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SFPUC - Wastewater Enterprise

URBAN WATERSHED MANAGEMENT PROGRAM

COMBINED SEWER SYSTEM (CSS) AND MUNICIPAL SEPARATE STORM SEWER SYSTEM (MS4) BMP SIZING CALCULATORS: CALCULATION APPROACH using the SANTA BARBARA URBAN HYDROGRAPH METHOD

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The San Francisco Public Utilities Commission (SFPUC) has developed two calculators: *Combined Sewer System BMP Sizing Calculator for Quantity Control* and *Municipal Separate Storm Sewer System BMP Sizing Calculator for Water Quality* (Sizing Calculators). The purpose of these Sizing Calculators is to assist developers and design professionals working on projects that are served by the combined sewer system (CSS) or municipal separate storm sewer (MS4) to comply with the *San Francisco Stormwater Management Requirements and Design Guidelines* (SMR). These Sizing Calculators are considered acceptable hydrologic calculation methods that San Francisco development projects may use to size selected stormwater Best Management Practices (BMPs) to meet the stormwater management performance requirements outlined in the SMR. These Sizing Calculators have been set up to be allowable for use in the design of most sites, however they cannot incorporate all design solutions and may require supplemental engineering design, calculations, or modeling for larger and more complex approaches. Please refer to *SFPUC Accepted Hydrologic Calculation Methods*, located at http://sfwater.org/smr for information on when this or other methods are accepted by the SFPUC. The full text of the SMR is also available for download at http://sfwater.org/smr.

INTRODUCTION

The primary regulatory objectives of the stormwater management performance requirements for projects vary by location in the City sewer system.

- Projects located in CSS areas: The objective is to reduce the rate and volume of stormwater runoff prior to discharge to the CSS.

- Projects located in MS4 areas: The objective is to capture and treat all runoff prior to discharge to the MS4.

In general, compliance with either performance requirement may be achieved by reducing site imperviousness, by using rainwater harvesting to meet non-potable demands, or by implementing other site-appropriate stormwater BMPs.

The CSS performance requirements were originally based on the LEED Sustainable Sites 6.1 Stormwater Quantity Credit (LEED v2.2, SS6.1) to be consistent with citywide green building requirements. The performance requirements may vary depending on the existing site conditions. For sites that are 50 percent or less impervious, the post-project peak discharge rate and total volume must not exceed pre-project values for the 1- and 2-year, 24-hour design storms. For sites with over 50 percent of impervious area, the post-project runoff volume and peak flow must be 25 percent less than that of the pre-project values with respect to the 2-year, 24-hour design storm.

Due to the increased constraints seen when developing in the urban realm, project sites within the CSS area that have restricting site conditions and/or programmatic constraints may be allowed to modify the stormwater management performance from the standard performance requirements. These sites must apply for and be granted Modified Compliance by the SFPUC prior to submitting a Stormwater Control Plan (SCP) for review and approval. If your project is located in the CSS area and you believe your project has restricting site conditions, please refer to the Modified Compliance Application located at http://sfwater.org/smr.

The MS4 performance requirements are based on the *California State Water Resources Control Board (SWRCB), Water Quality Order No. 2013-0001-DWQ, Waste Discharge Requirements for Storm Water Discharges from Small Municipal Separate Storm Sewer Systems* (MS4 Permit). Performance requirements may vary depending upon project size, project location, and proposed site conditions. The MS4 Sizing Calculator is only intended to be used for projects that create or replace 5,000 square feet (sf) or more of impervious area. For projects that create or replace less than 2,500 sf, there are no stormwater management requirements and for projects that create or replace between 2,500 and 5,000 sf, it is recommended that the project use the SWRCB's *Stormwater Multiple Application and Report Tracking System (SMARTS)* calculator to estimate runoff reduction. For sites that meet the size requirements of the MS4 Sizing Calculator, they must implement BMPs to capture and treat all impervious area runoff from the design storm. The magnitude and intensity of the treatment design storm is determined based on the project's location. Projects located in the jurisdiction of the Port of San Francisco must capture and treat all impervious area runoff from an 85th percentile storm event: 0.63 inches of rainfall with an average intensity of 0.2 in/hr. This is consistent with the project requirements laid out in the MS4 Permit. Projects located in the SFPUC's jurisdiction must capture and treat the runoff from a 90th percentile storm event: 0.75 inches of rainfall with an average intensity of 0.24 in/hr.

This memorandum is presented as two parts to provide the user with a better understanding to the Sizing Calculators' (CSS and MS4) two primary functions (i.e., worksheet tabs) and their corresponding approaches and assumptions: the *BMP Sizing Calculator* and the *Rainwater Harvesting Calculator*. The Sizing Calculators have been created with and contain two core functions using two separate but connected calculator worksheets; the primary BMP Sizing Calculator worksheet is for determining a site's overall stormwater runoff performance based on the selected BMPs and site conditions, and the RWH Calculator worksheet is for evaluating the effective stormwater performance of a proposed rainwater harvesting system.[1] Both the CSS and MS4 Sizing Calculators have a similar Rainwater Harvesting (RWH) calculator module.

[1] The MS4 Sizing Calculator also includes a worksheet for sloped bioretention swales ("Swale Calculator") and a worksheet for flow-based media filters ("Media Filter Calculator"). However, the swale sizing approach is largely the same as the BMP Sizing Calculator, and the media filters use a simplified flow-based sizing approach explained within the Calculator.

I. CSS AND MS4 BMP SIZING CALCULATORS

The Sizing Calculators assist project applicants in estimating runoff from their site and determining the size of stormwater management BMPs needed to comply with the SMR. While the Sizing Calculators generally use nationally-based hydrologic assumptions, the calculators continue to be refined to address the City of San Francisco's specific stormwater requirements, typical project massing and programing, as well as the currently proven and effective BMP types used.

For the CSS BMP Sizing Calculator, overall runoff reductions are determined by:

1. Calculating the site's total runoff volume and peak runoff flow under existing and proposed project conditions (i.e., calculates pre-project and post-project runoff).
2. Calculating the percent runoff reduction that results from incorporating various BMPs at the site.

For the MS4 BMP Sizing Calculator, overall capture and treatment volumes are determined by:

1. Calculating the site's total impervious area runoff volume from proposed project conditions.
2. Calculating the total impervious area runoff volume that is captured and treated by incorporating BMPs at the site. Runoff that is not directed to a BMP or that overflows from a BMP is considered uncaptured and untreated.

Determining Site Runoff

To determine peak flows and total runoff volumes, the timing of runoff flows from the site's various drainage management areas must be known so that they can be added together to determine the overall runoff characteristics from the existing and proposed conditions. This is accomplished in the Sizing Calculators by generating runoff hydrographs from each drainage area using the Santa Barbara Urban Hydrograph Method (SBUH). The existing conditions hydrographs are then summed at the point of discharge from the site while the proposed conditions hydrographs are routed through the BMPs, as discussed in the following section.

Hydrograph generation requires the following data:

- Rainfall distribution (i.e., hyetograph)
- Existing and Proposed runoff surface characteristics (e.g., surface areas and associated runoff curve numbers
- Time of concentration information (e.g., flow length and slope)

Determining Stormwater Management Performance

Determining the stormwater management performance of BMPs at the site requires that the critical design parameters for the BMPs be defined. Once defined, BMPs are treated in the Sizing Calculators as storage devices. The hydrographs for the drainage management areas for proposed conditions are routed through the BMPs where stormwater runoff is retained, detained, or filtered based on the BMPs' general properties and specific design configurations. The output hydrographs from the BMPs are then totaled prior to discharge from the site.

User-Defined BMP design parameters include:

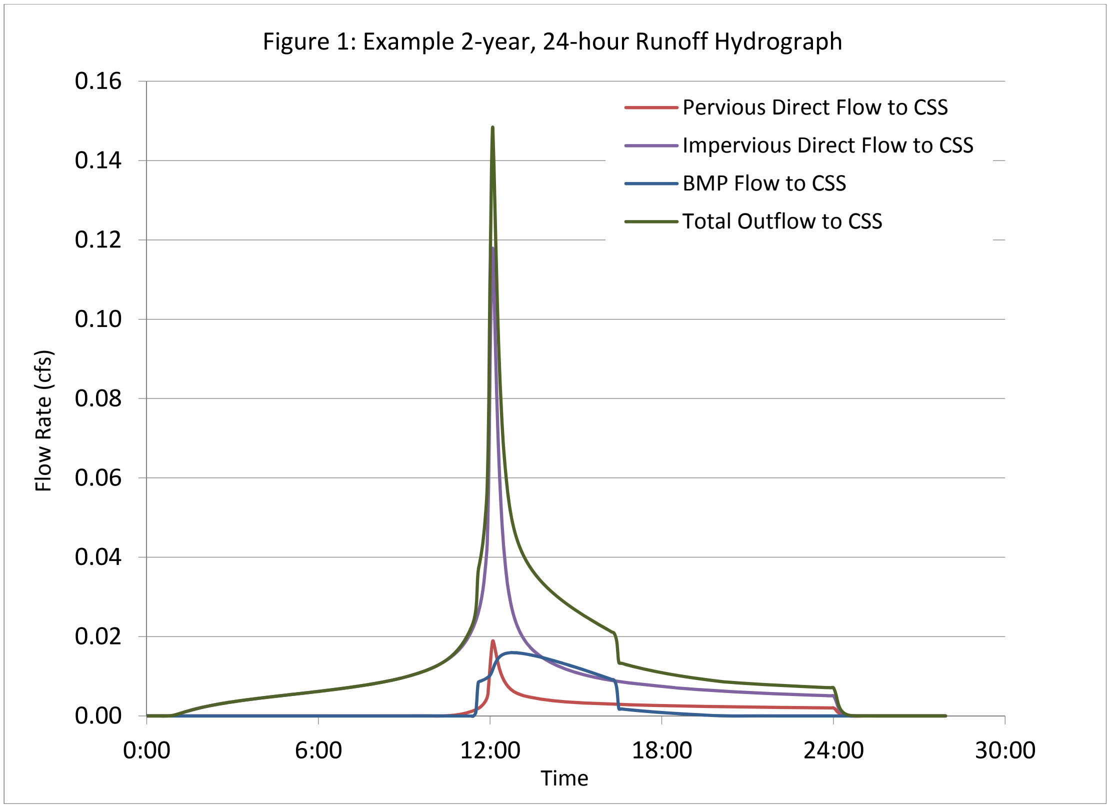
- BMP surface area
- Drainage area (including the area of surface BMPs, as applicable)
- Infiltration rate
- BMP Ponding Depth
- BMP Media Depth
- Gravel Storage Depth
- Height of Underdrain Above Base
- Storage Volume
- Outlet or Orifice Diameter (as applicable)

The Sizing Calculators have been set up to either guide the user (via use of flags) for entry of site specific data or to provide a default BMP parameter value to generate the output hydrographs and calculate a BMP's performance. The default BMP parameter values may be altered if site or design conditions are known or proposed to differ, and can be adequately documented within the Stormwater Control Plan. Common BMP schematic design layout and associated Sizing Calculator inputs are shown in Appendix A: Typical BMP Schematics.

Santa Barbara Urban Hydrograph Method

Pre-project and post-project runoff hydrographs are generated by the Sizing Calculators, which use the SBUH method. The SBUH method was developed by the Santa Barbara County Flood Control and Water Conservation District to determine runoff hydrographs for small and medium-sized urban areas.

The SBUH method is based on the Soil Conservation Service (SCS) curve number (CN) approach. The SBUH method is generally easier to implement in a spreadsheet calculation procedure than the SCS approach because it computes the runoff hydrograph directly without going through the intermediate steps of generating unit hydrographs. It uses SCS equations for computing soil absorption and precipitation excess to generate incremental runoff depths for a given drainage area and design storm. The incremental runoff depths from the drainage basin are converted into instantaneous hydrographs that are then routed through an imaginary reservoir with a time delay equal to the drainage area's time of concentration. The corresponding outflows from each drainage area are then summed to determine the site's overall runoff hydrograph. An example hydrograph from the CSS BMP Sizing Calculator is shown in Figure 1 below and the corresponding SBUH calculations can be found in Appendix B.



Soil Characteristics (Step 1)

Runoff curve numbers (CN) were developed by the Natural Resources Conservation Service (NRCS) after studying the runoff characteristics of various types of land. Curve numbers reduce diverse characteristics such as soil type, land usage, and vegetation into a single variable for doing runoff calculations.

Unless the surface type is completely impervious, the CN for a surface will vary based on the hydrologic soil group (HSG) of the native (or existing) soils at the site. The HSG is a NRCS classification system in which soils are categorized into four runoff potential groups. The groups range from A soils, with high permeability and little runoff production, to D soils, which have low permeability rates and produce much more runoff. The HSG for the site is entered in **Step 1** of the Sizing Calculator to determine the runoff curve numbers for the pervious surfaces as the site. The definitions of the HSGs are summarized in Table 1.

Table 1 – HSG Definitions (Source: SCS 1986)

Group	Soil Types	Description
A	Sand, loamy sand, or sandy loam	Low runoff potential. Soils having high infiltration rates even when thoroughly wetted and consisting chiefly of deep, well to excessively drained sands or gravels.
B	Silt loam or loam	Soils having moderate infiltration rates when thoroughly wetted and consisting chiefly of moderately deep to deep, moderately well to well-drained soils with moderately fine to moderately coarse textures.
C	Sandy clay loam	Soils having slow infiltration rates when thoroughly wetted and consisting chiefly of soils with a layer that impedes downward movement of water, or soils with moderately fine to fine textures.
D	Clay loam, sandy clay, silty clay, or clay	High runoff potential. Soils having very slow infiltration rates when thoroughly wetted and consisting chiefly of clay soils with a high swelling potential, soils with a permanent high water table, and shallow soils over nearly impervious material.

Although HSG soil types are regularly used for stormwater analyses, local boring logs more accurately classify soils using the Unified Soil Classification System (USCS). If soils at the site have been classified according to USCS, the information presented in Table 2 can be used to help estimate the corresponding HSG soil type. When two soil classifications are given, the poorer draining soil type should be used as the prevailing HSG soil type. For example, the poorer draining soil within classification GP-SM is soil type SM, and therefore, the corresponding HSG to select is Type B.

If infiltration testing has been required for localized accuracy at the site and the field infiltration rate is known, the measured infiltration rate from the approximate depth of the BMP base should be entered directly in **Step 1** of the calculator. A Design Infiltration Rate is assigned based on the testing method's Correction Factor (CF). The poorest draining strata layer within the top 3 feet beneath the base of the proposed infiltration facilities should be used to estimate the prevailing HSG soil type in accordance with Table 1 above. If infiltration testing has not yet been conducted, the HSG soil type entered into the Sizing Calculator should be based on the poorest draining strata layer within 10 feet beneath the base of proposed infiltration facilities. The calculator will automatically estimate the site's Design Infiltration Rate based on this HSG soil type.

Due to special site conditions, infiltration may not be allowed or feasible at many project sites. These conditions may include: contaminated soil below the site, high groundwater table or shallow bedrock, the existence of a geotechnical hazard, or that the project location is atop an elevated structure. Even if no infiltration is proposed for the project site, the HSG soil type must still be entered in **Step 1** as the soil type is used to determine the CN number and calculate runoff as described in the subsequent paragraphs.

Table 2 – Guidance on Converting USCS to HSG Soil Type

Hydrologic Soil Group	Soil Textures	Corresponding Unified Soil Classification
A	Gravel, sandy gravel and silty gravels	**GW** - Well-graded gravels, sandy gravels **GP** – Gap-graded or uniform gravels, sandy gravels **GM** - Silty gravels, silty sandy gravels **SW** - Well-graded, gravelly sands
	Sand, loamy sand or sandy loam	**SP** - Gap-graded or uniform sands, gravelly sands
B	Silty sands, silty loam	**SM** - Silty sands, silty gravelly sands
	Loam	**MH** – Micaceous silts, diatomaceous silts, volcanic ash
C	Sandy clay loam	**ML –** Silts, very fine sands, silty or clayey fine sands
D	Clay loam, silty clay loam, sandy clay, silty clay or clay	**GC** – Clayey gravels, clayey sandy gravels **SC** – Clayey sands, clayey gravelly sands **CL** – Low plasticity clays, sandy or silty clays **OL** – Organic silts and clays of low plasticity **CH** – Highly plastic clays and sandy clays **OH** – Organic silts and clays of high plasticity

Source: Adapted from the table presented in the Minnesota Stormwater Management Manual (2013), which presents compiled infiltration rate recommendations based on a review of thirty guidance manuals and many other stormwater references.

The runoff curve numbers (CN) for surfaces used in the Sizing Calculators are based on values given for similar surfaces in the SCS document *Technical Release 55 – Urban Hydrology for Small Watersheds* (TR-55). The traditional CN values used in the Sizing Calculators are summarized in Table 3. Table 4 summarizes the CN values accepted by SFPUC for surfaces common in development projects but not addressed in TR-55.

Table 3 – Runoff Curve Numbers

Surface Type	Runoff Curve Number[a]			
	A	B	C	D
Impervious Areas				
Pavement (conventional)	98	98	98	98
Roof (conventional)	98	98	98	98
Gravel	76	85	89	91
Pervious Areas				
Grass/Lawn Areas[b]	49	61	74	80
Landscaped (Lower Density)[c]	39	56	70	77
Landscaped (Higher Density)[d]	35	48	65	73
Tree Well[e]	35	35	35	35

Notes:
(a) Curve numbers are based on SCS *Technical Release 55 - Urban Hydrology for Small Watersheds* (TR-55).
(b) Based on TR-55 CN values for "Open Space – Good Condition".
(c) Based on TR-55 CN values for "Brush – Fair Condition".
(d) Based on TR-55 CN values for "Brush – Good Condition".
(e) Based on TR-55 CN value for "Woods – Good Condition" for Type A soils.

Table 4 – SFPUC Accepted Runoff Curve Numbers

Surface Type	SFPUC Accepted Runoff Curve Numbers
Tree Well Areas	35
Traditional Planters on Podium (i.e. lined)	74
Aggregate-Set Permeable Pavers on Podium	95
Enhanced Gravel/Stone Roof Gardens on Podium	95
Traditional Decomposed Granite (i.e. on grade)	95
Pedestal Pavers on Podium	98
Exposed Gravel on Podium	98
Traditional Gravel Roofs	98
Resin-Based Decomposed Granite	98
Natural Resin-Based Decomposed Granite	98
Open Water	98

Time of Concentration (Step 2)

The time of concentration (T_c) is the time for a drop of water to travel from the farthest point on the upstream end of the drainage area to the downstream end. T_c influences the shape and peak of the runoff hydrograph. T_c is calculated in the Sizing Calculators for both existing and proposed conditions at the site. Development and urbanization typically increases the impervious area of the site and decreases T_c, thereby increasing the peak discharge. Increasing pervious area and adding stormwater BMPs that detain runoff will increase the site's T_c and reduce the peak discharge. The proposed T_c calculations include the delay from BMPs implemented at the site.

T_c varies based on the type of flow path at the site (e.g., overland, channel, or pipe), and the slope, roughness, and length of that flow path. User-defined site information is entered into **Step 2** of the Sizing Calculator to allow for an estimation of the time of concentration from the conventional surfaces at the site. Because the Sizing Calculator is typically used for small, urban sites, the pre-project Tc at these sites will be low (typically between 5 and 15 minutes). The Sizing Calculator therefore does not allow for multiple mode flow paths typical of larger site designs.

