# Appendix A. Stormwater Design Methodologies

This appendix describes many of the methodologies and assumptions used in establishing standards for the various design approaches.

# A.1 Santa Barbara Urban Hydrograph Method

The Santa Barbara Urban Hydrograph (SBUH) method was developed by the Santa Barbara County Flood Control and Water Conservation District to determine a runoff hydrograph for an urbanized area. It is a simpler method than some other approaches, as it computes a hydrograph directly without going through intermediate steps (i.e., a unit hydrograph) to determine the runoff hydrograph.

The SBUH method is a popular method for calculating runoff, since it can be done with a spreadsheet or by hand relatively easily. The SBUH method is the method approved by the Bureau of Environmental Services (BES) for determining runoff when doing flow control calculations.

## Elements of the SBUH Method

The SBUH method depends on several variables:

- Pervious ($A_p$) and impervious ($A_{imp}$) land areas
- Time of concentration ($T_c$) calculations
- Runoff curve numbers (CN) applicable to the site
- Design storm

These elements shall all be presented as part of the submittal process for review by BES staff. In addition, maps showing the pre-development and post-development conditions shall be presented to BES to help in the review.

### Land Area

The total area, including the pervious and impervious areas within a drainage basin, shall be quantified in order to evaluate critical contributing areas and the resulting site runoff. Each area within a basin shall be analyzed separately and their hydrographs combined to determine the total basin hydrograph. Areas shall be selected to represent homogenous land use/development units.

### Time of Concentration

Time of concentration, $T_c$, is the time for a theoretical drop of water to travel from the furthest point in the drainage basin to the facility being designed. (In this case, $T_c$ is derived by calculating the overland flow time of concentration and the channelized flow time of concentration.) $T_c$ depends on several factors, including ground slope, ground roughness, and distance of flow. The following formula for determining $T_c$ is found in BES's *Sewer and Drainage Facilities Design Manual*.

### Formulas

$$T_c = T_{t1} + T_{c2} + T_{c3} + \cdots + T_{cn}$$

$T_t = L/60V$ (Conversion of velocity to travel time)

$T_t = \frac{0.42(nL)^{0.8}}{1.58(s)^{0.4}}$ (Manning's kinematic solution for sheet flow less than 300 feet

Shallow concentrated flow for slopes less than 0.005 ft/ft. (For steeper slopes, consult *Sewer and Drainage Facilities Design Manual*):

$V = 16.1345(s)^{0.5}$ (Unpaved surfaces)

$V = 20.3282(s)^{0.5}$ (Paved surfaces)

Where,

$T_t$ = travel time, minutes

$T_c$ = total time of concentration, minutes (minimum Tc = 5 minutes)

L = flow length, feet

V = average velocity of flow, feet per second

n = Manning's roughness coefficient for various surfaces (see *Sewer and Drainage Facilities Design Manual*)

s = slope of the hydraulic grade line (land or watercourse), feet per foot

When calculating $T_c$, the following limitations apply:

- Overland sheet flow (flow across flat areas that does not form into channels or rivulets) shall not extend for more than 300 feet.
- For flow paths through closed conveyance facilities such as pipes and culverts, standard hydraulic formulas shall be used for establishing velocity and travel time. (See the *Sewer and Drainage Facilities Design Manual* for more data on pipe flow rates and velocities.)
- Flow paths through lakes or wetlands may be assumed to be zero (i.e. $T_c$ = 0).

### Runoff Curve Numbers

Runoff curve numbers were developed by the Natural Resources Conservation Service (NRCS) after studying the runoff characteristics of various types of land.

Curve numbers (CN) were developed to reduce diverse characteristics such as soil type, land usage, and vegetation into a single variable for doing runoff calculations. The runoff curve numbers approved by BES for water quantity/quality calculations are included as Table A-2, Table A-3, and Table A-4 of this appendix.

The curve numbers presented in Table A-2,A-3 and Table A-4 are for wet antecedent moisture conditions.  Wet conditions assume previous rainstorms have reduced the capacity of soil to absorb water.  Given the frequency of rainstorms in the Portland area, wet conditions are most likely, and give conservative hydrographic values. Hydrologic soil group descriptions references in Tables A-2, A-3 and A-4 are found in Table A-5.

## Design Storm

The SBUH method also requires a design storm to perform the runoff calculations. For flow control calculations, BES uses a NRCS Type 1A 24-hour storm distribution. This storm is shown in Table A-1 and Figure A-1.  The depth of rainfall for the 2 through 100-year storm events is shown below in Table A-1.

