# Demonstration of Opti-Tool:

# Buzzards Bay Watershed Case Study

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# Abstract

Managing nutrients in stormwater continues to be a high priority for Environmental Protection Agency (EPA) Region 1 and many of the New England states. Retrofitting existing development with stormwater controls to adequately reduce nutrient loadings presents both technical and economic challenges that require a comprehensive planning process. A watershed-scale, decision support system that is based on cost optimization is needed to developing the most cost effective program to achieve needed load reductions to be in compliance with permit requirements based on TMDLs or other watershed goals.

Consequently, EPA Region 1 has developed a spreadsheet-based Stormwater Management Optimization Tool (Opti-Tool) to assist stormwater managers in developing technically sound and economically feasible management plans to address stormwater impacts and reduce excessive nutrient loadings. Opti-Tool consists of a Microsoft-Excel platform and external EPA SUSTAIN BMP process and optimization modules. The user interacts with the Excel platform for data input, and can direct Excel to call the SUSTAIN module to estimate BMP performance and provide optimization at a given assessment point in the watershed.

The user-friendly Opti-Tool provides the ability to evaluate options for determining the best mix of structural BMPs in a particular geographic area to achieve quantitative water resource goals. The tool incorporates long-term runoff responses (Hydrologic Response Unit [HRU] timeseries) for regional climate conditions that are calibrated to regionally representative stormwater data and annual average load export rates from 9 major land uses. The tool includes regionally representative BMP cost functions and regionally calibrated BMP performance parameters for four pollutants, including total phosphorus (TP) and total nitrogen (TN), in order to calculate long-term cumulative load reductions for a variety of structural controls. Structural controls simulated by the tool include low impact development (LID) and green infrastructure (GI) practices, such as infiltration systems, bio-filtration, and gravel wetlands.

This document demonstrates the Opti-Tool's capabilities through a case study in a pilot watershed in southern New England. The selected pilot watershed (758 acres in size) is located in the Town of Fairhaven, MA, and drains to the Buzzards Bay Estuary. This Buzzards Bay case study had three primary objectives:

1. Develop a boundary condition using the calibrated SWMM model developed for Opti-Tool and using the local hourly precipitation and daily temperature data to represent site-specific loading and climate conditions.
2. Evaluate the trade-offs in cost and management performance between design standard criteria and an aggregated BMP optimization approach at the watershed scale, using the planning level mode in Opti-Tool.
3. Estimate the additional benefits of developing a cost and water quality performance curve (cost-effectiveness curve) for a more detailed spatial optimization approach at the land use level in the study watershed, using the implementation level mode in Opti-Tool.

This case study documents the various steps taken in developing this application to demonstrate three primary objectives.

The first objective demonstrates the development of the HRU timeseries for each land use category using the precipitation and temperature data collected at the New Bedford Airport gage. The Opti-Tool installation package includes calibrated HRU-SWMM models and step-by-step instructions through a HRU utility tool to apply the HRU-SWMM models using the local climate data. The HRU utility tool is used to reformat the SWMM model output timeseries into the format required for use with Opti-Tool in this case study.

The second objective evaluates two design scenarios to identify the BMP storage volume needed to meet a given design criterion (e.g., sized to hold 1 inch and 0.25 inch of runoff from the contributing impervious cover). Design storage capacities for holding 1 inch and 0.25 inches of runoff depth from 217.4 acres of impervious drainage yielded nitrogen load reductions of 44.8% and 29.9%, respectively, with associated BMP cost estimates of $18.25 million ($7,970/lb. N reduced) and $ 4.56 million ($1,190/lb. N reduced, respectively. In terms of evaluating the scenarios on a cost per pound of nitrogen reduced, the smaller design storage capacity is significantly more cost efficient. The optimized solution within the Planning Level Analysis to target the 29.9% TN load reduction, comprises a mixture of 3 BMP categories of different sizes for a cost of $4.31 million (a saving of $250,000).

The third objective develops a cost-effectiveness curve, which provides decision makers the opportunity to pick the most cost-effective solution for achieving reduction targets. An optimized solution for 29.9% TN load reduction target in the Implementation Level Analysis provides a more detailed mixture of 20 different BMP sizes for a total cost of $2.55 million and shows a $1.75 million saving over the optimized solution in the Planning Level Analysis.

The results of this case study provide quantitative technical guidance to support the watershed-based MS4 permit. The planning level mode is applied to look at the “bigger picture” of available management opportunities in the study area, while the more detailed Implementation Level Analysis mode demonstrates the power of optimization using more detailed information and analysis, culminating in the development of a cost-effectiveness curve showing a wide range of TN annual load reduction solutions and associated costs.

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# Acronyms and Abbreviations

| | |
|---|---|
| BMP | Best Management Practice |
| CE-Curve | Cost Effectiveness Curve |
| DEM | Digital Elevation Model |
| DSV | Design Storage Volume |
| EPA | United States Environmental Protection Agency |
| GI | Green Infrastructure |
| GIS | Geographic Information System |
| HRU | Hydrologic Response Unit |
| HSG | Hydrologic Soil Group |
| in. | Inches |
| ISR | Internal Storage Reservoir |
| lb | Pounds |
| LID | Low Impact Development |
| MA | Massachusetts |
| MS | Microsoft |
| MS4 | Municipal Separate Storm Sewer System |
| NCDC | National Climatic Data Center |
| NEP | Buzzards Bay National Estuary Program |
| NH | New Hampshire |
| NOAA | National Oceanic and Atmospheric Administration |
| NPDES | National Pollutant Discharge Elimination System |
| O&M | Operation and Maintenance |
| Opti-Tool | Stormwater Management Optimization Tool |
| PET | Potential Evapotranspiration |
| SUSTAIN | System for Urban Stormwater Treatment and Analysis Integration |
| SW | Stormwater |
| SWMM | Storm Water Management Model |
| TIC | Total Impervious Cover |
| TMDL | Total Maximum Daily Load |
| TN | Total Nitrogen |
| TP | Total Phosphorus |
| TSS | Total Suspended Solids |
| Zn | Zinc |

# 1. Introduction

Stormwater (SW) is a leading cause of poor water quality. Controlling and treating discharges of SW runoff involve reducing pollutant loads of nutrients, sediments and metals commonly found in SW runoff, as well as addressing excessive volumes of runoff that cause flooding.

Managing stormwater runoff, especially from highly developed urban areas, and designing SW controls can be technically difficult and costly. To address these issues, EPA Region 1 has developed the **Opti-Tool**, a spreadsheet-based stormwater best management practices optimization tool with two different design levels for use by municipal SW managers and their consultants. The tool supports development of technically sound, robust, and optimized cost-effective SW management plans, which are capable of demonstrating accountable progress and compliance with stormwater (MS4) permit requirements.

The user-friendly Opti-Tool provides the ability to evaluate options for determining the best mix of structural BMPs in a particular geographic area to achieve quantitative water resource goals. The tool incorporates long-term runoff responses (Hydrologic Response Unit [HRU] timeseries) for regional climate conditions that are calibrated to regionally representative stormwater data and annual average load export rates from 9 major land uses. The tool includes regionally representative BMP cost functions and regionally calibrated BMP performance parameters for four pollutants, including total phosphorus (TP) and total nitrogen (TN), in order to calculate long-term cumulative load reductions for a variety of structural controls. Structural controls simulated by the tool include low impact development (LID) and green infrastructure (GI) practices, such as infiltration systems, bio-filtration, and gravel wetlands.

The *Planning Level Analysis* in Opti-Tool provides an easy and quick way for managers and decision makers to develop and evaluate management scenarios for applying BMPs at the watershed-scale and determining simplified watershed-scale optimized solutions that identify the best mix of BMPs and associated design capacities to achieve a specified reduction pollutant target for the least cost. The MS Excel Solver quickly searches hundreds of possible BMP sizing combinations through the lookup function using the BMP performance curves developed for EPA Region 1. It must be noted that the land use specific annual loading rates and BMP specific performance curves have been calibrated to be representative of the New England Region. Opti-Tool can be readily adapted to represent site-specific loading and climate conditions at specific locations of interest both within and outside of the New England Region.

The *Implementation Level Analysis* in Opti-Tool provides stormwater engineers/professionals with a more detailed and flexible analysis tool to determine the best mix of structural BMPs for achieving watershed management goals and maximizing other ancillary environmental benefits, while also minimizing BMP costs. The resulting cost-effectiveness curve provides decision makers the opportunity to pick among the most cost-effective solutions for achieving a range of reduction targets. The watershed managers can also use this curve to identify the estimated costs associated with varying load reduction goals.

In order to illustrate a roadmap toward watershed management planning designed to meet watershed management goals including MS4 permit load requirements, EPA supported this case study in a pilot watershed in southern New England. The selected pilot watershed (758 acres in size) is located in the Town of Fairhaven, MA, and drains to the Buzzards Bay Estuary, see Figure 1. The Buzzards Bay Stormwater Collaborative program has a goal of identifying stormwater discharges that are contributing to shellfish bed closures and other pollutant impairments, including nitrogen, which is the nutrient that usually limits the growth of algae in estuarine and marine waters.

In this case study, the management objective of reducing stormwater nitrogen loads from the study area's watershed was used to demonstrate the functionality of the tool in both the Planning Level and Implementation Level Analysis modes. The planning level mode was applied to look at the "bigger picture" of available management opportunities in the study area, while the more detailed Implementation Level Analysis mode demonstrated the power of optimization using more detailed information and analysis, culminating in the development of a cost-effectiveness curve showing a wide range of TN annual load reduction solutions and associated costs.

This case study also demonstrates the development of the HRU timeseries for each land use category using local precipitation and temperature data representative of the study area. The Opti-Tool installation package includes calibrated HRU-SWMM models and step-by-step instructions through a HRU utility tool to apply the HRU-SWMM models using the local climate data. The HRU utility tool also reformats the SWMM model output timeseries into the format required for use with Opti-Tool.

This document includes 6 chapters starting with this *Introduction*, and followed by *2. Data Review*, *3. Develop Management Categories*, *4. Establish Baseline Conditions*, *5. Setup Opti-Tool*, and the *6. Summary of Case Study Results*. This document also provides step-by-step instructions for setting up the Opti-Tool for both the *Planning Level Analysis* and *Implementation Level Analysis*.

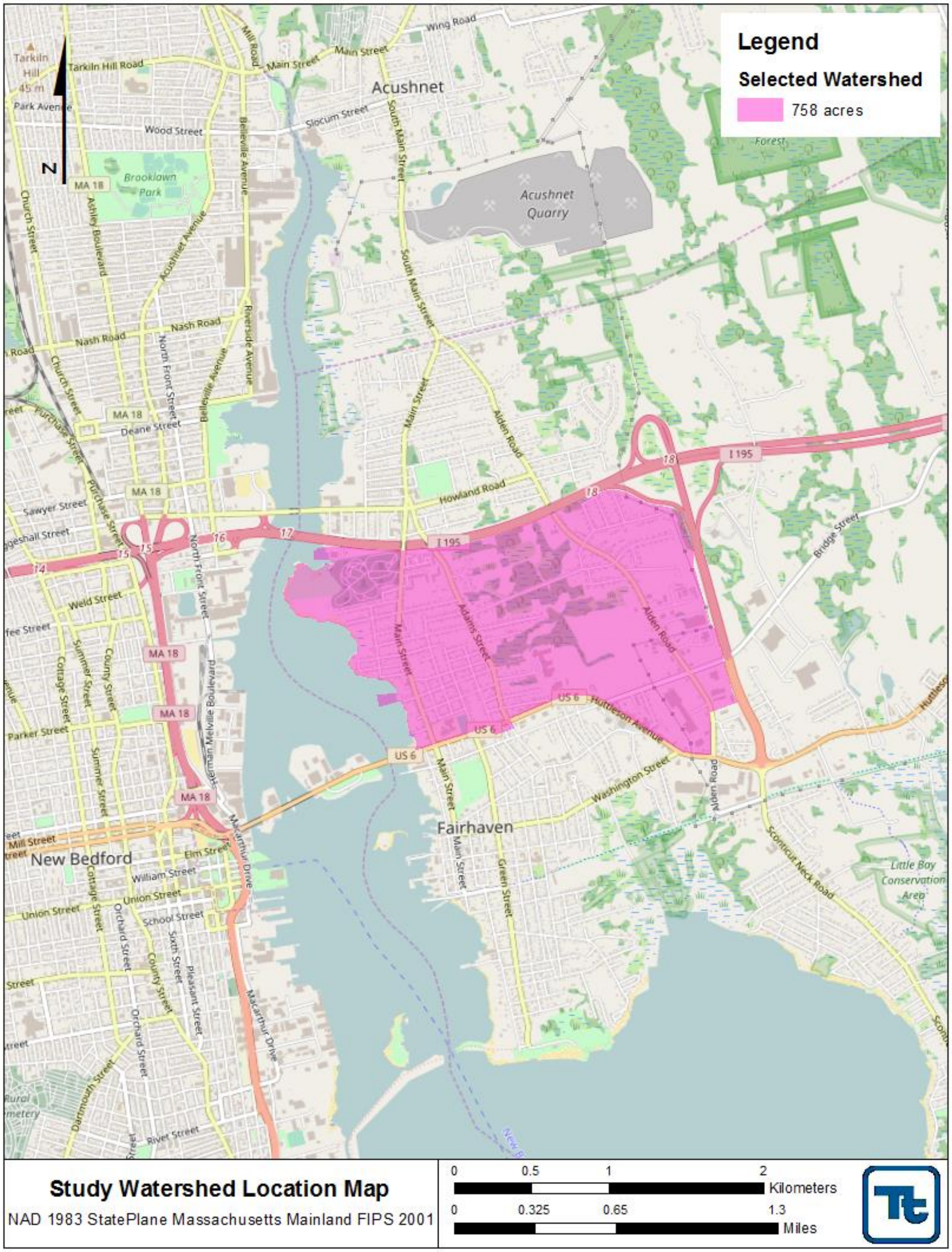



Figure 1. Selected pilot watershed location in the Town of Fairhaven, MA

# 2. Data Review

The data collection effort was carried out in collaboration with the Buzzards Bay National Estuary Program (NEP) and EPA Region 1. The following datasets were collected and reviewed for this case study.

## 2.1. GIS Data

The NEP provided the watershed boundaries, MA GIS land use coverage, impervious cover, Digital Elevation Model (DEM) for ground slopes, hydrologic soil group (HSG), depth to bedrock, and depth to groundwater.

The land use layer, from Massachusetts GIS, was classified into 10 land use category groups based on the land use mapping scheme used in Massachusetts MS4 (Municipal Separate Storm Sewer System) permit, see Table 1. The land use area distribution was estimated within the selected pilot watershed, see Table 2.

Figure 2 shows the spatial distribution of the land use categories in the study area. Forest is the dominant land cover (23%) followed by high density residential (20%), medium density residential (18%), commercial (15%), and open land (14%). There was no highway land use category within the study area.

Table 1. Cross-walk between Mass GIS Land Use Category and Land Use Category groups used in MA MS4 Permit.

| Mass GIS Land Use LU_CODE | Description | Land Use Category group used in MA MS4 Permit |
|---|---|---|
| 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 |

| Mass GIS Land Use LU_CODE | Description | Land Use Category group used in MA MS4 Permit |
|---|---|---|
| 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 | Brushland/Successional | Forest |

Table 2. Land use area distribution in the selected pilot watershed

| Land Use Category Group | Area (acres) |
|---|---|
| Forest | 174.07 |
| High Density Residential | 149.70 |
| Medium Density Residential | 137.64 |
| Commercial | 113.37 |
| Open Land | 108.71 |
| Low Density Residential | 22.69 |
| Industrial | 22.57 |
| Agriculture | 22.37 |
| Water | 7.30 |
| Highway | 0.00 |
| **Total** | **758.42** |

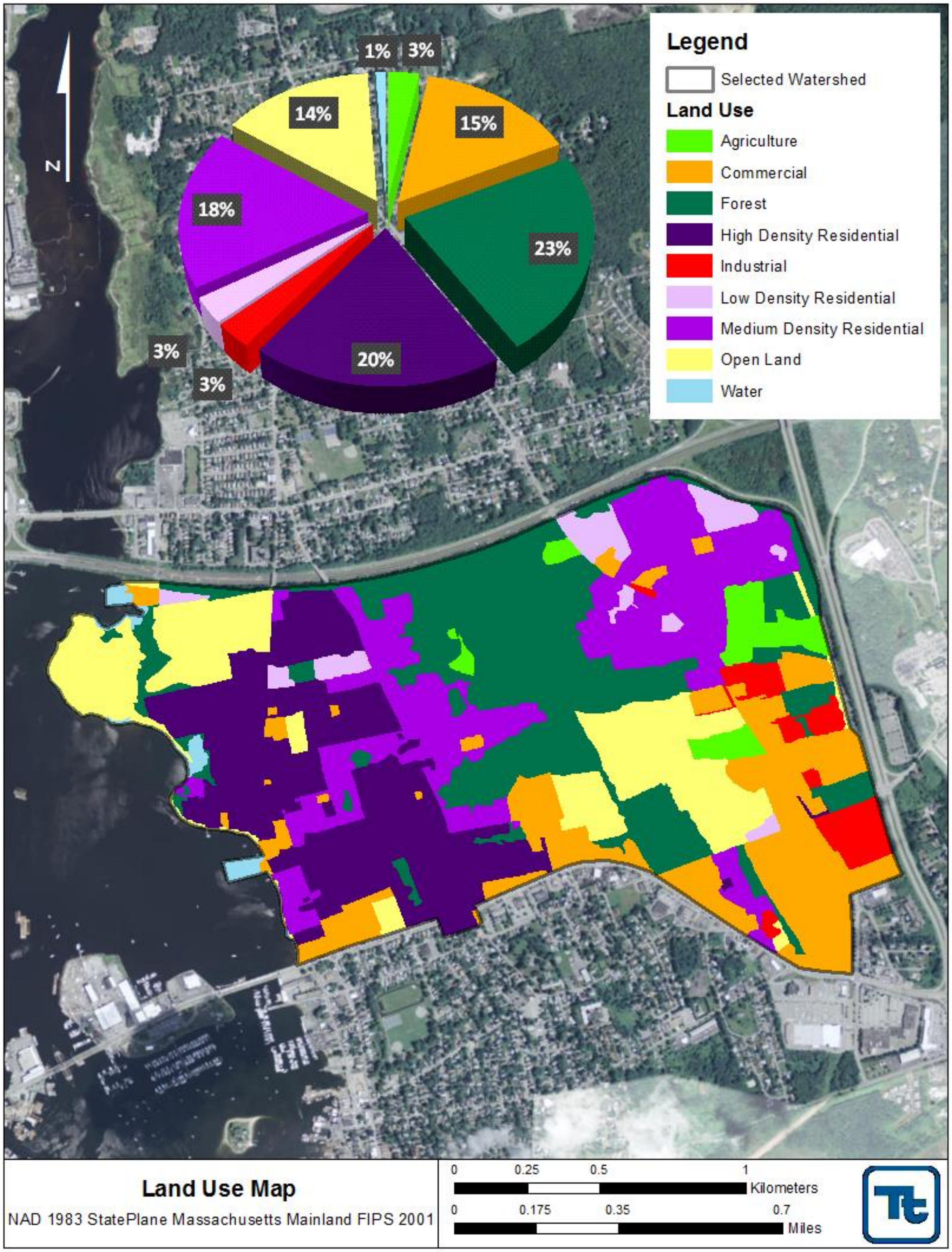



Figure 2. Land use distribution in the selected pilot watershed

The study watershed area of 758 acres is comprised of 217 acres or 29% of total impervious cover (TIC). Table 3 shows the TIC area distribution by land use category and Figure 3 shows the spatial distribution of TIC footprint in the study area. The commercial land use category has the highest TIC footprint (38% of TIC area in the watershed), followed by high density residential (27%), and medium density residential (17%) areas and consequently, are the dominant stormwater runoff and pollutant source areas in the watershed.

