Comprehensive Stormwater Control Measure (SCM) Hydrologic Performance Modeling

Preliminary SCM Performance Assessment as part of the NERRS Science Collaborative Project in Northern Ohio

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11/21/2014

This material is based on work supported by the National Oceanic and Atmospheric Association under Cooperative Agreement No. NA09NOS4190153 through the University of New Hampshire. Any opinions, findings, and conclusions or recommendations are those of the author and do not necessarily reflect those of the National Oceanic and Atmospheric Association or the University of New Hampshire.

PROJECT BACKGROUND

This project is led by the Old Woman Creek National Estuarine Research Reserve (OWC NERR) and the Chagrin River Watershed Partners, Inc. (CRWP). The ultimate goal is to develop science-based tools to help minimize the impact of stormwater on Ohio's coastal communities and Lake Erie. The project team is using the Collaborative Learning method to work with municipal and consulting engineers, stormwater utilities, developers, regulators, and watershed organizations to generate credible and locally verified performance information about innovative stormwater controls. Based on these results, the team will develop credits and incentives to encourage the use of the most effective systems. This work was funded by the National Oceanic and Atmospheric Administration through the National Estuarine Research Reserve System Science Collaborative Program (NERRS SC) administered by the University of New Hampshire.

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EXECUTIVE SUMMARY

This technical memorandum summarizes the goals and objectives, model analyses, assumptions, shortcomings, results and recommendations for the preliminary modeling work of the National Estuarine Research Reserve System Science Collaborative (NERRS SC)-funded stormwater monitoring and modeling project in northern Ohio. This modeling effort entailed more than 30,000 dynamic hydrologic and hydraulic model runs for individual design storm events and for continuous, annual stormwater control measure (SCM) performance simulations. These analyses have helped lay the foundation for a SCM design/crediting system to be developed by ODNR for inclusion in the Ohio Rainwater and Land Development Manual.

The objectives of the NERRS SC modeling work include:

- Build believable and defensible models of Low Impact Development (LID) SCMs to assess volume reduction and peak discharge attenuation capabilities. The models need to reasonably account for Ohio stormwater standards, site conditions and climate.

- Develop and apply a wide-ranging sensitivity analysis to determine the relative importance of site conditions and SCM design variables to volume and peak discharge reductions using both individual storm event models and continuous, year-long simulations.

- Assess the capability of LID SCMs, across the range of applied site and design variables, to meet State of Ohio water quality volume (WQv) and critical storm event control guidelines.

- Suggest procedures for development of a crediting system that will help provide designers, owners, regulators, etc., a convenient way to design and take credit for the use of LID SCMs.

Ultimately, this work, in combination with the monitoring and follow-on modeling, will be used to:

- Appropriately credit LID SCMs for volume reduction and peak discharge attenuation

- Refine SCM design specifications where needed

- Develop design and accounting guidance and tools consistent with specifications, research results, and models

The USEPA Storm Water Management Model (SWMM, v.5.0) was the primary model used in this analysis. The selection of climatic data and model parameterization for nine SCMs – bioretention, permeable pavement, dry detention, underground storage, green roofs, infiltration trenches, filter strips, swales, and soil renovation – was a collaborative effort between the Ohio Department of Natural Resources (ODNR) Division of Soil and Water Resources, Chagrin River Watershed Partners, Inc. (CRWP) and Cardno JFNew, the consultant on the project. A Collaborative Learning Group (CLG) of stormwater engineers, regulators, and professionals convened for the NERRS SC project also provided input on modeling parameters and results. Two general sets of model runs were performed: 1) single storm

event analyses for ten synthetic rainfall events from 0.25-inch depth up to 3.5-inches; and 2) continuous, annual runs for representative dry, average and wet years using data from the Cleveland Hopkins Airport National Oceanic and Atmospheric Administration (NOAA) weather station.

SWMM was used to quantify pre- and post-development runoff and the effectiveness of LID SCMs for managing post-development site hydrology and meeting stormwater management requirements. A set of base pre-development model scenarios was created, one for each of the Natural Resource Conservation Service (NRCS) hydrologic soil groups - A, B, C and D. As the basis for the post-development analysis, half of the drainage area was "developed" as impervious area and the site modeled to determine runoff volume and peak flow rates with no stormwater controls in place. The LID SCMs were applied to the developed watershed, and reductions in runoff volume and peak flow rate estimated.

In general, we found most modeling results were consistent with expectations and field data. While the models have not yet been calibrated with field monitoring data, some initial comparisons of model-estimated and data-calculated volume reductions appear to show a reasonable correspondence.

The ratio of SCM area to total drainage area (the Drainage Area Ratio or DAR) is the most influential variable for generating inflows, while permanent volume losses are most dependent on underlying soil type. Design variables such as sump depth (also known as Internal Water Storage or IWS), depth of engineered media, etc., variably impact performance depending on the underlying soil type, the DAR, and type of SCM. Generally the more functional attributes, such as surface ponding, subsurface storage, IWS (or "sump"), etc., an SCM possesses, the better its hydrologic performance. Although we did not quantify the impact, actual performance of SCMs will vary based on antecedent moisture conditions. If pore space or ponding volume is already occupied when a follow-on event occurs, the SCM performance will suffer. All individual event analyses were run with initial soil moisture at field capacity.

We believe this analysis helps lay the foundation for an LID SCM crediting system. While the Ohio Rainwater and Land Development Manual provides guidance for meeting the state WQv requirement, there is no explicit guidance to credit runoff volume reduction provided by LID SCMs. This work shows clear relationships between DAR, underlying soil types, and performance. It also provides estimates of volume reductions as a function of design variables. The performance results permit direct evaluation of the LID system's ability to meet the WQv (0.75-inch event) and a simple way to credit that volume reduction toward reducing the critical storm event recurrence interval.

The conservative approach to SCM volume reduction credits assumes that credits are additive whether multiple SCMs on a site are installed in parallel or in series. In reality, when SCMs are applied in series actual volume reductions may exceed reductions calculated for each SCM separately; designers will still need to route runoff through their systems as part of a permit application process. Routing may demonstrate peak flow reductions provided by LID SCMs exceed those attributable to volume reduction alone. Additional research to understand the systematic differences between SCMs in parallel and in series is needed.

Before a crediting system can be finalized, model performance needs to be tested against monitoring data. North Carolina State University Stormwater Engineering Group (NCSU) performed hydrologic and water quality monitoring of several newly installed bioretention and permeable pavement in northern Ohio SCMs for the NERRS SC project. This monitoring will provide detailed data sets for SCM model calibration and validation.

In addition, results from the continuous, annual event runs should be used to pro-rate projected single storm event performance with adjustments that account for performance variation as a function of antecedent moisture conditions. Volume credits can then be calculated as active SCM storage volume plus some discounted infiltration volume. Peak flow credits will require additional analysis in order to connect SCM sizing, selection, and placement with reasonable and justifiable performance.

Project results suggest another line of research and potentially another crediting mechanism. Volume reductions are highly correlated to underlying soil hydrology. Despite knowing that quantifying soil hydrology involves a variety of factors, many of which cannot be controlled during or following the land conversion process, the stormwater industry has over-simplified soil hydrology with the assignment of curve numbers based on hydrologic soil group (HSG-A, B, C, D).

Unfortunately, there is a dearth of information on how to appropriately maintain, recover or even characterize soil hydrologic function in our urban landscapes. As a result, modeled volume reductions driven by SCM surficial soil quality – soil renovation, filter strips, grass swales, dry detention basins – carry a higher level of uncertainty than those based on capture of a stored volume (bioretention, permeable pavement, underground detention, infiltration trench). Additional research to augment our understanding of how to preserve inherent hydrologic function, use soil renovation (compost amendments, tillage, etc.), plant selection and vegetation management to enhance soil quality, or measure or model soil hydrology resulting from typical or innovative site development practices, will aid in development of appropriate credits and reward the conservation or development of more ecologically functional landscapes.

1. BACKGROUND

Stormwater runoff from impervious surfaces severely impacts Ohio's coastal communities and environments. It erodes streams, overloads drainage systems and wastewater treatment facilities, and increases flooding, causing damage to property and infrastructure. Increased runoff also impairs water quality and degrades habitats, and heightens the risk of waterborne diseases. The severity of these impacts has increased with the number of heavy storms in Ohio, which are up 31 percent over the past 50 years according to the U.S. Global Change Research Program (Pryor, et al., 2009; Pryor, et al., 2014). This has been reflected in widespread and frequent flooding in Lake Erie counties over the last five years.

Ohio Environmental Protection Agency (Ohio EPA) stormwater regulations require new development to treat the first 3/4-inch of rain, also known as the "water quality volume" (WQv). Redeveloped sites must treat 20% of the WQv or reduce impervious cover by 20%. Most communities have peak discharge requirements for infrequent recurrence interval events (typically the 1 – 100 year return period) targeted at flood control. Most new developments meet these requirements with traditional "end-of-pipe" ponds that do not reduce the volume of stormwater runoff, allowing further degradation of Ohio’s streams (Ohio EPA, 2007; Ohio EPA, 2011).

Low impact development (LID) attempts to address these problems by integrating the functions inherent to natural landscapes into site design and stormwater systems. This methodology includes open space preservation, clustered development, rainwater reuse, and distributed SCMs (in contrast to centralized, end-of-pipe solutions). Ohio communities and design engineers have asked for design criteria, credits, and other incentives to catalyze a shift to LID approaches.

1.1 NERRS Science Collaborative Project

The primary goal of the “Implementing Credits and Incentives for Innovative Stormwater Management” project, funded through the National Estuarine Research Reserve System (NERRS) Science Collaborative program, is to develop science-based tools to help minimize the impact of stormwater on Ohio's coastal communities and Lake Erie. This project, spearheaded by the Old Woman Creek National Estuarine Research Reserve (OWC NERR) and the Chagrin River Watershed Partners, Inc. (CRWP), will: (1) provide guidance and tools to help engineers, reviewers, and permitting agencies determine whether LID stormwater systems are appropriate for their sites to meet state and local requirements; and (2) demonstrate the design, construction, performance, and maintenance of these stormwater practices in local soils and climate. The project team is using a collaborative learning approach to engage a group of interested experts for input and feedback throughout this project and to ensure the developed tools and trainings are useful to the intended users. The project’s collaborative learning group (CLG) - comprised of stormwater engineers, regulators, educators, stormwater utility managers, and watershed organizations - has provided iterative guidance and feedback to the project team on the design, construction, and monitoring processes of six SCM demonstration sites. The collaborative learning process has enabled group members to share a broad range of knowledge, concerns, and ideas for addressing complex stormwater challenges in northern Ohio.

Project partners and Collaborative Learning Group members include:

1. National Oceanic and Atmospheric Administration (NOAA)
2. Chagrin River Watershed Partners, Inc. (CRWP)
3. Old Woman Creek National Estuarine Research Reserve (OWC-NERR)
4. Ohio Department of Natural Resources, Division of Soil and Water Resources (ODNR-DSWR)
5. Erie Soil and Water Conservation District (Erie SWCD)
6. Firelands Coastal Tributaries
7. Ohio Department of Natural Resources, Division of Wildlife (ODNR-DOW)
8. Ohio Environmental Protection Agency (Ohio EPA)
9. GPD Group
10. CT Consultants
11. City of Aurora
12. Northeast Ohio Regional Sewer District (NEORSD)
13. Perkins Township, Erie County

14. Erie County Engineers Office
15. John Hancock & Associates
16. City of Sandusky
17. Forest City Land Group
18. Village of Kirtland Hills
19. Orange Village
20. Willoughby Hills
21. Pepper Pike
22. Ursuline College
23. Holden Arboretum
24. North Carolina State University Stormwater Engineering Group (NCSU)
25. Chagrin Valley Engineering
26. Stephen Hovansek and Associates
27. Cardno JFNew

1.1.1 Modeling Project

The modeling portion of the NERRS project included four main tasks: 1) develop base ("default") unit-scale SCM models for individual storm event analysis of SCMs; 2) perform a sensitivity analysis of SCM design parameter impacts on runoff reductions; 3) perform an analysis of unit-scale SCMs, both base and selected sensitivity analysis model runs, for average, wet, and dry continuous annual hydrographs; and 4) develop site models for quantification, evaluation, and comparison of SCM performance for runoff volume reduction, peak discharge control, and flow duration. Task 4 is a stand-alone task and will be reported in a separate document.

USEPA SWMM v5 was used for all the modeling efforts. As part of future NERRS SC project work, some of these models will be calibrated to field data being collected by NCSU on several sites in northern Ohio. NCSU also will simulate bioretention and permeable pavement in DRAINMOD, a model typically used to design and predict the impact of drain tiles on groundwater in agricultural fields. Work done at NCSU (Brown, et.al., 2013) has already suggested DRAINMOD may be better suited than SWMM for estimating the performance of SCMs outfitted with underdrains.

2. METHODOLOGY

The analysis mirrored standard engineering practice for analyzing stormwater impacts for a "green field" development site by estimating runoff for 1) undeveloped conditions, 2) developed conditions without SCMs, and 3) developed conditions with SCMs. This comparative analysis allows the engineer/designer to estimate the volume and peak flow reduction requirements and develop initial SCM design parameters for their site. Each SCM was modeled over a range of sizes (as a fraction of total drainage area) for a range of rainfall events including single events and annual, continuous rainfall data runs. Individual SCM design parameters, such as ponding height, sump depth, etc., were varied between model runs. Volume and peak flow reductions were estimated and where applicable compared to Ohio Rainwater and Land Development Manual requirements.

Development of model inputs was a collaborative effort between the Ohio Department of Natural Resources, Division of Soil and Water Resources (ODNR-DSWR) and Cardno JFNew with input from the entire NERRS team, including the CLG and NCSU. SCM design variables were compiled from the Ohio Rainwater and Land Development Manual (ODNR, 2006), the Michigan Low Impact Development Manual (SEMCOG, 2008), professional experience, and a collection of data from research (Dierks, 2013; Dierks, 2014; Fassman-Beck, et al., 2013; Toronto and Region Conservation, 2008; University of Guelph, 2013 and Van Seters, et al., 2006). Model inputs for the base cases and the design variable sensitivity analyses can be found in Appendix A, attached.

2.1. Unit Base Models

The unit scale modeling assumed a one-acre watershed for all scenarios, except dry detention. Standard engineering design for dry detention, usually designed as a centralized, regional SCM, typically utilizes a larger contributing watershed. Therefore, the dry detention contributing watershed area was set at ten acres. Three pre-development land use scenarios were modeled - row-crop agriculture, pasture and forest - with each scenario run using generalized soil properties representing the four Natural Resources Conservation Service (NRCS) hydrologic soil classifications – A (well-drained), B (moderately drained), C (poorly drained) and D (very poorly drained) – for a total of twelve pre-development scenarios. Infiltration and runoff from pervious areas were simulated using the Green-Ampt equation in order to explicitly represent dynamic soil water storage. Post-developed conditions assumed half the watershed was converted to impervious surface and the other half to turf grass. The pre-development and post-development conditions were used to calculate the recurrence interval, and thus the size of the critical storm event for peak discharge control per Ohio DNR guidance.

Model inputs for the pre-developed watershed scenarios are shown in **Tables 1** and **2** below. Watershed width defines the shape of the watershed. Watershed area divided by the width gives the flow path length across the watershed. Watershed slope (% slope) is the average fall divided by flow path length (expressed as a percentage) across the watershed area. Mannings n is a friction factor, or measure of surface roughness, used to estimate the velocity of sheet flow across the ground surface. The higher the n-value the greater the energy loss and the longer it takes water to flow across the watershed. The n-value increased in magnitude from agriculture to pasture to forest per USEPA SWMM guidance (Huber, et al., 1988). The surface storage parameter Dstore defines the micro-topographical interception storage created by small, surficial depressions that fill with water before runoff occurs.

Table 1. Subcatchment Properties – Existing Conditions

Model Property	Land Use		
	Agriculture	Pasture	Forest
Area (acres)	1	1	1
Width (feet)	200	200	200
% Slope	2	2	2
% Impervious area	0	0	0
Sheet flow Mannings n	0.1	0.3	0.6
Surface Storage (Dstore) (inches)	0.05	0.05	0.075
Infiltration Parameters	Green-Ampt	Green-Ampt	Green-Ampt

The Green-Ampt infiltration equation, used to simulate water movement through the unsaturated soil column above groundwater (also referred to as the vadose zone), relies on three soil parameters: 1) the initial moisture deficit, 2) the matric suction (or suction head) and 3) hydraulic conductivity. The initial moisture deficit is the pore void space available to temporarily store water. The matric suction or suction head can be thought of as the suction (negative pressure) necessary to break the force of attraction between pore water and soil particles. At saturation the matric suction equals zero – water flows via gravity. As the volumetric water content in the pores decreases, the matric suction, expressed as a negative pressure, increases; i.e., it gets harder to “pull” the water away from the soil. Conductivity is saturated hydraulic conductivity, the rate at which water moves through saturated soil.

The selected values for the HSG A, B, C and D soils used in the model represent the average values for sandy loam, loam, sandy clay loam, and silty clay, respectively, as estimated from thousands of soils samples collected by the United States Department of Agriculture (USDA), almost exclusively from agricultural land (Rawls, et al., 1982). It is worth noting there are no sandy clay loam soils in Ohio, but the predominant silt loam, silty clay loam and clay loam soils found in Ohio can be adequately represented by the generic C or D soil characteristics used in this study.

The Green-Ampt parameters used in the model are summarized in **Table 2** below. The matric suction and initial moisture deficit values assume the soil is at field capacity. Field capacity is the volume of water left in a soil after all the water that can drain via gravity has drained away. SWMM dynamically tracks the changes in soil moisture and infiltration over the course of a simulation. Any water that cannot infiltrate because the soil is saturated and cannot be accommodated by micro-topographical storage (Dstore) becomes runoff.

Table 2. Green-Ampt Parameters

Model Properites	Soil Hydrologic Class			
	A	B	C	D
Suction Head (in)	2.41	3.5	8.6	11.5
Conductivity (in/hr)	2.35	0.52	0.12	0.04
Initial Deficit (fraction)	0.312	0.193	0.143	0.092

For “developed” watersheds, turf grass was given an n-value of 0.2 and a surface storage of 0.05. The developed watersheds were then “treated” with one of nine SCMs using the SWMM LID tool where possible. The SWMM LID tool has built-in sub-routines to store and infiltrate runoff for bioretention, porous pavers, vegetated swales, infiltration trenches, green roofs, rain gardens and rain barrels. The built-in LID tool was used to simulate SCMs except for underground detention, dry detention and soil renovation. Soil renovation was simulated as a change in post-development pervious area infiltration rates. Underground detention and dry detention were simulated as storage units with bottom seepage in the hydraulic routing portion of SWMM.

Unit-scale SCMs analyzed for this project included:

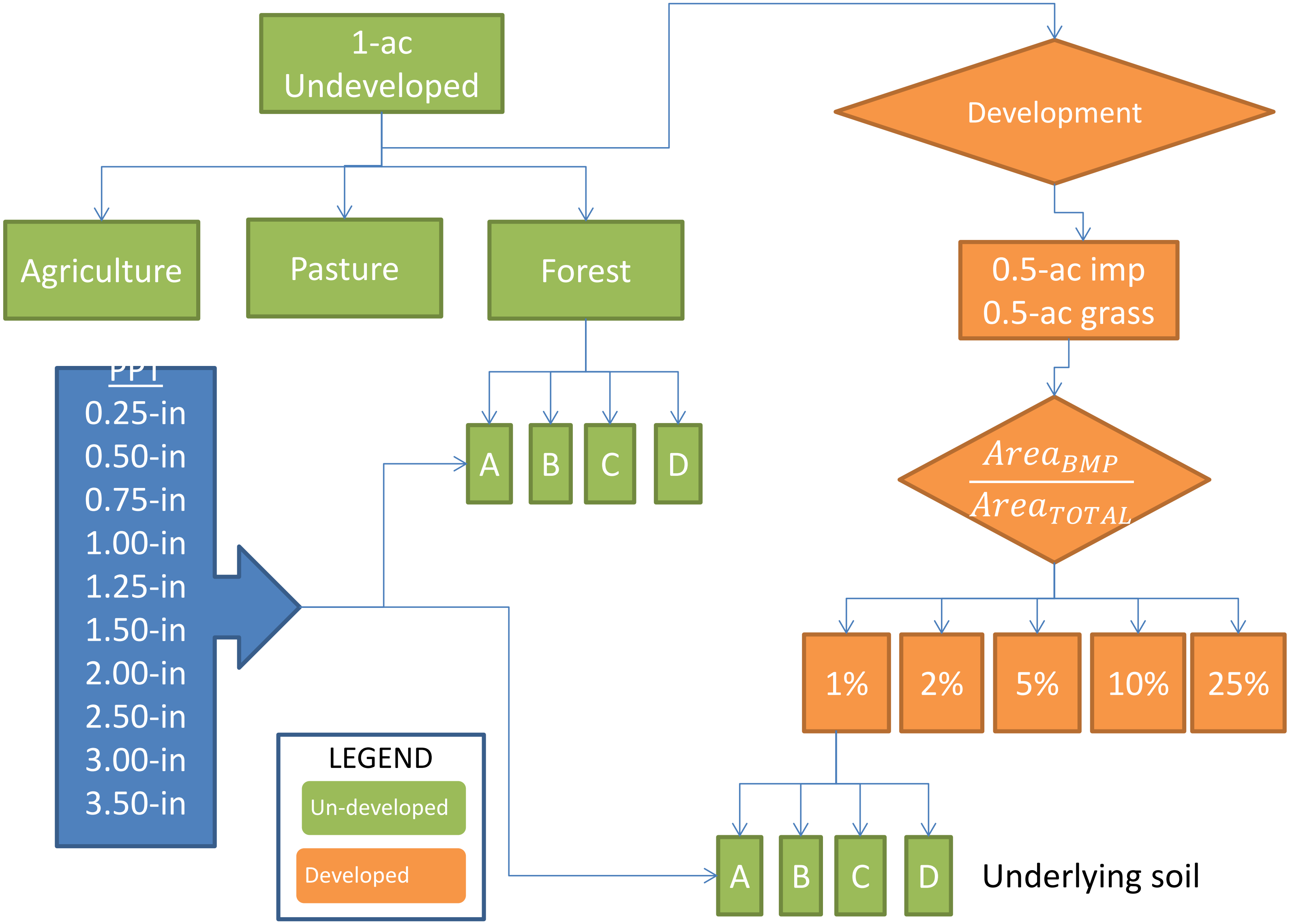
1. Bioretention
2. Permeable pavement
3. Underground detention/retention
    a. Alt 1: water quality volume storage and outlet, with excess inflow discarded from the system as runoff
    b. Alt 2: storage and outlets for both water quality volume and peak discharge control
4. Infiltration trench
5. Dry detention
    a. Alt 1: water quality volume storage and outlet, with all excess inflow above depth of water quality volume leaving as surface runoff
    b. Alt 2: storage and outlets for both water quality volume and peak discharge control
6. Water quality swale (with infiltration)
7. Vegetated/grassed filter strip
8. Soil renovation
9. Green roof

With the exceptions of permeable pavement, green roof, and soil renovation SCMs, models for each SCM type covered a range of drainage area ratios (DARs) - the ratio of SCM area to total contributing area – of 1%, 2%, 5%, 10% and 25%. For permeable pavement, the 1% and 2% DARs were not modeled since they far exceed recommended hydrologic loading; instead a 50% DAR was added (Smith, 2011). Likewise for green roofs, the unreasonably small DARs of 1%, 2% and 5% were dropped and 50%, 75% and 100% scenarios were added. For soil renovation, only the 50% DAR was analyzed. For soil renovation the impervious area runoff was routed over the pervious area.

Each modeling scenario involved many factors: the combination of pervious and impervious area, various DARs for each SCM, the four different HSGs, and ten separate rainfall events – 0.25-inch, 0.5-

inch, 0.75-inch, 1.0-inch, 1.25-inch, 1.5-inch, 2.0-inch, 2.5-inch, 3.0-inch, and 3.5-inch. Rainfall was modeled by distributing it over three hours using the Huff 2nd quartile distribution (Huff and Angel, 1992). Evapotranspiration was set to zero for all single event runs. The assumption here is during a rain event, with relative humidity near 100%, there is little gradient to drive water back into the atmosphere. To the extent this may not be the case in reality, this assumption errs on the conservative side. A flowchart to exemplify how this simulation process works is shown in **Figure 1**.

Figure 1. Flow Chart of Individual-Event SCM Analyses



2.2. SCM Design Variable Sensitivity Analyses

Following development of the unit base models, a sensitivity analysis was devised to vary SCM design parameters within a set of ranges an engineer or designer might consider. The idea was to identify which SCM design parameters were most responsible for runoff volume reduction and peak flow mitigation. **Table 3** below summarizes the range of variables applied to the set of SCMs. A full set of parameters and base case for each SCM are detailed in **Appendix A**. Note, due to the similarity of the results for permeable pavements and infiltration trenches, no sensitivity runs were performed for the infiltration trench.

Table 3. Summary of SCM Variables and Their Associated Ranges

Design Variables	Bioretention	Porous Pavers	Dry Detention	Underground Detention	Green Roof	Grassed Swale	Filter Strip	Soil Renovation
Drainage Area Ratio (%)	1-25	5-50	1-25	1-25	10-100	1-25	1-25	50
HSGs	A-D	A-D	A-D	A,C		A,C	A-D	A-D
Surface Ponding Depth (in)	6-18	0	1-22		0	24*	0.05	0.05
Subsurface Storage Height (in)	18-30	12-36	0	30	2-4	0	0	0
Drain Offset (in)	3-18	0-6	0	0-12	0			
Media Thickness (in)	24-48				2-4			
Media Composition	LS, LS/SL, SL				Mix , LS/SL			
Pavement Permeability (in/hr)		10-1000						
Vegetative Fraction (%)	5				5	0-5		
Surface Roughness (n value)	0	0.012			0.2	0.05-0.41	0.12-0.36	0.2
Slope (%)	0	2			0.5	0.5-2	1-5	2
Side Slope (H:V)						3:1-5:1		
Outlet Diameter (in)			1.3-3.1	2-4				
Underdrain coeff (unitless)	Varies	Varies			Varies			
Hydraulic Conductivity (in/hr)	Based on media				Based on Media			0.04-20.47

**For grassed swales, the depth variable is maximum potential flow depth, not ponding depth. Mix = typical green roof media. LS = loamy sand. SL = sandy loam*

2.3. Annual, Continuous SCM Simulations

The model results necessary to assess the impact of antecedent moisture conditions on the performance of SCMs were created by running continuous, year-long simulations of both the base and selected design parameter sensitivity cases. We compiled three continuous rainfall and temperature data sets from the 62-year data record at Cleveland-Hopkins Airport: a dry year, 1963, with 18.63 inches of total precipitation; an average year, 1979, with 37.95 inches; and a wet year, 2011, with 65.32 inches (**Figure 2**).

The continuous, annual runs calculated daily ET within SWMM using the built-in Hargreaves equation. The Hargreaves method is based on temperature and a correction factor for the amount of solar radiation reaching the earth. This correction factor is based on the difference between the minimum and maximum recorded temperatures for a day. The main energy source that drives ET is solar radiation and the amount of solar radiation reaching the ground is mediated by cloud cover. The assumption is under clear skies the atmosphere is transparent to solar radiation and the maximum temperature is high, while night temperatures are low due to outgoing longwave radiation. Under cloudy skies less radiation reaches the earth, so the maximum temperature is lower and night temperatures are relatively higher as clouds limit outgoing longform radiation. Shahidan, et al. (2012) noted that because at least 80% of reference potential evapotranspiration can be explained by temperature and solar radiation and the difference in temperature over a day is related to humidity and cloudiness, this method, while approximate, provides a reasonable estimate of daily ET.

It is worth noting the Cleveland Hopkins average annual temperature and total rainfall data exhibit a consistent upward trend for both data sets over the period of record. Although we did not explicitly develop “climate change” model scenarios, the 2011 continuous model run represented the largest total annual rainfall over the entire data record from the airport. In work yet to be completed, the NERRS SC project will use precipitation data based on moderate and severe climate change scenarios for mid-century (2050s) to simulate SCM performance under future climate conditions in SWMM and DRAINMOD to evaluate climate change adaptation benefits of LID stormwater controls. Those data have been provided by Drs. Fu and Hathaway of University of Tennessee/Oak Ridge National Laboratory.

