Memorandum

TO: Lisa Rhodes, MassDEP

FROM: David Roman and Matt Lundsted, Comprehensive Environmental

DATE: November 9, 2021

SUBJECT: Re-evaluation Summary of MassDEP Stormwater Scenario Analysis

Background

The Massachusetts Department of Environmental Protection (MassDEP) is in the process of revising the Stormwater Management Standards (Standards). An essential component of the update is to evaluate the effect that the potential revisions may have on different types of site development. MassDEP performed an initial evaluation of three potential site development scenarios in 2020 (i.e., one "tight" urban site, one roadway redevelopment site, and one 26-lot subdivision). These results were presented at Stormwater Advisory Committee Meeting #5 on December 2, 2020.[1] The site development scenarios were intentionally developed to be challenging and to put potential revisions to the Standards "to the test" (e.g., steep slopes, tight space constraints, low infiltration). Results from the 26-lot subdivision scenario (i.e.., new development) indicated that the cost of the Stormwater Management System could increase by as much as $18,500 per unit based on potential revisions to the Standards for a site of this type.

As part of ongoing revisions to the Standards and development of Environmentally Sensitive Site Design (ESSD) Credits, MassDEP has since created an additional new development scenario at a less challenging site to enable comparison and cost optimization of multiple treatment options. The purpose of this memorandum is to compare the 26-lot scenario with this additional new development scenario.

Scenario Identification

The two scenarios that this memorandum compares are summarized as follows.

Scenario A, 26-Lot Residential Subdivision

The site is comprised of open space and forest and is bordered by freshwater wetlands. Site slopes range from 5-10% with Hydrologic Soils Group (HSG) type C soils. The proposed condition is to subdivide the site into 26 half-acre single family lots. This site was intentionally selected to be challenging with steep slopes, low potential infiltration rates, and run-on from free steep upgradient areas.

When this site was first evaluated in December 2020, the proposed Stormwater Management System included extraneous Stormwater Control Measures (SCMs) intended to "showcase" the use of ESSD – these extraneous SCMs included rooftop disconnection to dry wells and implementation of raingardens at the corner of each driveway and contributed to the estimated $18,500/lot cost increase. The site therefore exceeded minimum criteria required to meet the Standards and was not optimized for cost. As part of this revised evaluation, those extraneous SCMs have been removed. The following treatment option was evaluated for this scenario:

- Treatment Option 1: Treat all impervious surfaces with stormwater collection system that discharges to downgradient centralized infiltration basins.

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[1] Results of previous site development scenario analysis: https://www.mass.gov/doc/stormwater-advisory-committee-meeting-5-scenario-analysis-report/download.

Scenario B, Simplified Site

The existing site has slopes ≤ 3%, is entirely forested, is bordered by freshwater wetlands, and is comprised of HSG type B soils. The proposed condition is to add 1/4-acre of impervious area as new development. This site affords the opportunity to implement cost savings through use of the ESSD Credits. The following treatment options were evaluated for this scenario:

- Treatment Option 1 (Base): Treat all impervious surfaces with decentralized downstream infiltration basin with minimal stormwater piping.
- Treatment Option 2 (ESSD): Treat 2/3 of impervious surfaces with decentralized downstream infiltration basin with minimal stormwater piping. Treat remaining 1/3 of impervious surface with a **new** buffer (ESSD Credit 7).

Note: This site was designed to be "modular" such that results can be normalized to a per acre (or per lot) basis. This design could be "repeated" on a larger site to promote decentralized controls. Results presented below therefore assume a 1-acre site with four (4) infiltration basins.

Results

Refer to **Table 1** for a comparison of anticipated costs for each scenario. New development projects are required to meet all Standards. The 100-year TP40 evaluation was required to meet all existing Standards while the 100-year NOAA Atlas 14+ evaluation was required to meet all potential Standards. Results are presented on a cost per lot basis to enable direct comparison of each scenario.

The calculated cost increase from TP40 to NOAA Atlas 14+ ranges from $2,831 per lot (*Scenario B, Option 2*), to $7,313 per lot (*Scenario B, Option 1*), to $14,154 per lot (*Scenario A*). This large range is indicative of the wide array of potential site types and ways that any one site can be designed to meet the Standards. For example, if Scenario B (*Option 2*) were to utilize an existing buffer for treatment rather than a new buffer, the cost difference would be significantly lower than $2,831 per lot. These results also indicate that it is possible to reduce overall site costs through decentralized SCMs and strategic use of the ESSD Credits via a site that mimics design principals evaluated by Scenario B.

Table 1. Comparison of Scenario A vs. Scenario B

Storm	Estimated Cost per Lot ($/lot)		
	Scenario A	*Scenario B (Option 1 - Base)*	*Scenario B (Option 2 - ESSD)*
100-yr, TP40 *(Existing Standards)*	$ 32,846	$ 16,453	-
100-yr, NOAA 14+ *(Potential Standards)*	$ 47,000	$ 23,766	$ 19,284
Cost Difference, TP40 to NOAA 14+ :	**$ 14,154**	**$ 7,313**	**$ 2,831**

Table Notes:

1. The cost difference for Scenario B (Option 2 – ESSD) is calculated relative to the Scenario B (Option 1 – Base) because the ESSD Buffer credit was not available under the existing standards (i.e., $19,294 - $16,453 = $2,831).
2. Both Scenario A and Scenario B are New Development Projects and are subject to all Standards. Redevelopment projects are subject to certain Stormwater Standards only to the maximum extent practicable (i.e., Standard 2, Standard 3). Results from this analysis indicate that SCM sizing and subsequent cost of the Stormwater Management System is primarily driven by the peak rate standard (Standard 2). It is likely that the calculated cost increase between TP 40 (existing Standards) and NOAA Atlas 14+ (potential Standards) would be less for Redevelopment projects – most ongoing projects subject to the Massachusetts Stormwater Standards are Redevelopment.

Assumptions

This is a summary document. Refer to the following resources for detailed write-ups on the development and evaluation of each Scenario, including assumptions.

- **Scenario A**: See Footnote 1 for link to write-up.
- **Scenario B:** See **Attachment 1** for draft write-up.

Attachment 1

Detailed Write-up for Scenario B

MassDEP Stormwater Handbook Updates

Updated Analysis for New Scenario

BWR-DWM-2018-14-CW TECH SERVICES

Completed for

MassDEP Bureau of Water Resources

Divisions of Watershed Management and Wetlands & Waterways

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Boston, MA 02108

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November 9, 2020

Table of Contents

1 Introduction

The Massachusetts Department of Environmental Protection (MassDEP) is in the process of revising the Stormwater Management Standards (Standards). An essential component of the update is to evaluate the effect that the potential revisions may have on different types of site development. MassDEP performed an initial evaluation of three potential site development scenarios in 2020 (i.e., one "tight" urban site, one roadway redevelopment site, and one 26-lot subdivision). These results were presented at a Stormwater Advisory Committee Meeting #5 on December 2, 2020.[1] The site development scenarios were intentionally developed to be challenging and to put potential revisions to the Standards "to the test" (e.g., steep slopes, tight space constraints, low infiltration). Results from the 26-lot subdivision scenario indicated that the cost of the Stormwater Management System could increase by as much as $18,500 per unit based on potential revisions to the Standards for a site of this type.