Table 3. Total Impervious Cover (TIC) area distribution by land use category in the selected pilot watershed

| Land Use Category Group | Impervious Area (acres) |
|---|---|
| Commercial | 83.40 |
| High Density Residential | 58.39 |
| Medium Density Residential | 36.22 |
| Open Land | 13.71 |
| Industrial | 13.57 |
| Forest | 4.45 |
| Low Density Residential | 4.15 |
| Agriculture | 3.51 |
| Highway | 0.00 |
| Water | 0.00 |
| **Total** | **217.40** |

Since the provided soil layer was missing the hydrologic soil group (HSG) information for some of the developed footprints in the study area, the project team collectively decided to classify such areas as HSG-D type with the assumption of urbanized compact soil type. The soil area distribution comprises 71 acres of HSG-B (9%), 405 acres of HSG-C (54%), and 282 acres of HSG-D (37%) in the selected pilot watershed, see Table 4. There was no HSG-A soil type in the study area. The soil layer shows that HSG-C is dominant in the study area, see Figure 4.

Table 4. Hydrologic Soil Group area distribution in the selected pilot watershed

| Hydrologic Soil Group | Area (acres) |
|---|---|
| HSG-A | 0.00 |
| HSG-B | 71.03 |
| HSG-C | 405.25 |
| HSG-D | 282.12 |

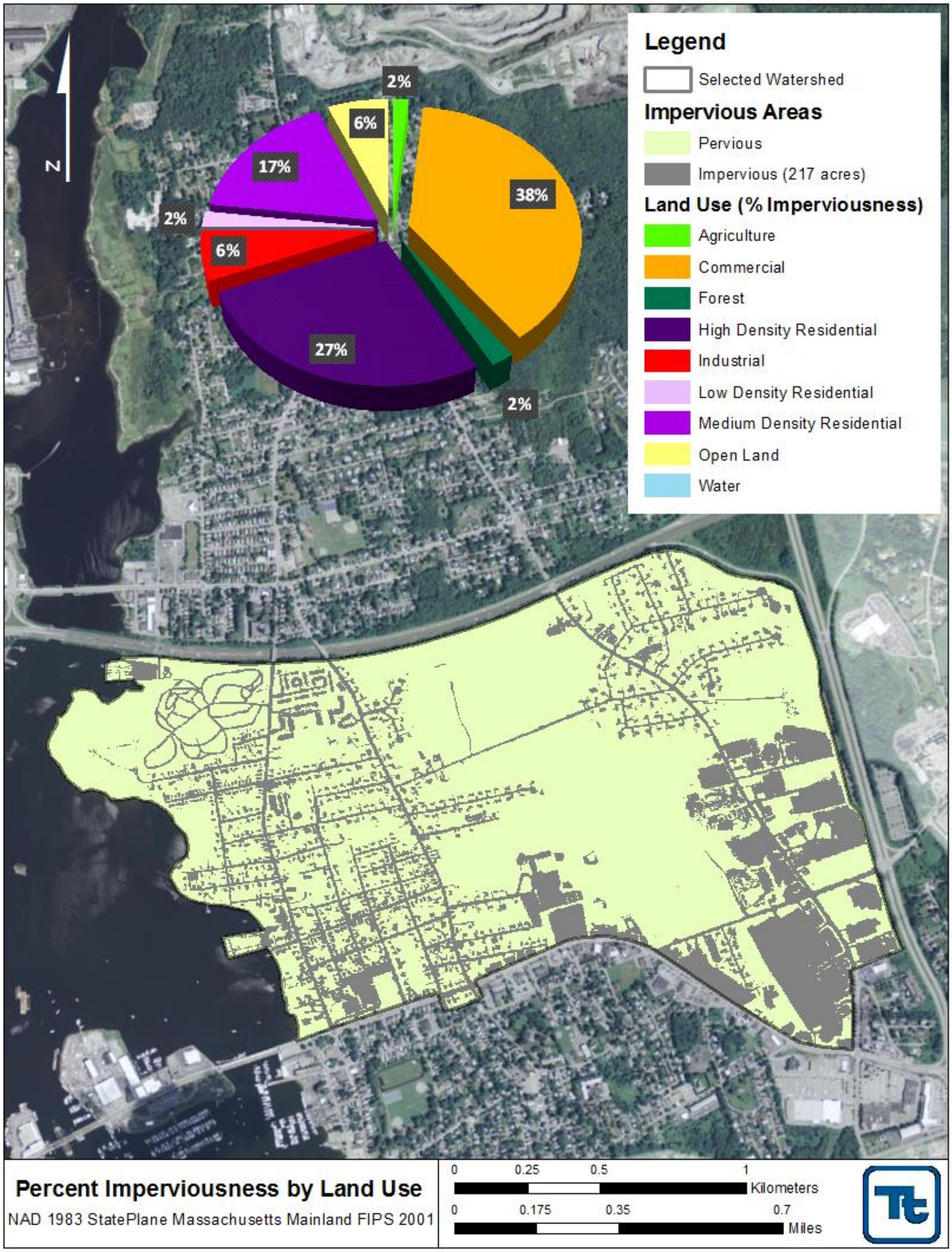



Figure 3. Impervious area distribution by land use in the selected pilot watershed

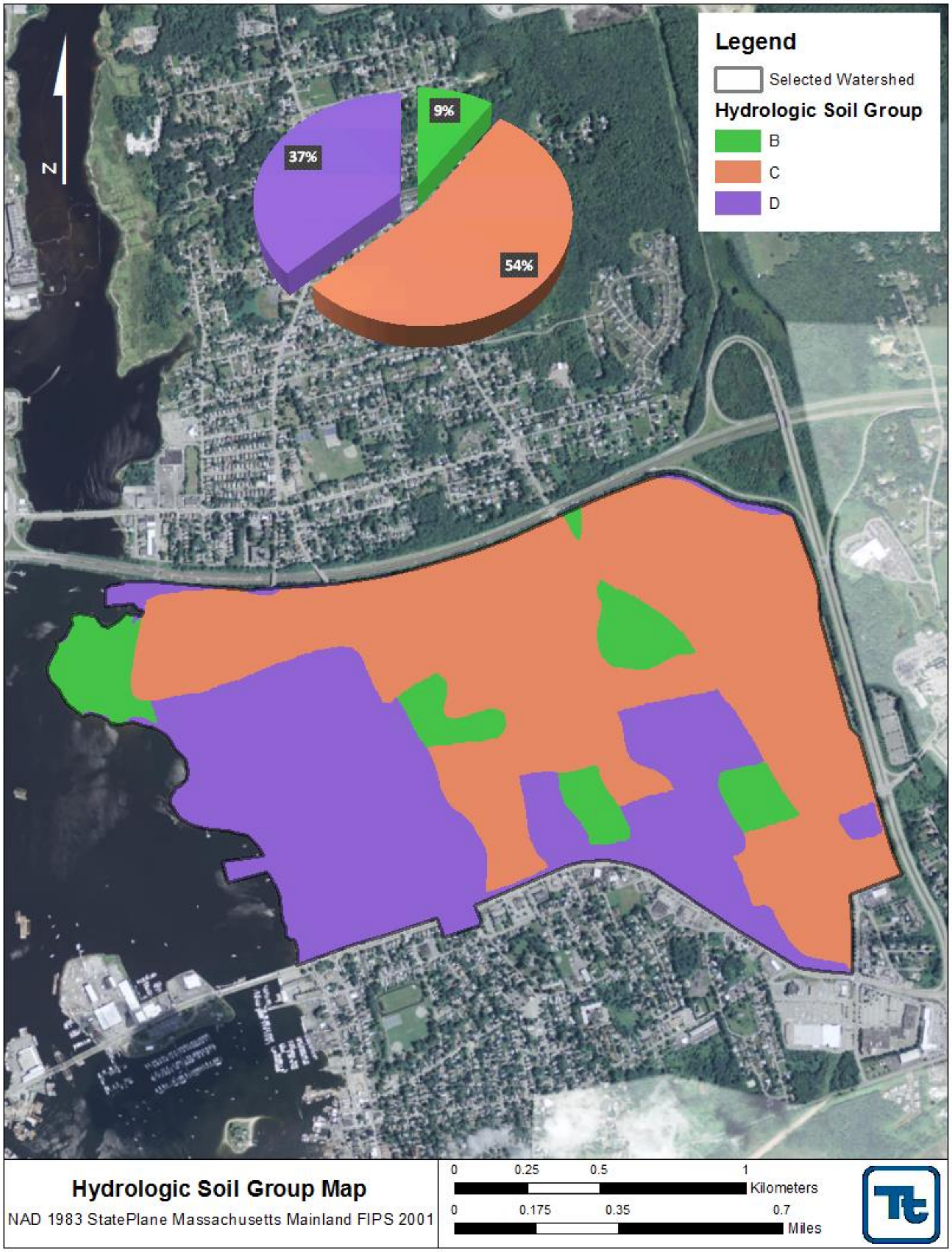



Figure 4. Hydrologic Soil Group (HSG) area distribution in the selected pilot watershed

## 2.2. Climate Data

The project team evaluated the local available weather data (provided by the Buzzards Bay NEP) and the national dataset (downloaded from NOAA website) for the quality and completeness of the records for the latest 10 years (2006 – 2015) at the New Bedford Airport location. Significant data gaps (missing records) were found in the local dataset as shown in Table 5. The NOAA dataset was found nearly complete as shown in Table 6. The hourly precipitation and daily minimum and maximum temperature data from National Climate Data Center were also selected for this case study. The selected data were further refined by filling the missing records and performing quality checks.

Table 5. The annual precipitation and percent missing data summary for the local gage (KEWB) at New Bedford Airport location (Utah Climate Center Datasets)

| Year | Total Precipitation (in./yr) | Percent Missing (%) |
|---|---|---|
| 2006 | 52.15 | 13.30% |
| 2007 | 35.04 | 27.00% |
| 2008 | 57.85 | 24.00% |
| 2009 | 51.12 | 28.00% |
| 2010 | 45.39 | 21.00% |
| 2011 | 50.90 | 06.00% |
| 2012 | 35.32 | 10.00% |
| 2013 | 35.52 | 22.00% |
| 2014 | 29.31 | 43.00% |
| 2015 | 21.62 | 36.00% |

Table 6. The annual precipitation and percent missing data summary for the NOAA gage (94726) at New Bedford Airport location (National Climate Data Center)

| Year | Total Precipitation (in./yr) | Percent Missing (%) |
|---|---|---|
| 2006 | 53.36 | 0.01% |
| 2007 | 42.89 | 0.01% |
| 2008 | 59.46 | 0.00% |
| 2009 | 57.54 | 0.01% |
| 2010 | 47.57 | 0.00% |
| 2011 | 53.50 | 0.00% |
| 2012 | 37.63 | 0.02% |
| 2013 | 44.88 | 0.00% |
| 2014 | 50.20 | 1.68% |
| 2015 | 40.29 | 0.00% |

The selected precipitation data were further summarized to look at the annual average and monthly average precipitation values. The results were compared with the NCDC gage at Logan Airport to check if the default data available in Opti-Tool would be appropriate to use for this case study. The storm separation analysis was also performed using 6 hour as minimum inter-event time and percentile rankings were determined for different storm sizes at New Bedford and Logan Airport locations, see Table 7.

Figure 5 below shows 48.76 inches of annual average precipitation for New Bedford Airport which is approximately 10% higher than the 43.35 inch of annual average precipitation at the Logan Airport gage. Figure 6 shows monthly precipitation comparison between these two gages.

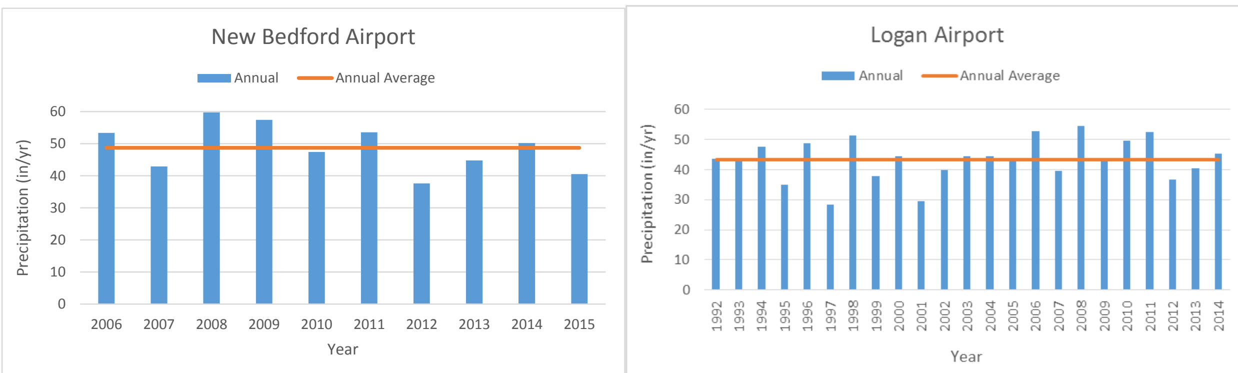



Figure 5. Annual precipitation comparison between New Bedford and Logan Airport gages

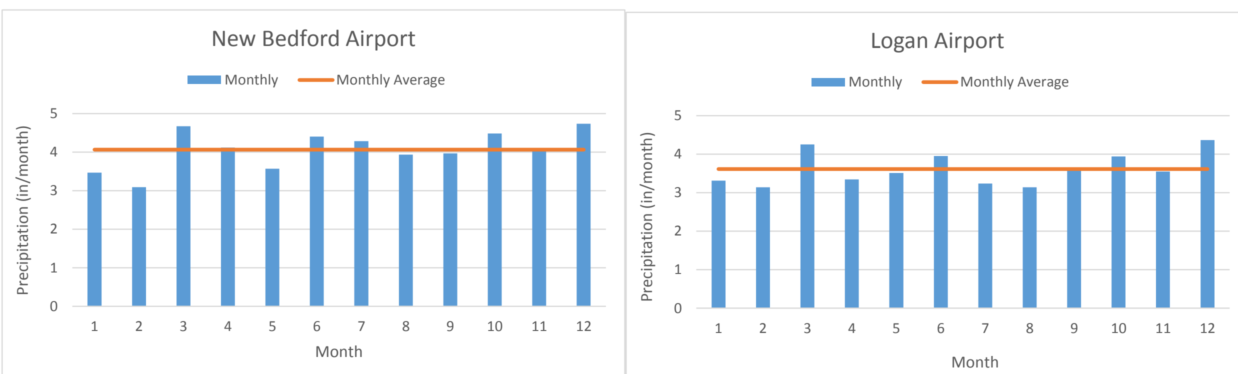



Figure 6. Monthly precipitation comparison between New Bedford and Logan Airport gages

Table 7 below shows the storm size distribution looks pretty similar at both locations.

Table 7. The storm size distribution comparison between New Bedford and Logan Airport gages

| Storm Size (in.) | Percentile Value at New Bedford Airport Gage | Percentile Value at Logan Airport Gage |
|---|---|---|
| 0.25 | 64% | 59% |
| 0.50 | 78% | 74% |
| 0.75 | 84% | 84% |
| 1.00 | 88% | 89% |

| Storm Size (in.) | Percentile Value at New Bedford Airport Gage | Percentile Value at Logan Airport Gage |
|---|---|---|
| 1.50 | 94% | 95% |
| 2.00 | 97% | 97% |
| 3.00 | 99% | 99% |

The daily minimum and maximum air temperature data are used in SWMM model to estimate the daily potential evapotranspiration (PET). Figure 7 and Figure 8 below show the annual average temperature and monthly average temperature comparisons at New Bedford and Logan Airport locations. The plots show that both locations have very similar patterns of daily air temperatures.

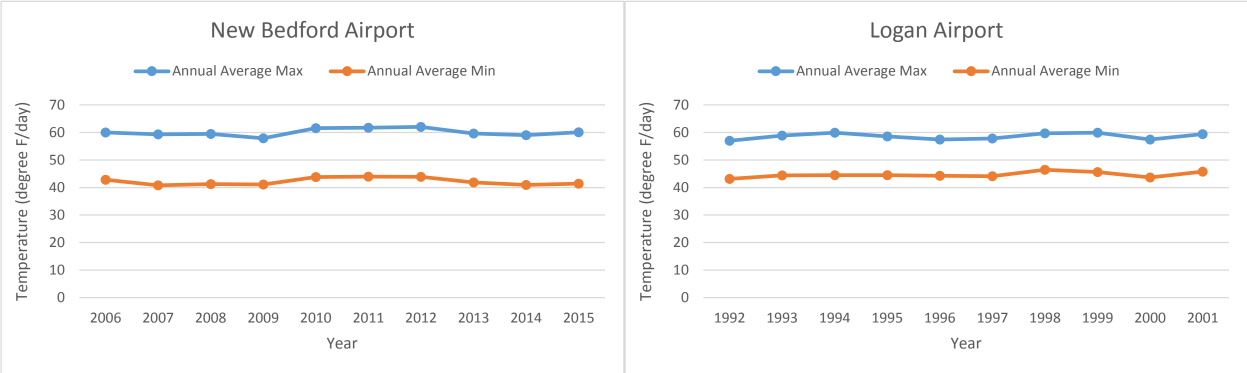



Figure 7. Annual average temperature comparison at New Bedford and Logan Airport locations

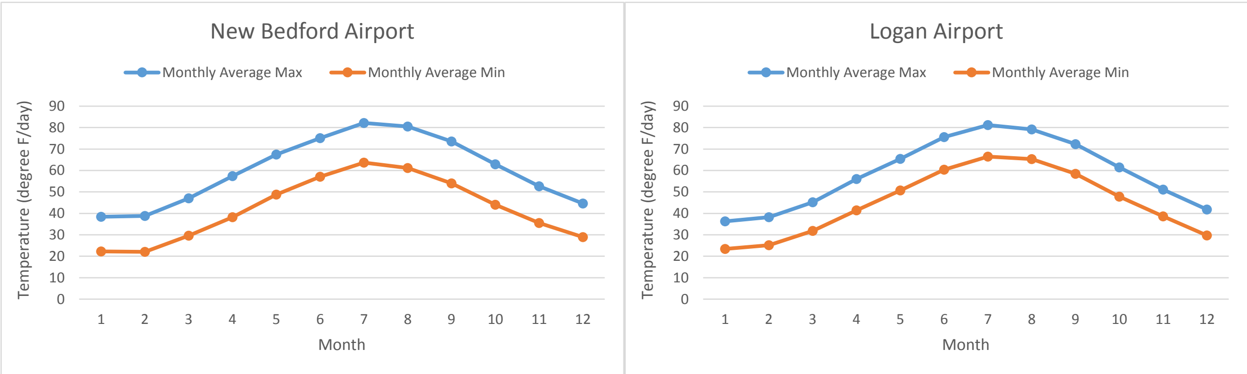



Figure 8. Monthly average temperature comparison at New Bedford and Logan Airport locations

## 2.3. Stormwater Quality Data

At the time of developing the case study, the Buzzards Bay Stormwater Collaboration was in the process of collecting and analyzing stormwater quality data collected for the region that encompasses the case study watershed. Consequently, the results of that data analysis were not available for consideration during the development of this case study. Therefore, the default stormwater quality information provided in the Opti-Tool was used for the case study.