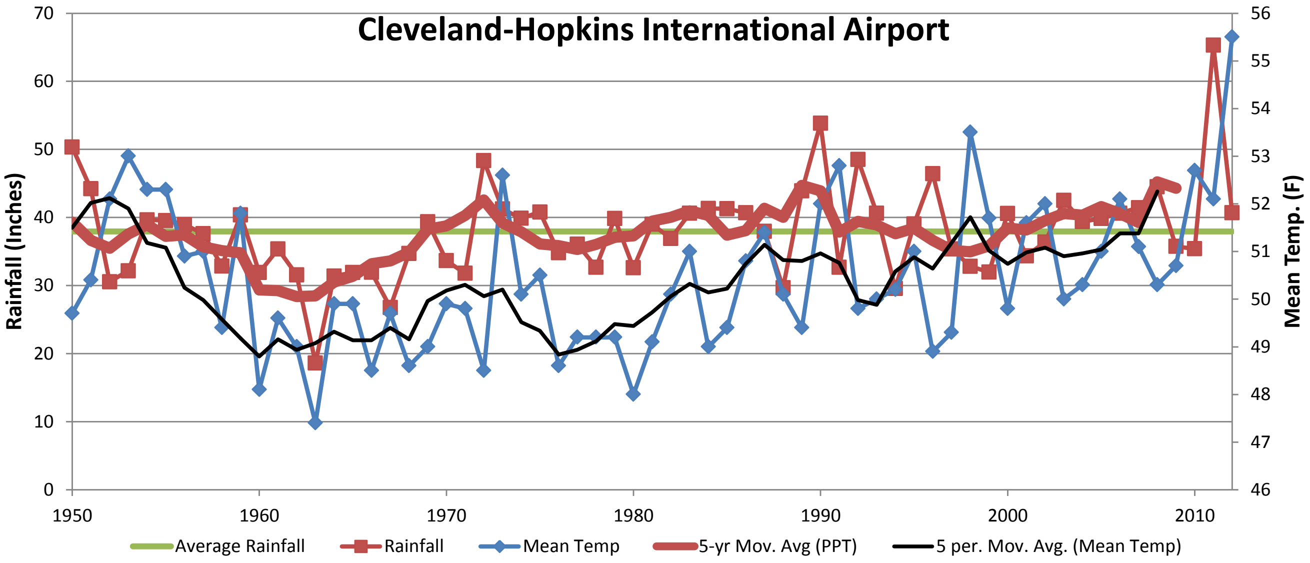


Figure 2. Average Annual Daily Temperature and Total Annual Rainfall for the Cleveland-Hopkins Airport from 1950-2012 (NOAA-NCDC)

2.4. Analysis of SCM Attainment of Water Quality Volume and Critical Storm Event Peak Flow Control

Development in Ohio routinely is subject to the following two post-construction stormwater management requirements:

1. State level requirement to capture and provide extended detention of the water quality volume (WQv), the runoff from an 0.75-inch precipitation event (Ohio EPA, 2013). This requirement is set by Ohio NPDES permits and is calculated as:

WQv = C*P*A/12
WQv = water quality volume (ac-ft)
C = runoff coefficient
P = precipitation (0.75-in)
A= area draining to BMP

For 0.5 acre impervious, assume C = 0.95 and A = 0.5 acre

$$WQv = (0.95)*(0.75in)*(0.5ac)/12 = 0.059ac - ft = 1{,}293ft^3$$

Add 20% for sediment storage:

$$WQv = 1{,}293ft^3 * 1.2 = 1{,}552ft^3$$

2. Local peak discharge (sometimes called flood control) regulations; many Ohio communities have adopted the Critical Storm Method (ODNR, 1980, 2006) for setting peak discharge requirements.

   Calculate Critical Storm Event – ODNR (1980, 2006)

   a. Assumed agriculture/pasture/forest pre-development area is converted to 50% impervious and 50% turf grass (except for green roofs)
   b. Must meet pre-development peak flow for critical event and all more frequent events
   c. 1-yr, 2-yr, 5-yr, 10-yr, 25-yr, 50-yr, 100-yr

The Critical Storm Method (CSM) developed by ODNR (1980) sets standards for stormwater detention based on the percent increase of runoff volume from the 1-year, 24-hour rainfall event for conversion from undeveloped land to post-developed conditions. As the percentage increase from pre- to post-development runoff volume gets larger, the recurrence interval for the event (the "critical storm") that must be captured and released at the 1-year pre-development discharge also gets larger. As would be expected, increasing the impervious area on a development site will result in a bigger increase in post-development runoff volume, a larger critical event size and hence a higher standard for runoff detention.

Though the 1-year, 24-hour rainfall event was not explicitly modeled as part of this study, we felt the modeled runoff volume from the 2.0" rainfall depth adequately represented this event; the depth of the 1-year, 24-hour rainfall event in northern Ohio generally falls between 1.9" and 2.2" (NOAA Atlas 14). **Table 4** summarizes the calculations to determine the critical storm.

Table 4. Calculation of Critical Storm Events for Three Pre-Development Conditions

1-yr Pre-Developed Runoff (cf)			**Post-Dev 1-yr Runoff (cf)**	**Runoff Increase (beyond 1-yr event predeveloped condition)**		
Forest	**Pasture**	**Ag**		**Forest**	**Pasture**	**Ag**
0	0	0	3556	> 500%	> 500%	> 500%
141	235	420	3767	> 500%	> 500%	> 500%
2093	2481	2840	4980	138%	101%	75%
4028	4387	4708	5911	47%	35%	26%

HSG	**Critical Storm Recurrence Interval**		
	Forest	**Pasture**	**Ag**
A	100-yr	100-yr	100-yr
B	100-yr	100-yr	100-yr
C	25-yr	25-yr	10-yr
D	5-yr	5-yr	5-yr

When determining the critical storm event, many communities require the pre- and post-development runoff volumes from the 1-year, 24-hour event be calculated using the NRCS curve number method (CN). Analysis conducted subsequent to the SWMM modeling reported here allowed comparison of SWMM and CN runoff volume predictions, highlighting consistencies and differences in prediction of how much stormwater is abstracted by impervious areas, open space, surface storage, etc. Those comparisons will be considered when further analyzing SCM volume reductions, and developing credits and guidance, to be applied to the Critical Storm Method. However, these are beyond the scope of this study.

3. RESULTS

The modeling outcomes can be divided into three groups based on our confidence in the results and their utility to the overall goals of the project. The first group consists of information invested with a high degree of confidence in its veracity and utility for informing stormwater design and regulatory guidance. These results are characterized by conformance with expectations and performance data from other studies and therefore should be useful for the development of stormwater design/regulatory guidance. This report will focus primarily on the discussion and explication of this first group of results.

The second group is characterized by either confounding results or results that lack sufficient outside verification. Thus, confidence in the veracity and usefulness of the data is somewhat compromised. These results may or may not be a fault of the modeling technique or assumptions; may be a problem endemic to the model software; or simply may currently lack sufficient external verification to draw useful conclusions. This group of results warrants further investigation.

The third group of results is characterized by software issues, in which the model output blatantly diverges from expectations. This issue appears to be traceable to a problem with the representation or algorithm used to model the hydrologic processes. Discussion of the software issues will follow first and then the discussion of the more useful results below.

3.1. SWMM Software Issues

In general the SWMM LID tool results (on a mass-balance basis) appear adequate for the purposes of this exercise. However, we did find three software issues that deserve mention: 1) the underdrain simulation routine, 2) underdrain offset from SCM bottom and 3) swale side slopes.

The first software issue was the apparent misrepresentation of underdrains in SWMM. The control of the outflow rate in the underdrain was set by an equation resembling the standard orifice equation, with a flow coefficient and flow exponent. But the equation given in the manual did not appear to be dimensionally consistent. SWMM model guidance for determining this coefficient appeared to be flawed. Using the SWMM guidance, outflow rates were many times higher than the rates we have observed from field monitoring data. We found it more reasonable to adjust the flow coefficient downward to produce target underdrain outflow rates based on monitoring data from other studies (Dierks, 2013; Toronto and Region Conservation, 2008; University of Guelph, 2013 and Van Seters, et al., 2006).

Another issue encountered in the SWMM LID control was model representation versus real world expectations for abstraction (temporary storage and subsequent exfiltration) of water when the underdrain invert was set exactly at the bottom of the SCM. SWMM assumes water will immediately leave the practice through the drain as soon as the water level reaches the drain invert, resulting in zero or near zero infiltration when the modeled drain invert is placed at the bottom of the SCM. In reality, the excavated bottom of the practice – especially if scarified to enhance exfiltration – will provide some small level of storage as well as a relatively rough, hydraulically inefficient lateral pathway to the drain. In our opinion, using a zero offset in SWMM overestimates the amount of water lost through the underdrain and underestimates the amount of water infiltrating through the bottom of the SCM. Using a small non-zero outlet offset above the bottom of the SCM substantially improved performance. The results below for SCMs with underdrains located at the bottom of the practice reflect SWMM models in which the underdrain invert was placed 0.01 ft above the bottom of the practice.

For the swale side slopes, increasing swale side slopes decreased velocity through the section. This is contrary to reality. Increasing side slopes creates a more hydraulically efficient open channel section. Increased hydraulic efficiency means water moves more quickly through the channel. This is an inherent problem with the model. We should note that since we started this work a new version of SWMM (5.1) has been released. We have not tested the new model swale sub-routine since using the previous version.

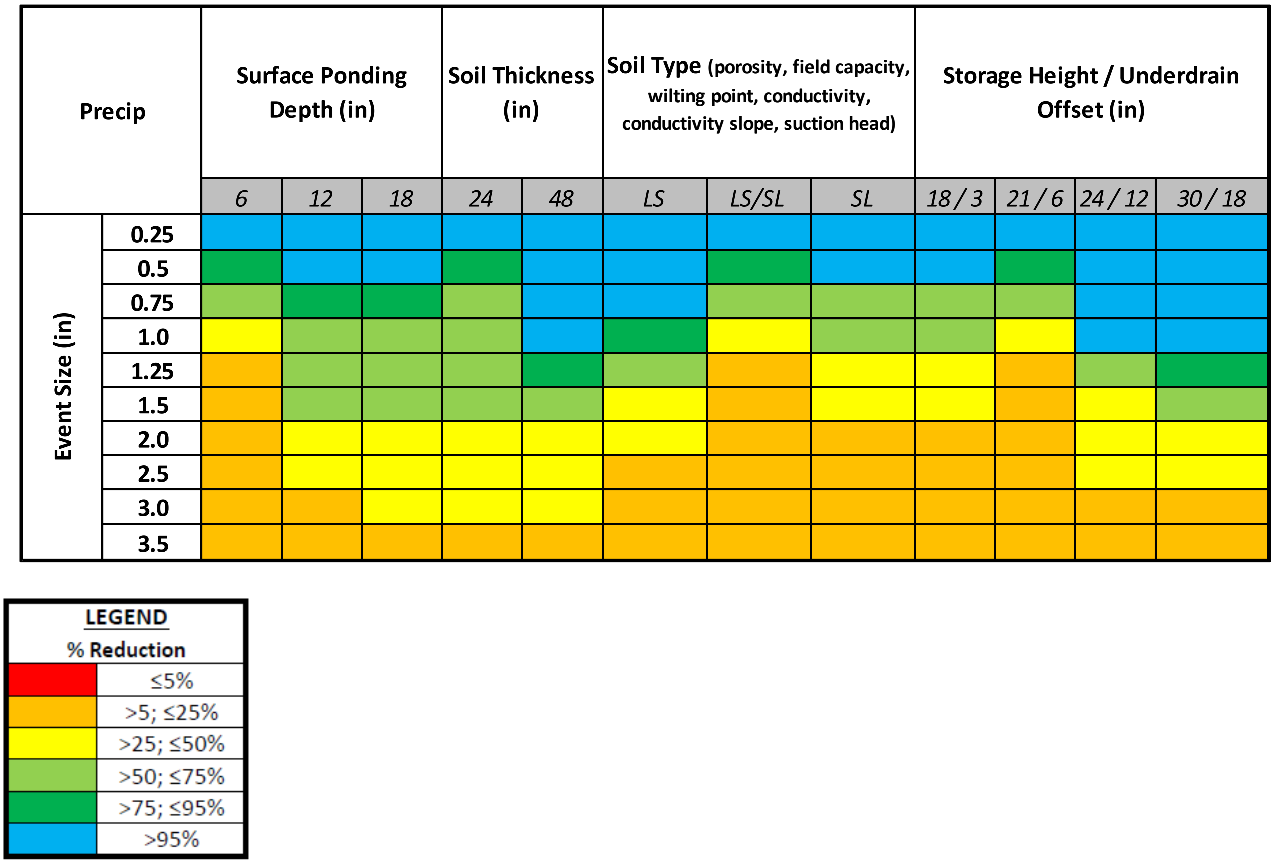
3.2. Single Event – Based Design and Sensitivity Analysis Results

In order to efficiently present the immense amount of information produced, we developed a color-coded interpretive display of the SCM volume and peak reduction performance. This display lays out thousands of data points at one time (bioretention volume and peak flow reduction graphs alone represent 4,800 data points) for a quick comparative survey of all the results. This graphical representation amalgamates the data into six performance categories based on percent volume or peak flow reduction from the developed watershed scenarios. These categories, and an example of their application to a set of volume reduction estimates for bioretention with underlying HSG C soils at a 5% DAR, are shown in **Figure 3** below.

Figure 3 shows this particular bioretention cell infiltrated more than 95% of the WQv (0.75”) event when (1) the base design was modified to include a media thickness of 48 inches, (2) the media was loamy sand, or (3) the underdrain offset was equal to or greater than 12 inches. One can also see performance was somewhat sensitive to all of the particular design variables investigated here; that is, changing the surface ponding, media thickness and type, and underdrain offset design variables all had an effect on performance.

Lastly, much of the post-modeling analysis to determine individual SCM capabilities to meet peak flow mitigation and volume reduction goals focused on C and D soils because most of northern Ohio has HSG C and D soils and these are the most challenging soils over which to implement LID stormwater controls.

Figure 3. Color-Coded Bioretention Volume Reduction Results for HSG C Soils at a 5% DAR



Precip		Surface Ponding Depth (in)			Soil Thickness (in)		Soil Type (porosity, field capacity, wilting point, conductivity, conductivity slope, suction head)			Storage Height / Underdrain Offset (in)			
		6	*12*	*18*	*24*	*48*	*LS*	*LS/SL*	*SL*	*18 / 3*	*21 / 6*	*24 / 12*	*30 / 18*
Event Size (in)	**0.25**	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
	0.5	🟩	🟦	🟦	🟩	🟦	🟦	🟩	🟦	🟦	🟩	🟦	🟦
	0.75	🟢	🟩	🟩	🟢	🟦	🟦	🟢	🟢	🟢	🟢	🟦	🟦
	1.0	🟨	🟢	🟢	🟢	🟦	🟩	🟨	🟢	🟢	🟨	🟦	🟦
	1.25	🟧	🟢	🟢	🟢	🟩	🟢	🟧	🟨	🟨	🟧	🟢	🟩
	1.5	🟧	🟢	🟢	🟢	🟢	🟨	🟧	🟨	🟨	🟧	🟨	🟢
	2.0	🟧	🟨	🟨	🟨	🟨	🟨	🟧	🟧	🟧	🟧	🟨	🟨
	2.5	🟧	🟨	🟨	🟨	🟨	🟧	🟧	🟧	🟧	🟧	🟨	🟨
	3.0	🟧	🟧	🟨	🟨	🟨	🟧	🟧	🟧	🟧	🟧	🟧	🟧
	3.5	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧

LEGEND **% Reduction**	
🟥	≤5%
🟧	>5; ≤25%
🟨	>25; ≤50%
🟢	>50; ≤75%
🟩	>75; ≤95%
🟦	>95%

**LS = loamy sand, SL=sandy loam*

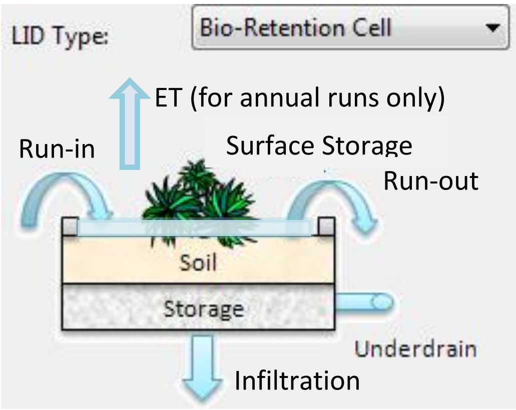
We divided the SCMs into five general types based on their functional characteristics:

- Type 1) storage + infiltration + optional elevated outlet (sump): bioretention, permeable pavements, underground detention/retention, and infiltration trench
- Type 2) storage + infiltration (no sump): dry detention
- Type 3) flow-through or conveyances (little to no storage and limited infiltration): grass swale and filter strips
- Type 4) source control: soil renovation
- Type 5) SCMs with limited storage and no infiltration as a permanent loss: green roofs.

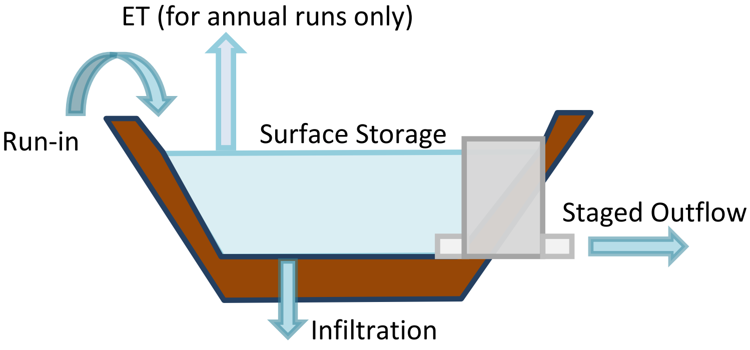
The differences in functional characteristics between these groups are exemplified in the SCM schematics in **Figure 4** below.

Figure 4. SCM Types and Their Functional Differences (each SCM type and their functional processes are exemplified by one example SCM schematic. All SCM schematics can be found in the Appendix)

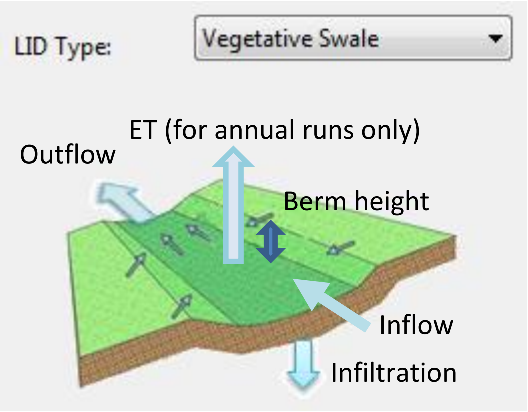
Type 1 SCM: Storage + Infiltration + Optional Sump
Bioretention
Permeable Pavement
Underground Storage
Infiltration Trench


LID Type: Bio-Retention Cell

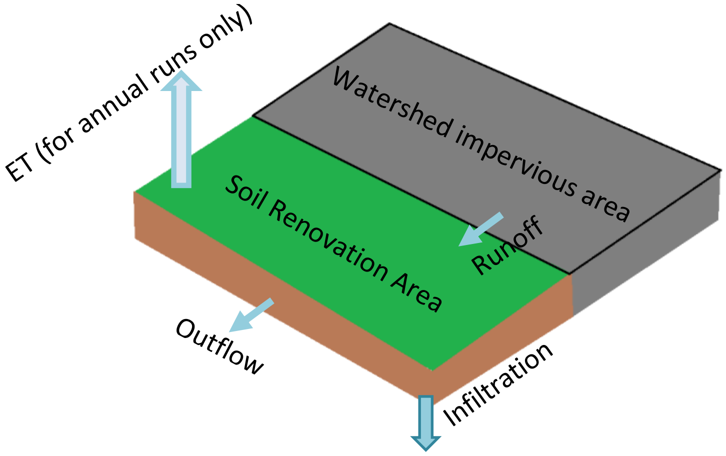
Type 2 SCM: Storage + Infiltration + No Sump
Dry Detention



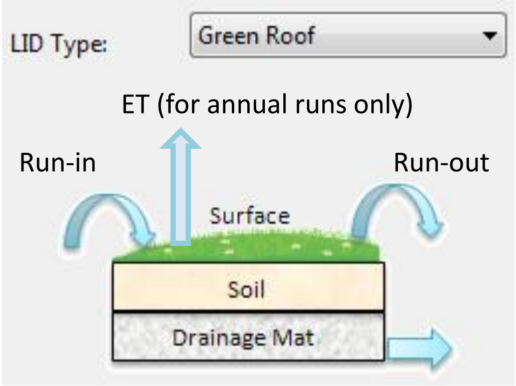
Type 3 SCM: Flow Through: Little to No Storage + Limited Infiltration
Grass Swale
Filter Strip


LID Type: Vegetative Swale

Type 4 SCM: Source Control
Soil Renovation



Type 5 SCM: Storage + No Infiltration
Green Roof


LID Type: Green Roof

The color-coded volume reduction and peak flow control figures for all the individual event analyses are included in **Appendix B**.

The sensitivity of the SCM design variables for Type 1 and 2 SCMs are represented by a semi-quantitative assessment of the change in performance between the base condition and the design variable sensitivity conditions. Sensitivity has been ranked by its capacity to change volume and peak flow control performance and is summarized in **Tables 5** and **6** below. 'Highly sensitive' results have performance improvements that span several rain event depths (more than three) and the maximum range of improvement jumps more than two categories in magnitude; e.g., from a reduction category of 5%-25% up to 50%-75% or more. Moderate sensitivity spans a few event depths (less than three) and a maximum range of improvement of up to two categories. Low sensitivity spans one or two event depths and a maximum increase of one category. 'No sensitivity' means there is no discernible change across the range of values for a design variable. These results are discussed in more detail below.

Table 5. Sensitivity of Volume Reduction Results to SCM Design Parameters for Type 1 and 2 SCMs

Design Variables	Bioretention				Porous Pavers				Dry Detention				Underground Detention			
	A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D
Surface Ponding Depth (in)	1	1	2	3					2		2					
Subsurface Storage Height (in)	4	4	1	1	4	4	4	4							3	
Drain Offset (in)					1	1	1	1						1	1	
Media Thickness (in)	4	4	1	2												
Media Composition (in)	2	2	2	2												
Pavement Permeability (in/hr)					4	4	4	4								
Outlet Diameter (in)														-1	-1	

(1=highly sensitive; 2=moderate; 3=low; 4= not sensitive; -1 = degradation of performance)

Table 6. Sensitivity of Peak Flow Reduction Results to SCM Design Parameters for Type 1 and 2 SCMs

Design Variables	Bioretention				Porous Pavers				Dry Detention				Underground Detention			
	A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D
Surface Ponding Depth (in)	1	1	2	3					2		2					
Subsurface Storage Height (in)	4	4	3	3	4	4	4	4							1	
Drain Offset (in)					1	1	1	1						1	1	
Media Thickness (in)	4	4	3	4												
Media Composition (in)	3	3	2	2												
Pavement Permeability (in/hr)					3	3	3	3								
Outlet Diameter (in)														-1	-1	

(1=highly sensitive; 2=moderate; 3=low; 4= not sensitive; -1 = degradation of performance)

3.2.1. Type 1 & Type 2 SCMs: Storage + Infiltration + (for Type 1 only) Optional Sump

Table 7 summarizes volume reduction in terms of the WQv event (0.75" ppt) for all SCMs and all soil classes.

SCM hydrologic performance was highly dependent on DAR and underlying soils, but also reflected the number of functional characteristics, total depth of storage (ponding + subsurface storage), and sump depth (raised outlet). The Type 1 and 2 SCMs with storage, infiltration and sumps produced the best volume and peak flow reductions. Type 1 and 2 SCMs provided retention time for water to be lost via infiltration and evapotranspiration, regardless of whether the storage was aboveground or below. Bioretention with a sump exhibited the best volume and peak flow control performance overall. Pervious pavements and underground detention outfitted with at least a 6-inch sump (orifice offset 6-inches above the bottom) met the WQv through infiltration.

Permeable pavements, underground storage and bioretention were the three most versatile SCMs. Permeable pavements offered versatility because they blended gray and green infrastructure. Permeable paving can be strategically used in a spatially extensive manner as part of the hardscape – parking lots and low-use roads and driveways – AND provided excellent hydrologic benefits. Similarly, underground detention provided extensive hydrologic benefits while not consuming valuable aboveground space. Bioretention offered versatility by possessing the greatest number of functional characteristics – both above-ground and below-ground detention to provide time for infiltration and ET of temporarily stored water, and the use of an optional sump to increase infiltration and ET.

Bioretention volume reduction was most sensitive to ponding depths for A and B soils and sump depth for C and D soils. Bioretention located in C and D soils was also fairly sensitive to media thickness. The effect of surface ponding depth on A and B soils diminished as the DAR increased. The effect of ponding depth was almost absent by the time the DAR reached 10% and was zero by 25%. At low DARs (1%-5%), additional surface ponding helped improve performance with A, B, and C soils but did not help for D soils because as soon as the sump filled, any additional water was lost out the underdrain due to low exfiltration rates.

For peak flow reduction with bioretention, all HSG cases were most sensitive to ponding depth, with C and D soils also moderately sensitive to media composition. Across all HSGs as the DAR increased, the smaller event peak flows get reduced more than 95%, so the increased storage with additional ponding and media depth became less relevant for these small event sizes. For larger events storage depths still mattered.

Table 7. Comparison of SCM Performance to Ohio EPA Water Quality Volume (WQv)

HSG	**A**					**B**				
DAR (%)	**2**	**5**	**10**	**25**	**50**	**2**	**5**	**10**	**25**	**50**
Bioretention	Ponding > 12"	🟦	🟦	🟦	*Not Run*	🟥	🟦	🟦	🟦	*Not Run*
Porous Pavers	*Not Run*	*6" sump*	🟦	🟦	🟦	*Not Run*	🟥	6" sump	🟦	🟦
Underground Storage	*Not Run*	*Not Run*	*Not Run*	*Not Run*	*Not Run*	🟥	*sump >3"*	*sump >0*	🟦	*Not Run*
Dry Detention	Alt 2	🟦	🟦	🟦	*Not Run*	🟥	🟥	🟥	🟦	*Not Run*
Grass Swales	🟥	🟥	🟥	🟦	*Not Run*	*Not Run*	*Not Run*	*Not Run*	*Not Run*	*Not Run*
Filter Strips	🟥	🟥	🟦	🟦	*Not Run*	🟥	🟥	🟥	🟥	*Not Run*
Infiltration Trenches	*Not Run*	*Not Run*	*Not Run*	*Not Run*	*Not Run*	*Not Run*	*Not Run*	*Not Run*	*Not Run*	*Not Run*
Green Roofs	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥
Soil Renovation	*Not Run*	*Not Run*	*Not Run*	*Not Run*	>base infil	*Not Run*	*Not Run*	*Not Run*	*Not Run*	>base infil

HSG	**C**					**D**				
DAR (%)	**2**	**5**	**10**	**25**	**50**	**2**	**5**	**10**	**25**	**50**
Bioretention	🟥	48" soil, LS or >12" sump	🟦	🟦	*Not Run*	🟥	30" storage & 18" sump	🟦	🟦	*Not Run*
Porous Pavers	*Not Run*	🟥	🟥	All but no sump	🟦	*Not Run*	🟥	🟥	All but no sump	🟦
Underground Storage	🟥	🟥	Sump > 3"	sump >0	*Not Run*	*Not Run*	*Not Run*	*Not Run*	*Not Run*	*Not Run*
Dry Detention*	🟥	🟥	🟥	Alt 2	*Not Run*	🟥	🟥	🟥	🟥	*Not Run*
Grass Swales	🟥	🟥	🟥	🟥	*Not Run*	*Not Run*	*Not Run*	*Not Run*	*Not Run*	*Not Run*
Filter Strips	🟥	🟥	🟥	🟥	*Not Run*	🟥	🟥	🟥	🟥	*Not Run*
Infiltration Trenches	🟥	🟥	🟥	🟦	*Not Run*	🟥	🟥	🟥	🟦	*Not Run*
Green Roofs	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥
Soil Renovation	*Not Run*	*Not Run*	*Not Run*	*Not Run*	≥ high infil	*Not Run*	*Not Run*	*Not Run*	*Not Run*	≥ max infil

Notes: Blue with no text = infiltrated WQv under all scenarios, blue with text = infiltrated WQv with designs indicated, red = WQv not infiltrated. All scenarios run without ET losses. Dry detention Alt. 2 run for A and C soils only.

The other Type 1 SCMs - permeable pavements, infiltration trenches and underground detention - were most sensitive to raised underdrains. This was consistent with observed behavior and intuition. Water stored below the underdrain had a longer residence time in the SCM and consequently more potential to infiltrate or evapotranspire. As expected, permeable pavements were relatively insensitive to the depth of the underground storage alone. The difference in travel time between the 12-inch and 24-inch aggregate depths in the model was insignificant so the impact on peak discharge was minimal, and volume reduction was not affected at all. However, as the IWS zone thickness increased, both runoff volumes and peak flows were reduced. Flow control added to the underdrain – in this case an orifice with a smaller diameter – allows further management of peak discharge. With added aggregate depth and flow rate control, it may be possible to totally meet peak discharge requirements with permeable pavement.

Pavement permeability did not appear to affect performance of permeable pavement systems. The lower limit of paver permeability was set at 10 inches/hour, a reasonable infiltration rate for a partially clogged paver surface. This lower infiltration rate still was fast enough to drain runoff without negatively affecting volume and peak flow reduction. This was not surprising since the mostly clogged paver infiltration rate is 4, 19, 83 and 250 times faster than the model infiltration rates for underlying A, B, C and D soils respectively. The underlying soils will have more of an impact on permeable pavement system performance than partially clogged pavements as long as the DAR is greater than 33% and the paver surface infiltration rate is $\geq$ 10 inches/hour.

Dry detention appeared to be the SCM most sensitive to underlying HSG for volume control. The DAR thresholds for fully infiltrating the WQv for A and B soils are 5% and 25%, whereas C soils and D soils can only infiltrate up to 90% and 67% of the WQv at the 25% DAR, respectively. These volume reduction outcomes carry over to peak discharge results, as the volume reduction benefits on C and D soils are not significant enough to affect peak discharge for the 2-inch and larger events targeted by peak discharge control requirements, whereas exfiltration from dry basins on HSG A and B soils may be significant.

3.2.2. Type 3 SCMs: Flow-Through or Conveyance

Type 3 SCMs are flow-through SCMs: grassed swales and filter strips. These SCMs possess fewer functional characteristics. Grassed swales and filter strips slow and filter stormwater as shallow flow moves through the grass. Neither practice detains stormwater, limiting opportunity for infiltration or evapotranspiration. However, it was possible to improve their respective modeled performance by slowing the rate of water movement through the SCM. In the case of grassed swales and filter strips, decreasing slope and/or increasing vegetation density (and therefore roughness) effectively slowed the water down and improved both volume and peak flow control performance. Decreasing swale side slopes will also help in this regard, though likely not much; however, what appears to be inaccurate representation of swale side slopes in SWMM prevented this analysis. Grass swales at 25% DARs and filter strips at 10% and 25% DARs on A soils can infiltrate the WQv.