As part of ongoing revisions to the Standards and development of Environmentally Sensitive Site Design (ESSD) Credits, MassDEP has since created an additional scenario at a less challenging site to enable comparison and cost optimization of multiple treatment options. The purpose of this memorandum is to describe the development and evaluation of this additional scenario and to compare results with the previously evaluated 26-lot subdivision scenario. Evaluation objectives are as follows:

- Identify which potential revisions to the Standards have the potential to drive sizing (and subsequent cost) of Stormwater Control Measures (SCMs).
- Compare the potential cost changes that may result from proposed revisions to the Standards.
- Compare how these potential changes compare with the previously evaluated 26-lot subdivision.

2 Scenario Identification

The existing site has slopes ≤ 3%, is entirely forested, is bordered by freshwater wetlands, and is comprised of HSG type B soils. The proposed condition is to add ¼-acre of impervious area to the site (**Figure 1A**). The following Stormwater Management System treatment options were evaluated for this scenario:

- Treatment Option 1 (Base): Treat all impervious surfaces with decentralized downstream infiltration basin with minimal stormwater piping **(Figure 1B)**.
- Treatment Option 2: Treat 2/3 of impervious surfaces with decentralized downstream infiltration basin with minimal stormwater piping. Treat remaining 1/3 of impervious surface with a **new** buffer (ESSD Credit 7) **(Figure 1C)**.
- Treatment Option 3: Same as Option 2, but incorporate Tree Canopy Credit, assuming existing trees (ESSD Credit 5) **(Figure 1D)**.
- Treatment Option 4: Same as Option 3, but assume an existing buffer is used for ESSD Credit 7 (i.e., no cost) **(Figure 1E)**.

Note: This site was designed to be "modular" such that results can be normalized to a per acre (or per lot) basis when evaluating results. For example, Treatment Option 1 is presented with an upgradient treatment area of ¼-acre which is the approximate rule of thumb amount of contributing impervious

[1] Results of previous site development scenario analysis: https://www.mass.gov/doc/stormwater-advisory-committee-meeting-5-scenario-analysis-report/download

drainage area that any one catch basin should capture. This design could be "repeated" on a larger site to promote decentralized controls – i.e., on a 1-acre site, there could be four (4) infiltration basins, each capturing ¼-acre of impervious surface with minimal to no drainage conveyance piping needed.

2.1.1 ESSD Credit Explanation

MassDEP is currently in the process of developing new ESSD Credits. Two Draft credits used as part of this evaluation include ESSD Credit 5 (Tree Canopy) and ESSD Credit 7 (Buffer Enhancement).

- The Tree Canopy Credit is available when new or existing tree canopy extends over ground level impervious cover. The credit consists of a reduction in Effective Impervious Cover (EIC) which may be deducted from the total area of impervious surface that must be managed as required by Standard 3 and Standard 4.
- The Buffer Enhancement Credit is available when runoff from upgradient impervious surfaces is directed to a vegetated buffer via sheet flow. The credit is applicable to projects that plant a new buffer, expand (enhance) an existing buffer, or protect an existing buffer. If all minimum required criteria are met, this credit meets the peak rate attenuation requirement (Standard 2), 1-inch required Recharge Volume (Standard 3), and 90% TSS / 60% TP removal requirement (Standard 4) for those portions of impervious area captured by the buffer.

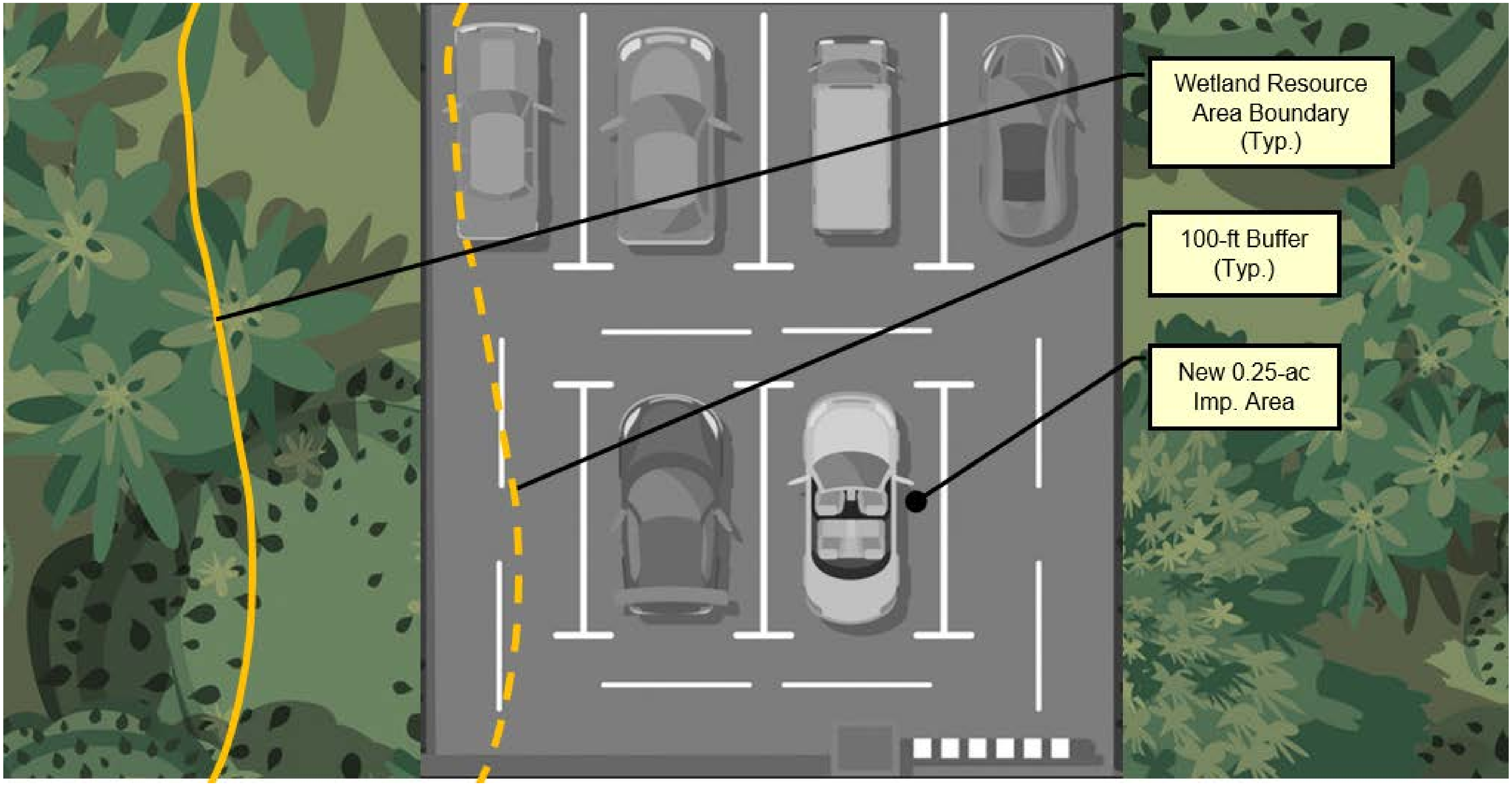

Figure 1A. Proposed Site Conditions (*add ¼-ac of impervious surface to existing forested site*)