The default stormwater quality data represented in Opti-Tool are considered to be generally representative of stormwater quality in the New England region. However, a user may adjust the quality represented in Opti-Tool by applying a pollutant load adjustment factor to each land use specific annual pollutant load export rates under "Watershed Information" section of planning level analysis. Similarly, a unit conversion factor for each pollutant can be applied to adjust the hourly quality in the HRU timeseries proportionally in the implementation level analysis mode.

It is worth noting that if local climate data are used with the provided HRU-SWMM models to develop localized HRU timeseries, as they were in this case study (described below in Chapter 4), then the stormwater quality simulated will be different than the default timeseries provided with Opti-Tool. Localized HRU timeseries will represent the local patterns of precipitation including dry periods between storm events when pollutants accumulate on impervious surfaces. Therefore, the localized timeseries will represent some of the key climate-related processes (e.g., build-up and wash-off of pollutants) that influence stormwater quality in an area.

# 3. Develop Management Categories

A GIS spatial data analysis was performed to identify potential storm water control technologies that would be technically feasible based on available GIS spatial data layers of land characteristics. Ground slope was derived from the Digital Elevation Model (DEM). Management categories were selected based on overlaying data layers associated with the following factors:

- Impervious cover;
- MS4 land use categories
- Ground slope;
- Hydrologic soil group;
- Depth to ground water; and
- Depth to bedrock.

For this case study, management categories were only considered for areas with pervious cover based on the suitability of site conditions for BMPs to treat stormwater runoff from impervious cover and reduce nitrogen loads, see Table 8 below.

The management categories option using the impervious cover could also be considered in future analysis which includes; eliminating the paved surfaces and restoring the underlying high infiltration pervious soil, installing subsurface infiltration facilities, and green street programs. These practices are costly as compared to the structural practices on the pervious cover but could be beneficial where opportunity space is limited and in terms of treating the direct source areas such as green streets practices (porous pavements and bioretention cells within road right-of-ways) adapted in southern California to reduce Zinc load, required under metal TMDL.

Table 8. Management categories defined on the basis of site conditions.

| Condition | Depth to Water Table (ft) | Depth to Bedrock (ft) | Ground Slope (%) | HSG | BMP Type in Opti-Tool | Management Category |
|---|---|---|---|---|---|---|
| 1 | > 6.5 | < 2.5 | <= 15 | A/B/C/D | Enhanced Bio-filtration (with ISR) | Shallow filtration-A/B/C/D |
| 2 | | | > 15 | -- | -- | Less likely for onsite BMP |
| 3 | | 2.5 ~ 6.5 | <= 15 | A/B/C | Bioretention with no underdrain | Infiltration-A/B/C |
| 4 | | | | D | Enhanced Bio-filtration (with ISR) | Bio-filtration w/ ISR |
| 5 | | | > 15 | -- | -- | Less likely for onsite BMP |
| 6 | | > 6.5 | <= 15 | A | Surface Infiltration Basin | Infiltration-high-A |
| 7 | | | | B | | Infiltration-high-B |
| 8 | | | | C | | Infiltration-high-C |
| 9 | | | | D | Gravel Wetland | Bio-filtration w ISR or Gravel Wetland system |
| 10 | | | > 15 | -- | -- | Less likely for onsite BMP |
| 11 | 2.5 ~ 6.5 | < 2.5 | <= 15 | A/B/C/D | Enhanced Bio-filtration (with ISR) | Shallow filtration-A/B/C/D |
| 12 | | | > 15 | -- | -- | Less likely for onsite BMP |
| 13 | | 2.5 ~ 6.5 | <= 15 | A/B/C | Bioretention with no underdrain | Infiltration-A/B/C |
| 14 | | | | D | Enhanced Bioretention (with ISR) | Bio-filtration -D |
| 15 | | | > 15 | -- | -- | Less likely for onsite BMP |
| 16 | | > 6.5 | <= 15 | A/B/C | Bioretention with no underdrain | Infiltration-A/B/C |

| Condition | Depth to Water Table (ft) | Depth to Bedrock (ft) | Ground Slope (%) | HSG | BMP Type in Opti-Tool | Management Category |
|---|---|---|---|---|---|---|
| 17 | | | | D | Gravel Wetland | Bio-filtration-D or Gravel wetland |
| 18 | | | > 15 | -- | -- | Less likely for onsite BMP |
| 19 | < 2.5 | -- | <= 15 | A/B/C/D | Enhanced Bio-filtration (with ISR) | Shallow filtration-A/B/C/D |
| 20 | | | > 15 | -- | -- | Less likely for onsite BMP |

Based on the GIS data analysis using the criteria shown in Table 8 above, three management categories were identified as potential BMP opportunities in the study area (known to be highly effective at reducing nitrogen loads) and are shown in Table 9 below.

Table 9. Potential management categories identified in the study area.

| Management Category | BMP Type Available in Opti-Tool |
|---|---|
| High Infiltration on B soil | Infiltration Basin (e.g., rain gardens) |
| Shallow Filtration on C/D soil | Enhanced Bio-filtration with internal storage reservoir (ISR) |
| Bio-filtration on D soil | Gravel Wetland |

Distribution of the potential BMP opportunity area (BMP footprints) was estimated by land use category group and is summarized in Table 10 below. Note that this distribution represents the maximum footprints available in the selected watershed, and these numbers are purely based on GIS spatial data analysis, and do not necessarily represent the actual opportunity areas. For this case study, *no field verification was performed* and maximum opportunity areas were set to limit the BMP footprints needed to capture up to 1 inch of runoff from the impervious drainage areas. The total impervious areas by land use group shown in Table 3 above were proportionally distributed to the BMP drainage areas based on the available percentage of opportunity area of that specific BMP type by land use type as determined through the Management Category analysis. For example, if the opportunity area of Enhanced Bio-filtration with ISR is 20% of the total available opportunity area in commercial land, then 20% of the impervious area in the commercial land were treated by Enhanced Bio-filtration located in commercial land.

Table 10. Potential BMP opportunity area (maximum footprints) distribution by land use category group in the selected pilot watershed

| Land Use Category Group | Enhanced Bio-filtration (acre) | Gravel Wetland (acre) | Infiltration Basin (acre) |
|---|---|---|---|
| Agriculture | 0.00 | 0.00 | 2.04 |
| Commercial | 13.00 | 0.83 | 9.91 |

| Land Use Category Group | Enhanced Bio-filtration (acre) | Gravel Wetland (acre) | Infiltration Basin (acre) |
|---|---|---|---|
| Forest | 0.00 | 2.53 | 18.19 |
| High Density Residential | 12.41 | 0.18 | 62.23 |
| Highway | 0.00 | 0.00 | 0.00 |
| Industrial | 6.05 | 0.00 | 1.49 |
| Low Density Residential | 9.64 | 1.72 | 3.98 |
| Medium Density Residential | 48.87 | 15.43 | 18.12 |
| Open Land | 20.53 | 24.96 | 17.02 |
| Water | 0.00 | 0.00 | 0.00 |
| **Totals** | **110.10** | **45.65** | **132.98** |

Almost 90 percent of the storms are less than or equal to 1-inch depth in the study watershed, see Table 7 above. Therefore, a runoff depth from impervious cover of 1-inch was selected as a design criterion for limiting the maximum BMP storage capacity and maximum BMP footprint area needed. Table 11 shows the BMP area distribution (footprints) by land use category group required to treat 1-inch of runoff from the impervious land cover. Table 12 shows the impervious drainage areas by land use group and BMP type. Figure 9 shows the spatial extent of maximum BMP opportunity areas available in the study watershed.

Table 11. BMP area (footprints) distribution by land use category group required to treat 1 inch of runoff from the impervious surface

| Land Use Category Group | Enhanced Bio-filtration (acre) | Gravel Wetland (acre) | Infiltration Basin (acre) |
|---|---|---|---|
| Agriculture | 0.00 | 0.00 | 0.09 |
| Commercial | 1.67 | 0.12 | 0.91 |
| Forest | 0.00 | 0.02 | 0.10 |
| High Density Residential | 0.35 | 0.01 | 1.26 |
| Highway | 0.00 | 0.00 | 0.00 |
| Industrial | 0.40 | 0.00 | 0.07 |
| Low Density Residential | 0.10 | 0.02 | 0.03 |
| Medium Density Residential | 0.78 | 0.28 | 0.21 |
| Open Land | 0.16 | 0.23 | 0.10 |
| Water | 0.00 | 0.00 | 0.00 |

Table 12. BMP-treated impervious area (drainage area) distribution by land use category group

| Land Use Category Group | Enhanced Bio-filtration (acre) | Gravel Wetland (acre) | Infiltration Basin (acre) |
|---|---|---|---|
| Agriculture | 0.00 | 0.00 | 3.51 |
| Commercial | 45.66 | 2.92 | 34.82 |
| Forest | 0.00 | 0.54 | 3.90 |

| Land Use Category Group | Enhanced Bio-filtration (acre) | Gravel Wetland (acre) | Infiltration Basin (acre) |
|---|---|---|---|
| High Density Residential | 9.69 | 0.14 | 48.56 |
| Highway | 0.00 | 0.00 | 0.00 |
| Industrial | 10.89 | 0.00 | 2.68 |
| Low Density Residential | 2.61 | 0.47 | 1.08 |
| Medium Density Residential | 21.48 | 6.78 | 7.96 |
| Open Land | 4.50 | 5.47 | 3.73 |
| Water | 0.00 | 0.00 | 0.00 |

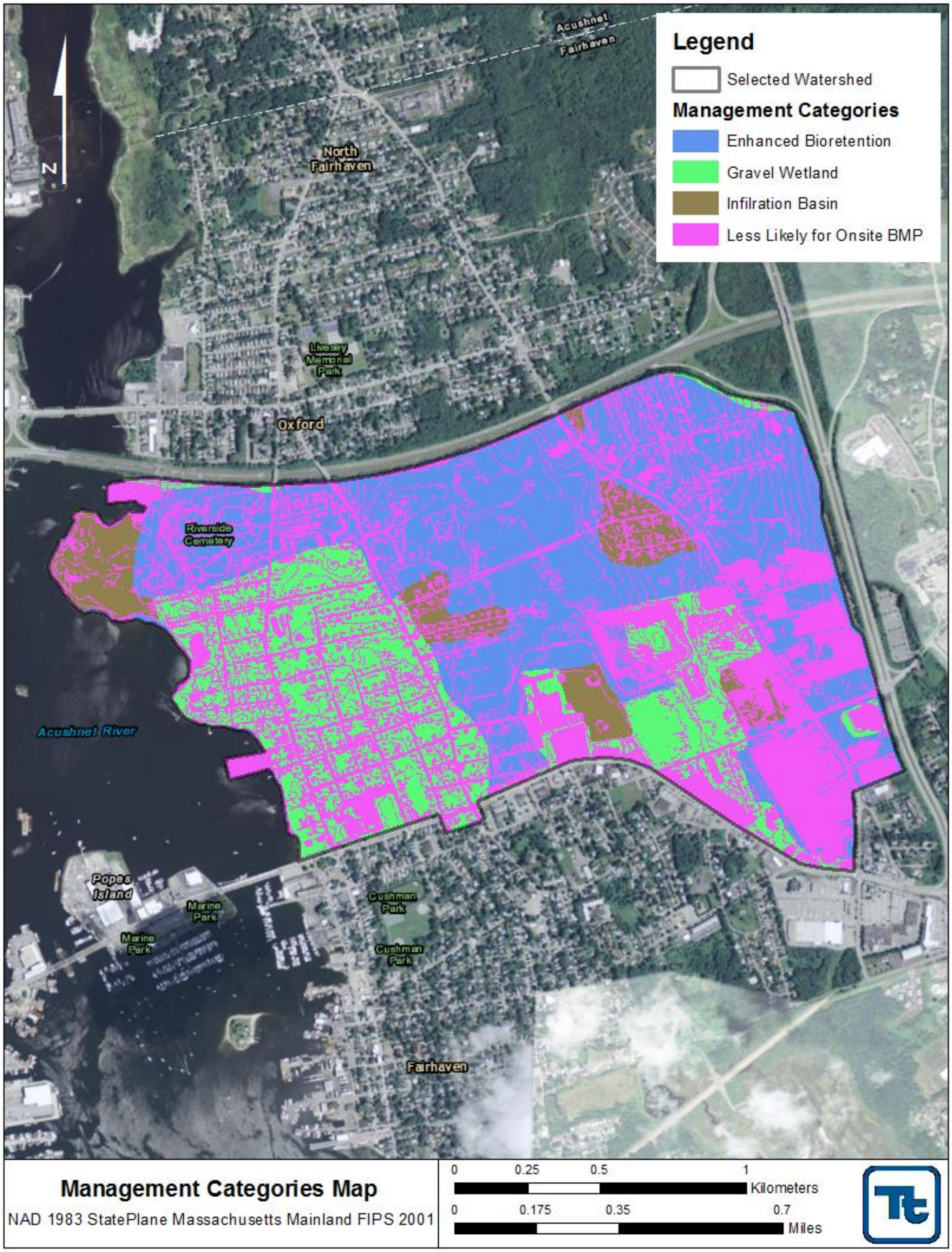



Figure 9. GIS-based Management Categories map (BMP opportunity areas)

# 4. Establish Baseline Conditions

One of the most import steps in stormwater management planning is establishing the baseline conditions. All management scenarios developed using the Opti-Tool estimate the load reductions based on the baseline loading in the study watershed. The climate data are the main drivers for generating stormwater runoff and transporting pollutants from impervious and pervious areas within a watershed. The Opti-Tool provides the rainfall-runoff response timeseries of hourly surface runoff volumes and concentrations for TN, TP, zinc (Zn), and solids (TSS) based on hydrologic and water quality modeling using the Storm Water Management Model (SWMM) and climatic data from the Logan Airport station for the land use categories identified in Table 2 (except for water). As discussed under data review (section 2.1), the spatial landscape was classified into ten major land use category groups. Those land use groups encompassed stormwater and non-point sources in the watershed.

As part of developing the BMP performance curves for EPA Region 1 (see *https://www3.epa.gov/region1/npdes/stormwater/assets/pdfs/BMP-Performance-Analysis-Report.pdf*), precipitation data analyses were conducted using long-term precipitation data from 10 locations located across the New England Region. Based on the results of this analysis, it was determined that precipitation patterns, in terms of the distributions of storm events by depth and inter-event dry periods, are very similar throughout the New England region. These precipitation characteristics are the primary factors that determine both stormwater quality and overall cumulative performances of BMPs. Because of the similarity in precipitation patterns across New England, EPA generally considers the default HRU timeseries provided with Opti-Tool to be reasonably representative of precipitation conditions in many areas of New England, especially when being used for conducting management analyses that focus on achieving relative percent (%) pollutant load reductions from the study area. In other words, use of the default Opti-Tool loading information should yield meaningful results about the management opportunities needed for achieving percent reductions.

Based on the climate data review (section 2.2), the summary tables show generally similar weather patterns between the Logan Airport gage (default in Opti-Tool) and the New Bedford Airport gage in terms of annual/monthly total precipitation, the storm depth distribution, and the annual/monthly average air temperature. It is expected that the slightly higher annual rainfall of 10% at the New Bedford gage would result in similarly higher annual stormwater nitrogen loads from the various land use groups than in the Boston area. For the case study watershed, New Bedford Airport gage was chosen for the precipitation and temperature data to develop HRU timeseries to better estimate overall annual stormwater nitrogen loads from the watershed area, as well as for demonstrating how to use local climatic data in an Opti-Tool analysis

The Opti-Tool installation package provides Hydrologic Response Unit (HRU)-SWMM models configured for a unit land-area (1 acre) for each of the land use categories (impervious cover and pervious cover), to develop rainfall-runoff response, using the Logan Airport climate data. The user needs to change the file paths for the precipitation and temperature data files in the SWMM model input file, see Figure 10. The installation package also includes a utility tool that converts the SWMM model output timeseries (i.e., hourly flow and pollutant concentrations) into the required format for the Opti-Tool. The utility tool provides the step-by-step instructions on downloading the local climate data, updating the provided SWMM models to use the local climate data, and to post process the SWMM-HRU timeseries output into the format required for the Opti-Tool, see Figure 11 and Figure 12. The utility tool also summarizes the HRU timeseries data and generates summary table for the annual flow rate and pollutant loading rate by land use categories used in the Opti-Tool, see Figure 13.

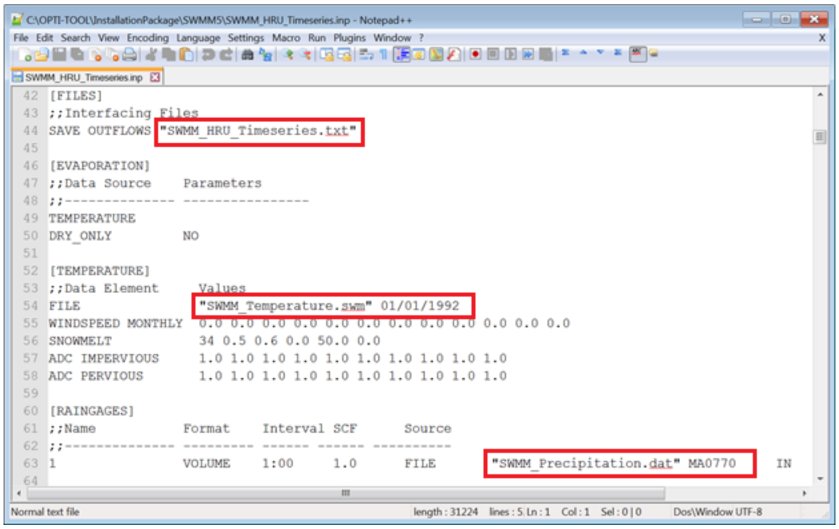


Figure 10. HRU-SWMM model input file.

