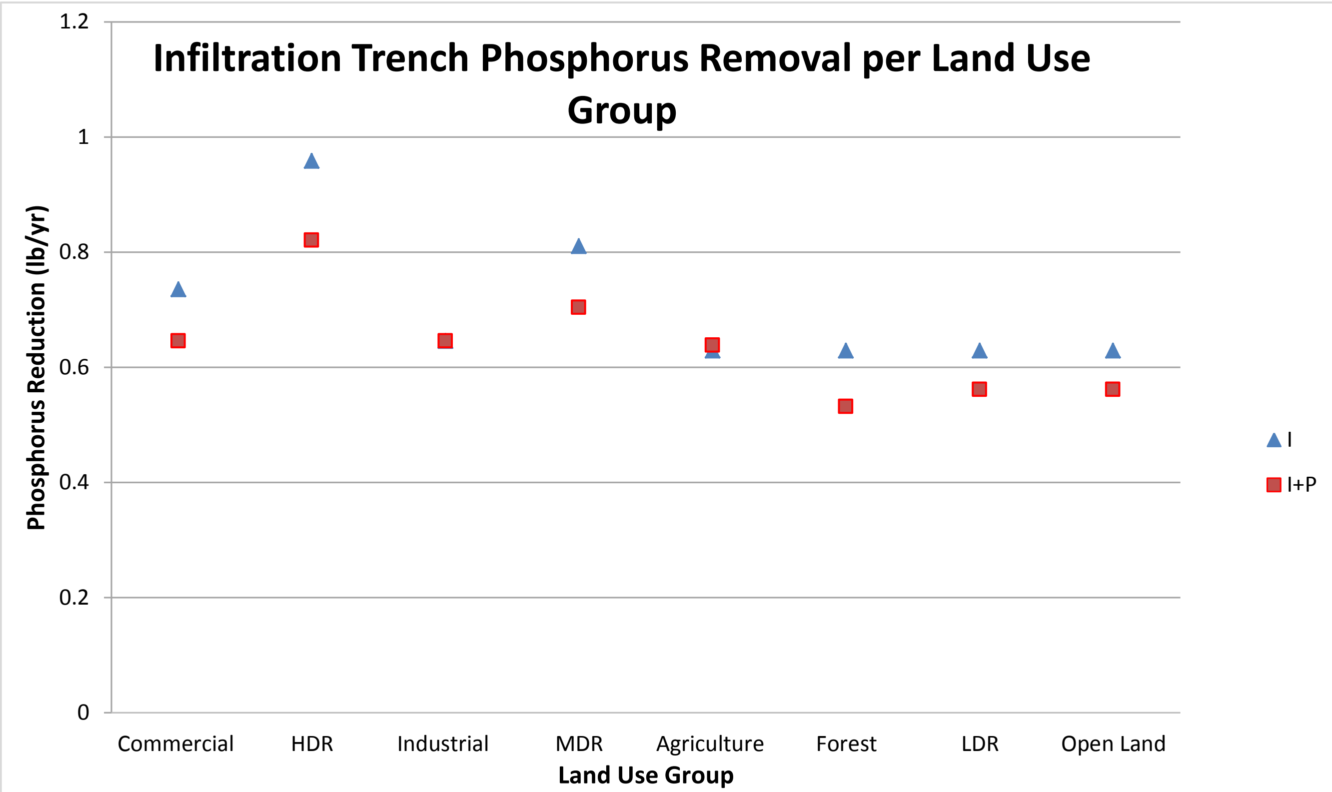

Infiltration Rate Sensitvity - MDR (Trench)
Phosphorus Reduction (lb/yr)
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0
2
4
6
8
10
Infiltration Rate (in/hr)
MDR 100% Impervious
MDR 50% Impervious


Infiltration Trench Commercial HSG Analysis
Phosphorus Reduction (lb/yr)
0.72
0.7
0.68
0.66
0.64
0.62
0.6
0.58
0.56
0.54
0.52
A
B
C
C/D
D
HSG

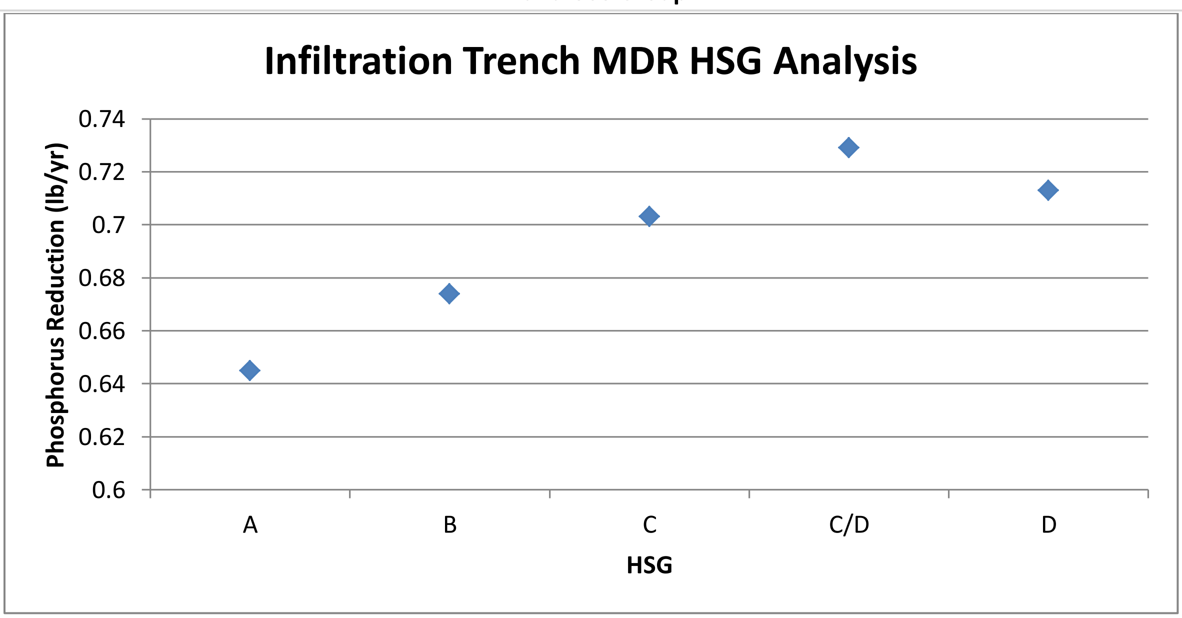

Dry Pond Commercial HSG Analysis
Phosphorus Reduction (lb/yr)
0.072
0.07
0.068
0.066
0.064
0.062
0.06
0.058
0.056
A
B
C
C/D
D
HSG


Dry Pond HDR HSG Analysis
Phosphorus Reduction (lb/yr)
0.09
0.088
0.086
0.084
0.082
0.08
0.078
0.076
0.074
A
B
C
C/D
D
HSG

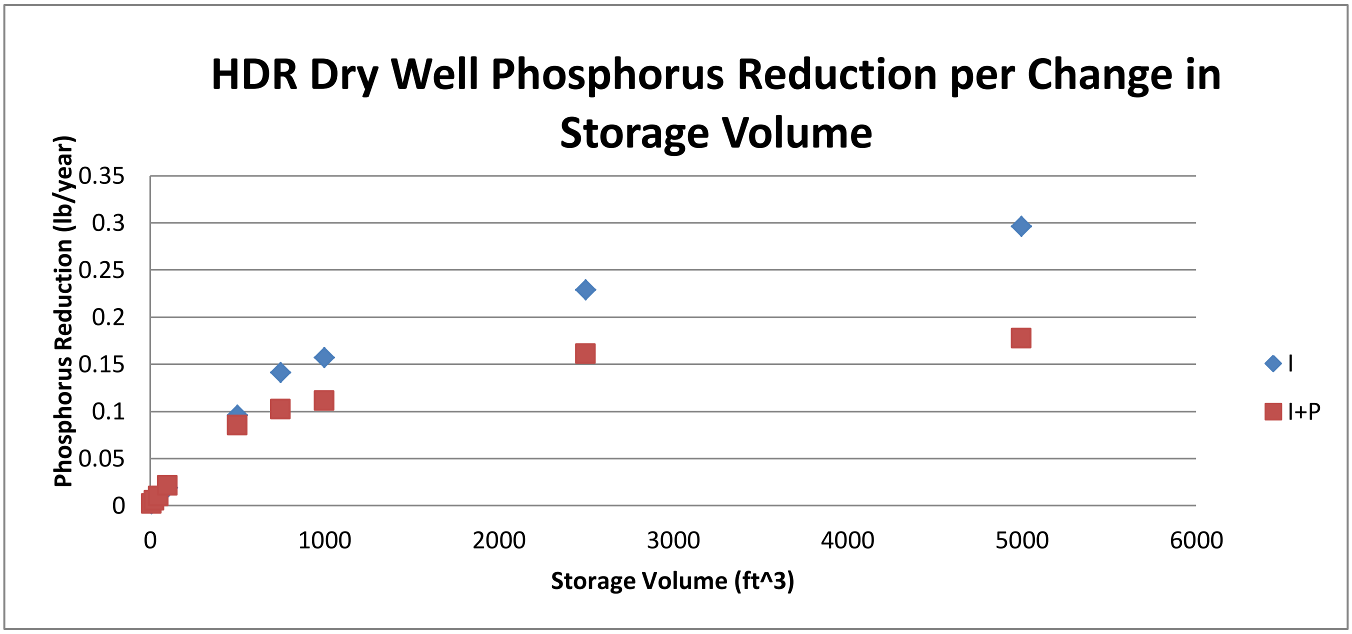

Dry Pond MDR HSG Analysis
Phosphorus Reduction (lb/yr)
0.078
0.076
0.074
0.072
0.07
0.068
0.066
0.064
0.062
A
B
C
C/D
D
HSG

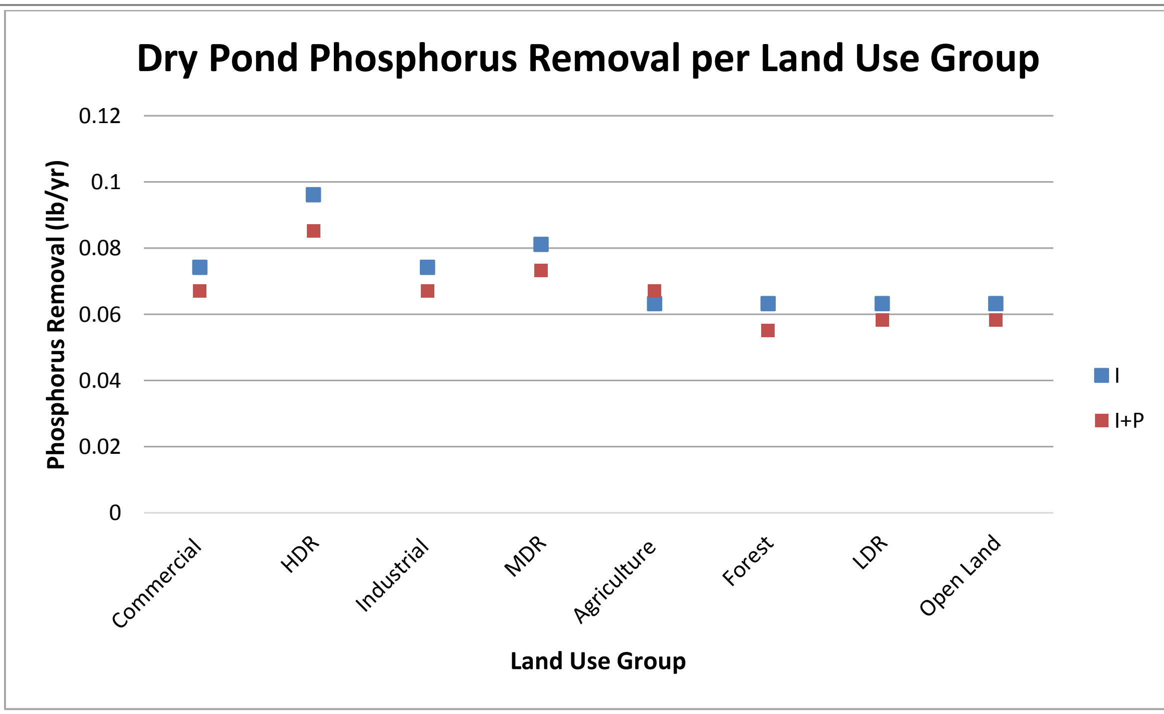


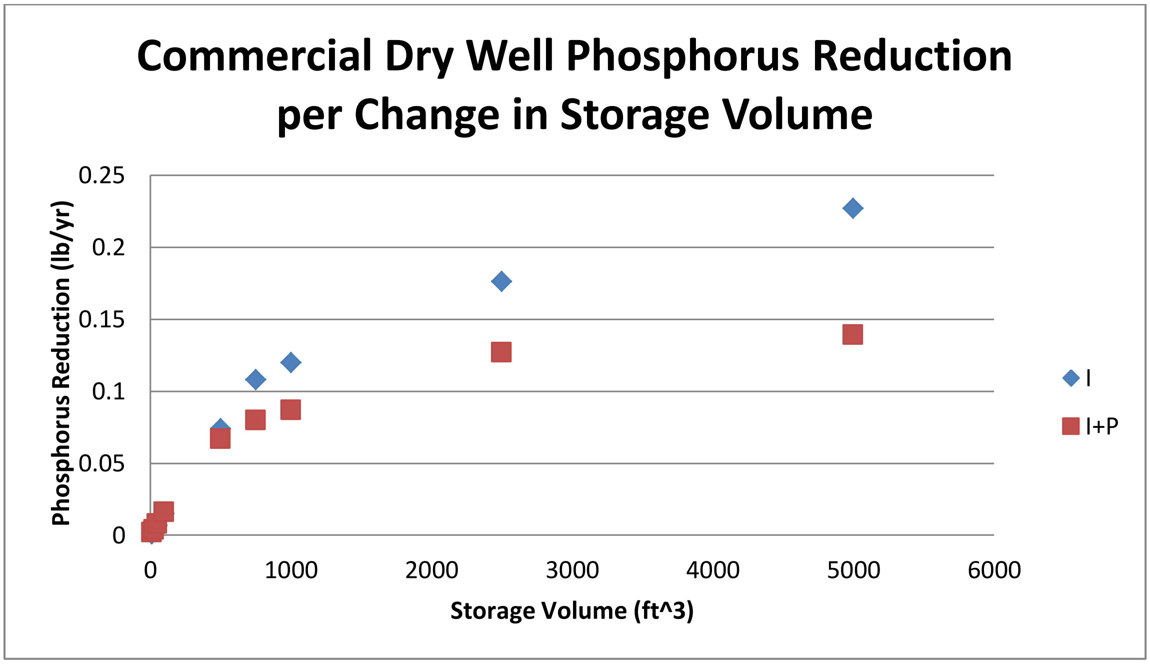
Infiltration Trench Phosphorus Removal per Land Use Group
Phosphorus Reduction (lb/yr)
1.2
1
0.8
0.6
0.4
0.2
0
Commercial
HDR
Industrial
MDR
Agriculture
Forest
LDR
Open Land
Land Use Group
I
I+P

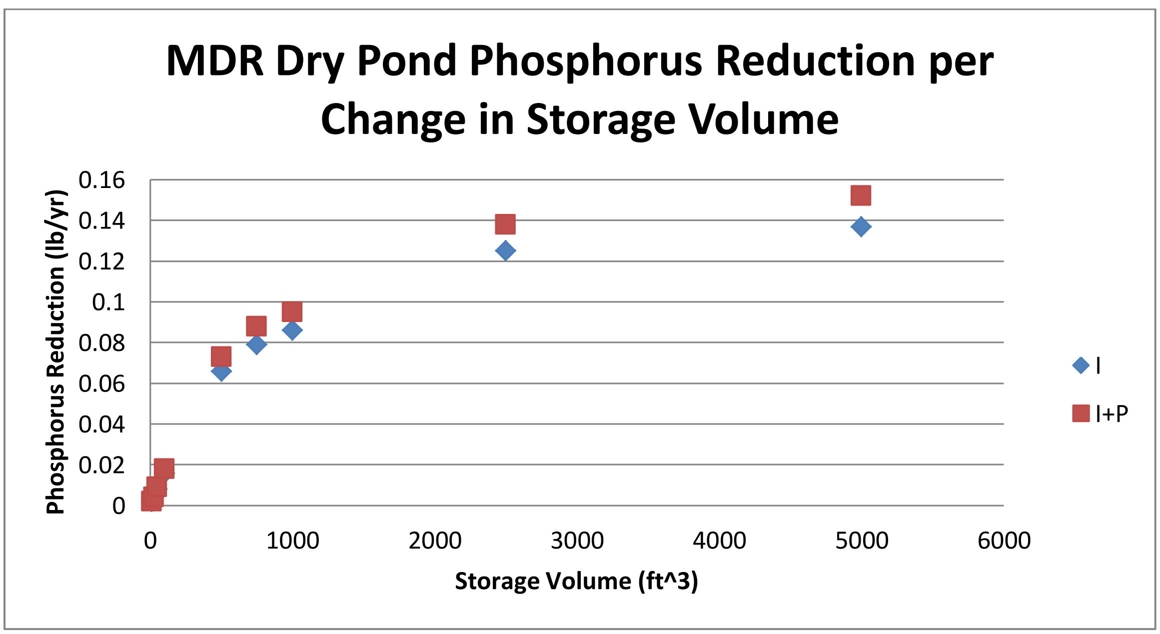


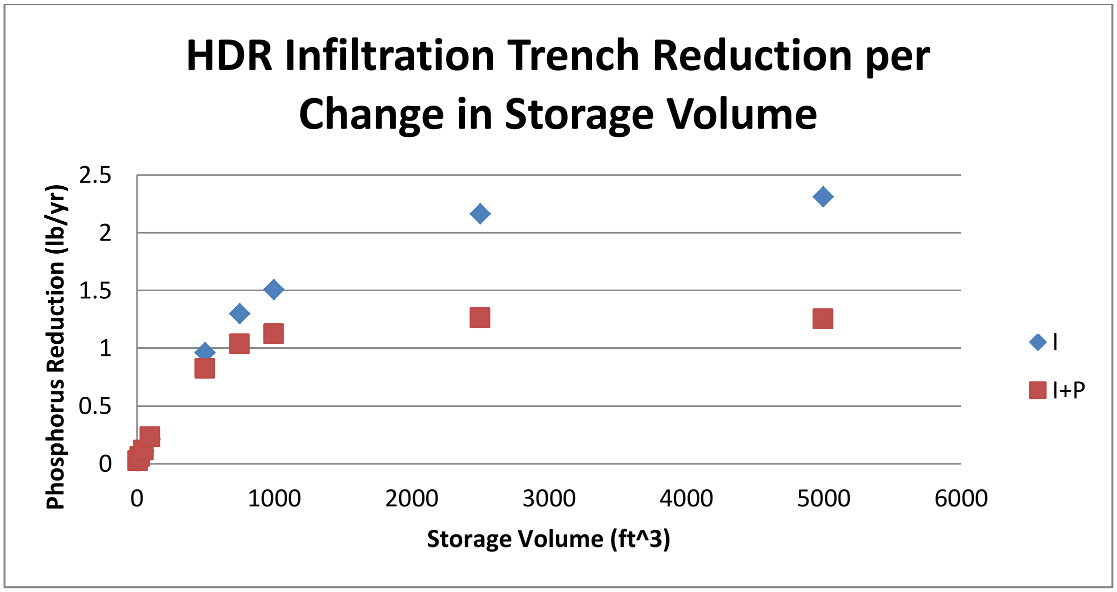
Infiltration Trench MDR HSG Analysis
Phosphorus Reduction (lb/yr)
0.74
0.72
0.7
0.68
0.66
0.64
0.62
0.6
A
B
C
C/D
D
HSG

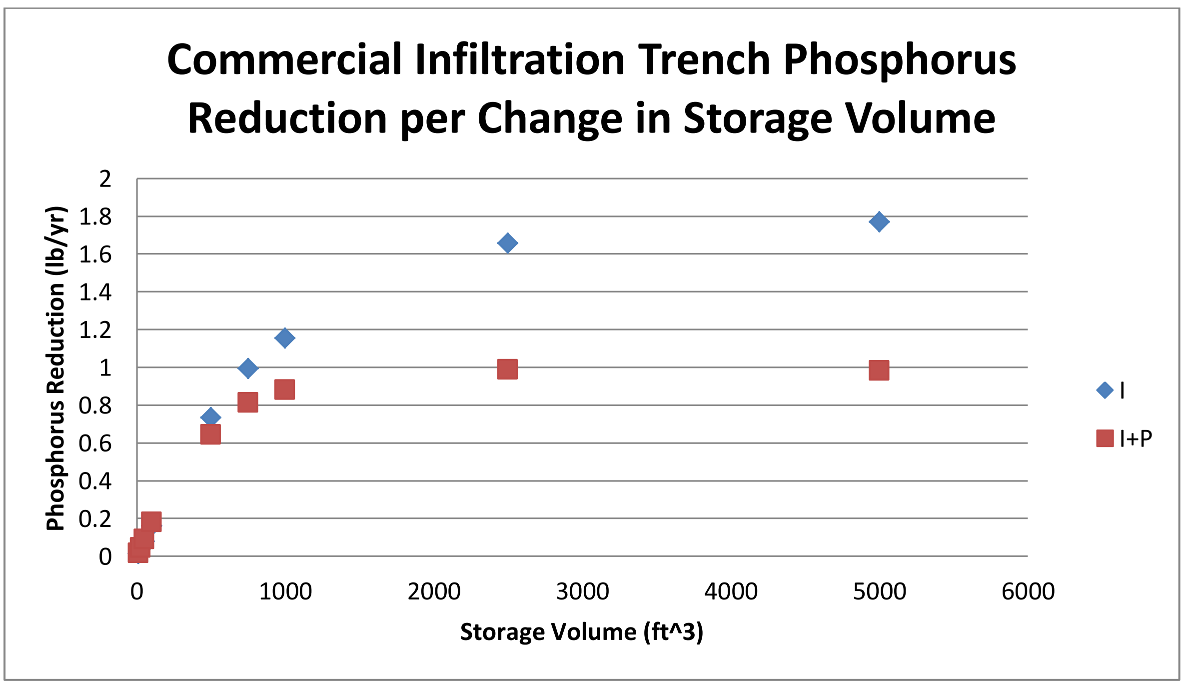

HDR Dry Well Phosphorus Reduction per Change in Storage Volume
Phosphorus Reduction (lb/year)
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0
1000
2000
3000
4000
5000
6000
Storage Volume (ft^3)
I
I+P

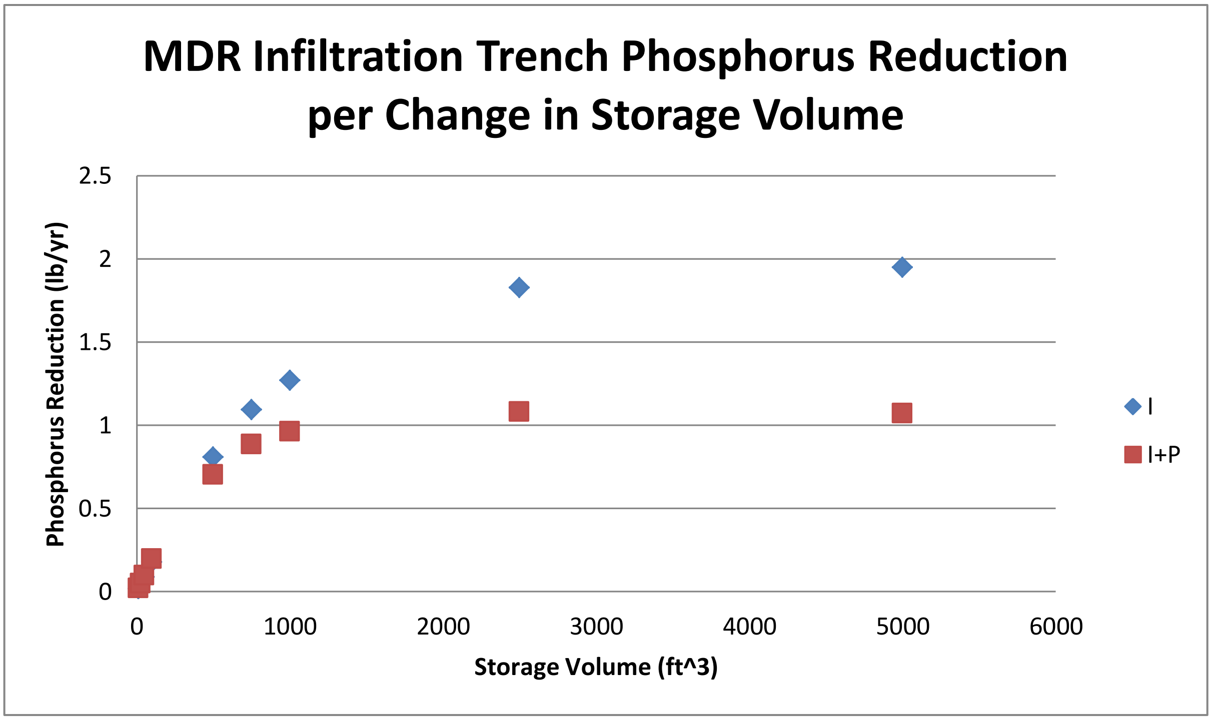

Dry Pond Phosphorus Removal per Land Use Group
Phosphorus Removal (lb/yr)
0.12
0.1
0.08
0.06
0.04
0.02
0
Commercial
HDR
Industrial
MDR
Agriculture
Forest
LDR
Open Land
Land Use Group
I
I+P