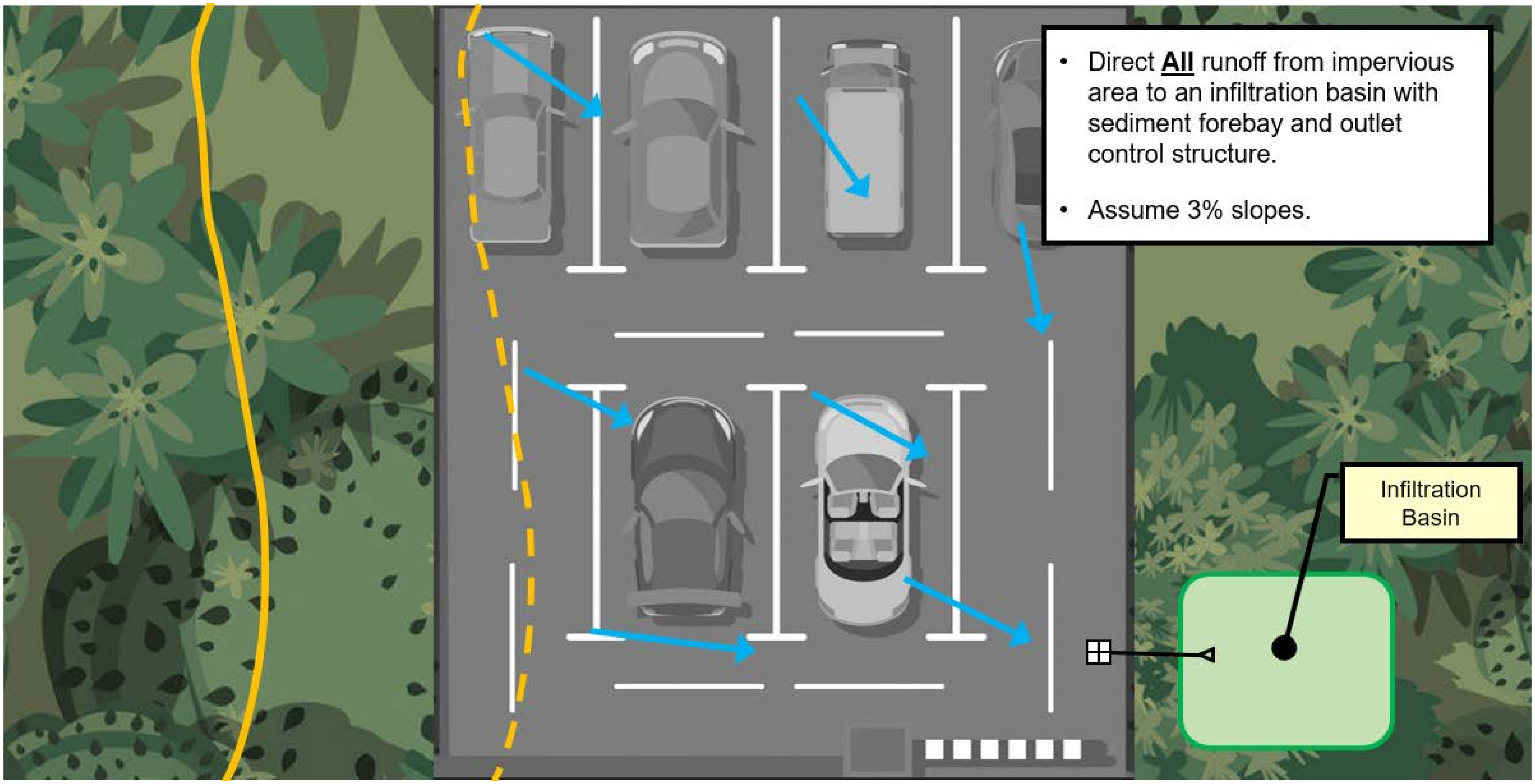

Figure 1B. Proposed Treatment Option 1
(*Treat all impervious surfaces with a downgradient infiltration basin.*)