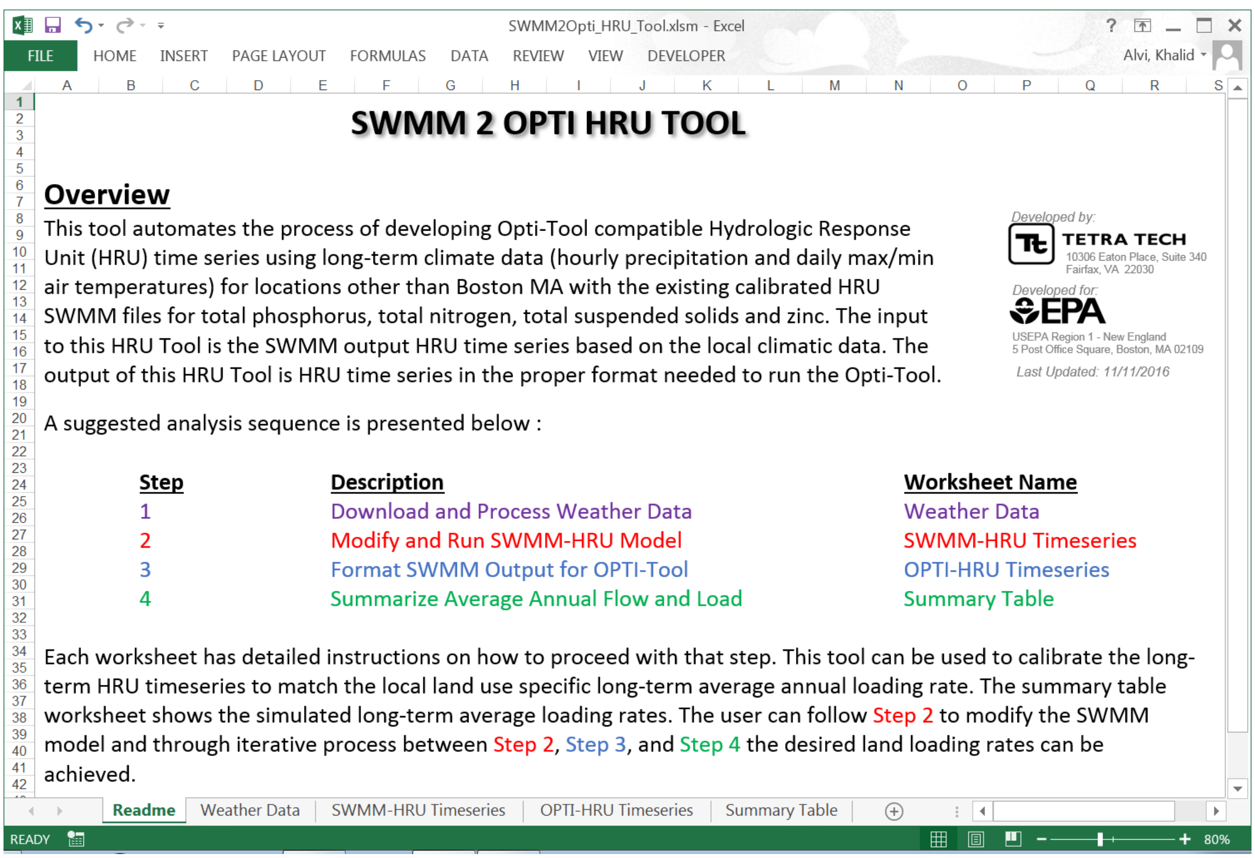


Figure 11. Instruction page (Readme tab) for the SWMM2OPTI HRU tool.

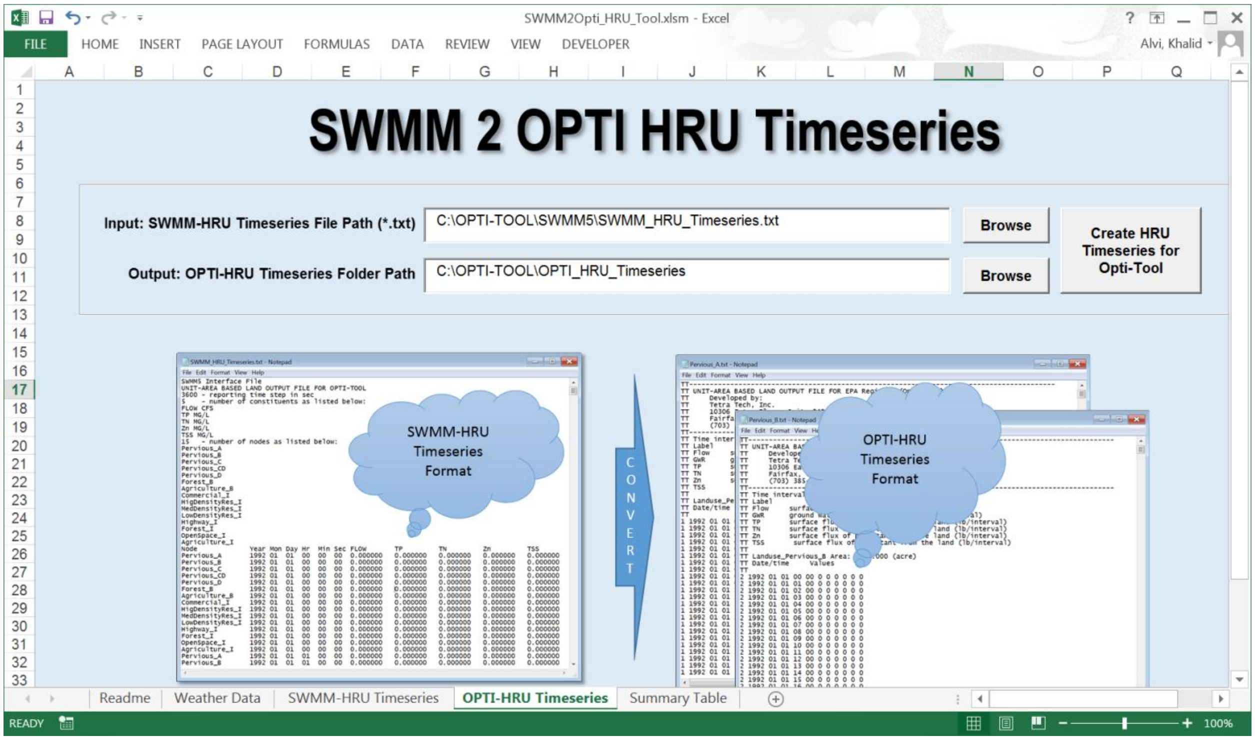
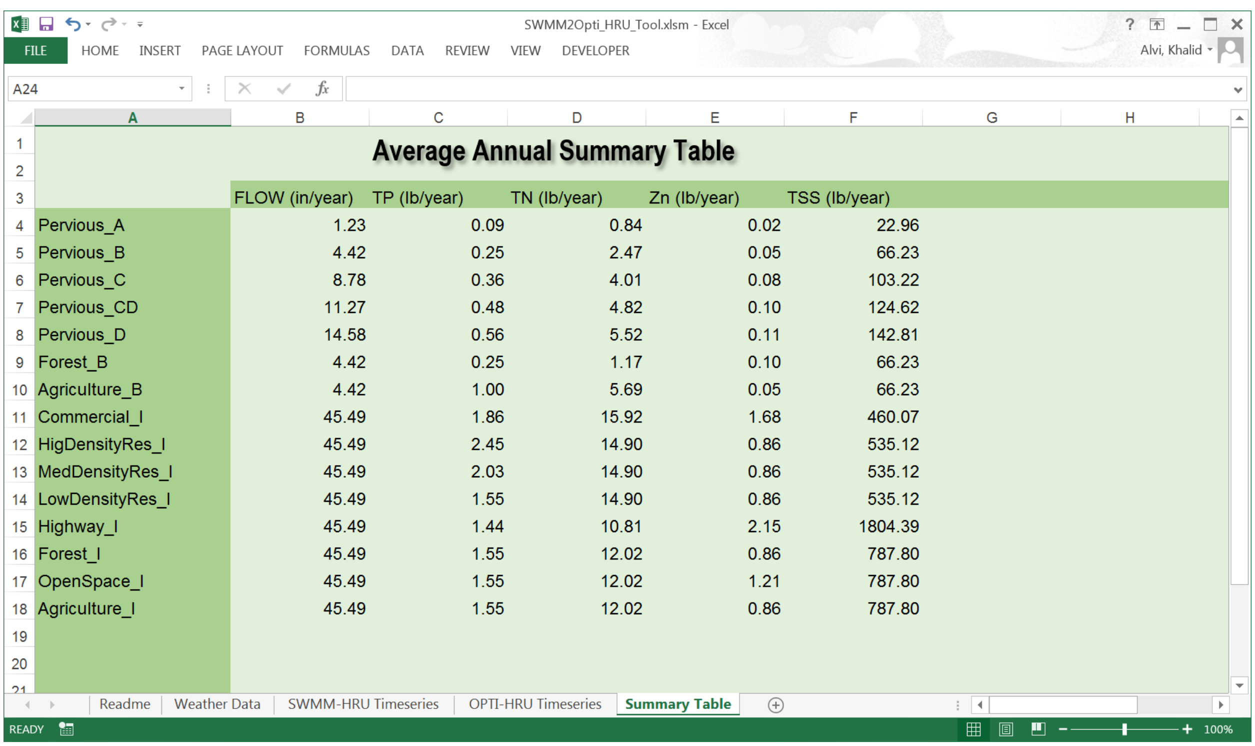



Figure 12. Main interface (Opti-HRU timeseries tab) for the SWMM2OPTI HRU tool



Average Annual Summary Table

| | FLOW (in/year) | TP (lb/year) | TN (lb/year) | Zn (lb/year) | TSS (lb/year) |
|---|---|---|---|---|---|
| Pervious_A | 1.23 | 0.09 | 0.84 | 0.02 | 22.96 |
| Pervious_B | 4.42 | 0.25 | 2.47 | 0.05 | 66.23 |
| Pervious_C | 8.78 | 0.36 | 4.01 | 0.08 | 103.22 |
| Pervious_CD | 11.27 | 0.48 | 4.82 | 0.10 | 124.62 |
| Pervious_D | 14.58 | 0.56 | 5.52 | 0.11 | 142.81 |
| Forest_B | 4.42 | 0.25 | 1.17 | 0.10 | 66.23 |
| Agriculture_B | 4.42 | 1.00 | 5.69 | 0.05 | 66.23 |
| Commercial_I | 45.49 | 1.86 | 15.92 | 1.68 | 460.07 |
| HigDensityRes_I | 45.49 | 2.45 | 14.90 | 0.86 | 535.12 |
| MedDensityRes_I | 45.49 | 2.03 | 14.90 | 0.86 | 535.12 |
| LowDensityRes_I | 45.49 | 1.55 | 14.90 | 0.86 | 535.12 |
| Highway_I | 45.49 | 1.44 | 10.81 | 2.15 | 1804.39 |
| Forest_I | 45.49 | 1.55 | 12.02 | 0.86 | 787.80 |
| OpenSpace_I | 45.49 | 1.55 | 12.02 | 1.21 | 787.80 |
| Agriculture_I | 45.49 | 1.55 | 12.02 | 0.86 | 787.80 |

Figure 13. Summary table for land use specific annual average loading rates derived from the long term HRU timeseries

# 5. Setup Opti-Tool

The only required inputs for Opti-Tool are: (1) Land use area distribution within the study area to estimate the existing loads; and (2) Drainage areas by land use tributary to the selected BMPs to estimate the load reductions. The following default dataset in the Opti-Tool should be updated to the site specific condition if the rainfall pattern and/or BMP cost information is notably different than the New England Region.

- HRU land use timeseries (hourly flow and pollutant loading from one acre of pervious or impervious land);
- Annual pollutant load export rates as determined by HRU development
- BMP cost information

The optimization scheme uses the existing loading as the baseline to estimate the benefits in terms of load reduction due to different BMP combinations selected under each optimized scenario, and compares the cost per load reduced among the scenarios to identify the most cost-effective solution. There are two levels of analysis available in Opti-Tool that can be used independently or in a sequential and coordinated manner: (1) Planning Level Analysis; and (2) Implementation Level Analysis. The Planning Level Analysis is intended to guide the user in identifying the "big picture" SW management opportunities that may exist in the study area, and which may be further evaluated in the more detailed Implementation Level Analysis mode. The Implementation Level Analysis in Opti-Tool provides the capability to incorporate much greater detail into the analysis including representation of spatially distributed watershed characteristics, flow routing and BMP designs. This level of analysis is designed to help stormwater engineers determine the best mix of structural BMPs to provide the greatest benefit for achieving watershed management goals while minimizing the BMP costs. Figure 14 shows the comparison between the planning level and implementation level analyses.

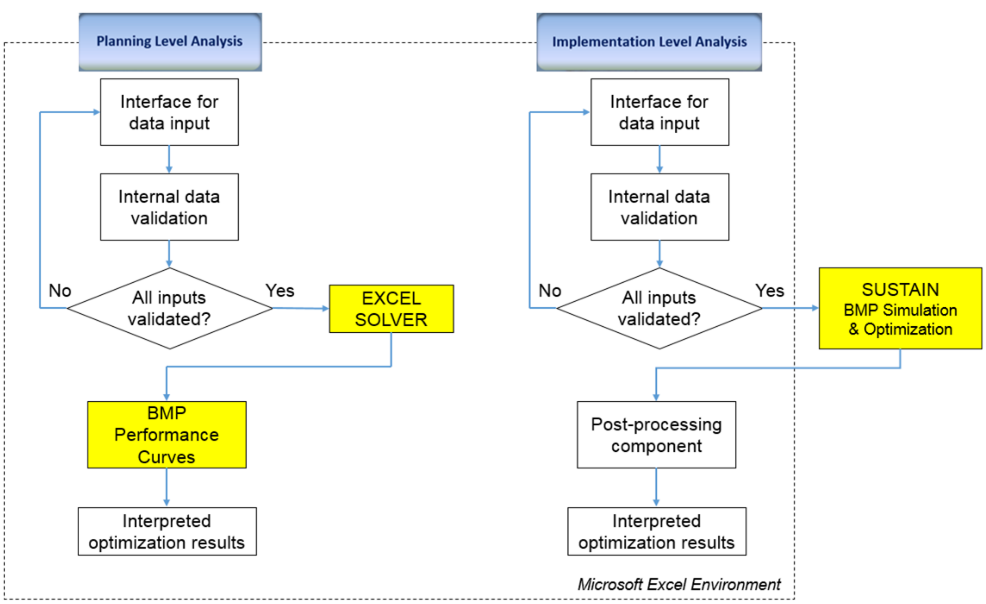



Figure 14. Flow chart comparison of Planning Level and Implementation Level analysis

The tool has built-in checks for the user input data and prompts the user to enter a valid data in case of missing or invalid entry. Figure 15 shows the main interface of the tool for selecting either Planning Level Analysis option or Implementation Level Analysis option.

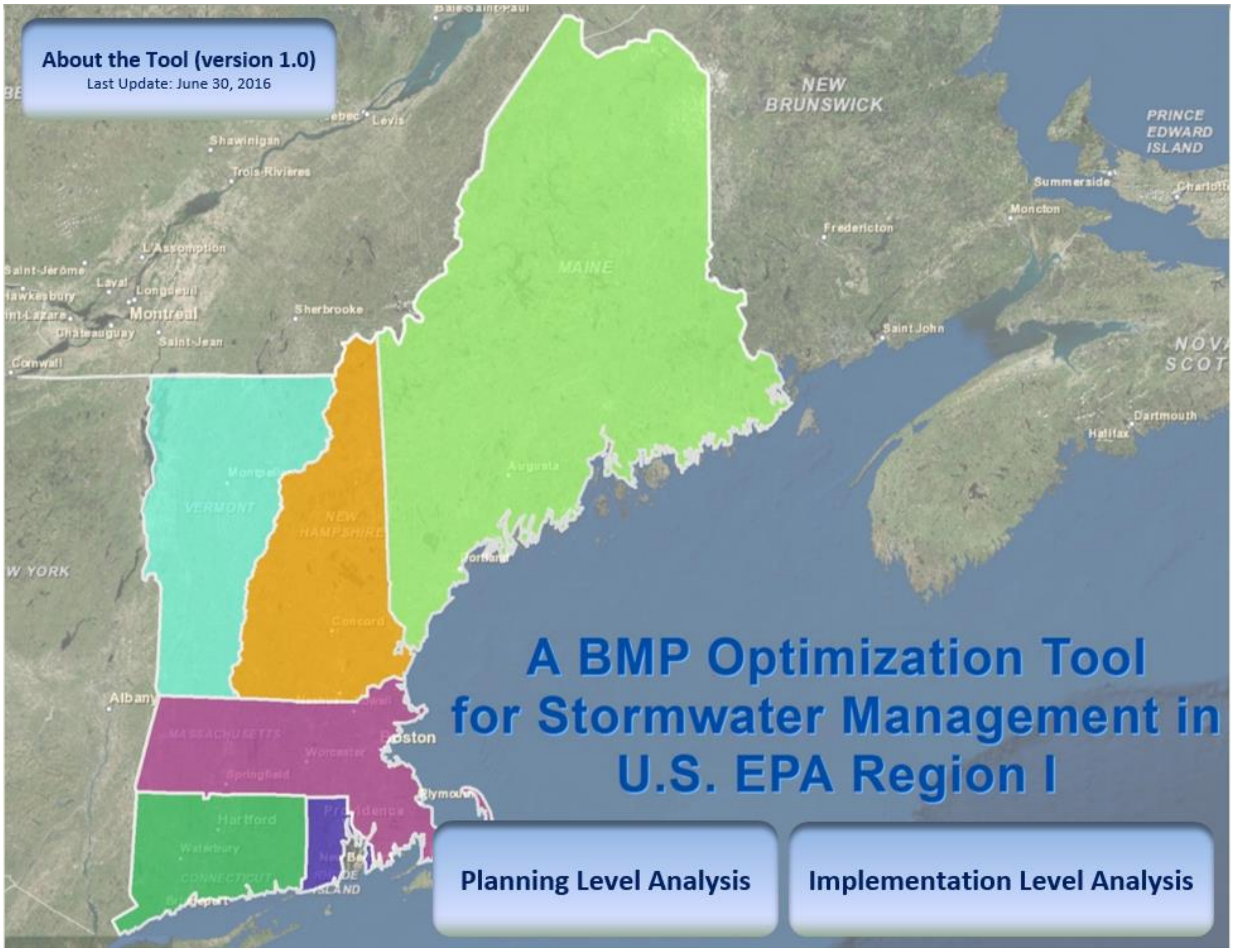



Figure 15. The Opti-Tool Home page

In this case study, an aggregate BMP approach at the watershed scale was used in which one BMP for each Management Category, previously deemed suitable for BMP implementation, was applied to estimate the load reductions from treating stormwater runoff from impervious cover from the different stormwater and non-point sources (land uses). A total of 20 BMPs comprised of 3 different types were selected to treat runoff from impervious cover from 8 land use categories (see Table 9).

## 5.1. Planning Level Analysis

The purpose of the Planning Level Analysis is to quickly evaluate multiple design scenarios with minimum data requirements, and compare them without running the continuous BMP simulation mode in the more detailed Implementation Level Analysis mode. Two design scenarios were evaluated to identify overall BMP storage volumes for specified design sizing criteria and the corresponding pollutant load reductions. BMPs were sized to hold 1 inch and 0.25 inch of runoff from the contributing impervious cover. Analyzing large and small design capacities in this first step was intended to help inform the user on a range of relative costs ($) and maximum load reductions (%) achievable for given design BMP capacities in the case study watershed. Next, an optimized scenario was developed to identify the best combination of BMP and associated capacities needed at the watershed scale to meet a given numeric load reduction target (%TN removal from the entire study area).

The Planning Level Analysis option uses the annual pollutant loading rate by land use category to estimate the baseline loads, a unit volume cost to estimate the BMP total cost, BMP performance curves (e.g., relationship between BMP size and associated TN load reduction) to estimate the load reduction and MS Excel Solver to run the optimization within Excel. By default the annual loading rates, BMP unit volume cost, and BMP performance curves are populated using the region-specific data provided in the Opti-Tool, and are not automatically recalculated if local climatic data are used to develop local HRU timeseries described above. Special attention should be given before using the Planning Level Analysis to make sure that default data are representative to your study area. In this case study, local precipitation data were used from New Bedford Airport station to develop the HRU timeseries, as described above. Consequently, localized annual pollutant loading rates were estimated from this process, and have been used in this case study to replace the default land loading rates provided in the Opti-Tool (*PL Lookup worksheet*, hidden by default).