Commercial Dry Well Phosphorus Reduction per Change in Storage Volume
Phosphorus Reduction (lb/yr)
0.25
0.2
0.15
0.1
0.05
0
0
1000
2000
3000
4000
5000
6000
Storage Volume (ft^3)
I
I+P

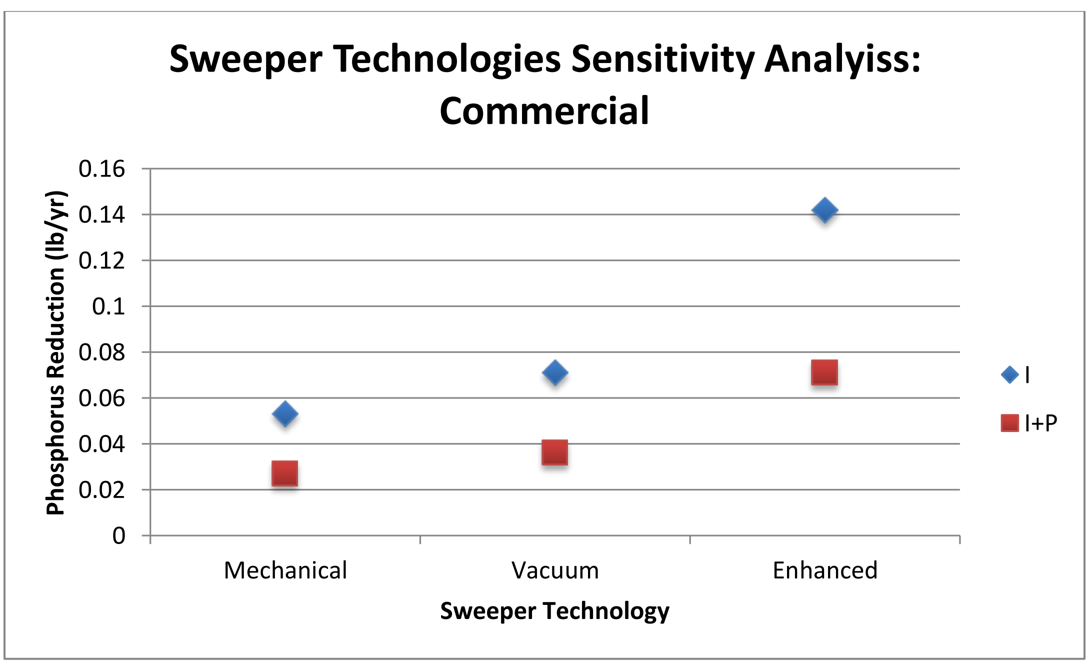

MDR Dry Pond Phosphorus Reduction per Change in Storage Volume
Phosphorus Reduction (lb/yr)
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
0
1000
2000
3000
4000
5000
6000
Storage Volume (ft^3)
I
I+P

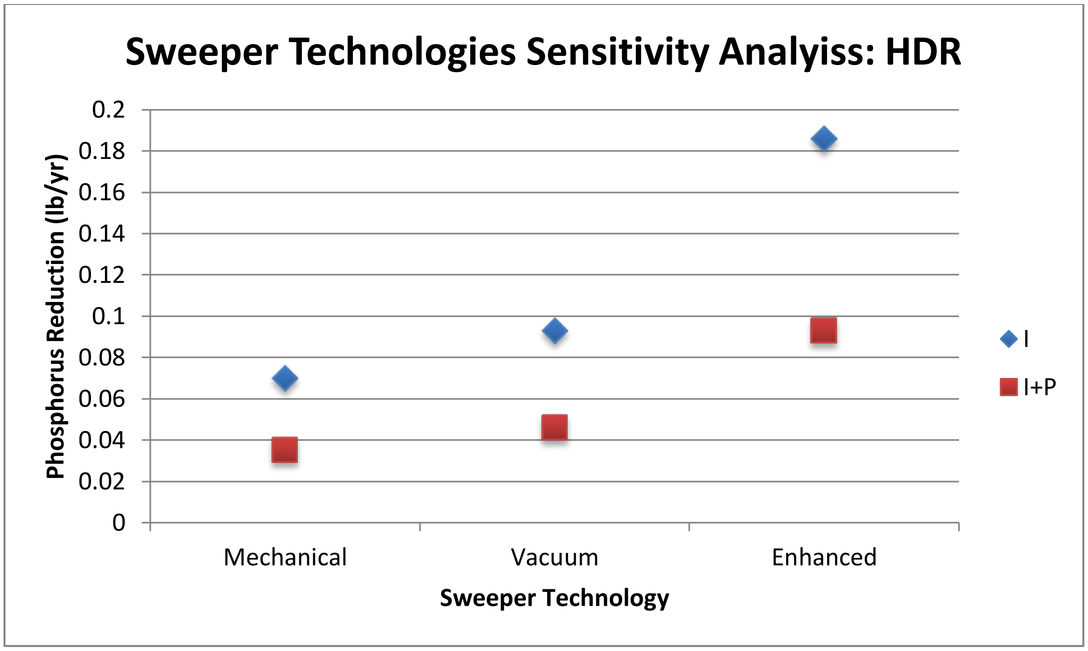

HDR Infiltration Trench Reduction per Change in Storage Volume
Phosphorus Reduction (lb/yr)
2.5
2
1.5
1
0.5
0
0
1000
2000
3000
4000
5000
6000
Storage Volume (ft^3)
I
I+P

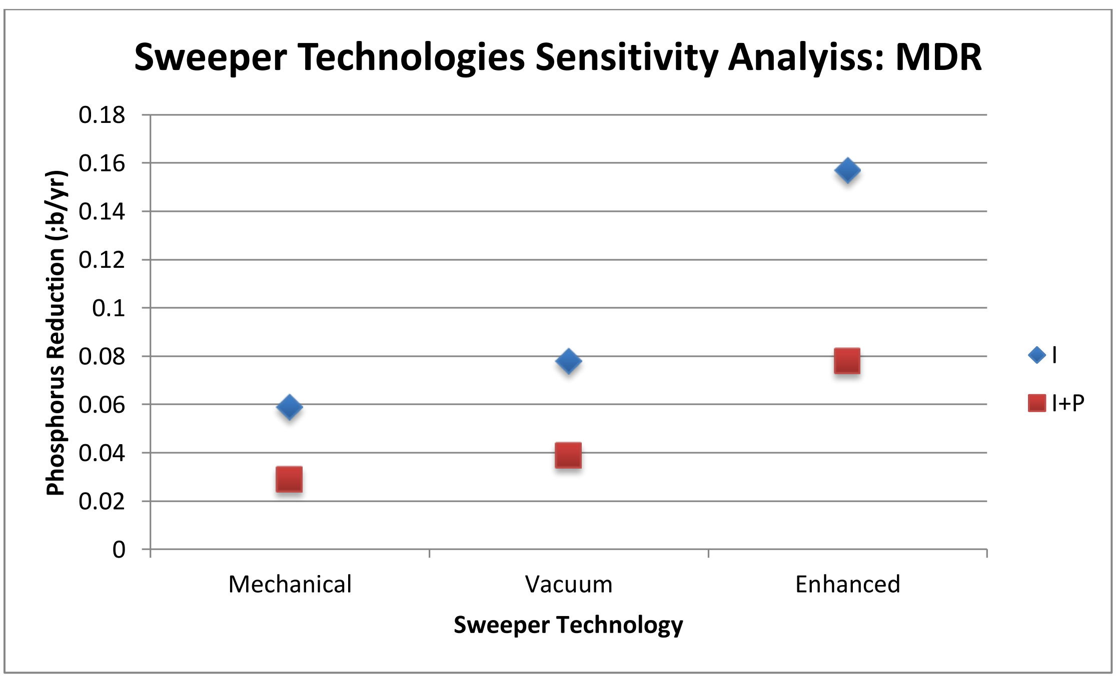

Commercial Infiltration Trench Phosphorus Reduction per Change in Storage Volume
Phosphorus Reduction (lb/yr)
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0
1000
2000
3000
4000
5000
6000
Storage Volume (ft^3)
I
I+P

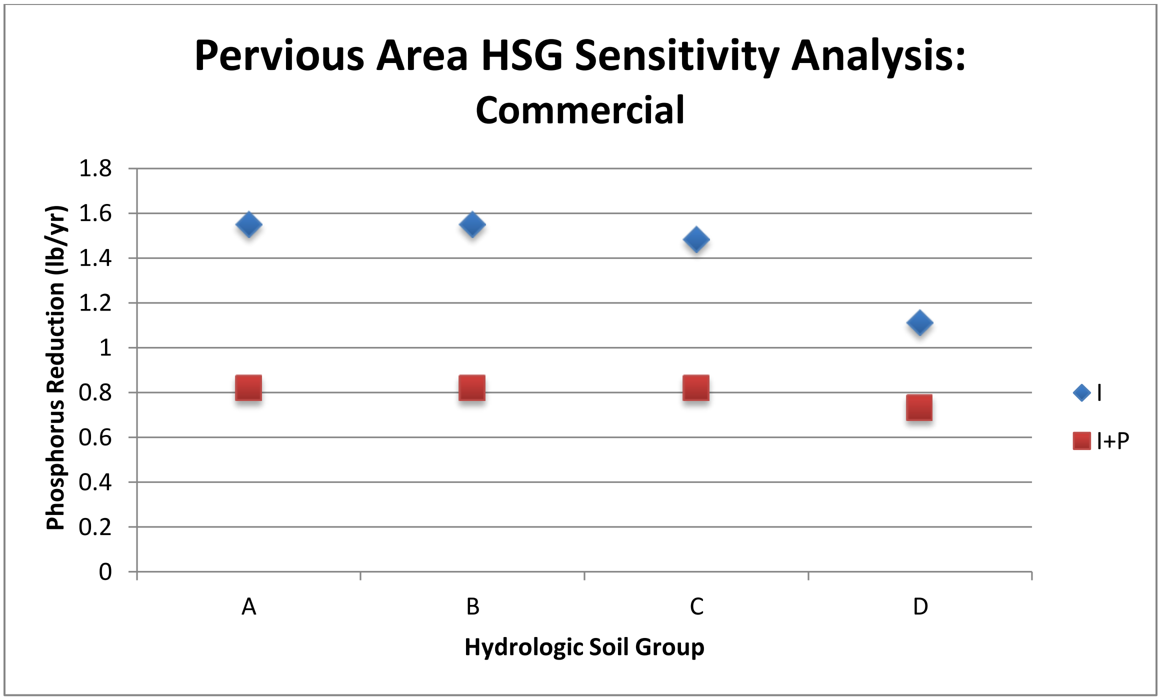


Non-Structural

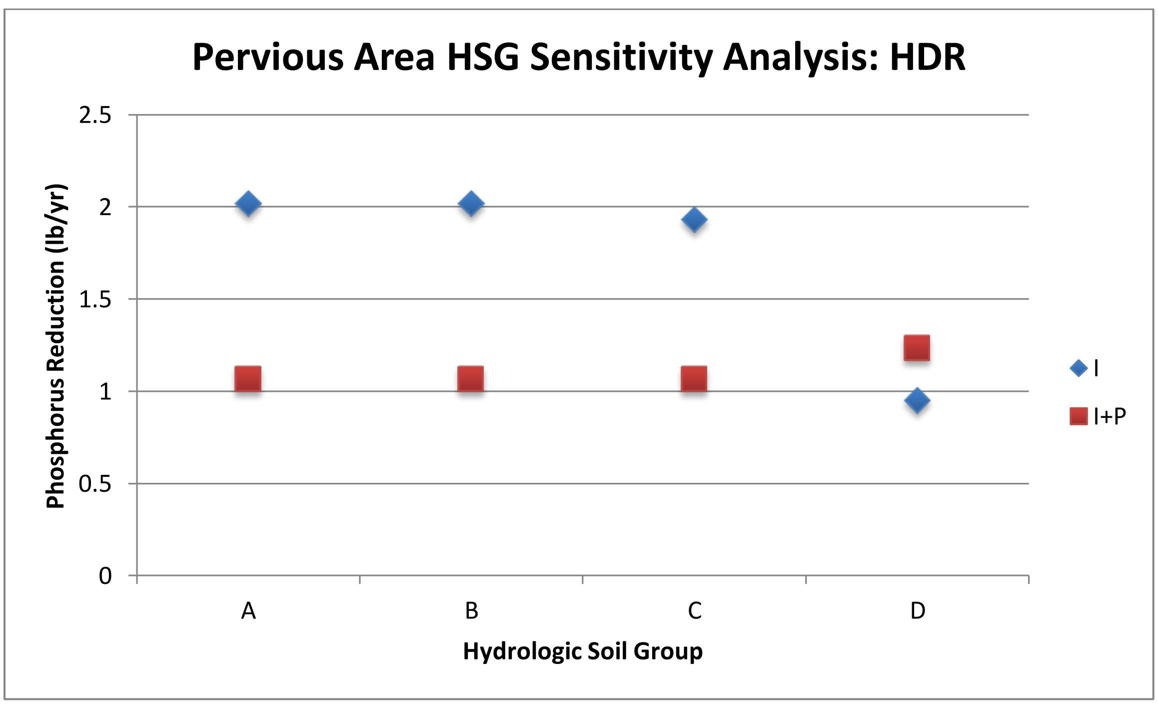



Sweeper Technologies Sensitivity Analyiss: HDR
Phosphorus Reduction (lb/yr)
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
Mechanical
Vacuum
Enhanced
Sweeper Technology
I
I+P

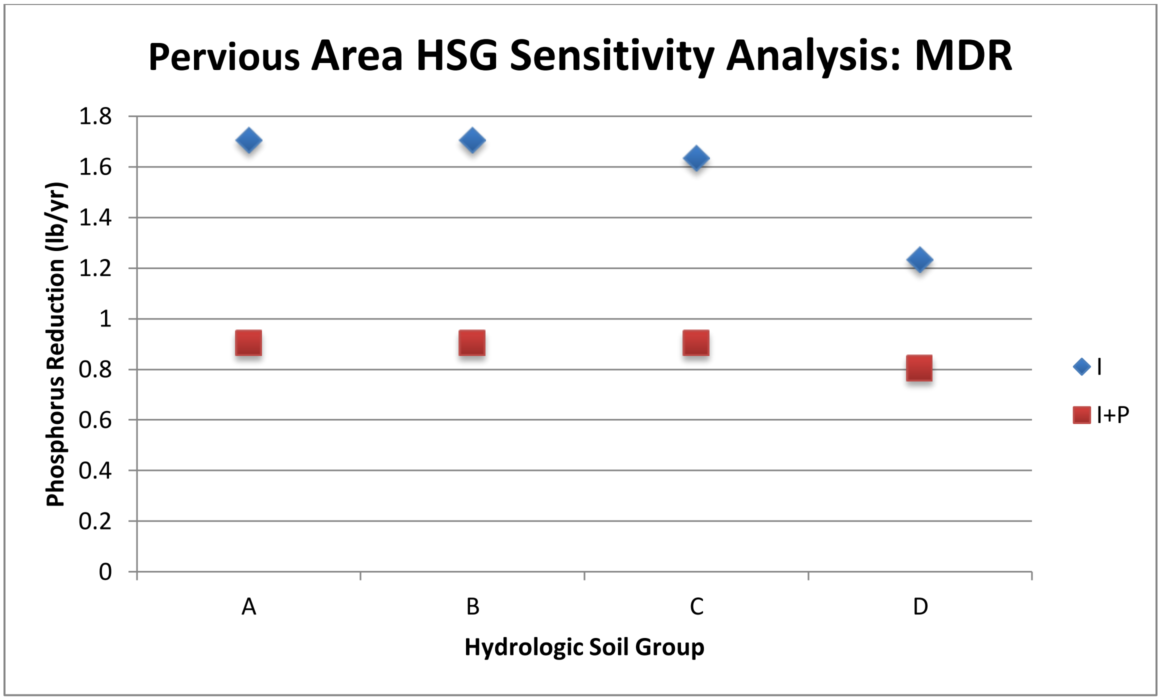

Sweeper Technologies Sensitivity Analyiss: MDR
Phosphorus Reduction (;b/yr)
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
Mechanical
Vacuum
Enhanced
Sweeper Technology
I
I+P

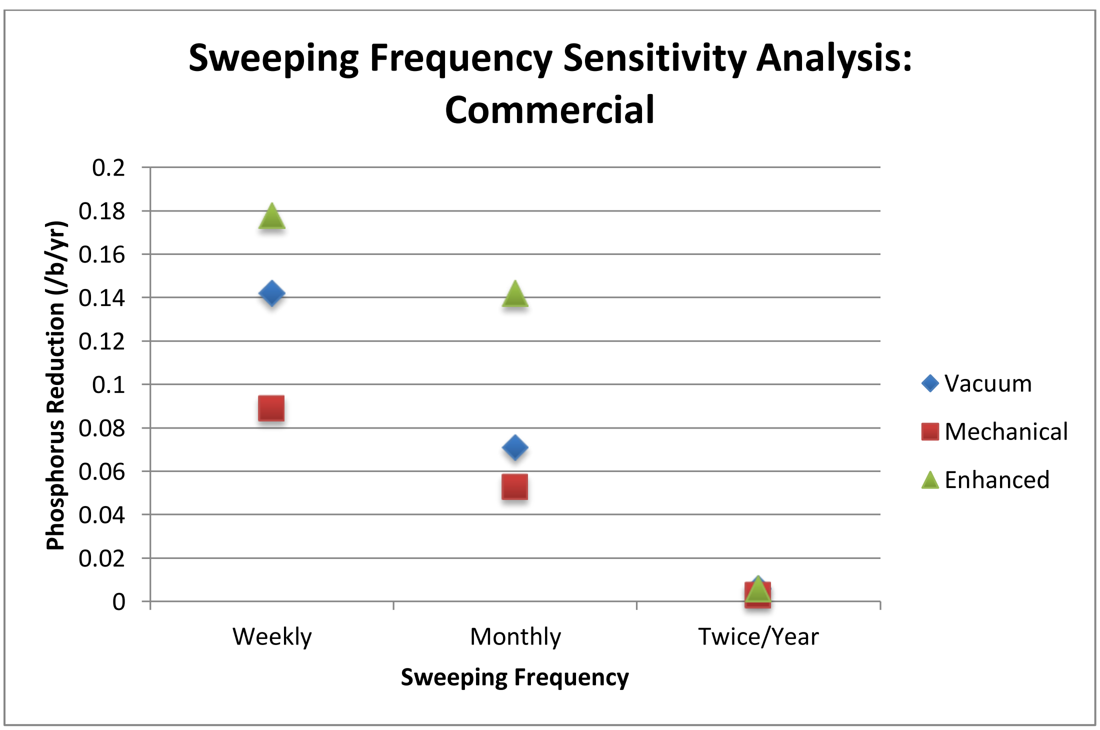


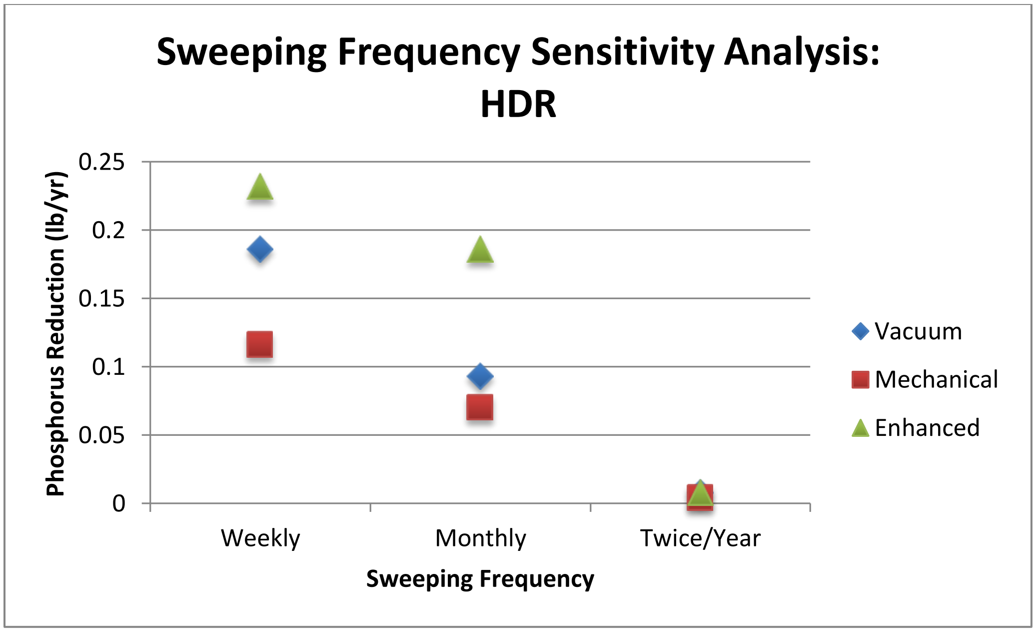
Pervious Area HSG Sensitivity Analysis: Commercial
Phosphorus Reduction (lb/yr)
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
A
B
C
D
Hydrologic Soil Group
I
I+P

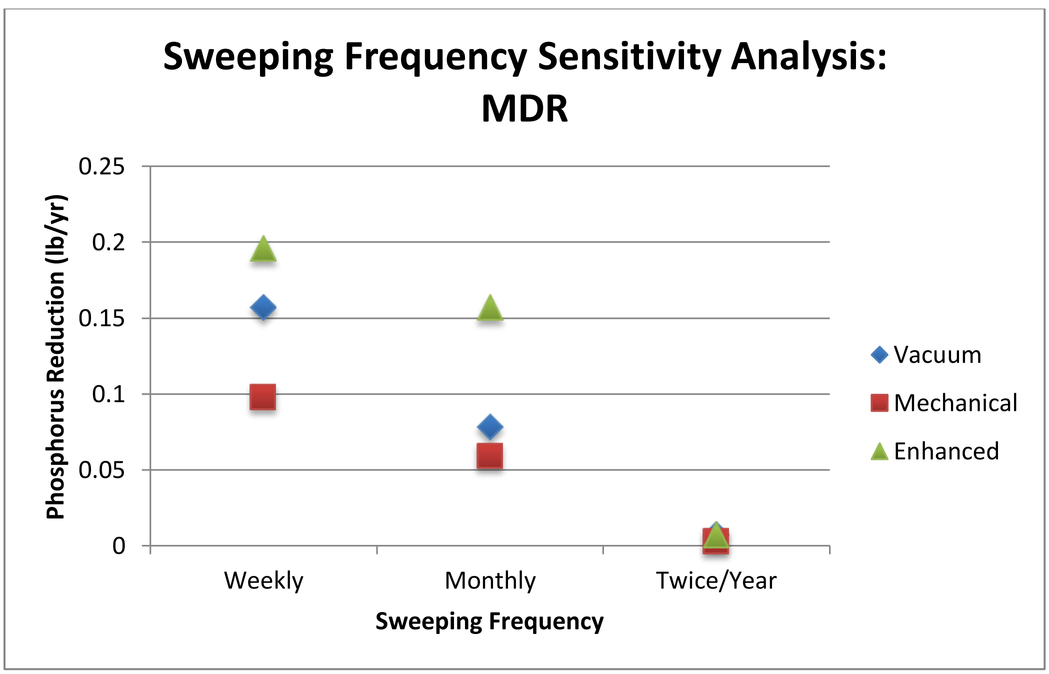


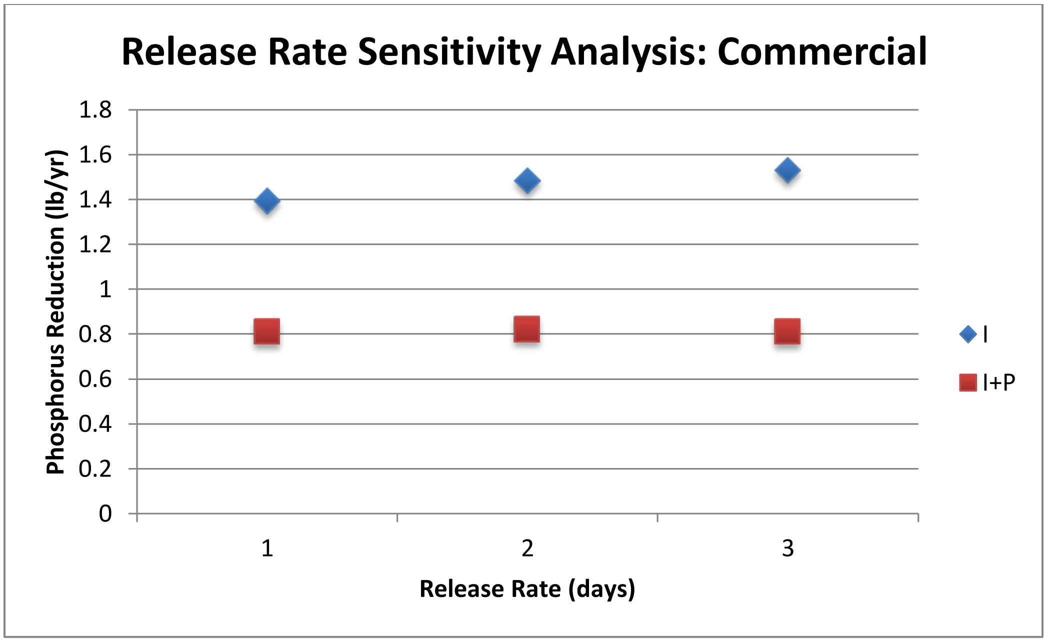
Pervious Area HSG Sensitivity Analysis: HDR
Phosphorus Reduction (lb/yr)
2.5
2
1.5
1
0.5
0
A
B
C
D
Hydrologic Soil Group
I
I+P