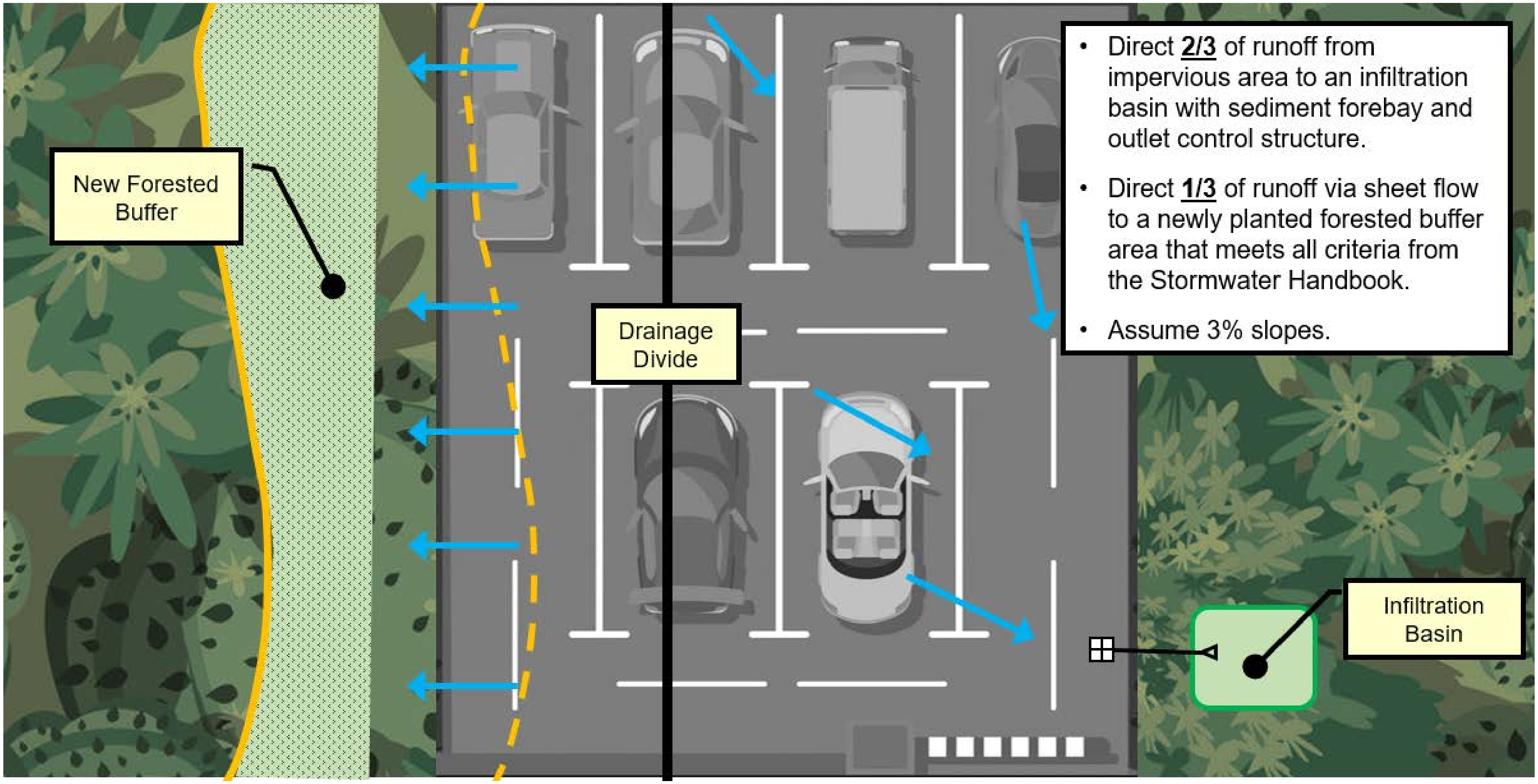

Figure 1C. Proposed Treatment Option 2

(*Treat 2/3 impervious area with infiltration basin; treat 1/3 impervious area with* *new* *buffer.*)

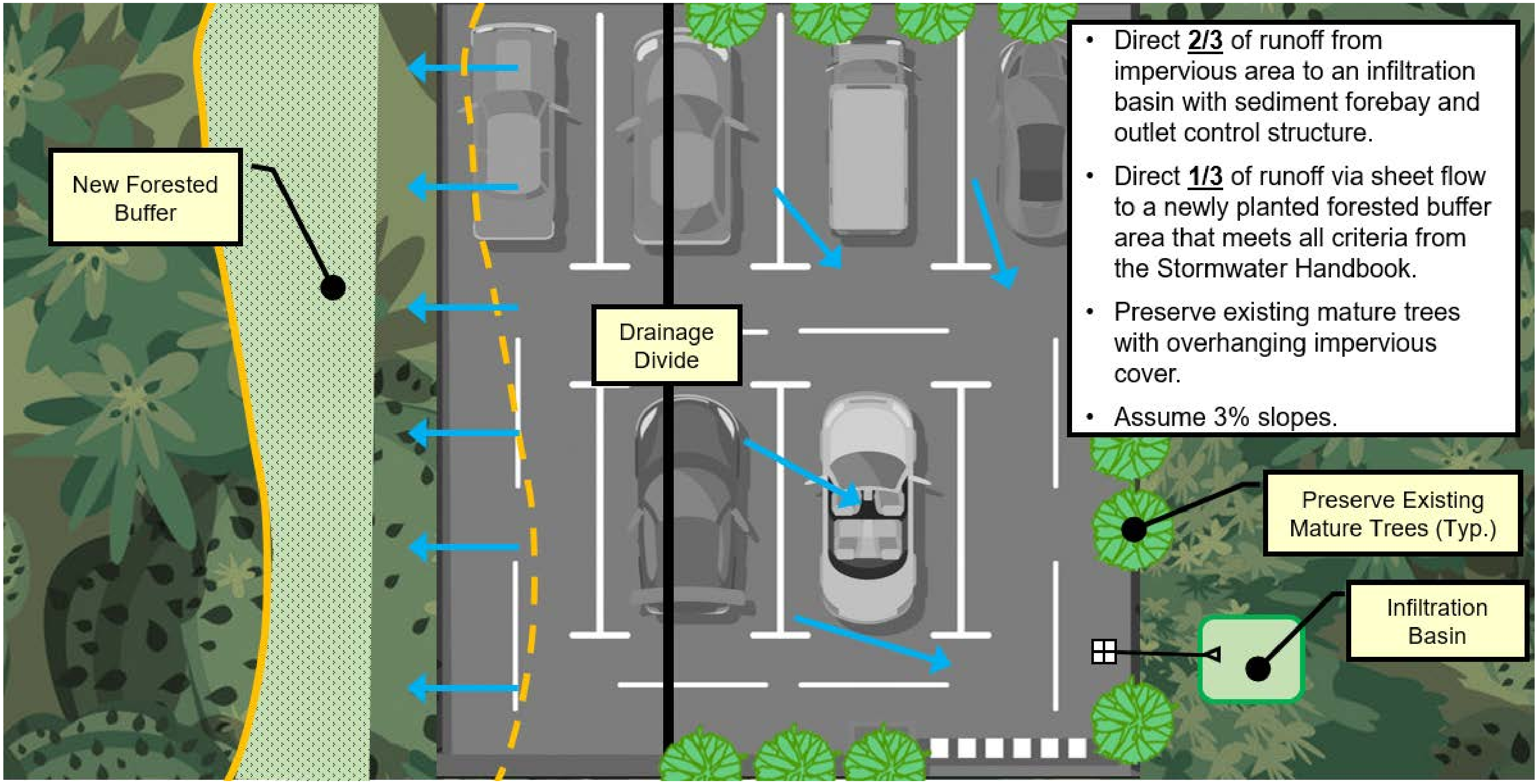

Figure 1D. Proposed Treatment Option 3

(*Treat 2/3 impervious area with infiltration basin; treat 1/3 impervious area with new buffer; preserve existing mature trees.*)