3.2.3. Type 4 SCM: Soil Renovation

Soil renovation as a source control is a unique SCM. Only a 50% DAR scenario for each HSG was modeled. At infiltration rates indicative of natural landscapes, soil renovation showed the capacity to capture the WQv and significantly reduce peak discharge, even on D soils. By renovating an existing soil, whether by soil amendments or by planting deep-rooting plants, the water holding and infiltration capacities increase. There is a growing body of literature that these impacts can be significant (Selbig and Balster, 2010; University of Minnesota, 2011, Dierks, 2014). The research showed on average, across all soil types, infiltration capacities increased between two and four times between cultivated landscapes – row crops, active pasture and turf grass - and restored or native landscapes. Infiltration rates increased up to ten and twenty times from cultivated to restored/native landscapes were observed.

Research into “Urban Soil Husbandry” and “Suburban Subsoiling” has shown potential to reclaim the runoff abstraction potential of our disturbed soils. Schwartz (2012) has been working with chisel plowing and deep-tilling in combination with compost amendment to decompact urban and suburban soils. As shown by Balousek (2003), chisel-plowing and deep tilling reduced runoff from silty soils during the 2002 growing season by 36% - 53% and, when compost was added, by 74% to 91%.

Soil renovation could simply entail exclusion of typical site development practices. Clear-cutting, clearing and grubbing, and indiscriminately compacting to homogenize the development envelope is unnecessary and destroys soil structure.

This SCM shows great promise because it has several linked benefits that accrue from its application, particularly by implementing it as part of a native planting project. These benefits include stormwater control, carbon sequestration, heat island mitigation, native habitat for pollinators, etc. It also shows promise as a way to renovate and/or improve the performance of other SCMs, particularly dry detention, filter strips, and grassed swales.

However, the benefits of a planted SCM tend to be time-dependent, on the scale of a few to many years after planting, and there is still a great deal of uncertainty about how to predict benefits in advance of performing the soil renovation. There is a need to investigate and learn how to credit this kind of practice in the future.

3.2.4. Type 5 SCM: Green Roof

For green roofs, short of increasing the total green roof area, increasing the depth of the planting media was the number one change in this analysis that improved both volume and peak flow control. Fassman-Beck, et al. (2013) also recommended lengthening the flow path and the use of “drainage-retarding” materials in the drainage layer. These recommendations were not tested in this analysis.

Without the capacity to infiltrate water into underlying soils, green roofs have only ET as the permanent loss route. This limits the use of this SCM to meet the WQv or reduce the critical storm event size. The green roof SCM reduced the WQv event less than 5% for 10% roof coverage and between 50% and 75% for 100% roof coverage. By comparison Fassman-Beck, et al. (2013) measured green roof rainfall retention of between 20% and 95% for rainfall near the WQv event (0.75-inches).

3.3. SCM Results for Continuous, Annual Hydrograph Runs

As expected, volume and peak reductions improved substantially moving from wet to dry years. As the total annual rainfall decreased, a higher percentage of runoff was stored, infiltrated or evapotranspired. In fact, after completing several early continuous, annual model runs, dry year runs were eliminated from further analysis because the average and wet years were more representative of the performance constraints we were interested in testing.

The differences between single event and continuous annual runs were not compared systematically. We initially thought we might be able to compare annual statistics versus individual event statistics, but realized the individual events contained in the continuous, annual simulation need to be tallied and categorized by antecedent moisture conditions and event size. The annual event runs were meant as a check on SCM performance as predicted by the individual event runs, but this proved more difficult than initially expected.

The individual event runs assumed all soils were at field capacity, that is, all the pore space that could drain via gravity was available to infiltrate water. In the continuous run mode, SWMM calculated the dynamic changes in pore space availability and determined the impact of ET over time as part of the overall hydrologic calculations. If water was available at the surface or subsurface, then SWMM abstracts up to the PET-calculated amount for the day.

Without more detailed comparison of individual event and continuous, annual simulations, it can only be hypothesized that during wet seasons ET will not completely offset the impact of antecedent moisture conditions on SCM volume and peak flow reductions. More antecedent moisture means less available water storage over an average water year for any given SCM, even considering ET losses. Rainfall that occurs over several days will tend to lower the amount of available storage, meaning incoming water is more likely to completely or partially bypass the SCM. However, this conclusion was based on a cursory analysis and impacts of back-to-back runoff events on SCM volume and peak flow reduction deserve more detailed analysis.

One result that deserves comment is a comparison of estimated average annual green roof volume reductions and the results from a recent green roof hydrology study. Fassman-Beck, et al. (2013) collected eight months of data over two years of monitoring four extensive living roofs and three control roofs in Auckland, New Zealand. The green roof media depths were between two and six inches. Interestingly, they found an average 56% retention of total rainfall over that period, compared to our modeled average annual year reductions of 5%-25% for a 2-inch thick roof and 25%-50% reductions for a 4-inch thick roof.

4. CONCLUSIONS AND RECOMMENDATIONS

Even with poorly drained soils, there is a place for LID SCMs in the stormwater toolbox for stormwater management in northern Ohio. In fact, for SCMs that combine multiple functional characteristics like surface ponding, subsurface storage, and sumps to enhance infiltration, there appeared to be a reasonable range of realistic design options to partially or completely meet the Ohio EPA WQv requirement through infiltration and evapotranspiration. These volume reductions may help to reduce the critical storm event and meet other local stormwater management requirements.

While this study managed to produce more than 30,000 model runs, not all the results were analyzed exhaustively. We did not spend much time analyzing the year-long, continuous simulations. Before developing a crediting system for LID SCMs, we believe the continuous simulations deserve additional analysis. For instance, if a crediting system counts above and below ground storage, should any allowance be made for antecedent moisture conditions? If so, how would adjustments to below ground storage be made to account for antecedent moisture?

Another aspect of stormwater management not included in this study is the impact of winter conditions – snow, ice and ground freezing. While it is appropriate to be concerned about this aspect of performance, winter typically does not generate a lot of runoff. Spring thaw has a greater impact on SCM hydrologic performance. However, there is work that shows freezing and thawing are complicated and spatially varied processes. For example, Davidson, et al. (2008) found three out of four bioretention cells continued to infiltrate runoff during three winter monitoring seasons in Minnesota, while the fourth cell was limited primarily by tight soils.

Drainage area ratio (DAR) and the underlying soil are key criteria when selecting SCMs and considering design options. DAR is a simple criterion that should provide designers a tool for preliminarily sizing their SCMs. The importance of soils to modeled SCM performance reinforces the importance of knowing a site's soils and soil properties. As a corollary, this work also emphasizes the value that can accrue from managing soil ecological resources in a manner that enhances their hydrologic properties.

4.1. Conclusions

1. SCM performance was most sensitive to DAR and underlying soil types. They were the primary drivers of SCM sizing to meet runoff reduction goals. The crediting system should start from allowable or recommended DARs, as a function of the type of SCM, and underlying soil type.

2. Sumps or IWS zones improve SCM performance for all infiltrating SCMs even over the tightest of soils. These sumps or IWS zones require some offset of the outlet above the interface of the bottom of the SCM.

3. Bioretention was the most hydrologically effective SCM studied and has the capacity to fully infiltrate the WQv at DARs between 5% and 10% for all soil types with appropriate designs. This was due to the number of functional characteristics it employs.

4. Permeable pavement, bioretention and underground storage appear to be the most versatile SCMs studied. Permeable pavement is an effective SCM that doubles as a parking or driving surface. Underground storage provides hydrologic benefits without sacrificing any buildable area. Bioretention is a versatile SCM due to both its hydrologic performance and versatility for placement in the built landscape.

5. The lowest DAR threshold for Type 1 and 2 SCMs (bioretention, permeable pavements, underground storage, infiltration trenches, and dry detention) on C and D soil should be set no lower than 2%. DARs of 1% may have some utility on A and B soils but other design considerations, such as limiting potential clogging, can also dictate DAR thresholds. For instance, design guidance for permeable paving systems typically recommends no more than 2 acres of impermeable pavement drain to each acre of permeable pavement, in particular to limit solids clogging of the open spaces in the permeable pavement surface.

6. While flow-through SCMs (swales and filter strips) do not by themselves meet the WQv or peak flow control criteria, they have utility for protecting other SCMs that primarily rely on infiltration for flow control. In addition, the effectiveness of these flow-through SCMs can be improved by slowing water velocity through the SCM.

7. The relationship between using explicit infiltration modeling versus the curve number method has not been explored as part of this project. There may or may not be a conflict between modeling with the Green Ampt method but providing credits via curve numbers. This issue will also need to be addressed before finalizing a crediting system.

4.2. Recommendations

This section presents recommendations to expand or improve on the research described in this report. A set of general recommendations is followed by a more detailed treatment of crediting systems.

1. Before finalizing any crediting system, model performance should be calibrated and/or validated to the monitoring data being collected through this project.
2. Analyze the cistern - rainwater harvesting volume credit (SWMM)
3. Analyze wet detention basin and stormwater wetland hydrologic performance (SWMM)
4. Conduct a sensitivity analysis to evaluate sensitivity of model results to climate predictions (e.g., 50%, 200% of projected change)
5. Determine via modeling if/how offsetting WQv and/or peak flow through infiltration affects WQv drain time
6. Develop detailed performance curves based on percent reductions
7. Confirm the infiltration trench SCM performs hydrologically similarly to the permeable pavement SCM.
8. While there has been some work to show DRAINMOD is a better model for simulating seepage and underdrain flows (Brown, 2013), the movement of water through soil media and aggregate to underdrains, and out of the SCM, will benefit from more detailed research.

9. Monitor the drainage changes of grass-lined and mowed detention basin converted to a deep-rooted, native landscape. This should be done for several combinations of drainage areas, soil types, native landscapes, and time since naturalization in order to systematize the impacts of naturalization on BMP hydrologic improvements.

Proceeding on to a crediting system can move in several parallel directions. These directions include: 1) development of a WQv crediting system; 2) development of a critical storm event crediting system and 3) development of a soil renovation crediting system. The first two crediting systems can proceed directly from this project, while the soil renovation credit will require more direct research, including field and modeling investigations, along with collaboration with other researchers, organizations and agencies also working on this issue.

4.2.1. Recommendations for Development of a WQv Credit

The foundation of a WQv crediting system has been developed here. The next step should be to use the NERRS SCM monitoring data to validate and calibrate SWMM and DRAINMOD models of these SCMs. This validation/calibration process should help confirm or refine the standard model set-up used to evaluate SCM performance for this project. The full monitoring results are just now becoming available. The comparison of field monitored and modeled data will occur following completion of this report.

The validation process should compare SWMM and DRAINMOD models of the same SCM type. It would be useful, in particular, to see if more accurate simulation of underdrain with DRAINMOD could inform SWMM modeling. We do not believe detailed concurrence between the models is necessary to move ahead with a WQv crediting system based primarily on SWMM modeling, but it would be helpful to refine guidance for selecting appropriate values of the SWMM underdrain model parameters.

The WQv credit will likely be based on 1) an active storage volume definable outside of SWMM and 2) an estimate of infiltration that will primarily be defined by field testing. SWMM acts like a water accounting system that helps balance water inputs and outputs to develop reasonable estimates of SCM performance. The imprecision of monitoring and modeling has to be built into performance estimates and designs based on those estimates using a factor of safety approach.

A crediting system should be versatile enough to encourage the use of SCMs like filter strips and vegetated swales that perform relatively poorly for volume reduction but offer other benefits, most notably improved water quality. Criteria other than hydrologic control will have to be created that will locate and size these features appropriately. For instance, some kind of pretreatment criteria will be necessary to protect the surfaces of infiltrating SCMs from clogging. Filter strips and vegetated swales could contribute to meeting this sediment control goal.

The year-long, continuous simulations should be analyzed to determine the potential impact of event timing and duration on SCM hydrologic performance. This kind of analysis will help determine if the WQv credit could safely be based on the available storage, aboveground and belowground, or would have to be adjusted downward to provide a factor of safety for events occurring in succession. For instance, the event analysis could correlate reductions by event size with total precipitation during the previous 48-hours (or other duration) preceding the event. Obviously, the more precipitation that occurs before a particular event, the harder it is for an SCM to manage that event. The question to be answered is to what extent, if any, should this degradation in performance be accounted for in the crediting system?

4.2.2. Recommendations for Development of a Critical Storm Event Credit

While we did look at the capacity of SCMs to reduce peak discharge, we did not analyze the relationship of the proposed critical storm event credit to peak runoff performance. The proposed credit would reduce the estimated 1-year post-developed runoff volume used to calculate the critical storm event recurrence interval (refer back to Sec.2.4). That is, the permanent runoff volume reduction through the use of SCMs for the 1-year post-developed event would be deducted from the post-developed runoff volume to get a smaller event recurrence interval. We analyzed the capacity of the SCMs to reduce peak flow. Additional work is needed to determine how this credit would affect overall site design.

In the end, site peak flow reduction will have to be demonstrated via an appropriate site model. State guidance can provide recommended model parameterization. The example site models to be prepared outside of this technical memorandum will initiate the process of demonstrating appropriate modeling techniques for simulating system performance and capturing the most appropriate crediting system.

4.2.3. Recommendations for a Soil Renovation Credit System

Currently soil renovation is infrequently practiced and inconsistently applied. Development of a soil renovation credit would help promote more widespread application of soil renovation practices and would have wide-ranging implications for stormwater and landscape management. These practices could be applied to all open spaces with compacted soils as well as to the bottoms and sides of all vegetated SCMs, including detention basins.

Soil renovation should include a combination of:

1. Disturbance limitations; e.g., conservation development
2. Disturbance with associated renovation practices for open space development, and
3. Guidance that includes soil renovation practices as part of SCM design and construction

The crediting system would include some kind of credit for each of the three practices above. The current state guidance (Ohio DNR, 2006) already provides a “penalty” for open space development that assumes typical land development practices, such as clearing and grubbing, topsoil harvesting and compaction. This penalty essentially requires the designer/builder who will rely on these practices to assume the condition of the soil following construction will be equivalent to subsoil characteristics. In many cases this decreases the assumed HSG for modeling by one class; e.g., if the original soil was an A soil, following construction, it would be assumed to be a B soil, and so on. This is defined in more detail in the Rainwater manual.

For the first type of credit, for land not cleared and grubbed, graded and compacted, the designer/builder could be allowed to assume the soil retains its original HSG classification and associated hydrologic function. Beyond that it is conceivable credits could promote improvements to soil that would improve either its existing condition or its post-construction condition.

As noted previously, a growing body of research demonstrates soil renovation techniques (such as tillage and/or amending with compost and/or planting a native vegetative cover) can substantially improve surficial soil water properties including infiltration and water holding capacity (Schwartz, 2012: Balousek, 2003; Selbig and Balster, 2010; University of Minnesota, 2011, and Dierks, 2014). This kind of improvement potentially would conflict with current landscaping standards in the United States. We have all grown accustomed to manicured lawns, whether in our front lawns or in detention basins. Overcoming these social expectations may be the biggest impediment to widespread use of soil renovation techniques, especially those including native vegetation. Translating research results into significant, yet defensible, credits may begin to shift perceptions and expectations.

The change in soil water properties due to soil renovation is a highly variable and time-dependent process. Variability can be dealt with by defining it in statistical terms and defining the credit within a statistical “middle ground” – as some range around median behavior. Developing a credit based on a time dependent process, could be a little more complicated. Some ideas on how to address the issue of time-dependency could include:

1. Build the SCMs at the beginning of a land development process. Either evaluate or credit performance at or for the time they come on line, respectively.
2. Build SCMs concurrently with hardscape. Use appropriate credits to size SCMs. Reserve space for potential expansion or additional SCM(s). Test/monitor projected performance. If performance meets or exceeds expectations, the potential SCM expansion space can be used for hardscape development. If performance falls below expectations, the expansion space is used for SCMs.
3. Future soil renovation credits could be “banked” once realized and sold or used for additional development in a watershed.
4. Soil renovation credits could be used/applied as factor of safety credits or climate change credits.

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APPENDIX A

BMP INPUT PARAMETERS

BIORETENTION

🟩 Green = Default Parameters

Phase 2 Variable	SURFACE				
	Variable	Min	Median	Max	
1	Storage Depth (in)	6	12	18	
	Vegetative Fraction	0.05			
	Surface Roughness	0			
	Surface Slope	0			
	SOIL				
	Variable	Min	Median	Max	
2	Thickness (in)	24	-	48	
3	Soil Type	loamy sand	loamy sand/ sandy loam	sandy loam	
	Porosity	0.437	0.445	0.453	
	Field Capacity	0.105	0.145	0.19	
	Wilting Point	0.047	0.066	0.085	
	Conductivity	0.5	1	2	
	Conductivity Slope	6	6.5	7	
	Suction Head	2.41	3.37	4.33	
	STORAGE				
	Variable	Min			Max
4 (linked w/drain offset)	Height (in)	18	21	24	30
	Void Ratio	0.67			
	Conductivity	varies with HSG of existing soils			
	Clogging Factor	0			
	UNDERDRAIN				
	Variable	Min			Max
	Coefficient	Varies to reach peak discharge of 0.1-0.2 cfs			
	Drain Exponent	Set to represent orifice scenario			
4 (linked w/ storage height)	Drain Offset (in)	3	6	12	18

GRASS SWALE

🟩 Green = Default Parameters

Phase 2 Variable	SURFACE			
	Variable	Min	Median	Max
	Storage Depth (in)	24		
1	Vegetative Fraction	0	0.01	0.05
2	Surface Roughness	0.05	0.15	0.41
3	Surface Slope	0.5	1	2
4	Swale Side Slope	3:1		5:1

POROUS PAVEMENT

🟩 Green = Default Parameters

Phase 2 Variable	SURFACE			
	Variable	Min	Median	Max
	Storage Depth (in)	0		
	Vegetative Fraction	0		
	Surface Roughness	0.012		
	Surface Slope	2		
	PAVEMENT			
	Variable	Min	Median	Max
	Thickness (in)	3.15		
	Void Ratio	0.25		
	Impervious Surface Fraction	0		
1	Permeability (in/hr)	10	100	1000
	Clogging Factor	0		
	STORAGE			
	Variable	Min	Median	Max
2	Height (in)	12	24	36
	Void Ratio	0.54		
	Conductivity	varies with HSG of existing soils		
	Clogging Factor	0		
	UNDERDRAIN			
	Variable	Min	Median	Max
	Coefficient	Varies to reach peak discharge of 0.1-0.2 cfs		
	Drain Exponent	0.5		
3	Drain Offset (in)	0	3	6

DRY DETENTION

🟩	Green = Default Parameters					
Phase 2 Variable	Storage Unit					
No variables, 2 Scenarios	Variable	1%	2%	5%	10%	25%
	Storage Depth: WQv (ft)	1.8	1	0.42	0.21	0.1
	Storage Area: WQv (ft^2)	4,356	8,712	21,780	43,560	108,900
	Infiltration	Controlled by HSG				
	Outlet Diameter (in)	1.31	1.59	2.02	2.4	3.14

GRASS FILTER STRIP

🟩 Green = Default Parameters

Phase 2 Variable	Storage Unit					
	Variable	1%	2%	5%	10%	25%
	Strip Width: Flow Path to Drain (ft)	2	4	11	22	55
	Area (ft^2)	436	871	2,178	4,356	10,890
		Min		Medium	Max	
1	Slope (%)	1%		2%	5%	
2	Manning's n	0.12		0.24	0.36	
	Infiltration	Controlled by HSG				

SOIL RENOVATION

🟩 Green = Default Parameters

Phase 2 Variable	Soil Renovation			
	Variable	50% - 21,780 ft^2		
		Min	Medium	Max
	Slope	2%		
	Manning's n	0.2		
1	Hydraulic Conductivity - A	2.35	5.91	20.47
	Hydraulic Conductivity - B	0.52	2.28	7.09
	Hydraulic Conductivity - C	0.12	0.35	0.75
	Hydraulic Conductivity - D	0.04	0.12	1.42

UNDERGROUND DETENTION

🟩 Green = Default Parameters

Phase 2 Variable	Storage Unit				
2 Scenarios	Variable	Min	Median	Max	
	Storage Depth (in)	48			
	Infiltration	Controlled by HSG			
1	Outlet diameter (in)	2		4	
	Outlet Slope	5% at lowest; will increase as sump depth increases			
2	Sump depth (in)	0	3	6	12

GREEN ROOF

🟩	Green = Default Parameters			
Phase 2 Variable	SURFACE			
	Variable	Min	Median	Max
	Storage Depth (in)	0		
	Vegetative Fraction	0.05		
	Surface Roughness	0.2		
	Surface Slope	0.50%		
	SOIL			
	Variable	Min	Median	Max
1	Thickness (in)	2	-	4
2 (linked w/void ratio)	Soil Type		loamy sand/ sandy loam	typical green roof mix
	Porosity		0.445	0.453
	Field Capacity		0.145	0.19
	Wilting Point		0.066	0.085
	Conductivity		2.05	1.5
	Conductivity Slope		6.5	7
	Suction Head		3.37	4.33
	STORAGE			
	Variable	Min	Median	Max
3	Height (in)	2	-	4
2 (linked w/soil type)	Void Ratio		0.80	0.83
	Conductivity (in/hr)	0		
	Clogging Factor	0		
	UNDERDRAIN			
	Variable	Min	Median	Max
	Coefficient	Set high enough to ensure soil limits, not drain		
	Drain Exponent	0.5		
	Drain Offset (in)	0		

APPENDIX B

BMP SENSITIVITY RUNS

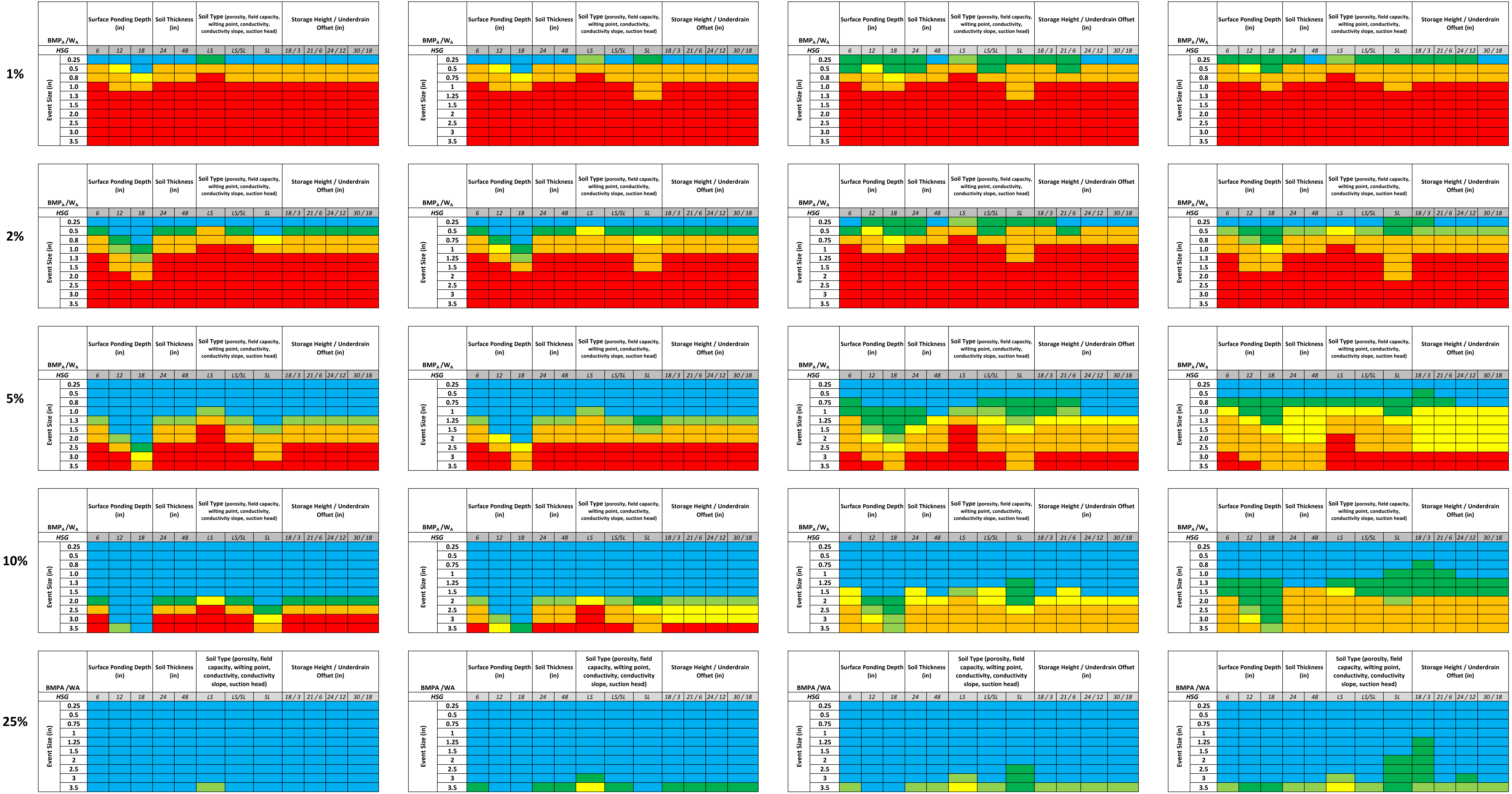
BIORETENTION

HSG A - Peak Outflow Rate (cfs)

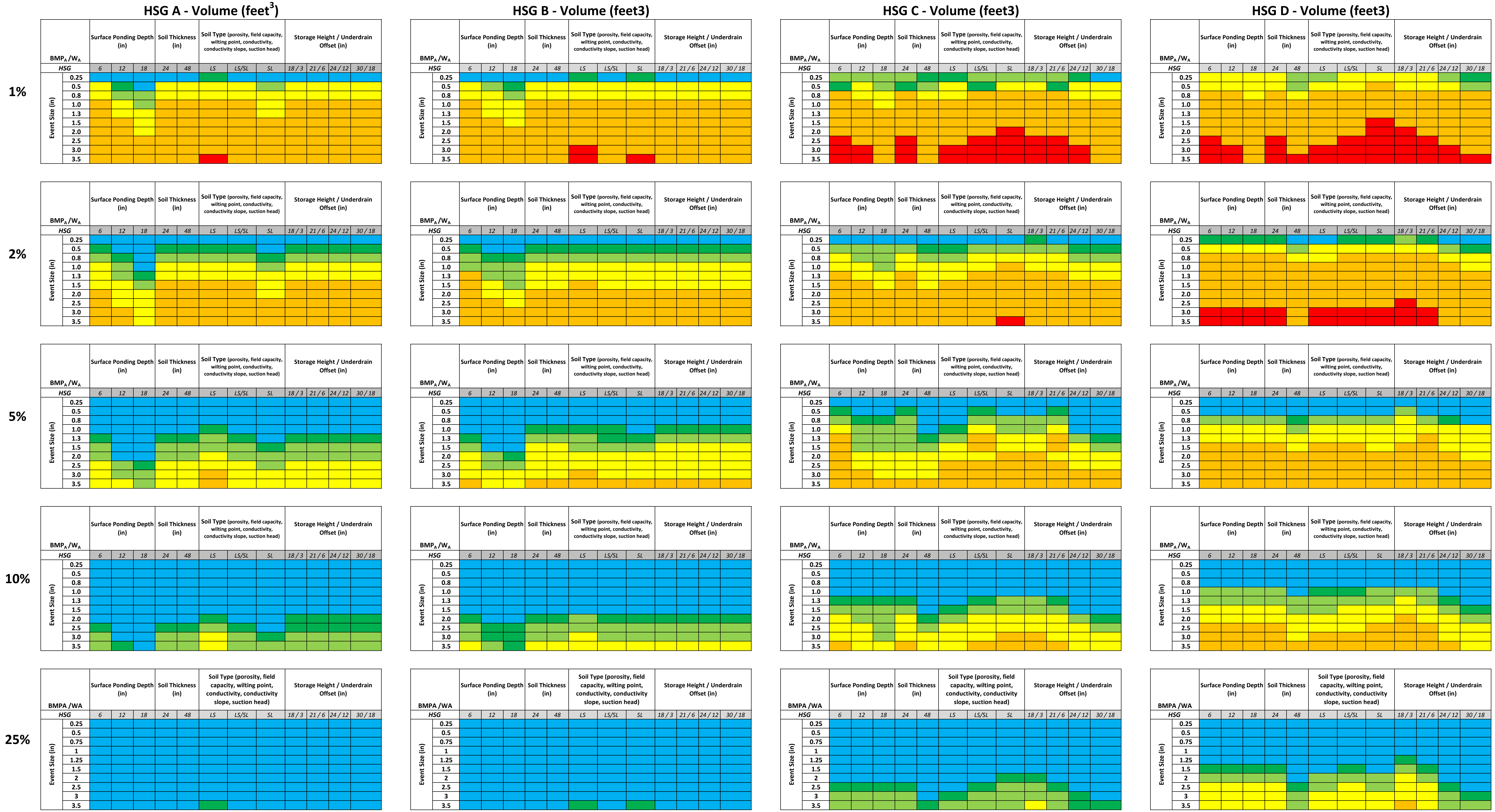
HSG B - Peak Outflow Rate (cfs)

HSG C - Peak Outflow Rate (cfs)