**Table A-1. 24-Hour Rainfall Depths at Portland Airport**

| Reoccurrence Interval (Years) | 24-Hour Depth (Inches) |
|---|---|
| **2** | 2.4 |
| **5** | 2.9 |
| **10** | 3.4 |
| **25** | 3.9 |
| **100** | 4.4 |

**Table A-2. Curve Numbers for Urban Areas**

| Cover type and hydrological condition | Average percent impervious area | Curve Numbers by Hydrologic Soil Group | | | |
|---|---|---|---|---|---|
| | | A | B | C | D |
| **Open Space (lawns, parks, golf courses, cemeteries, etc.):** | | | | | |
| **Poor condition (grass cover <50%)** | | 68 | 79 | 86 | 89 |
| **Fair condition (grass cover 50-75%)** | | 49 | 69 | 79 | 84 |
| **Good condition (grass cover >75%)** | | 39 | 61 | 74 | 80 |
| **Impervious Area:** | | | | | |
| **Paved parking lots, roofs, driveways, etc. (excluding right-of-way)** | | 98 | 98 | 98 | 98 |
| **Streets and roads:** | | | | | |
| **Paved; curbs and storm sewers (excluding right-of-way)** | | 98 | 98 | 98 | 98 |
| **Paved; open ditches (including right-of-way)** | | 83 | 89 | 92 | 93 |
| **Gravel (including right-of-way)** | | 76 | 85 | 89 | 91 |
| **Dirt (including right-of-way)** | | 72 | 82 | 87 | 93 |
| **Urban Districts:** | | | | | |
| **Commercial and business** | 85 | 85 | 92 | 94 | 95 |
| **Industrial** | 72 | 81 | 88 | 91 | 93 |
| **Residential districts by average lot size:** | | | | | |
| **1/8 acre or less (town houses)** | 65 | 77 | 85 | 90 | 82 |
| **1/4 acre** | 38 | 61 | 75 | 83 | 87 |
| **1/3 acre** | 30 | 57 | 72 | 81 | 86 |
| **1/2 acre** | 25 | 54 | 70 | 80 | 85 |
| **1 acre** | 20 | 51 | 68 | 79 | 84 |
| **2 acres** | 12 | 46 | 65 | 77 | 82 |

Soil Conservation Service, Urban Hydrology for Small Watersheds, Technical Release 55, pp. 2.5-2.8, June 1986.

## Table A-3. Runoff Curve Numbers for Other Agricultural Lands

| Cover type and hydrological condition | Hydrologic Condition | Curve Numbers by Hydrologic Soil Group | | | |
|---|---|---|---|---|---|
| | | A | B | C | D |
| **Pasture, grassland, or range-continuous forage for grazing:** | | | | | |
| **<50% ground cover or heavily grazed with no mulch** | Poor | 68 | 79 | 86 | 89 |
| **50 to 75% ground cover and not heavily grazed** | Fair | 49 | 69 | 79 | 84 |
| **>75% ground cover and lightly or only occasionally grazed** | Good | 39 | 61 | 74 | 80 |
| **Meadow-continuous grass, protected from grazing and generally mowed for hay** | | 30 | 58 | 71 | 78 |
| **Brush-weed-grass mixture with brush as the major element:** | | | | | |
| **<50% ground cover** | Poor | 48 | 67 | 77 | 83 |
| **50-75% ground cover** | Fair | 35 | 56 | 70 | 77 |
| **>75% ground cover** | Good | 30 | 48 | 65 | 73 |
| **Woods-grass combination (orchard or tree farm)** | Poor | 57 | 73 | 82 | 86 |
| | Fair | 43 | 65 | 76 | 82 |
| | Good | 32 | 58 | 72 | 79 |
| **Woods** | | | | | |
| **Forest litter, small trees, and brush are destroyed by heavy grazing or regular burning** | Poor | 45 | 66 | 77 | 83 |
| **Woods are grazed by not burned, and some forest litter covers the soil** | Fair | 36 | 60 | 73 | 79 |
| **Woods are protected from grazing and litter and brush adequately cover the soil** | Good | 30 | 55 | 70 | 77 |

Soil Conservation Service, Urban Hydrology for Small Watersheds, Technical Release 55, pp. 2.5-2.8, June 1986.

### Table A-4. Runoff Curve Numbers for Stormwater Facilities Designed Under the Simplified Approach

| Stormwater Facility Type | Hydrologic Condition | Curve Numbers by Hydrologic Soil Group | | | |
|---|---|---|---|---|---|
| | | A | B | C | D |
| **Ecoroof** | Good | n/a | 61 | n/a | n/a |
| **Planter** | Good | n/a | 48 | n/a | n/a |
| **Pervious Pavement** | n/a | 76 | 85 | 89 | n/a |
| **Trees (new or existing)** | n/a | 36 | 60 | 73 | 79 |

n/a - Does not apply, as design criteria for the relevant mitigation measures do not include the use of this soil type.

**CNs of various cover types were assigned to the Simplified Approaches with similar cover types as follows:

Eco-roof – assumed grass in good condition with soil type B.

Planter – assumed brush-weed-grass mixture with >75% ground cover and soil type B.

Pervious Pavement – assumed gravel.