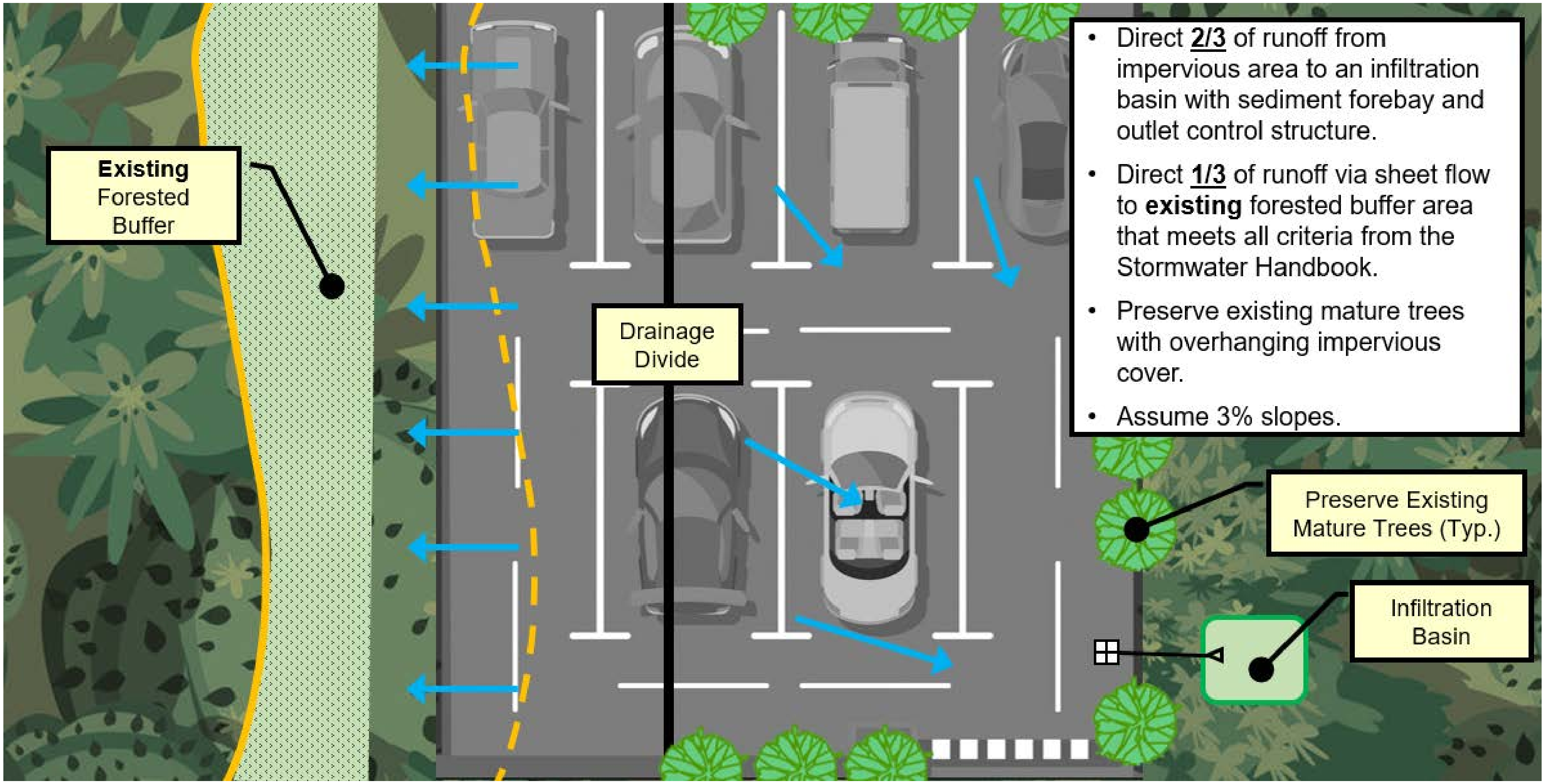

Figure 1E. Proposed Treatment Option 4

(*Treat 2/3 impervious area with infiltration basin; treat 1/3 impervious area with existing buffer; preserve existing mature trees.*)

3 Modeling and Calculation Methods

3.1 Model Runs and Evaluation Criteria

Model simulations were performed to test potential revisions to the Standards. Three site conditions were considered: 1) existing conditions, 2) proposed conditions to meet existing stormwater standards, and 3) proposed conditions to meet potential revisions to the stormwater standards. Stormwater Control Measures (SCMs) were sized to meet the following Standards as summarized by **Table 1**.

- **Standard 2**: Peak Site Discharge (Qp),
- **Standard 3**: Recharge Volume (Rv)
- **Standard 4**: Pollutant Removal / Water Quality Volume (WQv)

Table 1. Summary of Model Simulations and SCM Evaluation Criteria

Evaluation Type	Design Storm	SCM Sizing Criteria
Existing Standards	100-yr, TP 40	• **Qp**: Prop. Conditions < Ex. Conditions • **Pollutant Removal**: 80% TSS • **WQv**: 0.5-in WQv • **Rv**: 0.60-in Rv (*HSG A Soils*) 0.35-in Rv *(HSG B Soils)* *0.25-in Rv (HSG C Soils)*
Potential Revisions to Standards	100-yr, NOAA Atlas 14+	• **Qp**: Prop. Conditions < Ex. Conditions • **Pollutant Removal**: 90% TSS / 60% TP • **WQv**: N/A - Use EPA Curves • **Rv**: 1-in Rv

3.2 Evaluation Criteria Calculation Methods

The following calculation methods were used to evaluate required criteria from the Standards.

3.2.1 Standard 2: Peak Site Discharge (Qp)

AutoDesk's Storm and Sanitary Analysis (SSA) was used to simulate Qp based on the TR55 method. SSA is a comprehensive hydrology and hydraulic modeling package for analyzing and designing urban drainage systems. SSA was developed using the Environmental Protection Agency's (EPA) Stormwater Management Model (SWMM) version 5.0 computational engine. SSA can perform dynamic rainfall-runoff simulations using a variety of methods, including TR-55. The SSA model was run for each simulation for the 2-, 10-, and 100-yr storms to verify that the designed SCMs were configured to control peak discharges for each storm. Refer to **Section 3.3** for an explanation of SSA model inputs.

Note: *No Qp calculations were required for ESSD Credit 7 (Buffer). The Draft ESSD Buffer Credit assumes that the peak rate attenuation requirement is met for the portion of the site that drains to the buffer area if all minimum criteria are met.*

3.2.2 Standard 3: Recharge Volume (Rv)

Recharge Volume (Rv) is the site's runoff volume that requires infiltration from the stormwater management system. The proposed infiltration basin was sized using MassDEP's "Static Method" which is computed as the target runoff depth times contributing impervious site area (see **Table 1** for target runoff depths). All computations assume that a groundwater mounding analysis was not required – i.e., at least four (4) feet of separation between groundwater and the bottom of stormwater treatment features (including media).

A drawdown calculation was also performed to verify that the bottom of the infiltration basin is capable of infiltrating the full Rv within 72 hours. This calculation was performed by dividing the Rv by the product of the bottom area of the treatment measure by an assumed vertical saturated hydraulic conductivity (Ksat) of 0.52 in/hr which corresponds to the 1982 Rawls Rate for Hydrologic Soil Group Type B "Loam".

Note: *No recharge calculations were required for ESSD Credit 7 (Buffer). The Draft ESSD Buffer Credit provides for 1-inch of groundwater recharge for the portion of the site that drains to the buffer area if all minimum criteria are met.*

3.2.3 Standard 4: Pollutant Removal

Water Quality Volume (WQv) is the runoff volume requiring treatment – it is calculated as the required runoff depth multiplied by the total post-construction impervious site area (see **Table 1** for target WQv). Subsequent pollutant removals were calculated based on two methods as summarized below.

- Pollutant Removal Rates (Existing Standards): Pollutant removal rates for individual treatment measures under the existing stormwater standards were calculated using a treatment train approach (i.e., pre-treatment, conveyance, treatment, etc.) using MassDEP's TSS Removal Worksheet, last updated on March 4, 2008[2].
- Pollutant Removal Rates (Potential Revisions to Standards): Pollutant removal rates for individual treatment measures under proposed revisions to the Standards were calculated from TSS and TP performance curves developed by EPA Region 1 as published in version 2.1 of the the BMP Accounting & Tracking Tool (BMP-BATT).[3] Removal rates were obtained by selecting the infiltration rate of the surrounding soils (i.e., Type B = 0.52 in/hr), then identifying the estimated load reduction as a function of the treatment measure's physical storage capacity (i.e., the treated WQv depth).

Note: *No pollutant removal calculations were required for ESSD Credit 7 (Buffer). The Draft ESSD Buffer Credit provides for 90% TSS / 60% TP removal for the portion of the site that drains to the buffer area if all minimum criteria are met.*

3.2.4 Stormwater Management Feature Sizing

Stormwater management features were sized with the goal of taking up the least amount of space while meeting all evaluated stormwater standards criteria, as feasible. For example, under the existing stormwater standards, an infiltration basin may be required to have sufficient volume to accommodate 1 inch of upstream site runoff to meet Standard 2 (Qp) while only needing to capture and treat a 0.5 inch WQv.