The following steps are performed by selecting Planning Level Analysis (Figure 15) on Home screen in Opti-Tool. Building a project requires the user to select a pollutant type from the pull-down list, provide a target load reduction percentage, select an optimization target, enter watershed land use area, and enter BMP drainage area. The user is only required to fill in yellow highlighted cells shown in Figure 16.

| 1. Management Objective | | | |
|---|---|---|---|
| Select Pollutant Type -> | TN | Total BMP Cost ($) | $0 |
| Enter Target Load Reduction (%) -> | 0.0% | Total Pollutant Load Reduction (%) | 0.0% |

| 2. Optimization Target | | | |
|---|---|---|---|
| Select an option -> | BMP Storage Capacity | Total BMP Storage Capacity (gal) | 0 |

| 3. Watershed Information | | | |
|---|---|---|---|
| Enter Land Use Area -> | Click Here | Total Impervious Area (ac) | 0.0 |

| 4. BMP Information | | | |
|---|---|---|---|
| Enter Drainage Area -> | Click Here | Total Treated Impervious Area (ac) | 0.0 |

Figure 16. Planning Level Analysis form

Each step of the process is detailed in the sections below.

### 5.1.1. Management Objective

Select TN from the available pollutant type options and enter the target load reduction percentage ranging from 0-100%.

For this case study, a TN load reduction target of 29.9 % was selected to demonstrate the optimization analysis operations in both the Planning Level and Implementation Level Analysis modes. This target was selected based on some initial Planning Level Analysis mode results that evaluated nitrogen load reductions from the study area associated with user specified BMP design storage capacities (e.g., all BMPs are designed to hold 0.25 inches runoff depth from impervious cover).

### 5.1.2. Optimization Target

Select BMP Storage Capacity as the optimization target. The optimization targets are based on the two approaches of the Planning Level Analysis tool. The first option, BMP Storage Capacity, provides the optimal BMP storage capacity by evaluating the most cost-effective changes in water quality benefits as the BMP/LID sizes are changed. The second option, BMP Drainage Area, determines how much impervious area would require treatment to get the target load reduction. It is important to understand that for any given design storage volume; the optimized drainage area might not be the most cost-effective solution. In order to find the most cost-effective combination of the structural BMPs, the BMP Storage Capacity option should be evaluated.

### 5.1.3. Watershed Information

The *Click Here* link for Watershed Information navigates the user to a table for the user to provide the total land use area distribution within the entire drainage area to the assessment point. Table 13 shows the land use area distribution within the study area to be represented in Opti-Tool. Note: The total of 751.1 acres in Table 13 differs from the total of 758.4 in Table 2 because of 7.3 acres of water within the case study watershed. The user is responsible for filling in only the yellow highlighted cells. The selection of land use type is limited to the number of land use types available in the new MA/US EPA Region 1 MS4 permit, and includes both impervious and pervious areas. The user must break down the land use areas into pervious or impervious cover. For example, Agriculture land use must be divided into Agriculture Pervious and Agriculture Impervious. All urban land uses are represented as the impervious fraction and the pervious fractions are lumped together as one category called Developed Pervious which is further divided into 5 groups based on the underlying hydrologic soil group as shown in Table 13.

Table 13. Watershed Information - Land Use Area

| Landuse Type | Impervious/Pervious | Total Area (ac) |
|---|---|---|
| Agriculture Impervious | Impervious | 3.51 |
| Forest Impervious | Impervious | 4.45 |
| Highway Impervious | Impervious | 0 |
| Industrial Impervious | Impervious | 13.57 |
| Commercial Impervious | Impervious | 83.4 |
| High Density Residential Impervious | Impervious | 58.39 |
| Medium Density Residential Impervious | Impervious | 36.22 |
| Low Density Residential Impervious | Impervious | 4.15 |
| Open Land Impervious | Impervious | 13.71 |
| Agriculture Pervious | Pervious | 18.86 |
| Forest Pervious | Pervious | 169.62 |
| Developed Pervious A | Pervious | 0 |
| Developed Pervious B | Pervious | 52.19 |
| Developed Pervious C | Pervious | 142.23 |
| Developed Pervious C/D | Pervious | 0 |
| Developed Pervious D | Pervious | 150.81 |
| | TOTAL Area (ac) | 751.11 |

## 5.1.4. BMP Information

The *Click Here* link for BMP Information navigates to a table for the user to provide the BMP drainage area for single or multiple land use types. The user must provide the infiltration rate for infiltration system BMPs (infiltration chamber, infiltration trench, and infiltration basin) based on the underlying soil type. The user is responsible for filling in only the yellow highlighted cells. The BMP representation in the Planning Level Analysis is at the watershed scale, so all units of the same BMP type are lumped together. Table 14 shows the total impervious drainage area to three BMP types selected in this case study.

Table 14. BMP Information - Drainage Area

| Landuse Type | Impervious/ Pervious | Biofiltration with ISR (ac) | Bioretention (ac) | Dry Pond (ac) | Grass Swale* (ac) | Gravel Wetland (ac) | Infiltration Basin (ac) | Infiltration Chambers* (ac) | Infiltration Trench (ac) | Porous Pavement* (ac) | Sand Filter (ac) | Wet Pond (ac) | Total (ac) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Agriculture Impervious | Impervious | 0.00 | 0.00 | 0.00 | 0.00 | 3.51 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 3.51 |
| Forest Impervious | Impervious | 0.00 | 0.00 | 0.00 | 0.00 | 3.90 | 0.54 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 4.44 |
| Highway Impervious | Impervious | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Industrial Impervious | Impervious | 10.89 | 0.00 | 0.00 | 0.00 | 2.68 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 13.57 |
| Commercial Impervious | Impervious | 45.66 | 0.00 | 0.00 | 0.00 | 34.82 | 2.92 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 83.40 |
| High Density Residential Impervious | Impervious | 9.69 | 0.00 | 0.00 | 0.00 | 48.56 | 0.14 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 58.39 |
| Medium Density Residential Impervious | Impervious | 21.48 | 0.00 | 0.00 | 0.00 | 7.96 | 6.78 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 36.22 |
| Low Density Residential Impervious | Impervious | 2.60 | 0.00 | 0.00 | 0.00 | 1.08 | 0.47 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 4.15 |
| Open Land Impervious | Impervious | 4.50 | 0.00 | 0.00 | 0.00 | 3.73 | 5.47 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 13.70 |
| | TOTAL Area (ac) | 94.82 | 0.00 | 0.00 | 0.00 | 106.24 | 16.32 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 217.38 |
| | | | | | | | | | | | | | |
| | | | | | | Select BMP Infiltration Rate (in/hr) -> | 0.52 | 0.52 | 0.52 | | | | |
| Note:Only fill in the yellow highlighted cells. | | | | | | | | | | | | | |
| * Place holder for future option (not implemented) | | | | | | | | | | | | | |

## 5.1.5. Run Design Scenario – BMP Storage Capacity

The Run Single Scenario analysis estimates the BMP storage capacity needed for any given runoff treatment depth from the BMP impervious drainage areas. For example, select Run Single Scenario and then provide a runoff depth of 1 inch, see Figure 17 below. As discussed previously, a design storage capacity of 1 inch depth of runoff would provide complete treatment to approximately 90% of storm events in the local area. The Opti-tool calculates the BMP storage capacity (ft$^3$), BMP cost ($), treated impervious area (ac), annual operation and maintenance hours (hr), and pollutant load reduction (lbs) based on the given runoff depth.

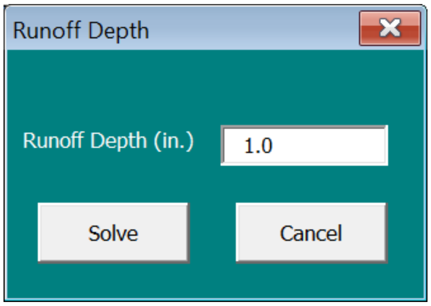


Figure 17. Run Single Scenario – Runoff Depth

Figure 18 shows that to meet a design storage capacity of holding 1 inch of runoff depth from 217.4 acres of impervious drainage, the total BMP cost will be $18.25 million with an associated total nitrogen load reduction of 44.8% (~2,300 lbs. N). Note that the BMP cost is assumed for a new development in this analysis but for developed landscapes, a scaling factor of 2 or 3 should be used to reflect the increased cost due to the technical challenges of retrofitting controls. Also, BMP sizes are strictly based on the design depth and are *not optimized*.

| 1. Management Objective | | | |
|---|---|---|---|
| Select Pollutant Type -> | TN | Total BMP Cost ($) | $18,257,188 |
| Enter Target Load Reduction (%) -> | 0.0% | Total Pollutant Load Reduction (%) | 44.8% |

| 2. Optimization Target | | | |
|---|---|---|---|
| Select an option -> | BMP Storage Capacity | Total BMP Storage Capacity (gal) | 5,902,799 |

| 3. Watershed Information | | | |
|---|---|---|---|
| Enter Land Use Area -> | Click Here | Total Impervious Area (ac) | 217.4 |

| 4. BMP Information | | | |
|---|---|---|---|
| Enter Drainage Area -> | Click Here | Total Treated Impervious Area (ac) | 217.4 |

**5. Optimal Solution**

| BMP Type | Design Storage Capacity (ft$^3$) | BMP Cost ($) | Treated Impervious Area (ac) | O&M (hr/yr) | Load Reduction (lbs) | Treated Runoff Depth (in) |
|---|---|---|---|---|---|---|
| Biofiltration with ISR | 344,197 | $ 10,745,818 | 94.82 | - | 1,078.31 | 1.00 |
| Bioretention | - | $ - | - | - | - | - |
| Dry Pond | - | $ - | - | - | - | - |
| Grass Swale* | - | $ - | - | - | - | - |
| Gravel Wetland | 385,651 | $ 6,772,035 | 106.24 | 2,305 | 985.05 | 1.00 |
| Infiltration Basin | 59,242 | $ 739,335 | 16.32 | - | 226.50 | 1.00 |
| Infiltration Chambers* | - | $ - | - | - | - | - |
| Infiltration Trench | - | $ - | - | - | - | - |
| Porous Pavement* | - | $ - | - | - | - | - |
| Sand Filter | - | $ - | - | - | - | - |
| Wet Pond | - | $ - | - | - | - | - |

Note:Only fill in the yellow highlighted cells.

* Place holder for future option (not implemented)

Figure 18. Design Scenario Solution – Runoff depth of 1 inch

The user might consider using a smaller design capacity as an additional alternative management objective to better understand the potential range in relative costs and nitrogen load reductions in the watershed area. Also, consideration of small design capacities for retrofitting BMPs into developed landscapes will increase the technical feasibility to implement BMPs in the watershed and will generally be more cost effective in terms of the cost per pound of pollutant load reduced.

For the case study watershed, an alternative design storage capacity of 0.25 inches of runoff depth from impervious cover was selected as an additional alternative management objective to be evaluated. This storage capacity was selected because it is significantly smaller than the1 inch design capacity evaluated and it would provide significant treatment of runoff from the watershed, as 64% of the storms are less than or equal to 0.25-inch depth, see Table 7. Now, for the management objective for BMPs to hold 0.25 inch of runoff depth from 217.4 acres of impervious drainage, the total BMP cost would be $4.56 million with an associated total nitrogen load reduction of 29.9% (~3,800 lbs. N), see Figure 19. Note that by reducing the load reduction from 44.8% to 29.9%, the cost dropped from $18.25 million ($7,970/lb. N reduced) to $4.56 million ($1,190/lb. N reduced). The differential cost would be $13.69 million ($ 6,780 /lb. N reduced) for reducing additional 15% of TN load.

| 1. Management Objective | | | |
|---|---|---|---|
| Select Pollutant Type -> | TN | Total BMP Cost ($) | $4,564,297 |
| Enter Target Load Reduction (%) -> | 0.0% | Total Pollutant Load Reduction (%) | 29.9% |

| 2. Optimization Target | | | |
|---|---|---|---|
| Select an option -> | BMP Storage Capacity | Total BMP Storage Capacity (gal) | 1,475,700 |

| 3. Watershed Information | | | |
|---|---|---|---|
| Enter Land Use Area -> | Click Here | Total Impervious Area (ac) | 217.4 |

| 4. BMP Information | | | |
|---|---|---|---|
| Enter Drainage Area -> | Click Here | Total Treated Impervious Area (ac) | 217.4 |

5. Optimal Solution

| BMP Type | Design Storage Capacity ($ft^3$) | BMP Cost ($) | Treated Impervious Area (ac) | O&M (hr/yr) | Load Reduction (lbs) | Treated Runoff Depth (in) |
|---|---|---|---|---|---|---|
| Biofiltration with ISR | 86,049 | $ 2,686,454 | 94.82 | - | 681.23 | 0.25 |
| Bioretention | - | $ - | - | - | - | - |
| Dry Pond | - | $ - | - | - | - | - |
| Grass Swale* | - | $ - | - | - | - | - |
| Gravel Wetland | 96,413 | $ 1,693,009 | 106.24 | 2,305 | 671.26 | 0.25 |
| Infiltration Basin | 14,810 | $ 184,834 | 16.32 | - | 177.88 | 0.25 |
| Infiltration Chambers* | - | $ - | - | - | - | - |
| Infiltration Trench | - | $ - | - | - | - | - |
| Porous Pavement* | - | $ - | - | - | - | - |
| Sand Filter | - | $ - | - | - | - | - |
| Wet Pond | - | $ - | - | - | - | - |

Note:Only fill in the yellow highlighted cells.

* Place holder for future option (not implemented)

Figure 19. Design Scenario Solution – Runoff depth of 0.25 inch

These analysis results indicate the value of having a flexible stormwater management program that allows for the optimized sizing of controls based on watershed conditions to treat runoff from existing impervious surfaces. Another use of setting the design storage capacity to a set value could be to evaluate costs and pollutant reductions associated with the development of local ordinances or by-laws that would require post construction stormwater management for new development and/or re-development within a municipality or watershed.

### 5.1.6. Run Optimize Scenario – BMP Storage Capacity

The design scenario does *not* consider the BMP *size* optimization for a minimum cost. *An optimized scenario identifies the best combination of different BMPs with optimized storage capacities needed at the watershed scale to meet the given numeric load reduction target with minimum cost. To demonstrate optimization scenario a management objective of 29.9% TN load reduction was used.* Select Run Optimize Scenario, and then after providing the maximum run time (30 sec by default), select Solve. A message box will appear prompting the user to select to continue or stop the optimization iterations. The optimization algorithm in MS Excel Solver searches different combination of BMP sizes and identifies the most cost-effective mixture of BMP types and sizes that meet the numeric load reduction target. It would cost $4.3 million ($1,120/lb. N reduced) to meet a 29.9% TN load reduction, see Figure 20 and, in this specific design scenario, prefers infiltration practices to treat 0.4 inch treatment depth, gravel wetland to treat 0.28 inch treatment depth, and enhanced bioretention to treat 0.2 inch treatment depth. Note that this optimization solution shows a $250,000 savings compared to using the set design capacity depth of 0.25 inch for all three BMP types, illustrated above.

| 1. Management Objective | | | |
|---|---|---|---|
| Select Pollutant Type -> | TN | Total BMP Cost ($) | $4,312,764 |
| Enter Target Load Reduction (%) -> | 29.9% | Total Pollutant Load Reduction (%) | 29.9% |

| 2. Optimization Target | | | |
|---|---|---|---|
| Select an option -> | BMP Storage Capacity | Total BMP Storage Capacity (gal) | 1,488,109 |

| 3. Watershed Information | | | |
|---|---|---|---|
| Enter Land Use Area -> | Click Here | Total Impervious Area (ac) | 217.4 |

| 4. BMP Information | | | |
|---|---|---|---|
| Enter Drainage Area -> | Click Here | Total Treated Impervious Area (ac) | 217.4 |

5. Optimal Solution

| BMP Type | Design Storage Capacity ($ft^3$) | BMP Cost ($) | Treated Impervious Area (ac) | O&M (hr/yr) | Load Reduction (lbs) | Treated Runoff Depth (in) |
|---|---|---|---|---|---|---|
| Biofiltration with ISR | 68,811 | $ 2,148,275 | 94.82 | - | 626.43 | 0.20 |
| Bioretention | - | $ - | - | - | - | - |
| Dry Pond | - | $ - | - | - | - | - |
| Grass Swale* | - | $ - | - | - | - | - |
| Gravel Wetland | 106,415 | $ 1,868,644 | 106.24 | 2,305 | 698.04 | 0.28 |
| Infiltration Basin | 23,706 | $ 295,845 | 16.32 | - | 203.63 | 0.40 |
| Infiltration Chambers* | - | $ - | - | - | - | - |
| Infiltration Trench | - | $ - | - | - | - | - |
| Porous Pavement* | - | $ - | - | - | - | - |
| Sand Filter | - | $ - | - | - | - | - |
| Wet Pond | - | $ - | - | - | - | - |

Note:Only fill in the yellow highlighted cells.

* Place holder for future option (not implemented)

Figure 20. Optimized Scenario Solution – Runoff depth of 0.25 inch

## 5.2. Implementation Level Analysis

The benefits of optimization have been proven through several case studies (Shoemaker, et. al., 2013, 2012, 2009) including a study on the Charles River watershed, which demonstrates that applying optimization techniques to identify the best mix of stormwater control technologies and design capacities is an essential step towards developing the most cost effective program to achieve needed load reductions (Tetra Tech, Inc. 2009). The Planning Level Analysis allows the user to optimize one aggregate BMP by each management category at watershed scale. In comparison, Implementation Level Analysis allows the user to model distributed BMPs (model every possible BMP footprint in the study area), or use an aggregated BMP approach (to model one aggregate BMP by each management category at the watershed level or catchment level, or land use level, or even at the combination of catchment and land use level). Note: Increasing the number of BMPs included in analysis will also significantly increase the Opti-Tool simulation time needed to get the optimal solution, as the number of possible combination of those BMPs grows exponentially, and can reach into trillions of possibilities. Although, considering more BMPs in the Opti-Tool spatial optimization process can identify more cost-effective scenarios (i.e., potential cost savings) the longer run time will eventually become a limiting factor in reaching the optimal solution.

For demonstrative purposes in this case study, a simple representation was used in which BMPs were selected at the land use level, and one aggregate BMP was selected for each management category by land use type in the study area. This resulted in the selection of 20 BMPs for the study area. The outcome of this analysis is the cost-effectiveness curve showing a range of optimal solutions for varying TN load reduction targets ranging from approximately 15% to just over 40% (see Figure 35 below).

Each step of the process is detailed in the sections below.

From the Home screen (Figure 15), begin by selecting Implementation Level Analysis.

### 5.2.1. Load Watershed Map (Optional)

From the left menu, select the Load Watershed Map (optional) button. On the Open form, select the watershed map (jpeg format) and click Open. The watershed map will appear within the BMP & Stream Network Sketch Design box, see Figure 21. The scroll bar under the Load Watershed Map (optional) button changes the transparency of the watershed map. Once the next step is activated, the option to load a watershed map or change the transparency will become disabled. The watershed map is a background image that helps in creating a BMP network in the study area and has no role in the model setup process.


Figure 21. The Opti-Tool *Background Map* screen

### 5.2.2.Watershed Information

From the left menu, select the *Watershed Information* button. The watershed characteristics are used to provide input for the *Key Information* form.

For Buzzards Bay pilot watershed; there were20 selected BMPs, the land uses were grouped into 9 major land use types. The 9 major land use categories were further broken down into 13 land uses based on pervious or imperious and hydrologic soil group.

On the *Key Information* form, enter 1 for the number of subbasins, 20 for the number of BMPs, and 13 for the number of land uses. Click *Default Pollutant Values* to populate 4 (by default, TP, TN, Zn, and TSS) for the number of pollutants, see Figure 22. A message box will appear explaining default pollutant information, Click *Ok*. Click *Save*. Once the next step is activated, the option to edit *Watershed Information* will become disabled.