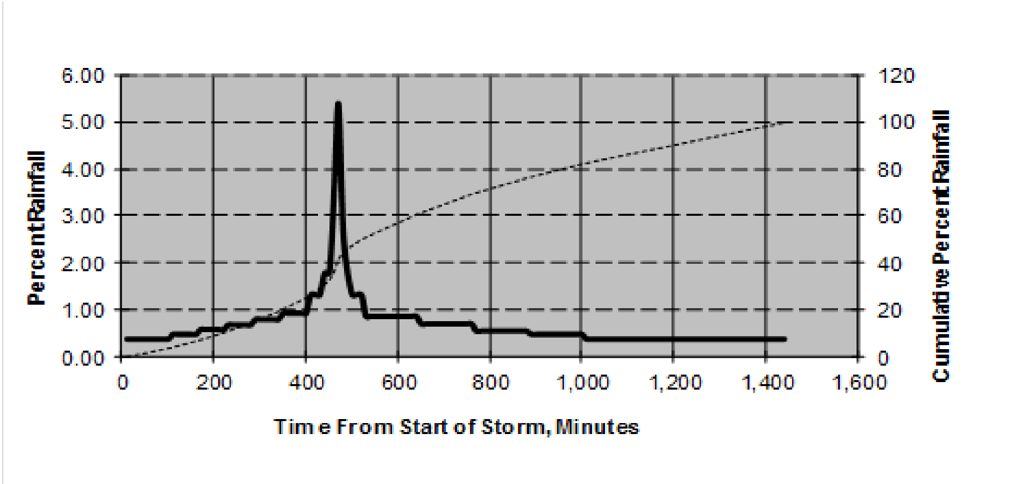
Trees – assumed woods with fair hydrologic conditions.

**Table A-5. NRCS Hydrologic Soil Group Descriptions**

| NRCS Hydrologic Soil Group | Description |
|---|---|
| **Group A** | Soils having a high infiltration rate (low runoff potential) when thoroughly wet. These consist chiefly of deep, well drained to excessively drained sands or gravels. These soils have a high rate of water transmission. |
| **Group B** | Soils having a moderate infiltration rate when thoroughly wet. These consist chiefly of moderately deep or deep, moderately well drained or well drained soils that have moderately fine texture to moderately coarse texture. These soils have a moderate rate of water transmission. |
| **Group C** | Soils having a slow infiltration rate when thoroughly wet. These consist chiefly of soils that have a layer that impedes the downward movement of water or soils that have moderately fine texture or fine texture. These soils have a slow rate of water transmission. |
| **Group D** | Soils having a very slow infiltration rate (high runoff potential) when thoroughly wet. These consist chiefly of clay soils that have a high shrink-swell potential, soils that have a permanent high water table, soils that have a fragipan or clay layer at or near the surface, and soils that are shallow over nearly impervious material. These soils have a very slow rate of water transmission. |

To determine hydrologic soil type, consult local USDA Soil Conservation Service Soil Survey.

## Figure A-1. NRCS 24-Hour Type 1A Hyetograph




NRCS Type 1A Hyetographic Distrubution - For Use In Water Quality/Quantity Design