[2] TSS Removal Worksheet: https://www.mass.gov/guides/massachusetts-stormwater-handbook-and-stormwater-standards#-stormwater-report-tools-.

[3] EPA Region 1 BMP-BATT (version 2.1): https://www.epa.gov/npdes-permits/stormwater-tools-new-england#swbmp.

3.3 Model Inputs

SSA was used to build a hydrologic and hydraulic model (H&H) for the site (aka Scenario) to enable computation of estimated site discharge and runoff for comparison and testing of potential revisions to the SMH. Primary inputs used to build the H&H model are described in the following sections.

3.3.1 Precipitation

Two different 24-hour duration design storm types were developed for the model simulations:

1. Traditional Design Storms: Traditional design storm depths were obtained from U.S Weather Bureau Technical Paper 40 (TP 40) for Worcester County and applied to a dimensionless Soil and Conservation Service (SCS) Type III synthetic rainfall distribution generated within SSA.
2. Updated Design Storms: Updated design storm depths were obtained from NOAA Atlas 14 at the 90% confidence interval based on a site located in Worcester County. Depths were applied to a dimensionless NOAA Type D distribution developed by the Natural Resources Conservation Service (NRCS) for the June 2016 Supplement to Chapter 2 of the Engineering Field Handbook. The NOAA Type D distribution corresponds to sites located in Worcester County and has a greater peak intensity than the SCS Type III distribution.

A summary of design storm depths and their corresponding dimensionless distribution is provided by **Table 2**. Total depth is significantly greater for the NOAA Atlas 14+ storms, particularly for the 100-year events. Note that for simplicity, model simulation results are only presented for the 100-year TP40 and 100-year NOAA Atlas 14+ storms.

Table 2. Design storm rainfall depth comparison.

Regulation Type	Name	Distribution	Return Period		
			2-year	10-year	100-year
Existing	TP 40	SCS Type III	3.1	4.5	6.5
Potential	NOAA Atlas 14+	NRCS Type D	3.5	5.5	9.7

3.3.2 Hydrology

Subcatchment drainage areas were delineated based **Figure 1**. Once delineated, the SCS TR-55 method was used to simulate potential peak runoff and total runoff from each subcatchment by assigning a subcatchment area, area-weighted curve number, and time of concentration. Curve numbers were assigned under the assumption that all underlying soils are Hydrologic Soil Group (HSG) B. A time of concentration (Tc) was computed for each subcatchment by summing potential sheet flow, shallow concentrated flow, and channelized flow travel times (as applicable). Travel times were calculated based on evaluation of manning's land surface roughness coefficient, typical flow length, and slope.

3.3.3 Hydraulics

SSA uses EPA SWMM's computational engine to perform hydraulic computations. Hydraulic computations are used to translate calculated subcatchment runoff into flow for routing through a hydraulic network. For this simple scenario, the hydraulic network is comprised of junctions (i.e., catch basin inlet, outfalls), conduits (e.g., inlet and outlet pipes), storage units (i.e., infiltration BMPs), and flow control devices (i.e., outlet control structures, overflow weirs, orifices).

Hydraulic inputs were calculated using the following general assumptions:

- The infiltration basin was modeled as "Storage Unit" in SSA with a constant overall depth. The surface area of the infiltration basin was adjusted for various model runs to meet required minimum sizing criteria.
- The infiltration basin was configured with a riser style outlet structure with a grated overflow and low level orifice. The overflow was represented as a rectangular weir (i.e., 1:1 side slope) and a pre-defined rating curve (i.e., water height vs. discharge). The low level orifice was included to ensure that the basin could infiltrate the required WQv and/or Rv within 72 hours. The low level orifice was represented as circular side orifice with a pre-defined rating curve (i.e., water height vs. discharge). The invert elevation and size of the low level orifice was adjusted for various model runs to meet required minimum sizing criteria.

See **Figure 2A** and **Figure 2B** for a representative schematic of model geometry and modeled infiltration basin configuration, respectively.