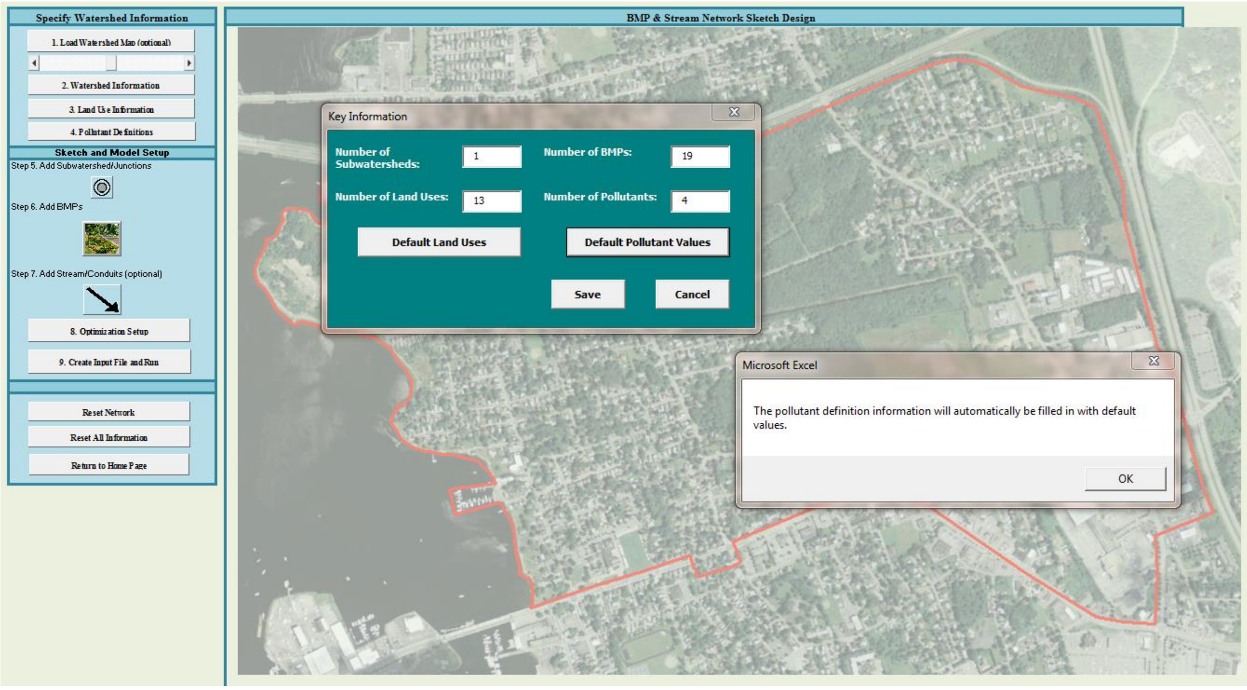


Figure 22. The Opti-Tool *Key Information* form

## 5.2.3.Land Use Information

From the left menu, click the *Land Use Information* button to activate *Add Land Use Definition* form, see Figure 23. Define land use categories. The number of land use IDs are determined by the number of land uses defined in Section 5.2.2. On the *Add Land Use Definition* form, select the land use IDs and enter associated information as shown in Table 15.

Do not use special characters or spaces in the Land Use Definitions. The use of an underscore ("_") is acceptable. Click *Save*. Save must be selected after inputting each individual land use information. Click *Close*. Once the next step is activated, the option to edit *Land Use Information* will become disabled.

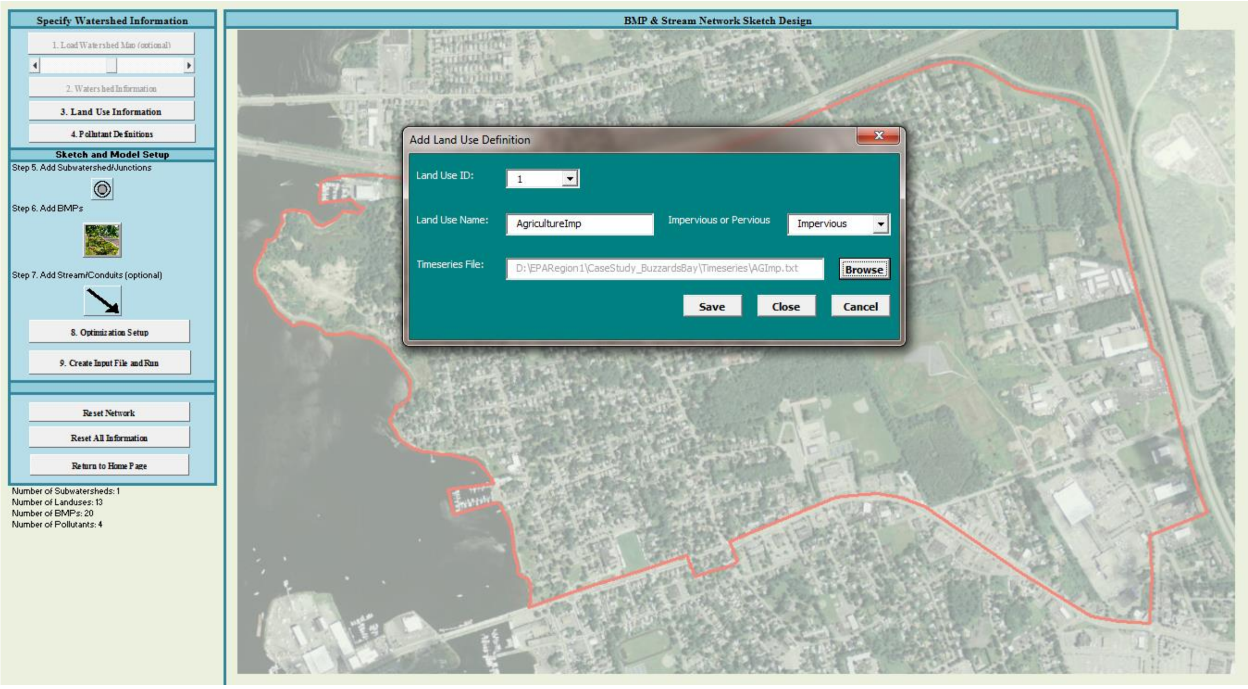



Figure 23. Defining land use categories

Table 15. HRU time series assignment

| Land Use ID | Land Use Name | Impervious or Pervious | HRU Time Series File |
|---|---|---|---|
| 1 | AGImp | Impervious | AGImp.txt |
| 2 | AGPervB | Pervious | AgPervBSoil.txt |
| 3 | COMImp | Impervious | ComImp.txt |
| 4 | FORImp | Impervious | FORImp.txt |
| 5 | FORPervB | Pervious | ForPervBSoil.txt |
| 6 | HDRImp | Impervious | HDRImp.txt |
| 7 | INDImp | Impervious | ComImp.txt |
| 8 | LDRImp | Impervious | LDRImp.txt |
| 9 | MDRImp | Impervious | MDRImp.txt |
| 10 | OPNImp | Impervious | OPNImp.txt |
| 11 | PervB | Pervious | PervBSoil.txt |
| 12 | PervC | Pervious | PervCSoil.txt |
| 13 | PervD | Pervious | PervDSoil.txt |

### 5.2.4.Pollutant Definition

From the left menu, click the *Pollutant Definitions* button to begin entering the pollutant definitions. Each pollutant must have a Pollutant ID, Pollutant Name, and a Pollutant Multiplier. The multiplier is a unit conversion factor. Opti-Tool assumes all pollutants in the time series are defined in lb/hr. Use the multiplier for unit conversion if the pollutant loads are not in pounds. The number of pollutant IDs are determined by the number of pollutants defined in Section 5.2.2.

Notice that all pollutants should already be defined because of selecting *Default Pollutant Values* during the *Watershed Information* step, see Figure 22. Do not use special characters or spaces in the Pollutant Definitions. The use of an underscore ("_") is acceptable. Click *Save*. Click *Close*. Once the next step is activated, the option to edit *Pollutant Definitions* will become disabled.

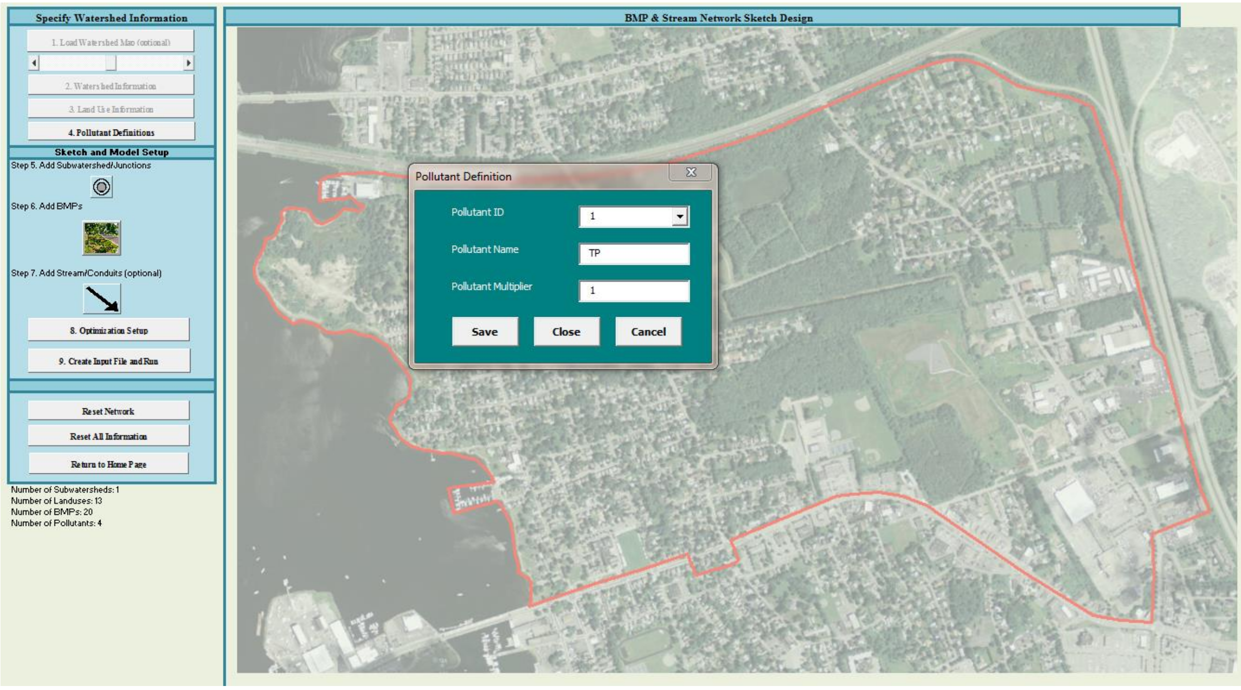
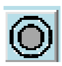



Figure 24. Define pollutant factors

## 5.2.5.Add Subwatersheds/Junctions

From the left menu, click the  button to create a new subwatershed. *Junction1* will appear within *BMP & Stream Network Sketch Design*. Move *Junction1* to the outlet point of the watershed (not required, for schematic purpose only). Click *Junction1* within the *BMP & Stream Network Sketch Design* to add junction information, see Figure 25. Each land use defined in the Land Use Information step will appear in the *Land Use Distribution* list box. The downstream junction is the outlet, and the total drainage area is 751.11 acres for this case study. Each land use type defined in Section 5.2.3 is shown in the *Land Use Distribution* list box. Enter the land use area as shown in Table 16. The watershed must have a Junction ID, Downstream Junction, and Total Drainage Area (acres). The sum of the Land Use Area (acres) must equal the Total Drainage Area (acres). Click *Save*. Click *Close*.

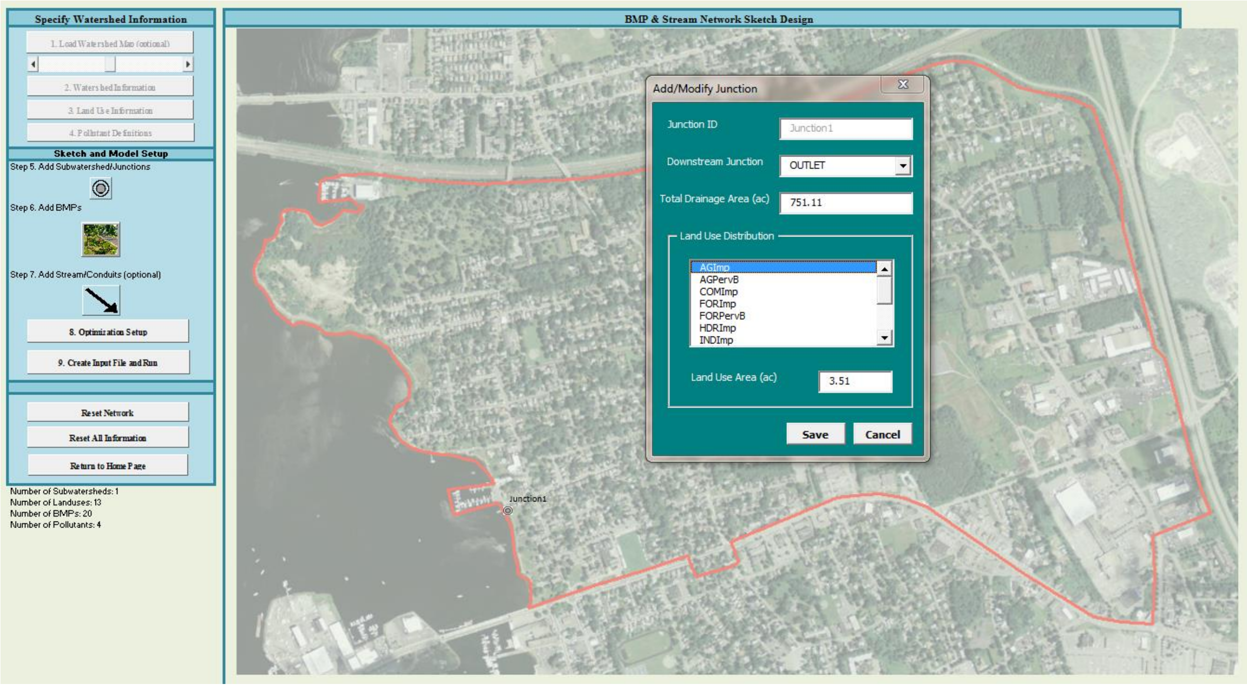


Figure 25. Define junctions and associated land use distribution

Table 16. Land use distribution for Junction1

| Land Use ID | Land Use Name | Area (acre) |
|---|---|---|
| 1 | AGImp | 3.51 |
| 2 | AGPervB | 18.86 |
| 3 | COMImp | 83.40 |
| 4 | FORImp | 4.45 |
| 5 | FORPervB | 169.62 |
| 6 | HDRImp | 58.39 |
| 7 | INDImp | 13.57 |
| 8 | LDRImp | 4.15 |
| 9 | MDRImp | 36.22 |
| 10 | OPNImp | 13.71 |
| 11 | PervB | 52.19 |
| 12 | PervC | 142.23 |
| 13 | PervD | 150.81 |

## 5.2.6.Add BMPs

From the left menu, click the  button to create a new BMP. A message will appear asking; "Have all the subwatersheds/junctions been defined?" click *Yes*. BMP1 will appear within *BMP & Stream Network Sketch Design*. Click *BMP1* within the *BMP & Stream Network Sketch Design* to add BMP information, see Figure 26. A BMP should be added for each land use and BMP type combination, twenty in total for this case study.

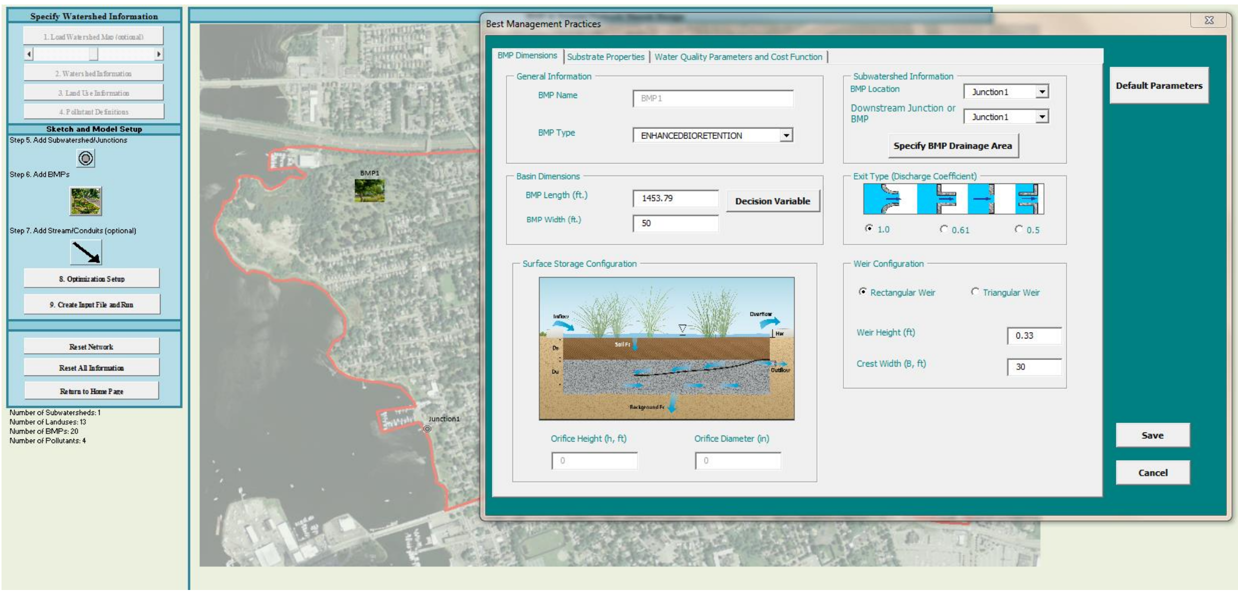


Figure 26. Define BMP surface dimensions

Defining a BMP starts on the BMP Dimensions tab, then add the BMP dimensions and BMP drainage impervious area from the corresponding land use type as shown in Table 11 and Table 12. Define the BMP length as a decision variable by clicking on the Decision Variable button in the Basin Dimensions box, and filling in the information as shown in **Appendix A**, dependent on the BMP type and land use. (In this case study, the BMPs were sized to hold a maximum of one inches of impervious runoff.) The decision variable increments (ft) are 100 times smaller than the maximum length (ft), see Figure 27. The BMP default parameters will automatically be populated based on the BMP type, and are provided in **Appendix A** based on the BMP type.

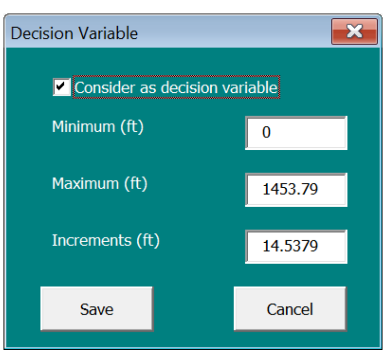


Figure 27. Define BMP length as decision variable

Click on the *Specify BMP Drainage Area* button, see Figure 28. Each land use type defined in Section 5.2.3 is shown in the *Land Use Distribution* list box. The BMP land use drainage area and land use distribution are based on the grouping of the HRU land use data. Enter the land use area dependent on the BMP type and land use combination. Click *Save*.

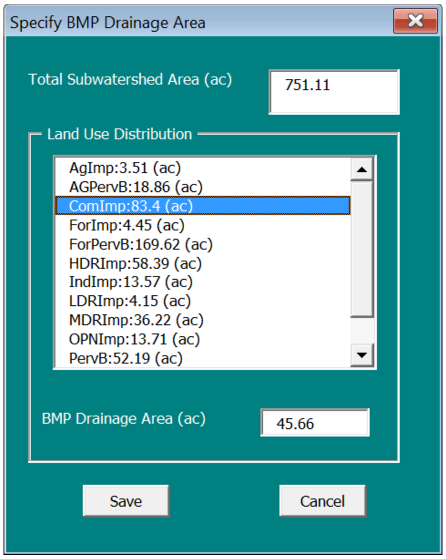



Figure 28. Define BMP drainage area

Click on the *Substrate Properties* tab, see Figure 29. The information on the tab will already be complete, according to the BMP type.