| Time From Start of Storm, Minutes | % Rainfall | Cumulative % Rainfall | Time From Start of Storm, Minutes | % Rainfall | Cumulative % Rainfall | Time From Start of Storm, Minutes | % Rainfall | Cumulative % Rainfall | Time From Start of Storm, Minutes | % Rainfall | Cumulative % Rainfall |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 - 10 | 0.40 | 0.40 | 360 - 370 | 0.95 | 22.57 | 720 - 730 | 0.72 | 67.40 | 1080 - 1090 | 0.40 | 86.00 |
| 10 - 20 | 0.40 | 0.80 | 370 - 380 | 0.95 | 23.52 | 730 - 740 | 0.72 | 68.12 | 1090 - 1100 | 0.40 | 86.40 |
| 20 - 30 | 0.40 | 1.20 | 380 - 390 | 0.95 | 24.47 | 740 - 750 | 0.72 | 68.84 | 1100 - 1110 | 0.40 | 86.80 |
| 30 - 40 | 0.40 | 1.60 | 390 - 400 | 0.95 | 25.42 | 750 - 760 | 0.72 | 69.56 | 1110 - 1120 | 0.40 | 87.20 |
| 40 - 50 | 0.40 | 2.00 | 400 - 410 | 1.34 | 26.76 | 760 - 770 | 0.57 | 70.13 | 1120 - 1130 | 0.40 | 87.60 |
| 50 - 60 | 0.40 | 2.40 | 410 - 420 | 1.34 | 28.10 | 770 - 780 | 0.57 | 70.70 | 1130 - 1140 | 0.40 | 88.00 |
| 60 - 70 | 0.40 | 2.80 | 420 - 430 | 1.34 | 29.44 | 780 - 790 | 0.57 | 71.27 | 1140 - 1150 | 0.40 | 88.40 |
| 70 - 80 | 0.40 | 3.20 | 430 - 440 | 1.80 | 31.24 | 790 - 800 | 0.57 | 71.84 | 1150 - 1160 | 0.40 | 88.80 |
| 80 - 90 | 0.40 | 3.60 | 440 - 450 | 1.80 | 33.04 | 800 - 810 | 0.57 | 72.41 | 1160 - 1170 | 0.40 | 89.20 |
| 90 - 100 | 0.40 | 4.00 | 450 - 460 | 3.40 | 36.44 | 810 - 820 | 0.57 | 72.98 | 1170 - 1180 | 0.40 | 89.60 |
| 100 - 110 | 0.50 | 4.50 | 460 - 470 | 5.40 | 41.84 | 820 - 830 | 0.57 | 73.55 | 1180 - 1190 | 0.40 | 90.00 |
| 110 - 120 | 0.50 | 5.00 | 470 - 480 | 2.70 | 44.54 | 830 - 840 | 0.57 | 74.12 | 1190 - 1200 | 0.40 | 90.40 |
| 120 - 130 | 0.50 | 5.50 | 480 - 490 | 1.80 | 46.34 | 840 - 850 | 0.57 | 74.69 | 1200 - 1210 | 0.40 | 90.80 |
| 130 - 140 | 0.50 | 6.00 | 490 - 500 | 1.34 | 47.68 | 850 - 860 | 0.57 | 75.26 | 1210 - 1220 | 0.40 | 91.20 |
| 140 - 150 | 0.50 | 6.50 | 500 - 510 | 1.34 | 49.02 | 860 - 870 | 0.57 | 75.83 | 1220 - 1230 | 0.40 | 91.60 |
| 150 - 160 | 0.50 | 7.00 | 510 - 520 | 1.34 | 50.36 | 870 - 880 | 0.57 | 76.40 | 1230 - 1240 | 0.40 | 92.00 |
| 160 - 170 | 0.60 | 7.60 | 520 - 530 | 0.88 | 51.24 | 880 - 890 | 0.50 | 76.90 | 1240 - 1250 | 0.40 | 92.40 |
| 170 - 180 | 0.60 | 8.20 | 530 - 540 | 0.88 | 52.12 | 890 - 900 | 0.50 | 77.40 | 1250 - 1260 | 0.40 | 92.80 |
| 180 - 190 | 0.60 | 8.80 | 540 - 550 | 0.88 | 53.00 | 900 - 910 | 0.50 | 77.90 | 1260 - 1270 | 0.40 | 93.20 |
| 190 - 200 | 0.60 | 9.40 | 550 - 560 | 0.88 | 53.88 | 910 - 920 | 0.50 | 78.40 | 1270 - 1280 | 0.40 | 93.60 |
| 200 - 210 | 0.60 | 10.00 | 560 - 570 | 0.88 | 54.76 | 920 - 930 | 0.50 | 78.90 | 1280 - 1290 | 0.40 | 94.00 |
| 210 - 220 | 0.60 | 10.60 | 570 - 580 | 0.88 | 55.64 | 930 - 940 | 0.50 | 79.40 | 1290 - 1300 | 0.40 | 94.40 |
| 220 - 230 | 0.70 | 11.30 | 580 - 590 | 0.88 | 56.52 | 940 - 950 | 0.50 | 79.90 | 1300 - 1310 | 0.40 | 94.80 |
| 230 - 240 | 0.70 | 12.00 | 590 - 600 | 0.88 | 57.40 | 950 - 960 | 0.50 | 80.40 | 1310 - 1320 | 0.40 | 95.20 |
| 240 - 250 | 0.70 | 12.70 | 600 - 610 | 0.88 | 58.28 | 960 - 970 | 0.50 | 80.90 | 1320 - 1330 | 0.40 | 95.60 |
| 250 - 260 | 0.70 | 13.40 | 610 - 620 | 0.88 | 59.16 | 970 - 980 | 0.50 | 81.40 | 1330 - 1340 | 0.40 | 96.00 |
| 260 - 270 | 0.70 | 14.10 | 620 - 630 | 0.88 | 60.04 | 980 - 990 | 0.50 | 81.90 | 1340 - 1350 | 0.40 | 96.40 |
| 270 - 280 | 0.70 | 14.80 | 630 - 640 | 0.88 | 60.92 | 990 - 1000 | 0.50 | 82.40 | 1350 - 1360 | 0.40 | 96.80 |
| 280 - 290 | 0.82 | 15.62 | 640 - 650 | 0.72 | 61.64 | 1000 - 1010 | 0.40 | 82.80 | 1360 - 1370 | 0.40 | 97.20 |
| 290 - 300 | 0.82 | 16.44 | 650 - 660 | 0.72 | 62.36 | 1010 - 1020 | 0.40 | 83.20 | 1370 - 1380 | 0.40 | 97.60 |
| 300 - 310 | 0.82 | 17.26 | 660 - 670 | 0.72 | 63.08 | 1020 - 1030 | 0.40 | 83.60 | 1380 - 1390 | 0.40 | 98.00 |
| 310 - 320 | 0.82 | 18.08 | 670 - 680 | 0.72 | 63.80 | 1030 - 1040 | 0.40 | 84.00 | 1390 - 1400 | 0.40 | 98.40 |
| 320 - 330 | 0.82 | 18.90 | 680 - 690 | 0.72 | 64.52 | 1040 - 1050 | 0.40 | 84.40 | 1400 - 1410 | 0.40 | 98.80 |
| 330 - 340 | 0.82 | 19.72 | 690 - 700 | 0.72 | 65.24 | 1050 - 1060 | 0.40 | 84.80 | 1410 - 1420 | 0.40 | 99.20 |
| 340 - 350 | 0.95 | 20.67 | 700 - 710 | 0.72 | 65.96 | 1060 - 1070 | 0.40 | 85.20 | 1420 - 1430 | 0.40 | 99.60 |
| 350 - 360 | 0.95 | 21.62 | 710 - 720 | 0.72 | 66.68 | 1070 - 1080 | 0.40 | 85.60 | 1430 - 1440 | 0.40 | 100.00 |