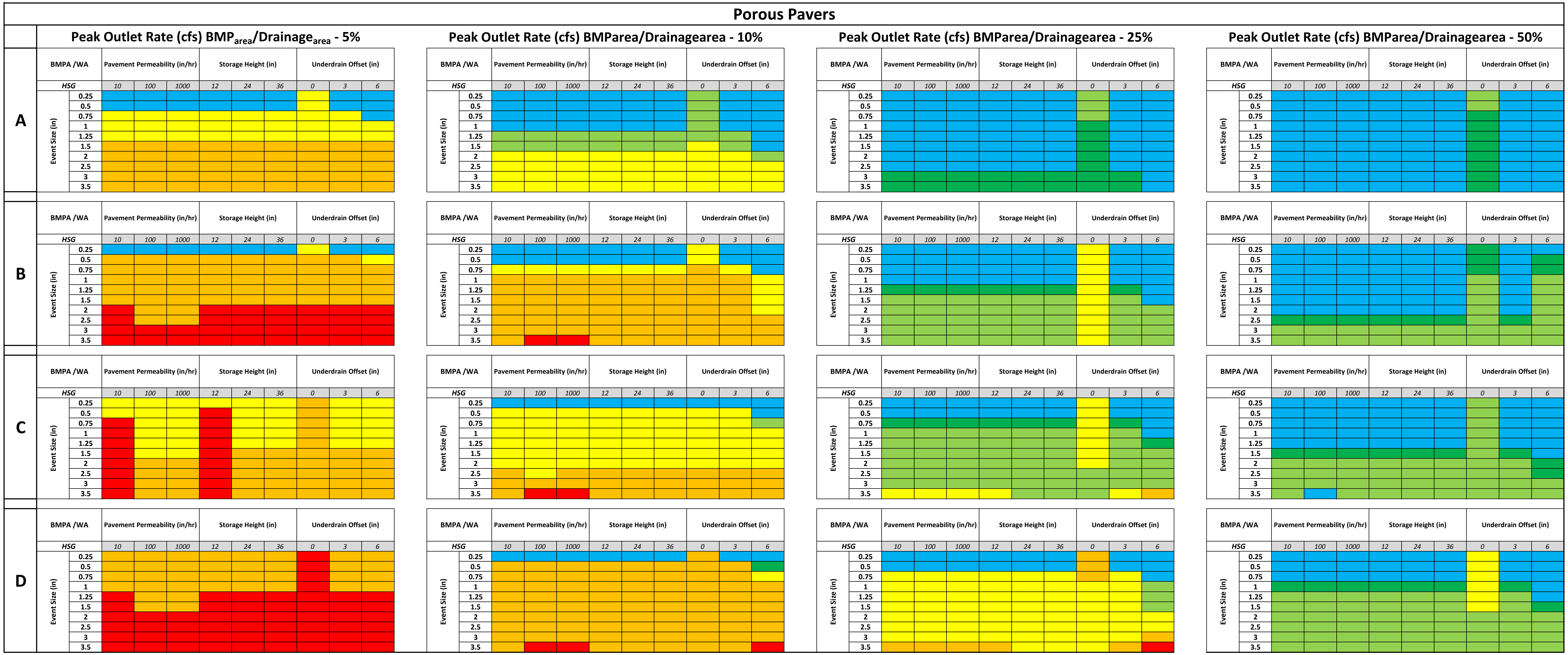
HSG D - Peak Outflow Rate (cfs)



BIORETENTION



Porous Pavers



Porous Pavers

Outlet Volume (feet3) BMParea/Drainagearea - 5%

A

BMPA /WA		Pavement Permeability (in/hr)			Storage Height (in)			Underdrain Offset (in)		
HSG		*10*	*100*	*1000*	*12*	*24*	*36*	*0*	*3*	*6*
Event Size (in)	0.25	🟦	🟦	🟦	🟦	🟦	🟦	🟨	🟦	🟦
	0.5	🟦	🟦	🟦	🟦	🟦	🟦	🟨	🟦	🟦
	0.75	🟩	🟩	🟩	🟩	🟩	🟩	🟨	🟩	🟦
	1	🟢	🟢	🟢	🟢	🟢	🟢	🟨	🟢	🟩
	1.25	🟢	🟢	🟢	🟢	🟢	🟢	🟨	🟢	🟢
	1.5	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟢
	2	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨
	2.5	🟨	🟨	🟨	🟨	🟨	🟨	🟧	🟨	🟨
	3	🟨	🟨	🟨	🟨	🟨	🟨	🟧	🟨	🟨
	3.5	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟨

B

BMPA /WA		Pavement Permeability (in/hr)			Storage Height (in)			Underdrain Offset (in)		
HSG		*10*	*100*	*1000*	*12*	*24*	*36*	*0*	*3*	*6*
Event Size (in)	0.25	🟦	🟦	🟦	🟦	🟦	🟦	🟨	🟦	🟦
	0.5	🟢	🟢	🟢	🟢	🟢	🟢	🟨	🟢	🟩
	0.75	🟨	🟨	🟨	🟨	🟨	🟨	🟧	🟨	🟢
	1	🟨	🟨	🟨	🟨	🟨	🟨	🟧	🟨	🟨
	1.25	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟨
	1.5	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟨
	2	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧
	2.5	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧
	3	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧
	3.5	🟧	🟧	🟧	🟧	🟧	🟧	🟥	🟧	🟧

C

BMPA /WA		Pavement Permeability (in/hr)			Storage Height (in)			Underdrain Offset (in)		
HSG		*10*	*100*	*1000*	*12*	*24*	*36*	*0*	*3*	*6*
Event Size (in)	0.25	🟢	🟢	🟢	🟢	🟢	🟢	🟨	🟢	🟦
	0.5	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨
	0.75	🟨	🟨	🟨	🟨	🟨	🟨	🟧	🟨	🟨
	1	🟨	🟨	🟨	🟨	🟨	🟨	🟧	🟨	🟨
	1.25	🟨	🟨	🟨	🟨	🟨	🟨	🟧	🟨	🟨
	1.5	🟨	🟨	🟨	🟨	🟨	🟨	🟧	🟨	🟨
	2	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧
	2.5	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧
	3	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧
	3.5	🟧	🟥	🟧	🟧	🟧	🟧	🟧	🟧	🟧

D

BMPA /WA		Pavement Permeability (in/hr)			Storage Height (in)			Underdrain Offset (in)		
HSG		*10*	*100*	*1000*	*12*	*24*	*36*	*0*	*3*	*6*
Event Size (in)	0.25	🟢	🟢	🟢	🟢	🟢	🟢	🟥	🟢	🟦
	0.5	🟧	🟧	🟧	🟧	🟧	🟧	🟥	🟧	🟨
	0.75	🟧	🟧	🟧	🟧	🟧	🟧	🟥	🟧	🟧
	1	🟧	🟧	🟧	🟧	🟧	🟧	🟥	🟧	🟧
	1.25	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟧
	1.5	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟧
	2	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟧
	2.5	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟧
	3	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥
	3.5	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥

Outlet Volume (feet3) BMParea/Drainagearea - 10%

A

BMPA /WA		Pavement Permeability (in/hr)			Storage Height (in)			Underdrain Offset (in)		
HSG		*10*	*100*	*1000*	*12*	*24*	*36*	*0*	*3*	*6*
Event Size (in)	0.25	🟦	🟦	🟦	🟦	🟦	🟦	🟢	🟦	🟦
	0.5	🟦	🟦	🟦	🟦	🟦	🟦	🟢	🟦	🟦
	0.75	🟦	🟦	🟦	🟦	🟦	🟦	🟢	🟦	🟦
	1	🟦	🟦	🟦	🟦	🟦	🟦	🟢	🟦	🟦
	1.25	🟩	🟩	🟩	🟩	🟩	🟩	🟢	🟩	🟦
	1.5	🟩	🟩	🟩	🟩	🟩	🟩	🟢	🟩	🟦
	2	🟢	🟢	🟢	🟢	🟢	🟢	🟨	🟢	🟩
	2.5	🟢	🟢	🟢	🟢	🟢	🟢	🟨	🟢	🟢
	3	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟢
	3.5	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟢

B

BMPA /WA		Pavement Permeability (in/hr)			Storage Height (in)			Underdrain Offset (in)		
HSG		*10*	*100*	*1000*	*12*	*24*	*36*	*0*	*3*	*6*
Event Size (in)	0.25	🟦	🟦	🟦	🟦	🟦	🟦	🟨	🟦	🟦
	0.5	🟦	🟦	🟦	🟦	🟦	🟦	🟨	🟦	🟦
	0.75	🟢	🟢	🟢	🟢	🟢	🟢	🟨	🟢	🟦
	1	🟢	🟢	🟢	🟢	🟢	🟢	🟨	🟢	🟩
	1.25	🟨	🟨	🟨	🟨	🟨	🟨	🟧	🟨	🟢
	1.5	🟨	🟨	🟨	🟨	🟨	🟨	🟧	🟨	🟢
	2	🟨	🟨	🟨	🟨	🟨	🟨	🟧	🟨	🟨
	2.5	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟨
	3	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧
	3.5	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧

C

BMPA /WA		Pavement Permeability (in/hr)			Storage Height (in)			Underdrain Offset (in)		
HSG		*10*	*100*	*1000*	*12*	*24*	*36*	*0*	*3*	*6*
Event Size (in)	0.25	🟦	🟦	🟦	🟦	🟦	🟦	🟨	🟦	🟦
	0.5	🟢	🟢	🟢	🟢	🟢	🟢	🟧	🟢	🟦
	0.75	🟨	🟨	🟨	🟨	🟨	🟨	🟧	🟨	🟢
	1	🟨	🟨	🟨	🟨	🟨	🟨	🟧	🟨	🟢
	1.25	🟨	🟨	🟨	🟨	🟨	🟨	🟧	🟨	🟨
	1.5	🟨	🟨	🟨	🟨	🟨	🟨	🟧	🟨	🟨
	2	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟨
	2.5	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟨
	3	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧
	3.5	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧

D

BMPA /WA		Pavement Permeability (in/hr)			Storage Height (in)			Underdrain Offset (in)		
HSG		*10*	*100*	*1000*	*12*	*24*	*36*	*0*	*3*	*6*
Event Size (in)	0.25	🟦	🟦	🟦	🟦	🟦	🟦	🟥	🟦	🟦
	0.5	🟨	🟨	🟨	🟨	🟨	🟨	🟥	🟨	🟦
	0.75	🟧	🟧	🟧	🟧	🟧	🟧	🟥	🟧	🟨
	1	🟧	🟧	🟧	🟧	🟧	🟧	🟥	🟧	🟨
	1.25	🟧	🟧	🟧	🟧	🟧	🟧	🟥	🟧	🟧
	1.5	🟧	🟧	🟧	🟧	🟧	🟧	🟥	🟧	🟧
	2	🟧	🟧	🟧	🟧	🟧	🟧	🟥	🟧	🟧
	2.5	🟧	🟧	🟧	🟧	🟧	🟧	🟥	🟧	🟧
	3	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟧
	3.5	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟧

Outlet Volume (feet3) BMParea/Drainagearea - 25%

A

BMPA /WA		Pavement Permeability (in/hr)			Storage Height (in)			Underdrain Offset (in)		
HSG		*10*	*100*	*1000*	*12*	*24*	*36*	*0*	*3*	*6*
Event Size (in)	0.25	🟦	🟦	🟦	🟦	🟦	🟦	🟢	🟦	🟦
	0.5	🟦	🟦	🟦	🟦	🟦	🟦	🟢	🟦	🟦
	0.75	🟦	🟦	🟦	🟦	🟦	🟦	🟢	🟦	🟦
	1	🟦	🟦	🟦	🟦	🟦	🟦	🟢	🟦	🟦
	1.25	🟦	🟦	🟦	🟦	🟦	🟦	🟢	🟦	🟦
	1.5	🟦	🟦	🟦	🟦	🟦	🟦	🟢	🟦	🟦
	2	🟦	🟦	🟦	🟦	🟦	🟦	🟢	🟦	🟦
	2.5	🟦	🟦	🟦	🟦	🟦	🟦	🟢	🟦	🟦
	3	🟦	🟦	🟦	🟦	🟦	🟦	🟢	🟦	🟦
	3.5	🟩	🟩	🟩	🟩	🟩	🟩	🟢	🟩	🟦

B

BMPA /WA		Pavement Permeability (in/hr)			Storage Height (in)			Underdrain Offset (in)		
HSG		*10*	*100*	*1000*	*12*	*24*	*36*	*0*	*3*	*6*
Event Size (in)	0.25	🟦	🟦	🟦	🟦	🟦	🟦	🟢	🟦	🟦
	0.5	🟦	🟦	🟦	🟦	🟦	🟦	🟢	🟦	🟦
	0.75	🟦	🟦	🟦	🟦	🟦	🟦	🟢	🟦	🟦
	1	🟦	🟦	🟦	🟦	🟦	🟦	🟢	🟦	🟦
	1.25	🟦	🟦	🟦	🟦	🟦	🟦	🟨	🟦	🟦
	1.5	🟩	🟩	🟩	🟩	🟩	🟩	🟨	🟩	🟦
	2	🟢	🟢	🟢	🟢	🟢	🟢	🟨	🟢	🟩
	2.5	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟢
	3	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨
	3.5	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨

C

BMPA /WA		Pavement Permeability (in/hr)			Storage Height (in)			Underdrain Offset (in)		
HSG		*10*	*100*	*1000*	*12*	*24*	*36*	*0*	*3*	*6*
Event Size (in)	0.25	🟦	🟦	🟦	🟦	🟦	🟦	🟨	🟦	🟦
	0.5	🟦	🟦	🟦	🟦	🟦	🟦	🟨	🟦	🟦
	0.75	🟦	🟦	🟦	🟦	🟦	🟦	🟨	🟦	🟦
	1	🟩	🟩	🟦	🟩	🟩	🟩	🟨	🟩	🟦
	1.25	🟢	🟢	🟢	🟢	🟢	🟢	🟨	🟢	🟩
	1.5	🟢	🟢	🟢	🟢	🟢	🟢	🟨	🟢	🟢
	2	🟨	🟨	🟨	🟨	🟨	🟨	🟧	🟨	🟢
	2.5	🟨	🟨	🟨	🟨	🟨	🟨	🟧	🟨	🟨
	3	🟨	🟨	🟨	🟨	🟨	🟨	🟧	🟨	🟨
	3.5	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟨

D

BMPA /WA		Pavement Permeability (in/hr)			Storage Height (in)			Underdrain Offset (in)		
HSG		*10*	*100*	*1000*	*12*	*24*	*36*	*0*	*3*	*6*
Event Size (in)	0.25	🟦	🟦	🟦	🟦	🟦	🟦	🟨	🟦	🟦
	0.5	🟦	🟦	🟦	🟦	🟦	🟦	🟧	🟦	🟦
	0.75	🟢	🟢	🟢	🟢	🟢	🟢	🟧	🟢	🟦
	1	🟨	🟨	🟨	🟨	🟨	🟨	🟧	🟨	🟩
	1.25	🟨	🟨	🟨	🟨	🟨	🟨	🟥	🟨	🟢
	1.5	🟨	🟨	🟨	🟨	🟨	🟨	🟥	🟨	🟨
	2	🟧	🟧	🟧	🟧	🟧	🟧	🟥	🟧	🟨
	2.5	🟧	🟧	🟧	🟧	🟧	🟧	🟥	🟧	🟨
	3	🟧	🟧	🟧	🟧	🟧	🟧	🟥	🟧	🟧
	3.5	🟧	🟧	🟧	🟧	🟧	🟧	🟥	🟧	🟧

Outlet Volume (feet3) BMParea/Drainagearea - 50%

A

BMPA /WA		Pavement Permeability (in/hr)			Storage Height (in)			Underdrain Offset (in)		
HSG		*10*	*100*	*1000*	*12*	*24*	*36*	*0*	*3*	*6*
Event Size (in)	0.25	🟦	🟦	🟦	🟦	🟦	🟦	🟢	🟦	🟦
	0.5	🟦	🟦	🟦	🟦	🟦	🟦	🟢	🟦	🟦
	0.75	🟦	🟦	🟦	🟦	🟦	🟦	🟢	🟦	🟦
	1	🟦	🟦	🟦	🟦	🟦	🟦	🟩	🟦	🟦
	1.25	🟦	🟦	🟦	🟦	🟦	🟦	🟩	🟦	🟦
	1.5	🟦	🟦	🟦	🟦	🟦	🟦	🟩	🟦	🟦
	2	🟦	🟦	🟦	🟦	🟦	🟦	🟩	🟦	🟦
	2.5	🟦	🟦	🟦	🟦	🟦	🟦	🟩	🟦	🟦
	3	🟦	🟦	🟦	🟦	🟦	🟦	🟩	🟦	🟦
	3.5	🟦	🟦	🟦	🟦	🟦	🟦	🟩	🟦	🟦

B

BMPA /WA		Pavement Permeability (in/hr)			Storage Height (in)			Underdrain Offset (in)		
HSG		*10*	*100*	*1000*	*12*	*24*	*36*	*0*	*3*	*6*
Event Size (in)	0.25	🟦	🟦	🟦	🟦	🟦	🟦	🟩	🟦	🟦
	0.5	🟦	🟦	🟦	🟦	🟦	🟦	🟩	🟦	🟦
	0.75	🟦	🟦	🟦	🟦	🟦	🟦	🟩	🟦	🟦
	1	🟦	🟦	🟦	🟦	🟦	🟦	🟩	🟦	🟦
	1.25	🟦	🟦	🟦	🟦	🟦	🟦	🟩	🟦	🟦
	1.5	🟦	🟦	🟦	🟦	🟦	🟦	🟩	🟦	🟦
	2	🟦	🟦	🟦	🟦	🟦	🟦	🟢	🟦	🟦
	2.5	🟩	🟩	🟩	🟩	🟩	🟩	🟢	🟩	🟢
	3	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢
	3.5	🟢	🟢	🟢	🟢	🟢	🟢	🟨	🟢	🟨

C

BMPA /WA		Pavement Permeability (in/hr)			Storage Height (in)			Underdrain Offset (in)		
HSG		*10*	*100*	*1000*	*12*	*24*	*36*	*0*	*3*	*6*
Event Size (in)	0.25	🟦	🟦	🟦	🟦	🟦	🟦	🟢	🟦	🟦
	0.5	🟦	🟦	🟦	🟦	🟦	🟦	🟨	🟦	🟦
	0.75	🟦	🟦	🟦	🟦	🟦	🟦	🟨	🟦	🟦
	1	🟦	🟦	🟦	🟦	🟦	🟦	🟨	🟦	🟦
	1.25	🟦	🟦	🟦	🟦	🟦	🟦	🟨	🟦	🟦
	1.5	🟩	🟩	🟩	🟩	🟩	🟩	🟨	🟩	🟦
	2	🟢	🟢	🟢	🟢	🟢	🟢	🟨	🟢	🟩
	2.5	🟨	🟨	🟨	🟨	🟨	🟨	🟧	🟨	🟢
	3	🟨	🟨	🟨	🟨	🟨	🟨	🟧	🟨	🟢
	3.5	🟨	🟨	🟨	🟨	🟨	🟨	🟧	🟨	🟢

D

BMPA /WA		Pavement Permeability (in/hr)			Storage Height (in)			Underdrain Offset (in)		
HSG		*10*	*100*	*1000*	*12*	*24*	*36*	*0*	*3*	*6*
Event Size (in)	0.25	🟦	🟦	🟦	🟦	🟦	🟦	🟨	🟦	🟦
	0.5	🟦	🟦	🟦	🟦	🟦	🟦	🟧	🟦	🟦
	0.75	🟦	🟦	🟦	🟦	🟦	🟦	🟧	🟦	🟦
	1	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟩	🟦
	1.25	🟢	🟢	🟢	🟢	🟢	🟢	🟧	🟢	🟦
	1.5	🟢	🟢	🟢	🟢	🟢	🟢	🟧	🟢	🟦
	2	🟨	🟨	🟨	🟨	🟨	🟨	🟥	🟨	🟢
	2.5	🟨	🟨	🟨	🟨	🟨	🟨	🟥	🟨	🟢
	3	🟧	🟧	🟧	🟧	🟧	🟧	🟥	🟧	🟨
	3.5	🟧	🟧	🟧	🟧	🟧	🟧	🟥	🟧	🟨

DRY DETENTION

SCENARIO 1 - PEAK

BMP$_A$ /W$_A$		1%				2%				5%				10%				25%			
HSG		*A*	*B*	*C*	*D*	*A*	*B*	*C*	*D*	*A*	*B*	*C*	*D*	*A*	*B*	*C*	*D*	*A*	*B*	*C*	*D*
Event Size (in)	0.25	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
	0.5	🟦	🟦	🟩	🟩	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
	0.75	🟢	🟨	🟨	🟨	🟦	🟢	🟢	🟨	🟦	🟢	🟢	🟨	🟦	🟦	🟢	🟢	🟦	🟦	🟩	🟢
	1	🟨	🟧	🟥	🟥	🟢	🟨	🟧	🟧	🟦	🟢	🟧	🟧	🟦	🟢	🟧	🟨	🟦	🟦	🟢	🟨
	1.25	🟧	🟥	🟥	🟥	🟨	🟧	🟥	🟥	🟩	🟨	🟧	🟧	🟦	🟨	🟨	🟧	🟦	🟩	🟨	🟨
	1.5	🟧	🟥	🟥	🟥	🟧	🟥	🟥	🟥	🟨	🟧	🟥	🟥	🟩	🟨	🟨	🟧	🟦	🟢	🟨	🟨
	2	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟧	🟥	🟥	🟥	🟢	🟧	🟥	🟥	🟦	🟨	🟧	🟧
	2.5	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟧	🟥	🟥	🟥	🟨	🟥	🟥	🟥	🟩	🟧	🟧	🟧
	3	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟧	🟥	🟥	🟥	🟢	🟧	🟧	🟧
	3.5	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟧	🟥	🟥	🟥	🟢	🟧	🟧	🟧

SCENARIO 1 - VOLUME

BMP$_A$ /W$_A$		1%				2%				5%				10%				25%			
HSG		*A*	*B*	*C*	*D*	*A*	*B*	*C*	*D*	*A*	*B*	*C*	*D*	*A*	*B*	*C*	*D*	*A*	*B*	*C*	*D*
Event Size (in)	0.25	🟩	🟢	🟨	🟧	🟦	🟩	🟢	🟧	🟦	🟦	🟢	🟨	🟦	🟦	🟩	🟩	🟦	🟦	🟦	🟦
	0.5	🟩	🟢	🟨	🟧	🟩	🟩	🟨	🟧	🟦	🟩	🟢	🟨	🟦	🟦	🟢	🟨	🟦	🟦	🟩	🟩
	0.75	🟩	🟨	🟧	🟧	🟩	🟢	🟨	🟧	🟦	🟢	🟨	🟧	🟦	🟩	🟢	🟧	🟦	🟦	🟩	🟨
	1	🟢	🟨	🟧	🟧	🟢	🟢	🟧	🟧	🟦	🟨	🟨	🟧	🟦	🟢	🟨	🟧	🟦	🟦	🟢	🟨
	1.25	🟨	🟨	🟧	🟧	🟨	🟨	🟧	🟧	🟩	🟨	🟧	🟧	🟦	🟨	🟧	🟧	🟦	🟩	🟢	🟧
	1.5	🟨	🟨	🟧	🟥	🟨	🟨	🟧	🟥	🟢	🟨	🟧	🟧	🟦	🟨	🟧	🟧	🟦	🟢	🟨	🟧
	2	🟨	🟧	🟥	🟥	🟨	🟨	🟧	🟥	🟢	🟧	🟧	🟥	🟢	🟧	🟧	🟥	🟦	🟨	🟨	🟧
	2.5	🟧	🟧	🟥	🟥	🟨	🟧	🟥	🟥	🟨	🟧	🟧	🟥	🟢	🟧	🟧	🟥	🟩	🟧	🟨	🟧
	3	🟧	🟧	🟥	🟥	🟧	🟧	🟥	🟥	🟨	🟧	🟥	🟥	🟨	🟧	🟥	🟥	🟩	🟧	🟥	🟥
	3.5	🟧	🟧	🟥	🟥	🟧	🟧	🟥	🟥	🟨	🟧	🟥	🟥	🟨	🟧	🟥	🟥	🟢	🟧	🟥	🟥

SCENARIO 2 - PEAK

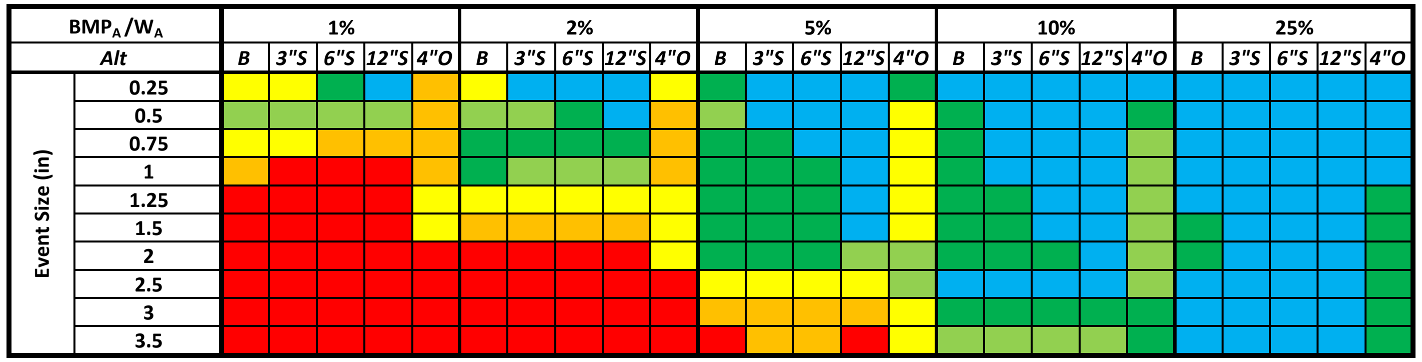
BMP$_A$ /W$_A$		1%				2%				5%				10%				25%			
HSG		*A*	*B*	*C*	*D*	*A*	*B*	*C*	*D*	*A*	*B*	*C*	*D*	*A*	*B*	*C*	*D*	*A*	*B*	*C*	*D*
Event Size (in)	0.25	🟦		🟦		🟦		🟦		🟦		🟦		🟦		🟦		🟦		🟦	
	0.5	🟦		🟦		🟦		🟦		🟦		🟦		🟦		🟦		🟦		🟦	
	0.75	🟩		🟢		🟦		🟢		🟦		🟩		🟦		🟩		🟦		🟦	
	1	🟢		🟨		🟩		🟨		🟦		🟢		🟦		🟩		🟦		🟩	
	1.25	🟢		🟧		🟢		🟨		🟩		🟢		🟦		🟢		🟦		🟩	
	1.5	🟢		🟨		🟢		🟨		🟩		🟨		🟦		🟢		🟦		🟩	
	2	🟢		🟢		🟢		🟢		🟢		🟢		🟩		🟢		🟦		🟩	
	2.5	🟢		🟢		🟢		🟢		🟢		🟢		🟩		🟢		🟦		🟩	
	3	🟢		🟢		🟢		🟢		🟢		🟩		🟢		🟩		🟩		🟩	
	3.5	🟢		🟢		🟢		🟩		🟢		🟩		🟢		🟩		🟩		🟩	

SCENARIO 2 - VOLUME

BMP$_A$ /W$_A$		1%				2%				5%				10%				25%			
HSG		*A*	*B*	*C*	*D*	*A*	*B*	*C*	*D*	*A*	*B*	*C*	*D*	*A*	*B*	*C*	*D*	*A*	*B*	*C*	*D*
Event Size (in)	0.25	🟦		🟨		🟦		🟢		🟦		🟢		🟦		🟩		🟦		🟦	
	0.5	🟦		🟨		🟦		🟨		🟦		🟢		🟦		🟢		🟦		🟦	
	0.75	🟩		🟧		🟦		🟨		🟦		🟨		🟦		🟢		🟦		🟩	
	1	🟢		🟧		🟩		🟧		🟦		🟨		🟦		🟨		🟦		🟢	
	1.25	🟨		🟧		🟢		🟧		🟩		🟧		🟦		🟨		🟦		🟢	
	1.5	🟨		🟧		🟢		🟧		🟩		🟧		🟦		🟧		🟦		🟨	
	2	🟨		🟥		🟨		🟧		🟢		🟧		🟩		🟧		🟦		🟨	
	2.5	🟧		🟥		🟨		🟥		🟨		🟧		🟩		🟧		🟦		🟧	
	3	🟧		🟥		🟨		🟥		🟨		🟧		🟢		🟧		🟩		🟧	
	3.5	🟧		🟥		🟧		🟥		🟨		🟧		🟢		🟧		🟩		🟧	