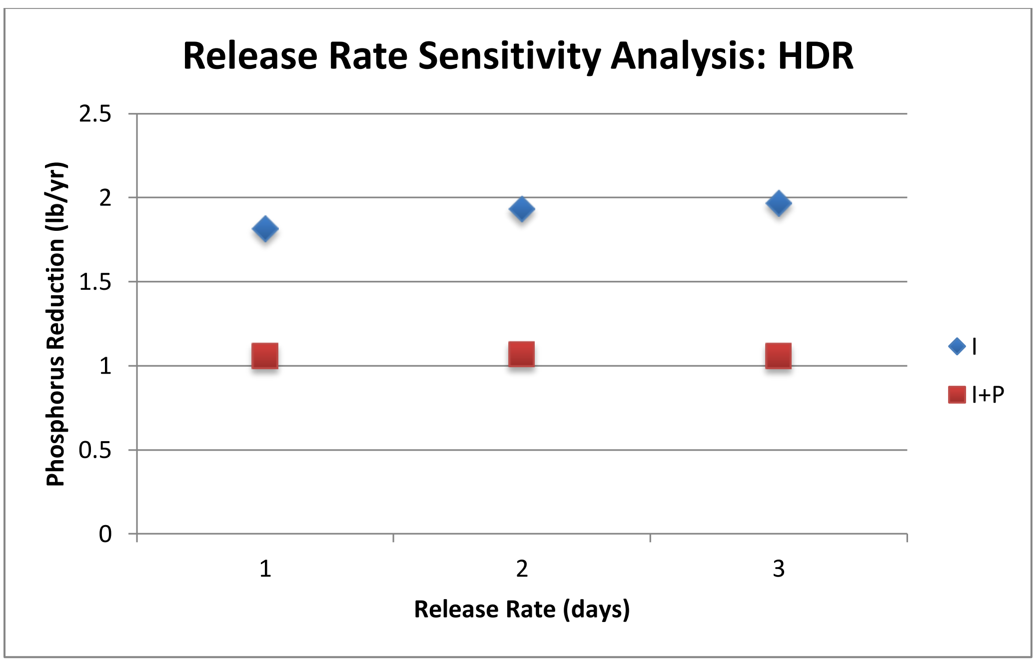

Pervious Area HSG Sensitivity Analysis: MDR
Phosphorus Reduction (lb/yr)
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
A
B
C
D
Hydrologic Soil Group
I
I+P

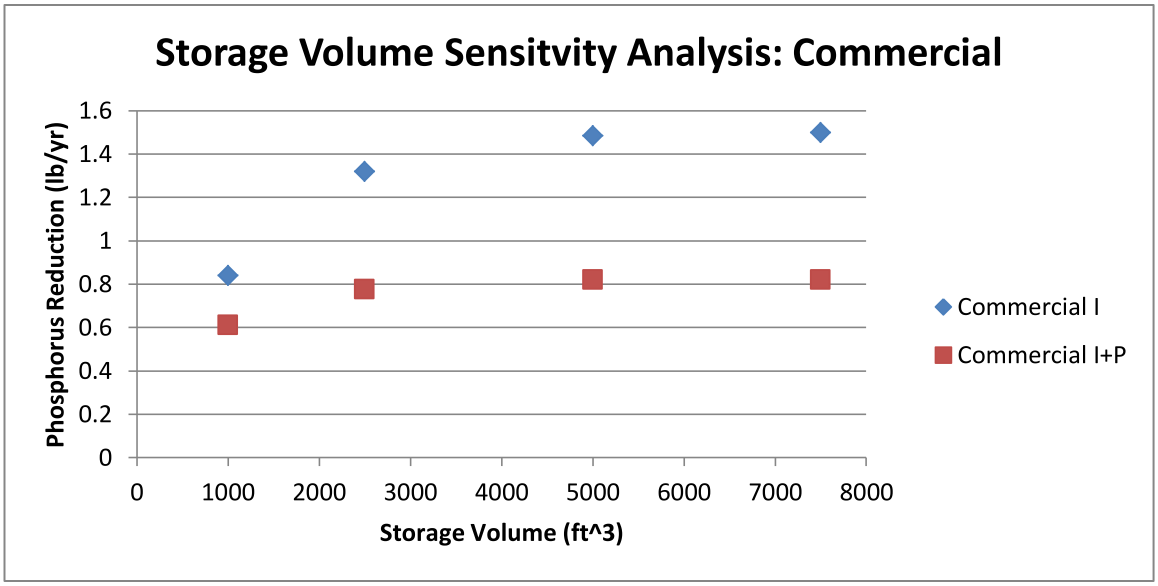

Sweeping Frequency Sensitivity Analysis: Commercial
Phosphorus Reduction (/lb/yr)
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
Weekly
Monthly
Twice/Year
Sweeping Frequency
Vacuum
Mechanical
Enhanced

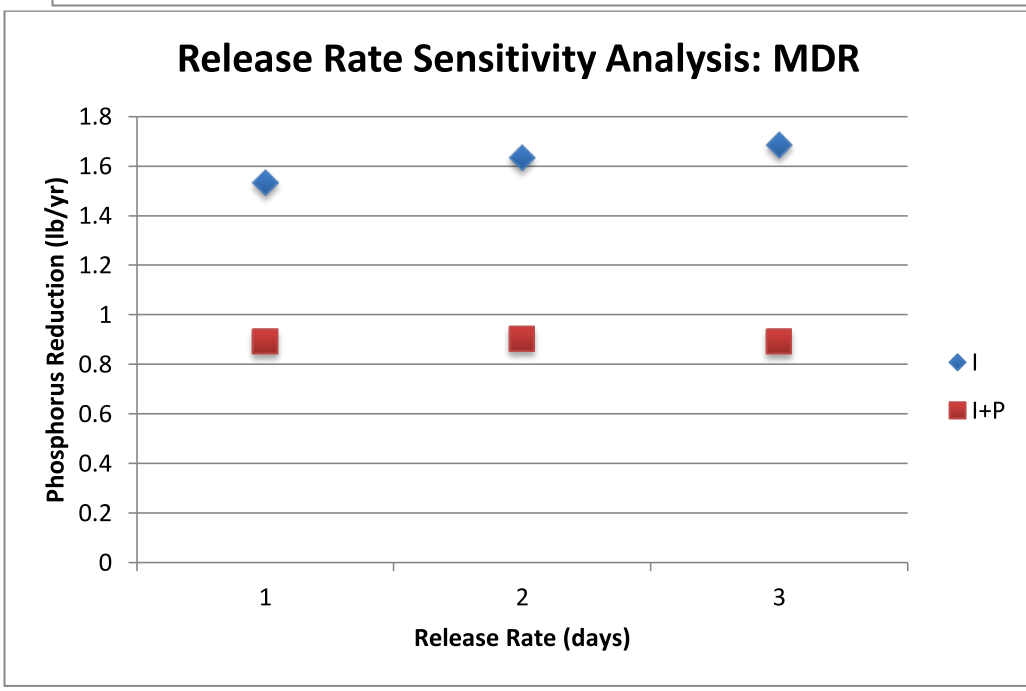

Sweeping Frequency Sensitivity Analysis: HDR
Phosphorus Reduction (lb/yr)
0.25
0.2
0.15
0.1
0.05
0
Weekly
Monthly
Twice/Year
Sweeping Frequency
Vacuum
Mechanical
Enhanced

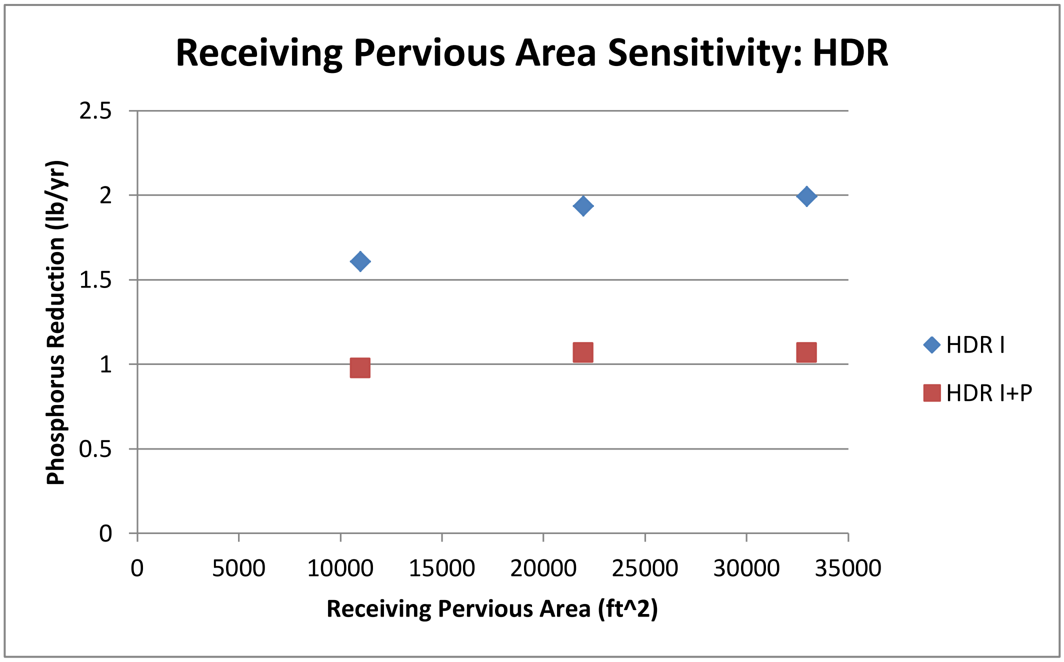

Sweeping Frequency Sensitivity Analysis: MDR
Phosphorus Reduction (lb/yr)
0.25
0.2
0.15
0.1
0.05
0
Weekly
Monthly
Twice/Year
Sweeping Frequency
Vacuum
Mechanical
Enhanced


Release Rate Sensitivity Analysis: Commercial
Phosphorus Reduction (lb/yr)
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
1
2
3
Release Rate (days)
I
I+P

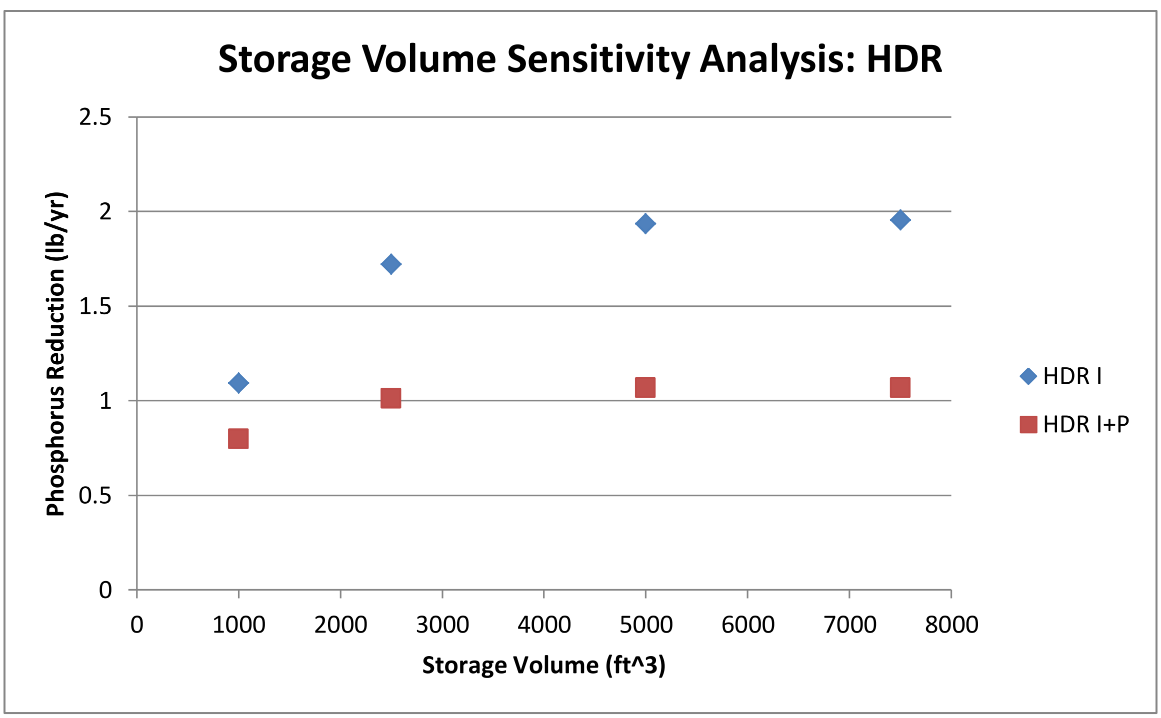

Release Rate Sensitivity Analysis: HDR
Phosphorus Reduction (lb/yr)
2.5
2
1.5
1
0.5
0
1
2
3
Release Rate (days)
I
I+P


Storage Volume Sensitvity Analysis: Commercial
Phosphorus Reduction (lb/yr)
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0
1000
2000
3000
4000
5000
6000
7000
8000
Storage Volume (ft^3)
Commercial I
Commercial I+P

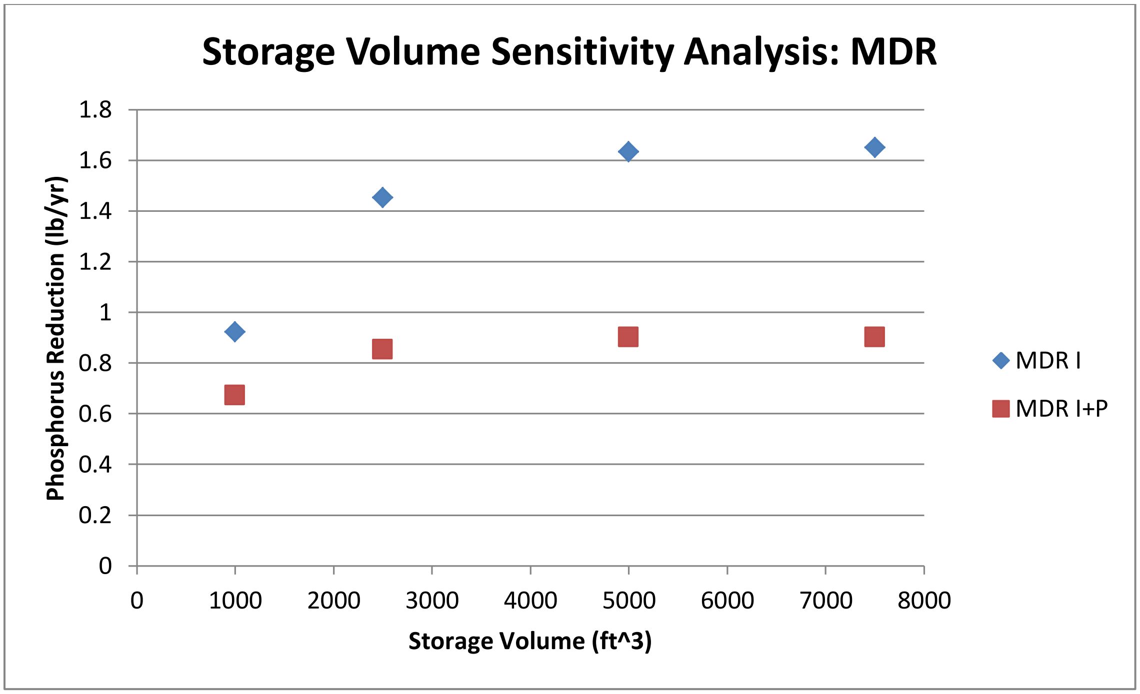

Release Rate Sensitivity Analysis: MDR
Phosphorus Reduction (lb/yr)
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
1
2
3
Release Rate (days)
I
I+P

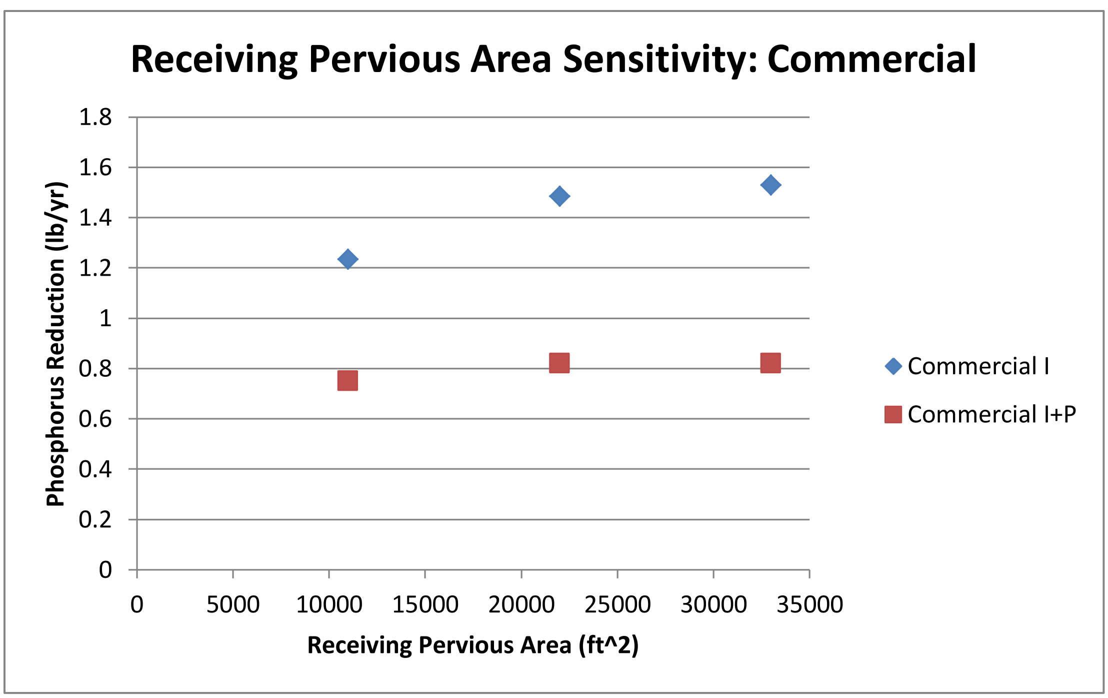


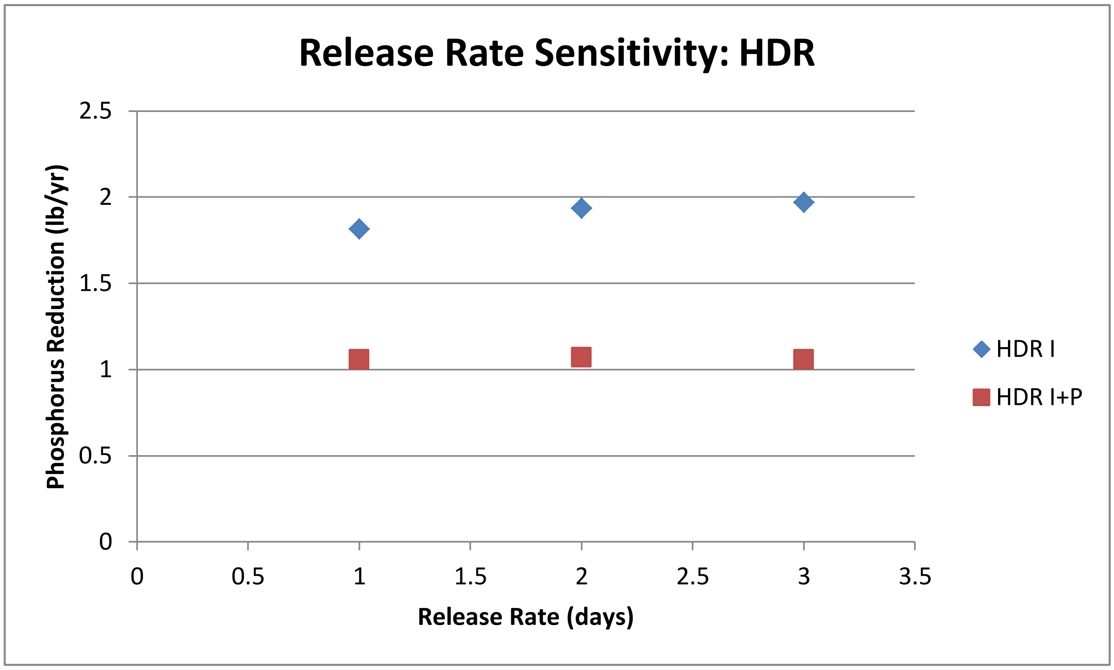
Receiving Pervious Area Sensitivity: HDR
2.5
2
1.5
1
0.5
0
Phosphorus Reduction (lb/yr)
0
5000
10000
15000
20000
25000
30000
35000
Receiving Pervious Area (ft^2)
HDR I
HDR I+P

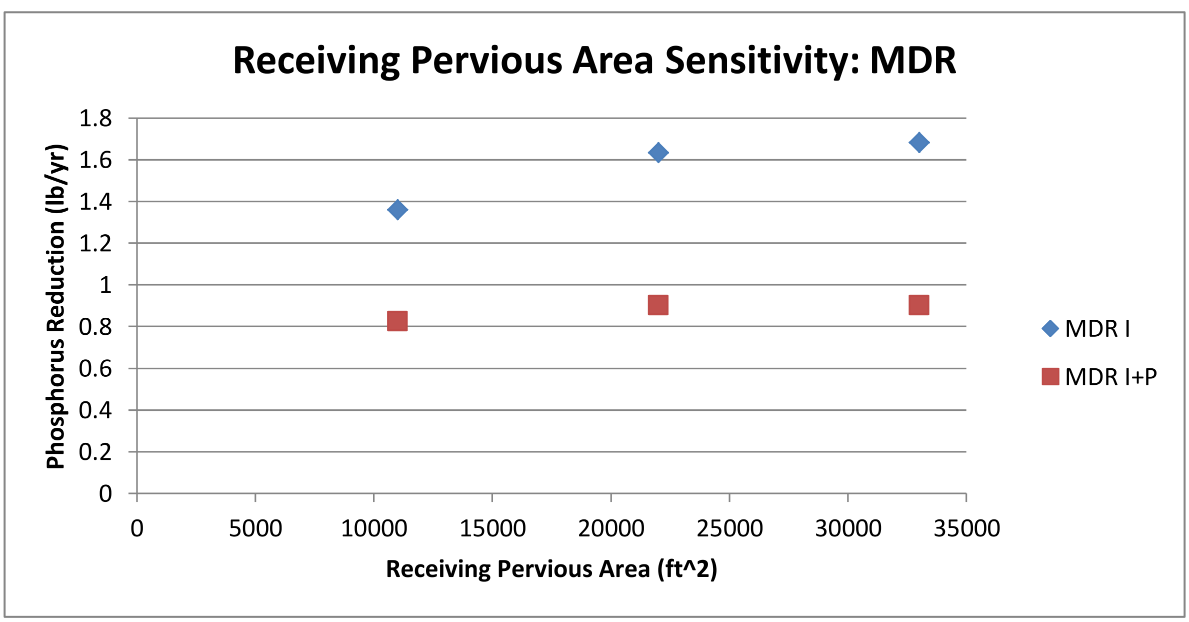


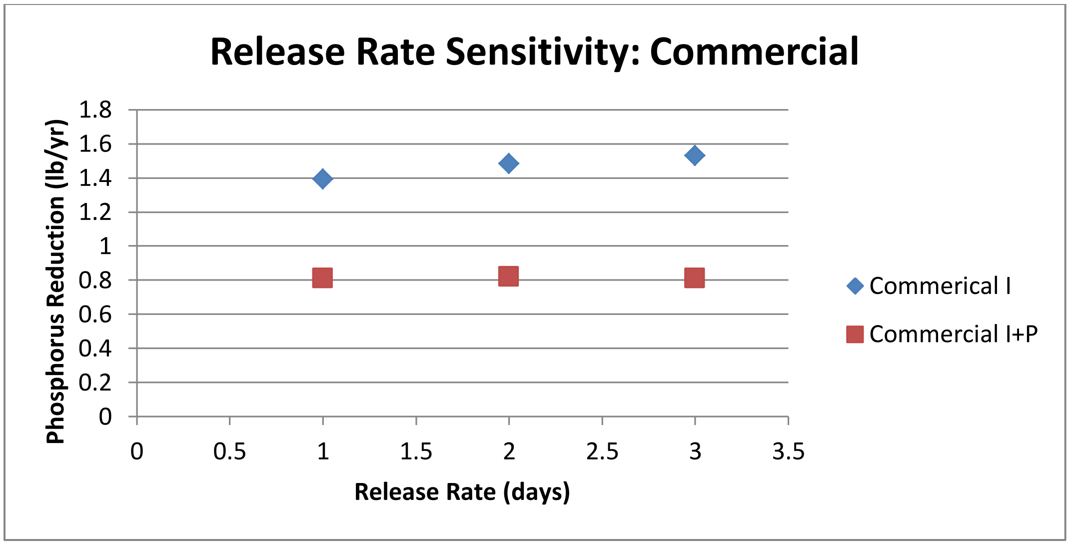
Storage Volume Sensitivity Analysis: HDR
2.5
2
1.5
1
0.5
0
Phosphorus Reduction (lb/yr)
0
1000
2000
3000
4000
5000
6000
7000
8000
Storage Volume (ft^3)
HDR I
HDR I+P