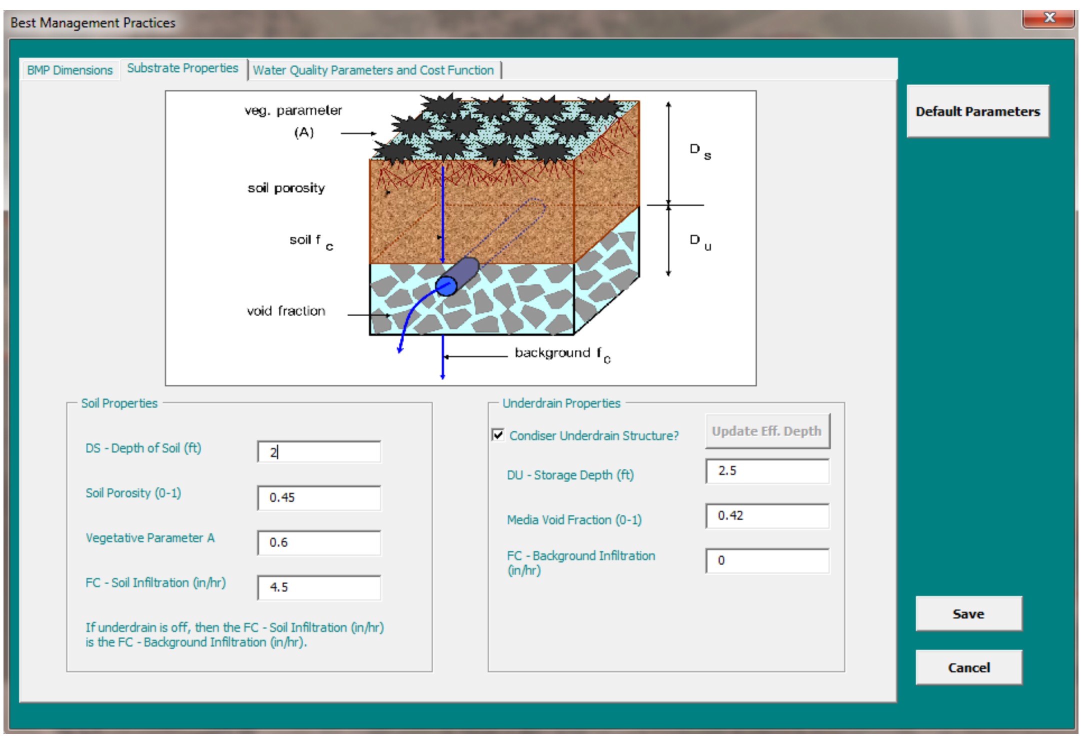



Figure 29. Define BMP substrate properties

Next, click on the *Water Quality Parameters and Cost Function* tab, see Figure 30. The decay rates and underdrain removal rates will be populated based on BMP type.

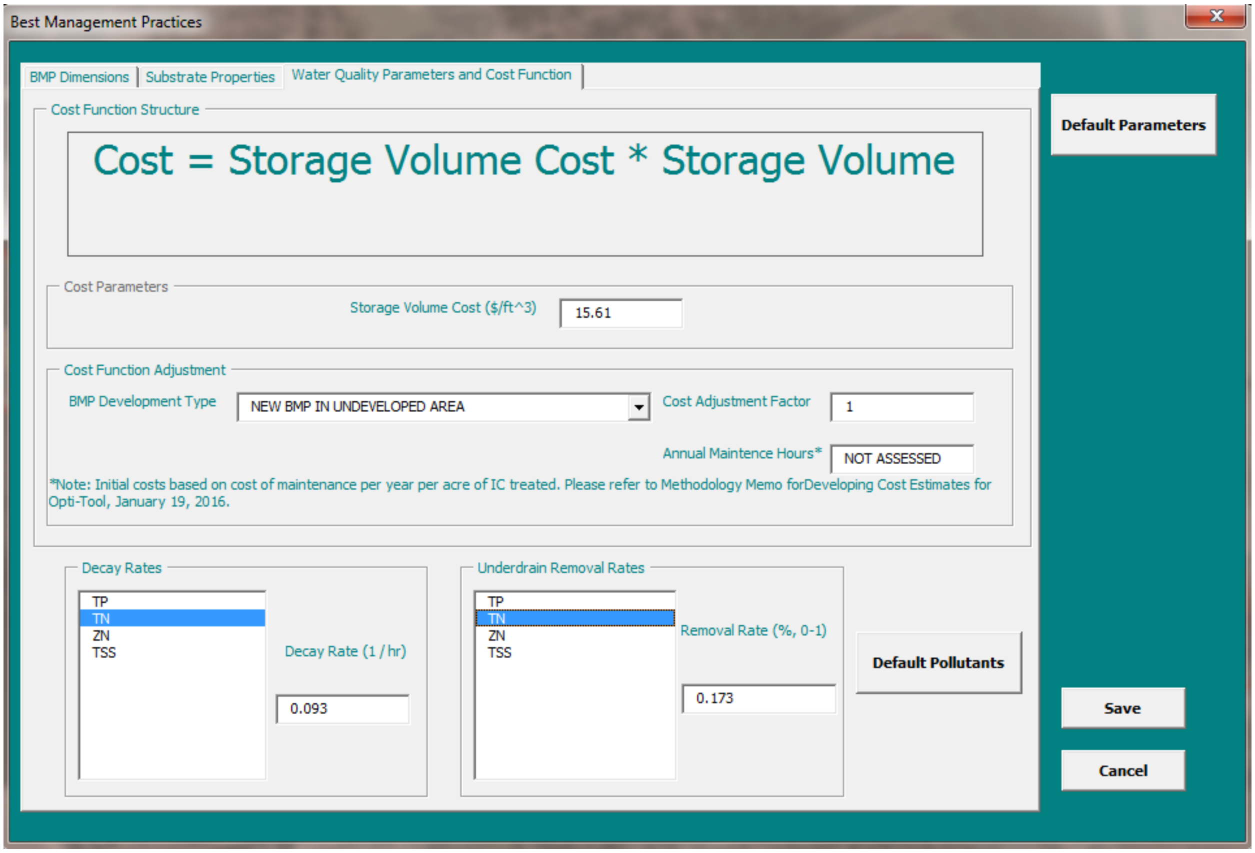


Figure 30. Define BMP water quality parameters and cost function

Note: Decay rates are specified with units of $hr^{-1}$ and apply to pollutants in the water column. Underdrain removal rates are specified as a percentage and apply only to pollutants flowing out of the underdrain once it has filled.

Repeat Section 5.2.6 to create the remaining 19 BMPs on the watershed sketch page as shown in Figure 31.

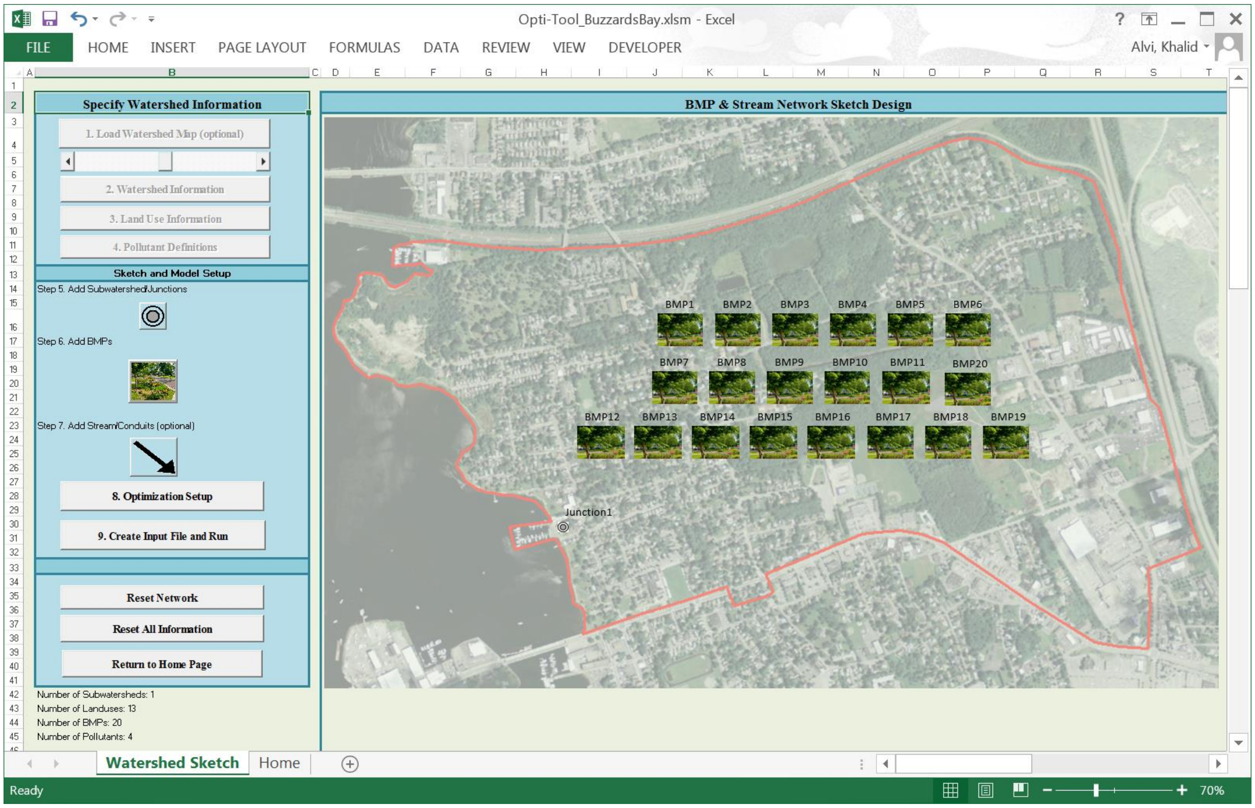


Figure 31. Watershed Sketch screen

### 5.2.7.Optimization Setup

From the left menu, click the *Optimization Setup* button to begin defining the optimization objective, see Figure 32. Define the *Cost-Effectiveness Curve* as the *Assessment Method*. The cost-effectiveness curve method provides the means to visualize the full spectrum of trade-offs between cost and the evaluation factor (e.g., annual average load reduction). Click *Save*.

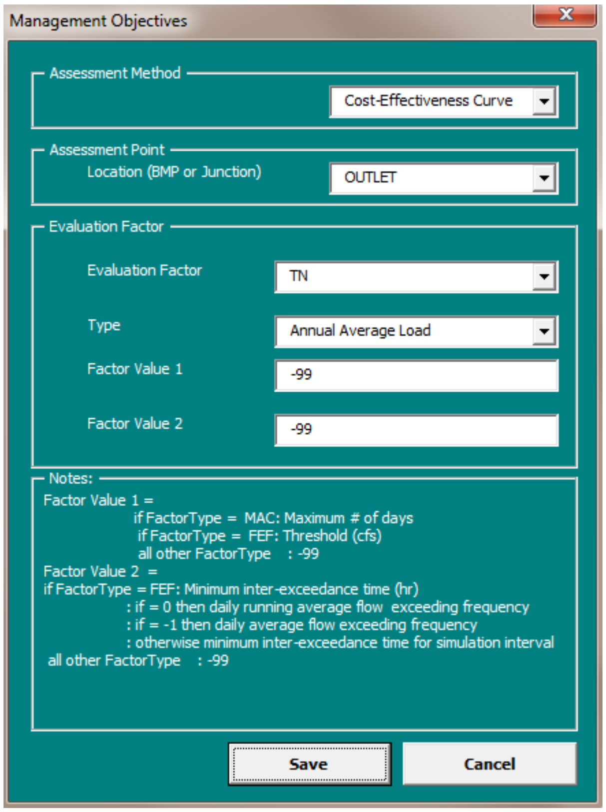


Figure 32. Define management objectives

Next, the *Optimization Settings* form will appear, complete the form as shown in Figure 33. The options allow the user to set a maximum number of runs, and a cost improvement required of each successive solution to continue the optimization. Click *OK*.

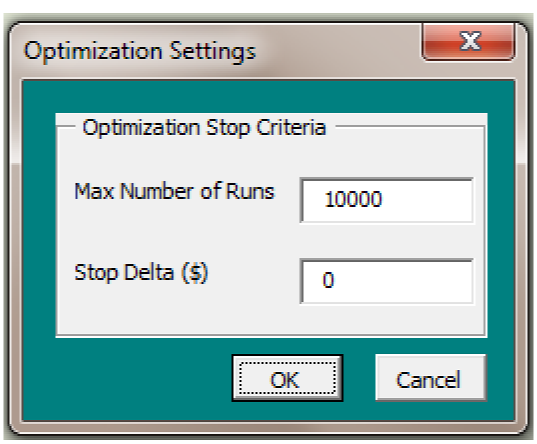


Figure 33. Define the optimization stop criteria

### 5.2.8.Create Input File and Run

From the left menu, click the *Create Input File and Run* button. (For this case study, the simulation start date and simulation end date were selected based on the Opti-Tool land use time series.) The pre-development land use options are the land uses defined in Section 5.2.3. The selected pre-development land use will be used to run an alternative baseline scenario. The input file path, output folder path, and SUSTAIN executable file path should not contain any special characters or spaces, the use of an underscore ("_") is acceptable. After simulation time period, pre-development land use, input file path, output folder path, and SUSTAIN executables path are all filled in, click Create Input File, see Figure 34. After the input file is successfully created, click *Run Simulation*.

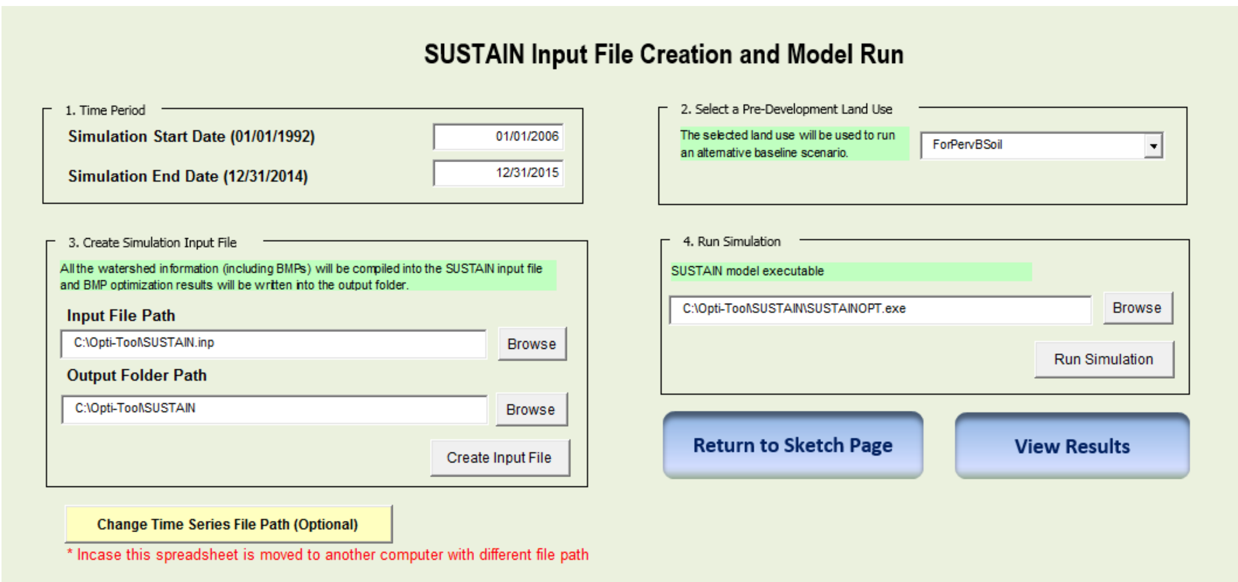



Figure 34. Create SUSTAIN model input file and run SUSTAIN model

### 5.2.9.View Results

After the simulation is complete, click the *View Results* button. The cost-effectiveness curve plots the solutions from the model simulation. The curve is an interactive plot showing the target solution (red triangle) and all the iterations performed during the optimization process. The grey dots on the curve are the inferior solutions and the blue diamonds on the front form the cost-effectiveness curve for a wide range of load reduction targets, see Figure 35. Based on the value in *Target Reduction (%)* box, Opti-Tool searches for the closest solution, and provides the information on the selected BMPs under that target solution (BMP ID, BMP type, surface area, storage depth, treated impervious area, runoff depth, annual maintenance hours, and BMP cost).

Figure 35 shows that it would cost $2.55 million to meet a 29.9% TN load reduction. The optimized solution prioritize the most cost-effective BMPs over the others and shows large size for the infiltration practices as compared to gravel wetland and enhanced bioretention, see Table 17. By increasing 10% to the TN load reduction target the cost would increase to $6.63 million (Figure 35) with the differential cost increase of $4.08 million.

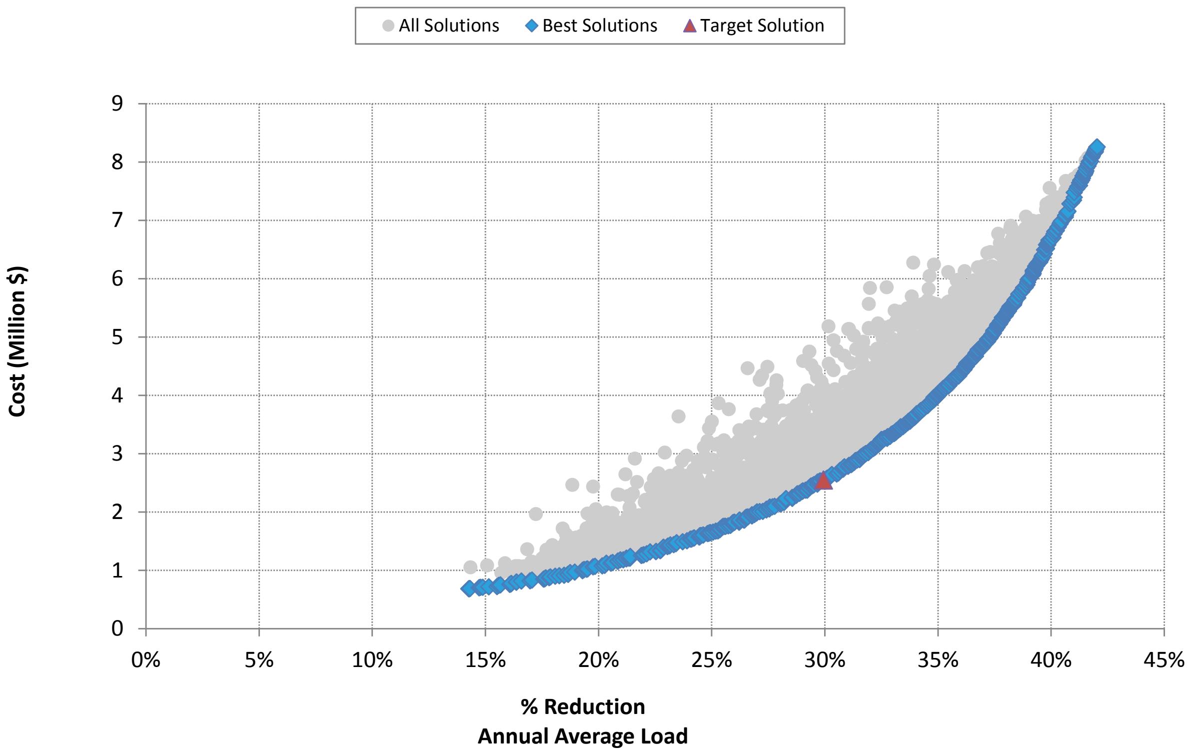



Figure 35. Cost–effectiveness curve results for 29.9% TN load reduction

Table 17 provides a breakdown of the *Solution Total Cost (Million $)* for each listed BMP. (Note: A value of zero for *BMP Area* indicates the BMP was not required for the selected solution, although it may be used for other solutions).