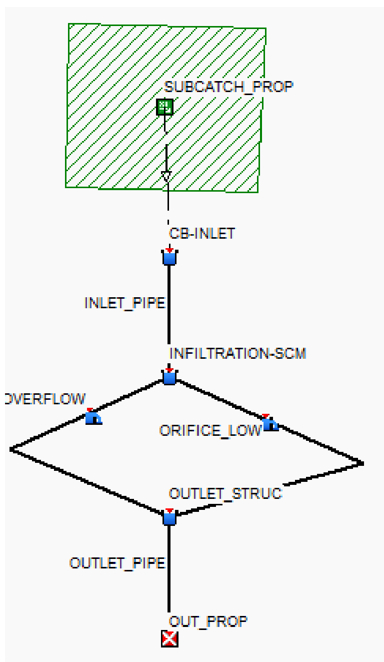

Figure 2A. SSA Model Geometry

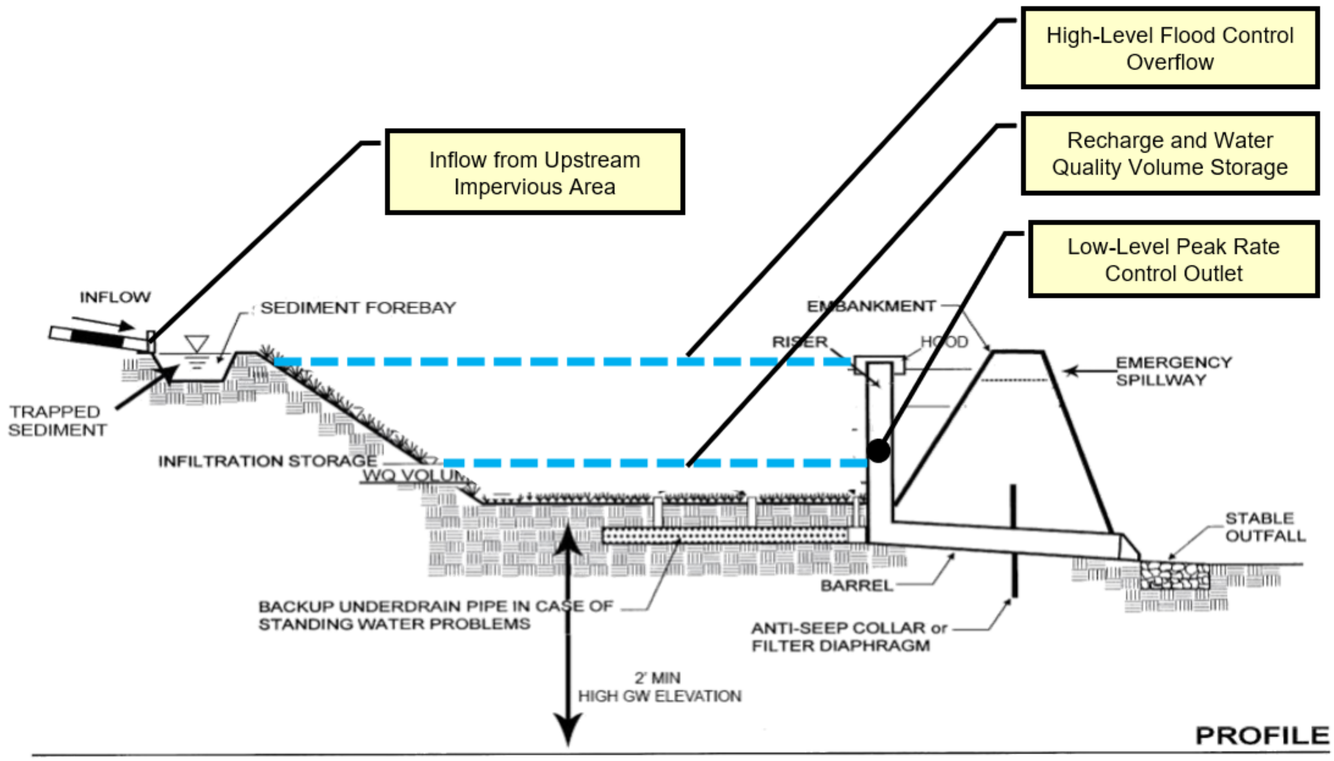

Figure 2B. Modeled Infiltration Basin Configuration

3.3.4 Flow Routing and Model Timing

Flow routing within SSA is performed using EPA SWMM's computational engine which is governed by the conservation of mass and momentum equations for gradually varied, unsteady flow. The three routing options are: (i) Steady Flow Routing, (ii) Kinematic Wave Routing, and (iii) Dynamic Wave Routing. Dynamic Wave Routing was selected as the routing methodology for the model. Dynamic Wave Routing solves the complete one-dimensional Saint Venant flow equations and therefore produces the most theoretically accurate results. These equations consist of continuity and momentum in conduits and volume continuity at nodes. With this form of routing, it is also possible to represent pressurized flow (i.e., when a closed conduit becomes full) in which the actual flow in the conduit can exceed the full-flow Manning's equation value.

Model runs were configured to simulate the 24-hour design storms. Simulations were run for a period of 26 hours to ensure that the runoff hydrograph had sufficient time to complete.

3.4 Cost Estimates

Cost estimates were prepared for the proposed stormwater management system for all considered model simulations. The American Association of Cost Engineers has defined levels of accuracy that are commonly used by professional cost estimators. Three categories of accuracy include: (1) order-of-magnitude, (2) budget, and (3) definitive estimates. The cost estimates presented in this report are considered order-of-magnitude, and were developed with limited engineering detail for comparison purposes.

The order-of-magnitude cost estimates were prepared as follows:

- Infiltration Basin: Infiltration basin cost estimates were obtained from EPA Region 1 BMP Fact Sheets for the 2016 MS4 Permit[4]. The fact sheet includes estimated unit pricing for materials and installation cost based on anticipated land use (i.e., rural, mixed, urban). An infiltration basin installed in an urban setting has an expected materials and installation cost of $12.29 per cubic foot. A cost of $13 per cubic was used for this estimate.
- ESSD Credit 5 (Tree Canopy): Costs for Tree Canopy implementation assumed that existing mature trees were used at no additional cost to the Stormwater Management System.
- ESSD Credit 7 (Buffer): Costs for new buffer implementation were estimated based on an installation density of at least 200 trees per acre at a cost of $250 per tree based on best professional judgement and past project data. Cost for existing buffer implementation were assumed to add no additional cost to the Stormwater Management System.
- Other Items**:** The purpose of this evaluation was to compare potential cost differences across various model runs. Cost estimates for drainage infrastructure (i.e., manholes, pipes, catch basins, outlet structures), engineering design, and permitting costs were not estimated because they are expected to be virtually identical across each evaluated model run.

Cost per Lot Evaluation

As discussed in **Section 2**, this site was designed to be "modular" to enable development of cost estimates on a per acre or per lot basis. Cost per lot results presented in the sections below were developed as follows:

1. Started with initial cost estimates for the ¼-acre impervious site.
2. Multiplied by four (4) to adjust the site to an assumed 1-acre impervious site.
3. Developed an estimate of the amount of an impervious area that a "typical" residential lot could require for a development with 1-acre of impervious surface. This is a conservative estimate, in many cases, an impervious lot would take up much less impervious area (i.e., smaller house, smaller driveway).
    a. House (50' x 50') = 2,500 sf
    b. Garage (30' x 20') = 600 sf
    c. Driveway (15' x 50') = 750 sf
    d. Roadway Portion (200' x 15') = 3,000 sf
    e. **Total** = 6,850 sf of impervious surface per lot.
4. Determined how many lots could be fit into 1-acre of impervious area
    a. 43,560 sf / acre/ 6,850 sf per lot = 6.4 lots per acre of impervious area treated.

4 Results Evaluation

Once the SSA model and all supporting calculations were completed, an analysis was performed to:

- Identify which potential revisions to the Stormwater Management Standards have the potential to drive sizing (and subsequent cost) of Stormwater Control Measures (SCMs).

[4] EPA Region 1 BMP Fact Sheets: https://www3.epa.gov/region1/npdes/stormwater/assets/pdfs/ms4-permit-nomographs.pdf.

- Compare potential cost changes that may result from potential revisions to the Stormwater Management Standards.
- Compare how these potential changes compare with the previously evaluated 26-lot subdivision.

4.1 Which Stormwater Management Standards Drive SCM Sizing?

The first goal of this evaluation was to identify which potential revisions to the Stormwater Management Standards have the potential to drive sizing (and subsequent cost) of Stormwater Control Measures (SCMs). The Base Scenario (Option 1) was used for the evaluation (i.e., all runoff is treated by an infiltration basin). This goal was evaluated by performing SCM sizing using various calculation methods to meet **Table 1** criteria. Results of this evaluation are summarized by **Table 2**.

- Recharge Volume (Standard 3): The required recharge volume (Rv) can vary significantly based on the calculation method that is used and the field measured saturated hydraulic conductivity (K_{sat}) of underlying soils. The calculated required Rv in **Table 2** ranges from 1,333 cf/acre assuming the "*Simple Dynamic*" method with a K_{sat} of 8.27 in/hr to 3,630 cf/acre assuming that the "*Static*" method is used.
- Water Quality Volume (Standard 4): In this example, the required Water Quality Volume (WQv) is significantly less than the required Rv except for the condition where a Project Site discharges to a Critical Area (or other site requiring a WQv of 1-inch).
- Peak Discharge (Standard 2): The peak discharge standard overwhelmingly drives sizing to meet potential revisions to the standards. For example, the infiltration basin must be sized to capture at least 3.22-inches of upstream impervious area to meet Standard 2 for the 100-year NOAA Atlas 14+ storm, assuming a required Rv of at least 1-inch (i.e., 11,700 cf / acre). Sizing of the infiltration basin could decrease by up to 25% (i.e., from 11,700 cf / ac to 8,552 cf/acre assuming that the "*Simple Dynamic*" method with a K_{sat} of 8.27 in/hr is used.