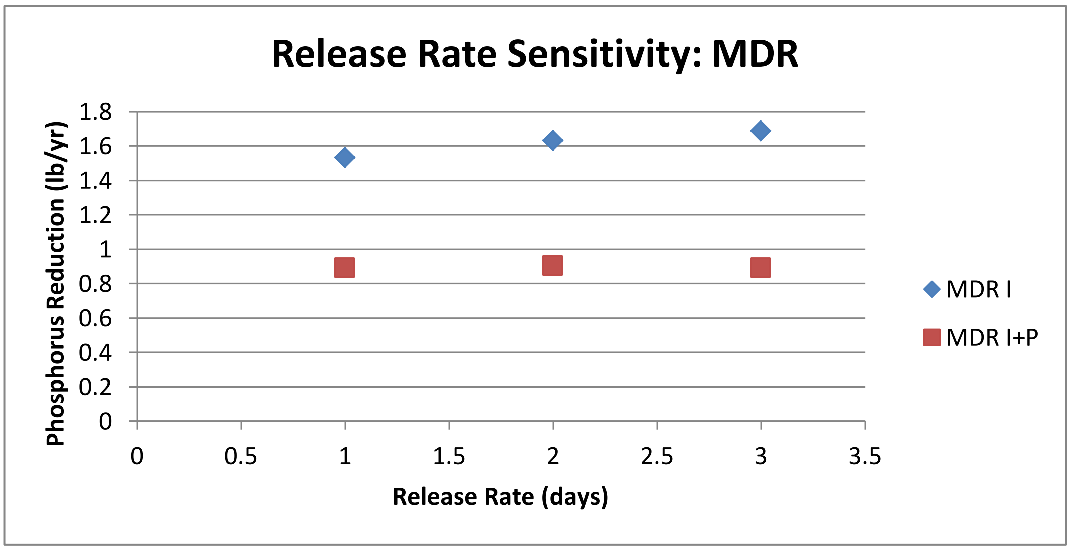

Storage Volume Sensitivity Analysis: MDR
Phosphorus Reduction (lb/yr)
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0
1000
2000
3000
4000
5000
6000
7000
8000
Storage Volume (ft^3)
MDR I
MDR I+P

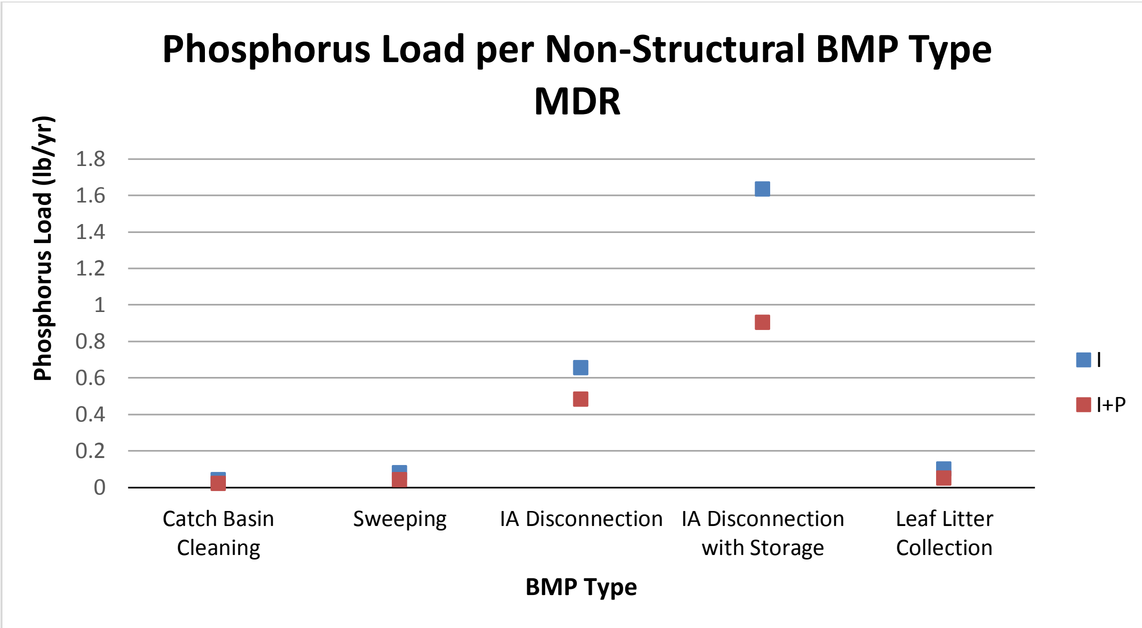

Receiving Pervious Area Sensitivity: Commercial
Phosphorus Reduction (lb/yr)
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0
5000
10000
15000
20000
25000
30000
35000
Receiving Pervious Area (ft^2)
Commercial I
Commercial I+P

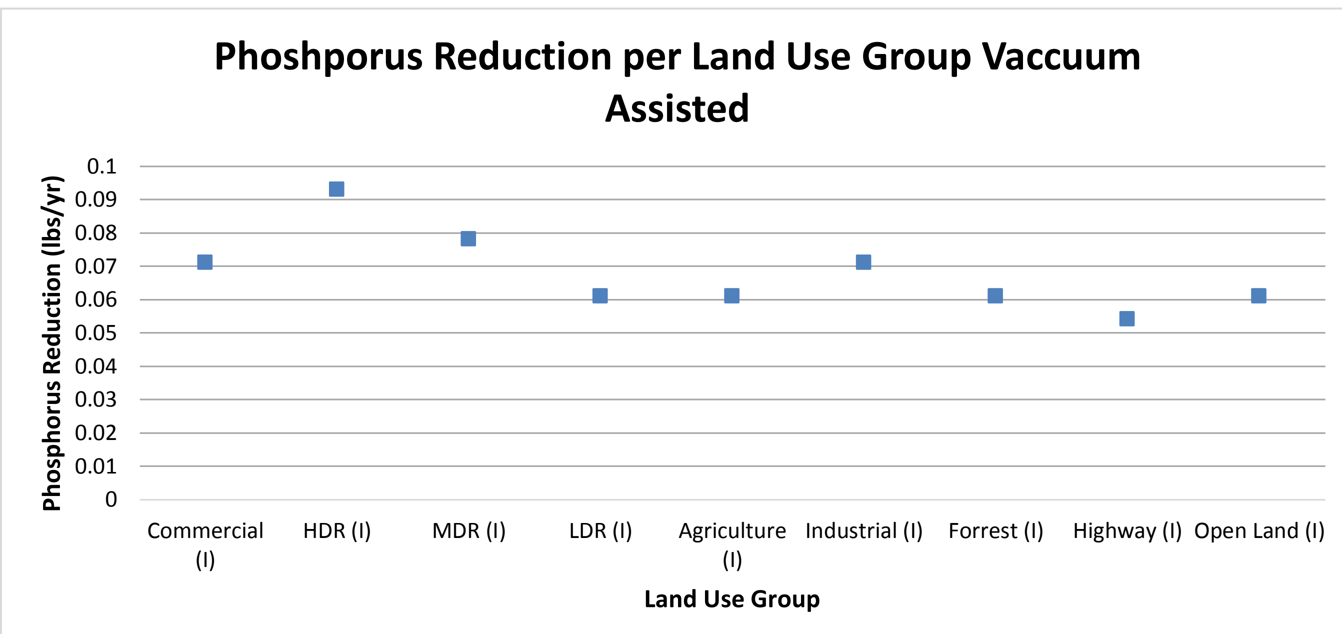

Release Rate Sensitivity: HDR
Phosphorus Reduction (lb/yr)
2.5
2
1.5
1
0.5
0
0
0.5
1
1.5
2
2.5
3
3.5
Release Rate (days)
HDR I
HDR I+P

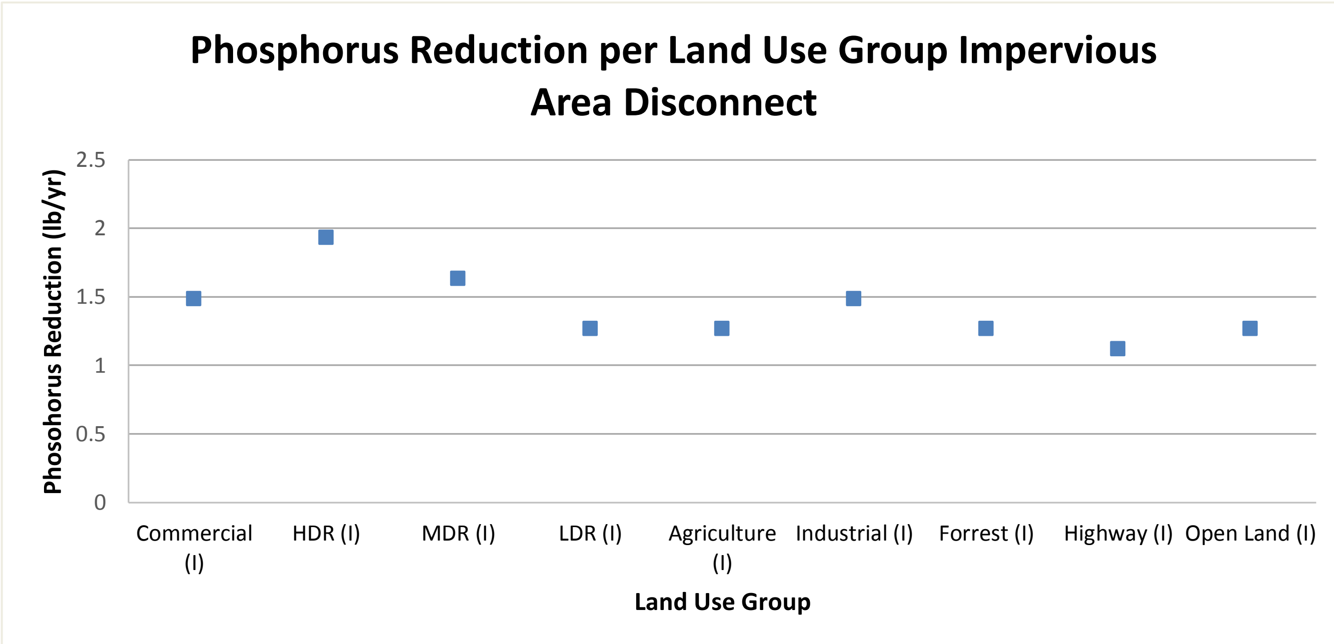

Receiving Pervious Area Sensitivity: MDR
Phosphorus Reduction (lb/yr)
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0
5000
10000
15000
20000
25000
30000
35000
Receiving Pervious Area (ft^2)
MDR I
MDR I+P

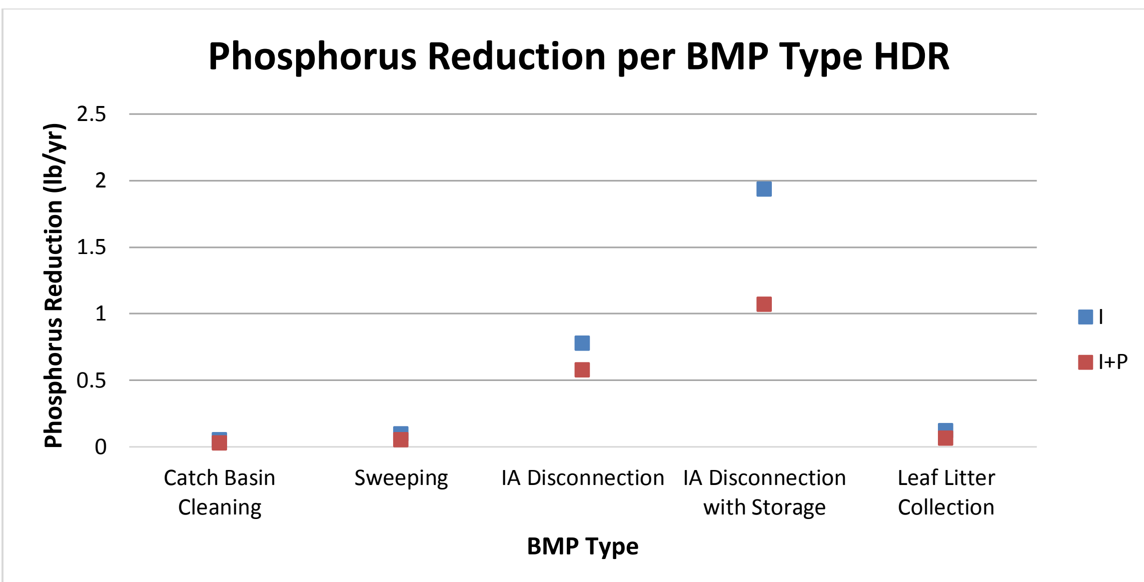

Release Rate Sensitivity: Commercial
Phosphorus Reduction (lb/yr)
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0
0.5
1
1.5
2
2.5
3
3.5
Release Rate (days)
Commerical I
Commercial I+P


Release Rate Sensitivity: MDR
Phosphorus Reduction (lb/yr)
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0
0.5
1
1.5
2
2.5
3
3.5
Release Rate (days)
MDR I
MDR I+P


Phosphorus Load per Non-Structural BMP Type MDR
Phosphorus Load (lb/yr)
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
Catch Basin Cleaning
Sweeping
IA Disconnection
IA Disconnection with Storage
Leaf Litter Collection
BMP Type
I
I+P

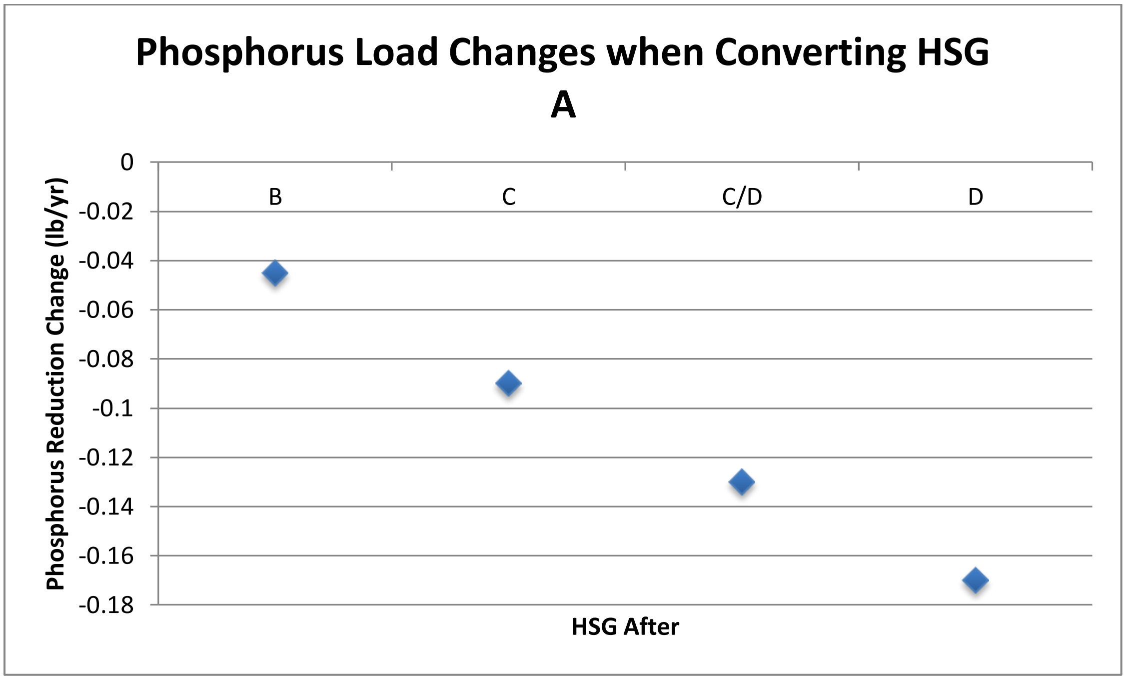

Phoshporus Reduction per Land Use Group Vaccuum Assisted
Phosphorus Reduction (lbs/yr)
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
Commercial (I)
HDR (I)
MDR (I)
LDR (I)
Agriculture (I)
Industrial (I)
Forrest (I)
Highway (I)
Open Land (I)
Land Use Group

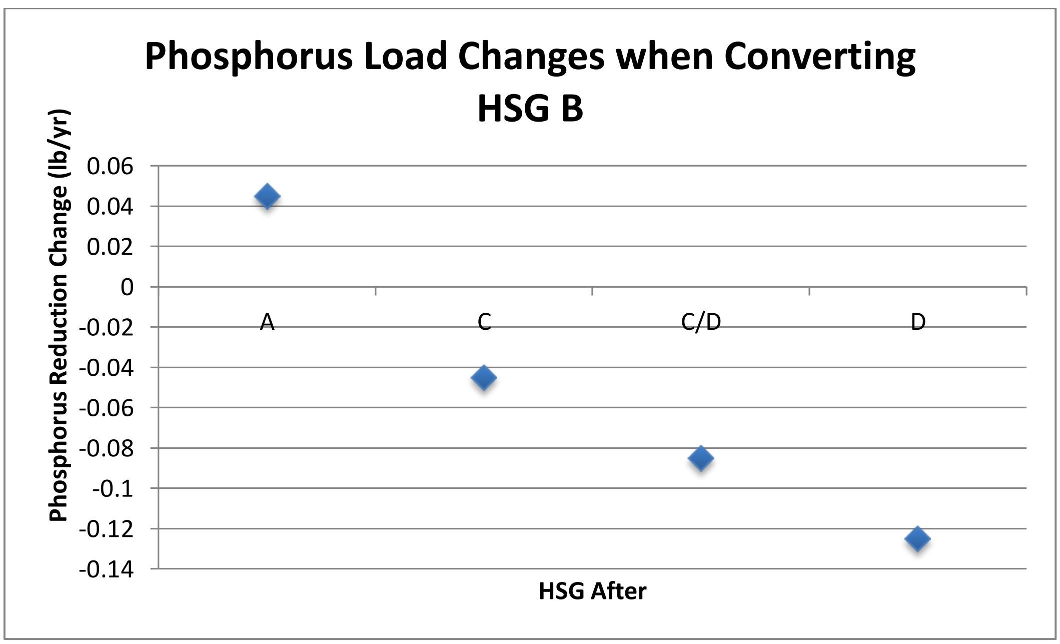

Phosphorus Reduction per Land Use Group Impervious Area Disconnect
Phosohorus Reduction (lb/yr)
2.5
2
1.5
1
0.5
0
Commercial (I)
HDR (I)
MDR (I)
LDR (I)
Agriculture (I)
Industrial (I)
Forrest (I)
Highway (I)
Open Land (I)
Land Use Group

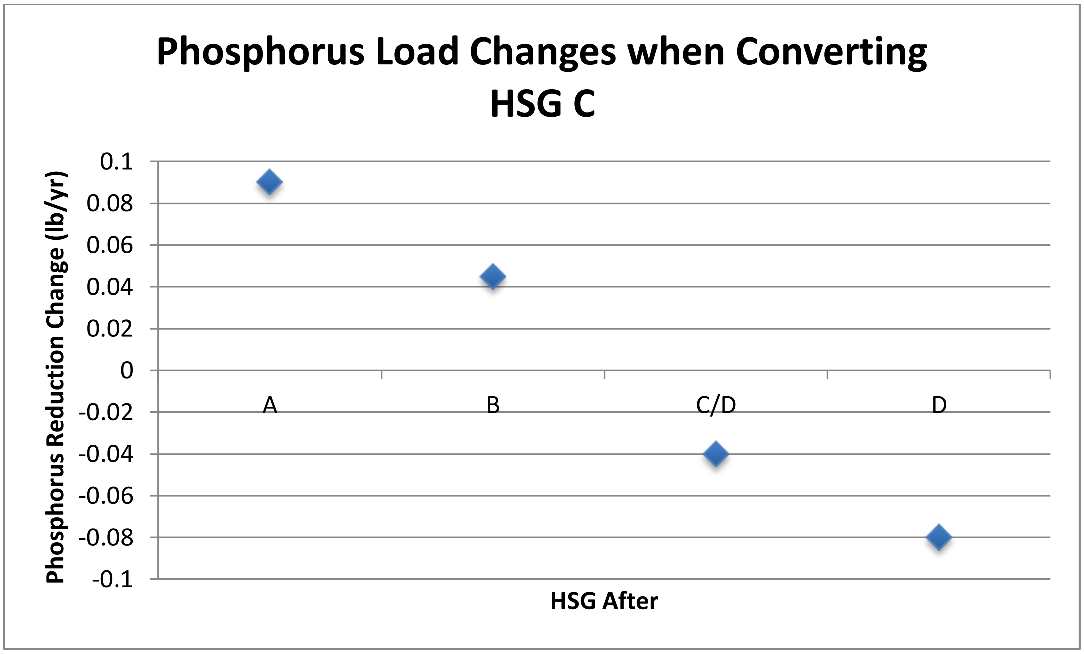

Phosphorus Reduction per BMP Type HDR
Phosphorus Reduction (lb/yr)
2.5
2
1.5
1
0.5
0
Catch Basin Cleaning
Sweeping
IA Disconnection
IA Disconnection with Storage
Leaf Litter Collection
BMP Type
I
I+P

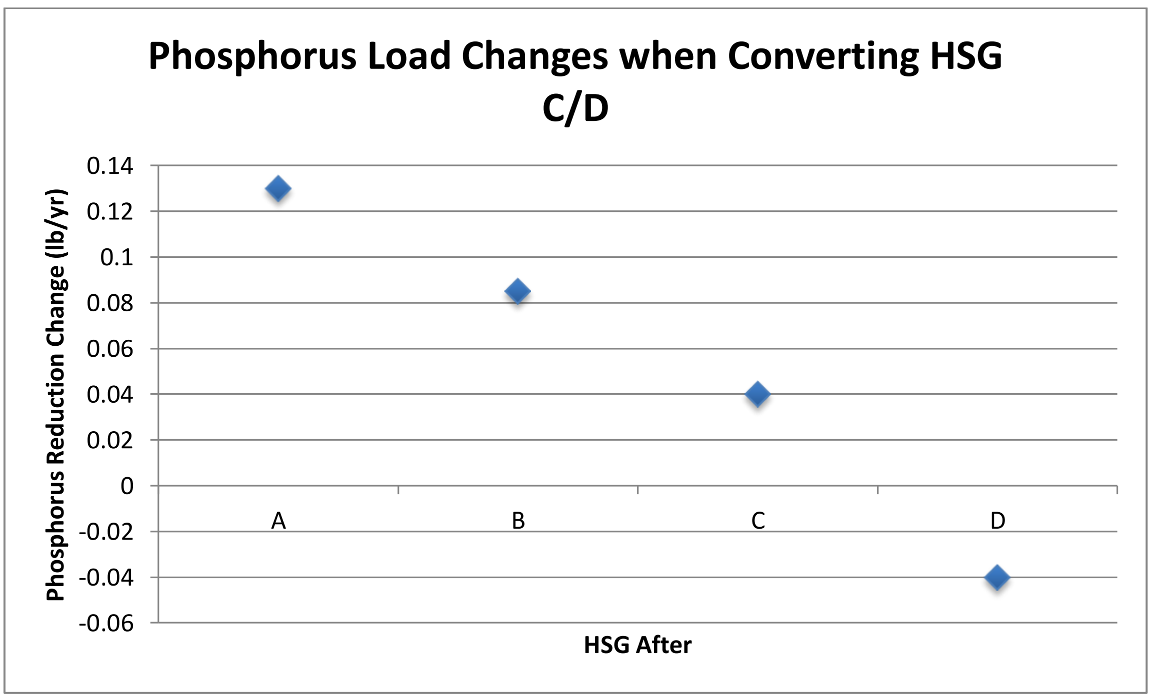
Land Use Change

**Done changing HDR with a certain HSG group and 0.5 Impervious, 0.5 Pervious to a different HSG






Phosphorus Load Changes when Converting HSG C
Phosphorus Reduction Change (lb/yr)
0.1
0.08
0.06
0.04
0.02
0
-0.02
-0.04
-0.06
-0.08
-0.1
A
B
C/D
D
HSG After


Phosphorus Load Changes when Converting HSG C/D
Phosphorus Reduction Change (lb/yr)
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
-0.02
-0.04
-0.06
A
B
C
D
HSG After

Appendix E: UNHSC Questions & Transcript

Questions:

1. Because the Stormwater Center has been in place for many years, have there been many updates to the BMPs throughout time?
2. What is your process for deciding to add or remove BMPs? What is your thought process when changing designs for BMPs over time (e.g. slopes, plant types, soil amendments, etc.)?
3. Are there controls on the water that flows into your BMPs or do they process regular stormwater?
    a. Is the effect of phosphorus partitioning taken into account? There may be differences based on how much phosphorus is free in solution versus how much is attached to TSS particles.
4. Since part of your stormwater comes from the parking lot near campus, are there differences when school is out of session in your data and, if so, how do you account for those differences?
5. How is UNH using climate change models to create BMPs to handle current and future storms? Are older models being used, or are newer ones used to help make the BMPs more efficient?
6. How closely did the EPA work with you to create BATT?