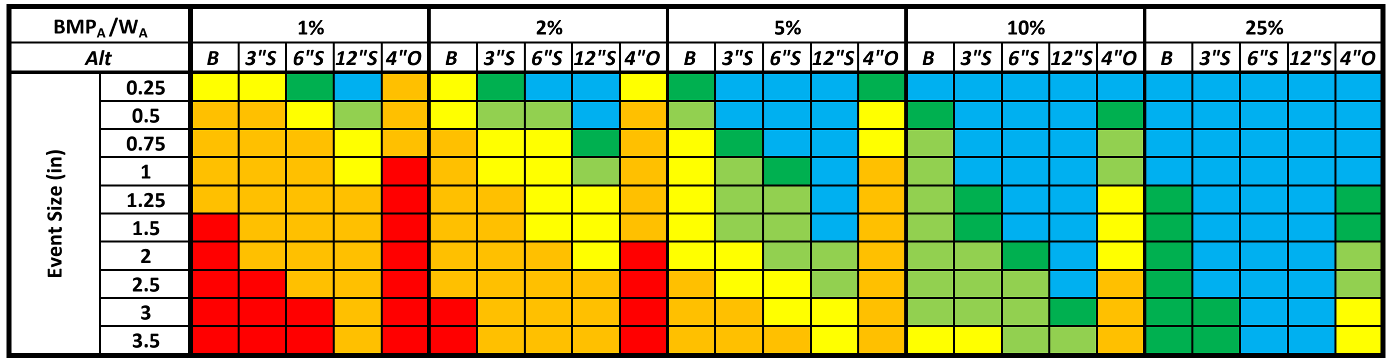
Underground Storage

HSG B - Peak



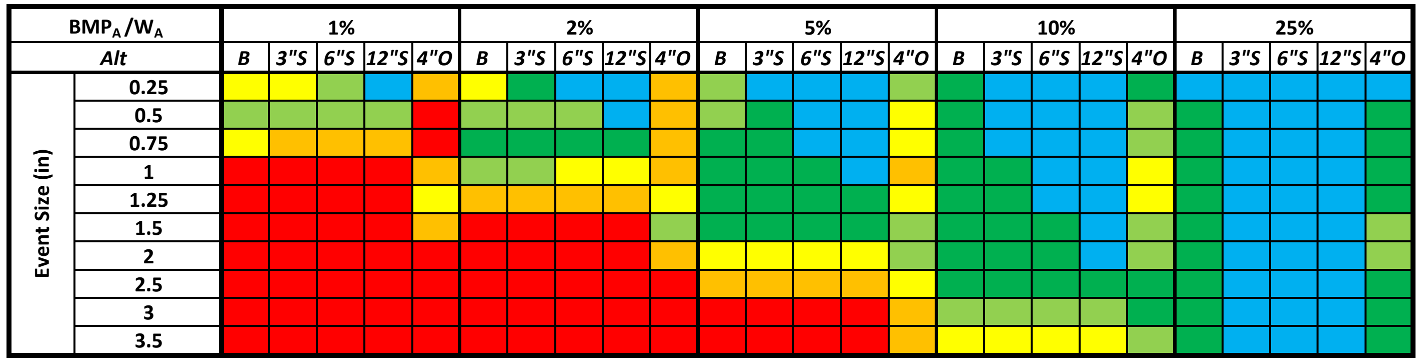
BMP_A/W_A		1%					2%					5%					10%					25%				
Alt		B	3"S	6"S	12"S	4"O	B	3"S	6"S	12"S	4"O	B	3"S	6"S	12"S	4"O	B	3"S	6"S	12"S	4"O	B	3"S	6"S	12"S	4"O
Event Size (in)	0.25	🟨	🟨	🟩	🟦	🟧	🟨	🟦	🟦	🟦	🟨	🟩	🟦	🟦	🟦	🟩	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
	0.5	🟢	🟢	🟢	🟢	🟧	🟢	🟢	🟩	🟦	🟧	🟢	🟦	🟦	🟦	🟨	🟩	🟦	🟦	🟦	🟩	🟦	🟦	🟦	🟦	🟦
	0.75	🟨	🟨	🟧	🟧	🟧	🟩	🟩	🟩	🟩	🟧	🟩	🟩	🟦	🟦	🟨	🟩	🟦	🟦	🟦	🟢	🟦	🟦	🟦	🟦	🟦
	1	🟧	🟥	🟥	🟥	🟧	🟩	🟢	🟢	🟢	🟧	🟩	🟩	🟩	🟦	🟨	🟩	🟦	🟦	🟦	🟢	🟦	🟦	🟦	🟦	🟦
	1.25	🟥	🟥	🟥	🟥	🟨	🟨	🟨	🟨	🟨	🟨	🟩	🟩	🟩	🟦	🟨	🟩	🟩	🟦	🟦	🟢	🟦	🟦	🟦	🟦	🟩
	1.5	🟥	🟥	🟥	🟥	🟨	🟧	🟧	🟧	🟧	🟨	🟩	🟩	🟩	🟦	🟨	🟩	🟩	🟦	🟦	🟢	🟩	🟦	🟦	🟦	🟩
	2	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟨	🟩	🟩	🟩	🟢	🟢	🟩	🟩	🟩	🟦	🟢	🟩	🟦	🟦	🟦	🟩
	2.5	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟨	🟨	🟨	🟨	🟢	🟦	🟦	🟦	🟦	🟢	🟦	🟦	🟦	🟦	🟩
	3	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟧	🟧	🟧	🟧	🟨	🟩	🟩	🟩	🟩	🟩	🟦	🟦	🟦	🟦	🟩
	3.5	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟧	🟧	🟥	🟨	🟢	🟢	🟢	🟢	🟩	🟦	🟦	🟦	🟦	🟩

Volume



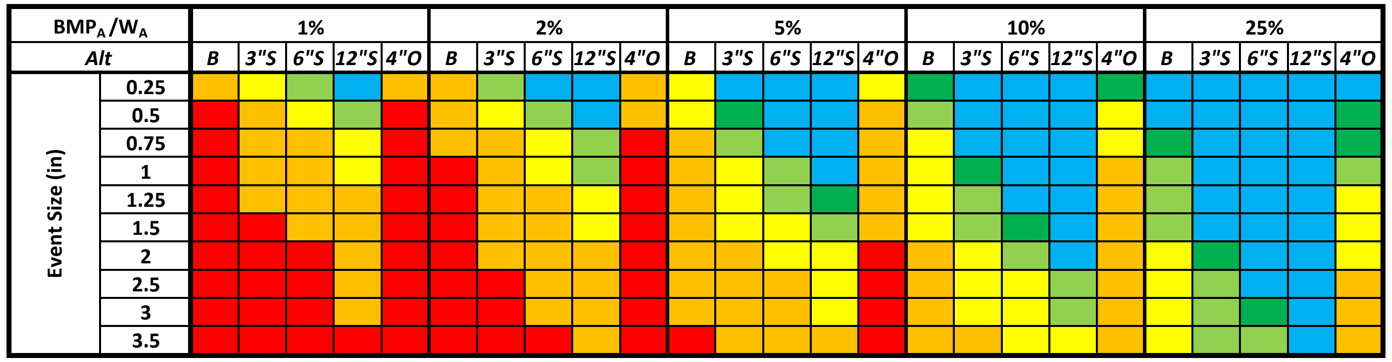
BMP_A/W_A		1%					2%					5%					10%					25%				
Alt		B	3"S	6"S	12"S	4"O	B	3"S	6"S	12"S	4"O	B	3"S	6"S	12"S	4"O	B	3"S	6"S	12"S	4"O	B	3"S	6"S	12"S	4"O
Event Size (in)	0.25	🟨	🟨	🟩	🟦	🟧	🟨	🟩	🟦	🟦	🟨	🟩	🟦	🟦	🟦	🟩	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
	0.5	🟧	🟧	🟨	🟢	🟧	🟨	🟢	🟢	🟦	🟧	🟢	🟦	🟦	🟦	🟨	🟩	🟦	🟦	🟦	🟩	🟦	🟦	🟦	🟦	🟦
	0.75	🟧	🟧	🟧	🟨	🟧	🟧	🟨	🟨	🟩	🟧	🟨	🟩	🟦	🟦	🟨	🟢	🟦	🟦	🟦	🟢	🟦	🟦	🟦	🟦	🟦
	1	🟧	🟧	🟧	🟨	🟥	🟧	🟨	🟨	🟢	🟧	🟨	🟢	🟩	🟦	🟧	🟢	🟦	🟦	🟦	🟢	🟦	🟦	🟦	🟦	🟦
	1.25	🟧	🟧	🟧	🟧	🟥	🟧	🟧	🟨	🟨	🟧	🟨	🟢	🟢	🟦	🟧	🟢	🟩	🟦	🟦	🟨	🟩	🟦	🟦	🟦	🟩
	1.5	🟥	🟧	🟧	🟧	🟥	🟧	🟧	🟨	🟨	🟧	🟨	🟢	🟢	🟦	🟧	🟢	🟩	🟦	🟦	🟨	🟩	🟦	🟦	🟦	🟩
	2	🟥	🟧	🟧	🟧	🟥	🟧	🟧	🟧	🟨	🟥	🟨	🟨	🟢	🟢	🟧	🟢	🟢	🟩	🟦	🟨	🟩	🟦	🟦	🟦	🟢
	2.5	🟥	🟥	🟧	🟧	🟥	🟧	🟧	🟧	🟧	🟥	🟧	🟨	🟨	🟢	🟧	🟢	🟢	🟢	🟦	🟧	🟩	🟦	🟦	🟦	🟢
	3	🟥	🟥	🟥	🟧	🟥	🟥	🟧	🟧	🟧	🟥	🟧	🟧	🟨	🟨	🟧	🟢	🟢	🟢	🟩	🟧	🟩	🟩	🟦	🟦	🟨
	3.5	🟥	🟥	🟥	🟧	🟥	🟥	🟧	🟧	🟧	🟥	🟧	🟧	🟧	🟨	🟧	🟨	🟨	🟢	🟢	🟧	🟩	🟩	🟦	🟦	🟨

HSG C_1 - Peak



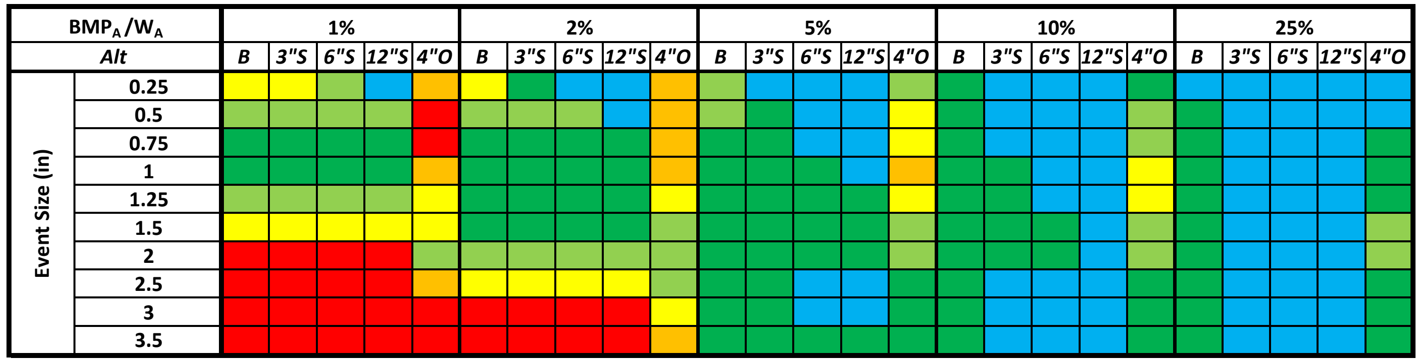
BMP_A/W_A		1%					2%					5%					10%					25%				
Alt		B	3"S	6"S	12"S	4"O	B	3"S	6"S	12"S	4"O	B	3"S	6"S	12"S	4"O	B	3"S	6"S	12"S	4"O	B	3"S	6"S	12"S	4"O
Event Size (in)	0.25	🟨	🟨	🟢	🟦	🟧	🟨	🟩	🟦	🟦	🟧	🟢	🟦	🟦	🟦	🟢	🟩	🟦	🟦	🟦	🟩	🟦	🟦	🟦	🟦	🟦
	0.5	🟢	🟢	🟢	🟢	🟥	🟢	🟢	🟢	🟦	🟧	🟢	🟩	🟦	🟦	🟨	🟩	🟦	🟦	🟦	🟢	🟩	🟦	🟦	🟦	🟩
	0.75	🟨	🟧	🟧	🟧	🟥	🟩	🟩	🟩	🟩	🟧	🟩	🟩	🟦	🟦	🟨	🟩	🟦	🟦	🟦	🟢	🟩	🟦	🟦	🟦	🟩
	1	🟥	🟥	🟥	🟥	🟧	🟢	🟢	🟨	🟨	🟧	🟩	🟩	🟩	🟦	🟧	🟩	🟩	🟦	🟦	🟨	🟩	🟦	🟦	🟦	🟩
	1.25	🟥	🟥	🟥	🟥	🟨	🟧	🟧	🟧	🟧	🟨	🟩	🟩	🟩	🟩	🟨	🟩	🟩	🟦	🟦	🟨	🟩	🟦	🟦	🟦	🟩
	1.5	🟥	🟥	🟥	🟥	🟧	🟥	🟥	🟥	🟥	🟢	🟩	🟩	🟩	🟩	🟢	🟩	🟩	🟩	🟦	🟢	🟩	🟦	🟦	🟦	🟢
	2	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟧	🟨	🟨	🟨	🟨	🟢	🟩	🟩	🟩	🟦	🟢	🟩	🟦	🟦	🟦	🟢
	2.5	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟧	🟧	🟧	🟧	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟦	🟦	🟦	🟩
	3	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟧	🟢	🟢	🟢	🟢	🟩	🟩	🟦	🟦	🟦	🟩
	3.5	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟧	🟨	🟨	🟨	🟨	🟢	🟩	🟦	🟦	🟦	🟩

Volume



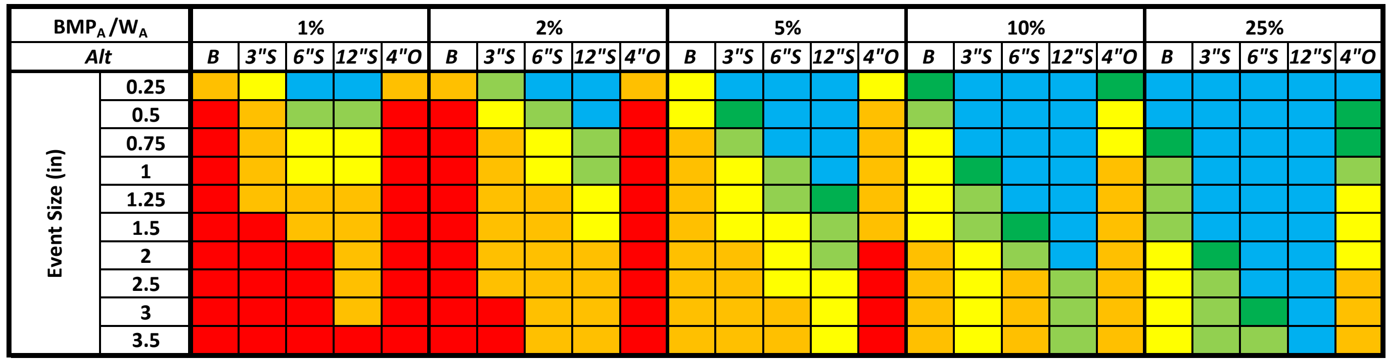
BMP_A/W_A		1%					2%					5%					10%					25%				
Alt		B	3"S	6"S	12"S	4"O	B	3"S	6"S	12"S	4"O	B	3"S	6"S	12"S	4"O	B	3"S	6"S	12"S	4"O	B	3"S	6"S	12"S	4"O
Event Size (in)	0.25	🟧	🟨	🟢	🟦	🟧	🟧	🟢	🟦	🟦	🟧	🟨	🟦	🟦	🟦	🟨	🟩	🟦	🟦	🟦	🟩	🟦	🟦	🟦	🟦	🟦
	0.5	🟥	🟧	🟨	🟢	🟥	🟧	🟨	🟢	🟦	🟧	🟨	🟩	🟦	🟦	🟧	🟢	🟦	🟦	🟦	🟨	🟦	🟦	🟦	🟦	🟩
	0.75	🟥	🟧	🟧	🟨	🟥	🟧	🟧	🟨	🟢	🟥	🟧	🟢	🟦	🟦	🟧	🟨	🟦	🟦	🟦	🟨	🟩	🟦	🟦	🟦	🟩
	1	🟥	🟧	🟧	🟨	🟥	🟥	🟧	🟨	🟢	🟥	🟧	🟨	🟢	🟦	🟧	🟨	🟩	🟦	🟦	🟧	🟢	🟦	🟦	🟦	🟢
	1.25	🟥	🟧	🟧	🟧	🟥	🟥	🟧	🟧	🟨	🟥	🟧	🟨	🟢	🟩	🟧	🟨	🟢	🟦	🟦	🟧	🟢	🟦	🟦	🟦	🟨
	1.5	🟥	🟥	🟧	🟧	🟥	🟥	🟧	🟧	🟨	🟥	🟧	🟨	🟨	🟢	🟧	🟨	🟢	🟩	🟦	🟧	🟢	🟦	🟦	🟦	🟨
	2	🟥	🟥	🟥	🟧	🟥	🟥	🟧	🟧	🟧	🟥	🟧	🟧	🟨	🟨	🟥	🟧	🟨	🟢	🟦	🟧	🟨	🟩	🟦	🟦	🟨
	2.5	🟥	🟥	🟥	🟧	🟥	🟥	🟥	🟧	🟧	🟥	🟧	🟧	🟧	🟨	🟥	🟧	🟨	🟨	🟢	🟧	🟨	🟢	🟦	🟦	🟧
	3	🟥	🟥	🟥	🟧	🟥	🟥	🟥	🟧	🟧	🟥	🟧	🟧	🟧	🟨	🟥	🟧	🟨	🟨	🟢	🟧	🟨	🟢	🟩	🟦	🟧
	3.5	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟧	🟥	🟥	🟧	🟧	🟧	🟥	🟧	🟧	🟨	🟨	🟧	🟨	🟢	🟢	🟦	🟧

HSG C_2 - Peak



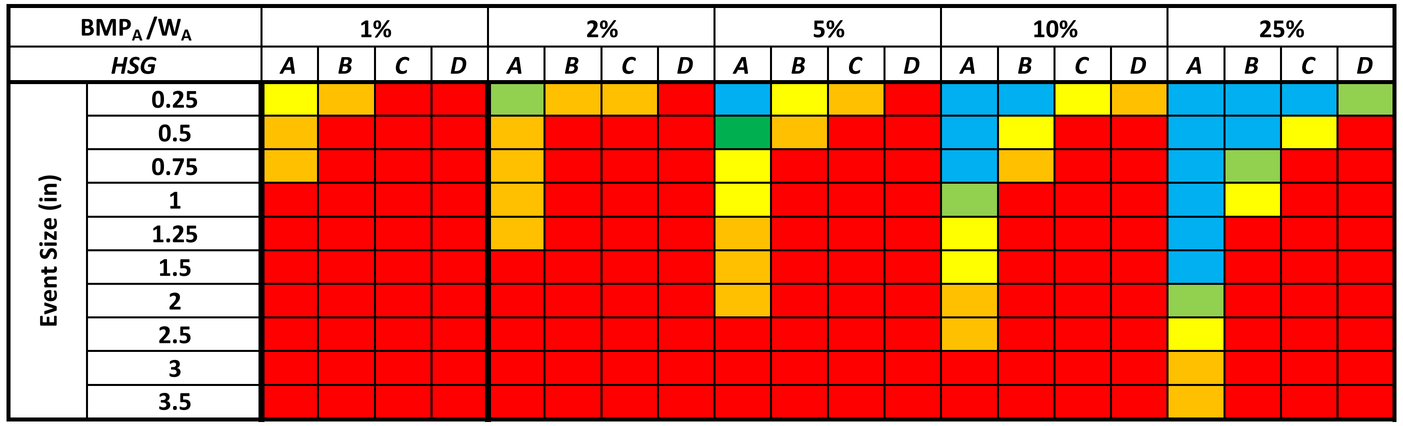
BMP_A/W_A		1%					2%					5%					10%					25%				
Alt		B	3"S	6"S	12"S	4"O	B	3"S	6"S	12"S	4"O	B	3"S	6"S	12"S	4"O	B	3"S	6"S	12"S	4"O	B	3"S	6"S	12"S	4"O
Event Size (in)	0.25	🟨	🟨	🟢	🟦	🟧	🟨	🟩	🟦	🟦	🟧	🟢	🟦	🟦	🟦	🟢	🟩	🟦	🟦	🟦	🟩	🟦	🟦	🟦	🟦	🟦
	0.5	🟢	🟢	🟢	🟢	🟥	🟢	🟢	🟢	🟦	🟧	🟢	🟩	🟦	🟦	🟨	🟩	🟦	🟦	🟦	🟢	🟩	🟦	🟦	🟦	🟦
	0.75	🟩	🟩	🟩	🟩	🟥	🟩	🟩	🟩	🟩	🟧	🟩	🟩	🟦	🟦	🟨	🟩	🟦	🟦	🟦	🟢	🟩	🟦	🟦	🟦	🟩
	1	🟩	🟩	🟩	🟩	🟧	🟩	🟩	🟩	🟩	🟧	🟩	🟩	🟩	🟦	🟧	🟩	🟩	🟦	🟦	🟨	🟩	🟦	🟦	🟦	🟩
	1.25	🟢	🟢	🟢	🟢	🟨	🟩	🟩	🟩	🟩	🟨	🟩	🟩	🟩	🟩	🟨	🟩	🟩	🟦	🟦	🟨	🟩	🟦	🟦	🟦	🟩
	1.5	🟨	🟨	🟨	🟨	🟨	🟩	🟩	🟩	🟩	🟢	🟩	🟩	🟩	🟩	🟢	🟩	🟩	🟩	🟦	🟢	🟩	🟦	🟦	🟦	🟢
	2	🟥	🟥	🟥	🟥	🟢	🟢	🟢	🟢	🟢	🟢	🟩	🟩	🟩	🟩	🟢	🟩	🟩	🟩	🟦	🟢	🟩	🟦	🟦	🟦	🟢
	2.5	🟥	🟥	🟥	🟥	🟧	🟨	🟨	🟨	🟨	🟢	🟩	🟩	🟦	🟦	🟩	🟩	🟦	🟦	🟦	🟩	🟩	🟦	🟦	🟦	🟩
	3	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟨	🟩	🟩	🟦	🟦	🟩	🟩	🟦	🟦	🟦	🟩	🟩	🟦	🟦	🟦	🟩
	3.5	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟧	🟩	🟩	🟩	🟩	🟩	🟩	🟦	🟦	🟦	🟩	🟩	🟦	🟦	🟦	🟩

Volume



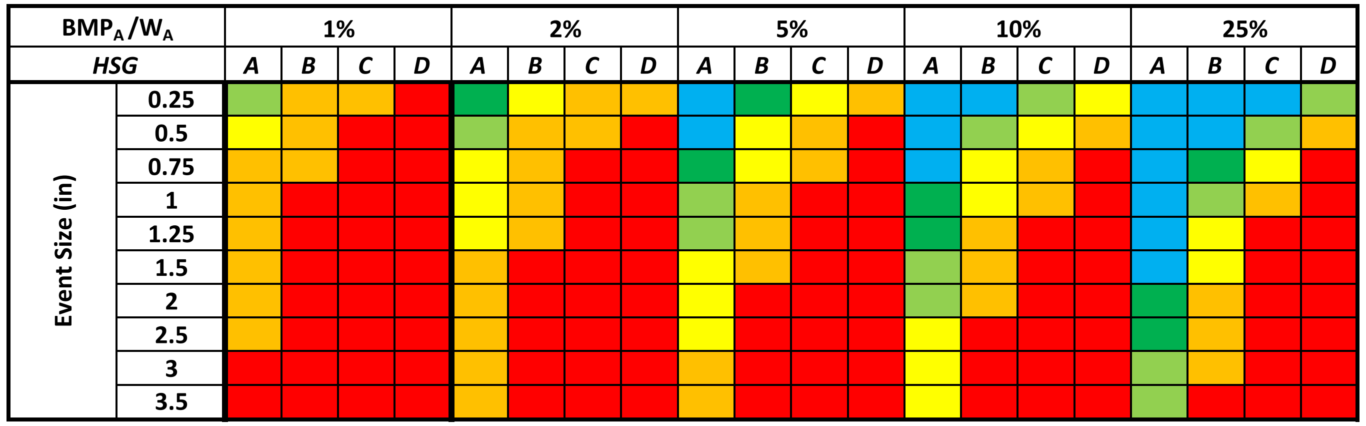
BMP_A/W_A		1%					2%					5%					10%					25%				
Alt		B	3"S	6"S	12"S	4"O	B	3"S	6"S	12"S	4"O	B	3"S	6"S	12"S	4"O	B	3"S	6"S	12"S	4"O	B	3"S	6"S	12"S	4"O
Event Size (in)	0.25	🟧	🟨	🟦	🟦	🟧	🟧	🟢	🟦	🟦	🟧	🟨	🟦	🟦	🟦	🟨	🟩	🟦	🟦	🟦	🟩	🟦	🟦	🟦	🟦	🟦
	0.5	🟥	🟧	🟢	🟢	🟥	🟥	🟨	🟢	🟦	🟥	🟨	🟩	🟦	🟦	🟧	🟢	🟦	🟦	🟦	🟨	🟦	🟦	🟦	🟦	🟩
	0.75	🟥	🟧	🟨	🟨	🟥	🟥	🟧	🟨	🟢	🟥	🟧	🟢	🟦	🟦	🟧	🟨	🟦	🟦	🟦	🟨	🟩	🟦	🟦	🟦	🟩
	1	🟥	🟧	🟨	🟨	🟥	🟥	🟧	🟨	🟢	🟥	🟧	🟨	🟢	🟦	🟧	🟨	🟩	🟦	🟦	🟧	🟢	🟦	🟦	🟦	🟢
	1.25	🟥	🟧	🟧	🟧	🟥	🟥	🟧	🟧	🟨	🟥	🟧	🟨	🟢	🟩	🟧	🟨	🟢	🟦	🟦	🟧	🟢	🟦	🟦	🟦	🟨
	1.5	🟥	🟥	🟧	🟧	🟥	🟥	🟧	🟧	🟨	🟥	🟧	🟨	🟨	🟢	🟧	🟨	🟢	🟩	🟦	🟧	🟢	🟦	🟦	🟦	🟨
	2	🟥	🟥	🟥	🟧	🟥	🟥	🟧	🟧	🟧	🟥	🟧	🟧	🟨	🟢	🟥	🟧	🟨	🟢	🟦	🟧	🟨	🟩	🟦	🟦	🟨
	2.5	🟥	🟥	🟥	🟧	🟥	🟥	🟧	🟧	🟧	🟥	🟧	🟧	🟨	🟨	🟥	🟧	🟨	🟧	🟢	🟧	🟨	🟢	🟦	🟦	🟧
	3	🟥	🟥	🟥	🟧	🟥	🟥	🟥	🟧	🟧	🟥	🟧	🟧	🟧	🟨	🟥	🟧	🟨	🟧	🟢	🟧	🟨	🟢	🟩	🟦	🟧
	3.5	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟧	🟧	🟥	🟧	🟧	🟧	🟨	🟥	🟧	🟨	🟧	🟢	🟧	🟨	🟢	🟢	🟦	🟧

Filter Strips - Baseline Peak Reductions



BMP$_A$/W$_A$		1%				2%				5%				10%				25%			
HSG		*A*	*B*	*C*	*D*	*A*	*B*	*C*	*D*	*A*	*B*	*C*	*D*	*A*	*B*	*C*	*D*	*A*	*B*	*C*	*D*
Event Size (in)	0.25	🟨	🟧	🟥	🟥	🟢	🟧	🟧	🟥	🟦	🟨	🟧	🟥	🟦	🟦	🟨	🟧	🟦	🟦	🟦	🟢
	0.5	🟧	🟥	🟥	🟥	🟧	🟥	🟥	🟥	🟩	🟧	🟥	🟥	🟦	🟨	🟥	🟥	🟦	🟦	🟨	🟥
	0.75	🟧	🟥	🟥	🟥	🟧	🟥	🟥	🟥	🟨	🟥	🟥	🟥	🟦	🟧	🟥	🟥	🟦	🟢	🟥	🟥
	1	🟥	🟥	🟥	🟥	🟧	🟥	🟥	🟥	🟨	🟥	🟥	🟥	🟢	🟥	🟥	🟥	🟦	🟨	🟥	🟥
	1.25	🟥	🟥	🟥	🟥	🟧	🟥	🟥	🟥	🟧	🟥	🟥	🟥	🟨	🟥	🟥	🟥	🟦	🟥	🟥	🟥
	1.5	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟧	🟥	🟥	🟥	🟨	🟥	🟥	🟥	🟦	🟥	🟥	🟥
	2	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟧	🟥	🟥	🟥	🟧	🟥	🟥	🟥	🟢	🟥	🟥	🟥
	2.5	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟧	🟥	🟥	🟥	🟨	🟥	🟥	🟥
	3	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟧	🟥	🟥	🟥
	3.5	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟧	🟥	🟥	🟥

Volumes



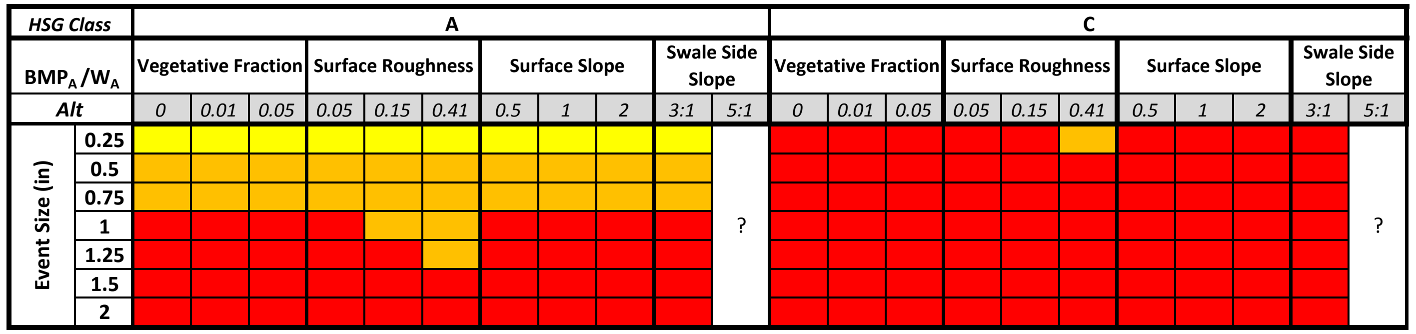
BMP$_A$/W$_A$		1%				2%				5%				10%				25%			
HSG		*A*	*B*	*C*	*D*	*A*	*B*	*C*	*D*	*A*	*B*	*C*	*D*	*A*	*B*	*C*	*D*	*A*	*B*	*C*	*D*
Event Size (in)	0.25	🟢	🟧	🟧	🟥	🟩	🟨	🟧	🟧	🟦	🟩	🟨	🟧	🟦	🟦	🟢	🟨	🟦	🟦	🟦	🟢
	0.5	🟨	🟧	🟥	🟥	🟢	🟧	🟧	🟥	🟦	🟨	🟧	🟥	🟦	🟢	🟨	🟧	🟦	🟦	🟢	🟧
	0.75	🟧	🟧	🟥	🟥	🟨	🟧	🟥	🟥	🟩	🟨	🟧	🟥	🟦	🟨	🟧	🟥	🟦	🟩	🟨	🟥
	1	🟧	🟥	🟥	🟥	🟨	🟧	🟥	🟥	🟢	🟧	🟥	🟥	🟩	🟨	🟧	🟥	🟦	🟢	🟧	🟥
	1.25	🟧	🟥	🟥	🟥	🟨	🟧	🟥	🟥	🟢	🟧	🟥	🟥	🟩	🟧	🟥	🟥	🟦	🟨	🟥	🟥
	1.5	🟧	🟥	🟥	🟥	🟧	🟥	🟥	🟥	🟨	🟧	🟥	🟥	🟢	🟧	🟥	🟥	🟦	🟨	🟥	🟥
	2	🟧	🟥	🟥	🟥	🟧	🟥	🟥	🟥	🟨	🟥	🟥	🟥	🟢	🟧	🟥	🟥	🟩	🟧	🟥	🟥
	2.5	🟧	🟥	🟥	🟥	🟧	🟥	🟥	🟥	🟨	🟥	🟥	🟥	🟨	🟥	🟥	🟥	🟩	🟧	🟥	🟥
	3	🟥	🟥	🟥	🟥	🟧	🟥	🟥	🟥	🟧	🟥	🟥	🟥	🟨	🟥	🟥	🟥	🟢	🟧	🟥	🟥
	3.5	🟥	🟥	🟥	🟥	🟧	🟥	🟥	🟥	🟧	🟥	🟥	🟥	🟨	🟥	🟥	🟥	🟢	🟥	🟥	🟥