Therefore, in this evaluated scenario, sizing is primarily driven by the peak rate standard; however, depending on Rv or WQv requirements and calculation methods, the basin could be slightly smaller.

Table 3. Evaluation of Potential Infiltration Basin Sizing Based on Various Conditions

Standards Met	**Sizing Criteria**	**Min. Treated Depth of Upstream Impervious Area** (in)	**Required Storage Vol. per Treated Acre** (cf / ac)
What are some potential SCM sizing variations to meet the required Recharge Volume (Rv)?			
Standard 3 (Recharge Volume)	Static Method (Dt = 1.0-in)	1.00	3,630
	Simple Dynamic Method (Dt = 1.0-in; K_{sat} = 0.27 in/hr)	0.95	3,437
	Simple Dynamic Method (Dt = 1.0-in; K_{sat} = .52 in/hr)	0.90	3,275
	Simple Dynamic Method (Dt = 1.0-in; K_{sat} = 1.02 in/hr)	0.82	2,994
	Simple Dynamic Method (Dt = 1.0-in; K_{sat} = 2.41 in/hr)	0.67	2,417
	Simple Dynamic Method (Dt = 1.0-in; K_{sat} = 8.27 in/hr)	0.37	1,333
What are some potential SCM sizing variations to meet the required Water Quality Volume (WQv)?			
Standard 4 (Water Quality Volume)	Critical Areas and Other Misc. Sites (Dt = 1.0-in)	1	3,630
	HSG C Soils (Dt = EPA Curves; K_{sat} = .27 in/hr)	0.35	1,271
	HSG B Soils (Dt = EPA Curves; K_{sat} = 0.52 in/hr)	0.32	1,162
	HSG A Soils (Dt = EPA Curves; K_{sat} = 2.41 in/hr)	0.25	908
	HSG A Soils (Dt = EPA Curves; K_{sat} = 8.27 in/hr)	0.15	544
What are some potential SCM sizing variations to meet Peak Discharge (Qp) while also meeting the required Rv and WQv?			
Standard 2 (Peak Discharge); Standard 3; and Standard 4	Qp post < Qp pre for 100-yr NOAA Atlas 14+ w/ Dt = 1.0-in	3.22-in Total (1.15-in Rv)	11,700
	Qp post < Qp pre for 100-yr NOAA Atlas 14+ w/ Dt = 0.95-in	3.10-in Total (0.96-in Rv)	11,252
	Qp post < Qp pre for 100-yr NOAA Atlas 14+ w/ Dt = 0.90-in	3.04-in Total (0.94-in Rv)	11,024
	Qp post < Qp pre for 100-yr NOAA Atlas 14+ w/ Dt = 0.82-in	2.98-in Total (0.93-in Rv)	10,800
	Qp post < Qp pre for 100-yr NOAA Atlas 14+ w/ Dt = 0.67-in	2.73-in Total (0.73-in Rv)	9,900
	Qp post < Qp pre for 100-yr NOAA Atlas 14+ w/ Dt = 0.37-in	2.36-in Total (0.42-in Rv)	8,552

Table Abbreviations:
- Qp = Peak Discharge Rate
- Rv = Recharge Volume
- WQv = Water Quality Volume
- Dt = Target Depth Factor
- HSG = Hydrologic Soil Group

4.2 Cost Comparison of Potential Standard Revisions and Treatment Options

The next evaluation goal was to compare the potential cost changes that may result from potential revisions to the Stormwater Management Standards. Refer to **Table 4** for a comparison of anticipated costs for each scenario. The 100-year TP40 evaluation was required to meet all existing Stormwater Management Standards. The 100-year NOAA Atlas 14+ evaluation was required to meet all potential Stormwater Management Standards. The required Rv was calculated using the "*Static Method*". Results are presented on a cost per lot basis to enable direct comparison of each scenario.

As indicated by the table, the potential cost increase from TP40 to NOAA Atlas 14+ for the 100-year storm ranges from -$1,371 (Option 4) to $7,313 (Option 1). The cost for Option 4 is much lower than the other treatment options because it is assumed that an existing buffer is already present that meets all criteria of ESSD Credit 7 and therefore has no associated cost. These results indicate that it is possible to reduce overall site costs through decentralized SCMs and strategic use of the ESSD Credits via a similar site of this type.

Table 4. Cost Comparison of Each Treatment Option on a per Lot Basis
(assumes 1-acre impervious surface treated)

Storm	Estimated Cost per Lot ($/lot)			
	Option 1 (Base)	*Option 2 (ESSD 1)*	*Option 3 (ESSD 2)*	*Option 4 (ESSD 3)*
100-yr TP40 (*Existing Standards*)	$16,453	-	-	-
100-yr, NOAA 14 + (*Potential Standards*)	$23,766	$19,284	$18,827	$15,082
Cost Difference, TP 40 (Base) vs. NOAA 14+	**$7,313**	**$2,831**	**$2,374**	**($1,371)**

Table Notes:

1. The cost difference for the ESSD Options (Option 2, 3, and 4) for the 100-yr NOAA+ storm is calculated relative to (Option 1 (Base) because the ESSD Buffer credit was not available under the existing standards.
2. This scenario is new development and is therefore subject to all Standards. Redevelopment projects are subject to certain Stormwater Standards only to the maximum extent practicable (i.e., Standard 2, Standard 3). Results from this analysis indicate that SCM sizing and subsequent cost of the Stormwater Management System is primarily driven by the peak rate standard (Standard 2). It is likely that the calculated cost increase between TP 40 (existing Standards) and NOAA Atlas 14+ (potential Standards) would be less for Redevelopment projects – most ongoing projects subject to the Massachusetts Stormwater Standards are Redevelopment.

4.3 Cost Comparison Relative to 26-lot Subdivision

As previously indicated, an intentionally challenging 26-lot subdivision was previously evaluated and presented at a Stormwater Advisory Committee Meeting #5 on December 2, 2020 (*see footnote 1 for the report*). Results from the 26-lot subdivision indicated that the cost of the Stormwater Management System could increase by as much as $18,500 per unit as a result of potential revisions to the Stormwater Management Standards for a site of this type.

When this site was first evaluated in December 2020, the proposed Stormwater Management System included extraneous SCMs intended to "showcase" the use of ESSD – these extraneous SCMs included rooftop disconnection to dry wells and implementation of raingardens at the corner of each driveway and contributed to the $18,500/ lot cost increase. The site therefore exceeded minimum criteria required to meet the Standards and was not optimized for cost.

When these extraneous SCMs are removed from the site evaluation, the estimated costs per lot for the 100-year TP 40 event are $32,846 versus $47,000 for the 100-year NOAA Atlas 14+ event, a difference of $14,154. The 26-lot subdivision is more expensive than the newly evaluated scenario presented above by **Table 4**.

The range of costs presented by this results evaluation are indicative of the wide array of potential site types and ways that any one site can be designed to meet the Stormwater Management Standards. These results also indicate that it is possible to reduce overall site costs through decentralized SCMs and strategic use of the ESSD Credits.