Two types of time of concentration can be calculated: overland flow and channelized flow. Overland flow occurs in sheet flow, across an evenly-sloped uniform land parcel. Flows can only be designated as overland for less than 300 linear feet as it is assumed that runoff will naturally channelize after this distance. Overland flow is typical of un-developed parcels or parkland without ephemeral water features or eroded channels. Channelized flow occurs in all other conditions, such as when the land parcel is not uniform, the flow length is greater than 300 feet, or the land contains natural or man-made channels. Additionally, stormwater runoff that is captured and piped is considered channelized flow. Channelized flow is typical in previously-developed and urban infill sites.

For **overland flow less than 300 feet**, the Sizing Calculator uses the following Manning's kinematic sheet flow equation to calculate the T_c of the site's conventional surfaces:

$$T_c = \frac{0.42 * (n * L)^{0.8}}{P^{0.5} * s^{0.4}}$$

Where,
T_c = Time of concentration [min]
n = Friction slope (Manning's n for shallow flow depths)
L = Flow length [ft]
P = Design storm depth [inches]
s = Land slope (along flow path) [ft/ft]

For **pipe and channelized flow** or **flow lengths greater than 300 feet**, the Sizing Calculator uses the following TR-55 Shallow Concentrated Flow equation to calculate the T_c of the site's conventional surfaces:

$$T_c = \frac{L}{60\ x\ V} \quad where\ V = K_v\sqrt{s}$$

Where,
T_c = Time of concentration [min]
V = Average velocity [ft/sec]
L = Flow length [ft]
s = Land slope (along flow path) [ft/ft]

In the MS4 BMP Sizing Calculator, **Step 2** also contains the option to include a conveyance swale. Due to the City's MS4 permit, conveyance swales do not count as a treatment BMP in the MS4 BMP Sizing Calculator, however they may be used as an acceptable pretreatment facility if located upstream of bioretention BMPs. The use of a pretreatment conveyance swale in the MS4 BMP Sizing Calculator will improve the performance of downstream bioretention BMPs, and thus should reduce the required downstream BMP footprint. Performance is improved in the Calculator by eliminating the factor of safety applied to the bioretention soil's hydraulic conductivity, resulting in an effective conductivity of 5 in/hr. There is no option, or need, for a pretreatment conveyance swale in the CSS BMP Sizing Calculator.

Land / BMP Surface Areas (Step 3a)

The impervious and pervious areas for both the conventional surfaces and BMP surfaces are entered into **Step 3a** of the Sizing Calculators for both the existing and proposed conditions. These inputs are used in this and future steps to set the site imperviousness, contributing drainage areas, area of selected BMP types, and the resulting site runoff.

The impervious and pervious areas are analyzed separately, and their resulting hydrographs are then combined to determine the total site hydrograph. The input impervious or pervious areas for the Conventional Surfaces are represented as a homogenous surface type by determining the weighted average. These weighted averages are used to represent the make-up of impervious and pervious drainage areas directed to each BMP based on the input drainage area (**Step 3b**). Traditional Planters on Podium and Tree Well Areas are represented as conventional surfaces rather than BMPs in the Sizing Calculators. All pervious, impervious, BMP and drainage management areas are summed in Step 4 to ensure that all areas are entered properly and the entire site is accounted for in the Sizing Calculator.

The Sizing Calculator has been developed to include the most common BMPs used within the City of San Francisco to reduce, capture, and treat runoff. With the exception of BMPs that are typically installed sub-surface (e.g., cisterns and infiltration galleries), the BMPs are treated as surface BMPs (i.e., open to the atmosphere/rainfall) that take up real surface space at the site. Surface BMPs should have an associated BMP area or footprint. Sub-surface BMPs are sized based on storage volume and are presumed to constitute an insignificant amount of the site area. The total project site area for existing conditions should equal the total project area for proposed conditions, including the proposed surface BMP areas.

In the CSS BMP Sizing Calculator, the BMPs are generally divided into retention and detention facilities. Retention facilities typify BMPs designed for reuse or infiltration (with no underdrain system). Detention facilities typify BMPs that slow runoff before releasing it back to the sewer (e.g., detention tanks or BMPs with an underdrain). In the MS4 BMP Sizing Calculator, the BMPs are generally divided into runoff reduction and biotreatment facilities. Runoff reduction facilities are BMPs designed to capture and reduce the total volume of runoff through infiltration, evapotranspiration, or reuse. Biotreatment facilities are BMPs designed to capture and treat runoff from impervious areas then discharge the treated runoff through an underdrain to the MS4. A full listing and description of all BMPs available in the Sizing Calculators can be found in Table 5. Figures depicting common schematic layouts to provide a visual depiction of the Sizing Calculator inputs can be found Appendix A: Typical BMP Schematics.

Table 5 – Stormwater BMPs used in the Sizing Calculators

CSS Calculator Classification	MS4 Calculator Classification	BMPs	Description	Outflows
Retention	Reduce	Bioretention (No Underdrain, No Liner)	Bioretention (No Underdrain, No Liner) are BMPs designed to retain water in the subsurface media pore space and also in above-surface ponding. Bioretention (No Underdrain, No Liner) can be in basin (e.g., rain garden) or planter form.	Infiltration, Evapotranspiration, Overflow
Retention	Reduce	Cistern (Rainwater Harvester)	Cisterns are the storage component of a rainwater harvesting system. They are designed to retain water in closed tanks for reuse to meet irrigation and/or non-potable indoor demand. Cisterns may also have an additional detention volume above the retention component to reduce the peak runoff flow.	Reuse, Overflow, Discharge (if detention is available)
Retention	Reduce	Infiltration Trench	Infiltration trenches are designed to retain runoff in a porous, subsurface media until it can infiltrate into the underlying soil.	Infiltration, Overflow
Retention	Reduce	Dry Well / Infiltration Gallery	Dry wells /Infiltration Galleries are subsurface storage volumes without an unlined bottom that are filled with a porous media and designed to retain stormwater until it can infiltrate into the underlying soil. They differ from infiltration trenches in that they are assumed to be subsurface and have little to no surface area.	Infiltration, Overflow
Retention	Reduce	Permeable Pavement (No Underdrain)	Permeable pavements are any hardscapes, such as pavers, porous asphalt, or pervious concrete that allow for infiltration of water directly into the underlying soils. A layer of porous material is located under the hardscape for storage.	Infiltration, Overflow
Detention	Biotreat	Bioretention (Underdrain, No Liner) /Flow-Through Planter without Liner	Bioretention (Underdrain, No Liner) /Flow-Through Planters without Liners are BMPs designed to store runoff for a period of time in subsurface media pore space and above-surface ponding prior to discharge through an outlet. The temporary detention of runoff allows for infiltration and evapotranspiration to reduce total volume in addition to peak runoff flow reduction.	Infiltration, Evapotranspiration, Discharge, Overflow
Detention	Biotreat	Bioretention (Underdrain, Liner) /Flow-Through Planter with Liner	Bioretention (Underdrain, Liner) / Flow-through planters with Liners work in the same manner as those without liners but they do not allow for infiltration into the underlying soils.	Evapotranspiration, Discharge, Overflow
Detention	Reduce	Vegetated Roof	Vegetated roofs consist of a layer of soil with vegetation atop an underdrain system. They provide for the storage of runoff and the reduction of volume through evapotranspiration prior to discharge.	Evapotranspiration, Discharge, Overflow
Detention	Reduce	Permeable Pavement (Underdrain)	Permeable pavements with underdrains have the same properties of traditional permeable pavements except they have an underdrain below the storage layer to allow for drainage.	Infiltration, Discharge, Overflow
Detention	*N/A*	Detention Vaults	Detention vaults are closed sub-surface storage areas filled with a porous media that are designed to detain runoff and discharge it at a controlled rate through an outlet to reduce the peak flow rate.	Discharge, Overflow
N/A	Reduce	Bioretention Swale (No Underdrain)	Bioretention Swales (No Underdrain) are designed to retain runoff in the subsurface media and also in above-surface ponding. Bioretention Swales (No Underdrain) do not provide treatment for runoff that does not infiltrate through the subsurface media into the underlying soils and function primarily as sloped bioretention without underdrains.	Infiltration, Overflow
N/A	Biotreat	Bioretention Swale (Underdrain)	Bioretention Swales (Underdrain) are designed to store runoff for a period of time in subsurface media and above-surface ponding prior to discharge through an outlet. Bioretention Swales (Underdrain) do not provide treatment for runoff that does not filter through the subsurface media and function primarily as sloped bioretention with underdrains.	Infiltration, Discharge, Overflow

BMP Design Information (Step 3b)

Each of the BMP measures listed in Table 5 requires several design parameters to be defined in order to be accurately evaluated using the SBUH method. Most of these parameters must be defined by the user however the calculators have been set up to provide typical default values which can be altered to reflect the proposed BMP design. For typical design guidance on acceptable design parameter ranges refer to the *Green Stormwater Infrastructure Typical Details*, located online at http://sfwater.org/smr. Typical BMP Schematics are also provided to help depict the input design parameters for common BMP designs (refer to Appendix A). The following list describes the user-defined BMP design parameters required for Sizing Calculator function.

- Drainage Areas **–** BMPs can accept runoff from both the contributing impervious and pervious drainage areas. Users should include only those areas completely draining to the associated BMP as part of that drainage area. The BMP footprint should not be included as part of the drainage area as it is a separate input in **Step 3a**. The total of the drainage areas for all BMPs must be less than the total project site area.

- BMP Ponding Depth – Bioretention BMPs are the only BMPs that allow for design ponding on the surface. Ponding depths are assumed to be the height between the top of the BMP soil media and the rim elevation of the overflow. The depth of any mulch atop the BMP's soil media is allowed to be included in the ponding depth. For dry wells and detention vaults, the ponding depth is assumed to be the depth of the active storage volume (e.g. 100% open void, or determined "effective" aggregate void space). Designed ponding is not allowed for infiltration trenches, permeable pavements, traditional planter, or vegetated roofs.

- BMP Media Depth – This is the depth of the bioretention soil media or lightweight media layer for bioretention BMPs and vegetated roofs, respectfully. The minimum depth of this layer is 18-inches for all except the vegetated roof, which has minimum depth of 5-inches.

- Gravel Storage Depth – The layer, or multiple layers, of clean aggregates or gravel. This depth comprises of the overall storage layer for bioretention BMPs, infiltration trenches, dry wells, and permeable pavements. The storage depth may include all clean aggregate layer types including aggregate layers such as the choking course, leveling bed, base course, and reservoir course. Rain gardens may have a gravel storage layer to increase designed storage volume, while bioretention planters require a gravel storage minimum depth of 8- to 12-inches when an underdrain is present.

- Height of Underdrain Above Base – Where an underdrain is present, this is thickness of the layer of aggregate or gravel between the underlying sub-base soil (or liner) and the bottom (invert) of the underdrain. A maximum of 2-inches is recommended for underdrains.

- Storage Volume – The volume of the storage is automatically calculated based on design parameters and assumed void space for all BMPs except for dry wells and detention vaults. These two BMPs require direct input of the storage volume.

- Outlet or Orifice Diameter – Orifices may be used to control the rate of discharge from BMPs with separate underdrain system. If no orifice control is present in the BMP, then the diameter of the underdrain pipe, typically 4- to 6-inches, should be input in its place. Constraining orifices have a minimum diameter of 0.5-inches and are typically recommended with a minimum of 1- to 2-inches in diameter. **The proposal of an orifice structure will require an enhanced design understanding, additional team and client collaboration, more precise detailing, and more critical SFPUC review and approval.**

- Approximate Drawdown Time – Drawdown time is calculated in two ways: media-controlled drawdown time and orifice-controlled drawdown time. Whichever is slower – the media filtration rate or flow through the orifice – governs the flow rate through the BMPs bioretention soil media. The media-controlled drawdown time is calculated based on Darcy's Law and is based on the ponding depth, media depth, BMP area, and assumed hydraulic conductivity. The orifice drawdown time is calculated from the orifice equation and is determined by the ponding depth, media depth, and effective orifice area. Only a single drawdown time is applicable for most BMPs in the Sizing Calculators. However, in BMPs where both equations are applicable, the longer drawdown time calculated from the BMP design parameters is assumed to be the controlling factor.

  In addition to the user-defined design parameters, there are several other assumed parameters that are used in the SBUH evaluation of BMP performance. These parameters, based on observation and testing, are defined as constant in the Sizing Calculator and cannot be changed by the user.

- Porosity – The porosity is used to calculate the available storage volume for all BMPs. It is assumed to be **30% (0.30) for all bioretention soils** or BMP media and **40% (0.40) for all clean aggregate or gravel storage layers**. Porosity is assumed to be **100% (1.00) for all open volumes** such as cisterns, detention tanks, and the ponding layer.

- Hydraulic Conductivity – The long-term design hydraulic conductivity for bioretention soil is 5 in/hr. A factor of safety of 1.25 is applied within the Sizing Calculator resulting in an effective conductivity of **4 in/hr**. This parameter is used to calculate media-controlled drawdown and filtration of runoff into the BMP media layer. The gravel storage layer does not have an assigned hydraulic conductivity as filtration into the gravel is assumed to be instantaneous.

- Orifice Coefficient – An orifice coefficient of **0.66** is used in the orifice equation to calculate orifice drawdown and the orifice discharge rate.

- BMP Evapotranspiration – The rate of evapotranspiration used in the Sizing Calculators varies depending upon depth, soil type, and BMP design properties. The base evapotranspiration rates used in the calculator were taken from the evapotranspiration zone maps for California published by the Department of Water Resources (DWR 2015). The base evapotranspiration values were then calibrated for bioretention BMPs and vegetated roofs to achieve volume reductions consistent with EPA SWMM and published monitoring data.[2] The Sizing Calculators volume reduction ranges from 4% to 14% for lined bioretention BMPs based on typical sizing ratios and media depths. For example, a lined bioretention BMP with a 6-inch ponding depth, 18-inch media depth, and 10% BMP to drainage management area ratio has a resulting 8% runoff volume reduction for the CSS 2-year, 24-hour design storm. The CSS BMP Sizing Calculator runoff volume reduction ranges from 20% to 34% for vegetated roofs for typical media depths and sizes. A vegetated roof with a 6-inch media depth and an area equaling approximately 80% of the project area has a resulting 21% runoff volume reduction for the CSS 2-year, 24-hour design storm. Evapotranspiration is a less critical parameter for MS4 projects, as all runoff that filters through vegetated roof or bioretention media is considered treated.

- Design Storms – The SBUH method requires a design storm to perform the runoff calculations. In the CSS BMP Sizing Calculator, the requirements of the SMR are based on performance for the 1-year and 2-year, 24-hour design storms. In the MS4 BMP Sizing Calculator, the performance of the proposed BMP is determined by the capture and treatment of impervious area runoff from design storms based on the 85th or 90th percentile rainfall events and intensities. These design storms have been established for San Francisco based on more than 100 years of local historical rain gauge data. Neighborhood specific (micro-climate) design storm data are not provided in the Sizing Calculators. The design storm data are provided in the "Rainfall and Hydrographs" worksheet tab of the Sizing Calculators. An excel spreadsheet containing the design storms for the CSS BMP Sizing Calculator called *Design Storms: 1-year and 2-year 24-hour Design Storms* is available for download at http://sfwater.org/smr.

[2] Sources include: BASMAA 2011, CWP 2008, EPA 2009, International BMP Database 2011.

BMPs in Series

As the designers understanding of BMP function expand, BMPs may be designed and installed such that the outflow from one BMP flows into another BMP prior to discharge from the site. A typical setup involves the outflow including overflow from a BMP with a primary function of retention (CSS) or reduction (MS4), such as a rainwater harvesting cistern, that flows into a BMP with a primary function of detention (CSS) or biotreatment (MS4), such as a lined bioretention cell. This setup allows a project to meet runoff reduction or capture and treatment requirements in a potentially more efficient and cost effective manner. The Sizing Calculator allows for a maximum of two BMPs to be set up in series provided that the BMPs in Series are different BMP types. The discharge hydrograph from the First BMP in the series is included as part of the input hydrograph for the Receiving BMP. The Receiving BMP is allowed to have a separate drainage management area that flows directly into the Receiving BMP and does not pass through the first BMP in series. BMP types that are permitted to be included as part of a BMPs in Series are shown in the drop-down menus. **The use of BMPs in Series must be proposed and approved by SFPUC prior to the submittal of the Stormwater Control Plan.**

BMP Water Balance Results (Steps 5 and 6)

Each user-defined BMP is treated as a storage box that receives runoff from the contributing drainage management area. The volume of runoff stored in a BMP will change over time based on the inflow and outflow rate for each BMP. The inflow is equal to the runoff hydrograph generated from the BMP’s delineated contributing drainage area. Possible outflows from the BMP can be rainwater reuse, infiltration, evapotranspiration, controlled discharge, and overflow. The rates of outflow are determined by the ratio of drainage area to BMP size, the site’s user-defined infiltration characteristics, the BMP type, and the BMP design parameters. A schematic flow diagram displaying the BMP inputs and outputs is presented in Figure 2 and a discussion of the calculations follows. Typical BMP Schematics can be found in Appendix A and example SBUH and Water Balance calculations can be found in Appendix B.

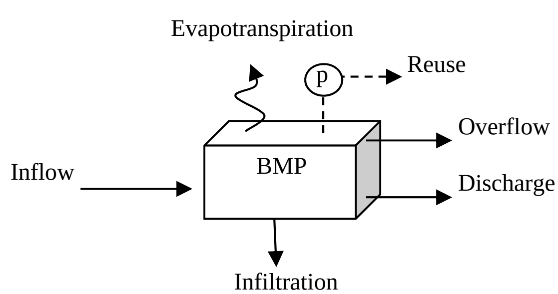


Figure 2. User-Defined BMP Representation

- Inflow – The inflow for each time step in the model is equal to the runoff from the BMP’s contributing area for that time step. For all BMPs except for bioretention BMPs and vegetated roof, the model assumes that inflow to the BMP immediately goes into the storage volume. However, for the bioretention BMPs and vegetated roof, an additional calculation takes place. The filtration into the media storage is not immediate for these BMPs but is instead limited by the hydraulic conductivity of the media. Thus, in cases where the routed runoff per time step is greater than the maximum allowable filtration into BMP storage, the model assumes the remaining water that cannot filter is either stored in the ponding layer, if possible, or overflows. Water stored in the ponding layer in this scenario will eventually infiltrate into the media in a subsequent time step when the inflow rate is less than the maximum allowable filtration rate.

- Infiltration – Infiltration into the underlying soils is controlled by the site's infiltration rate. This number is either based on the HSG soil group at the site or defined by the user based on site-specific infiltration tests. Though the measured field infiltration rate tests may result in a high site-specific infiltration rate, the measured infiltration rate will be multiplied by a correction factor (CF) in the Sizing Calculators based on the field infiltration testing method to set a long-term Design Infiltration Rate. The maximum allowable Design Infiltration Rate in the Sizing Calculator is set at 5 in/hr. The user-defined infiltration rates should be based on the measured infiltration rate resulting from the specific infiltration test conducted at the approximate depth of the base storage layer of the BMP.

- Evapotranspiration – Evapotranspiration rates used in the model are based on published evapotranspiration zone maps and model calibration tests.

- Reuse – The reuse outflow is only applicable to the cistern component of the rainwater harvester. Reuse is calculated to be the sum of both the indoor and outdoor non-potable water demand, which are dependent upon site-specific user inputs. Refer to Section II of this report for more information regarding the rainwater harvester.

- Discharge – The discharge rate through an underdrain or outlet is controlled by either the BMP media or the outlet orifice size. Discharge control is determined by whichever property has the longest average drawdown time.