GRASS SWALE

Drainage Area to BMP Area 1%: Model Unstable

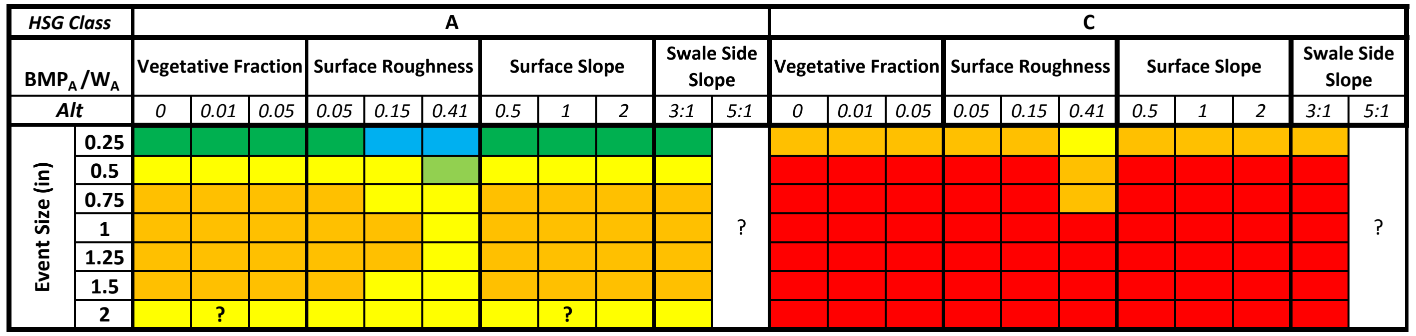
Peak Reductions

Drainage Area to BMP Area 2%



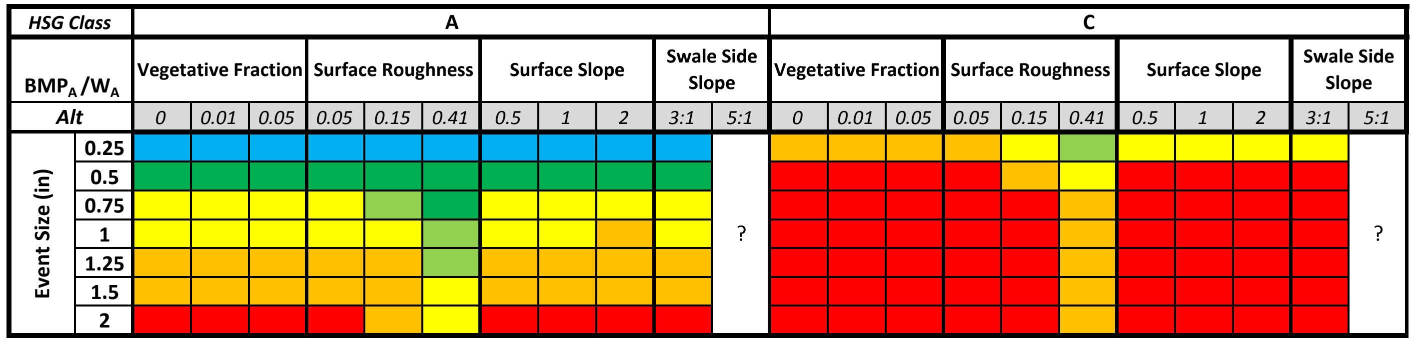
HSG Class		A											C										
BMP_A/W_A		Vegetative Fraction			Surface Roughness			Surface Slope			Swale Side Slope		Vegetative Fraction			Surface Roughness			Surface Slope			Swale Side Slope	
Alt		0	0.01	0.05	0.05	0.15	0.41	0.5	1	2	3:1	5:1	0	0.01	0.05	0.05	0.15	0.41	0.5	1	2	3:1	5:1
Event Size (in)	0.25	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨		🟥	🟥	🟥	🟥	🟥	🟧	🟥	🟥	🟥	🟥	
	0.5	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧		🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	
	0.75	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧		🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	
	1	🟥	🟥	🟥	🟥	🟧	🟧	🟥	🟥	🟥	🟥	?	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	?
	1.25	🟥	🟥	🟥	🟥	🟥	🟧	🟥	🟥	🟥	🟥		🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	
	1.5	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥		🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	
	2	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥		🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	

Drainage Area to BMP Area 5%



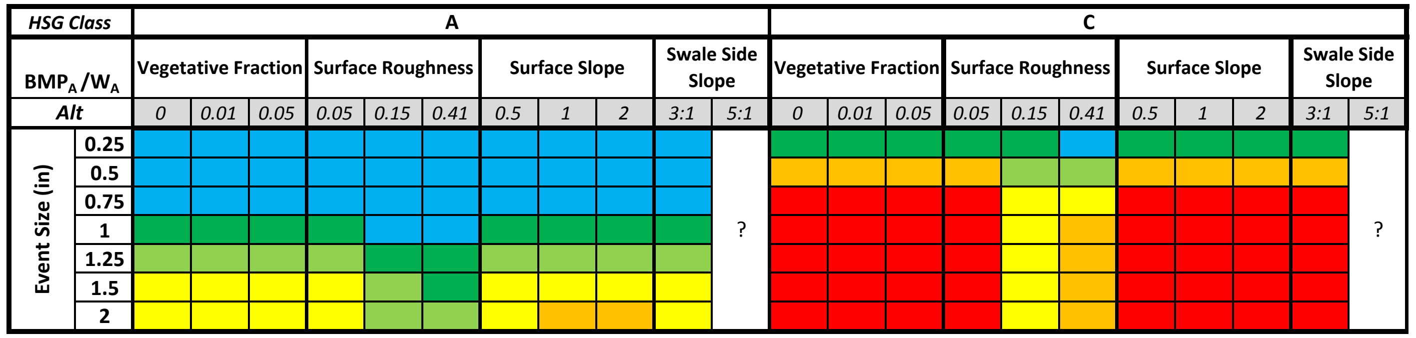
HSG Class		A											C										
BMP_A/W_A		Vegetative Fraction			Surface Roughness			Surface Slope			Swale Side Slope		Vegetative Fraction			Surface Roughness			Surface Slope			Swale Side Slope	
Alt		0	0.01	0.05	0.05	0.15	0.41	0.5	1	2	3:1	5:1	0	0.01	0.05	0.05	0.15	0.41	0.5	1	2	3:1	5:1
Event Size (in)	0.25	🟩	🟩	🟩	🟩	🟦	🟦	🟩	🟩	🟩	🟩		🟧	🟧	🟧	🟧	🟧	🟨	🟧	🟧	🟧	🟧	
	0.5	🟨	🟨	🟨	🟨	🟨	🟢	🟨	🟨	🟨	🟨		🟥	🟥	🟥	🟥	🟥	🟧	🟥	🟥	🟥	🟥	
	0.75	🟧	🟧	🟧	🟧	🟨	🟨	🟧	🟧	🟧	🟧		🟥	🟥	🟥	🟥	🟥	🟧	🟥	🟥	🟥	🟥	
	1	🟧	🟧	🟧	🟧	🟧	🟨	🟧	🟧	🟧	🟧	?	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	?
	1.25	🟧	🟧	🟧	🟧	🟧	🟨	🟧	🟧	🟧	🟧		🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	
	1.5	🟧	🟧	🟧	🟧	🟨	🟨	🟧	🟧	🟧	🟧		🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	
	2	🟨	🟨 ?	🟨	🟨	🟨	🟨	🟨	🟨 ?	🟨	🟨		🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	

Drainage Area to BMP Area - 10%



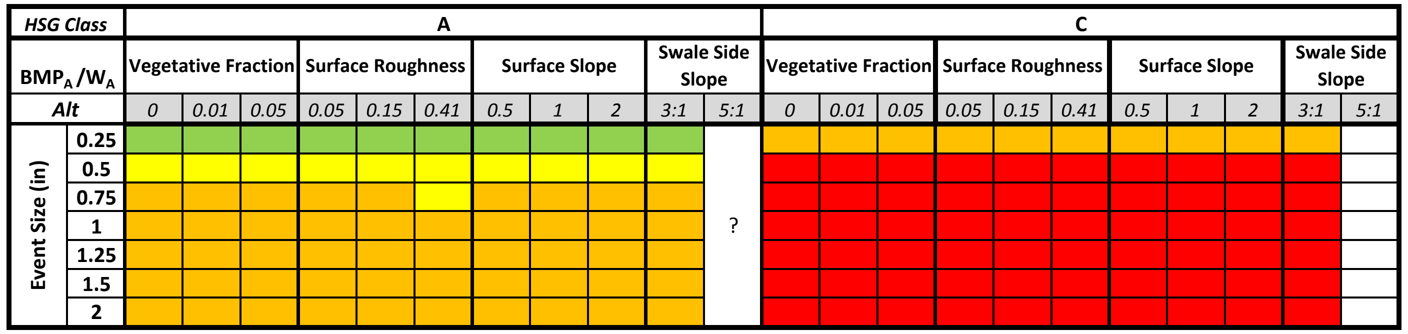
HSG Class		A											C										
BMP_A/W_A		Vegetative Fraction			Surface Roughness			Surface Slope			Swale Side Slope		Vegetative Fraction			Surface Roughness			Surface Slope			Swale Side Slope	
Alt		0	0.01	0.05	0.05	0.15	0.41	0.5	1	2	3:1	5:1	0	0.01	0.05	0.05	0.15	0.41	0.5	1	2	3:1	5:1
Event Size (in)	0.25	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦		🟧	🟧	🟧	🟧	🟨	🟢	🟨	🟨	🟨	🟨	
	0.5	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩		🟥	🟥	🟥	🟥	🟧	🟨	🟥	🟥	🟥	🟥	
	0.75	🟨	🟨	🟨	🟨	🟢	🟩	🟨	🟨	🟨	🟨		🟥	🟥	🟥	🟥	🟥	🟧	🟥	🟥	🟥	🟥	
	1	🟨	🟨	🟨	🟨	🟨	🟢	🟨	🟨	🟧	🟨	?	🟥	🟥	🟥	🟥	🟥	🟧	🟥	🟥	🟥	🟥	?
	1.25	🟧	🟧	🟧	🟧	🟧	🟢	🟧	🟧	🟧	🟧		🟥	🟥	🟥	🟥	🟥	🟧	🟥	🟥	🟥	🟥	
	1.5	🟧	🟧	🟧	🟧	🟧	🟨	🟧	🟧	🟧	🟧		🟥	🟥	🟥	🟥	🟥	🟧	🟥	🟥	🟥	🟥	
	2	🟥	🟥	🟥	🟥	🟧	🟨	🟥	🟥	🟥	🟥		🟥	🟥	🟥	🟥	🟥	🟧	🟥	🟥	🟥	🟥	

Drainage Area to BMP Area - 25%

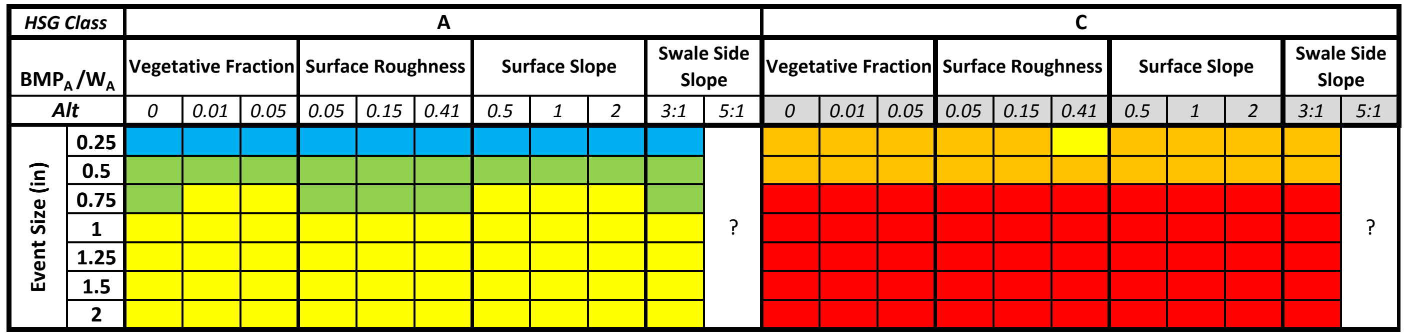


HSG Class		A											C										
BMP_A/W_A		Vegetative Fraction			Surface Roughness			Surface Slope			Swale Side Slope		Vegetative Fraction			Surface Roughness			Surface Slope			Swale Side Slope	
Alt		0	0.01	0.05	0.05	0.15	0.41	0.5	1	2	3:1	5:1	0	0.01	0.05	0.05	0.15	0.41	0.5	1	2	3:1	5:1
Event Size (in)	0.25	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦		🟩	🟩	🟩	🟩	🟩	🟦	🟩	🟩	🟩	🟩	
	0.5	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦		🟧	🟧	🟧	🟧	🟢	🟢	🟧	🟧	🟧	🟧	
	0.75	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦		🟥	🟥	🟥	🟥	🟨	🟨	🟥	🟥	🟥	🟥	
	1	🟩	🟩	🟩	🟩	🟦	🟦	🟩	🟩	🟩	🟩	?	🟥	🟥	🟥	🟥	🟨	🟧	🟥	🟥	🟥	🟥	?
	1.25	🟢	🟢	🟢	🟢	🟩	🟩	🟢	🟢	🟢	🟢		🟥	🟥	🟥	🟥	🟨	🟧	🟥	🟥	🟥	🟥	
	1.5	🟨	🟨	🟨	🟨	🟢	🟩	🟨	🟨	🟨	🟨		🟥	🟥	🟥	🟥	🟨	🟧	🟥	🟥	🟥	🟥	
	2	🟨	🟨	🟨	🟨	🟢	🟢	🟨	🟧	🟧	🟨		🟥	🟥	🟥	🟥	🟨	🟧	🟥	🟥	🟥	🟥	

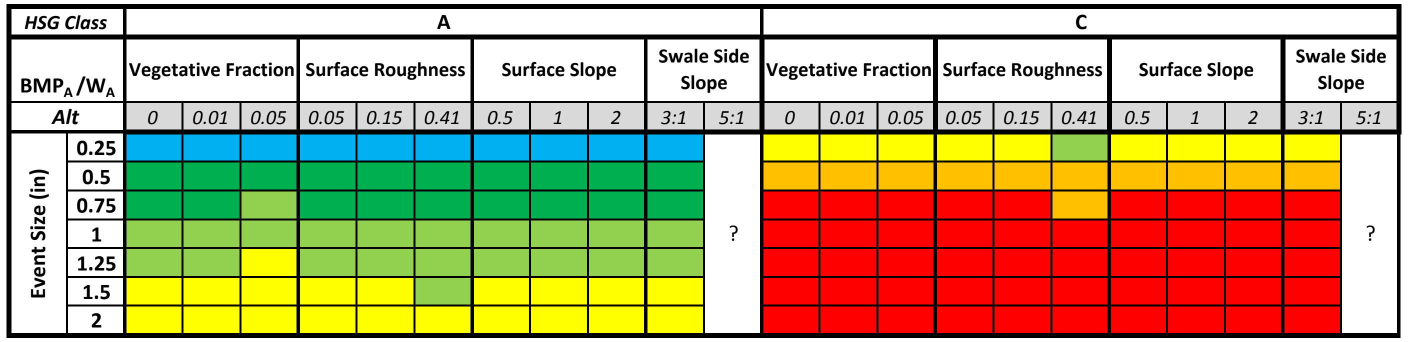
Volume Reductions



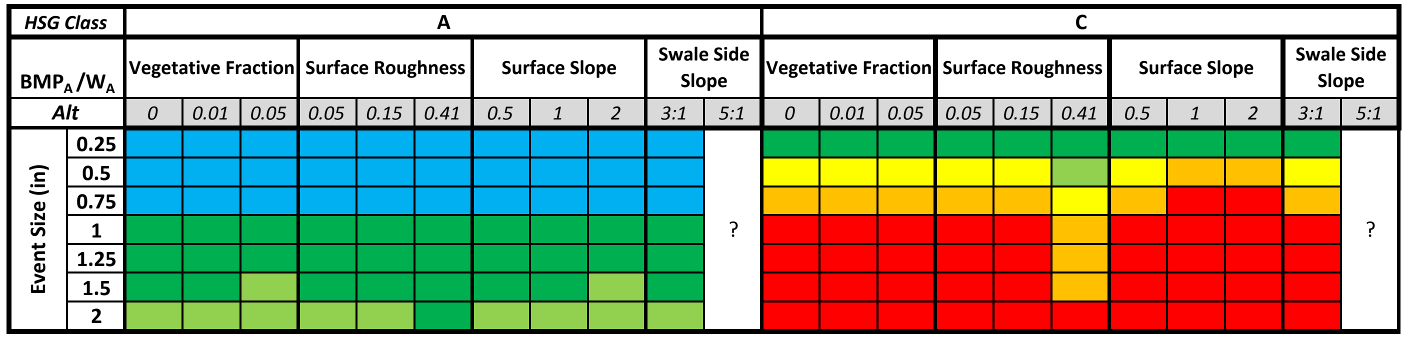
HSG Class		A											C										
BMP_A/W_A		Vegetative Fraction			Surface Roughness			Surface Slope			Swale Side Slope		Vegetative Fraction			Surface Roughness			Surface Slope			Swale Side Slope	
Alt		0	0.01	0.05	0.05	0.15	0.41	0.5	1	2	3:1	5:1	0	0.01	0.05	0.05	0.15	0.41	0.5	1	2	3:1	5:1
Event Size (in)	0.25	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢		🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	
	0.5	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨		🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	
	0.75	🟧	🟧	🟧	🟧	🟧	🟨	🟧	🟧	🟧	🟧		🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	
	1	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	?	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	
	1.25	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧		🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	
	1.5	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧		🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	
	2	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧		🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	



HSG Class		A											C										
BMP_A/W_A		Vegetative Fraction			Surface Roughness			Surface Slope			Swale Side Slope		Vegetative Fraction			Surface Roughness			Surface Slope			Swale Side Slope	
Alt		0	0.01	0.05	0.05	0.15	0.41	0.5	1	2	3:1	5:1	0	0.01	0.05	0.05	0.15	0.41	0.5	1	2	3:1	5:1
Event Size (in)	0.25	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦		🟧	🟧	🟧	🟧	🟧	🟨	🟧	🟧	🟧	🟧	
	0.5	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢		🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	
	0.75	🟢	🟨	🟨	🟢	🟢	🟢	🟨	🟨	🟨	🟢		🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	
	1	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	?	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	?
	1.25	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨		🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	
	1.5	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨		🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	
	2	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨		🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	



HSG Class		A											C										
BMP_A/W_A		Vegetative Fraction			Surface Roughness			Surface Slope			Swale Side Slope		Vegetative Fraction			Surface Roughness			Surface Slope			Swale Side Slope	
Alt		0	0.01	0.05	0.05	0.15	0.41	0.5	1	2	3:1	5:1	0	0.01	0.05	0.05	0.15	0.41	0.5	1	2	3:1	5:1
Event Size (in)	0.25	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦		🟨	🟨	🟨	🟨	🟨	🟢	🟨	🟨	🟨	🟨	
	0.5	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩		🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	
	0.75	🟩	🟩	🟢	🟩	🟩	🟩	🟩	🟩	🟩	🟩		🟥	🟥	🟥	🟥	🟥	🟧	🟥	🟥	🟥	🟥	
	1	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	?	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	?
	1.25	🟢	🟢	🟨	🟢	🟢	🟢	🟢	🟢	🟢	🟢		🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	
	1.5	🟨	🟨	🟨	🟨	🟨	🟢	🟨	🟨	🟨	🟨		🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	
	2	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨		🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	



HSG Class		A											C										
BMP_A/W_A		Vegetative Fraction			Surface Roughness			Surface Slope			Swale Side Slope		Vegetative Fraction			Surface Roughness			Surface Slope			Swale Side Slope	
Alt		0	0.01	0.05	0.05	0.15	0.41	0.5	1	2	3:1	5:1	0	0.01	0.05	0.05	0.15	0.41	0.5	1	2	3:1	5:1
Event Size (in)	0.25	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦		🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	
	0.5	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦		🟨	🟨	🟨	🟨	🟨	🟢	🟨	🟧	🟧	🟨	
	0.75	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦		🟧	🟧	🟧	🟧	🟧	🟨	🟧	🟥	🟥	🟧	
	1	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	?	🟥	🟥	🟥	🟥	🟥	🟧	🟥	🟥	🟥	🟥	?
	1.25	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩		🟥	🟥	🟥	🟥	🟥	🟧	🟥	🟥	🟥	🟥	
	1.5	🟩	🟩	🟢	🟩	🟩	🟩	🟩	🟩	🟢	🟩		🟥	🟥	🟥	🟥	🟥	🟧	🟥	🟥	🟥	🟥	
	2	🟢	🟢	🟢	🟢	🟢	🟩	🟢	🟢	🟢	🟢		🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	

Green Roof

Outlet Volume ($feet^3$)

10%

BMPA /WA		Soil Thickness (in)		Soil Type (porosity, field capacity, wilting point, conductivity, conductivity slope, suction head, storage void ratio)		Storage Height (in)	
		2	*4*	*Loamy sand/sandy loam*	*typical green roof mix*	*2*	*4*
Event Size (in)	**0.25**	🟧	🟧	🟧	🟧	🟧	🟧
	0.5	🟥	🟥	🟥	🟥	🟥	🟥
	0.75	🟥	🟥	🟥	🟥	🟥	🟥
	1	🟥	🟥	🟥	🟥	🟥	🟥
	1.25	🟥	🟥	🟥	🟥	🟥	🟥
	1.5	🟥	🟥	🟥	🟥	🟥	🟥
	2	🟥	🟥	🟥	🟥	🟥	🟥
	2.5	🟥	🟥	🟥	🟥	🟥	🟥
	3	🟥	🟥	🟥	🟥	🟥	🟥
	3.5	🟥	🟥	🟥	🟥	🟥	🟥

25%

BMPA /WA		Soil Thickness (in)		Soil Type (porosity, field capacity, wilting point, conductivity, conductivity slope, suction head, storage void ratio)		Storage Height (in)	
		2	*4*	*Loamy sand/sandy loam*	*typical green roof mix*	*2*	*4*
Event Size (in)	**0.25**	🟧	🟨	🟧	🟧	🟧	🟧
	0.5	🟧	🟧	🟥	🟧	🟧	🟧
	0.75	🟧	🟧	🟥	🟧	🟧	🟧
	1	🟥	🟧	🟥	🟥	🟥	🟥
	1.25	🟥	🟧	🟥	🟥	🟥	🟥
	1.5	🟥	🟧	🟥	🟥	🟥	🟥
	2	🟥	🟥	🟥	🟥	🟥	🟥
	2.5	🟥	🟥	🟥	🟥	🟥	🟥
	3	🟥	🟥	🟥	🟥	🟥	🟥
	3.5	🟥	🟥	🟥	🟥	🟥	🟥

50%

BMPA /WA		Soil Thickness (in)		Soil Type (porosity, field capacity, wilting point, conductivity, conductivity slope, suction head, storage void ratio)		Storage Height (in)	
		2	*4*	*Loamy sand/sandy loam*	*typical green roof mix*	*2*	*4*
Event Size (in)	**0.25**	🟨	🟨	🟨	🟨	🟨	🟨
	0.5	🟧	🟨	🟧	🟧	🟧	🟧
	0.75	🟧	🟨	🟧	🟧	🟧	🟧
	1	🟧	🟧	🟥	🟧	🟧	🟧
	1.25	🟧	🟧	🟥	🟧	🟧	🟧
	1.5	🟧	🟧	🟥	🟧	🟧	🟧
	2	🟥	🟧	🟥	🟥	🟥	🟥
	2.5	🟥	🟧	🟥	🟥	🟥	🟥
	3	🟥	🟧	🟥	🟥	🟥	🟥
	3.5	🟥	🟧	🟥	🟥	🟥	🟥

Peak Outlet Rate (cfs)

BMPA /WA		Soil Thickness (in)		Soil Type (porosity, field capacity, wilting point, conductivity, conductivity slope, suction head, storage void ratio)		Storage Height (in)	
		2	*4*	*Loamy sand/sandy loam*	*typical green roof mix*	*2*	*4*
Event Size (in)	**0.25**	🟧	🟧	🟧	🟧	🟧	🟧
	0.5	🟥	🟧	🟥	🟥	🟥	🟥
	0.75	🟥	🟧	🟥	🟥	🟥	🟥
	1	🟥	🟧	🟥	🟥	🟥	🟥
	1.25	🟥	🟧	🟥	🟥	🟥	🟥
	1.5	🟥	🟧	🟥	🟥	🟥	🟥
	2	🟥	🟧	🟥	🟥	🟥	🟥
	2.5	🟥	🟧	🟥	🟥	🟥	🟥
	3	🟥	🟧	🟥	🟥	🟥	🟥
	3.5	🟥	🟧	🟥	🟥	🟥	🟥

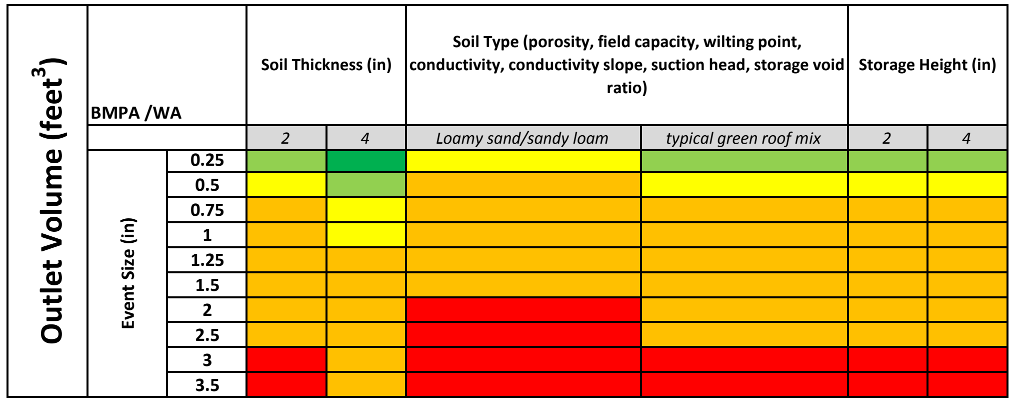
BMPA /WA		Soil Thickness (in)		Soil Type (porosity, field capacity, wilting point, conductivity, conductivity slope, suction head, storage void ratio)		Storage Height (in)	
		2	*4*	*Loamy sand/sandy loam*	*typical green roof mix*	*2*	*4*
Event Size (in)	**0.25**	🟧	🟧	🟧	🟧	🟧	🟧
	0.5	🟧	🟧	🟧	🟧	🟧	🟧
	0.75	🟧	🟧	🟧	🟧	🟧	🟧
	1	🟧	🟧	🟧	🟧	🟧	🟧
	1.25	🟧	🟧	🟧	🟧	🟧	🟧
	1.5	🟧	🟧	🟧	🟧	🟧	🟧
	2	🟧	🟧	🟧	🟧	🟧	🟧
	2.5	🟥	🟧	🟧	🟥	🟥	🟥
	3	🟥	🟧	🟥	🟥	🟥	🟥
	3.5	🟥	🟧	🟥	🟥	🟥	🟥

BMPA /WA		Soil Thickness (in)		Soil Type (porosity, field capacity, wilting point, conductivity, conductivity slope, suction head, storage void ratio)		Storage Height (in)	
		2	*4*	*Loamy sand/sandy loam*	*typical green roof mix*	*2*	*4*
Event Size (in)	**0.25**	🟨	🟨	🟨	🟨	🟨	🟨
	0.5	🟧	🟨	🟧	🟧	🟧	🟧
	0.75	🟧	🟨	🟧	🟧	🟧	🟧
	1	🟧	🟨	🟧	🟧	🟧	🟧
	1.25	🟧	🟨	🟧	🟧	🟧	🟧
	1.5	🟧	🟨	🟧	🟧	🟧	🟧
	2	🟧	🟨	🟧	🟧	🟧	🟧
	2.5	🟥	🟨	🟧	🟥	🟥	🟥
	3	🟥	🟨	🟥	🟥	🟥	🟥
	3.5	🟥	🟥	🟥	🟥	🟥	🟥