. What kind of data did you provide to calibrate the tool?

7. Is your BMP monitoring data public? We noticed that you have data on the International BMP Database. http://www.bmpdatabase.org/

. Could you supplement us with more data?

8. In the 2012 Report, an elaborate set of tables is provided for phosphorus removal followed by a description of each BMP with 'Fast Facts' including sizing specifications. We wanted to check if these 'Fast Facts' correlated to the BMP information in the table?
9. How frequently do you collect data during the winter months? Do you notice fluctuations in BMP performances during different seasons?
10. Could you please describe the process of maintaining the process of some of the BMPs?
11. How do you decide which BMPs to install in the Stormwater Center?

. What BMPs do you see yourselves working on in the future to study?

12. Do you have multiple locations with the same type of BMP where you vary some design criteria?
13. Are there any proprietary BMPs?
14. ***Possibly ask about data collection, look in reports first, Ask about lab testing*
15. Have you found any breakthroughs with phosphorus in any of your BMPs?*(breakthroughs are like when the CRWA bioretention fed phosphorus into the water with their soil choice)*
16. Do you sample the soils as well as water quality?
17. Do you have any design drawings of the BMPs you have implemented?

Winter Questions:

18. Are there any BMPs that operate in the winter or are all of them dormant?
19. How are the BMPs re-energized in the Spring? Is any replacement of the soil necessary for functionality?
20. By what we've described about our project, do you have any questions for us about what we are working on?

21. Are there any outcomes or research from our project that may be useful to you? We want to provide anything helpful that we can to the UNH Stormwater center.

Transcript:
First Question Not Recorded

Question: Because the Stormwater Center has been in place for many years, have there been many updates to the BMPs throughout time?

Yes, 2 major updates. One is the filter media used for bioretention. They found it had the capacity to export phosphorus from the soil mix. Soil mixes with compost leached phosphorus and could be source of pollution. So they have advocated for a soil mix where compost is not used. Rather, they use amendment from water treatment residuals that yield a high level of phosphorus absorbance. This concept is incorporated in the standards for soil mix outlined on their website to revitalize those standards. Secondly, their updates deal with developments of retrofits where a site already exists and conventional designs are hard to use. Conventional designs are provided by the state in the manuals. Retrofits have limitations on what they can be, how we can make them, where we can design them. Their research largely validates BATT in such that they helped create the performance curves, though the New Hampshire curves are more up to date. It is based on a DSV (design storage volume). The BATT model is cumbersome and the Opti-Tool has the same stuff constituents may use to assess any BMP (the process is cumbersome). "Curves are the machinery, everything else is a modeled assumption." So much goes into optimization of the model that seldom goes into the design as things change on the ground. It would be more effective to get more detailed on the ground versus the desktop approach for modeling.

Recording started

April (A): So I guess we can move on to the next question. What is your process for deciding to add or remove BMPs to the UNH Stormwater Center specifically?

Dr. James Houle (H): Like what to..?

A: Like which ones to…

H: Research?

A: Yeah. And which ones you would want to like, how do you decide to put the ones you have in the Stormwater Center? To put those ones in?

H: Well, in 2004 when the center was developed we took voluntary, I would say it's all linked to funding.

A: OK.

H: So, the first ten years of operation the stormwater center was funded by NOAA essentially and in the beginning we took volunteers. So, we had a couple of nonproprietary and proprietary systems, and there's nonproprietary systems, like a lot of the green infrastructure are nonproprietary, they exist in the manuals, no one owns the rights to them so people can modify them and update them as they see fit, and then there's proprietary systems. So, we identified the top nonproprietary systems, those being: permeable pavements, bioretention systems, sand filters--surface sand filters, swales, retention ponds, detention ponds, and, you know, that comprised the nonproprietary units in our original site. And then we took volunteers for proprietary systems, so we had a number of hydrodynamic separators that volunteered, we had some canned filter systems, and we did some testing on that. After that, we continued with the nonproprietary systems and made modifications based on our designs. For instance, the, I mean we took them right out of existing manuals and sometimes it just didn't work, we had to repeat the soil specifications or the sizing, or so many different things around the design. Some worked some didn't. We went through a number of reiterations with bioretention systems. A number of iterations with swales, looking at vegetated, berm swales, you know, the iterations that are out there. Detention ponds we looked at wet ponds, dry ponds. And, you know, just kind of keeping an eye on what was out there. So, moving forward, once we lost our core funding, and we started to monitor things that we could get funding, there were grants for or people were interested in, so, I mean, we looked at some soil specifications for bioretention use that were being developed by MaineDOT. We looked at berms on swales that were being developed by MaineDOT. And, and I think that's the basic history of it.

Jessica (J): For the stormwater that flows into your BMPs…

H: Wait we didn't finish that question though.

J: Oh, we didn't?

H: What is your thought process when changing your designs for BMPs over time? This is an important point and it's imperative. It's imperative that we continue to modify and innovate BMPs such that they better suit designs. I mean I think for me the worst case scenario is in a, when a regulatory body tells you how to design a system. It's, you know like, it's very inflexible, so often times when we work with regulators, that seems to be the tendency because sometimes people they don't want flexibility, so there's a tendency to just make it very rigid, but we find that you have to be able to adapt these systems to site specific. And, more importantly, you have to be able to adapt these systems and the system configurations based on the operation and maintenance culture of the owner. So, a good case and point, you have plants down there, plants, there's a big to-do, it's detailed, report, our take on plants and you'll find if you go to any stormwater conference, you'll find, this debate is very active, you'll find some people espousing the virtues of native wetland plants. If you look at the New Hampshire manual, the New Hampshire rules, they actually require that you select facultative wetland plants for bioretention systems from a list developed in 1988. When I see that, you know, I try to keep my head from exploding. It's where the regulations, and particularly the rigid regulations, are in step in the science which is fast moving. So, you're telling people they need to put facultative wetland plants in a bioretention system, but we're developing soil mixes and they have no relation whatsoever or no characteristics of wetland soils. You're essentially asking to plant, to invest in plants that will never survive. So, we've adopted more of a strategy with seed mixes, and so you can pick different seed mixes and the seeds will self select and they will grow in that given environment. We've also advocated for grassed systems versus planted systems. Our research doesn't necessarily identify a penalty from a water quality perspective from a grassed system versus a planted system. There might be penalties with respect to habitat or carbon sequestration, or, I mean there's a range of possible penalties, maybe aesthetics in some people's minds, but there's no water quality performance penalty that we've uncovered and we've researched that. Really what we find is the need for dense vegetation. Grass, sure, clover, meadow plants, anything but woody plants. We find that woody plants don't do well. We have a couple of trees at the site that were planted in 2004 in the original bioretention system, and you'll find a lot of designs in manuals that spec out trees, and we planted them as 2" caliper. And I can imagine this in the parking lot of a shopping mall or something, and this River Birch is immense now with a huge canopy and all kinds of potential transportation visual, visual blocking sight lines, and just pretty unruly. So, you have to make sure you have the space because you expect the system to be around for 20 years or so. That's at least the type of design life that we are considering. So, when we look at those types of selections, from our perspective, and what the science tells us, it should be flexible because what's going to determine the long-term performance and the long-term life expectancy of the system is operation and maintenance. So, if you can, whatever you're going to maintain, that's how I like to design systems. To facilitate maintenance from the owner.

J: Sorry, I got ahead of myself, jumping to the next question. But, for this one, we were wondering about the controls for the water that flows into your BMPs, or if it's just regular stormwater that's processed.

H: I'm having a little trouble understanding this. We do not like flow controls going into our system. We like flow controls at the outlet structure, if that makes sense. So, we are trying to bring flow into the system, and then we have flow controls at the end of the system that modulate flow. So…

J: I think what we meant by are there controls in the water that flow into your BMPs, is there water with a certain amount of phosphorus put into the BMPs, or is it just handled by regular stormwater?

H: No, we do not spike our stormwater. In our original system, our original site was designed to convey natural hydrographs, so we don't modify the hydrographs either. It's rainfall from a parking lot. There's no pumping involved, we don't spike. The only thing that we did on site is that we, there was a bunch of deep sump catch basins throughout the west edge parking lot, and we filled them and capped them with concrete. So, we took out any pretreatment, so there was no treatment I guess from the infrastructure in the parking lot. We were getting the full suit of pollutants coming, representative of a parking area, coming into our site. That said, what made our site unique was we have a distribution box that splits the box to various devices.

Stephanie (S): Oh, OK. That makes more sense now I think, cause I was reading one of the reports and it had, like, two parallel streams coming, and I just didn't understand that language at the time. Your description of it makes more sense now.

H: I mean, I can show you a cartoon what it looks like. I think this report (*O&M 2016*) has a pretty good depiction of it. So this is what, this is the configuration of our site so we have a distribution box that splits the flow into the various different devices.

S: So are there the same flow rates in all these?

pointing to all the BMP flow paths in the cartoon

H: There are, yes, the assumption is that we split equally and evenly and we did a lot of work in the distribution box to modify it with, diversion weirs on the floor, weirs on the flowline in order to get equal distribution and good mixing within the box itself. So, a lot of work went into it. Actually, that box in and of itself, upstream from our site made a lot of the early studies very economical because we could do an analysis of one influent location and then every system is basically lined in clay and has an underdrain. So, we take a measurement of water quality coming in at the distribution box and then we look at water coming out of the systems through the underdrains at the end, under our sample gallery.

S: OK. Thank you.
J: Given that you try to process the natural stormwater flow, we had a follow-up question about if the effect of partitioning taken into account because we had researched that there are some differences between phosphorus free in solution and phosphorus that attaches to TSS and initially is caught and is later washed away.

H: Yep. So, our, so, partitioning is something we don't control. Especially in the environment, it's happening on our parking lot, we looked at both soluble reactive phosphorus and we looked at particulate bound phosphorus, and we saw about 98% of the phosphorus of the total phosphorus was particulate bound. That's coming in. But you're right in that we don't see that consistently on the effluent. So, whatever be the case, I mean, phosphorus does not tend to like to be in suspension, I guess, in water, so it has an affinity for sediment and it associates at least temporarily on the influent side with sediment. But just because a system is removing sediment, doesn't necessarily mean it's removing phosphorus. And that's one of the things that we did discover early on which was a little bit of a myth largely from the early studies. If you look back, 10, 20 years ago there was a heavy emphasis on sediment removal and TSS standards largely because it was felt that most of the pollutants in stormwater are hydrophobic in nature and thus have an affinity for sediment. And so the thought was if you're taking out the sediment, you're taking out the other stuff, but we didn't necessarily find that to be true throughout the whole system. And in some cases we had treatment systems that were sources of phosphorus such as the early bioretention systems that had a lot of organic material. And really when we look at these systems, quite honestly, it's not when we look at the performance of a treatment system, there's not much dissection into the unit process and the unit operations. It's a box, it's a black box. Water goes in, we look at the quality of that water going in, and water goes out, and we look at, well we compare, the quality of that water coming out. And that's really the basis for a removal efficiency. And that's about as sophisticated as we've gotten so far.

S: So, our next question kind of has to deal with, because you're doing research on a college campus, and the water is coming from a parking lot here…

H: Sorry, so let me just button that up for you. In the world of pollutants that we are generally concerned with, and that would be: sediment, metals, hydrocarbons, nitrogen, and phosphorus, those are really the flag bearers, I mean there's bacteria, but bacteria isn't everywhere and God bless you if you're studying bacteria because it's hard to figure out. So, of those 5 pollutants, I would say hydrocarbons and metals are heavily sediment associated. So, when we look at long-term removal efficiencies in systems, if you're doing good at TSS removal, you're equally doing good for metal removal, represented by Zinc primarily, that's the metal, there's about 80% of the metal in phosphorus, in stormwater, and you're doing good in hydrocarbons. So those 3 pollutants of the 5 tend to be, sediment removal is a good flag bearer. Where it breaks down is nitrogen and phosphorus, the same doesn't hold true. And those are mediated by different removal mechanisms. Phosphorus is absorption to organic material, otherwise it's just flowing through the system if there's no organic material or absorption sites available. And nitrogen is either vegetative uptake, although that can be somewhat temporary especially in cold climates, or some microbial mediated process. So, that kind of puts a button on it, right, and if you look at the vast majority of the TMDLs or impairments out there, if you remove bacteria just for convenience, there largely nitrogen and phosphorus is used. Phosphorus more inland freshwater, nitrogen in coastal brackish environments. So, sorry. That puts a nice little button on it for you.

S: Just, how do you account for differences in maybe like flow rates or in pollution levels when it's out of school versus when you're in school?

H: Yes, so historically, flow isn't mitigated by the number of cars out there, it's directly proportional to impervious surface. So, there's no flow changes per say, but there is pollution load changes from when we have high traffic counts to lower traffic counts. For the most part the biggest difference that we saw wasn't necessarily with respect to the individual cars, because it stays pretty full, at least 80% of the year, and we don't necessarily see a big drop off in the summer months. There's still activity going on, and sometimes there's even specialized activity like horse shows let's say, or they have in the summer, they'll often have motorcycle training, so there's other activities going on on the parking lot, so we don't see much of a drop off in the pollutant load. Where we did see a really big drop off, and this is sort of anecdotal, because we haven't researched it or studied it, but the university in 2009 made a decision to switch from diesel buses to natural gas buses, and so the buses, essentially the buses, the way it works is the people park in a satellite parking spot and the buses come around every 7 to 9 minutes all day long and sometimes they idle and sit there waiting for kids, so we saw a huge drop off based on that one switch of our, of our nutrients, our nitrogen and phosphorus, and our diesel range organic loading in the parking lot. They kind of dropped off the map to non-detect. We also see similar things happening as fuel efficiency and more, less polluting fuels are being used. We see a drop-off of nutrients that are largely associated with those traffic counts and maybe the more stopping and starting of cars. We have done, MassDOT has done some research and showed higher traffic count roadways lead to higher pollutant loading. We tried to replicate that in New Hampshire and we couldn't, we couldn't distinguish from high useroadways, high traffic count roadways and lower traffic count highways. They all had very similar loading, so I wonder if it all comes down to the stop and go of traffic, we don't have a lot of traffic backup. So, I imagine in those high traffic count areas, you also have a lot of congestion, a lot of idling, a lot of stop and go, and that's a lot, largely, where we see more of the pollutant emissions.

J: Yeah, that makes sense, that's an interesting point.

A: Our next question, number 5, we were wondering about climate change models and how UNH is using them to create BMPs to handle current and future storms?

H: This is a really good one. And it's possible that I will differentiate myself from others in this discussion of climate change because when we look at the design criteria for stormwater management, we are using more frequent, more routine storm events. Even if we look at peak flow control, often times the regulations require us to mitigate peak flows on the 2-year rainfall, the 10-year, the 25, and the 50-year rainfall events. If you look at the statistical data, the climate change variability is not in that domain, it's on the extremes, right. And the extremes is not what we design to. So, when we look at design changes, climate change, I mean, we've seen, in water quality too we're capturing the 1" rainfall event. That of course is based on a more economic sizing, because we know we can't treat the 100-yr event, so we treat the 1-yr (*1"*) event and we think that is associated with the most pollutants because of the first flush, so, you know, the pollutants accumulate on the surface, the first flush of water, i.e. the 1" rain event washes that off and that's where the vast majority of pollutants are associated with. And so, those design storms haven't changed at all and likely will not change. The median is not changing with climate change. The extremes and the standard deviation is changing, but the mean is not, so it doesn't really affect the way we design systems. Some will tell you it should, and essentially what it means is you're building bigger and bigger systems. It's just not something that, I don't necessarily subscribe to the need for that. In fact, our data is showing us that the way we model storms and the delivery of water to our BMPs is really (*add emphasis to really*) simplistic. It's, like a kerplunk model; a 1" rain event instantaneously over a landscape and delivered to your BMP. Like that **snap**. Instant. We find that, in nature, the flow pass and the time of concentration is highly variable, and what it means is these systems are far more efficient at routing water than what we give them credit to in our models. And that's OK, it's conservative, but if we're looking to place BMPs and we can't size it conventionally within an existing landscape, we should understand that the modeling is very conservative and that we can still achieve good benefits putting what we can where we can when we can. And that is, we've written a paper and published a paper. It's on our website, it was EPA funded research, and it's a really, it was really surprising to us and changing the way we think about system design. In fact it's, yeah, I'll leave it at that. There is summary in here (*2016 Report*). Oh yeah, so this is a good summary, we were actually, we worked with Boston Water & Sewer. John Sullivan there, and we see on the Charles River, on phosphorus abatement solution, we think that is a big, and it's based on BAT(*T*) or the performance curves, and we think this is a key design criteria in order to meet permit obligations and reduce costs of these systems because when you look, people are upset that they've modeled, projected certain costs of these systems and I don't know how. I mean you guys projected certain costs, WPI, students before you projected costs of what the MS4 permit would cost communities, and I don't know what it's based in, if it's based in talking to someone at DEP. I think using the tools that we have we can reduce the size and decrease the costs. I think the costs might be a little bit exaggerated, but therein lies the need to embrace innovation and better modeling which the BATT (*Opti-Tool*) would be able to do.

J: We also were wondering if you could elaborate on the process of working with the EPA to create the BATT tool and what kind of data you provided for calibration?

H: Oh, yeah. I will send you a memo on the calibration process.

J: That would be great.

H: Essentially Tetra Tech did it. We didn't do any of the calibration. We provided raw data based on the performance of our system. And that's where the, that means sometimes the tool is a little bit too prescriptive in the way it designs the systems because it takes the original cross sections of our systems and that's what it models. *In terms of the Opti-Tool here* You know, and we see a lot of flexibility in all 3 dimensions, width and length and depth, that we can vary in order to fit systems in and maximize performance. So, you know, the tool itself needs to be calibrated by something. But, in the end, it is, I mean that's the data we have. I wouldn't advocate and I don't think it would be possible for everybody, for every community and municipality to be able to go out and monitor their treatment systems. If you've ever tried to monitor it's not an easy process, and that's not what we'd advocate. In some ways, it's a little self serving because it's been at this for a long time and we know the community of researchers that are out there monitoring BMPs and I would say support those research communities that know how to do it and then use that local information to better calibrate your model. There seems, and maybe it's endemic in early fields and I think stormwater management is an early field, we are a utility. Linear foot for linear foot we have as much infrastructure in the ground as wastewater minus the power inputs, we have as much infrastructure in the ground and pipes, linear foot of pipes as drinking water utilities, but you'll be hard pressed to find stormwater called out as its own operation in municipalities. Most of the time it's out of a general fund or it's not tracked or the wastewater department does some or the highway department does some. It's a mixed bag. So, I guess where I was going with that is, often times there is, especially in a new field, you try to perfect, you try to go for accuracy. You know, you think about it, hitting the darts, you try to hit the bullseye, and there's a certain folly to that in my mind because you're trying to hit the bullseye with a very small subset of BMPs in a very specific configuration and we started out talking about the amazing world and the amazing opportunities surrounding innovation and my guess is when people do embrace implementation they're will be an explosion of innovation, and we should expect that. We shouldn't go back to our regulations and say "Oh, no, you've got to do it like this". I think that's the best way to drive up costs and decrease the effectiveness of these systems. And that's a big fear of mine, I guess, and it's you have to look at the sophistication of the information you're putting in your model versus what you actually need out of it. And I think that where we are now, I don't see any reason why performance curves and the credits we do have right now should hamper implementation, we should get moving. Because I think it's going to change and we're going to have to find ways to incorporate innovations in these crediting schemes versus vice versa. On the other side you could be really be getting an accurate model and then you'd be much more prescriptive in how you'll design a system. Oh, you don't get credit unless you design a system exactly like this, and I think that would be very limiting, whereas if we take a flexible approach, we have a good basis, and I would call it aiming for precision rather than accuracy, right. We're all doing it in the same way, so we can be flexible as we learn how to credit these systems or as we learn how to improve performance, we can adjust the metrics, but we all have to be measuring the same way. We need that precision, so this is a case early on in the science, stormwater science, where I think precision trumps accuracy. That's on record now. Scientist argue against the need for more accurate science. I hope that makes sense.

J: Yeah, when we. We met with Suzanne Warner in the EPA and she provided a lot of great information, we asked her about the flexibility of what BMPs BATT accounts for because there's only a select number of structural allowed and no proprietary option, but she was saying they would be willing to work with vendors to make that more flexible since a proprietary BMP would give credit based on the unique designs of each vendor themselves.

H: Yep, and that's just for proprietary devices. We have been developing tools for New Hampshire and Maine, basically crosswalks to help engineers bring different designs let's say are referenced in the BMP manuals in Massachusetts and New Hampshire into the tool. So the tool, you know, says infiltration basin, and there's times, let's say you're building a bioretention bed, there are times you call it a biofiltration system which is what the tool references, and there are other times where you should be calling it a infiltration basin and it's a little bit, you know, you got to be very close to the crumbs and the, you know, I guess the insides of how this all goes together, but we tried to develop documentation that will help people crosswalk diverse systems into the tool since we only have 10 right now. They all have to fit. And we can do that, and ones that don't we can put them on a list for future research. And, you know, that's where I say let's not let perfect be the good enough, not let perfect be the enemy of good enough. We have enough to move forward and where we need to, let's device these tools to help people bring in their system, because it's good enough for now. So, I'd be happy to provide you with those tools as well. We have also developed design sheets for how to use, you know, with a pencil and a ruler, how to design systems in a retrofit scenario without having to go into the graphical user interface of a tool. We find a lot of times in the consulting world too that they have their own tools already. They don't want to learn someone else's tool, and it's very hard to promote the tool. We've been trying to promote the Opti-Tool and I've been finding myself not so much promoting the graphical user interface, the machinery that allows you to put data in versus promoting the utility of how the tool is making decisions. You know again it goes back to the thing I started with. Again any tool we get, we generally dissect anyway. Like, TR-55 is the most common tool used to design systems, but the manual has all the rules and you don't need to use the computer software. You can do it all by hand like they used to do. And I just find it, the tools can be a little bit dangerous if you have a little bit of information because you could be not calculating a lot of different things, or calculating a lot of different things incorrectly and the tool will still give you an answer. It won't tell you, "Oh, you don't know what time of concentration is". You know, so, there's a benefit to understanding how the tool itself and the model itself makes those decisions.

S: It would be very to have those. We've been having some trouble when we've been looking at the Cambridge projects to go and put those BMPs into the different categories.

H: Yeah, and when you're doing that are you calculating design storage volume?

S: We're just using what they have in the HydroCAD reports.

H: You're going through HydroCAD output files?

S: Yeah.

H: Oh, God. All right. I'll be happy to share those with you. We also have a new tool online, it's a database that we're trying to track nonpoint sources of nitrogen here--nitrogen is the issue. So, it's about, 30% of the problem is wastewater treatment plants and communities have already made strides to reduce their discharges of nitrogen from their wastewater treatment facilities. 70% of the problem is nonpoint source and they really have no, we have no tracking mechanism for it. Nonpoint source which is just the prolific pollution which is largely governed by, the delivery is largely governed by stormwater. So, we have a tool online, it's called PTAP, it's on our website and there's directions for using the tool and in those directions are explicit instructions of how to calculate design storage volume for the system and how to back calculate the rainfall treatment depth. And, you might want to take a look at that. That might help you find the necessary information that you need from HydroCAD which would be the drainage area, and more specifically, the impervious surface draining to the BMP.