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## A.2 Simplified Approach Sizing Calculations

BES staff conducted a technical process to determine facility designs and sizes that would be appropriate for small development sites. The process included a review of technical literature, review of BES monitoring data, calculations, and theoretical analysis. The sizing factors on the Simplified Form were developed as a simple site planning tool for small projects and to accelerate permit review and approval. Generalized assumptions were used and are documented in the Simplified Sizing requirements in Section 2.2. Facilities sized through this approach assume that there is an overflow to an approved discharge point. Facilities built to the standards of Simplified Sizing are assumed to meet pollution reduction and flow control requirements but not infiltration and discharge requirements. Applicants have the option to use the sizing factors provided on the Simplified Approach Form or to follow the Presumptive or Performance Approach and submit an alternative facility size, along with supporting engineering or PAC calculations for BES review and consideration.

**Table A-6. Simplified Sizing Spreadsheet Column Descriptions**

| Column | Description |
|---|---|
| **Column (1)** | Time in Minutes |
| **Column (2)** | Inflow (cfs)<br>Note: Contributing Impervious area = 1 acre<br>Note: 10-year storm event (3.4"/24 hours) |
| **Column (3)** | Inflow volume (cf) = Inflow (cfs) x 60 (sec/min) x 10 (min) |
| **Column (4)** | Cumulative Volume (cf) = Inflow volume (cf) + Inflow of previous step (cf) |
| **Column (5)** | Infiltration (cfs) = If(Inflow<Max infiltration, Inflow, Maximum Infiltration) |
| **Column (6)** | Maximum Infiltration (cfs) = Infiltration area (sf) x Infiltration rate (ft/s)<br>Note: Infiltration rate is assumed to be 2.00"/hr |
| **Column (7)** | Incremental Storage (cf) = [Inflow(cfs) – Infiltration (cfs)] x 60 (sec/min) x 10 (min) |
| **Column (8)** | Cumulative Storage (cf) |
| **Column (9)** | Percentage Storage Capacity = Cumulative Storage/Facility Storage x 100<br><br>Planter Facility Storage = Facility Bottom Area (sf) x Storage Depth (ft)<br>Note: Bottom Area = 2,825<br>Note: Storage Depth = 1 ft<br>Storage capacity does not exceed 100% and the maximum depth of 12 inches is not exceeded. Facility sizing does not result in an overflow condition.<br><br>Planter sizing divided by impervious area equals a 0.065 sizing factor. |