Green Roof

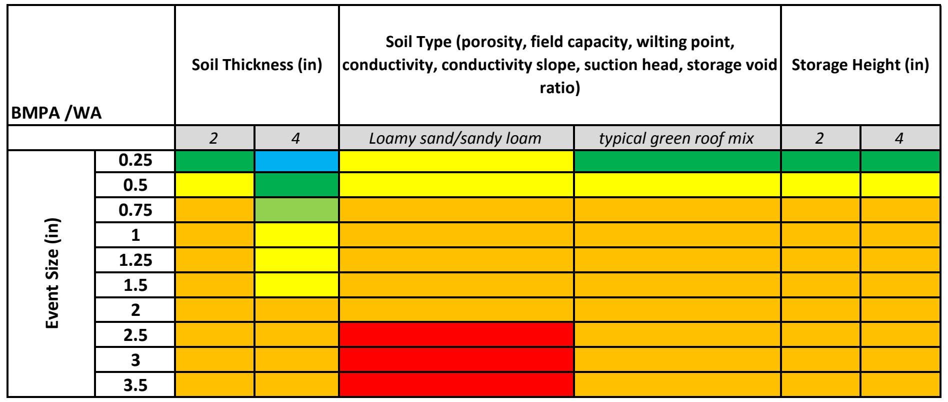
Outlet Volume (feet^3)

75%



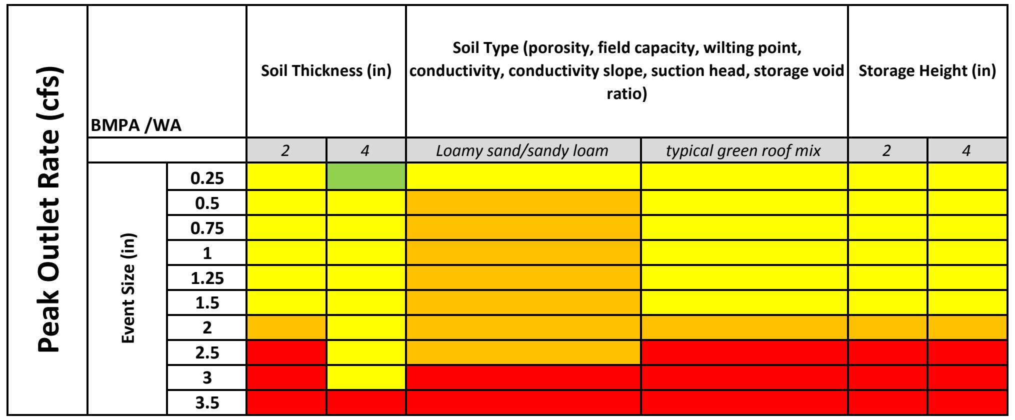
BMPA /WA		Soil Thickness (in)		Soil Type (porosity, field capacity, wilting point, conductivity, conductivity slope, suction head, storage void ratio)		Storage Height (in)	
		2	*4*	*Loamy sand/sandy loam*	*typical green roof mix*	*2*	*4*
Event Size (in)	**0.25**	🟢	🟩	🟨	🟢	🟢	🟢
	0.5	🟨	🟢	🟧	🟨	🟨	🟨
	0.75	🟧	🟨	🟧	🟧	🟧	🟧
	1	🟧	🟨	🟧	🟧	🟧	🟧
	1.25	🟧	🟧	🟧	🟧	🟧	🟧
	1.5	🟧	🟧	🟧	🟧	🟧	🟧
	2	🟧	🟧	🟥	🟧	🟧	🟧
	2.5	🟧	🟧	🟥	🟧	🟧	🟧
	3	🟥	🟧	🟥	🟥	🟥	🟥
	3.5	🟥	🟧	🟥	🟥	🟥	🟥

100%

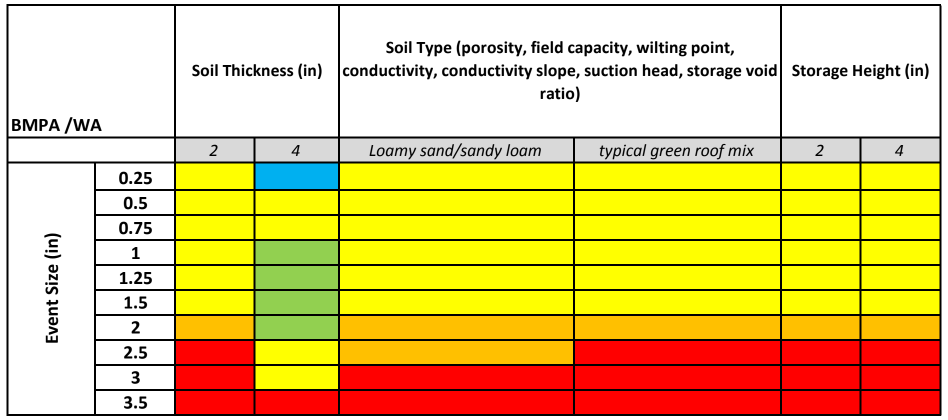


BMPA /WA		Soil Thickness (in)		Soil Type (porosity, field capacity, wilting point, conductivity, conductivity slope, suction head, storage void ratio)		Storage Height (in)	
		2	*4*	*Loamy sand/sandy loam*	*typical green roof mix*	*2*	*4*
Event Size (in)	**0.25**	🟩	🟦	🟨	🟩	🟩	🟩
	0.5	🟨	🟩	🟨	🟨	🟨	🟨
	0.75	🟧	🟢	🟧	🟧	🟧	🟧
	1	🟧	🟨	🟧	🟧	🟧	🟧
	1.25	🟧	🟨	🟧	🟧	🟧	🟧
	1.5	🟧	🟨	🟧	🟧	🟧	🟧
	2	🟧	🟧	🟧	🟧	🟧	🟧
	2.5	🟧	🟧	🟥	🟧	🟧	🟧
	3	🟧	🟧	🟥	🟧	🟧	🟧
	3.5	🟧	🟧	🟥	🟧	🟧	🟧

Peak Outlet Rate (cfs)



BMPA /WA		Soil Thickness (in)		Soil Type (porosity, field capacity, wilting point, conductivity, conductivity slope, suction head, storage void ratio)		Storage Height (in)	
		2	*4*	*Loamy sand/sandy loam*	*typical green roof mix*	*2*	*4*
Event Size (in)	**0.25**	🟨	🟢	🟧	🟨	🟨	🟨
	0.5	🟨	🟨	🟧	🟨	🟨	🟨
	0.75	🟨	🟨	🟧	🟨	🟨	🟨
	1	🟨	🟨	🟧	🟨	🟨	🟨
	1.25	🟨	🟨	🟧	🟨	🟨	🟨
	1.5	🟨	🟨	🟧	🟨	🟨	🟨
	2	🟧	🟨	🟧	🟧	🟧	🟧
	2.5	🟥	🟨	🟧	🟥	🟥	🟥
	3	🟥	🟨	🟥	🟥	🟥	🟥
	3.5	🟥	🟥	🟥	🟥	🟥	🟥



BMPA /WA		Soil Thickness (in)		Soil Type (porosity, field capacity, wilting point, conductivity, conductivity slope, suction head, storage void ratio)		Storage Height (in)	
		2	*4*	*Loamy sand/sandy loam*	*typical green roof mix*	*2*	*4*
Event Size (in)	**0.25**	🟨	🟦	🟨	🟨	🟨	🟨
	0.5	🟨	🟨	🟨	🟨	🟨	🟨
	0.75	🟨	🟨	🟨	🟨	🟨	🟨
	1	🟨	🟢	🟨	🟨	🟨	🟨
	1.25	🟨	🟢	🟨	🟨	🟨	🟨
	1.5	🟨	🟢	🟨	🟨	🟨	🟨
	2	🟧	🟢	🟧	🟧	🟧	🟧
	2.5	🟥	🟨	🟧	🟥	🟥	🟥
	3	🟥	🟨	🟥	🟥	🟥	🟥
	3.5	🟥	🟥	🟥	🟥	🟥	🟥

Soil Renovation - Peaks

HSG		A			B			C			D		
Alt		*Base*	*High*	*Max*	*Base*	*High*	*Max*	*Base*	*High*	*Max*	*Base*	*High*	*Max*
Event Size (in)	0.25	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
	0.5	🟦	🟦	🟦	🟦	🟦	🟦	🟩	🟦	🟦	🟧	🟩	🟦
	0.75	🟦	🟦	🟦	🟦	🟦	🟦	🟨	🟦	🟦	🟥	🟨	🟦
	1	🟦	🟦	🟦	🟢	🟦	🟦	🟥	🟢	🟦	🟥	🟧	🟦
	1.25	🟦	🟦	🟦	🟢	🟦	🟦	🟥	🟧	🟦	🟥	🟧	🟦
	1.5	🟦	🟦	🟦	🟧	🟦	🟦	🟥	🟧	🟢	🟥	🟧	🟦
	2	🟦	🟦	🟦	🟥	🟦	🟦	🟥	🟧	🟨	🟥	🟧	🟩
	2.5	🟩	🟦	🟦	🟥	🟩	🟦	🟥	🟧	🟨	🟥	🟧	🟢
	3	🟢	🟦	🟦	🟥	🟢	🟦	🟥	🟧	🟧	🟥	🟧	🟢
	3.5	🟨	🟦	🟦	🟥	🟢	🟦	🟥	🟧	🟧	🟥	🟧	🟨

Volumes

HSG		A			B			C			D		
Alt		*Base*	*High*	*Max*	*Base*	*High*	*Max*	*Base*	*High*	*Max*	*Base*	*High*	*Max*
Event Size (in)	0.25	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
	0.5	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟨	🟩	🟦
	0.75	🟦	🟦	🟦	🟦	🟦	🟦	🟢	🟦	🟦	🟥	🟢	🟦
	1	🟦	🟦	🟦	🟩	🟦	🟦	🟧	🟩	🟦	🟥	🟨	🟦
	1.25	🟦	🟦	🟦	🟢	🟦	🟦	🟧	🟢	🟦	🟥	🟨	🟦
	1.5	🟦	🟦	🟦	🟢	🟦	🟦	🟧	🟢	🟩	🟥	🟧	🟦
	2	🟦	🟦	🟦	🟨	🟦	🟦	🟧	🟨	🟢	🟥	🟧	🟦
	2.5	🟦	🟦	🟦	🟧	🟦	🟦	🟥	🟨	🟢	🟥	🟧	🟩
	3	🟩	🟦	🟦	🟧	🟩	🟦	🟥	🟨	🟢	🟥	🟧	🟩
	3.5	🟩	🟦	🟦	🟧	🟩	🟦	🟥	🟧	🟨	🟥	🟧	🟢

APPENDIX C

BMP ANNUAL RUNS

Bioretention

1979 - Average Year (39.83 in)

Longterm Average Annual Rainfall (37.95 in)

		Surface Ponding Depth (in)			**Soil Thickness (in)**		**Soil Type** (porosity, field capacity, wilting point, conductivity, conductivity slope, suction head)			**Storage Height / Underdrain Offset (in)**			
HSG	**A**	*6*	*12*	*18*	*24*	*48*	*LS*	*LS/SL*	*SL*	*18 / 3*	*21 / 6*	*24 / 12*	*30 / 18*
BMP_A/W_A	1%	🟨	🟢	🟢	🟨	🟨	🟨	🟨	🟢	🟨	🟨	🟨	🟨
	2%	🟢	🟩	🟩	🟢	🟢	🟢	🟢	🟩	🟢	🟢	🟢	🟢
	5%	🟩	🟦	🟦	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
	10%	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
	25%	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦

		Surface Ponding Depth (in)			**Soil Thickness (in)**		**Soil Type** (porosity, field capacity, wilting point, conductivity, conductivity slope, suction head)			**Storage Height / Underdrain Offset (in)**			
HSG	**B**	*6*	*12*	*18*	*24*	*48*	*LS*	*LS/SL*	*SL*	*18 / 3*	*21 / 6*	*24 / 12*	*30 / 18*
BMP_A/W_A	1%	🟨	🟨	🟢	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨
	2%	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢
	5%	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
	10%	🟩	🟦	🟦	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
	25%	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦

		Surface Ponding Depth (in)			**Soil Thickness (in)**		**Soil Type** (porosity, field capacity, wilting point, conductivity, conductivity slope, suction head)			**Storage Height / Underdrain Offset (in)**			
HSG	**C**	*6*	*12*	*18*	*24*	*48*	*LS*	*LS/SL*	*SL*	*18 / 3*	*21 / 6*	*24 / 12*	*30 / 18*
BMP_A/W_A	1%	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟨
	2%	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨
	5%	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟨	🟨	🟢	🟢	🟢
	10%	🟢	🟢	🟢	🟢	🟩	🟩	🟢	🟢	🟢	🟢	🟩	🟩
	25%	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟩	🟩	🟦	🟦	🟦

		Surface Ponding Depth (in)			**Soil Thickness (in)**		**Soil Type** (porosity, field capacity, wilting point, conductivity, conductivity slope, suction head)			**Storage Height / Underdrain Offset (in)**			
HSG	**D**	*6*	*12*	*18*	*24*	*48*	*LS*	*LS/SL*	*SL*	*18 / 3*	*21 / 6*	*24 / 12*	*30 / 18*
BMP_A/W_A	1%	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧
	2%	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧
	5%	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨
	10%	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟨	🟨	🟢	🟢	🟢
	25%	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟢	🟩	🟩	🟦

<u>LEGEND</u> **% Reduction**	
🟥	≤5%
🟧	>5; ≤25%
🟨	>25; ≤50%
🟢	>50; ≤75%
🟩	>75; ≤95%
🟦	>95%

Bioretention

2011 - Wet Year (64.49 in)

Longterm Average Annual Rainfall (37.95 in)

		Surface Ponding Depth (in)			**Soil Thickness (in)**		**Soil Type** (porosity, field capacity, wilting point, conductivity, conductivity slope, suction head)			**Storage Height / Underdrain Offset (in)**			
HSG	**A**	*6*	*12*	*18*	*24*	*48*	*LS*	*LS/SL*	*SL*	*18 / 3*	*21 / 6*	*24 / 12*	*30 / 18*
BMP_A/W_A	1%	🟨	🟢	🟢	🟨	🟨	🟨	🟨	🟢	🟨	🟨	🟨	🟨
	2%	🟢	🟩	🟩	🟢	🟢	🟢	🟢	🟩	🟢	🟢	🟢	🟢
	5%	🟩	🟩	🟦	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
	10%	🟦	🟦	🟦	🟦	🟦	🟩	🟦	🟦	🟦	🟦	🟦	🟦
	25%	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦

		Surface Ponding Depth (in)			**Soil Thickness (in)**		**Soil Type** (porosity, field capacity, wilting point, conductivity, conductivity slope, suction head)			**Storage Height / Underdrain Offset (in)**			
HSG	**B**	*6*	*12*	*18*	*24*	*48*	*LS*	*LS/SL*	*SL*	*18 / 3*	*21 / 6*	*24 / 12*	*30 / 18*
BMP_A/W_A	1%	🟨	🟨	🟢	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨
	2%	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢
	5%	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
	10%	🟩	🟦	🟦	🟩	🟦	🟩	🟩	🟩	🟩	🟩	🟩	🟦
	25%	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦

		Surface Ponding Depth (in)			**Soil Thickness (in)**		**Soil Type** (porosity, field capacity, wilting point, conductivity, conductivity slope, suction head)			**Storage Height / Underdrain Offset (in)**			
HSG	**C**	*6*	*12*	*18*	*24*	*48*	*LS*	*LS/SL*	*SL*	*18 / 3*	*21 / 6*	*24 / 12*	*30 / 18*
BMP_A/W_A	1%	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧
	2%	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟧	🟧	🟨	🟨	🟨
	5%	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟨	🟨	🟢	🟢	🟢
	10%	🟢	🟢	🟢	🟢	🟩	🟩	🟢	🟢	🟢	🟢	🟩	🟩
	25%	🟩	🟩	🟩	🟩	🟩	🟦	🟩	🟩	🟩	🟩	🟦	🟦

		Surface Ponding Depth (in)			**Soil Thickness (in)**		**Soil Type** (porosity, field capacity, wilting point, conductivity, conductivity slope, suction head)			**Storage Height / Underdrain Offset (in)**			
HSG	**D**	*6*	*12*	*18*	*24*	*48*	*LS*	*LS/SL*	*SL*	*18 / 3*	*21 / 6*	*24 / 12*	*30 / 18*
BMP_A/W_A	1%	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧
	2%	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧
	5%	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟧	🟨	🟨	🟨
	10%	🟨	🟨	🟨	🟨	🟨	🟢	🟨	🟨	🟨	🟨	🟢	🟢
	25%	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟢	🟢	🟩	🟩	🟦

<u>LEGEND</u> **% Reduction**	
🟥	≤5%
🟧	>5; ≤25%
🟨	>25; ≤50%
🟢	>50; ≤75%
🟩	>75; ≤95%
🟦	>95%

Porous Pavement

1979 - Average Year (39.83 in)

Longterm Average Annual Rainfall (37.95 in)

		Pavement Permeability (in/hr)			Storage Height (in)			Underdrain Offset (in)		
HSG	**A**	10	100	1000	12	24	36	0	3	6
	5%	🟩	🟩	🟩	🟩	🟩	🟩	🟥	🟩	🟩
	10%	🟩	🟩	🟩	🟩	🟩	🟩	🟥	🟩	🟦
	25%	🟦	🟦	🟦	🟦	🟦	🟦	🟥	🟦	🟦
	50%	🟦	🟦	🟦	🟦	🟦	🟦	🟥	🟦	🟦

		Pavement Permeability (in/hr)			Storage Height (in)			Underdrain Offset (in)		
HSG	**B**	10	100	1000	12	24	36	0	3	6
	5%	🟢	🟢	🟢	🟢	🟢	🟢	🟨	🟢	🟢
	10%	🟩	🟩	🟩	🟩	🟩	🟩	🟨	🟩	🟩
	25%	🟩	🟩	🟦	🟩	🟩	🟩	🟨	🟩	🟩
	50%	🟦	🟦	🟦	🟦	🟦	🟦	🟢	🟦	🟦

		Pavement Permeability (in/hr)			Storage Height (in)			Underdrain Offset (in)		
HSG	**C**	10	100	1000	12	24	36	0	3	6
	5%	🟨	🟨	🟨	🟨	🟨	🟨	🟧	🟨	🟨
	10%	🟢	🟢	🟢	🟢	🟢	🟢	🟧	🟢	🟢
	25%	🟢	🟢	🟢	🟢	🟢	🟢	🟨	🟢	🟩
	50%	🟩	🟩	🟩	🟩	🟩	🟩	🟨	🟩	🟦

		Pavement Permeability (in/hr)			Storage Height (in)			Underdrain Offset (in)		
HSG	**D**	10	100	1000	12	24	36	0	3	6
	5%	🟧	🟧	🟧	🟧	🟧	🟧	🟥	🟧	🟨
	10%	🟨	🟨	🟨	🟨	🟨	🟨	🟧	🟨	🟨
	25%	🟢	🟢	🟢	🟢	🟢	🟢	🟧	🟢	🟢
	50%	🟢	🟢	🟢	🟢	🟢	🟢	🟧	🟢	🟩

LEGEND **% Reduction**	
🟥	≤5%
🟧	>5; ≤25%
🟨	>25; ≤50%
🟢	>50; ≤75%
🟩	>75; ≤95%
🟦	>95%

Porous Pavement

2011 - Wet Year (64.49 in)

Longterm Average Annual Rainfall (37.95 in)

		Pavement Permeability (in/hr)			Storage Height (in)			Underdrain Offset (in)		
HSG	**A**	10	100	1000	12	24	36	0	3	6
	5%	🟩	🟩	🟩	🟩	🟩	🟩	🟥	🟩	🟩
	10%	🟦	🟦	🟦	🟦	🟦	🟦	🟥	🟦	🟦
	25%	🟦	🟦	🟦	🟦	🟦	🟦	🟥	🟦	🟦
	50%	🟦	🟦	🟦	🟦	🟦	🟦	🟥	🟦	🟦

		Pavement Permeability (in/hr)			Storage Height (in)			Underdrain Offset (in)		
HSG	**B**	10	100	1000	12	24	36	0	3	6
	5%	🟢	🟢	🟢	🟢	🟢	🟢	🟨	🟢	🟢
	10%	🟩	🟩	🟩	🟩	🟩	🟩	🟨	🟩	🟩
	25%	🟩	🟩	🟦	🟩	🟩	🟩	🟨	🟩	🟦
	50%	🟦	🟦	🟦	🟦	🟦	🟦	🟢	🟦	🟦

		Pavement Permeability (in/hr)			Storage Height (in)			Underdrain Offset (in)		
HSG	**C**	10	100	1000	12	24	36	0	3	6
	5%	🟨	🟨	🟨	🟨	🟨	🟨	🟧	🟨	🟨
	10%	🟨	🟨	🟨	🟨	🟨	🟨	🟧	🟨	🟢
	25%	🟢	🟢	🟢	🟢	🟢	🟢	🟨	🟢	🟩
	50%	🟩	🟩	🟩	🟩	🟩	🟩	🟨	🟩	🟩

		Pavement Permeability (in/hr)			Storage Height (in)			Underdrain Offset (in)		
HSG	**D**	10	100	1000	12	24	36	0	3	6
	5%	🟧	🟧	🟧	🟧	🟧	🟧	🟥	🟧	🟧
	10%	🟨	🟨	🟨	🟨	🟨	🟨	🟧	🟨	🟨
	25%	🟢	🟢	🟢	🟢	🟢	🟢	🟧	🟢	🟢
	50%	🟢	🟢	🟢	🟢	🟢	🟢	🟧	🟢	🟩

<u>LEGEND</u> **% Reduction**	
🟥	≤5%
🟧	>5; ≤25%
🟨	>25; ≤50%
🟢	>50; ≤75%
🟩	>75; ≤95%
🟦	>95%

Dry Detention

1979 - Average Year (39.83 in)

Longterm Average Annual Rainfall (37.95 in)

		Scenario 1	Scenario 2
HSG	**A**		
BMP_A/W_A	1%	🟩	🟩
	2%	🟩	🟩
	5%	🟩	🟦
	10%	🟦	🟦
	25%	🟦	🟦

		Scenario 1
HSG	**B**	
BMP_A/W_A	1%	🟨
	2%	🟢
	5%	🟢
	10%	🟩
	25%	🟩

		Scenario 1	Scenario 2
HSG	**C**		
BMP_A/W_A	1%	🟧	🟧
	2%	🟨	🟨
	5%	🟨	🟨
	10%	🟨	🟢
	25%	🟢	🟢

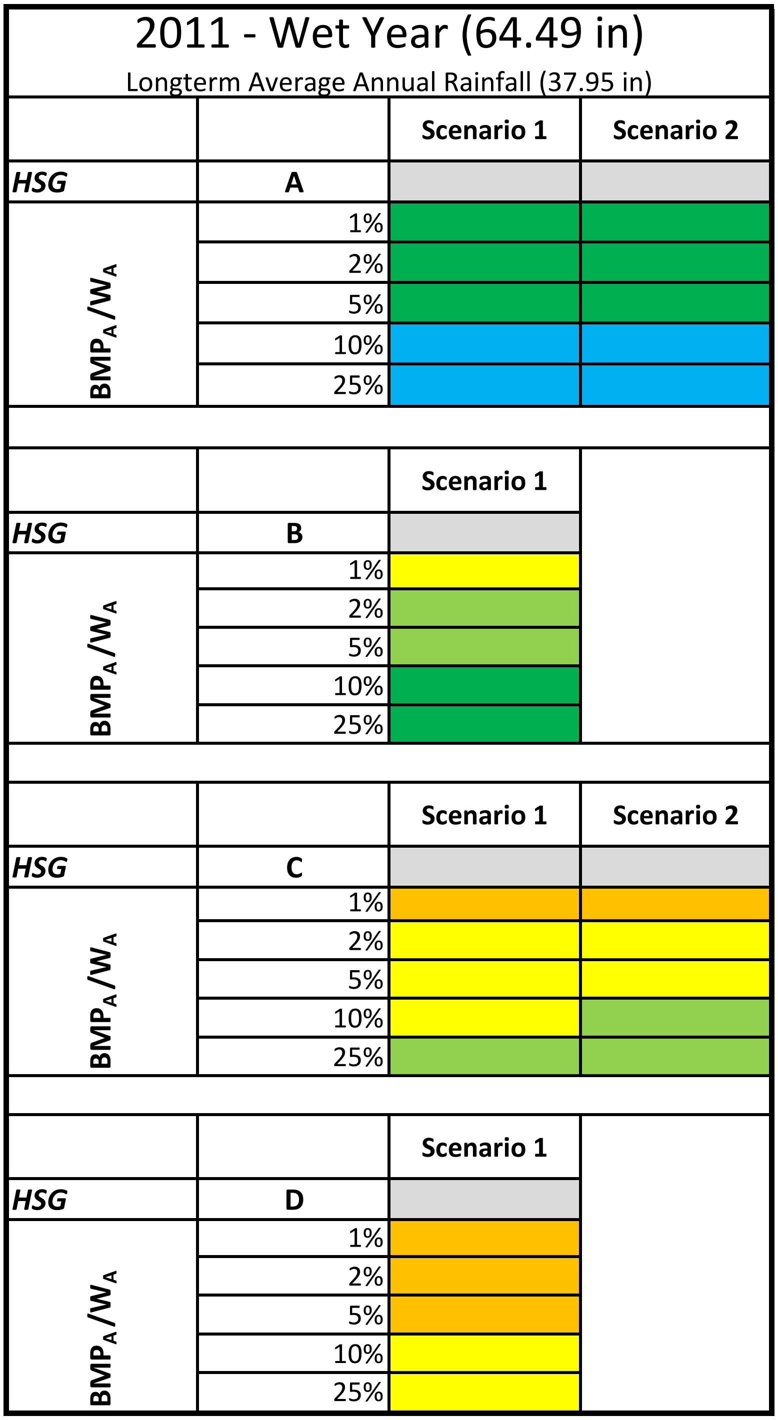
		Scenario 1
HSG	**D**	
BMP_A/W_A	1%	🟧
	2%	🟧
	5%	🟧
	10%	🟨
	25%	🟨

LEGEND

% Reduction

🟥	≤5%
🟧	>5; ≤25%
🟨	>25; ≤50%
🟢	>50; ≤75%
🟩	>75; ≤95%
🟦	>95%

Dry Detention



2011 - Wet Year (64.49 in)

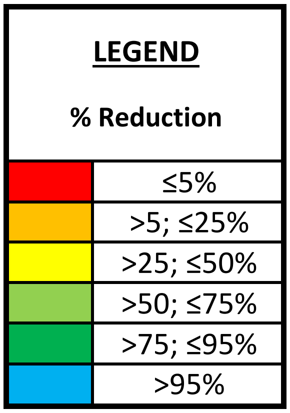
Longterm Average Annual Rainfall (37.95 in)

		Scenario 1	Scenario 2
HSG	**A**		
BMP_A/W_A	1%	🟩	🟩
	2%	🟩	🟩
	5%	🟩	🟩
	10%	🟦	🟦
	25%	🟦	🟦

		Scenario 1
HSG	**B**	
BMP_A/W_A	1%	🟨
	2%	🟢
	5%	🟢
	10%	🟩
	25%	🟩

		Scenario 1	Scenario 2
HSG	**C**		
BMP_A/W_A	1%	🟧	🟧
	2%	🟨	🟨
	5%	🟨	🟨
	10%	🟨	🟢
	25%	🟢	🟢

		Scenario 1
HSG	**D**	
BMP_A/W_A	1%	🟧
	2%	🟧
	5%	🟧
	10%	🟨
	25%	🟨



LEGEND

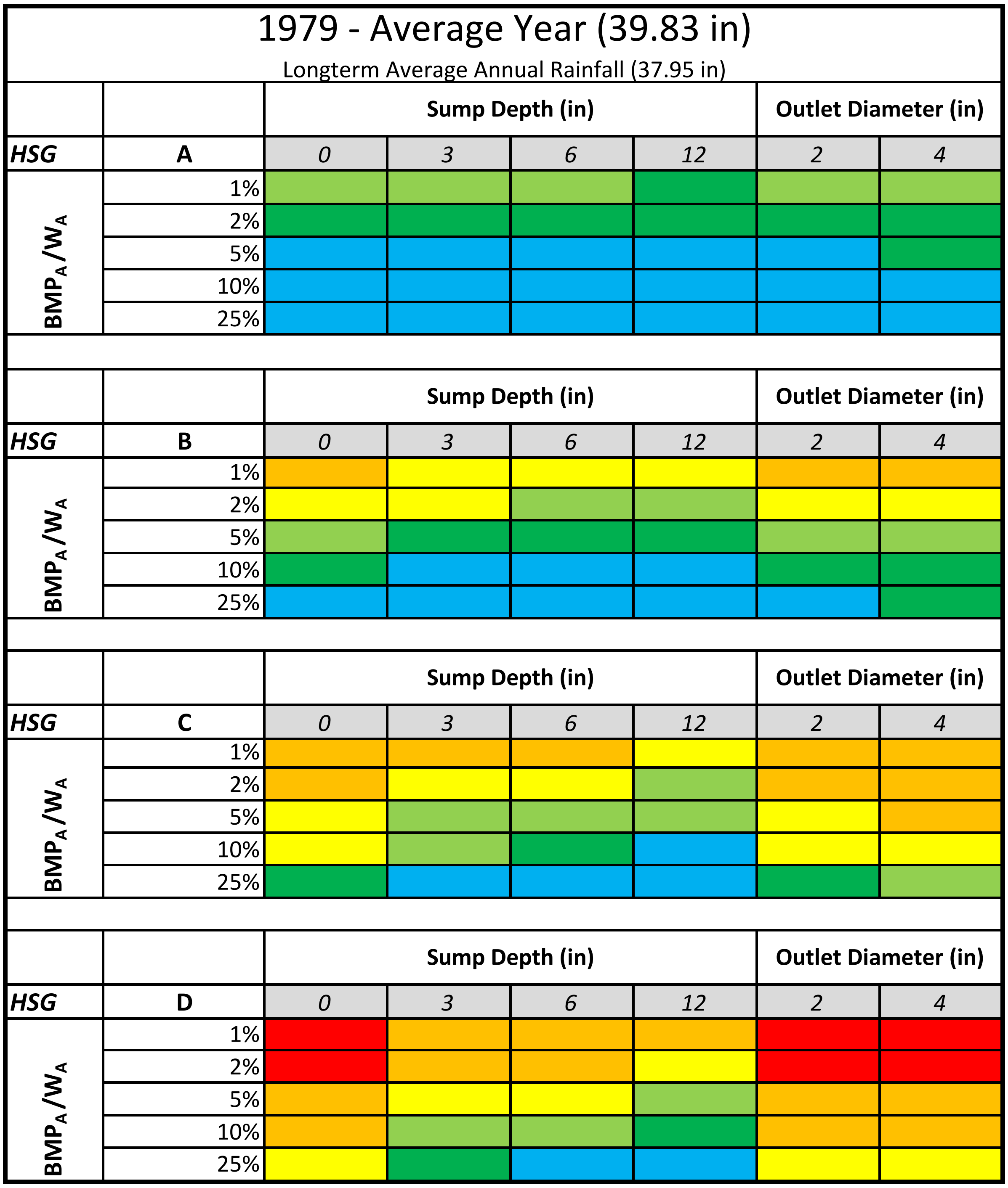
% Reduction

🟥	≤5%
🟧	>5; ≤25%
🟨	>25; ≤50%
🟢	>50; ≤75%
🟩	>75; ≤95%
🟦	>95%

Underground Storage - Scenario 1

1979 - Average Year (39.83 in)