Darcy's Law: In media-controlled discharge, the discharge rate is calculated using Darcy's Law.

$$Q_d = \frac{K \ x \ A \ x \ H}{L}$$

Where,

Q_d	=	Flow Rate [cfs]
K	=	Media Hydraulic Conductivity [ft/s]
L	=	Flow length [ft]
A	=	Cross-Sectional Area [ft^2]
H	=	Hydraulic Head [ft]

Orifice Discharge Equation: In orifice-controlled discharge, the discharge rate is calculated using the orifice flow equation.

$$Q_o = C_d \ x \ A \ x \ \sqrt{2 \ x \ G \ x \ H}$$

Where,

Q_o	=	Flow Rate [cfs]
C_d	=	Discharge Coefficient
A	=	Orifice Area [ft^2]
G	=	Gravitational Acceleration [ft/s^2]
H	=	Hydraulic Head [ft]

Both of these discharge rates vary depending on the height of water in the BMP, which is calculated for each time step based on the accumulated volume, volume losses per time step, BMP area, and average porosity of the BMP.

- Overflow – There are two types of overflow in the Sizing Calculator: traditional overflow and surge overflow. Traditional overflow is determined to occur at any time step where the volume of water minus all of the other potential outflows is greater than the available storage in the BMP. Surge overflow, as discussed in the inflow description above, occurs when the inflow rate is greater than the media filtration rate and ponding storage is either not available or full. This is typically only a factor in BMPs such as bioretention, where the media filtration rate can be a controlling factor.

  In the CSS BMP Sizing Calculator, once the water balances have been completed, the discharge hydrographs for the BMPs as well as those of the non-contributing drainage areas, are totaled for each time step to determine the peak outflow rate for the design storm. Additionally, the total outflow volumes for each time step are summed to calculate the total runoff volume. The results of the site's proposed peak flows and total runoff volumes are compared to existing conditions in **Step 5**. If the proposed conditions do not result in sufficient percent reductions in design storm peak flow and total runoff, the BMPs' design parameters and/or overall stormwater approach should be adjusted until the target percent reductions are met.

In the MS4 BMP Sizing Calculator, after the water balances have been completed, the discharge hydrographs for the BMPs and the non-contributing drainage areas are totaled for each time step to determine the incremental runoff volume and summed to calculate the total runoff volume. The runoff volume captured and treated by the proposed BMPs are compared to the total impervious area runoff volume for the appropriate design storm in **Step 5**. If there is an untreated runoff volume due to BMP overflow, the BMPs' design parameters and/or overall stormwater approach should be adjusted until there is no overflow volume from the BMPs. If there is untreated impervious area runoff that is not captured by a BMP, the drainage management areas should be expanded or reconfigured and the overall stormwater approach should be adjusted until there is no impervious area runoff that flows directly to the MS4.

The performance of each BMP is separately displayed in **Step 6** to allow for the evaluation of the individual BMPs. If BMPs in Series are proposed for the site, **Step 6** also shows the volume of runoff that flows from the First BMP to the Receiving BMP in Series. This information can be helpful in refining the design of BMPs in Series and the overall stormwater approach.

II. RAINWATER HARVESTING CALCULATOR

The water balance equations and SBUH calculations for the rainwater harvester vary slightly from those of the other BMPs in the Sizing Calculators. The main difference is that the cistern is not assumed empty, but rather the volume of the cistern at the start of the design storm events is dependent upon the results of the long-term simulation conducted on the RWH Calculator worksheet. The long-term simulation uses ten years of local daily rainfall data to assess the performance of the cistern over several rainy seasons. Additionally, cisterns also have a reuse outflow rate in the water balance that is dependent upon the proposed non-potable water demand at the site. Because of this, rainwater harvesting cisterns require their own design worksheet to calculate the water demand and the average volume of water in the cistern prior to a storm event. The worksheet allows for the input of a number of variables needed to effectively evaluate rainwater harvesting performance. These variables and the rainwater harvesting performance calculations are discussed in the following sections.

> **NOTE:** At this time this calculator cannot evaluate the combined function of rainwater reuse and greywater reuse. The calculator assumes that the collected rainwater is immediately re-used until the cistern is empty after a storm event where both rainwater and greywater are proposed as part of the same reuse treatment system.

Irrigation Demand (Step 1)

Rainwater is typically, and most simply, collected to be used as a supplement to the non-potable water supply and reduce potable water demand for irrigation purposes. The irrigation demand for a given project site is determined by the size of the irrigated area, the type of plants in that landscaped area, the density of the plants, and the efficiency of the chosen irrigation system. Many of these factors are site and plant species specific but can be estimated based on the methodology outlined in the documents *Guide to Estimating Irrigation Water Needs of Landscape Plantings in California* and *Using Reference Evapotranspiration and Crop Coefficients to Estimate Crop Evapotranspiration*, both published by the California Department of Water Resources. Links to these documents can be found in “References” tab of the Sizing Calculators. The notes for **Step 1** also list typical design values for most of the inputs to assist the user. The monthly irrigation demand is calculated based on the average daily rainfall and evapotranspiration rates per month for the irrigated areas, as well as the user-defined irrigation system parameters.

Indoor Non-Potable Demand (Step 2)

Rainwater can also be collected for indoor use. The two indoor non-potable uses directly calculated in the Sizing Calculators are toilet flushing and laundry. The only user-defined parameter required in **Step 2** is the number of people that will be using the indoor facilities. The default values for toilet flush frequency and volume as well as washing machine volume and use are based on *California Green Building Standards* and the *2010 SFPUC Urban Water Management Plan*. This step also has an option for any other non-potable demand that may be present at the project site (e.g., cooling water). The total indoor non-potable demand per day and month are calculated by multiplying and totaling the user input and default parameters. Indoor non-potable water demand is assumed to be constant throughout the year.

Cistern Design and Performance (Step 3)

This step in the RWH Calculator worksheet allows for the input of drainage areas and the cistern design properties. Though it is typical that rainwater harvesters capture only the runoff from an impervious roof drainage area, it is also possible to route non-roof drainage areas to a cistern if the site allows.[3] Cisterns can have either circular or rectangular footprints. Cistern depth is the depth of retention storage of the cistern. When using RWH to help achieve rate and volume control in the CSS areas, an additional detention component may also be proposed for the cistern. If so, a detention depth and discharge orifice can be added as part of the cistern design. It is assumed that any detention volume will have the same footprint as the retention volume.

The user-defined cistern design and other input parameters are used to measure the rainwater harvesting system's performance over the course of a ten year simulation. Ten years of daily rainfall data, from 2001 to 2010, has been input into the Sizing Calculators. This data was selected from an available 30 years of daily precipitation data from the San Francisco downtown National Weather Service (NWS) rain gauge. The years 2001 to 2010 were chosen as model years because that ten-year period seemed the most representative of the overall 30-year annual average rainfall statistics and several of those years contained storms equal or greater to the 1-year and 2-year 24-hour storm events.

The RWH Calculator uses the input parameters to calculate daily runoff, capture, demand, use, storage, and overflow over the ten year simulation period. This provides average annual performance results for the rainwater harvesting system. To translate those average annual results into performance during an individual design storm event, the volume in the cistern at the start of those storms must be known. This value is calculated by averaging the volume in the cistern one day prior to a rain event, during the rainy season, over the course of the ten year simulation. As mentioned above, this value is then automatically input into the Sizing Calculators' worksheet and SBUH calculations as the cistern's starting volume for the design storm calculations. Any additional detention volume included as part of the cistern design is not taken into account during the ten year simulation but is included as part of the SBUH method for the Sizing Calculator.

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[3] Roof runoff and ground-surface runoff have different treatment and monitoring requirements. Refer to the Department of Public Health for requirements (sfdph.org).

The ten-year daily simulation rain event is also used to calculate the percent of annual storm runoff captured as well as the percent of annual non-potable water demand met by the rainwater harvesting system. These performance characteristics are not used in the SBUH method but are valuable in evaluating overall rainwater harvesting efficiency and performance.

> **NOTE:** While the SFPUC can only require compliance to meet the target percent runoff reduction and performance requirements; we highly encourage those who chose rainwater harvesting to consider the primary intention and benefit of rainwater harvesting during system sizing, namely water conservation. It is typical that the base cistern size required to meet stormwater management performance requirements may result in an inefficient system performance. Therefore, it is highly recommended that an iterative sizing analysis be conducted to increase the overall efficiency of the rainwater harvesting system.

III. REFERENCES AND RESOURCES

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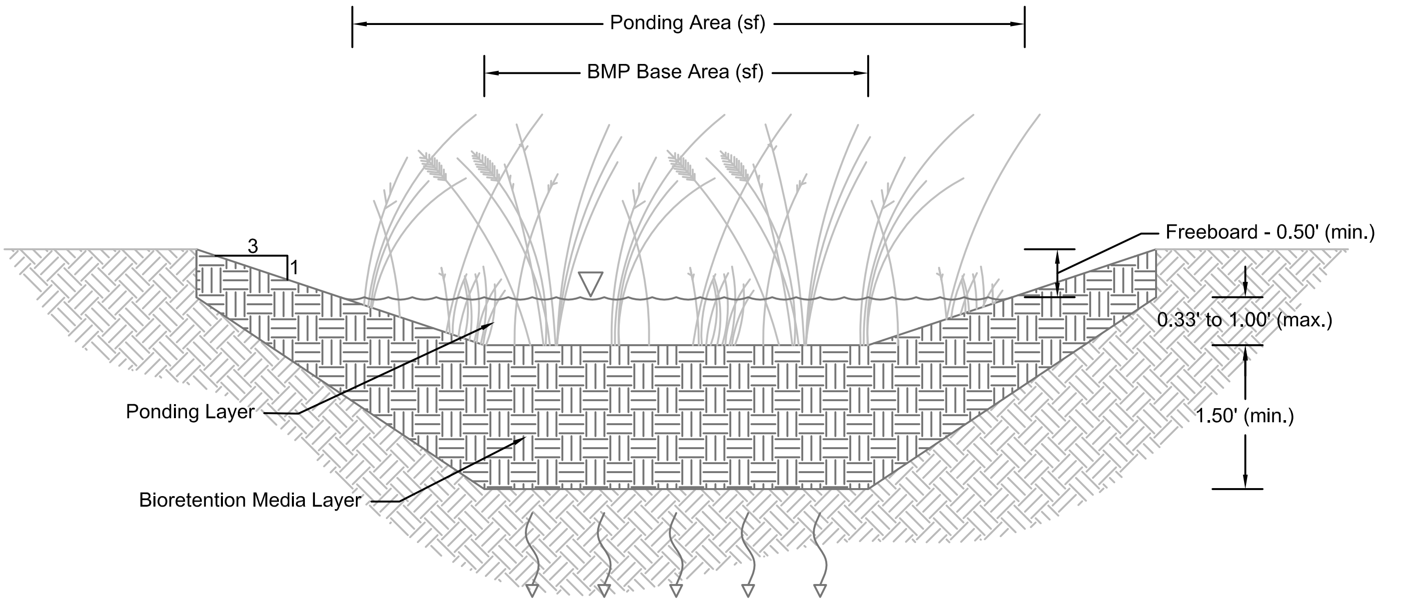
APPENDIX A –

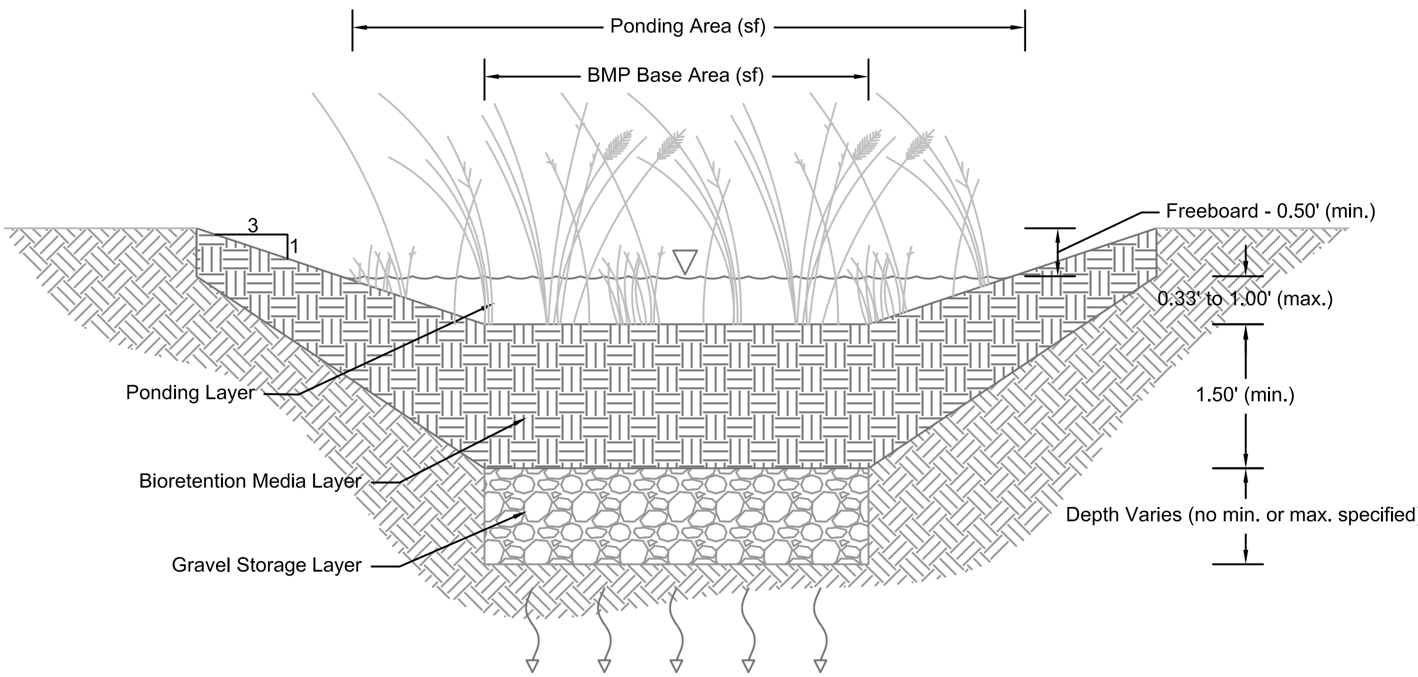
TYPICAL BMP SCHEMATICS
FOR
CSS AND MS4 BMP SIZING CALCULATORS

(Not to be used as Construction Details)



A Bioretention (No Underdrain, No Liner)

Basin Configuration



B Bioretention (No Underdrain, No Liner)

Basin Configuration (With Gravel Storage)

NOTES:
1. A 2- to 3-inch thick layer of mulch should be placed above the media layer. However, this layer is **not** included in the CSS BMP sizing calculations.
2. The BMP Footprint entered into the CSS BMP Sizing Calculator should be the average of the Ponding Area and the BMP Base Area.
3. All basins with liners or underdrains should be modeled as Bioretenion (Underdrain) shown in Figure 7.
4. Modeled Outflows from Bioretention (No Underdrain, No Liner): Infiltration, Evapotranspiration, Overflow

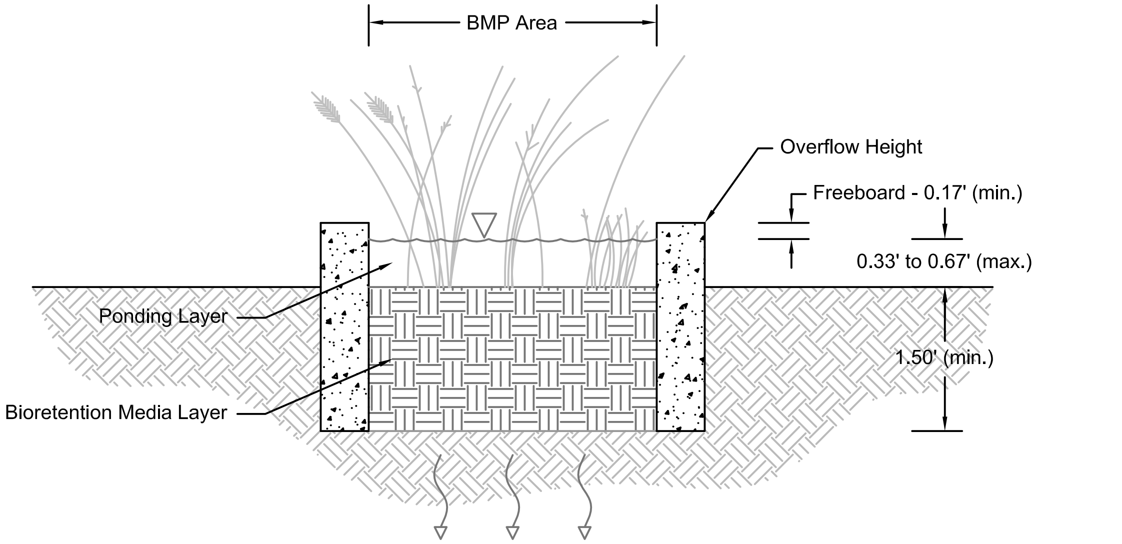
San Francisco Water Power Sewer

TYPICAL BMP SCHEMATICS
FOR
COMBINED SEWER SYSTEM BMP SIZING CALCULATOR

DATE AUGUST 2015 | VERSION v2.0 | REVISION

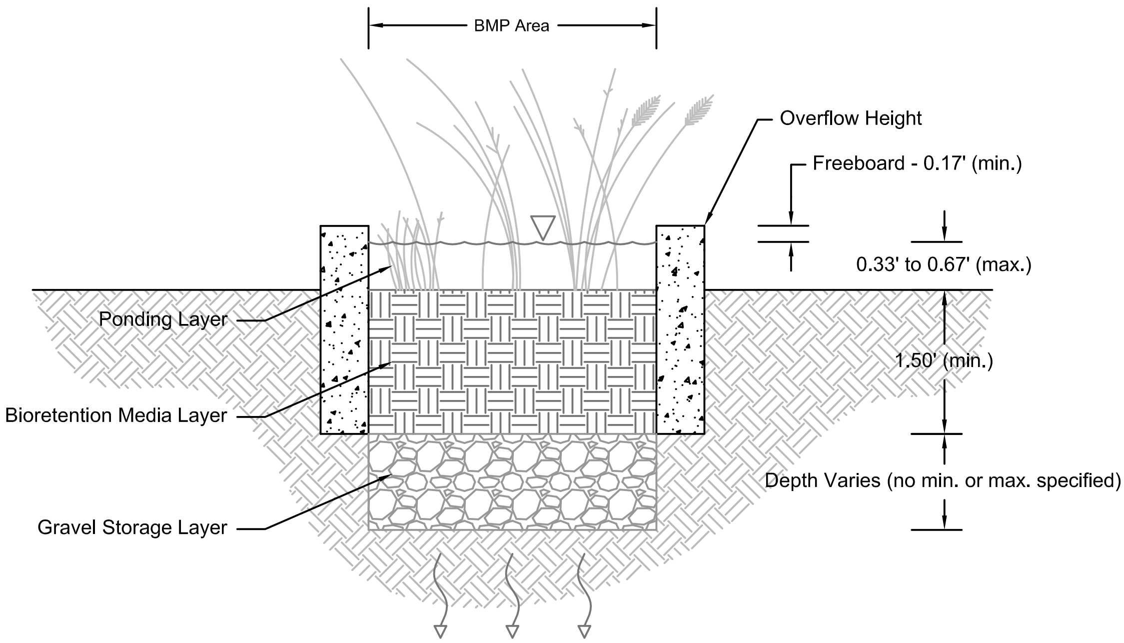
BIORETENTION (NO UNDERDRAIN, NO LINER)
BASIN CONFIGURATION

FIGURE NO. 1



C Bioretention (No Underdrain, No Liner)