## Table A-7. Simplified Sizing Spreadsheet

| (1) Time (minutes) | (2) Inflow (cfs) | (3) Inflow Volume (cf) | (4) Cummulative Volume (cf) | (5) Infiltration (cfs) | (6) Max. Infiltration (cfs) | (7) Incremental Storage (cf) | (8) Cummulative Storage Volume (cf) | (9) % Storage Capacity (%) |
|---|---|---|---|---|---|---|---|---|
| 0 | 0.0000 | 0.00 | 0.00 | 0.0000 | 0.1308 | -78.47 | 0.00 | 0% |
| 10 | 0.0000 | 0.00 | 0.00 | 0.0000 | 0.1308 | -78.47 | 0.00 | 0% |
| 20 | 0.0000 | 0.00 | 0.00 | 0.0000 | 0.1308 | -78.47 | 0.00 | 0% |
| 30 | 0.0000 | 0.00 | 0.00 | 0.0000 | 0.1308 | -78.47 | 0.00 | 0% |
| 40 | 0.0026 | 1.54 | 1.54 | 0.0026 | 0.1308 | -76.93 | 0.00 | 0% |
| 50 | 0.0097 | 5.80 | 7.34 | 0.0097 | 0.1308 | -72.67 | 0.00 | 0% |
| 60 | 0.0180 | 10.79 | 18.13 | 0.0180 | 0.1308 | -67.68 | 0.00 | 0% |
| 70 | 0.0249 | 14.97 | 33.10 | 0.0249 | 0.1308 | -63.50 | 0.00 | 0% |
| 80 | 0.0308 | 18.50 | 51.60 | 0.0308 | 0.1308 | -59.97 | 0.00 | 0% |
| 90 | 0.0359 | 21.52 | 73.12 | 0.0359 | 0.1308 | -56.95 | 0.00 | 0% |
| 100 | 0.0402 | 24.11 | 97.24 | 0.0402 | 0.1308 | -54.36 | 0.00 | 0% |
| 110 | 0.0499 | 29.94 | 127.17 | 0.0499 | 0.1308 | -48.54 | 0.00 | 0% |
| 120 | 0.0599 | 35.94 | 163.11 | 0.0599 | 0.1308 | -42.53 | 0.00 | 0% |
| 130 | 0.0642 | 38.51 | 201.62 | 0.0642 | 0.1308 | -39.96 | 0.00 | 0% |
| 140 | 0.0679 | 40.71 | 242.33 | 0.0679 | 0.1308 | -37.76 | 0.00 | 0% |
| 150 | 0.0710 | 42.61 | 284.95 | 0.0710 | 0.1308 | -35.86 | 0.00 | 0% |
| 160 | 0.0738 | 44.27 | 329.22 | 0.0738 | 0.1308 | -34.20 | 0.00 | 0% |
| 170 | 0.0841 | 50.43 | 379.65 | 0.0841 | 0.1308 | -28.04 | 0.00 | 0% |
| 180 | 0.0944 | 56.66 | 436.31 | 0.0944 | 0.1308 | -21.81 | 0.00 | 0% |
| 190 | 0.0971 | 58.24 | 494.55 | 0.0971 | 0.1308 | -20.24 | 0.00 | 0% |
| 200 | 0.0993 | 59.60 | 554.15 | 0.0993 | 0.1308 | -18.87 | 0.00 | 0% |
| 210 | 0.1013 | 60.80 | 614.95 | 0.1013 | 0.1308 | -17.67 | 0.00 | 0% |
| 220 | 0.1031 | 61.85 | 676.81 | 0.1031 | 0.1308 | -16.62 | 0.00 | 0% |
| 230 | 0.1135 | 68.10 | 744.90 | 0.1135 | 0.1308 | -10.38 | 0.00 | 0% |
| 240 | 0.1239 | 74.37 | 819.27 | 0.1239 | 0.1308 | -4.11 | 0.00 | 0% |
| 250 | 0.1256 | 75.35 | 894.62 | 0.1256 | 0.1308 | -3.12 | 0.00 | 0% |
| 260 | 0.1270 | 76.22 | 970.83 | 0.1270 | 0.1308 | -2.26 | 0.00 | 0% |
| 270 | 0.1283 | 76.99 | 1047.82 | 0.1283 | 0.1308 | -1.49 | 0.00 | 0% |
| 280 | 0.1294 | 77.67 | 1125.49 | 0.1294 | 0.1308 | -0.80 | 0.00 | 0% |
| 290 | 0.1417 | 85.04 | 1210.53 | 0.1308 | 0.1308 | 6.57 | 6.57 | 0% |
| 300 | 0.1541 | 92.45 | 1302.98 | 0.1308 | 0.1308 | 13.98 | 20.55 | 1% |
| 310 | 0.1552 | 93.11 | 1396.09 | 0.1308 | 0.1308 | 14.64 | 35.19 | 1% |
| 320 | 0.1562 | 93.70 | 1489.79 | 0.1308 | 0.1308 | 15.23 | 50.42 | 2% |
| 330 | 0.1571 | 94.23 | 1584.03 | 0.1308 | 0.1308 | 15.76 | 66.18 | 2% |
| 340 | 0.1578 | 94.71 | 1678.73 | 0.1308 | 0.1308 | 16.23 | 82.41 | 3% |
| 350 | 0.1712 | 102.71 | 1781.44 | 0.1308 | 0.1308 | 24.24 | 106.65 | 4% |
| 360 | 0.1845 | 110.73 | 1892.17 | 0.1308 | 0.1308 | 32.26 | 138.90 | 5% |
| 370 | 0.1853 | 111.19 | 2003.36 | 0.1308 | 0.1308 | 32.72 | 171.62 | 6% |
| 380 | 0.1860 | 111.60 | 2114.96 | 0.1308 | 0.1308 | 33.13 | 204.75 | 7% |
| 390 | 0.1866 | 111.98 | 2226.94 | 0.1308 | 0.1308 | 33.50 | 238.26 | 8% |
| 400 | 0.1872 | 112.31 | 2339.25 | 0.1308 | 0.1308 | 33.84 | 272.10 | 10% |
| 410 | 0.2263 | 135.80 | 2475.06 | 0.1308 | 0.1308 | 57.33 | 329.43 | 12% |
| 420 | 0.2657 | 159.39 | 2634.45 | 0.1308 | 0.1308 | 80.92 | 410.35 | 15% |
| 430 | 0.2664 | 159.87 | 2794.32 | 0.1308 | 0.1308 | 81.40 | 491.75 | 17% |
| 440 | 0.3131 | 187.88 | 2982.20 | 0.1308 | 0.1308 | 109.41 | 601.16 | 21% |
| 450 | 0.3600 | 215.98 | 3198.18 | 0.1308 | 0.1308 | 137.51 | 738.66 | 26% |
| 460 | 0.5219 | 313.11 | 3511.29 | 0.1308 | 0.1308 | 234.64 | 973.31 | 34% |
| 470 | 0.8866 | 531.96 | 4043.26 | 0.1308 | 0.1308 | 453.49 | 1426.80 | 51% |
| 480 | 0.8183 | 491.00 | 4534.26 | 0.1308 | 0.1308 | 412.53 | 1839.32 | 65% |