Longterm Average Annual Rainfall (37.95 in)

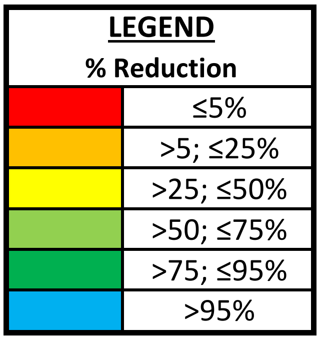


		Sump Depth (in)				Outlet Diameter (in)	
HSG	**A**	*0*	*3*	*6*	*12*	*2*	*4*
BMP_A/W_A	1%	🟩	🟩	🟩	🟢	🟩	🟩
	2%	🟢	🟢	🟢	🟢	🟢	🟢
	5%	🟦	🟦	🟦	🟦	🟦	🟢
	10%	🟦	🟦	🟦	🟦	🟦	🟦
	25%	🟦	🟦	🟦	🟦	🟦	🟦

		Sump Depth (in)				Outlet Diameter (in)	
HSG	**B**	*0*	*3*	*6*	*12*	*2*	*4*
BMP_A/W_A	1%	🟧	🟨	🟨	🟨	🟧	🟧
	2%	🟨	🟨	🟩	🟩	🟨	🟨
	5%	🟩	🟢	🟢	🟢	🟩	🟩
	10%	🟢	🟦	🟦	🟦	🟢	🟢
	25%	🟦	🟦	🟦	🟦	🟦	🟢

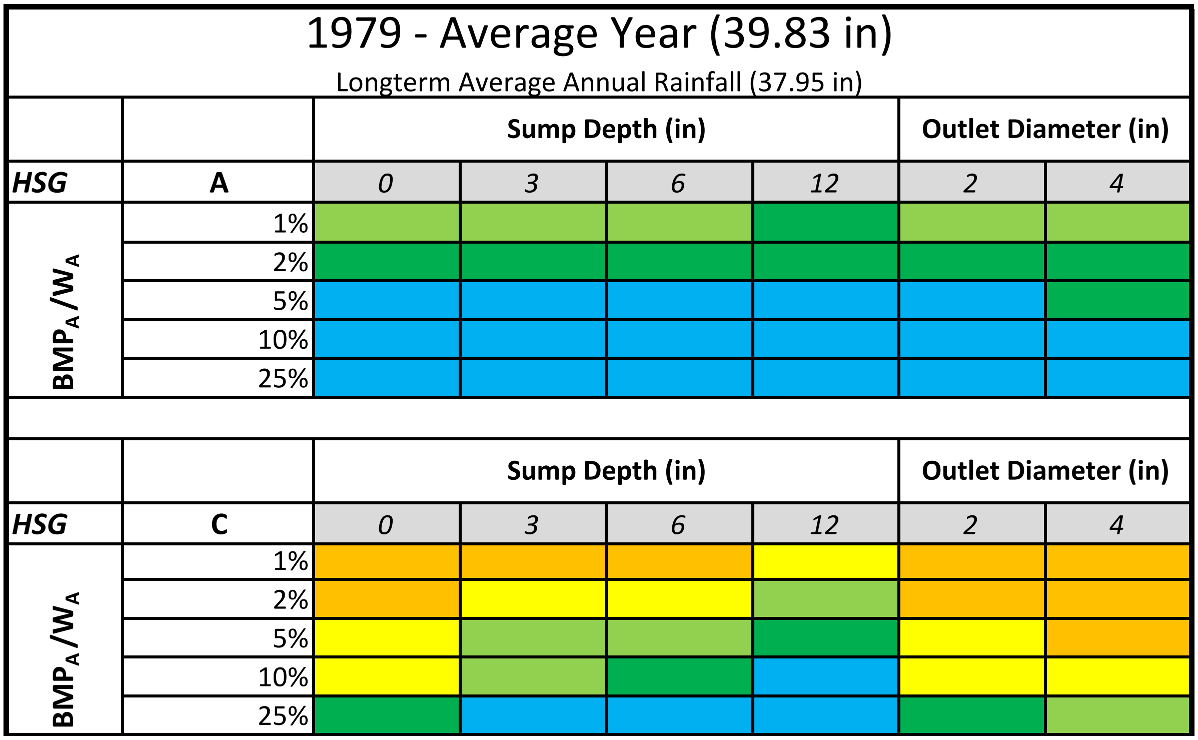
		Sump Depth (in)				Outlet Diameter (in)	
HSG	**C**	*0*	*3*	*6*	*12*	*2*	*4*
BMP_A/W_A	1%	🟧	🟧	🟧	🟨	🟧	🟧
	2%	🟧	🟨	🟨	🟩	🟧	🟧
	5%	🟨	🟩	🟩	🟩	🟨	🟧
	10%	🟨	🟩	🟢	🟦	🟨	🟨
	25%	🟢	🟦	🟦	🟦	🟢	🟩

		Sump Depth (in)				Outlet Diameter (in)	
HSG	**D**	*0*	*3*	*6*	*12*	*2*	*4*
BMP_A/W_A	1%	🟥	🟧	🟧	🟧	🟥	🟥
	2%	🟥	🟧	🟧	🟨	🟥	🟥
	5%	🟧	🟨	🟨	🟩	🟧	🟧
	10%	🟧	🟩	🟩	🟢	🟧	🟧
	25%	🟨	🟢	🟦	🟦	🟨	🟨



<u>LEGEND</u> % Reduction	
🟥	≤5%
🟧	>5; ≤25%
🟨	>25; ≤50%
🟩	>50; ≤75%
🟢	>75; ≤95%
🟦	>95%

Underground Storage - Scenario 2

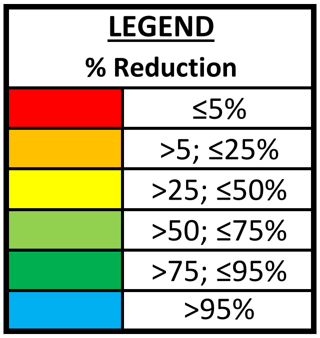


1979 - Average Year (39.83 in)

Longterm Average Annual Rainfall (37.95 in)

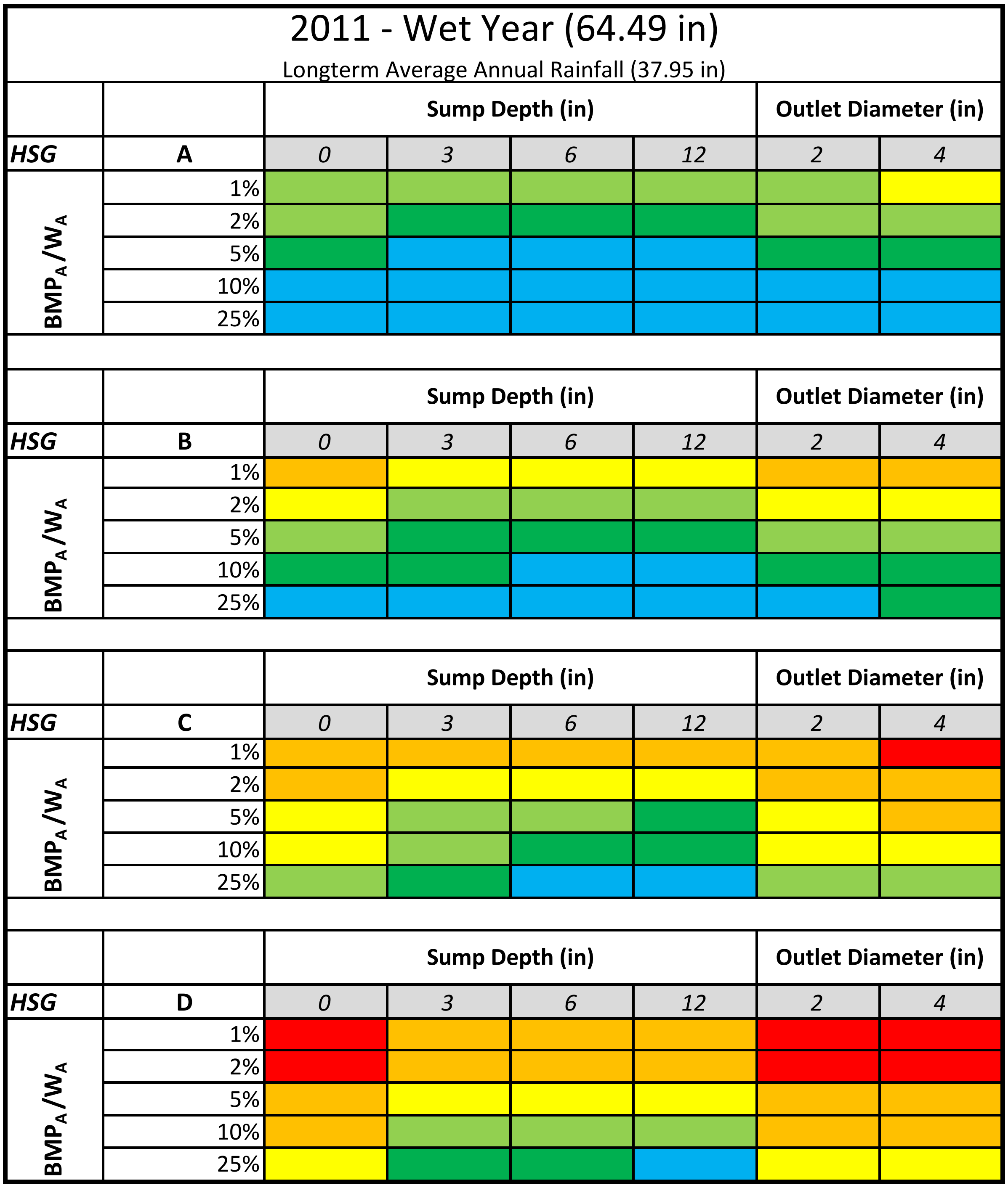
		Sump Depth (in)				Outlet Diameter (in)	
HSG	**A**	*0*	*3*	*6*	*12*	*2*	*4*
BMP_A/W_A	1%	🟩	🟩	🟩	🟢	🟩	🟩
	2%	🟢	🟢	🟢	🟢	🟢	🟢
	5%	🟦	🟦	🟦	🟦	🟦	🟢
	10%	🟦	🟦	🟦	🟦	🟦	🟦
	25%	🟦	🟦	🟦	🟦	🟦	🟦

		Sump Depth (in)				Outlet Diameter (in)	
HSG	**C**	*0*	*3*	*6*	*12*	*2*	*4*
BMP_A/W_A	1%	🟧	🟧	🟧	🟨	🟧	🟧
	2%	🟧	🟨	🟨	🟩	🟧	🟧
	5%	🟨	🟩	🟩	🟢	🟨	🟧
	10%	🟨	🟩	🟢	🟦	🟨	🟨
	25%	🟢	🟦	🟦	🟦	🟢	🟩



<u>LEGEND</u> **% Reduction**	
🟥	≤5%
🟧	>5; ≤25%
🟨	>25; ≤50%
🟩	>50; ≤75%
🟢	>75; ≤95%
🟦	>95%

Underground Storage - Scenario 1



2011 - Wet Year (64.49 in)

Longterm Average Annual Rainfall (37.95 in)

		Sump Depth (in)				**Outlet Diameter (in)**	
HSG	**A**	*0*	*3*	*6*	*12*	*2*	*4*
BMP_A/W_A	1%	🟩	🟩	🟩	🟩	🟩	🟨
	2%	🟩	🟢	🟢	🟢	🟩	🟩
	5%	🟢	🟦	🟦	🟦	🟢	🟢
	10%	🟦	🟦	🟦	🟦	🟦	🟦
	25%	🟦	🟦	🟦	🟦	🟦	🟦

		Sump Depth (in)				**Outlet Diameter (in)**	
HSG	**B**	*0*	*3*	*6*	*12*	*2*	*4*
BMP_A/W_A	1%	🟧	🟨	🟨	🟨	🟧	🟧
	2%	🟨	🟩	🟩	🟩	🟨	🟨
	5%	🟩	🟢	🟢	🟢	🟩	🟩
	10%	🟢	🟢	🟦	🟦	🟢	🟢
	25%	🟦	🟦	🟦	🟦	🟦	🟢

		Sump Depth (in)				**Outlet Diameter (in)**	
HSG	**C**	*0*	*3*	*6*	*12*	*2*	*4*
BMP_A/W_A	1%	🟧	🟧	🟧	🟧	🟧	🟥
	2%	🟧	🟨	🟨	🟨	🟧	🟧
	5%	🟨	🟩	🟩	🟢	🟨	🟧
	10%	🟨	🟩	🟢	🟢	🟨	🟨
	25%	🟩	🟢	🟦	🟦	🟩	🟩

		Sump Depth (in)				**Outlet Diameter (in)**	
HSG	**D**	*0*	*3*	*6*	*12*	*2*	*4*
BMP_A/W_A	1%	🟥	🟧	🟧	🟧	🟥	🟥
	2%	🟥	🟧	🟧	🟧	🟥	🟥
	5%	🟧	🟨	🟨	🟨	🟧	🟧
	10%	🟧	🟩	🟩	🟩	🟧	🟧
	25%	🟨	🟢	🟢	🟦	🟨	🟨

<u>LEGEND</u> **% Reduction**	
🟥	≤5%
🟧	>5; ≤25%
🟨	>25; ≤50%
🟩	>50; ≤75%
🟢	>75; ≤95%
🟦	>95%

Underground Storage - Scenario 2

2011 - Wet Year (64.49 in)

Longterm Average Annual Rainfall (37.95 in)

		Sump Depth (in)				**Outlet Diameter (in)**	
HSG	**A**	*0*	*3*	*6*	*12*	*2*	*4*
BMP_A/W_A	1%	🟢	🟢	🟢	🟢	🟢	🟨
	2%	🟩	🟩	🟩	🟩	🟩	🟢
	5%	🟩	🟦	🟦	🟦	🟩	🟩
	10%	🟦	🟦	🟦	🟦	🟦	🟦
	25%	🟦	🟦	🟦	🟦	🟦	🟦

		Sump Depth (in)				**Outlet Diameter (in)**	
HSG	**C**	*0*	*3*	*6*	*12*	*2*	*4*
BMP_A/W_A	1%	🟧	🟧	🟧	🟧	🟧	🟥
	2%	🟧	🟨	🟨	🟨	🟧	🟧
	5%	🟨	🟢	🟢	🟩	🟨	🟧
	10%	🟨	🟢	🟩	🟩	🟨	🟨
	25%	🟢	🟩	🟦	🟦	🟢	🟢

<u>LEGEND</u> **% Reduction**	
🟥	≤5%
🟧	>5; ≤25%
🟨	>25; ≤50%
🟢	>50; ≤75%
🟩	>75; ≤95%
🟦	>95%

Grass Swale

1979 - Average Year (39.83 in)

Longterm Average Annual Rainfall (37.95 in)

		Vegetative Fraction			**Surface Roughness**			**Surface Slope**			**Swale Side Slope**	
HSG	**A**	*0*	*0.01*	*0.05*	*0.05*	*0.15*	*0.41*	*0.5*	*1*	*2*	*3:1*	*5:1*
BMP_A / W_A	1%	🟧	🟧	🟧	🟧	🟨	🟨	🟧	🟥	🟥	🟧	🟥
	2%	🟨	🟨	🟨	🟨	🟨	🟩	🟨	🟨	🟨	🟨	🟨
	5%	🟩	🟩	🟩	🟩	🟩	🟢	🟩	🟩	🟩	🟩	🟨
	10%	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟩
	25%	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢

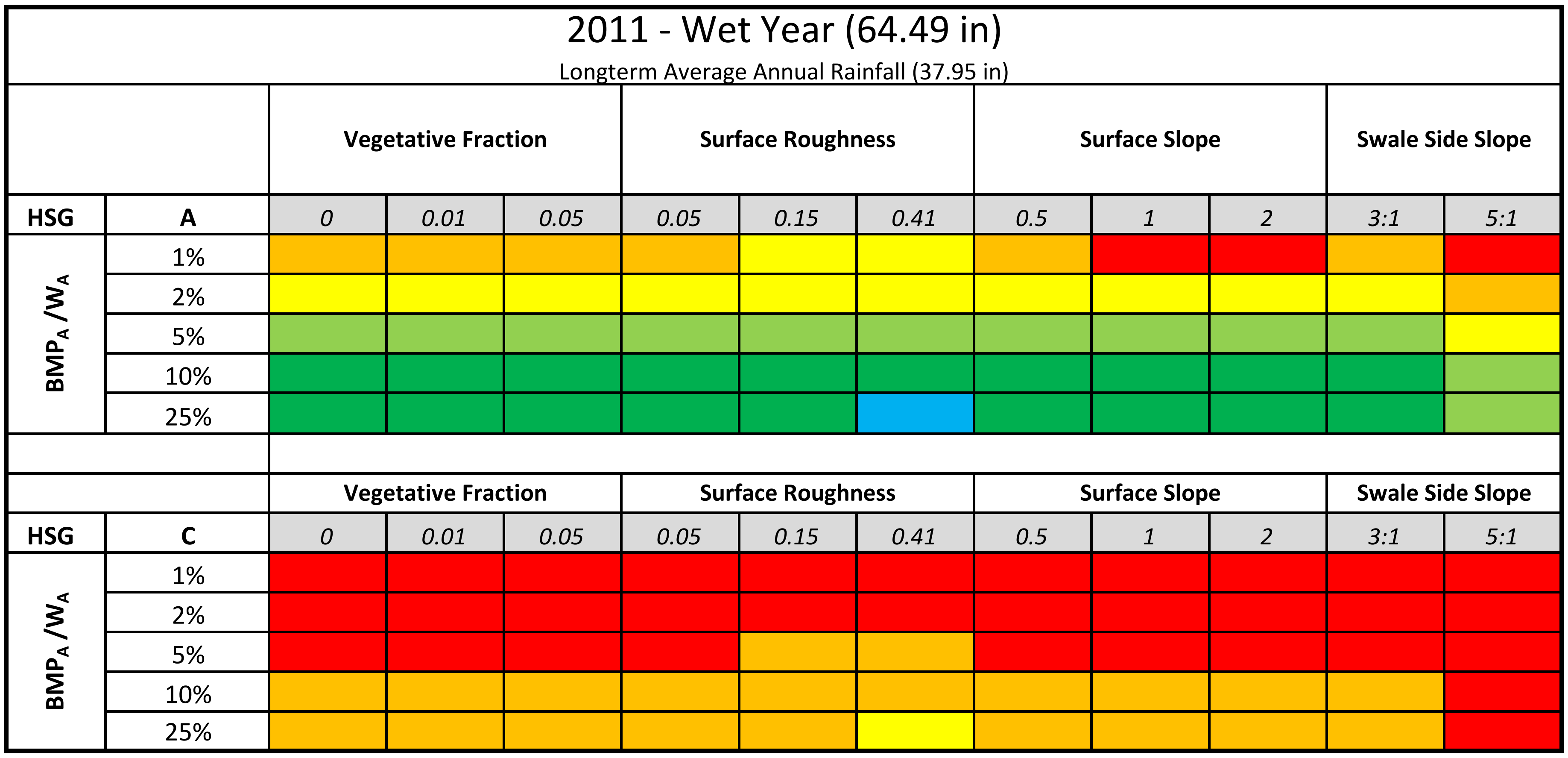
		Vegetative Fraction			**Surface Roughness**			**Surface Slope**			**Swale Side Slope**	
HSG	**C**	*0*	*0.01*	*0.05*	*0.05*	*0.15*	*0.41*	*0.5*	*1*	*2*	*3:1*	*5:1*
BMP_A / W_A	1%	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥
	2%	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥
	5%	🟥	🟥	🟥	🟥	🟧	🟧	🟥	🟥	🟥	🟥	🟥
	10%	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟥
	25%	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟥

<u>LEGEND</u> % Reduction	
🟥	≤5%
🟧	>5; ≤25%
🟨	>25; ≤50%
🟩	>50; ≤75%
🟢	>75; ≤95%
🟦	>95%

Grass Swale

2011 - Wet Year (64.49 in)

Longterm Average Annual Rainfall (37.95 in)



		Vegetative Fraction			**Surface Roughness**			**Surface Slope**			**Swale Side Slope**	
HSG	**A**	*0*	*0.01*	*0.05*	*0.05*	*0.15*	*0.41*	*0.5*	*1*	*2*	*3:1*	*5:1*
BMP_A/W_A	1%	🟧	🟧	🟧	🟧	🟨	🟨	🟧	🟥	🟥	🟧	🟥
	2%	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟧
	5%	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟨
	10%	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟢
	25%	🟩	🟩	🟩	🟩	🟩	🟦	🟩	🟩	🟩	🟩	🟢

		Vegetative Fraction			**Surface Roughness**			**Surface Slope**			**Swale Side Slope**	
HSG	**C**	*0*	*0.01*	*0.05*	*0.05*	*0.15*	*0.41*	*0.5*	*1*	*2*	*3:1*	*5:1*
BMP_A/W_A	1%	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥
	2%	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥
	5%	🟥	🟥	🟥	🟥	🟧	🟧	🟥	🟥	🟥	🟥	🟥
	10%	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟥
	25%	🟧	🟧	🟧	🟧	🟧	🟨	🟧	🟧	🟧	🟧	🟥

<u>LEGEND</u> % Reduction	
🟥	≤5%
🟧	>5; ≤25%
🟨	>25; ≤50%
🟢	>50; ≤75%
🟩	>75; ≤95%
🟦	>95%

Filter Strip

1979 - Average Year (39.83 in)

Longterm Average Annual Rainfall (37.95 in)

		Slope (%)			**Manning's n**		
HSG	**A**	*1*	*2*	*5*	*0.12*	*0.24*	*0.36*
BMP_A / W_A	1%	🟨	🟨	🟨	🟨	🟨	🟨
	2%	🟢	🟢	🟢	🟢	🟢	🟢
	5%	🟩	🟩	🟩	🟩	🟩	🟩
	10%	🟩	🟩	🟩	🟩	🟩	🟩
	25%	🟦	🟩	🟩	🟩	🟩	🟦

		Slope (%)			**Manning's n**		
HSG	**B**	*1*	*2*	*5*	*0.12*	*0.24*	*0.36*
BMP_A / W_A	1%	🟧	🟧	🟧	🟧	🟧	🟧
	2%	🟨	🟨	🟨	🟨	🟨	🟨
	5%	🟨	🟨	🟨	🟨	🟨	🟨
	10%	🟢	🟢	🟢	🟢	🟢	🟢
	25%	🟩	🟩	🟩	🟩	🟩	🟩

		Slope (%)			**Manning's n**		
HSG	**C**	*1*	*2*	*5*	*0.12*	*0.24*	*0.36*
BMP_A / W_A	1%	🟥	🟥	🟥	🟥	🟥	🟥
	2%	🟧	🟧	🟧	🟧	🟧	🟧
	5%	🟧	🟧	🟧	🟧	🟧	🟧
	10%	🟧	🟧	🟧	🟧	🟧	🟧
	25%	🟨	🟨	🟨	🟨	🟨	🟨

		Slope (%)			**Manning's n**		
HSG	**D**	*1*	*2*	*5*	*0.12*	*0.24*	*0.36*
BMP_A / W_A	1%	🟥	🟥	🟥	🟥	🟥	🟥
	2%	🟥	🟥	🟥	🟥	🟥	🟥
	5%	🟥	🟥	🟥	🟥	🟥	🟥
	10%	🟧	🟧	🟥	🟥	🟧	🟧
	25%	🟧	🟧	🟧	🟧	🟧	🟧

<u>LEGEND</u> % Reduction	
🟥	≤5%
🟧	>5; ≤25%
🟨	>25; ≤50%
🟢	>50; ≤75%
🟩	>75; ≤95%
🟦	>95%

Filter Strip

2011 - Wet Year (64.49 in)

Longterm Average Annual Rainfall (37.95 in)

		Slope (%)			Manning's n		
HSG	**A**	*1*	*2*	*5*	*0.12*	*0.24*	*0.36*
BMP_A /W_A	1%	🟨	🟨	🟨	🟨	🟨	🟨
	2%	🟢	🟢	🟢	🟢	🟢	🟢
	5%	🟩	🟩	🟩	🟩	🟩	🟩
	10%	🟩	🟩	🟩	🟩	🟩	🟩
	25%	🟦	🟦	🟦	🟦	🟦	🟦

		Slope (%)			Manning's n		
HSG	**B**	*1*	*2*	*5*	*0.12*	*0.24*	*0.36*
BMP_A /W_A	1%	🟧	🟧	🟧	🟧	🟧	🟧
	2%	🟧	🟧	🟧	🟧	🟧	🟧
	5%	🟨	🟨	🟨	🟨	🟨	🟨
	10%	🟢	🟢	🟢	🟢	🟢	🟢
	25%	🟢	🟢	🟢	🟢	🟢	🟢

		Slope (%)			Manning's n		
HSG	**C**	*1*	*2*	*5*	*0.12*	*0.24*	*0.36*
BMP_A /W_A	1%	🟥	🟥	🟥	🟥	🟥	🟥
	2%	🟧	🟧	🟧	🟧	🟧	🟧
	5%	🟧	🟧	🟧	🟧	🟧	🟧
	10%	🟧	🟧	🟧	🟧	🟧	🟧
	25%	🟨	🟨	🟨	🟨	🟨	🟨

		Slope (%)			Manning's n		
HSG	**D**	*1*	*2*	*5*	*0.12*	*0.24*	*0.36*
BMP_A /W_A	1%	🟥	🟥	🟥	🟥	🟥	🟥
	2%	🟥	🟥	🟥	🟥	🟥	🟥
	5%	🟥	🟥	🟥	🟥	🟥	🟥
	10%	🟥	🟥	🟥	🟥	🟥	🟥
	25%	🟧	🟧	🟧	🟧	🟧	🟧

<u>LEGEND</u> % Reduction	
🟥	≤5%
🟧	>5; ≤25%
🟨	>25; ≤50%
🟢	>50; ≤75%
🟩	>75; ≤95%
🟦	>95%

Green Roof

1979 - Average Year (39.83 in)

Longterm Average Annual Rainfall (37.95 in)

		Soil Thickness (in)		**Soil Type (porosity, field capacity, wilting point, conductivity, conductivity slope, suction head)**		**Storage Height (in)**	
HSG	**B**	*2*	*4*	*typical green roof mix*	*LS/SL*	*2*	*4*
BMP_A / W_A	10%	🟥	🟥	🟥	🟥	🟥	🟥
	25%	🟥	🟧	🟥	🟥	🟥	🟥
	50%	🟧	🟧	🟧	🟧	🟧	🟧
	75%	🟧	🟧	🟧	🟧	🟧	🟧
	100%	🟧	🟨	🟧	🟧	🟧	🟧

<u>LEGEND</u> **% Reduction**	
🟥	≤5%
🟧	>5; ≤25%
🟨	>25; ≤50%
🟩	>50; ≤75%
🟩	>75; ≤95%
🟦	>95%

Green Roof

2011 - Wet Year (64.49 in)

Longterm Average Annual Rainfall (37.95 in)

		Soil Thickness (in)		**Soil Type (porosity, field capacity, wilting point, conductivity, conductivity slope, suction head)**		**Storage Height (in)**	
HSG	**B**	*2*	*4*	*typical green roof mix*	*LS/SL*	*2*	*4*
BMP_A /W_A	10%	🟥	🟥	🟥	🟥	🟥	🟥
	25%	🟥	🟧	🟥	🟥	🟥	🟥
	50%	🟧	🟧	🟧	🟧	🟧	🟧
	75%	🟧	🟧	🟧	🟧	🟧	🟧
	100%	🟧	🟨	🟧	🟧	🟧	🟧

<u>LEGEND</u> % Reduction	
🟥	≤5%
🟧	>5; ≤25%
🟨	>25; ≤50%
🟩	>50; ≤75%
🟩	>75; ≤95%
🟦	>95%