Flow-Through Planter Configuration



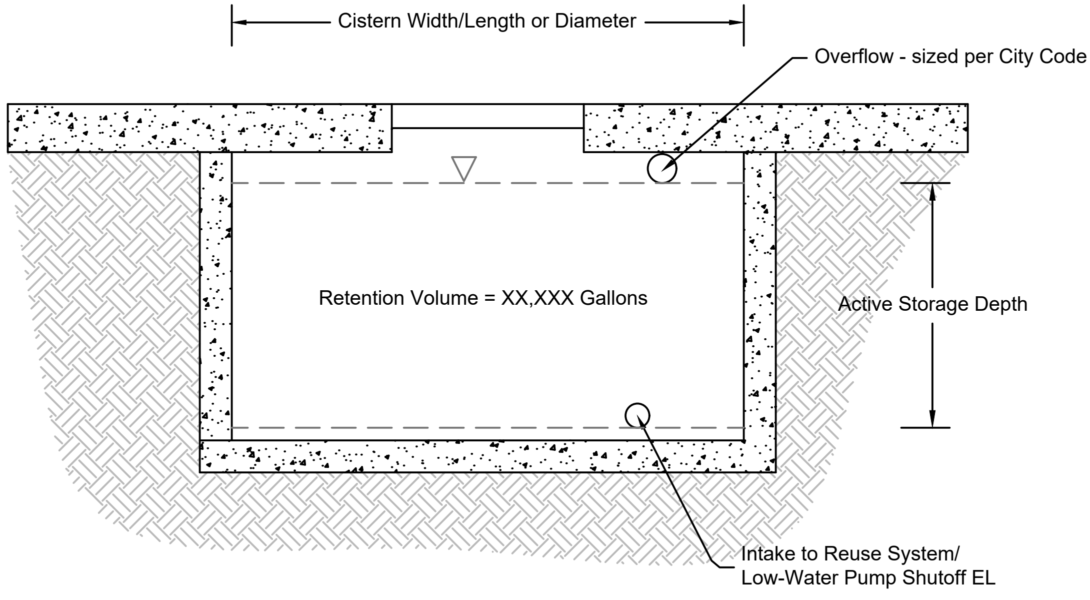
D Bioretention (No Underdrain, No Liner)

Flow-Through Planter Configuration (With Gravel Storage)

NOTES:

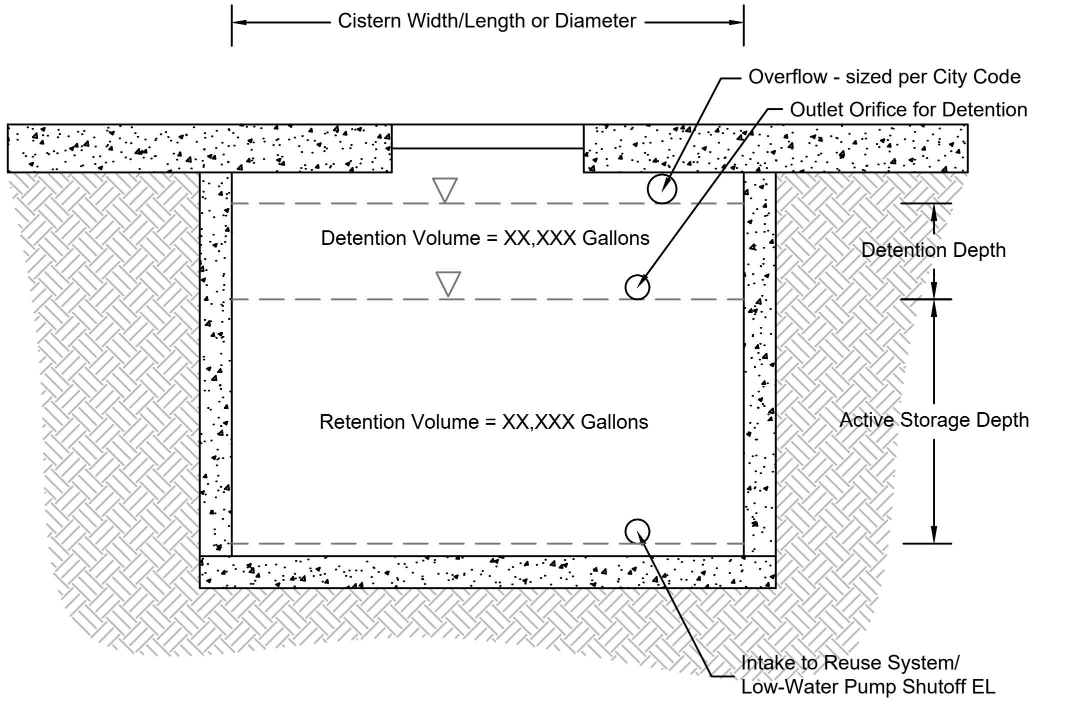
1. A 2- to 3-inch thick layer of mulch should be placed above the media layer. However, this layer is **not** included in the CSS BMP Sizing calculations.
2. All planters with liners or underdrains should be modeled as Bioretention (Underdrain) shown in Figures 8 and 9.
3. Modeled Outflows from Bioretention (No Underdrain, No Liner): Infiltration, Evapotranspiration, Overflow

San Francisco Water Power Sewer	TYPICAL BMP SCHEMATICS FOR COMBINED SEWER SYSTEM BMP SIZING CALCULATOR	BIORETENTION (NO UNDERDRAIN, NO LINER) PLANTER CONFIGURATION	FIGURE NO. 2
	DATE: AUGUST 2015 / VERSION: v2.0 / REVISION:		



E Rainwater Harvester Cistern

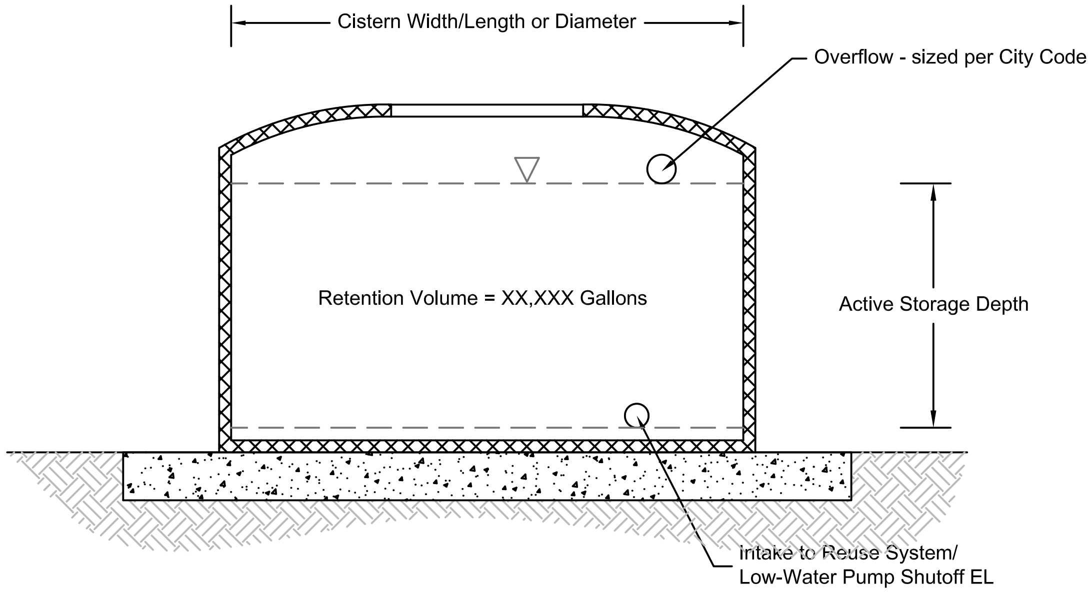
(Sub-Grade)



F Rainwater Harvester Cistern

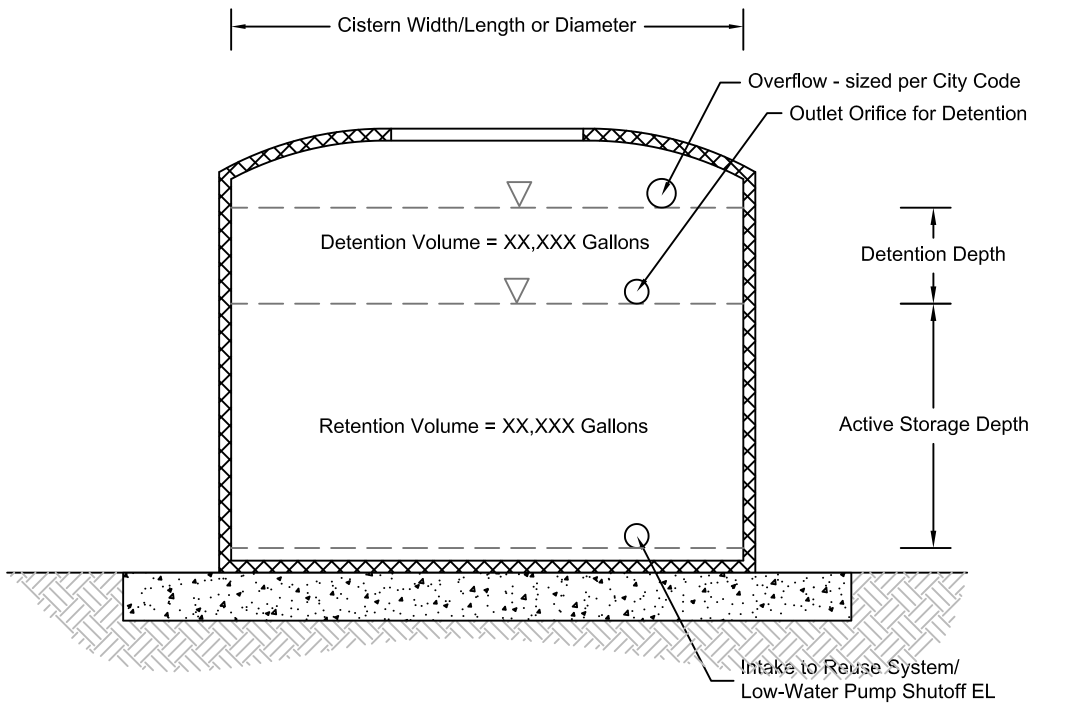
(Sub-Grade with Dual-Stage Detention Component)

NOTES:
1. Rainwater harvester cisterns are assumed to have no footprint or BMP area in the CSS BMP Sizing Calculator.
2. Modeled Outflows from a Rainwater Harvester Cistern: Reuse, Discharge (if Detention Component present), Overflow.
3. If detention and retention are provided in the same cistern enter them as 2 BMPs in series in the CSS BMP Sizing Calculator; Cistern to Detention Vault.



G — Rainwater Harvester Cistern

(On-Grade)



H — Rainwater Harvester Cistern

(On-Grade with Dual-Stage Detention Component)

NOTES:
1. Rainwater harvester cisterns are assumed to have no footprint or BMP area in the CSS BMP Sizing Calculator.
2. Modeled Outflows from a Rainwater Harvester Cistern: Reuse, Discharge (if Detention Component present), Overflow.
3. If detention and retention are provided in the same cistern enter them as 2 BMPs in series in the CSS BMP Sizing Calculator; Cistern to Detention Tank.

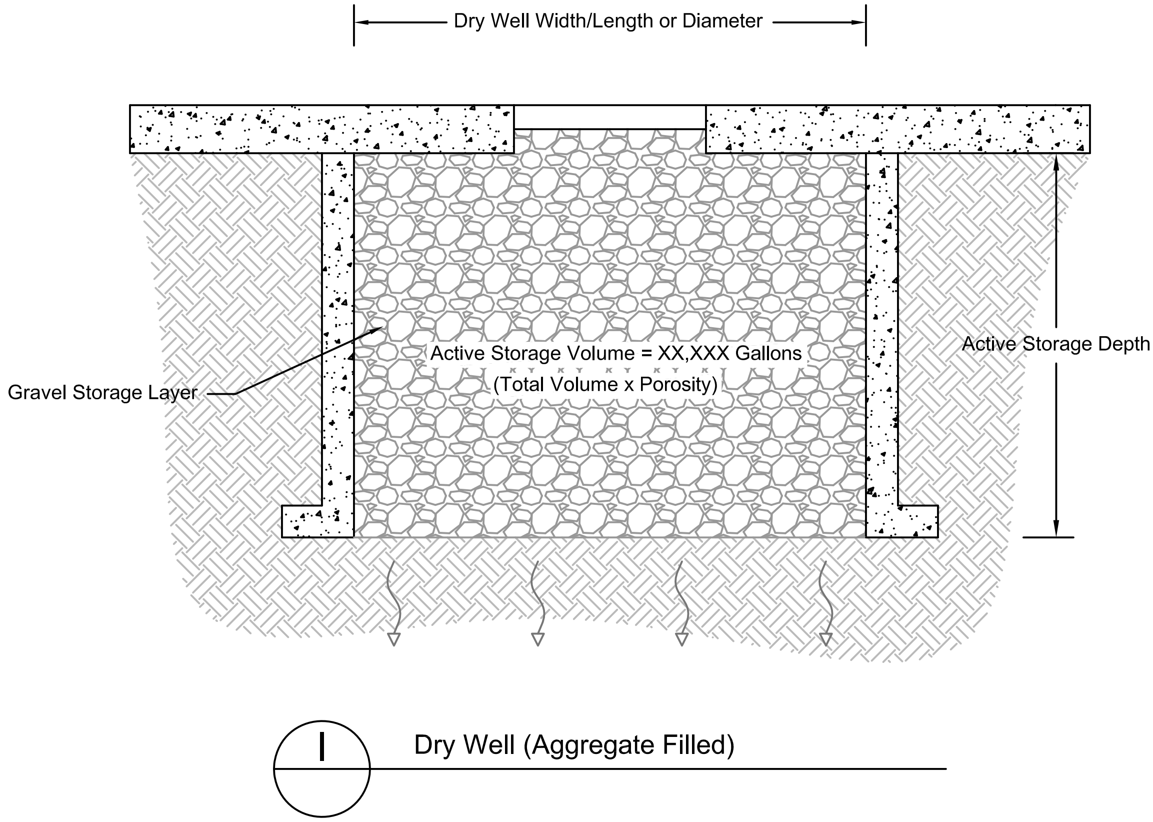
San Francisco Water Power Sewer

TYPICAL BMP SCHEMATICS
FOR
COMBINED SEWER SYSTEM BMP SIZING CALCULATOR

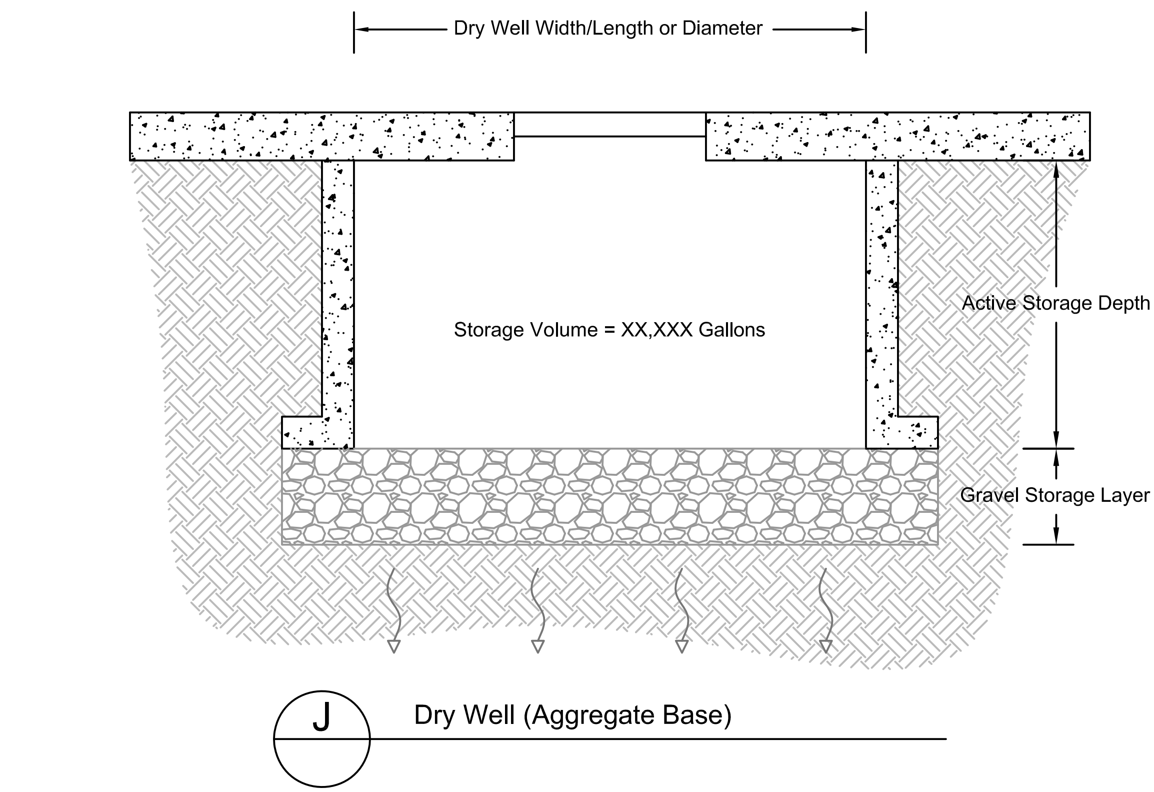
DATE: AUGUST 2015 | VERSION: v2.0 | REVISION:

RAINWATER HARVESTER CISTERN
ON-GRADE

FIGURE NO. 4



Dry Well (Aggregate Filled)



Dry Well (Aggregate Base)

NOTES:

1. Dry Wells are assumed to have no footprint or BMP area in the CSS BMP Sizing Calculator.
2. Storage volume is equal to the total volume, if the dry well is not filled with aggregate. If the dry well is filled with aggregate, the storage volume is equal to the available pore space. Typically, available pore space equals the total volume multiplied by a porosity of 0.4.
3. Modeled Outflows from a Dry Well: Infiltration, Overflow

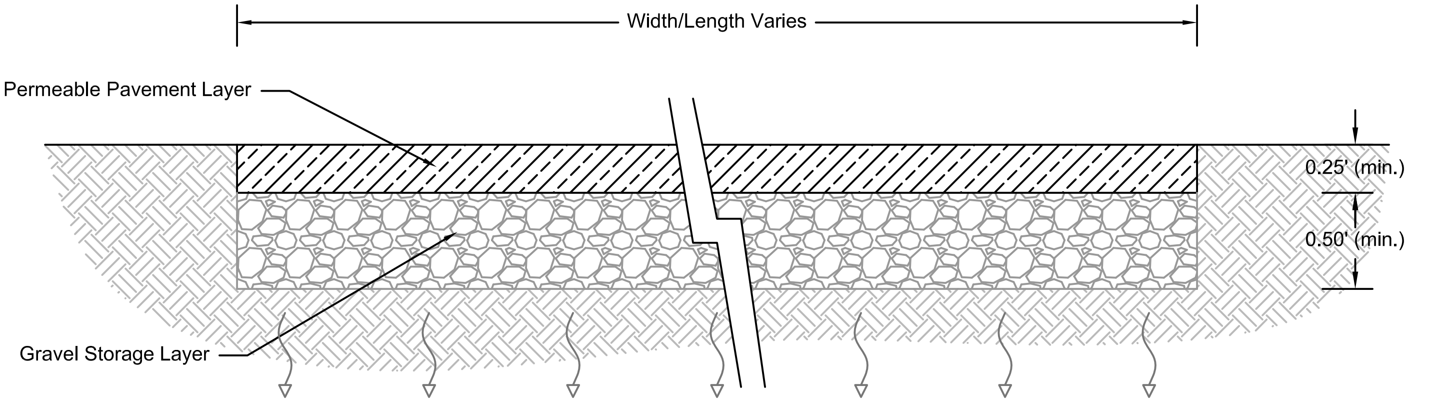
San Francisco Water Power Sewer

TYPICAL BMP SCHEMATICS
FOR
COMBINED SEWER SYSTEM BMP SIZING CALCULATOR

DATE: AUGUST 2015 | VERSION: v2.0 | REVISION:

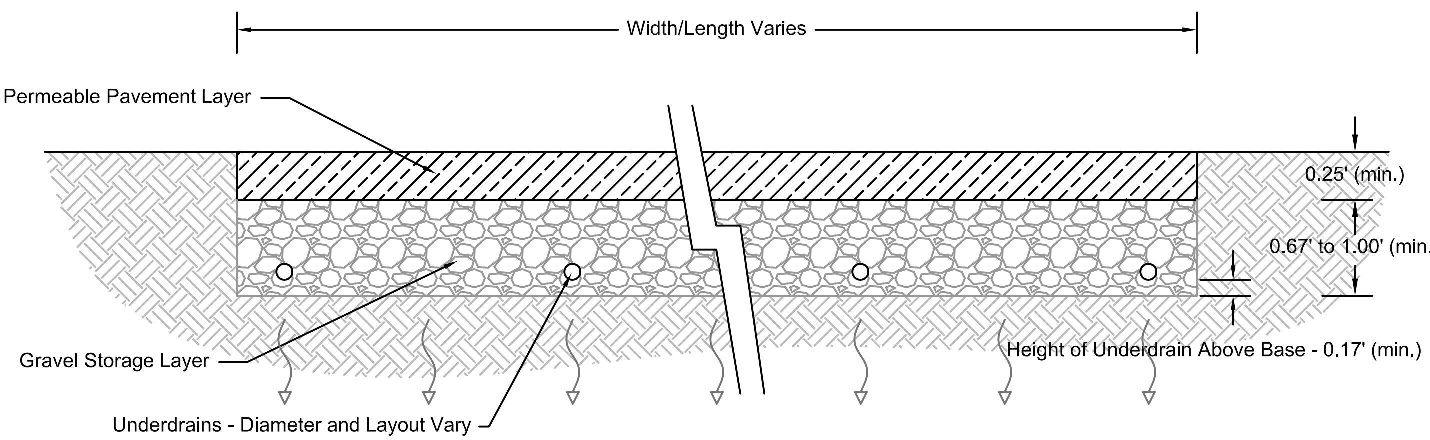
DRY WELL

FIGURE NO. 5



K Permeable Pavement

(No Underdrain)

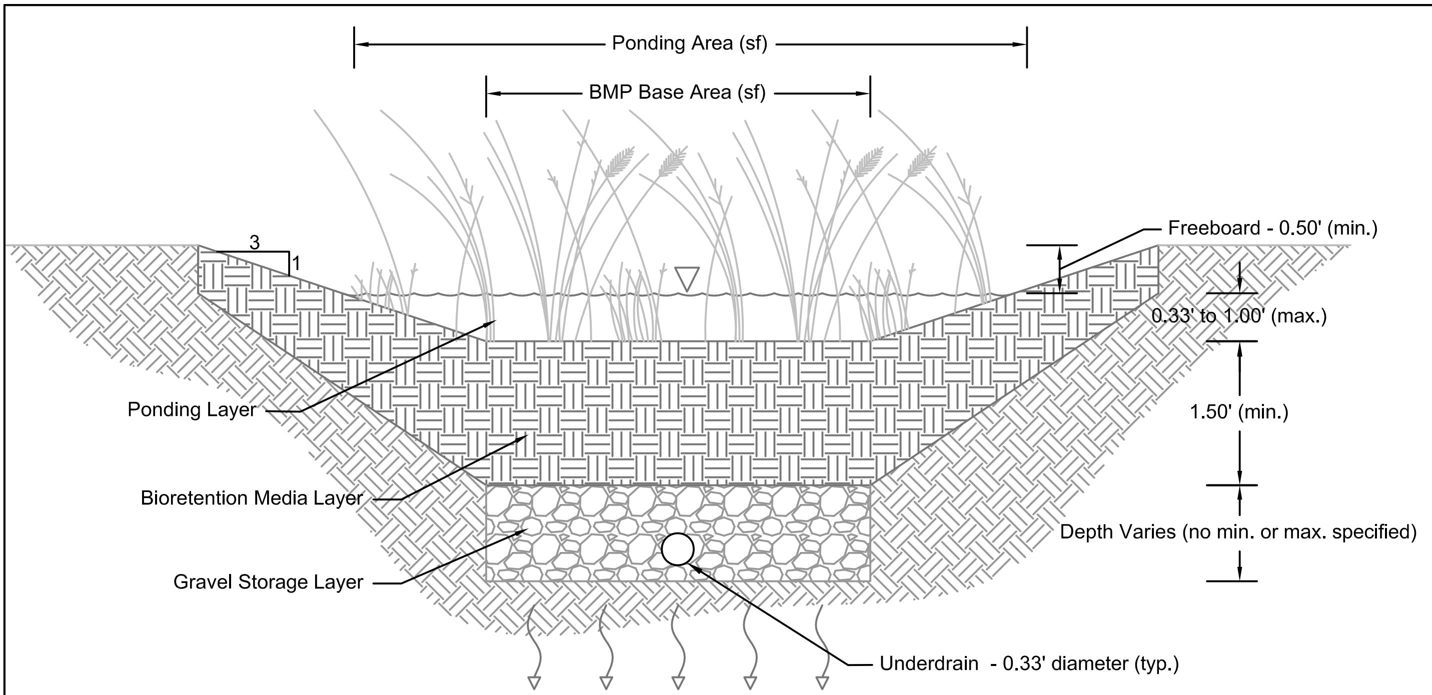


L Permeable Pavement

(with Underdrain)

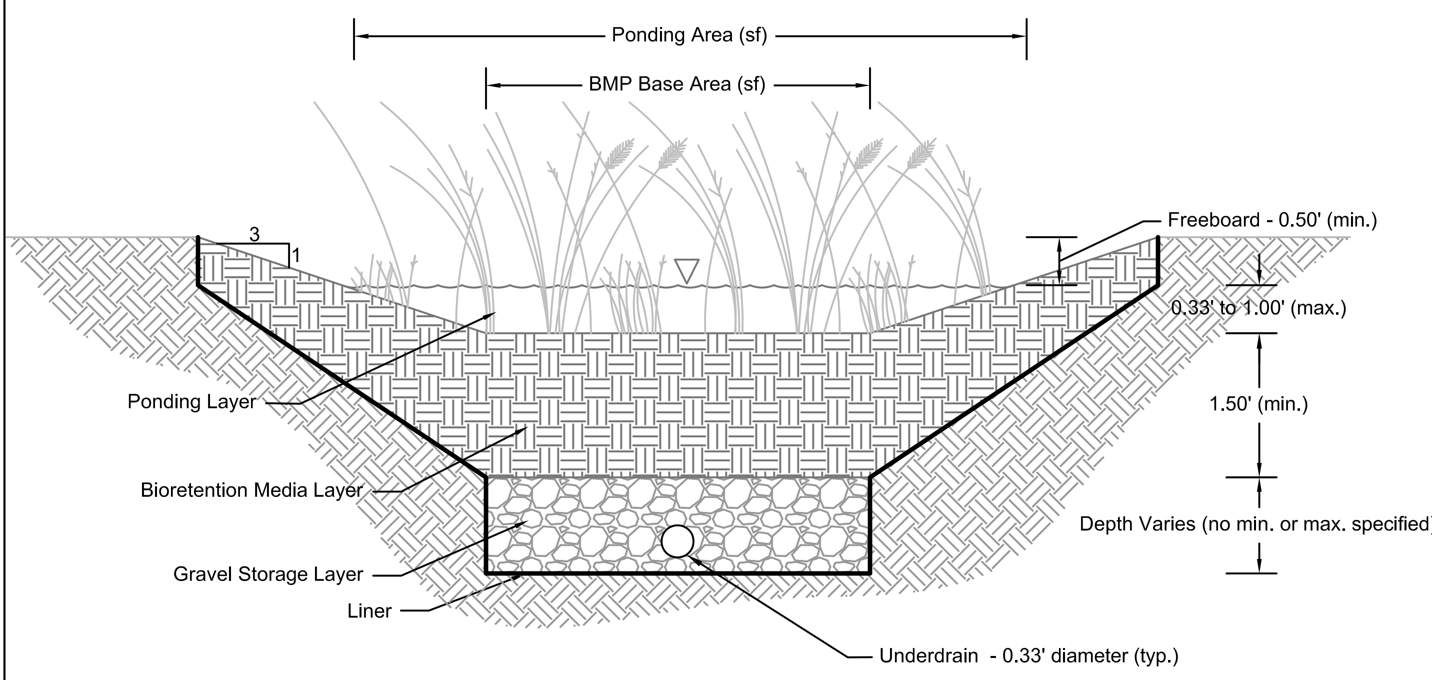
NOTES:
1. Permeable Pavements include Pavers, Pervious Concrete, and Porous Asphalt.
2. The gravel storage layers should include all sub-surface courses: reservoir course, base course, and leveling course, where appropriate.
3. Control orifices may be added to the underdrain outlets to reduce the peak discharge flow rate.
4. Modeled Outflows from a Permeable Pavement: Infiltration, Discharge from Underdrain (if present), Overflow

San Francisco Water Power Sewer	**TYPICAL BMP SCHEMATICS** FOR COMBINED SEWER SYSTEM BMP SIZING CALCULATOR	**PERMEABLE PAVEMENT**	FIGURE NO. 6
	DATE AUGUST 2015 · VERSION v2.0 · REVISION		



M **Bioretention (Underdrain, No Liner)**

Basin Configuration



N **Bioretention (Underdrain, Liner)**

Basin Configuration

NOTES:

1. A 2- to 3-inch thick layer of mulch should be placed above the media layer. However, this layer is **not** included in the CSS BMP Sizing calculations.
2. The BMP Footprint entered into the CSS BMP Sizing Calculations should be the average of the Ponding Area and the BMP Base Area.
3. Control orifices may be added to the underdrain outlets to reduce the peak discharge flow rate.
4. Modeled Outflows from Bioretention (Underdrain): Evapotranspiratio, Discharge from Underdrain, Infiltration (No Liner only), Overflow

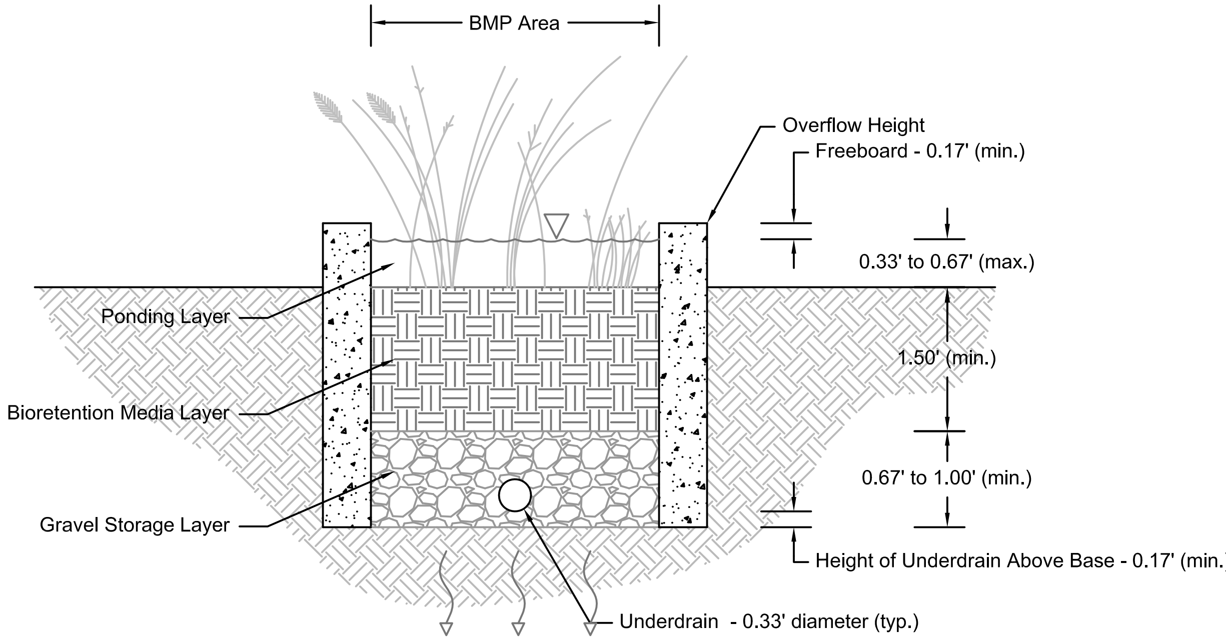
San Francisco Water Power Sewer

TYPICAL BMP SCHEMATICS
FOR
COMBINED SEWER SYSTEM BMP SIZING CALCULATOR

DATE AUGUST 2015 | VERSION v2.0 | REVISION

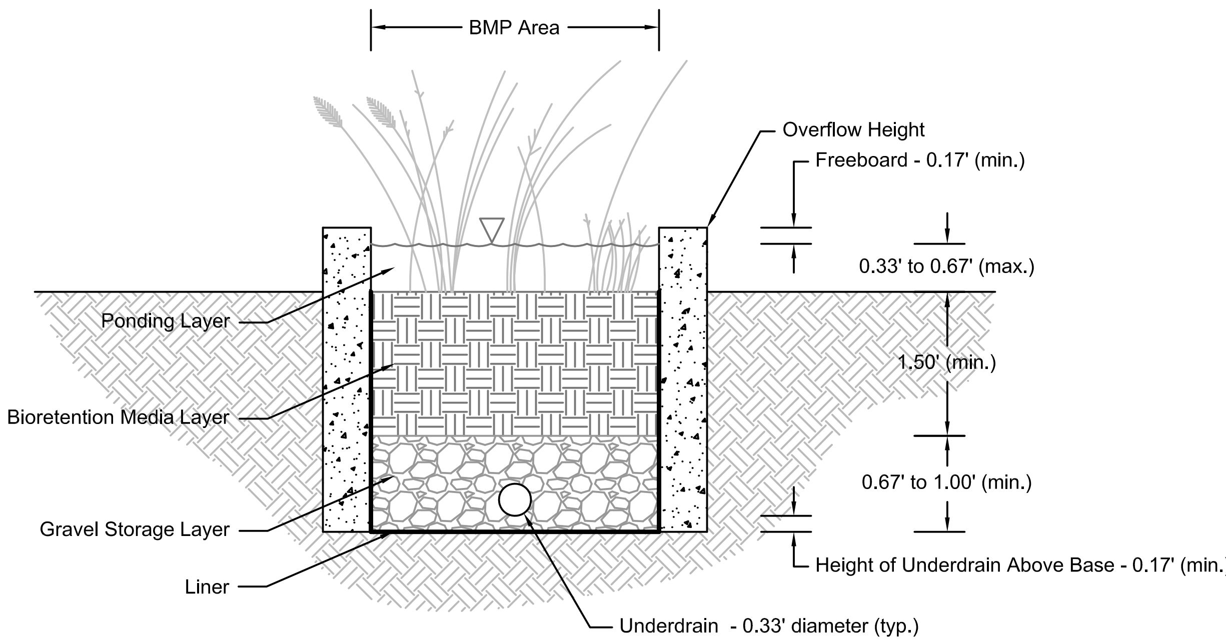
BIORETENTION (UNDERDRAIN)
BASIN CONFIGURATION

FIGURE NO. 7



O Bioretention (Underdrain, No Liner)

Flow-Through Planter Configuration



P Bioretention (Underdrain, Liner)

Flow-Through Planter Configuration

NOTES:
1. A 2- to 3-inch thick layer of mulch should be placed above the media layer. However, this layer is **not** included in the CSS BMP Sizing calculations.
2. Control orifices may be added to the underdrain outlets to reduce the peak discharge flow rate.
3. Modeled Outflows from Bioretention (Underdrain): Evapotranspiration, Discharge from Underdrain, Infiltration (No Liner only), Overflow