S: And then our next question…

H: So before, let me, I don't know if I have a pen, can I use your pen for a second?

S: Yeah.

H: What did I offer you? I got to keep track. We're not even off the first page yet.

J: Sorry, we have lots of questions, but the memo for calibration of the tool, you mentioned Tetra Tech, and then information about the tool you were providing for incorporating different unique BMPs into the subsets into communities.

H: So the crosswalk.

J: Yeah, the crosswalk.

H: And Treatment Fact Sheet, got it.

Writing these down so he can remember to provide them

J: I think they will be very useful for our project.

S: And then is all the data all online in either the international BMP database or on your website in the various sheets like this or publications?

H: Yeah, generally we don't release raw data because there's a lot of interpretation that goes into it. You know, we've had bad experiences where people misuse the data or cherry pick or. So, we don't just broadcast raw data, so the data that's available is represented in our peer reviewed publications and our reports. With respect to the, the Opti-Tool, and I'm not exactly sure, I'm using the BATT and the Opti-Tool interchangeably because I think that they are. But, I'm not sure who developed the BATT.

J: Both by Tetra Tech, but our impression, we haven't worked as closely with the Opti-Tool, but that was more for design of BMPs while BATT is just the back end of that tool for accreditation.

H: OK, so that's the performance curves.

H: OK. With respect to Tetra Tech, what they did is, they gave us their data requirements, the data they needed, what systems they needed it for, how, you know, how they wanted the statistical representation of the data that they wanted and we consolidated that for them. And that was a funded effort because it just doesn't happen, so they actually funded us to compile the data in their forms. We have submitted data to the international BMP database and a lot of our systems are in there. And again that's a lot of work to, because these databases all have different ways to enter data, so everything has to be in the same format, so there's a lot of work, just reformatting data.

J: For the purpose of our project, we wanted to use UNH monitoring data in order to validate the tool, so like entering in all the similar design sizing information and then the conditions of impervious area runoff into the tool and seeing what your real monitoring data was versus what BATT outputted as a result.

H: Yeah, the one thing though that you won't get is, there's two components of getting an output from a model like that. One is the individual performance of the actual treatment system and two is the, I guess is the hydrology. So as far as I know these models use SWMM to model the hydrology and also volume reduction, and then they use build up wash off coefficients as well in order to deliver pollutants to the system. So a system that manages more water than it potentially designed for will get a higher pollutant load reduction. All I'm saying is, and I did this in the beginning to when I saw the outputs I thought the outputs in the performance curves were ambitious. You know when we look at treatment systems and just the water quality performance of the system itself we add some lower numbers, but we're not looking at volume reduction as a removal mechanism or infiltration as a removal mechanism and that tool is as well. So it's including hydrology and volume reduction into that load reduction, so you have to consider that, you can't just compare removal efficiencies. What you can do, and what you can look at is our paper on undersized systems, so that's on our website. It's called, if you go to our website and you go to publications, specs, and info, it's the first one: "The performance analysis of two relatively small retrofit urban stormwater controls". And that basically has real time monitoring of a treatment system performance compared to the BMP performance curves.

A: As we were reading through your reports we noticed that a lot of them have "Fast Facts" about the BMPs that you guys have put in, like the 2012 report has those, and when we were reading through them, we weren't sure if those were specs specific to the BMPs you guys have been using or if they're just general information?

H: Those are specific to the systems that we monitor.
A: OK.

J: OK. We thought so, but we just wanted to make sure.

H: Yeah.

J: Additionally, how frequently, if at all, do you collect data during the winter months and do you notice fluctuation in the BMP performances during the different seasons?

H: Yeah, I'm pretty sure we published on this. We do monitor in the winter. Right now, monitoring is not a huge component of what we do. Just because there's not a lot of funding for science. We have, again, the biannual reports, we, there are some reports that are. This one (*picking up 2009 biannual report*) we break down system performance between winter and summer seasons, and annual performance. You can see that right there that's our annual performance (*pointing out the graph in that report*) charts. And there's some effect for some systems and for other systems there's not. You know, we were told that bioretention systems wouldn't work in the winter and based on our data, it shows that they continued to work. We have a couple of, master theses on the performance of porous asphalt in the winter. So, for the most part, our data all includes winter research. When and where we can, we'll partition it out, but you know a lot of times we're collecting 20 storms. It doesn't always rain in the winter, so as a subset we might not have as many, just the amount of data where we can break it out seasonally.

J: Is the porous asphalt covered in snow?

H: Right now, it's not because it's being used as a parking lot, it's being used by campus. They clear it and treat it with salt.

S: Do any of the other BMPs go through any maintenance?

H: When we study a BMP, we do the maintenance in parallel, because everything needs to work for us to monitor it. At our facility, we wrote a whole paper on operation and maintenance, I don't know if you've seen it. "A comparison to labor costs, and system demands and system performances for LID and conventional stormwater management systems". That was published in 2003 in ASCE (*American Society of Civil Engineers*) so that details specifically the types of maintenance we did, the maintenance categories, and the number of hours across the range of nonproprietary BMPs that we studied. So, we do do maintenance. So when we work on campus after let's say our research projects are ending, we don't typically continue that maintenance. And what we found from other studies is that maintenance might be one of the thousand pound gorillas in the room. We don't often consider maintenance. I think for the most part, BMPs are installed, they take credit for performance, and long-term maintenance is sort of there's not many viable ways to verify maintenance is ongoing and occurring. So, we do know that over time not maintained, these systems, the system functions cease, and the performance expectations reduce. So we have clogged porous asphalt all over campus. To the extent that we've stopped installing porous asphalt, not because it doesn't work, but because the owners, they don't maintain it. So, I think it's a key component to me. And that ducktails into plant selection, you know. Our approach is to ask the owner what they will maintain and what kind of equipment they have for maintenance, and then we design basically around that. So, I will take a inferior treatment system, over a superior treatment system if I know the maintenance is going to be done on the inferior system, because I know long term that's going to out perform. The superior system is going to work 2 or 3 years and then it's going to stop because it's going to clog or it's going to stop working. But we don't have many mechanisms, I'm sure the tool, any of these tools don't have any mechanisms for counting maintenance.

S: I think there's a box you can check for Operation and Maintenance, but I don't think it has anything to do with calculations.

H: So, at some point it seems like you get credit for let's say 3 years for a system, and then in 3 years you have to kind of recertify that credit by showing your operation and maintenance records.

J: We've already covered the next question about how to decide which BMPs to install, but are there any types specifically you see in the future working with in the stormwater center?
H: Yeah, we've been working with Philadelphia pretty closely, who, Philadelphia as you may know signed one of the largest consent agreements with the EPA for combined sewer separation in their downtown, in their urban sewer shed which involves implementation of somewhere in the order of $1.27 billion for green infrastructure. So they're installing green infrastructure at a rapid pace and one of their go to systems, it's called a linear tree trench. It's basically a subsurface dome stored infiltration system. We've been studying those for a long time. There's some of that detailed in here (*2016*). We've, we worked with communities like Bill and Dover, Bill Ballanger, who wanted to do with storm, with porous pavement and we designed subsurface system that was the same cross section as porous pavement but had a different hydraulic inlet. So, those type of systems we find very adaptable and flexible to urban environments. And, as far as I can tell, they are relatively recent innovation even though we've been using leach fields forever. It approximates leach field for stormwater, but the details and the design characteristics as far as I know are not in many manuals. So when we design one for a community let's say, and it goes through some type of external revenue like from DEES, they don't like it because it doesn't fit in their rules, so you know we're trying to change that a little bit. But, we call them subsurface gravel filters now, and that's something I can see us working a lot with in the future. And there's all kinds of cool things. In Dover, as we've been implementing their DPW director came up with this cool idea of when they were rehabilitating or fixing drainage structures, conventional drainage structures, in certain parts of the city, where they had good soils, they used a slotted pipe in between catch basins rather than a solid pipe. And it just seems like, "Wow", the, that is, the potential for an innovation like that and the effect done opportunistically everywhere you can throughout the city would be phenomenal. So, that's what I, what really gets me excited, is those little things that we're not doing. Like, I guess I've shied away from the optimization modeling and developing a huge treatment structure, which I know it's important to do, and you know in some of the large urban areas they need to do that because they have huge reductions that they need to achieve. Here, where we're not managed by TMDLs, we can make some of these opportunistic simple improvements, and I think that's going to get us a long way.

J: It's been exciting to see the small low cost.

H: Yeah, small low cost is beautiful. I know! Who would've thought! Slotted pipe, and then they added a bit more stone and make it essentially a linear infiltration trench between two catch basins and the only thing they did is swap out a slotted pipe for a solid pipe and used some stone. It's like not in a million years would I have thought of that. But that also gets back to my point of, innovation is simple to understand and I think simple to implement, I don't see it in manuals, I don't see it in models. If you were to evaluate the effectiveness of a system like that, we would call it a linear infiltration trench, and we'd measure it back into the curves like a linear infiltration trench. And we've done that for one of our projects. And it treats like 0.1" of rain, that's what it's sized for, but you still get 40% sediment removal.

A: Going on to our next question. This is about your stormwater center. If you have multiple locations with the same BMP where you vary some design criteria?

H: I would say, the simple answer to that is no. We do have systems where we vary design criteria. We've been through a lot of iterations with respect to bioretention soil mix, sorry, bioretention systems. And we've studied bioretention soil, bioretention systems in different locations, but it's very hard to compare because the loading functions are different depending on…

A: The site

H: The site. But for the most part, regardless of that, we find that, the performance is all similar. There are some limitations with respect to nitrogen and phosphorus in bioretention systems, and thus, we look for ways to change the characteristics of the system to better address those pollutants of concern. So, I think it has less to do with the locations that you're placing them and more to do with enhancing the unit processes that better address the pollutants of concern. So, phosphorus, we need a way to rehabilitate absorptive capacity of the soil. We do that through adding things like, we use water treatment residuals, there's proprietary mixes out there that are just like aggregate that's been coated with some kind of cation exchange capacity like iron, metal ion that attracts phosphorus and binds phosphorus. And there's other things like iron filings that you can just add. So, we look for ways to do that. And I think that will get better and more used in the future as well.

S: So, we've already touched on a few proprietary BMPs like the hydrology, I forgot what you said.

H: Hydrodynamic Separators.

S: Yes. Is there any more that you were, that you tested here?

H: We just became a testing center for Washington State and I mean really what drives the verification end of this is the requirement for verification. And right now there's really only one state that's doing that, and that's Washington State. So, we're testing systems for Washington State and we spent 4 years trying to convince them that the physical properties of water don't change between the coasts, you know, it's wet, goes downhill. If you exclude certain months of the year, our precipitation intensities and even our depths, our precipitation depths are in par with

the west coast. Just the delivery is a little bit different. And they have problems finding sites, because they have a seasonal first flush; it starts raining in September and doesn't stop till February, March.
J: As far as analyzing your data, do you analyze it in a lab here yourselves?

H: We do not. We send it to a laboratory outside the university. An EPA certified lab. The issue with that is if we processed it on campus, we would have to, well we can generate up to 150 samples from a storm event. And we would have to send different aliquots to different laboratories to different areas of campus all within our holding times. And so it's a lot easier for us to send it to one location and have them do everything. Just because that sampling handling not only is difficult and time consuming, but it interjects a lot of potential bias and empirical error. Handling and splitting samples. So, not many people talk about it, but a lot of people develop composite samples and the details on how those samples are developed are very, very important. So if you… go to something like the international BMP database, it is difficult to differentiate, did they use a cone splitter, did they use a turn splitter, did they split their samples at all? Did they take aliquots with a pipette. Those are very important details that get lost. So you fixate on this one number. The power of the international BMP database is that you have hundreds of data points. So you can statistically identify outliers and apply statistics and use it in that sense.

A: Our next question, I know you already addressed this with the compost in your bioretention fields being a source of phosphorus. Have you noticed breakthroughs with phosphorus in any of your other BMPs or mainly just bioretention?

H: Yeah so we started to use these additives so drinking water residuals that are in the water treatment processor, that's right down the road, they have ponds full of flocculant sludge and, you know, the flocculation process involved in drinking water treatment, cleaning the drinking water. They pay, its about 99% water, they pay to get rid of that. We have dewatered it, and reduced it to, it looks like a soil or coffee grounds, and we add that to our systems, 5% by volume to our treatment systems. So we can generate it cheaply here, it's free. So we've added that to our bioretention soils, 5% by volume. S we can take out a little bit of our wood chips or the load and we add a little bit of the sludge. And I think that's the key. And another thing is that when we maintain our systems, we can mix up a little of that and replenish our soils in that respect. I think a lot of innovations in phosphorus removal, you can do a lot with enhancing the absorbent capacity of the media but you have to be able to regenerate it and that's largely through maintenance.

S: How do you know when to regenerate the soil? Do you test the soil?

H: No, we just do it opportunistically. Because what we should be doing is every year or so we should be scraping half an inch or so, a couple millimeters of surface. And then every three or so years, we replace it to meet design elevations. We have done some studies that have shown a 20 year absorbent capacity, you know, so every 3-5 years should be good.

S: And are the lab testing procedures on your website? Do you just go and give the EPA the samples in a stale container?

H: No, umm

S: Maybe they are just in the back of these (gestures to UNHSC Reports) and I haven't looked?

H: They are governed by what's called the Quality Assurance Project Protocol.

S: Yeah, the CRWA kind of mentioned that also

J: Are the design drawings for the UNH BMPs publicly available or just held in your own records?

H: I don't know that we have made those public. Thats been a little bit of contention among our peers, you know, that it's been reported differently. So we have addressed that in our maintenance paper, so for all of the non-proprietary BMPs, we have reported the characteristics of the BMPs. Again that's the third publication on our website. You can download that on our website. (1.05.15) And that has the whole section on that. Otherwise I don't know if the memo goes into it or not. But certainly within the operators manual which is available from the EPA, it goes into each system from the Opti-Tool that has been sized and that's all from our system

A: We are skipping question 19 because we already covered the BMPs that are operating in the Winter but we were wondering how the BMPs were energized in the Spring, but it seems like you guys do that as needed?

H: Yeah we have operation and maintenance standards on our website as well and we try to follow those but we've installed probably 42, 40 so we do not maintain all of those. A lot of times we do work for a community and hand over operation and maintenance to them. At our facility, when we are testing systems, we keep up on the maintenance. Like I said, we aren't testing anything right now. We do at least annually go through and maintain them. Like I said on our website in the home row it has our maintenance with all of our guidelines. Bioretention, tree box filter, subsurface gravel wetlands, pervious pavement, and subsurface gravel filter which is the new one I was talking about. So we generally follow those. There's a whole new area of study on, like I said but for the most part we look at these systems as a black box, phytoremediation is a big idea, but we haven't really looked at what plants do. We typically design our soils for urban areas and for fast drainage so they are very open graded sands and that's not really the area you want to be when youre a plant. There's ways to engineer these systems to facilitate plant growth. We tend to engineer them for urban areas for fast removal and fast drainage. That's not to say that there aren't benefits to the plants but its largely unstudied and largely secondary, I guess, to designing in urban environments. If it's not secondary, its in that, a lot of those plants if you look long term and visit the site two or three years after, a lot of those plants won't be there anymore. So you can say you designed this with facultative wetland plants but go back in three years and see if they are still there. That all comes down to maintenance too because those plants don't maintain themselves but often get choked with weeds. So again you can't underestimate the need and function of operation and maintenance. And quite honestly I might differ from my peers but I think that should be more of a guiding criteria when selecting a system to a site than water quality performance.

J: So that covers most of the questions we have about the UNH Stormwater Center. By what we've described for our project, do you have any questions for us about what we are working on?

H: Um, Not really. I don't really understand what the overall objective is, who you are for and what your audience is? Do you have one?

S: So we are working for Stantec and their client is Cambridge. We are just trying to have them understand the BATT tool. The permit hasn't come out for another year so we are helping them get a handle on BATT before it goes into effect. They don't have very much BMPs yet.

H: I mean I dont have questions I just, understand everything. I would have more of a caution that you have more of an emphasis on the personnel and the people doing the work and less on the model. The model is wrong, its always wrong. There is more potential in the innovation and on the human side, and they can design things and they can fit it into the model rather than let the model dictate what you design. If you look at what happens in the Chesapeake, and the Chesapeake has lots of challenges, they have a huge Bay model that decides everything and basically its very difficult to get innovations into that model. But they have done a lot of groundbreaking work and we are following their lead, but trying not to make the same mistakes in not letting the model dictate design. It should be the other way around. We should be finding what we could pragmatically, effectively do, what we can maintain, what fits our maintenance culture, what fits our urban environment best. What fits our community and then fit that into the model because that's easier. So that's just a caution. We are also working up in Burlington with one of the public works directors up there who is very smart and understands all the intervention points and kind of has all of the optimization model in her head because she knows her system. And we are at a meeting and she is talking with their DPC thats developing the model. And she has these questions that are right and reflective of the real world but the model can't really develop a sophisticated enough model. Therein, do not let the model dictate, find ways to incorporate what you are doing and what you can do into the model. That flexibility is the winning recipe. Because when we learn more, the models will get more sophisticated but but there's a huge blank canvas on the BMP side. I think in 10 years, the Cambridge bioretention is developed in the way they like it in the way they can maintain, but there may be a Durham bioretention model. They are different names and different things that work differently.

J: And the model categorizes them as bioretention either way even though they worked so differently.

H: Yes, I mean you can take a well-studied BMP like a Wet Pond and focus in on removal efficiency and performance, etc. But the number of iterations of wet ponds in the world is unfathomable and they don't all subscribe to the modeling approach used. And we studied one gravel wetlands system. We had people coming up to us saying you have a two cell gravel wetland, what about a one cell gravel wetland system. We did a lot of work with DOTs that couldn't fit gravel wetland systems the way we specified them into a linear transportation environment and we worked with them to develop a specification that did allow for that, basically adjusting the spec. And that's the way we are going to move forward. We argue with our DES all the time and they say well there's no data on this. And it's like yeah you don't ask that question of a Wet Pond. Within your rules, all wet ponds within this criteria operate the same and there's no rules. These iterations are important and I think they are going to lead to economic and effective improvements in operation and performance. And just keep in mind, what's the quote, all models are wrong, some are useful. The model is a very two dimensional representation of a 3 maybe 5 dimensional problem.

J: Yeah Especially the BATT tool is very simplistic in how many input options it has.

H: It may be that when we send you these materials, we anticipate that with the performance curves and the opti tool. We are trying to find a way to utilize the tool in the way thats more flexible and iterative. Because if you just look at the model, if the opti tool is a design tool and you try to model it, its very cumbersome.

J: And finally just because we really do appreciate you making time for us and don't want this to be too one ended, are there any research outcomes in our project that you can benefit from? I guess our primary deliverable are our user guide from BATT, and we are looking at Cambridge project analysis how their inputs can be incorporated into the tool and alternative analysis of their BMPs, Model validation with CRWA and UNH data, and finally the developers template so that developers can better incorporate their BMPs into BATT. Thats a short overview.

H: The most useful thing for us is to, you know, reference us in your work. Thats a very useful outcome for us as an academic institution.

J: Yes definitely, if we take anything directly from this interview, we will be sure to send that over. And I know that, Professor LePage and Professor Mathisen really wanted to be there today and look forward to further work between UNH and WPI.

H: Yeah and our big message to communities is that it's not that hard and if it is that had, then you're thinking about it wrong. If you think this is going to cost you $1.3 million in additional funds or the ranges are all over the place, then you have to rethink it. The permit is kind of political so I look forward to the day when it's just boots on the ground or shovels on the ground. I think that when the DPW's embrace it, not only do they innovate and come up with better systems, they find cheaper ways to do it than we can predict.

J: I know we are short on time, but is there anything you would recommend we walk around to look at, any of the BMPs.

Appendix F: UNHSC Inputs for BATT

Gravel Wetland BATT Inputs

Subcatchment Area (Acre)	Storage Volume (ft^3)	Surface Area of Pretreatment (ft^2)	Pretreatment Depth (ft)	Wetland Area (ft^2)	Ponding Depth (ft)	ISR Surface Area (ft^2)	Gravel Depth (ft)
0.988	1263.43	1926	0.6	243.26	0.4	57.5	0.6

Bioretention

BMP	Subcatchment Area (acres)	Storage Volume (ft^3)	Bed Surface Area (ft^2)	Ponding Depth (ft)	Soil Depth (ft)	Soil Porosity (ft)
Bioretention 1	0.988	1501.78	2346.53	0.2	1.1	0.38
Bioretention 2, 3	0.988	136.38	269.10	0.2	0.8	0.38

Porous Asphalt

Subcatchment Area (acre)	Depth of Filter (in)
0.124	15.60

Vegetated Swale

Subcatchment Area (acre)	Storage Volume (ft^3)	Swale Length (ft)	Cross Sectional Area (ft^2)
0.988	238721.77	85.30	2798.61

Wet Pond

Subcatchment Area (acre)	Storage Volume (ft^3)	Area (ft^2)	Depth (ft)
0.988	1609.20	3218.41	0.5

Dry Pond

Subcatchment Area (acre)	Storage Volume (ft^3)	Surface Area (ft^2)	Depth (ft)
0.988	2896.57	3218.41	0.9

Appendix G: Project Master List

Project Name	Watershed	BMP Type	Land Use	HydroCAD or Rational Method?	Pursue for Alternative Analysis?
58 Plympton Street	Charles River	Impervious area Disconnection with Storage	HDR	HydroCAD	Yes
10 Glassworks Avenue	Charles River	Jellyfish (proprietary)	HDR	HydroCAD	No
15-33 Richdale Avenue	Did not Analyze – Part of Mystic River Watershed				
131 Harvard Street	Charles River	Dry Pond	HDR	HydroCAD	Yes
88 Cambridge Park Drive	Charles River	Infiltration Trench	HDR	HydroCAD	No
76 Prospect Street	Charles River	Infiltration Trench	Commercial	HydroCAD	No
19-21 Wendell Street	Did not Analyze – Part of Mystic River Watershed				
625 Putnam Avenue	Charles River	Infiltration Trench	HDR	HydroCAD	No
1066 Cambridge Street	Charles River	Infiltration Trench	HDR	HydroCAD	No
Bolton Street	No Stormwater Information Available				
430 Windsor Street	Charles River	Dry Pond	Industrial	HydroCAD	Yes
1-7 Brattle Street	Charles River	Dry Pond, Infiltration Trench	HDR	HydroCAD	Yes

130 Brookline Street	Charles River	Porous Pavement, Rain Garden	HDR	HydroCAD	Yes
7 Cameron Avenue	Charles River	Dry Well	HDR	HydroCAD	Yes
22 Cottage Park Drive	Did not Analyze – Part of Mystic River Watershed				
240 Sidney Street	Charles River	Infiltration Trench, Jellyfish, Subsurface Basin	HDR	HydroCAD	No
8 Education Street	No Stormwater Information Available				
168 Hampshire Street	Charles River	Infiltration Trench	HDR	HydroCAD	No
147 Prospect Street	Charles River	Infiltration Trench	HDR	HydroCAD	No
North Point Street	No Stormwater Information Available				
Glassworks Avenue	Charles River	Only Proprietary	HDR	HydroCAD	No
97-141 Harvey Street	Not Enough Information is Provided				
1801 Massachusetts Avenue	Charles River	Infiltration Trench	Commercial	HydroCAD	No
16-18 Bellis Circle	Charles River	Rainwater Harvesting Tank (2)	HDR	HydroCAD	Yes
399 Binney Street	Charles River	Infiltration Trench	Commercial	HydroCAD	No – too complex for BATT
225 Binney Street	Charles River	Roof Detention, Infiltration Trench	HDR	HydroCAD	No – too complex for BATT

130 Brookline Street	Charles River	Porous Pavement (2), Rain Garden (2)	HDR	HydroCAD	Yes
1868 Massachusetts Avenue	Did not Analyze – Part of Mystic River Watershed				
1924 Massachusetts Avenue	Did not Analyze – Part of Mystic River Watershed				
1924 Massachusetts Avenue	Did not Analyze – Part of Mystic River Watershed				
1965-1975 Massachusetts Avenue	Did not Analyze – Part of Mystic River Watershed				
249 Third Street	Charles River	Only Proprietary BMPs	Commercial	HydroCAD	No
219-221 Monsignor O'Brien	Charles River	Infiltration Trench, Dry Pond	Commercial	HydroCAD	Yes
15-33 Richdale Avenue	Did not Analyze – Part of Mystic River Watershed				
120 Rindge Avenue	Charles River	Drywell	Commercial	HydroCAD	Yes
160 Cambridge Park Drive	Charles River	Infiltration Basin	HDR	HydroCAD	No
33 Cottage Park Avenue	Too Complex for Team to Analyze				
131 Harvard Street	Charles River	Detention Tank	HDR	HydroCAD	Yes
262 McGrath O'Brien Highway	Charles River	Dry Well (2), Infiltration Trench	HDR	HydroCAD	Yes
288-320 Rindge Avenue	Not Enough Information is Provided				
50-60 Binney Street	Not Enough Information is Provided				