## Table A-7, continued

| (1)<br>Time<br>(minutes) | (2)<br>Inflow<br>(cfs) | (3)<br>Inflow Volume<br>(cf) | (4)<br>Cummulative Volume<br>(cf) | (5)<br>Infiltration<br>(cfs) | (6)<br>Max. Infiltration<br>(cfs) | (7)<br>Incremental Storage<br>(cf) | (8)<br>Cummulative Storage Volume<br>(cf) | (9)<br>% Storage Capacity<br>(%) |
|---|---|---|---|---|---|---|---|---|
| 490 | 0.4558 | 273.50 | 4807.76 | 0.1308 | 0.1308 | 195.03 | 2034.35 | 72% |
| 500 | 0.3185 | 191.07 | 4998.83 | 0.1308 | 0.1308 | 112.60 | 2146.95 | 76% |
| 510 | 0.2720 | 163.22 | 5162.05 | 0.1308 | 0.1308 | 84.75 | 2231.70 | 79% |
| 520 | 0.2722 | 163.32 | 5325.38 | 0.1308 | 0.1308 | 84.85 | 2316.55 | 82% |
| 530 | 0.2256 | 135.36 | 5460.73 | 0.1308 | 0.1308 | 56.89 | 2373.44 | 84% |
| 540 | 0.1789 | 107.36 | 5568.10 | 0.1308 | 0.1308 | 28.89 | 2402.33 | 85% |
| 550 | 0.1790 | 107.40 | 5675.50 | 0.1308 | 0.1308 | 28.93 | 2431.26 | 86% |
| 560 | 0.1791 | 107.44 | 5782.94 | 0.1308 | 0.1308 | 28.97 | 2460.23 | 87% |
| 570 | 0.1791 | 107.47 | 5890.41 | 0.1308 | 0.1308 | 29.00 | 2489.23 | 88% |
| 580 | 0.1792 | 107.51 | 5997.92 | 0.1308 | 0.1308 | 29.03 | 2518.26 | 89% |
| 590 | 0.1792 | 107.54 | 6105.46 | 0.1308 | 0.1308 | 29.07 | 2547.33 | 90% |
| 600 | 0.1793 | 107.57 | 6213.02 | 0.1308 | 0.1308 | 29.10 | 2576.42 | 91% |
| 610 | 0.1793 | 107.60 | 6320.62 | 0.1308 | 0.1308 | 29.13 | 2605.55 | 92% |
| 620 | 0.1794 | 107.63 | 6428.25 | 0.1308 | 0.1308 | 29.15 | 2634.70 | 93% |
| 630 | 0.1794 | 107.65 | 6535.90 | 0.1308 | 0.1308 | 29.18 | 2663.88 | 94% |
| 640 | 0.1795 | 107.68 | 6643.58 | 0.1308 | 0.1308 | 29.21 | 2693.09 | 95% |
| 650 | 0.1632 | 97.91 | 6741.49 | 0.1308 | 0.1308 | 19.44 | 2712.53 | 96% |
| 660 | 0.1469 | 88.14 | 6829.63 | 0.1308 | 0.1308 | 9.66 | 2722.19 | 96% |
| 670 | 0.1469 | 88.15 | 6917.78 | 0.1308 | 0.1308 | 9.68 | 2731.87 | 97% |
| 680 | 0.1469 | 88.17 | 7005.95 | 0.1308 | 0.1308 | 9.70 | 2741.57 | 97% |
| 690 | 0.1470 | 88.18 | 7094.13 | 0.1308 | 0.1308 | 9.71 | 2751.28 | 97% |
| 700 | 0.1470 | 88.20 | 7182.33 | 0.1308 | 0.1308 | 9.72 | 2761.00 | 98% |
| 710 | 0.1470 | 88.21 | 7270.54 | 0.1308 | 0.1308 | 9.74 | 2770.74 | 98% |
| 720 | 0.1470 | 88.22 | 7358.76 | 0.1308 | 0.1308 | 9.75 | 2780.49 | 98% |
| 730 | 0.1471 | 88.24 | 7446.99 | 0.1308 | 0.1308 | 9.76 | 2790.26 | 99% |
| 740 | 0.1471 | 88.25 | 7535.24 | 0.1308 | 0.1308 | 9.78 | 2800.03 | 99% |
| 750 | 0.1471 | 88.26 | 7623.50 | 0.1308 | 0.1308 | 9.79 | 2809.82 | 99% |
| 760 | 0.1471 | 88.27 | 7711.77 | 0.1308 | 0.1308 | 9.80 | 2819.62 | 100% |
| 770 | 0.1318 | 79.09 | 7790.86 | 0.1308 | 0.1308 | 0.61 | 2820.23 | 100% |
| 780 | 0.1165 | 69.90 | 7860.76 | 0.1165 | 0.1308 | -8.57 | 2811.66 | 100% |
| 790 | 0.1165 | 69.90 | 7930.66 | 0.1165 | 0.1308 | -8.57 | 2803.09 | 99% |
| 800 | 0.1165 | 69.91 | 8000.57 | 0.1165 | 0.1308 | -8.56 | 2794.53 | 99% |
| 810 | 0.1165 | 69.92 | 8070.49 | 0.1165 | 0.1308 | -8.55 | 2785.98 | 99% |
| 820 | 0.1165 | 69.92 | 8140.42 | 0.1165 | 0.1308 | -8.55 | 2777.43 | 98% |
| 830 | 0.1166 | 69.93 | 8210.35 | 0.1166 | 0.1308 | -8.54 | 2768.89 | 98% |
| 840 | 0.1166 | 69.94 | 8280.28 | 0.1166 | 0.1308 | -8.54 | 2760.35 | 98% |
| 850 | 0.1166 | 69.94 | 8350.23 | 0.1166 | 0.1308 | -8.53 | 2751.82 | 97% |
| 860 | 0.1166 | 69.95 | 8420.17 | 0.1166 | 0.1308 | -8.52 | 2743.30 | 97% |
| 870 | 0.1166 | 69.95 | 8490.13 | 0.1166 | 0.1308 | -8.52 | 2734.78 | 97% |
| 880 | 0.1166 | 69.96 | 8560.09 | 0.1166 | 0.1308 | -8.51 | 2726.27 | 97% |
| 890 | 0.1094 | 65.67 | 8625.76 | 0.1094 | 0.1308 | -12.80 | 2713.46 | 96% |
| 900 | 0.1023 | 61.38 | 8687.13 | 0.1023 | 0.1308 | -17.10 | 2696.37 | 95% |
| 910 | 0.1023 | 61.38 | 8748.51 | 0.1023 | 0.1308 | -17.09 | 2679.28 | 95% |
| 920 | 0.1023 | 61.38 | 8809.90 | 0.1023 | 0.1308 | -17.09 | 2662.19 | 94% |
| 930 | 0.1023 | 61.39 | 8871.29 | 0.1023 | 0.1308 | -17.08 | 2645.10 | 94% |
| 940 | 0.1023 | 61.39 | 8932.68 | 0.1023 | 0.1308 | -17.08 | 2628.03 | 93% |
| 950 | 0.1023 | 61.40 | 8994.08 | 0.1023 | 0.1308 | -17.08 | 2610.95 | 92% |
| 960 | 0.1023 | 61.40 | 9055.48 | 0.1023 | 0.1308 | -17.07 | 2593.88 | 92% |
| 970 | 0.1023 | 61.40 | 9116.88 | 0.1023 | 0.1308 | -17.07 | 2576.81 | 91% |