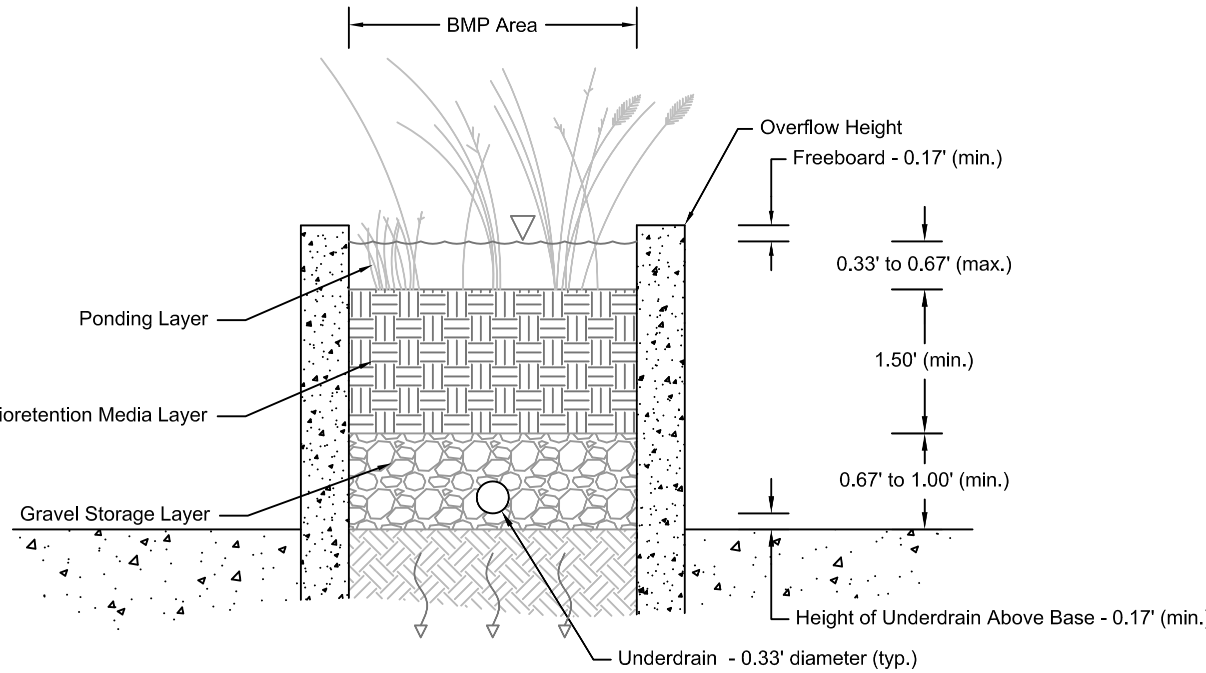
San Francisco Water Power Sewer

TYPICAL BMP SCHEMATICS
FOR
COMBINED SEWER SYSTEM BMP SIZING CALCULATOR

DATE AUGUST 2015 | VERSION v2.0 | REVISION

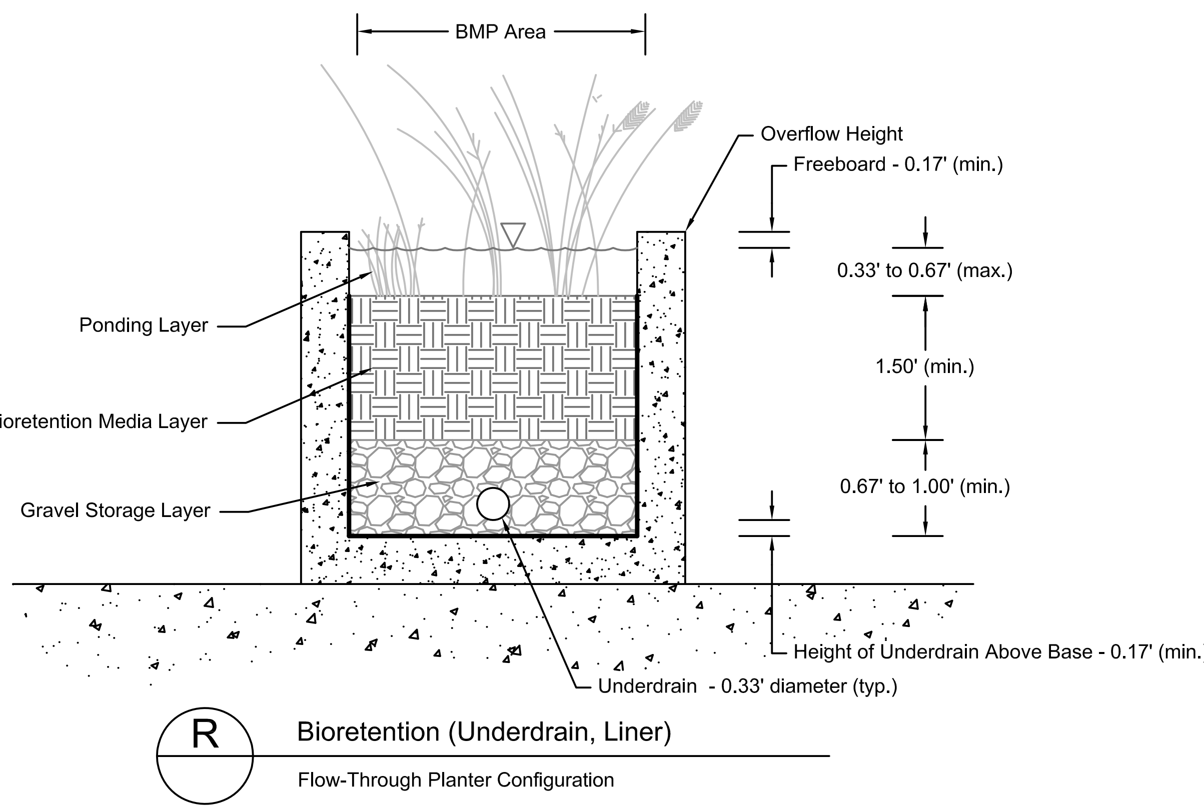
BIORETENTION (UNDERDRAIN)
PLANTER CONFIGURATION, SUB-GRADE

FIGURE NO. 8



Bioretention (Underdrain, No Liner)

Flow-Through Planter Configuration

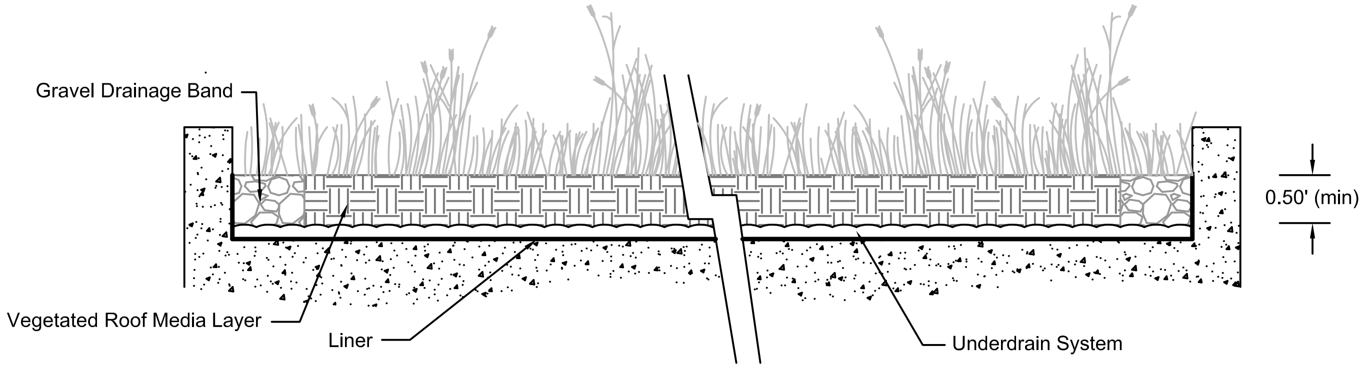


Bioretention (Underdrain, Liner)

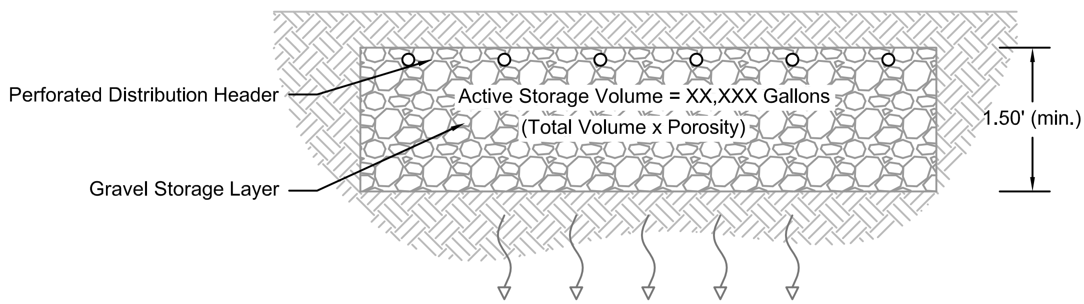
Flow-Through Planter Configuration

NOTES:
1. A 2- to 3-inch thick layer of mulch should be placed above the media layer. However, this layer is **not** included in the CSS BMP Sizing calculations.
2. Control orifices may be added to the underdrain outlets to reduce the peak discharge flow rate.
3. Modeled Outflows from Bioretention (Underdrain): Evapotranspiration, Discharge from Underdrain, Infiltraiton (No Liner only, Overflow

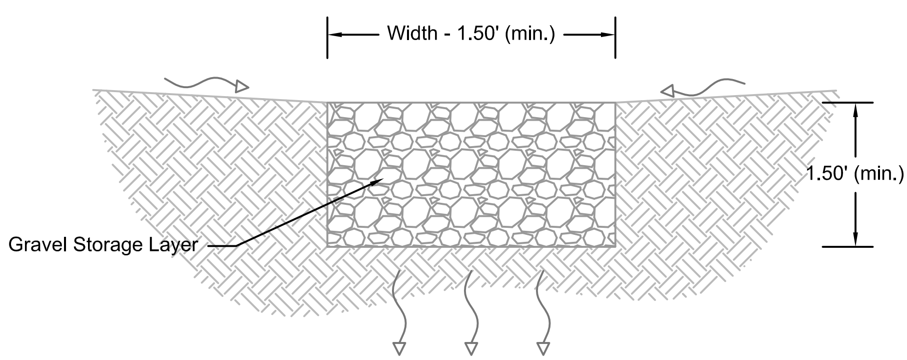
San Francisco Water Power Sewer	**TYPICAL BMP SCHEMATICS** FOR COMBINED SEWER SYSTEM BMP SIZING CALCULATOR	**BIORETENTION (UNDERDRAIN)** PLANTER CONFIGURATION, ON-GRADE	FIGURE NO. 9
	DATE AUGUST 2015 / VERSION v2.0 / REVISION		



S Vegetated Roof



T Infiltration Gallery



U Infiltration Trench

NOTES:

1. A 2- to 3-inch thick layer of mulch should be placed above the media layer. However, this layer is **not** included in the CSS BMP Sizing calculations.
2. Control orifices may be added to the underdrain outlets to reduce the peak discharge flow rate.
3. Infiltration Galleries should be entered as Dry Wells with aggregate in the CSS BMP Sizing Calculator.
4. Modeled Outflows from a Vegetated Roof: Evapotranspiration, Discharge from Underdrain, Overflow
5. Modeled Outflows from Infiltration Gallery/Trench: Infiltration, Overflow

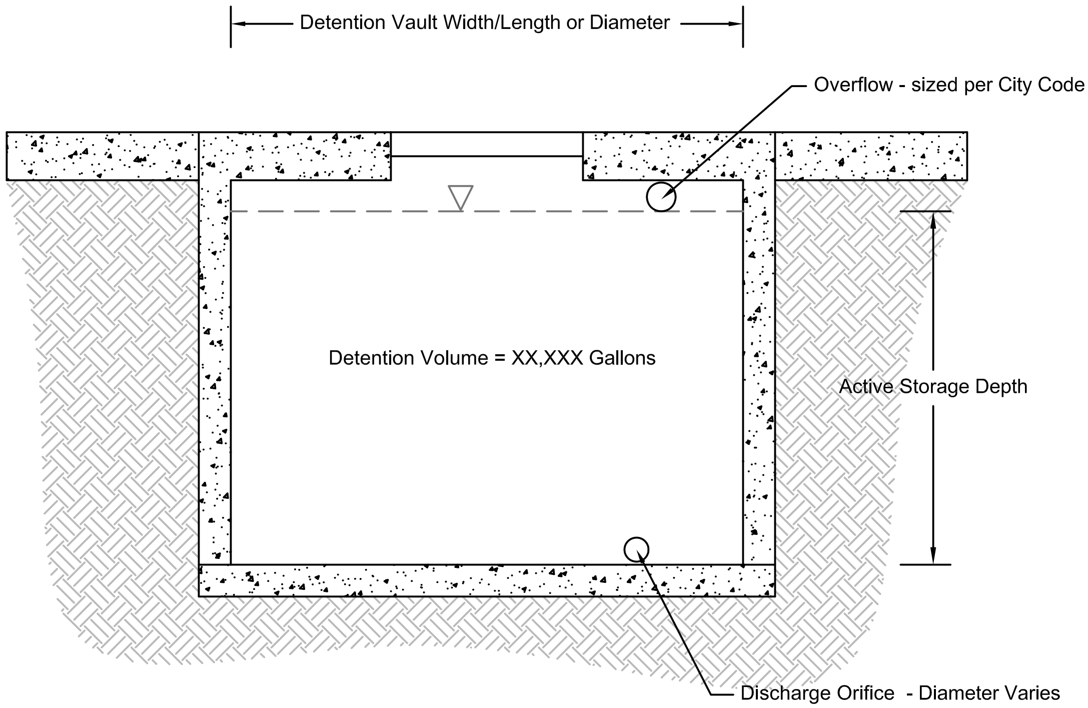
San Francisco Water Power Sewer

TYPICAL BMP SCHEMATICS
FOR
COMBINED SEWER SYSTEM BMP SIZING CALCULATOR

DATE	VERSION	REVISION
AUGUST 2015	v2.0	

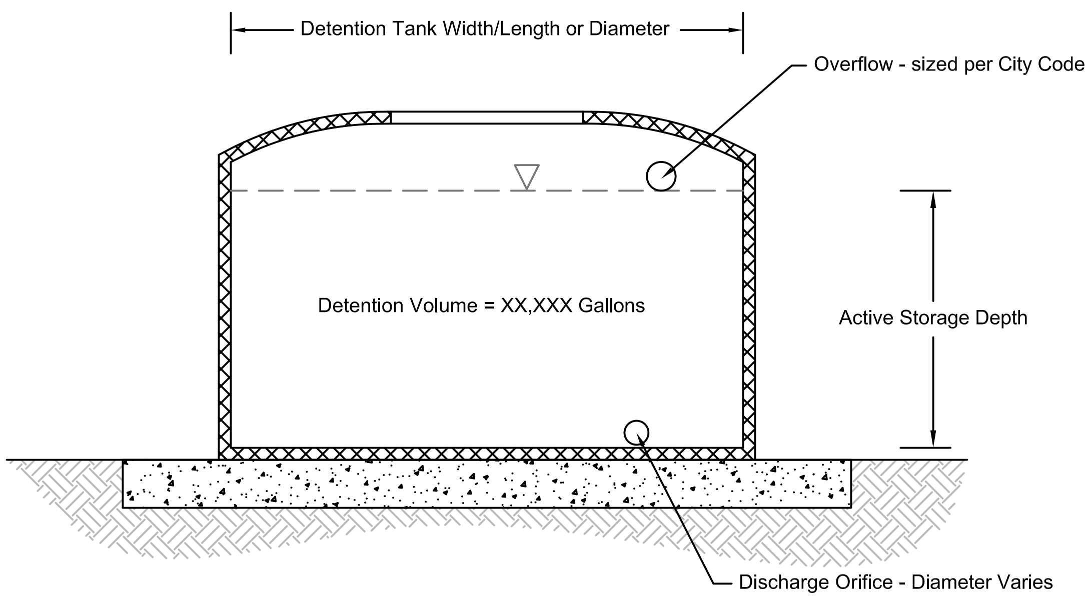
VEGETATED ROOF, INFILTRATION GALLERY, AND INFILTRATION TRENCH

FIGURE NO. 10



V Detention Vault

(Sub-Grade)



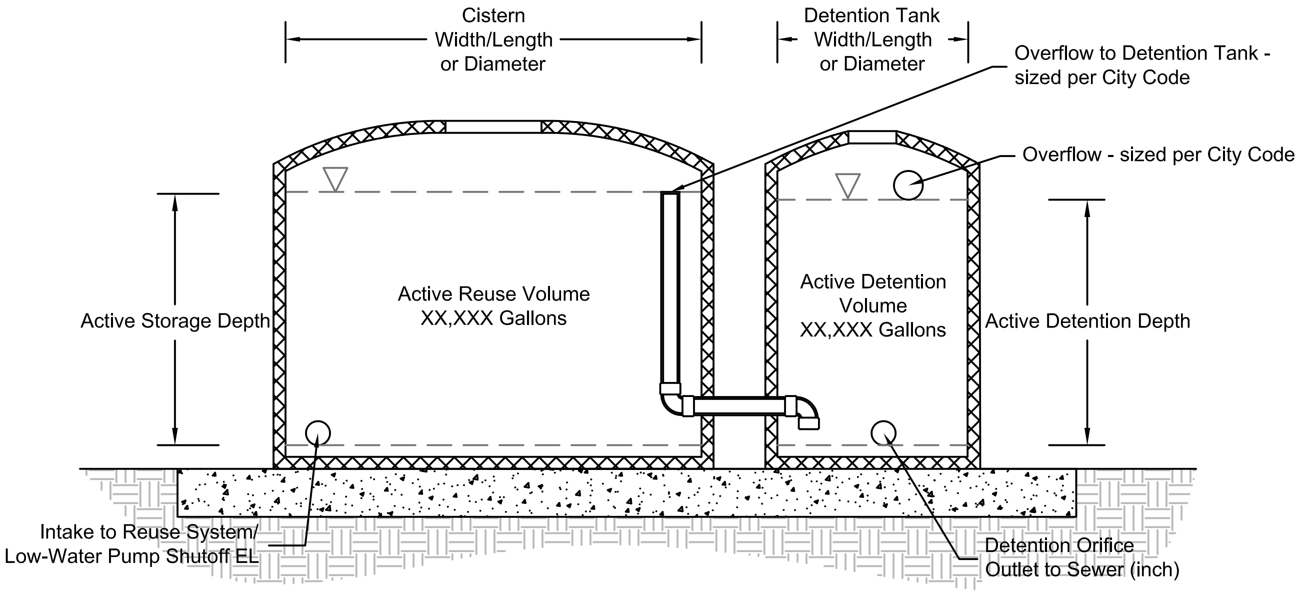
W Detention Tank

(On-Grade)

NOTES:

1. Detention Vaults and Tanks are assumed to have no footprint or BMP area in the CSS BMP Sizing Calculator.
2. Control orifices may be added to the outlets to reduce the peak discharge flow rate.
3. Modeled Outflows from a Detention Vault/Tank: Detained Discharge, Overflow

San Francisco Water Power Sewer	**TYPICAL BMP SCHEMATICS** FOR COMBINED SEWER SYSTEM BMP SIZING CALCULATOR	**DETENTION VAULT AND DETENTION TANK**	FIGURE NO. 11
	DATE: AUGUST 2015 / VERSION: v2.0 / REVISION:		



X — Rainwater Harvesting Cistern to Detention in Series

(Systems in Series, On-Grade)

NOTES:
1. Detention Vaults and Tanks are assumed to have no footprint or BMP area in the CSS BMP Sizing Calculator.
2. Control orifices may be added to the outlets to reduce the peak discharge flow rate.
3. Modeled Outflows from a Detention Vault/Tank: Detained Discharge, Overflow

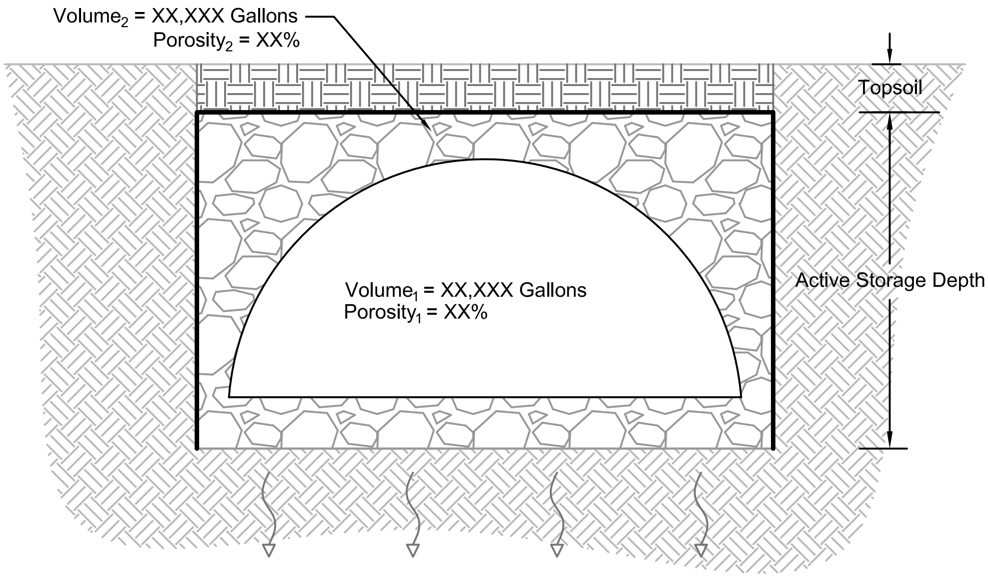
San Francisco Water Power Sewer

TYPICAL BMP SCHEMATICS
FOR
COMBINED SEWER SYSTEM BMP SIZING CALCULATOR

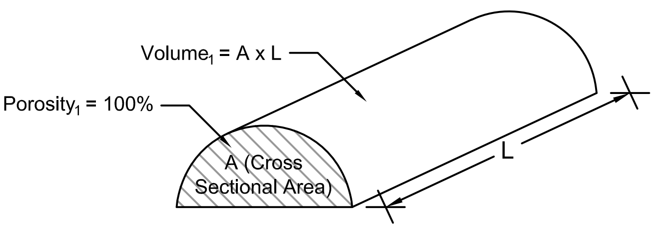
DATE: AUGUST 2018 | VERSION: v2.2 | REVISION:

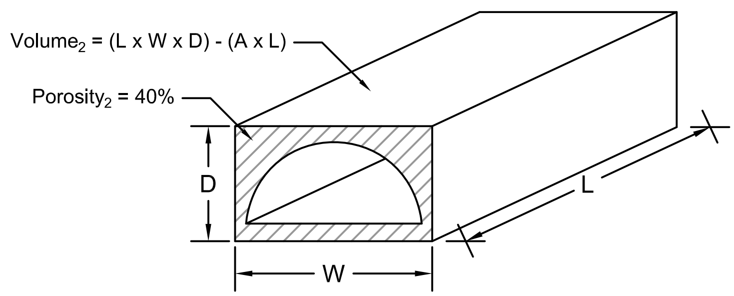
Rainwater Harvesting Cistern to Detention in Series

FIGURE NO. 12



Y — Proprietary Infiltration System





Storage Volume = ($Volume_1$ + $Volume_2$) x Effective Porosity

$$\text{Effective Porosity} = \frac{Porosity_1 \times Volume_1 + Porosity_2 \times Volume_2}{Volume_1 + Volume_2}$$

<u>CSS BMP Sizing Calculator Inputs</u>

"BMP Ponding Depth" = D x Effective Porosity

"Storage Volume" = Storage Volume

"Gravel Storage Depth" = 0

<u>NOTES:</u>

1. Proprietary Infiltration Systems should be entered as Dry Wells in the CSS BMP Sizing Calculator.
2. All the storage provided by the Infiltration System should be entered as "BMP Ponding Depth" and "Storage Volume" in the CSS BMP Sizing Calculator.
3. "Gravel Storage Depth" should be set to 0 in the CSS BMP Sizing Calculator.
4. "BMP Ponding Depth" should be set equal to the Effective Storage Depth (Active Storage Depth x Effective Porosity).
5. "Storage Volume" should be set equal to the total storage volume provided by the system including aggregate and chamber storage.