270 Third Street	Not Enough Information is Provided
159 First Street	Not Enough Information is Provided
1344-1360 Massachusetts Avenue	Not Enough Information is Provided
215 McGrath O'Brien Highway	Not Enough Information is Provided
40 Norris Street	Did not Analyze – Part of Mystic River Watershed

Appendix H: User Guide

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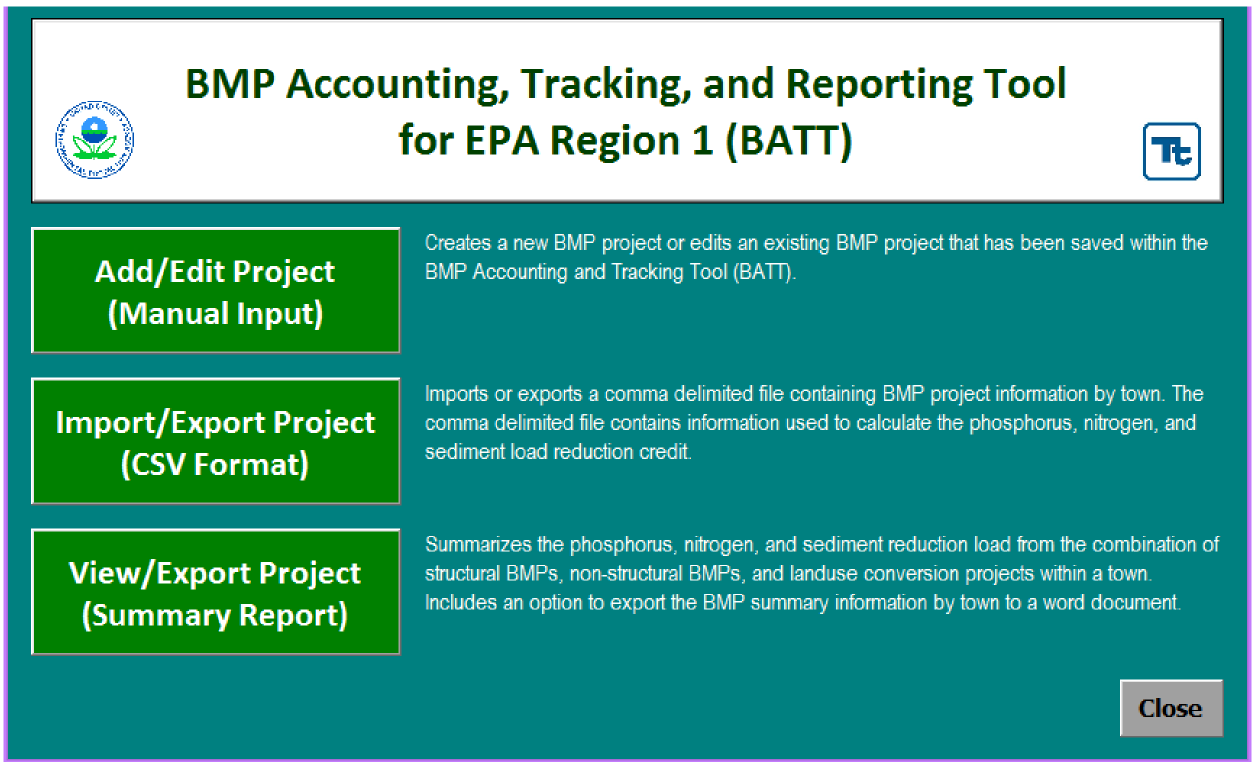
Supplemental BATT User Guide



Stephanie Cappelli
April Locke
Jessica Wey

Worcester Polytechnic Institute
students working in collaboration
with Stantec, LLC.

Introduction:

This User Manual was created by Worcester Polytechnic Institute (WPI) students as part of their fulfillment of their Major Qualifying Project (MQP). The students worked in collaboration with Stantec, LLC. in understanding the fundamentals of the Best Management Practices (BMP) Accounting and Tracking Tool (BATT). However, all views herein are the students' alone and should not be affiliated with WPI or Stantec.

The students found a supplementary BATT User Guide necessary for users unfamiliar with the interface, looking for best tips to install and understand the said software. To provide such materials, the students created this manual as an add-on to the EPA BATT User Guide, a more tutorial approach.

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Last Updated: 12/31/2016

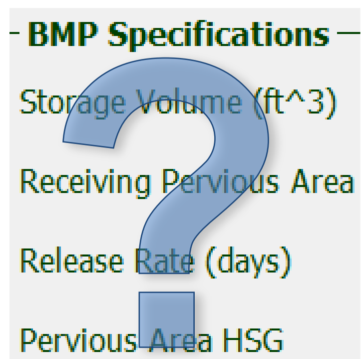
Launch BATT

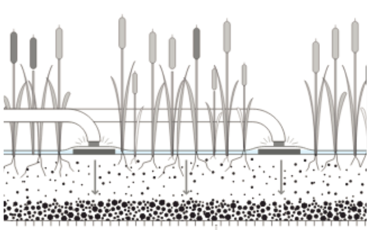
Steps to Set Up BATT on Computers

pg. 1

Tips & Tricks

pg. 5





Created Wetland

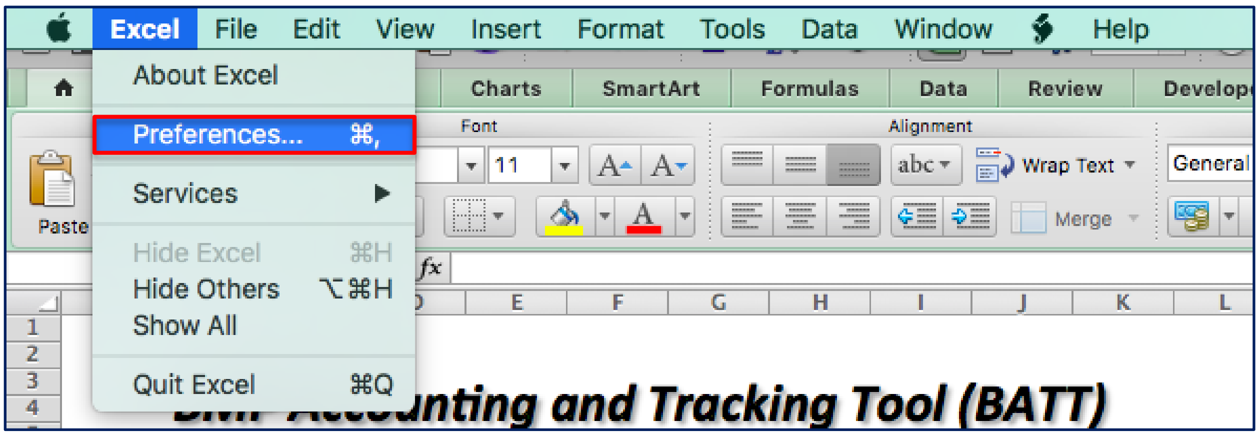
Guide to BMPs

pg. 12

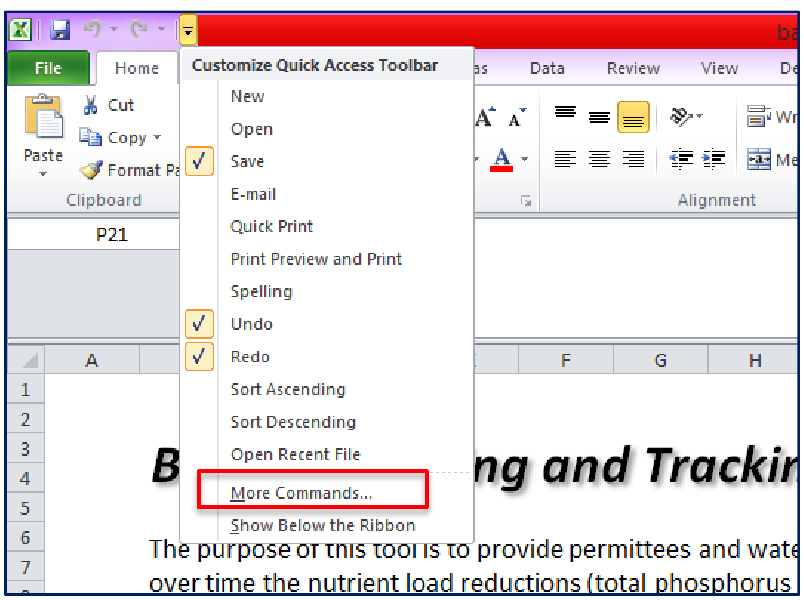
Steps to Set Up BATT on Computers

To run properly, BATT is designed to work on the 2013 versions of Microsoft Word and Excel. If the user does not have these versions, his or her computer will likely be missing at least one reference library that BATT refers to. Once BATT is opened, the user must select “Enable Macros”. After doing so, the user will need to start the process of unselecting missing reference libraries. The steps are different in the beginning between Mac and PC interfaces, but converge by the end. Instructions are provided for both. The directions are as follows:

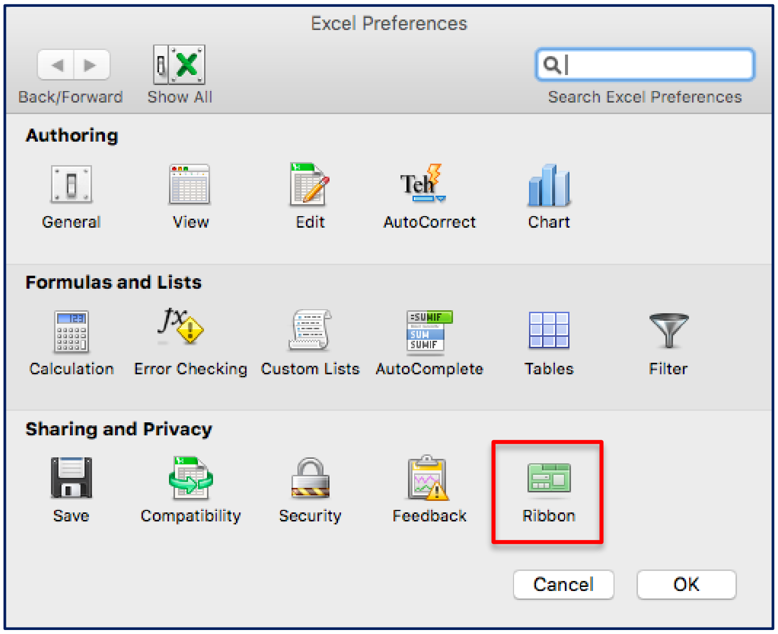
Step 1 (Mac): Hover over “Excel” next to the Apple symbol, and select “Preferences”



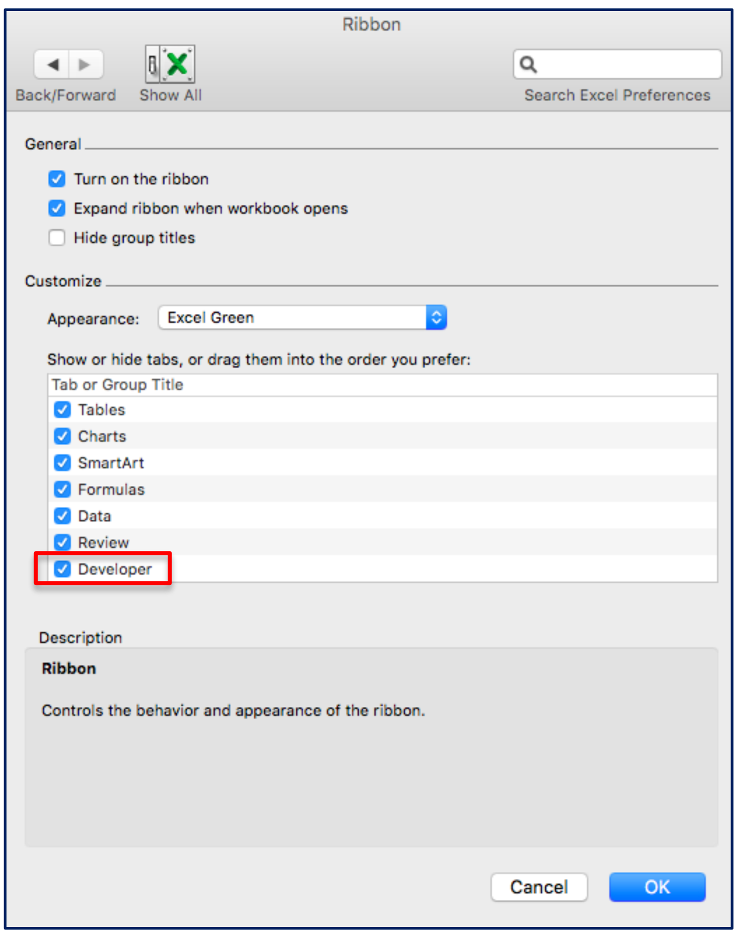
Step 1 (PC): Hover over the down arrow near “Save,” and select “More Commands” (Skip to Step 3 for PC)



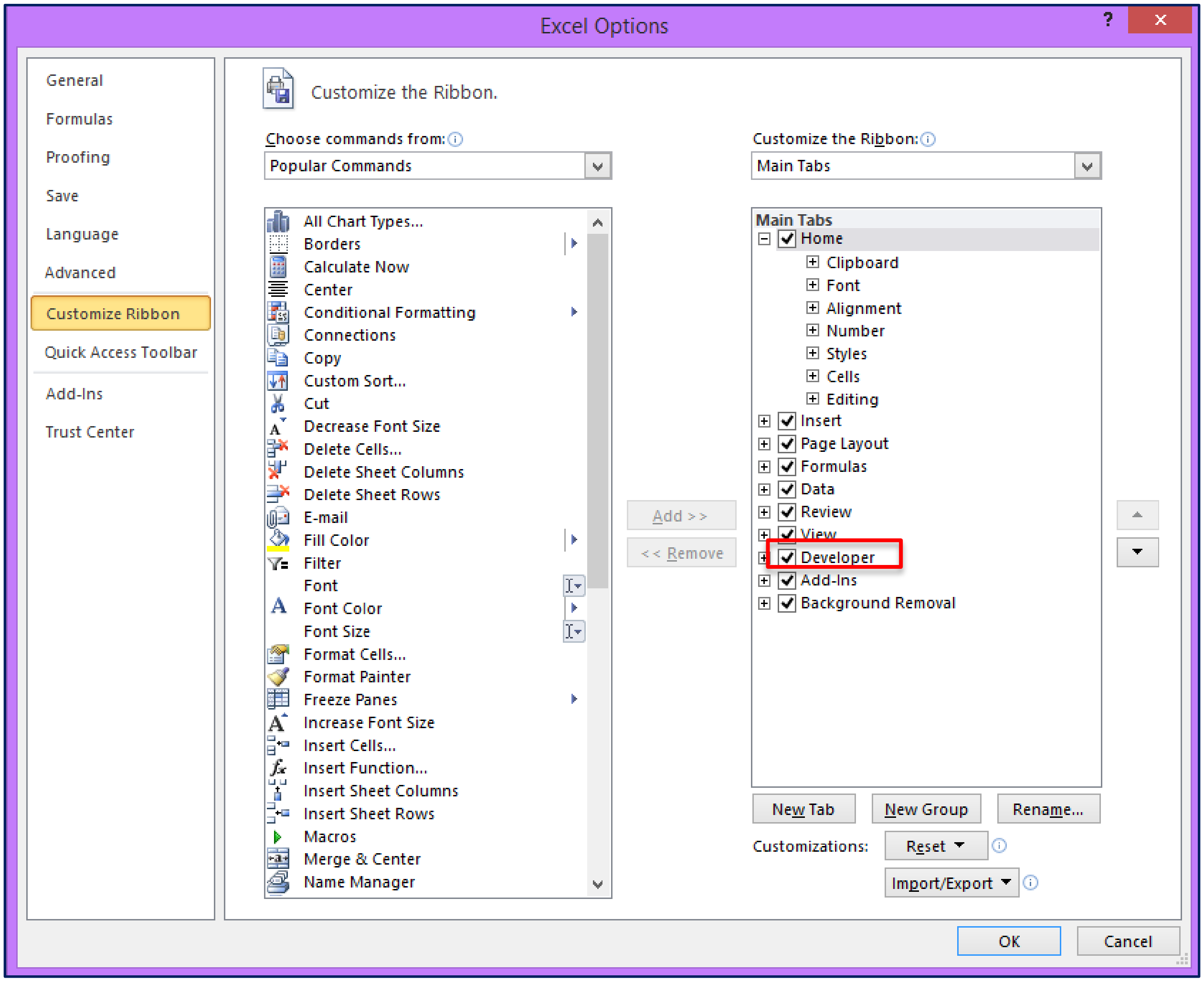
Step 2 (Mac): Select "Ribbon" in the Excel Preference options



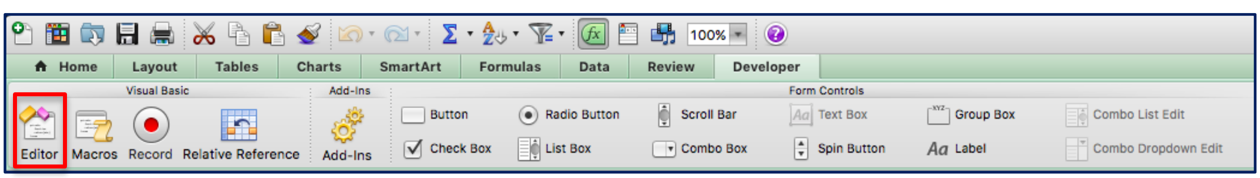
Step 3 (Mac): Make sure that "Developer" is checked, and hit "OK"



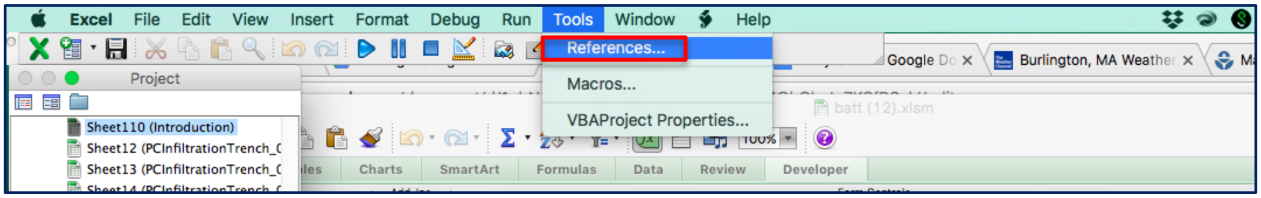
Step 3 (PC): Select "Customize Ribbon" in Excel Options box. In "Main Tabs" options on the right pane, make sure "Developer" is clicked. Click "OK"



Step 4: In the "Developer" tab, select "Editor"

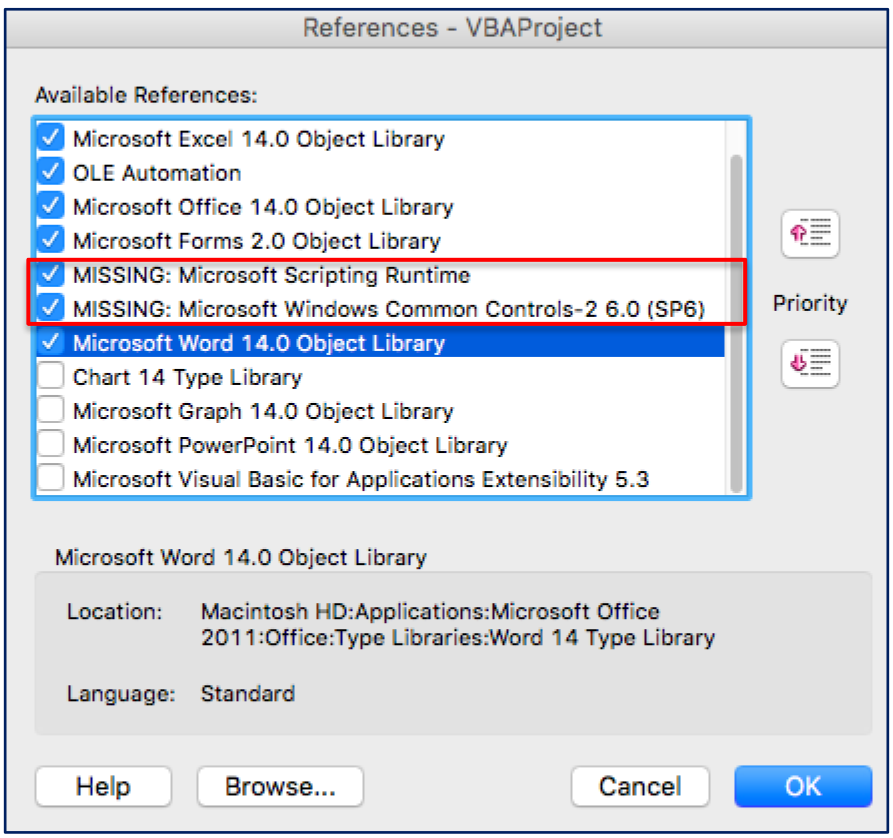


Step 5: Under "Tools," select "References"



Step 6: The user will notice that there are missing References. Uncheck the missing references and hit "OK". In this case, the following would be unselected:

a. MISSING: Microsoft Scripting Runtime
b. MISSING: Microsoft Windows Common Controls - 2 6.0 (SP6)

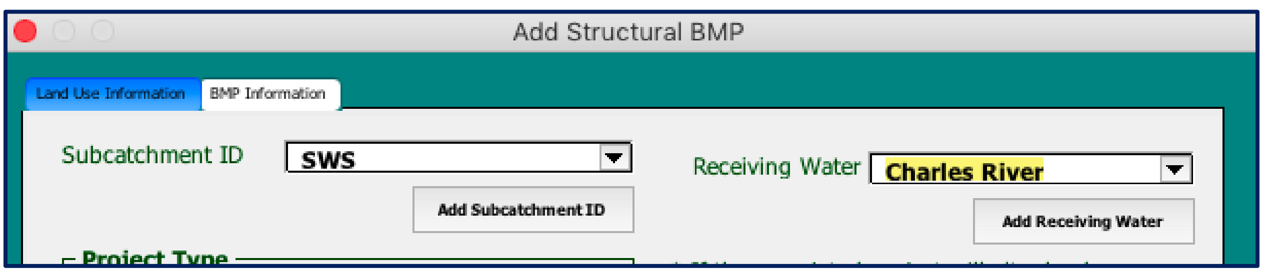


Once both missing libraries are unchecked, BATT will only be referring to functioning libraries and BATT runs properly.

Tips & Tricks

Tip 1: Subcatchment ID and Receiving Water

Subcatchment ID and Receiving Water are values entered manually and primarily for keeping track of projects in a saved list. BATT does not supply libraries with options for these categories and they do not affect the result. The receiving water should be the general watershed where the project is located (Charles River, Mystic River, etc.). The user can create any name for the Subcatchment ID.

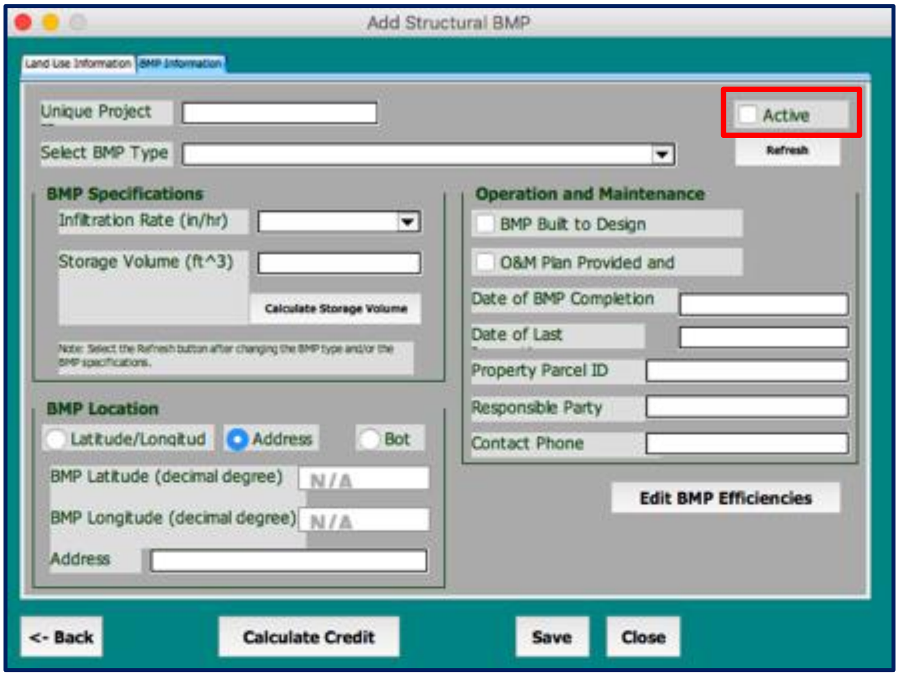


Tip 2: Pervious-only Subcatchments are Not Credited

Subcatchments entered into the first tab of BATT "Land Use Information" that contain only pervious area will not produce a credit in BATT. At least a small amount of impervious area must be entered to calculate credits.