Table 17. Optimal solution for 29.9% TN load reduction

| Target Reduction (%) | Solution Total Cost (Million $) | Solution Reduction (%) |
|---|---|---|
| 29.9% | 2.55 | 29.94% |

| BMP ID | BMP Type | BMP Area (ft^2) | BMP Storage Depth (ft) | System Storage Capacity(ft^3) | Treated Impervious Area (ac) | Runoff Depth (in) | Annual Maintenance (hours) | Cost ($) |
|---|---|---|---|---|---|---|---|---|
| BMP1 | ENHANCEDBIORETENTION | 16718.59 | 2.28 | 38118.37 | 45.66 | 0.23 | NOT ASSESSED | 595,027.82 |
| BMP2 | ENHANCEDBIORETENTION | 2947.04 | 2.28 | 6719.24 | 10.89 | 0.17 | NOT ASSESSED | 104,887.33 |
| BMP3 | ENHANCEDBIORETENTION | 3393.50 | 2.28 | 7737.18 | 9.69 | 0.22 | NOT ASSESSED | 120,777.38 |
| BMP4 | ENHANCEDBIORETENTION | 9916.41 | 2.28 | 22609.40 | 21.48 | 0.29 | NOT ASSESSED | 352,932.79 |
| BMP5 | ENHANCEDBIORETENTION | 1909.23 | 2.28 | 4353.04 | 2.61 | 0.46 | NOT ASSESSED | 67,951.02 |
| BMP6 | ENHANCEDBIORETENTION | 1720.20 | 2.28 | 3922.06 | 4.50 | 0.24 | NOT ASSESSED | 61,223.29 |
| BMP7 | INFILTRATIONBASIN | 4350.10 | 2.00 | 8701.94 | 2.92 | 0.82 | NOT ASSESSED | 54,300.11 |
| BMP8 | INFILTRATIONBASIN | 4674.00 | 2.00 | 9349.87 | 6.78 | 0.38 | NOT ASSESSED | 58,343.19 |
| BMP9 | INFILTRATIONBASIN | 364.00 | 2.00 | 728.14 | 0.47 | 0.43 | NOT ASSESSED | 4,543.57 |
| BMP10 | INFILTRATIONBASIN | 649.44 | 2.00 | 1299.14 | 0.54 | 0.66 | NOT ASSESSED | 8,106.63 |
| BMP11 | INFILTRATIONBASIN | 4965.75 | 2.00 | 9933.49 | 5.47 | 0.50 | NOT ASSESSED | 61,984.95 |
| BMP12 | SUBSURFACEGRAVELWETLAND | 13035.00 | 3.27 | 42598.38 | 34.82 | 0.34 | 755.594 | 374,013.78 |
| BMP13 | SUBSURFACEGRAVELWETLAND | 1003.70 | 3.27 | 3280.08 | 2.68 | 0.34 | 58.156 | 28,799.06 |
| BMP14 | SUBSURFACEGRAVELWETLAND | 13771.75 | 3.27 | 45006.08 | 48.56 | 0.26 | 1053.752 | 395,153.37 |
| BMP15 | SUBSURFACEGRAVELWETLAND | 4245.75 | 3.27 | 13875.09 | 7.96 | 0.48 | 172.732 | 121,823.33 |
| BMP16 | SUBSURFACEGRAVELWETLAND | 231.80 | 3.27 | 757.52 | 1.08 | 0.19 | 23.436 | 6,651.05 |
| BMP17 | SUBSURFACEGRAVELWETLAND | 995.88 | 3.27 | 3254.52 | 3.51 | 0.26 | 76.167 | 28,574.68 |
| BMP18 | SUBSURFACEGRAVELWETLAND | 1549.98 | 3.27 | 5065.32 | 3.90 | 0.36 | 84.63 | 44,473.49 |
| BMP19 | SUBSURFACEGRAVELWETLAND | 1947.64 | 3.27 | 6364.89 | 3.73 | 0.47 | 80.941 | 55,883.71 |
| BMP20 | INFILTRATIONBASIN | 200.00 | 2.00 | 400.08 | 0.14 | 0.79 | NOT ASSESSED | 2,496.50 |

# 6. Summary of Case Study Results

Opti-Tool is designed to provide a flexible and yet consistent platform for local decision-makers and stormwater practitioners, so they can develop and implement technically sound and robust nutrient management plans, capable of demonstrating accountable progress and compliance with permit requirements based on TMDLs or other watershed goals. These include stormwater impacts and excessive nutrient loadings.

The Planning Level Analysis in Opti-Tool provides an easy way for the managers and decision makers to quickly evaluate the management opportunities in the watershed area of interest using a specific design capacity for BMPs fora simplified watershed-scale optimized solution to achieving a specific reduction target at the lowest cost. The MS Excel Solver quickly searches hundreds of possible BMP sizing combinations through the lookup function using the BMP performance curves. It must be noted that the default land use-specific annual loading rates and BMP-specific performance curves are calibrated to the New England Region in Opti-Tool. Special attention should be paid when using the default data for any other geographic location where the climate conditions are different than this region.

The Implementation Level Analysis in Opti-Tool helps stormwater engineers determine the best mix of structural BMPS to provide the greatest benefit for achieving watershed management goals, while minimizing the BMP costs. The cost-effectiveness curve provides decision makers the opportunity to pick the most cost-effective solution for achieving reduction targets. The watershed managers can also use this curve to identify the required cost associated with interim load reduction goals.

This Buzzards Bay case study demonstrates that Opti-Tool can be readily adapted to represent site-specific loading and climate conditions for a specific study area of interest. The companion utility tool (provided with the Opti-Tool), SWMM 2 OPTI HRU Tool, provides the step-by-step instructions to the user and guides the user from the climate data download step to the final reformatting of the HRU timeseries required for the Opti-Tool Implementation Level Analysis mode.

This case study also demonstrates that Planning Level Analysis can provide both: (1) the “big picture” in terms of maximum possible load reductions based on the possible extent of the management practices and the treatment of runoff from impervious cover in the study area; and (2) optimization of the selected BMPs at the watershed scale.

In the Planning Level Analysis mode, the case study evaluates two design scenarios to identify the BMP storage volume needed to meet a given design criterion (e.g., sized to hold 1 inch and 0.25 inch of runoff from the contributing impervious cover). Analyzing small and large design capacities in this first step is intended to help inform the user on a range of relative costs ($) and maximum load reductions (%) achievable for given design BMP capacities in the case study watershed. An optimized scenario was also run to identify the best combination of BMP and design capacities needed at the watershed scale to meet the given numeric load reduction target (%TN removal from the entire study area).

Design storage capacities for holding 1 inch and 0.25 inches of runoff depth from 217.4 acres of impervious drainage yielded nitrogen load reductions of 44.8% and 29.9%, respectively, with associated BMP cost estimates of $18.25 million ($7,970/lb. N reduced) and $ 4.56 million ($1,190/lb. N reduced, respectively. In terms of evaluating the scenarios on a cost per pound of nitrogen reduced, the smaller design storage capacity is significantly more cost efficient. The optimized solution within the Planning Level Analysis to target the 29.9% TN load reduction, comprises a mixture of 3 BMP categories of different sizes for a cost of $4.31 million (a saving of $250,000).

The analytical strength and flexibility of the Opti-Tool lies in the Implementation Level Analysis where the optimization focus can be set at the watershed scale, at catchment level, land use level, and a combination of catchment and land use level. The finer resolution will allow the optimization engine to search through a large domain of possible combinations of BMP mixtures and to find the most cost-effective solution within the given matrix of decision variables.

An optimized solution for 29.9% TN load reduction target in the Implementation Level Analysis provides a more detailed mixture of 20 different BMP sizes for a total cost of $2.55 million and shows a $1.75 million saving over the optimized solution in the Planning Level Analysis. Also, any inferior solution (grey dot symbols in Figure 35) (potentially chosen by human judgement) would be much more costly as compared to the cost-effective solution (blue diamond symbols in Figure 35) for the same load reduction target.

# References

Shoemaker, L., J. Riverson, K. Alvi, J. X. Zhen, R. Murphy, B. Wood. 2013. *Stormwater Management for TMDLs in an Arid Climate: A Case Study Application of SUSTAIN in Albuquerque, New Mexico*. EPA/600/R-13/004. U.S. Environmental Protection Agency, Water Supply and Water Resources Division, National Risk Management Research Laboratory, Cincinnati, OH.

Shoemaker, L., J. Riverson, K. Alvi, J. X. Zhen, and R. Murphy. 2012. *Report on Enhanced Framework (SUSTAIN) and Field Applications to Placement of BMPs in Urban Watersheds*. EPA/600/R-11/144. U.S. Environmental Protection Agency, Washington, DC.

Shoemaker, L., J. Riverson, K. Alvi, J. X. Zhen, S. Paul, and T. Rafi. 2009. *SUSTAIN—A Framework for Placement of Best Management Practices in Urban Watersheds to Protect Water Quality*. EPA/600/R-09/095. U.S. Environmental Protection Agency, Washington, DC.

Tetra Tech, Inc. 2009. *Optimal Stormwater Management Plan Alternatives: A Demonstration Project in Three Upper Charles River Communities*. Prepared for: U.S. EPA Region 1 and Massachusetts Department of Environmental Protection, Boston, MA. Prepared by: Tetra Tech, Inc. Fairfax, VA.

**Appendix A.** BMP design parameters used in the case study

| Land Use Category | BMP Maximum Length (ft) | | |
|---|---|---|---|
| | Enhanced Bioretention | Infiltration Basin | Subsurface Gravel Wetland |
| Commercial | 1453.79 | 106.10 | 790.00 |
| Industrial | 346.71 | 0.00 | 60.83 |
| High Density Residential | 308.50 | 4.97 | 1101.74 |
| Medium Density Residential | 683.89 | 246.23 | 180.67 |
| Low Density Residential | 83.01 | 16.93 | 24.40 |
| Agriculture | 0.00 | 0.00 | 79.67 |
| Forest | 0.00 | 19.68 | 88.57 |
| Open Land | 143.35 | 198.63 | 84.68 |

| General Information | BMP Type | Enhanced Bioretention | Infiltration Basin | Subsurface Gravel Wetland |
|---|---|---|---|---|
| Subbasin Information | BMP Location | Junction1 | Junction1 | Junction1 |
| | Downstream Junction or BMP | Junction1 | Junction1 | Junction1 |
| Basin Dimensions | BMP Length (ft) | See Appendix A | See Appendix A | See Appendix A |
| | BMP Width (ft) | 50 | 50 | 50 |
| Exit Type | Exit Type (Discharge Coefficient) | 1.0 | 1.0 | 1.0 |
| Surface Storage Configuration | Orifice Height (ft) | 0 | 0 | 0 |
| | Orifice Diameter (in) | 0 | 0 | 0 |

| General Information | BMP Type | Enhanced Bioretention | Infiltration Basin | Subsurface Gravel Wetland |
|---|---|---|---|---|
| Weir Configuration | Rectangular or Triangular Weir | Rectangular | Rectangular | Rectangular |
| | Weir Height (ft)/Ponding Depth (ft) | 0.33 | 2 | 2.2 |
| | Crest Width (ft)/Draining time (hr) | 30 | 30 | 6 |
| Soil Properties | Depth of Soil (ft) | 2 | 0.001 | 0.67 |
| | Soil Porosity (0-1) | 0.45 | 0.4 | 0.4 |
| | Vegetative Parameter A | 0.6 | 0.9 | 0.9 |
| | Soil Infiltration (in/hr) | 4.5 | 0.52 | 3.3 |
| Underdrain Properties | Consider Underdrain Structure? | Yes/ Check | No/ Uncheck | Yes/ Check |
| | Storage Depth (ft) | 2.5 | 0 | 2 |
| | Media Void Fraction (0-1) | 0.42 | 0 | 0.4 |
| | Background Infiltration (in/hr) | 0 | 0 | 0 |
| Cost Parameters | Storage Volume Cost ($/ft$^3$) | 15.61 | 6.24 | 8.78 |
| Cost Function Adjustment | BMP Development Type | New BMP in Undeveloped Area | New BMP in Undeveloped Area | New BMP in Undeveloped Area |
| | Cost Adjustment Factor | 1 | 1 | 1 |
| | Annual Maintenance Hours | Not Assessed | Not Assessed | 21.7 |
| Decay Rates | TN (1/hr) | 0.11 | 0.42 | 0.13 |
| Underdrain Removal Rates | TN (%,0-1) | 0.3 | 0 | 0.22 |

# **Appendix B.** Method for determining stormwater control design volume (DSV) (i.e., capacity) using long-term cumulative performance curves

| Stormwater Control Type | Description | Applicable Structural Stormwater Control Performance Curve | Equation for calculating Design Storage Capacity for Estimating Cumulative Reductions using Performances Curves |
|---|---|---|---|
| **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. | Infiltration Trench (6 infiltration rates: 0.17, 0.27, 0.52, 1.02, 2.41 and 8.27 inches per hour) | DSV = void space volumes of gravel and sand layers<br>$DSV = (L \times W \times D_{stone} \times n_{stone}) + (L \times W \times D_{sand} \times n_{sand})$ |
| **Subsurface Infiltration** | Provides temporary storage of runoff using the combination of storage structures (e.g., galleys, chambers, pipes, etc.) and void spaces within the soil/sand/gravel mixture that is used to backfill the system for subsequent infiltration into the surrounding sub-soils. | Infiltration Trench (6 infiltration rates: 0.17, 0.27, 0.52, 1.02, 2.41 and 8.27 inches per hour) | DSV = Water storage volume of storage units and void space volumes of backfill materials. Example for subsurface galleys backfilled with washed stone:<br>$DSV = (L \times W \times D)_{galley} + (L \times W \times D_{stone} \times n_{stone})$ |
| **Surface Infiltration** | Provides temporary storage of runoff through surface ponding storage structures (e.g., basin or swale) for subsequent infiltration into the underlying soils. | Infiltration Basin (6 infiltration rates: 0.17, 0.27, 0.52, 1.02, 2.41 and 8.27 inches per hour) | DSV = Water volume of storage structure before bypass. Example for linear trapezoidal vegetated swale<br>$DSV = (L \times ((W_{bottom}+W_{top@Dmax})/2) \times D)$ |
| **Rain Garden/Bio-retention (no underdrains)** | Provides temporary storage of runoff through surface ponding and possibly void spaces within the soil/sand/gravel mixture that is used to filter runoff prior to infiltration into underlying soils. | Infiltration Basin (6 infiltration rates: 0.17, 0.27, 0.52, 1.02, 2.41 and 8.27 inches per hour) | DSV = Ponding water storage volume and void space volumes of soil filter media. Example for raingarden:<br>$DSV = (A_{pond} \times D_{pond}) + (A_{soil} \times D_{soil} \times n_{soil\ mix})$ |
| **Tree Filter (no underdrain)** | Provides temporary storage of runoff through surface ponding and void spaces within the soil/sand/gravel mixture that is used to filter runoff prior to infiltration into underlying soils. | Infiltration Trench (6 infiltration rates: 0.17, 0.27, 0.52, 1.02, 2.41 and 8.27 inches per hour) | DSV = Ponding water storage volume and void space volumes of soil filter media.<br>$DSV = (L \times W \times D_{ponding}) + (L \times W \times D_{soil} \times n_{soil\ mix})$ |
| **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. | Bio-filtration | DSV = Ponding water storage volume and void space volume of soil filter media. Example of a linear biofilter:<br>$DSV = (L \times W \times D_{ponding}) + (L \times W \times D_{soil} \times n_{soil})$ |
| **Enhanced Bio-filtration w/ Internal Storage Reservoir (ISR) (no infiltration)** | Based on design by the UNH Stormwater Center (UNHSC). Provides temporary storage of runoff for filtering through an engineered soil media, augmented for enhanced phosphorus removal, followed by detention and denitrification in a subsurface internal storage reservoir (ISR) comprised of gravel. An elevated outlet control at the top of the ISR is designed to provide a retention time of at least 24 hours in the system to allow for sufficient time for denitrification and nitrogen reduction to occur prior to discharge. The design storage capacity for using the cumulative performance curves is comprised of void spaces in the filter media, temporary ponding at the surface of the practice and the void spaces in the gravel ISR. | Enhanced Bio-filtration w/ISR | DSV = Ponding water storage volume and void space volume of soil filter media and gravel ISR.<br>$DSV = (A_{bed} \times D_{ponding}) + (A_{bed} \times D_{soil} \times n_{soil}) + (A_{ISR} \times D_{gravel} \times D_{gravel})$ |
| **Gravel Wetland** | 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 to the top of the ISR layer and provides a retention time of at least 24 hours. | Gravel Wetland | DSV = pretreatment volume + ponding volume + void space volume of gravel ISR. $DSV = (A_{pretreatment} \times D_{preTreatment}) + (A_{wetland} \times D_{ponding}) + (A_{ISR} \times D_{gravel} \times n_{gravel})$ |
| **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. | Infiltration Trench (6 infiltration rates: 0.17, 0.27, 0.52, 1.02, 2.41 and 8.27 inches per hour) | DSV = void space volumes of gravel layer<br>$DSV = (L \times W \times D_{stone} \times n_{stone})$ |
| **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. | Porous Pavement | Depth of Filter Course = $D_{FC}$ |
| **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. | Sand Filter | DSV = pretreatment volume + ponding volume + void space volume of sand and washed stone layers.<br>$DSV = (A_{pretreatment} \times D_{preTreatment}) + (A_{bed} \times D_{ponding}) + (A_{bed} \times D_{sand} \times n_{sand}) + (A_{bed} \times D_{stone} \times n_{stone})$ |
| **Wet Pond** | Provides treatment of runoff through routing through permanent pool. | Wet Pond | DSV= Permanent pool volume prior to high flow bypass<br>$DSV = A_{pond} \times D_{pond}$ (does not include pretreatment volume) |
| **Extended Dry Detention Basin** | Provides temporary detention storage for the design storage volume to drain in 24 hours through multiple out let controls. | Dry Pond | DSV= Ponding volume prior to high flow bypass<br>$DSV = A_{pond} \times D_{pond}$ (does not include pretreatment volume) |
| **Dry Water Quality Swale/Grass Swale** | Based on MA design standards. Provides temporary surface ponding storage of runoff in an open vegetated channel through permeable check dams. Treatment is provided by filtering of runoff by vegetation and check dams and infiltration into subsurface soils. | Water Quality Grass swale | DSV = Volume of swale at full design depth<br>$DSV = L_{swale} \times A_{swale} \times D_{ponding\ swale}$ |
| **Definitions: DSV**= Design Storage Volume = physical storage capacity to hold water; **VSV** = Void Space Volume; **L** = length, **W** = width, **D** = depth at design capacity before bypass, **n** = porosity fill material, **A**= average surface area for calculating volume; **Infiltration rate** = saturated soil hydraulic conductivity | | | |