APPENDIX B –

EXAMPLE SBUH CALCULATIONS
AND
BMP WATER BALANCE

APPENDIX B - EXAMPLE SBUH CALCULATIONS

2-Year, 24-Hour Design Storm

Column — Description of Calculations

- [1] Time Step number
- [2] Time (in 5 minute increments)
- [3] Intensity of precipitation from Design Storm Hydrograph
- [4] Incremental Depth = Intensity x (5 min / 1 hour)
- [5] Acc. Depth = Sum of all Incremental Depths (4) through the Time Step

Design Storm Characteristics

Rainfall Depth (in):	2.8522
Storm Duration (hr):	24
Time Increment (min):	5
Peak Intensity (in/hr)	2.357

Proposed Conditions

Area and Flow Characteristics

Project Area (sf):	10,000
Existing Impervious (sf):	7,000
Existing Pervious (sf):	3,000
Proposed Impervious (sf):	6,000
Proposed Pervious (sf):	3,000
Proposed BMP Area (sf):	1,000
Pervious Area - CN:	70
Impervious Area - CN:	98
Pervious Area - S:	4.29
Impervious Area - S:	0.20
Time of Concentration - Tc:	8.54
Routing Constant - W:	0.22

Column — Description of Calculations

- [6] (Acc. Depth [5] - 0.2 x Pervious S)^2 / (Acc. Depth [5] + 0.8 x Pervious S)
- [7] Acc. Runoff [6] - Acc. Runoff [12] from previous Time Step
- [8] Incr. Runoff [7] x Area x (1 ft / 12 in) x (1 Time Step / 300 sec)
- [9] Design Flow [9] from previous Time Step + W x [(Inst. Flow [8] previous Time Step + Inst. Flow [8] current Time Step) - (2 x Design Flow [9] from previous Time Step)]
- [10] Design Flow [9] x (Pervious BMP Drainage Management Area / Total Pervious Area)
- [11] Design Flow [9] x (Pervious Area draining to CSS / Total Pervious Area)
- [12] (Acc. Depth [5] - 0.2 x Impervious S)^2 / (Acc. Depth [5] + 0.8 x Impervious S)
- [13] Acc. Runoff [12] - Acc. Runoff [12] from previous Time Step
- [14] Incr. Runoff [13] x Area x (1 ft / 12 in) x (1 Time Step / 300 sec)
- [15] Design Flow [15] from previous Time Step + W x [(Inst. Flow [14] previous Time Step + Inst. Flow [14] current Time Step) - (2 x Design Flow [15] from previous Time Step)]
- [16] Design Flow [15] x (Impervious BMP Drainage Management Area / Total Impervious Area)
- [17] Design Flow [15] x (Impervious Area draining to CSS / Total Impervious Area)

[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]	[10]	[11]	[12]	[13]	[14]	[15]	[16]	[17]
		Precipitation			*Pervious Area Flow Conditions*						*Impervious Area Flow Conditions*					
Time Step	Time	Intensity	Incremental Depth	Accumulated Depth	Accumulated Runoff	Incremental Runoff	Instantaneous Flow	Design Flow	Design Flow to BMP	Design Flow to CSS	Accumulated Runoff	Incremental Runoff	Instantaneous Flow	Design Flow	Design Flow to BMP	Design Flow to CSS
	(HH:MM)	(in/hr)	(in)	(in)	(in)	(in)	(cfs)	(cfs)	(cfs)	(cfs)	(in)	(in)	(cfs)	(cfs)	(cfs)	(cfs)
1	0:00	0	0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2	0:05	0.0547	0.0046	0.005	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
3	0:10	0.0549	0.0046	0.009	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
4	0:15	0.0551	0.0046	0.014	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
5	0:20	0.0553	0.0046	0.018	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
6	0:25	0.0555	0.0046	0.023	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
7	0:30	0.0557	0.0046	0.028	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
8	0:35	0.0559	0.0047	0.032	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
9	0:40	0.0562	0.0047	0.037	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
10	0:45	0.0564	0.0047	0.042	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
11	0:50	0.0566	0.0047	0.046	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
12	0:55	0.0568	0.0047	0.051	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000
13	1:00	0.0571	0.0048	0.056	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.001	0.001	0.001	0.000	0.000
14	1:05	0.0573	0.0048	0.061	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.001	0.001	0.001	0.000	0.000
15	1:10	0.0575	0.0048	0.065	0.000	0.000	0.000	0.000	0.000	0.000	0.003	0.001	0.002	0.001	0.001	0.001
16	1:15	0.0578	0.0048	0.070	0.000	0.000	0.000	0.000	0.000	0.000	0.004	0.001	0.002	0.001	0.001	0.001
17	1:20	0.0580	0.0048	0.075	0.000	0.000	0.000	0.000	0.000	0.000	0.005	0.001	0.002	0.002	0.001	0.001
18	1:25	0.0583	0.0049	0.080	0.000	0.000	0.000	0.000	0.000	0.000	0.006	0.001	0.003	0.002	0.001	0.001
19	1:30	0.0585	0.0049	0.085	0.000	0.000	0.000	0.000	0.000	0.000	0.008	0.002	0.003	0.002	0.001	0.001
20	1:35	0.0588	0.0049	0.090	0.000	0.000	0.000	0.000	0.000	0.000	0.009	0.002	0.003	0.003	0.001	0.002
21	1:40	0.0590	0.0049	0.095	0.000	0.000	0.000	0.000	0.000	0.000	0.011	0.002	0.003	0.003	0.001	0.002
22	1:45	0.0593	0.0049	0.100	0.000	0.000	0.000	0.000	0.000	0.000	0.013	0.002	0.004	0.003	0.001	0.002
23	1:50	0.0596	0.0050	0.105	0.000	0.000	0.000	0.000	0.000	0.000	0.015	0.002	0.004	0.004	0.002	0.002
24	1:55	0.0598	0.0050	0.110	0.000	0.000	0.000	0.000	0.000	0.000	0.017	0.002	0.004	0.004	0.002	0.002
25	2:00	0.0601	0.0050	0.115	0.000	0.000	0.000	0.000	0.000	0.000	0.020	0.002	0.004	0.004	0.002	0.002
136	11:15	0.2424	0.0202	1.032	0.007	0.001	0.001	0.001	0.000	0.001	0.822	0.020	0.038	0.035	0.015	0.020
137	11:20	0.2580	0.0215	1.053	0.009	0.002	0.001	0.001	0.000	0.001	0.842	0.021	0.041	0.037	0.016	0.021
138	11:25	0.2770	0.0231	1.076	0.011	0.002	0.002	0.001	0.000	0.001	0.865	0.022	0.044	0.039	0.017	0.022
139	11:30	0.3005	0.0250	1.101	0.013	0.003	0.002	0.002	0.000	0.002	0.889	0.024	0.047	0.042	0.018	0.024
140	11:35	0.3308	0.0276	1.129	0.016	0.003	0.003	0.002	0.000	0.002	0.916	0.027	0.052	0.046	0.020	0.026
141	11:40	0.3717	0.0310	1.160	0.020	0.004	0.003	0.002	0.000	0.002	0.946	0.030	0.059	0.050	0.021	0.029
142	11:45	0.4315	0.0360	1.196	0.025	0.005	0.004	0.003	0.000	0.003	0.982	0.035	0.068	0.056	0.024	0.032
143	11:50	0.5303	0.0442	1.240	0.031	0.007	0.005	0.004	0.000	0.004	1.025	0.043	0.084	0.065	0.028	0.037
144	11:55	0.7428	0.0619	1.302	0.042	0.010	0.009	0.005	0.000	0.005	1.085	0.061	0.118	0.081	0.035	0.046
145	12:00	2.3573	0.1964	1.498	0.083	0.042	0.035	0.013	0.000	0.013	1.278	0.193	0.375	0.155	0.067	0.089
146	12:05	1.0093	0.0841	1.582	0.105	0.022	0.018	0.019	0.000	0.019	1.361	0.083	0.161	0.206	0.088	0.118
147	12:10	0.6116	0.0510	1.633	0.119	0.014	0.012	0.017	0.000	0.017	1.412	0.050	0.098	0.172	0.074	0.098
148	12:15	0.4737	0.0395	1.673	0.130	0.011	0.009	0.014	0.000	0.014	1.451	0.039	0.076	0.134	0.057	0.076
149	12:20	0.3985	0.0332	1.706	0.140	0.010	0.008	0.012	0.000	0.012	1.483	0.033	0.064	0.105	0.045	0.060
150	12:25	0.3496	0.0291	1.735	0.149	0.009	0.007	0.010	0.000	0.010	1.512	0.029	0.056	0.085	0.036	0.048
151	12:30	0.3146	0.0262	1.761	0.158	0.008	0.007	0.009	0.000	0.009	1.538	0.026	0.050	0.071	0.030	0.040
152	12:35	0.2881	0.0240	1.785	0.165	0.008	0.006	0.008	0.000	0.008	1.562	0.024	0.046	0.061	0.026	0.035
153	12:40	0.2670	0.0223	1.808	0.173	0.007	0.006	0.007	0.000	0.007	1.584	0.022	0.043	0.053	0.023	0.030
154	12:45	0.2498	0.0208	1.828	0.179	0.007	0.006	0.007	0.000	0.007	1.605	0.021	0.040	0.048	0.021	0.027
155	12:50	0.2355	0.0196	1.848	0.186	0.007	0.006	0.006	0.000	0.006	1.624	0.019	0.038	0.044	0.019	0.025
156	12:55	0.2232	0.0186	1.867	0.192	0.006	0.005	0.006	0.000	0.006	1.642	0.018	0.036	0.041	0.017	0.023
157	13:00	0.2127	0.0177	1.884	0.199	0.006	0.005	0.006	0.000	0.006	1.660	0.018	0.034	0.038	0.016	0.022
158	13:05	0.2034	0.0170	1.901	0.205	0.006	0.005	0.005	0.000	0.005	1.677	0.017	0.033	0.036	0.015	0.021
159	13:10	0.1952	0.0163	1.918	0.210	0.006	0.005	0.005	0.000	0.005	1.693	0.016	0.031	0.034	0.015	0.020
160	13:15	0.1878	0.0157	1.933	0.216	0.006	0.005	0.005	0.000	0.005	1.708	0.016	0.030	0.033	0.014	0.019
161	13:20	0.1812	0.0151	1.948	0.221	0.005	0.005	0.005	0.000	0.005	1.723	0.015	0.029	0.031	0.013	0.018
162	13:25	0.1753	0.0146	1.963	0.227	0.005	0.004	0.005	0.000	0.005	1.738	0.014	0.028	0.030	0.013	0.017
163	13:30	0.1698	0.0142	1.977	0.232	0.005	0.004	0.005	0.000	0.005	1.752	0.014	0.027	0.029	0.012	0.017
164	13:35	0.1648	0.0137	1.991	0.237	0.005	0.004	0.004	0.000	0.004	1.765	0.014	0.026	0.028	0.012	0.016
165	13:40	0.1602	0.0134	2.004	0.242	0.005	0.004	0.004	0.000	0.004	1.779	0.013	0.026	0.027	0.012	0.016
166	13:45	0.1560	0.0130	2.017	0.247	0.005	0.004	0.004	0.000	0.004	1.791	0.013	0.025	0.026	0.011	0.015
167	13:50	0.1520	0.0127	2.030	0.252	0.005	0.004	0.004	0.000	0.004	1.804	0.013	0.024	0.026	0.011	0.015
168	13:55	0.1484	0.0124	2.042	0.257	0.005	0.004	0.004	0.000	0.004	1.816	0.012	0.024	0.025	0.011	0.014
169	14:00	0.1449	0.0121	2.054	0.261	0.005	0.004	0.004	0.000	0.004	1.828	0.012	0.023	0.024	0.010	0.014
170	14:05	0.1417	0.0118	2.066	0.266	0.005	0.004	0.004	0.000	0.004	1.840	0.012	0.023	0.024	0.010	0.014
171	14:10	0.1387	0.0116	2.078	0.271	0.005	0.004	0.004	0.000	0.004	1.851	0.011	0.022	0.023	0.010	0.013
172	14:15	0.1359	0.0113	2.089	0.275	0.004	0.004	0.004	0.000	0.004	1.863	0.011	0.022	0.023	0.010	0.013
173	14:20	0.1332	0.0111	2.100	0.279	0.004	0.004	0.004	0.000	0.004	1.874	0.011	0.021	0.022	0.010	0.013
174	14:25	0.1306	0.0109	2.111	0.284	0.004	0.004	0.004	0.000	0.004	1.884	0.011	0.021	0.022	0.009	0.012
175	14:30	0.1282	0.0107	2.122	0.288	0.004	0.004	0.004	0.000	0.004	1.895	0.011	0.021	0.021	0.009	0.012
295	24:30	0.000	0.000	2.852	0.634	0.000	0.000	0.000	0.000	0.000	2.621	0.000	0.000	0.000	0.000	0.000
296	24:35	0.000	0.000	2.852	0.634	0.000	0.000	0.000	0.000	0.000	2.621	0.000	0.000	0.000	0.000	0.000
297	24:40	0.000	0.000	2.852	0.634	0.000	0.000	0.000	0.000	0.000	2.621	0.000	0.000	0.000	0.000	0.000
298	24:45	0.000	0.000	2.852	0.634	0.000	0.000	0.000	0.000	0.000	2.621	0.000	0.000	0.000	0.000	0.000
299	24:50	0.000	0.000	2.852	0.634	0.000	0.000	0.000	0.000	0.000	2.621	0.000	0.000	0.000	0.000	0.000
300	24:55	0.000	0.000	2.852	0.634	0.000	0.000	0.000	0.000	0.000	2.621	0.000	0.000	0.000	0.000	0.000
301	25:00	0.000	0.000	2.852	0.634	0.000	0.000	0.000	0.000	0.000	2.621	0.000	0.000	0.000	0.000	0.000
302	25:05	0.000	0.000	2.852	0.634	0.000	0.000	0.000	0.000	0.000	2.621	0.000	0.000	0.000	0.000	0.000
303	25:10	0.000	0.000	2.852	0.634	0.000	0.000	0.000	0.000	0.000	2.621	0.000	0.000	0.000	0.000	0.000
304	25:15	0.000	0.000	2.852	0.634	0.000	0.000	0.000	0.000	0.000	2.621	0.000	0.000	0.000	0.000	0.000
305	25:20	0.000	0.000	2.852	0.634	0.000	0.000	0.000	0.000	0.000	2.621	0.000	0.000	0.000	0.000	0.000
306	25:25	0.000	0.000	2.852	0.634	0.000	0.000	0.000	0.000	0.000	2.621	0.000	0.000	0.000	0.000	0.000
307	25:30	0.000	0.000	2.852	0.634	0.000	0.000	0.000	0.000	0.000	2.621	0.000	0.000	0.000	0.000	0.000
308	25:35	0.000	0.000	2.852	0.634	0.000	0.000	0.000	0.000	0.000	2.621	0.000	0.000	0.000	0.000	0.000
309	25:40	0.000	0.000	2.852	0.634	0.000	0.000	0.000	0.000	0.000	2.621	0.000	0.000	0.000	0.000	0.000
310	25:45	0.000	0.000	2.852	0.634	0.000	0.000	0.000	0.000	0.000	2.621	0.000	0.000	0.000	0.000	0.000
311	25:50	0.000	0.000	2.852	0.634	0.000	0.000	0.000	0.000	0.000	2.621	0.000	0.000	0.000	0.000	0.000
312	25:55	0.000	0.000	2.852	0.634	0.000	0.000	0.000	0.000	0.000	2.621	0.000	0.000	0.000	0.000	0.000
313	26:00	0.000	0.000	2.852	0.634	0.000	0.000	0.000	0.000	0.000	2.621	0.000	0.000	0.000	0.000	0.000
314	26:05	0.000	0.000	2.852	0.634	0.000	0.000	0.000	0.000	0.000	2.621	0.000	0.000	0.000	0.000	0.000
315	26:10	0.000	0.000	2.852	0.634	0.000	0.000	0.000	0.000	0.000	2.621	0.000	0.000	0.000	0.000	0.000
316	26:15	0.000	0.000	2.852	0.634	0.000	0.000	0.000	0.000	0.000	2.621	0.000	0.000	0.000	0.000	0.000
317	26:20	0.000	0.000	2.852	0.634	0.000	0.000	0.000	0.000	0.000	2.621	0.000	0.000	0.000	0.000	0.000
318	26:25	0.000	0.000	2.852	0.634	0.000	0.000	0.000	0.000	0.000	2.621	0.000	0.000	0.000	0.000	0.000
319	26:30	0.000	0.000	2.852	0.634	0.000	0.000	0.000	0.000	0.000	2.621	0.000	0.000	0.000	0.000	0.000
320	26:35	0.000	0.000	2.852	0.634	0.000	0.000	0.000	0.000	0.000	2.621	0.000	0.000	0.000	0.000	0.000
321	26:40	0.000	0.000	2.852	0.634	0.000	0.000	0.000	0.000	0.000	2.621	0.000	0.000	0.000	0.000	0.000
322	26:45	0.000	0.000	2.852	0.634	0.000	0.000	0.000	0.000	0.000	2.621	0.000	0.000	0.000	0.000	0.000
323	26:50	0.000	0.000	2.852	0.634	0.000	0.000	0.000	0.000	0.000	2.621	0.000	0.000	0.000	0.000	0.000
324	26:55	0.000	0.000	2.852	0.634	0.000	0.000	0.000	0.000	0.000	2.621	0.000	0.000	0.000	0.000	0.000
325	27:00	0.000	0.000	2.852	0.634	0.000	0.000	0.000	0.000	0.000	2.621	0.000	0.000	0.000	0.000	0.000
326	27:05	0.000	0.000	2.852	0.634	0.000	0.000	0.000	0.000	0.000	2.621	0.000	0.000	0.000	0.000	0.000
327	27:10	0.000	0.000	2.852	0.634	0.000	0.000	0.000	0.000	0.000	2.621	0.000	0.000	0.000	0.000	0.000
328	27:15	0.000	0.000	2.852	0.634	0.000	0.000	0.000	0.000	0.000	2.621	0.000	0.000	0.000	0.000	0.000
329	27:20	0.000	0.000	2.852	0.634	0.000	0.000	0.000	0.000	0.000	2.621	0.000	0.000	0.000	0.000	0.000
330	27:25	0.000	0.000	2.852	0.634	0.000	0.000	0.000	0.000	0.000	2.621	0.000	0.000	0.000	0.000	0.000
331	27:30	0.000	0.000	2.852	0.634	0.000	0.000	0.000	0.000	0.000	2.621	0.000	0.000	0.000	0.000	0.000
332	27:35	0.000	0.000	2.852	0.634	0.000	0.000	0.000	0.000	0.000	2.621	0.000	0.000	0.000	0.000	0.000
333	27:40	0.000	0.000	2.852	0.634	0.000	0.000	0.000	0.000	0.000	2.621	0.000	0.000	0.000	0.000	0.000
334	27:45	0.000	0.000	2.852	0.634	0.000	0.000	0.000	0.000	0.000	2.621	0.000	0.000	0.000	0.000	0.000
335	27:50	0.000	0.000	2.852	0.634	0.000	0.000	0.000	0.000	0.000	2.621	0.000	0.000	0.000	0.000	0.000
336	27:55	0.000	0.000	2.852	0.634	0.000	0.000	0.000	0.000	0.000	2.621	0.000	0.000	0.000	0.000	0.000