Tip 3: Active Box Requirement for Functionality

After entering all of the specifications for the BMP, the user must first check the "Active" box for this BMP in order to execute the "Calculate Credit" function.



Tip 4: For accurate analysis of impervious area conversions, use MS4 Permit.

BATT does not credit changes in impervious and pervious areas properly during site retrofits, when the land use group stays the same. Therefore, to obtain the proper credit, the developer must use Attachment 3 of Appendix F. Attachment 3 includes Table 3-28, "Cumulative Reduction in Annual Stormwater Phosphorus Loads," in percentages for impervious area converted to pervious area for each soil type which should be factored into the equation.

Tip 5: Unknown HSGs are Categorized as HSG C

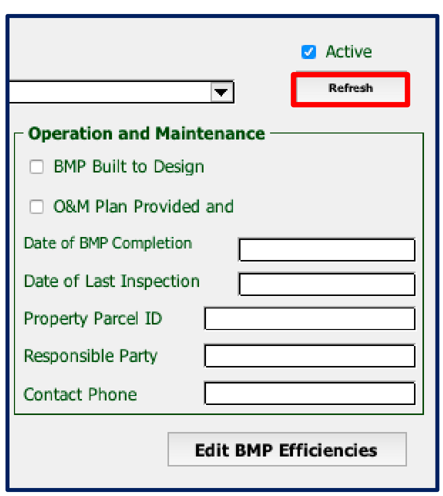
This is confusing, since several areas in the permit can give different information. However, the "Response to Comments" to Appendix F changed the unknown soil group form C/D to C.

Tip 6: Non-Structural BMP: Sweeping Technologies

The methodology for calculating credits in BATT does not match what is specified in Appendix F. The BATT method does not allow for an "Annual Frequency Factor" of total months of the year swept over twelve months. BATT only allows for the initial frequency of weekly, monthly, or twice per year. If the municipality sweeps for a certain amount of months of the year, the user must calculate this credit with Appendix F and not BATT.

Tip 7: Using the "Refresh" Button

If BMP conditions are changed such as the infiltration rate, storage volume, acreage, or BMP type, the user must click the "Refresh" button under the "Active" box in order to obtain a different credit. When changing land use conditions on the previous page, it is not necessary to click the "Refresh" button.



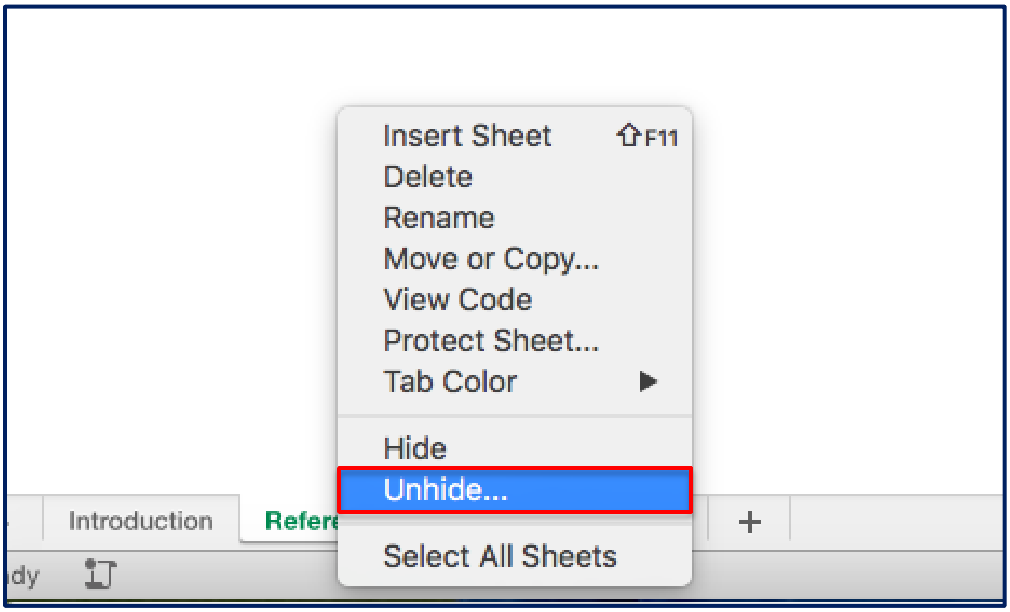
Tip 8: Non-structural BMP: No Applications of Fertilizer with Phosphorus Not Credited in BATT

Because Massachusetts has implemented a general ban on fertilizer with phosphorus, the EPA has credited each municipality already with a standard value in pounds per year assuming no fertilizers with phosphorus. To find a municipalities' credit and an explanation of the calculation, go to the "Response to Comments" document of the MS4 permit.

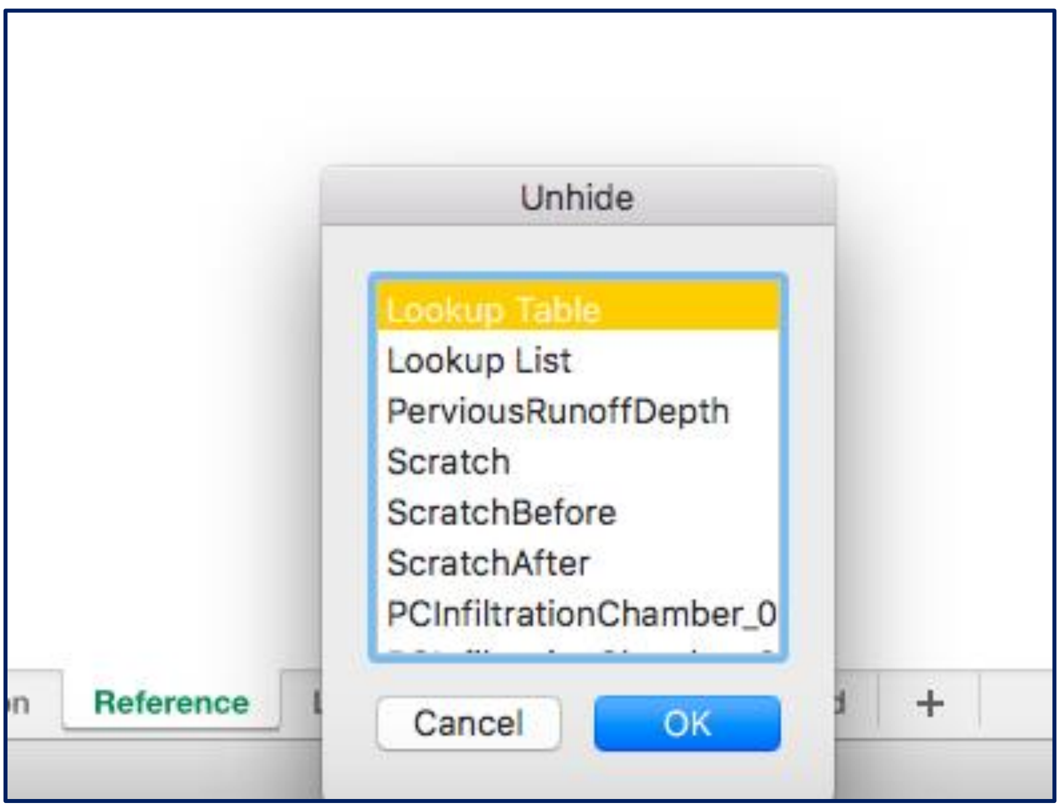
Tip 9: The Reference Tabs in BATT can be unhidden

The "Reference" tab to the right of the main "Introduction" screen in BATT contains useful information detailing the foundations of BATT calculations. When first opening the Reference tab, brief instructions on how to activate necessary libraries are given, similar to the first chapter of this User Guide. Then a description of BMPs is given and how they are categorized in BATT. Design storage volume (DSV) equations for each BMP are also given. Additionally, right clicking on the reference tab, as demonstrated in Step 1 below, will "Unhide" a variety of reference tables containing information in Appendix F that dictates BATT reduction calculations. Primarily the tabs contain tables of percentages representing performance curves for each BMP. Various tabs provide a layout of information from saved BATT calculations including efficiency percentages. A detailed list of each reference tab and information provided within is laid out below along with instructions to unhide the reference tabs.

1) Right click the bottom References Tab and click "Unhide."



2) A list will come up including Lookup Tables and Performance Tables for each BMP.



Reference Tab Name	Description
Look Up List	Gives information about the towns available in BATT, a land use list, HSG List, available structural BMPs in BATT, infiltration rates, non-structural BMPs list, release rate, sweeper technology choices, nutrient removal efficiencies for organic waste/leaf litter, nutrient removal efficiencies for catch basin cleaning, nutrient removal efficiencies for different types of street sweeping technologies
Land Loading Rate	Gives the nutrient loading rate for each type of land use in lb/ac/yr
Database Structural BMPs	Additional information about saved structural projects including nutrient removal efficiency percentages; info only appears if project is saved
Database Non-Structural BMPs	Additional information about saved non-structural projects including nutrient removal efficiency percentages; info only appears if project is saved
Database Land Use Conversions	Additional information about saved land use conversion projects including nutrient removal efficiency percentages; info only appears if project is saved
Scratch	Organizes information entered in past BATT projects
Scratch Before	Headings to table of Scratch
Scratch After	Headings to table of scratch
Pervious Runoff Depth	Gives runoff depths for each category of HSG based on the rainfall depth
PCInfiltrationChamber_0.17-8.27	Gives BMP Performance Tables for various infiltration rates (0.17, 0.27, 0.52, 1.02, 2.41, 8.27) of Infiltration Chambers
PCInfiltrationTrench_0.17-8.27	Gives BMP Performance Tables for various infiltration rates (0.17, 0.27, 0.52, 1.02, 2.41, 8.27) of Infiltration Trenches
PCInfiltrationBasin_0.17-8.27	Gives BMP Performance Tables for various infiltration rates (0.17, 0.27, 0.52, 1.02, 2.41, 8.27) of Infiltration Basins
PCIADisconnectStorage_1.1-8.1	Provides the nutrient reduction percentages per each Storage volume to impervious area ratio (1:1, 2:1, 4:1, 6:1, 8:1) and Hydraulic Soil Group. Organized by amount of days the water is retained in BMP before drained.

PCSandFilter	Provides the long-term nutrient load reductions based on the Sand Filter BMP Capacity
PCBiofiltration	Provides the long-term nutrient load reductions based on the Biofiltration BMP Capacity
PCWetPond	Provides the long-term nutrient load reductions based on the Wet Pond BMP Capacity
PCDryPond	Provides the long-term nutrient load reductions based on the Dry Pond BMP Capacity
PCGravelWetland	Provides the long-term nutrient load reductions based on the Gravel Wetland BMP Capacity
PCGrassSwale	Provides the long-term nutrient load reductions based on the Grass Swale BMP Capacity
PCDisconnect	The ratio of disconnected impervious area to pervious area related to the nutrient reduction percentages of each HSG

Guide to BMPs

Structural BMPs

Infiltration Trench

BMPs labeled as a trench: Porous pavement without permeable liner, subsurface infiltration, tree filter, dry well, leaching catch basin

- *Differentiating Characteristics:* Infiltration into subsoils instead of redirection, storage container (pipe, chamber, galley), provides temporary storage using void spaces

Infiltration Basin

BMPs labeled as a basin: Bioretention areas, rain gardens, wet pond, dry pond, gravel wetland (each without impermeable liners)

- *Differentiating Characteristics*: Infiltration into subsoils instead of redirection, stores runoff by standing water before infiltration

Bioretention

BMPs labeled as bioretention: Biofiltration, rain gardens (each with underdrains)

- *Differentiating Characteristics*: Primary removal mechanism is soil media filtering, water passes through without retention, Shallow depressions that contain soil, plants, and microbes

Gravel Wetland

BMPs labeled as gravel wetland: Various created wetlands based on the design

- *Differentiating Characteristics*: Gravel Internal Storage Reservoir (ISR), Retention time of at least 24 hours

Enhanced Bioretention

BMPs labeled as enhanced bioretention: Biofiltration, rain garden based on the design

- *Differentiating Characteristics*: Primary removal mechanism is soil media filtering, washed stone internal storage reservoir (ISR), retention time of at least 24 hours

Porous Pavement

BMPs labeled as porous pavement: Porous asphalt, porous concrete, porous pavements must have impermeable liner/underdrain

- *Differentiating Characteristics*: Porosity in paved surface allows filtration to an underdrain

Wet Pond/Created Wetland

BMPs labeled as wet pond/created wetland: Some created wetlands depending on design, wet pond, wet basin

- *Differentiating Characteristics*: Primary removal mechanism is settling and vegetative treatment, stormwater remains until displaced by incoming storm runoff

Extended Dry Detention Pond

BMPs labeled as dry pond: Dry detention basin, extended dry detention pond

- *Differentiating Characteristics*: Stormwater treatment through limited settling, rapid displacement, no vegetation required
- Dry detention basin (limited settling of sediments, designed to empty in less than 24 hours); Extended dry detention basin (provides a minimum detention time of 24 hours, removal of sediment can be enhanced with addition of shallow marshes, micropools, or forebays)

Grass Swale

BMPs Labeled as Grass Swale: Grass swale, vegetated swale, conveyance BMPs

- *Differentiating Characteristics*: Primary removal mechanism is conveyance, water must move across swale for treatment, infiltration is a factor (rate assumed in BATT)

Non-structural BMPs

Impervious Area Disconnection with Storage

BMPs labeled as impervious area disconnection with storage: Rain barrel, cistern, rainwater harvester

- *Differentiating Characteristics*: Primary mechanism is to collect runoff from an impervious area, storing it in a container, and releasing it to a pervious area after a time delay

Impervious Area Disconnection without Storage

BMPs labeled as impervious area disconnection without storage: Rain gutter downspout

- *Differentiating Characteristics*: Discharge of rainwater from an impervious area to a pervious area

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Appendix I: Developer Template

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Developer Template for Inputting Project Data into the BMP Accounting & Tracking Tool (BATT)

Stephanie Cappelli
April Locke
Jessica Wey

Worcester Polytechnic Institute
students working in collaboration
with Stantec, LLC.

This Template was created by Worcester Polytechnic Institute (WPI) students as part of their fulfillment of their Major Qualifying Project (MQP). The students worked in collaboration with Stantec, LLC. in understanding the fundamentals of the Best Management Practices (BMP) Accounting and Tracking Tool (BATT). However, all work herein is the students' alone and should not be affiliated with WPI or Stantec.

First, Cambridge as Stantec's client, requested detailed forms for organizing data for input into the BATT. Developers, looking at all of the inputs for the site, can fill out simple forms for structural BMPs, non-structural BMPs and land use conversions. Cambridge can then utilize these forms and easily perform calculations of phosphorus credits using BATT.

Since there are only nine structural BMP options in BATT, the team created a flow chart to help developers organize their BMPs based on how BATT interprets them. The flow chart (provided on page 8) is composed of questions related to BMP designs outlined in BATT, the MS4 Permit, and the Massachusetts Stormwater Handbook. These questions will help lead developers to the correct BMP categorization for BATT.

Project Details:

Town	Subcatchment ID	Receiving Water	Project Type

Project ID	Date of BMP Completion	Date of Last Inspection	Date of Land Conversion Completion

Address	Latitude/Longitude	Property Parcel ID	Responsible Party
			(000) 000-0000

Multi Sector General Permit	BMP Built to Design Specifications	O&M Plan Provided and Reviewed
☐	☐	☐

Land Use Details:

Existing Land Use:

Subcatchment	Land Use Group	HSG	Acres of Pervious	Acres of Impervious	Total Acreage

Proposed Land Use:

Subcatchment	Land Use Group	HSG	Acres of Pervious	Acres of Impervious	Total Acreage

Structural BMPs:

This section determines the design storage volume for your selected BMP. If referring to HydroCAD reports, the *storage volume is already calculated* and the parameters described for each BMP are not necessarily needed. In this case, report at table at bottom of page 6.

Bioretention

Bed Surface Area (sq. ft.)	
Ponding Depth (ft.)	
Soil Depth (ft.)	
Soil Porosity	

Enhanced Bioretention

Surface Area of filter bed (sq. ft.)	
Ponding Depth (ft.)	
Filter Depth (ft.)	
Soil Porosity	
ISR Surface Area (sq. ft.)	
Stone Depth (ft.)	
Stone Porosity	

Extended Dry Detention Pond

Surface Area of Pond (sq. ft.)	
Pond Depth (ft.)	

Grass Swale

Swale Length (ft.)	
Cross Sectional Area (sq. ft.)	

Gravel Wetland

Surface Area of Pretreatment (sq. ft.)	
Pretreatment Depth (ft.)	
Area of Wetland (sq. ft.)	
Depth of Ponding (ft.)	

Infiltration Basin

Infiltration Rate (in./hr.)	
Length (ft.)	
Width of the bottom (ft.)	
Width of the top at max depth (ft.)	
Depth (ft.)	

Infiltration Trench

Infiltration Rate (in./hr.)	
Trench Surface Area (sq. ft.)	
Stone Depth (ft.)	
Stone Porosity	
Sand Depth (ft.)	
Sand Porosity	

Porous Pavement

Depth of filter course (12-32 in.)	

Wet Pond/Created Wetland

Surface area of pond (sq. ft.)	
Pond Depth (ft.)	

Non-Structural BMPs:

Impervious Area Disconnection

Receiving Pervious Area (sq. ft.)	
Receiving Pervious Area HSG	

Impervious Area Disconnection through Storage

Storage Volume (cu. ft.)	
Receiving Pervious Area (sq. ft.)	
Release Rate (days)	
Receiving Pervious Area HSG	

Using HydroCAD for Storage Volume Calculations

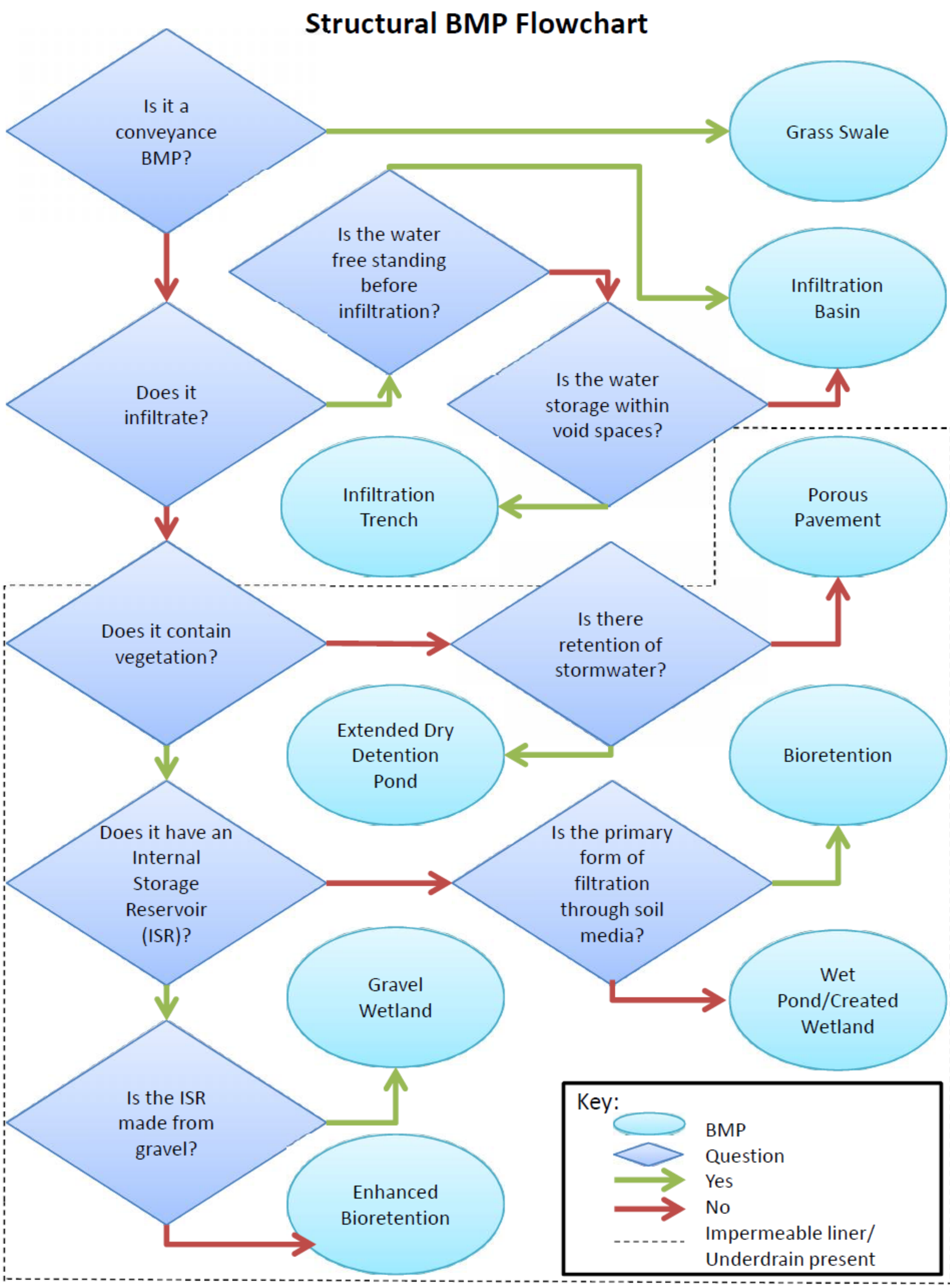
BMP	Storage Volume (cu. ft.)

BMP and Subcatchment Number: Subcatchments should come from the Proposed Land Use Chart. Multiple Subcatchment names may be used for one BMP. Please make it clear which areas (completed on page 3) relate to which BMPs on the form.

BMP	Subcatchment

Other Pertinent Information:

This is a flowchart to help categorize your BMP with one in BATT. The following pages also outline distinguishing characteristics for the structural and two non-structural BMPs.



Differentiating Characteristics for Structural BMPs in BATT

Infiltration Trench
Differentiating Characteristics: Infiltration into subsoils instead of redirection, Storage container (pipe, chamber, galley), provides temporary storage using void spaces
BMPs labeled as a trench:

- Porous pavement without impermeable liner
- Subsurface infiltration
- Tree filter
- Dry Well
- Leaching Catch Basin

Infiltration Basin
Differentiating Characteristics: Infiltration into subsoils instead of redirection; Stores runoff by standing water before infiltration
BMPs labeled as a basin:

- Bioretention areas
- Rain Gardens
- Wet Pond
- Dry Pond
- Gravel Wetland

Bioretention
Differentiating Characteristics: Primary removal mechanism is soil media filtering, Water passes through without retention, Shallow depressions that contain soil, plants, and microbes
BMPs labeled as bioretention:

- Biofiltration (w/underdrain)
- Rain Gardens (w/ underdrain)

Gravel Wetland
Differentiating Characteristics: Gravel Internal Storage Reservoir (ISR), Retention time of at least 24 hours

Enhanced Bioretention
Differentiating Characteristics: Primary removal mechanism is soil media filtering, Washed stone Internal Storage Reservoir (ISR), Retention time of at least 24 hours

Porous Pavement
Differentiating Characteristics: Porosity in paved surface allows filtration to an underdrain

Wet Pond/Created Wetland
Differentiating Characteristics: Primary removal mechanism is settling and vegetative treatment; Stormwater remains until displaced by incoming storm runoff

Dry Pond
Differentiating Characteristics: Stormwater treatment through limited settling, rapid displacement; No vegetation required
BMPs Labeled as Dry Pond:

Dry Detention Basin: Limited settling of sediments; designed to empty in less than 24 hours
Extended Dry Detention Pond: Provides a minimum detention time of 24 hours, removal of sediment can be enhanced with addition of shallow marshes, micropools, or forebays

Grass Swale
Differentiating Characteristics: Primary removal mechanism is conveyance: water must move across swale for treatment, Infiltration is a factor (Rate assumed in BATT)

Differentiating Characteristics for Non-Structural BMPs in BATT

Impervious Area Disconnection with Storage
Differentiating Characteristics: Primary mechanism is to collect runoff from an impervious area, storing it in a container, and releasing it to a pervious area after a time delay
BMPs Labeled as Impervious Area Disconnection with Storage:

Rain barrel
Cistern
Rainwater harvester

Impervious Area Disconnection without Storage
Differentiating Characteristics: Discharge of rainwater from an impervious area to a pervious area
BMPs Labeled as Impervious Area Disconnection without Storage:

Rain Gutter Downspout