APPENDIX B - EXAMPLE SBUH CALCULATIONS

Bioretention/FTP (Underdrain No Liner)

BMP Design Characteristics

BMP Area (sf):	1,000
Ponding Depth (ft):	0.5
Media Depth (ft):	1.5
Gravel Storage Depth (ft):	0.75
Height of Underdrain (ft):	0.167
Total Storage Volume (cf):	1,258
Sub-Underdrain Storage (cf):	68
Discharge Orifice (in):	1
Evapotranspiration Rate (in/hr):	0.0025
Infiltration Rate (in/hr):	0.20

Column	Description of Calculations
[18]	Pervious Design Flow to BMP [10]
[19]	Impervious Design Flow to BMP [16]
[20]	Pervious Flow [18] + Impervious Flow [19]
[21]	Total Flow [20] x (300 sec / 1 Time Step)
[22]	Incr. End Volume [27] from previous Time Step + Incr. Flow [21]
[23]	E/T Loss x (1 ft / 12 in) x BMP Area x (1 hr / 60 min) x (5 min / 1 Time Step) Provided Incr. Start Volume [22] > E/T Volume
[24]	Inf. Rate x (1 ft / 12 in) x BMP Area x (1 hr / 60 min) x (5 min / 1 Time Step) Provided Incr. Start Volume [22] - (E/T [23] + Discharge [25]) > Inf. Volume
[25]	Discharge Capacity (using orifice equation) x (300 sec / 1 Time Step)
[26]	Incr. Start Volume [22] - Total Storage Volume
[27]	Incr. Start Volume [22] - E/T [23] - Inf. [24] - Discharge [25] - Overflow [26]
[28]	Discharge [25] x (1 Time Step / 300 sec)
[29]	Incr. Overflow [27] x (1 Time Step / 300 sec)
[30]	Outflow [28] + Overflow [29]

Total Project Conditions Outflow

Column	Description of Calculations
[31]	Pervious Design Flow to CSS [11]
[32]	Impervious Design Flow to CSS [12]
[33]	Total BMP Outflow [30]
[34]	Pervious Direct Flow [31] + Impervious Direct Flow [32] + BMP Flow [33]

[1]	[18]	[19]	[20]	[21]	[22]	[23]	[24]	[25]	[26]	[27]	[28]	[29]	[30]	[31]	[32]	[33]	**[34]**
	Inflow to BMP			BMP Water Balance							Outflow from BMP			All Flows			
Time Step	Pervious Flow to BMP (cfs)	Impervious Flow to BMP (cfs)	Total Flow to BMP (cfs)	Incremental Flow Volume to BMP (cf)	Incremental Starting Volume (cf)	Incremental E/T Volume (cf)	Incremental Infiltration Volume cf	Incremental Discharge Volume (cf)	Incremental Overflow Volume (cf)	Incremental Ending Volume (cf)	Detained Outflow (cfs)	Overflow (cfs)	Total BMP Outflow (cfs)	Pervious Direct Flow to CSS (cfs)	Impervious Direct Flow to CSS (cfs)	BMP Flow to CSS (cfs)	**Total Outflow to CSS (cfs)**
1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
3	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
4	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
5	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
6	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
7	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
8	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
9	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
10	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
11	0.000	0.000	0.000	0.008	0.008	0.008	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
12	0.000	0.000	0.000	0.032	0.032	0.017	0.015	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
13	0.000	0.000	0.000	0.067	0.067	0.017	0.050	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
14	0.000	0.000	0.000	0.108	0.108	0.017	0.090	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
15	0.000	0.001	0.001	0.150	0.150	0.017	0.133	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.001
16	0.000	0.001	0.001	0.192	0.192	0.017	0.175	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.001
17	0.000	0.001	0.001	0.234	0.234	0.017	0.216	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.001
18	0.000	0.001	0.001	0.274	0.274	0.017	0.256	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.001
19	0.000	0.001	0.001	0.312	0.312	0.017	0.295	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.001
20	0.000	0.001	0.001	0.349	0.349	0.017	0.332	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.000	0.002
21	0.000	0.001	0.001	0.385	0.385	0.017	0.367	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.000	0.002
22	0.000	0.001	0.001	0.419	0.419	0.017	0.401	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.000	0.002
23	0.000	0.002	0.002	0.451	0.451	0.017	0.434	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.000	0.002
24	0.000	0.002	0.002	0.483	0.483	0.017	0.465	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.000	0.002
25	0.000	0.002	0.002	0.513	0.513	0.017	0.495	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.000	0.002
136	0.000	0.015	0.015	4.494	57.800	0.017	1.389	0.000	0.000	56.394	0.000	0.000	0.000	0.001	0.020	0.000	0.021
137	0.000	0.016	0.016	4.748	61.142	0.017	1.389	0.000	0.000	59.736	0.000	0.000	0.000	0.001	0.021	0.000	0.022
138	0.000	0.017	0.017	5.048	64.784	0.017	1.389	0.000	0.000	63.378	0.000	0.000	0.000	0.001	0.022	0.000	0.024
139	0.000	0.018	0.018	5.409	68.787	0.017	1.389	0.300	0.000	67.081	0.001	0.000	0.001	0.002	0.024	0.001	0.027
140	0.000	0.020	0.020	5.856	72.937	0.017	1.389	2.511	0.000	69.020	0.008	0.000	0.008	0.002	0.026	0.008	0.036
141	0.000	0.021	0.021	6.430	75.451	0.017	1.389	2.638	0.000	71.407	0.009	0.000	0.009	0.002	0.029	0.009	0.040
142	0.000	0.024	0.024	7.210	78.617	0.017	1.389	2.712	0.000	74.499	0.009	0.000	0.009	0.003	0.032	0.009	0.044
143	0.000	0.028	0.028	8.370	82.869	0.017	1.389	2.803	0.000	78.660	0.009	0.000	0.009	0.004	0.037	0.009	0.050
144	0.000	0.035	0.035	10.441	89.101	0.017	1.389	2.920	0.000	84.774	0.010	0.000	0.010	0.005	0.046	0.010	0.061
145	0.000	0.067	0.067	19.990	104.765	0.017	1.389	3.084	0.000	100.274	0.010	0.000	0.010	0.013	0.089	0.010	0.112
146	0.000	0.088	0.088	26.502	126.776	0.017	1.389	3.462	0.000	121.908	0.012	0.000	0.012	0.019	0.118	0.012	0.148
147	0.000	0.074	0.074	22.079	143.987	0.017	1.389	3.932	0.000	138.649	0.013	0.000	0.013	0.017	0.098	0.013	0.128
148	0.000	0.057	0.057	17.177	155.826	0.017	1.389	4.264	0.000	150.156	0.014	0.000	0.014	0.014	0.076	0.014	0.105
149	0.000	0.045	0.045	13.495	163.651	0.017	1.389	4.478	0.000	157.766	0.015	0.000	0.015	0.012	0.060	0.015	0.087
150	0.000	0.036	0.036	10.894	168.660	0.017	1.389	4.614	0.000	162.640	0.015	0.000	0.015	0.010	0.048	0.015	0.074
151	0.000	0.030	0.030	9.074	171.713	0.017	1.389	4.699	0.000	165.608	0.016	0.000	0.016	0.009	0.040	0.016	0.065
152	0.000	0.026	0.026	7.787	173.395	0.017	1.389	4.750	0.000	167.239	0.016	0.000	0.016	0.008	0.035	0.016	0.058
153	0.000	0.023	0.023	6.859	174.098	0.017	1.389	4.778	0.000	167.913	0.016	0.000	0.016	0.007	0.030	0.016	0.054
154	0.000	0.021	0.021	6.171	174.084	0.017	1.389	4.789	0.000	167.888	0.016	0.000	0.016	0.007	0.027	0.016	0.050
155	0.000	0.019	0.019	5.646	173.534	0.017	1.389	4.789	0.000	167.339	0.016	0.000	0.016	0.006	0.025	0.016	0.047
156	0.000	0.017	0.017	5.234	172.573	0.017	1.389	4.780	0.000	166.387	0.016	0.000	0.016	0.006	0.023	0.016	0.045
157	0.000	0.016	0.016	4.902	171.289	0.017	1.389	4.764	0.000	165.119	0.016	0.000	0.016	0.006	0.022	0.016	0.043
158	0.000	0.015	0.015	4.628	169.747	0.017	1.389	4.743	0.000	163.598	0.016	0.000	0.016	0.005	0.021	0.016	0.042
159	0.000	0.015	0.015	4.396	167.994	0.017	1.389	4.717	0.000	161.871	0.016	0.000	0.016	0.005	0.020	0.016	0.040
160	0.000	0.014	0.014	4.196	166.067	0.017	1.389	4.688	0.000	159.973	0.016	0.000	0.016	0.005	0.019	0.016	0.039
161	0.000	0.013	0.013	4.022	163.995	0.017	1.389	4.655	0.000	157.934	0.016	0.000	0.016	0.005	0.018	0.016	0.038
162	0.000	0.013	0.013	3.868	161.801	0.017	1.389	4.620	0.000	155.775	0.015	0.000	0.015	0.005	0.017	0.015	0.037
163	0.000	0.012	0.012	3.730	159.506	0.017	1.389	4.582	0.000	153.517	0.015	0.000	0.015	0.005	0.017	0.015	0.036
164	0.000	0.012	0.012	3.606	157.124	0.017	1.389	4.542	0.000	151.175	0.015	0.000	0.015	0.004	0.016	0.015	0.036
165	0.000	0.012	0.012	3.493	154.668	0.017	1.389	4.501	0.000	148.761	0.015	0.000	0.015	0.004	0.016	0.015	0.035
166	0.000	0.011	0.011	3.391	152.152	0.017	1.389	4.458	0.000	146.288	0.015	0.000	0.015	0.004	0.015	0.015	0.034
167	0.000	0.011	0.011	3.296	149.584	0.017	1.389	4.413	0.000	143.765	0.015	0.000	0.015	0.004	0.015	0.015	0.034
168	0.000	0.011	0.011	3.209	146.975	0.017	1.389	4.367	0.000	141.202	0.015	0.000	0.015	0.004	0.014	0.015	0.033
169	0.000	0.010	0.010	3.128	144.330	0.017	1.389	4.319	0.000	138.605	0.014	0.000	0.014	0.004	0.014	0.014	0.032
170	0.000	0.010	0.010	3.053	141.658	0.017	1.389	4.270	0.000	135.981	0.014	0.000	0.014	0.004	0.014	0.014	0.032
171	0.000	0.010	0.010	2.983	138.963	0.017	1.389	4.221	0.000	133.336	0.014	0.000	0.014	0.004	0.013	0.014	0.031
172	0.000	0.010	0.010	2.917	136.254	0.017	1.389	4.170	0.000	130.677	0.014	0.000	0.014	0.004	0.013	0.014	0.031
173	0.000	0.010	0.010	2.856	133.533	0.017	1.389	4.118	0.000	128.008	0.014	0.000	0.014	0.004	0.013	0.014	0.030
174	0.000	0.009	0.009	2.797	130.806	0.017	1.389	4.066	0.000	125.334	0.014	0.000	0.014	0.004	0.012	0.014	0.030
175	0.000	0.009	0.009	2.742	128.076	0.017	1.389	4.012	0.000	122.657	0.013	0.000	0.013	0.004	0.012	0.013	0.029
295	0.000	0.000	0.000	0.045	55.070	0.017	1.389	0.000	0.000	53.664	0.000	0.000	0.000	0.000	0.000	0.000	0.000
296	0.000	0.000	0.000	0.025	53.689	0.017	1.389	0.000	0.000	52.282	0.000	0.000	0.000	0.000	0.000	0.000	0.000
297	0.000	0.000	0.000	0.014	52.296	0.017	1.389	0.000	0.000	50.890	0.000	0.000	0.000	0.000	0.000	0.000	0.000
298	0.000	0.000	0.000	0.008	50.897	0.017	1.389	0.000	0.000	49.491	0.000	0.000	0.000	0.000	0.000	0.000	0.000
299	0.000	0.000	0.000	0.004	49.495	0.017	1.389	0.000	0.000	48.089	0.000	0.000	0.000	0.000	0.000	0.000	0.000
300	0.000	0.000	0.000	0.002	48.091	0.017	1.389	0.000	0.000	46.685	0.000	0.000	0.000	0.000	0.000	0.000	0.000
301	0.000	0.000	0.000	0.000	46.686	0.017	1.389	0.000	0.000	45.280	0.000	0.000	0.000	0.000	0.000	0.000	0.000
302	0.000	0.000	0.000	0.000	45.281	0.017	1.389	0.000	0.000	43.874	0.000	0.000	0.000	0.000	0.000	0.000	0.000
303	0.000	0.000	0.000	0.000	43.875	0.017	1.389	0.000	0.000	42.468	0.000	0.000	0.000	0.000	0.000	0.000	0.000
304	0.000	0.000	0.000	0.000	42.469	0.017	1.389	0.000	0.000	41.062	0.000	0.000	0.000	0.000	0.000	0.000	0.000
305	0.000	0.000	0.000	0.000	41.063	0.017	1.389	0.000	0.000	39.656	0.000	0.000	0.000	0.000	0.000	0.000	0.000
306	0.000	0.000	0.000	0.000	39.656	0.017	1.389	0.000	0.000	38.250	0.000	0.000	0.000	0.000	0.000	0.000	0.000
307	0.000	0.000	0.000	0.000	38.250	0.017	1.389	0.000	0.000	36.844	0.000	0.000	0.000	0.000	0.000	0.000	0.000
308	0.000	0.000	0.000	0.000	36.844	0.017	1.389	0.000	0.000	35.438	0.000	0.000	0.000	0.000	0.000	0.000	0.000
309	0.000	0.000	0.000	0.000	35.438	0.017	1.389	0.000	0.000	34.031	0.000	0.000	0.000	0.000	0.000	0.000	0.000
310	0.000	0.000	0.000	0.000	34.031	0.017	1.389	0.000	0.000	32.625	0.000	0.000	0.000	0.000	0.000	0.000	0.000
311	0.000	0.000	0.000	0.000	32.625	0.017	1.389	0.000	0.000	31.219	0.000	0.000	0.000	0.000	0.000	0.000	0.000
312	0.000	0.000	0.000	0.000	31.219	0.017	1.389	0.000	0.000	29.813	0.000	0.000	0.000	0.000	0.000	0.000	0.000
313	0.000	0.000	0.000	0.000	29.813	0.017	1.389	0.000	0.000	28.406	0.000	0.000	0.000	0.000	0.000	0.000	0.000
314	0.000	0.000	0.000	0.000	28.406	0.017	1.389	0.000	0.000	27.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
315	0.000	0.000	0.000	0.000	27.000	0.017	1.389	0.000	0.000	25.594	0.000	0.000	0.000	0.000	0.000	0.000	0.000
316	0.000	0.000	0.000	0.000	25.594	0.017	1.389	0.000	0.000	24.188	0.000	0.000	0.000	0.000	0.000	0.000	0.000
317	0.000	0.000	0.000	0.000	24.188	0.017	1.389	0.000	0.000	22.781	0.000	0.000	0.000	0.000	0.000	0.000	0.000
318	0.000	0.000	0.000	0.000	22.781	0.017	1.389	0.000	0.000	21.375	0.000	0.000	0.000	0.000	0.000	0.000	0.000
319	0.000	0.000	0.000	0.000	21.375	0.017	1.389	0.000	0.000	19.969	0.000	0.000	0.000	0.000	0.000	0.000	0.000
320	0.000	0.000	0.000	0.000	19.969	0.017	1.389	0.000	0.000	18.563	0.000	0.000	0.000	0.000	0.000	0.000	0.000
321	0.000	0.000	0.000	0.000	18.563	0.017	1.389	0.000	0.000	17.156	0.000	0.000	0.000	0.000	0.000	0.000	0.000
322	0.000	0.000	0.000	0.000	17.156	0.017	1.389	0.000	0.000	15.750	0.000	0.000	0.000	0.000	0.000	0.000	0.000
323	0.000	0.000	0.000	0.000	15.750	0.017	1.389	0.000	0.000	14.344	0.000	0.000	0.000	0.000	0.000	0.000	0.000
324	0.000	0.000	0.000	0.000	14.344	0.017	1.389	0.000	0.000	12.938	0.000	0.000	0.000	0.000	0.000	0.000	0.000
325	0.000	0.000	0.000	0.000	12.938	0.017	1.389	0.000	0.000	11.531	0.000	0.000	0.000	0.000	0.000	0.000	0.000
326	0.000	0.000	0.000	0.000	11.531	0.017	1.389	0.000	0.000	10.125	0.000	0.000	0.000	0.000	0.000	0.000	0.000
327	0.000	0.000	0.000	0.000	10.125	0.017	1.389	0.000	0.000	8.719	0.000	0.000	0.000	0.000	0.000	0.000	0.000
328	0.000	0.000	0.000	0.000	8.719	0.017	1.389	0.000	0.000	7.313	0.000	0.000	0.000	0.000	0.000	0.000	0.000
329	0.000	0.000	0.000	0.000	7.313	0.017	1.389	0.000	0.000	5.906	0.000	0.000	0.000	0.000	0.000	0.000	0.000
330	0.000	0.000	0.000	0.000	5.906	0.017	1.389	0.000	0.000	4.500	0.000	0.000	0.000	0.000	0.000	0.000	0.000
331	0.000	0.000	0.000	0.000	4.500	0.017	1.389	0.000	0.000	3.094	0.000	0.000	0.000	0.000	0.000	0.000	0.000
332	0.000	0.000	0.000	0.000	3.094	0.017	1.389	0.000	0.000	1.688	0.000	0.000	0.000	0.000	0.000	0.000	0.000
333	0.000	0.000	0.000	0.000	1.688	0.017	1.389	0.000	0.000	0.281	0.000	0.000	0.000	0.000	0.000	0.000	0.000
334	0.000	0.000	0.000	0.000	0.281	0.017	0.264	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
335	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
336	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000