## Table A-7, continued

| (1) Time (minutes) | (2) Inflow (cfs) | (3) Inflow Volume (cf) | (4) Cummulative Volume (cf) | (5) Infiltration (cfs) | (6) Max. Infiltration (cfs) | (7) Incremental Storage (cf) | (8) Cummulative Storage Volume (cf) | (9) % Storage Capacity (%) |
|---|---|---|---|---|---|---|---|---|
| 980 | 0.1023 | 61.41 | 9178.29 | 0.1023 | 0.1308 | -17.06 | 2559.74 | 91% |
| 990 | 0.1024 | 61.41 | 9239.70 | 0.1024 | 0.1308 | -17.06 | 2542.68 | 90% |
| 1000 | 0.1024 | 61.41 | 9301.11 | 0.1024 | 0.1308 | -17.06 | 2525.62 | 89% |
| 1010 | 0.0921 | 55.28 | 9356.39 | 0.0921 | 0.1308 | -23.20 | 2502.43 | 89% |
| 1020 | 0.0819 | 49.14 | 9405.53 | 0.0819 | 0.1308 | -29.34 | 2473.09 | 88% |
| 1030 | 0.0819 | 49.14 | 9454.66 | 0.0819 | 0.1308 | -29.33 | 2443.76 | 87% |
| 1040 | 0.0819 | 49.14 | 9503.80 | 0.0819 | 0.1308 | -29.33 | 2414.43 | 85% |
| 1050 | 0.0819 | 49.14 | 9552.95 | 0.0819 | 0.1308 | -29.33 | 2385.10 | 84% |
| 1060 | 0.0819 | 49.14 | 9602.09 | 0.0819 | 0.1308 | -29.33 | 2355.77 | 83% |
| 1070 | 0.0819 | 49.15 | 9651.24 | 0.0819 | 0.1308 | -29.33 | 2326.44 | 82% |
| 1080 | 0.0819 | 49.15 | 9700.39 | 0.0819 | 0.1308 | -29.32 | 2297.12 | 81% |
| 1090 | 0.0819 | 49.15 | 9749.54 | 0.0819 | 0.1308 | -29.32 | 2267.80 | 80% |
| 1100 | 0.0819 | 49.15 | 9798.69 | 0.0819 | 0.1308 | -29.32 | 2238.48 | 79% |
| 1110 | 0.0819 | 49.15 | 9847.84 | 0.0819 | 0.1308 | -29.32 | 2209.16 | 78% |
| 1120 | 0.0819 | 49.16 | 9897.00 | 0.0819 | 0.1308 | -29.32 | 2179.84 | 77% |
| 1130 | 0.0819 | 49.16 | 9946.16 | 0.0819 | 0.1308 | -29.31 | 2150.53 | 76% |
| 1140 | 0.0819 | 49.16 | 9995.32 | 0.0819 | 0.1308 | -29.31 | 2121.22 | 75% |
| 1150 | 0.0819 | 49.16 | 10044.48 | 0.0819 | 0.1308 | -29.31 | 2091.91 | 74% |
| 1160 | 0.0819 | 49.16 | 10093.64 | 0.0819 | 0.1308 | -29.31 | 2062.60 | 73% |
| 1170 | 0.0819 | 49.16 | 10142.81 | 0.0819 | 0.1308 | -29.31 | 2033.29 | 72% |
| 1180 | 0.0819 | 49.17 | 10191.97 | 0.0819 | 0.1308 | -29.31 | 2003.98 | 71% |
| 1190 | 0.0819 | 49.17 | 10241.14 | 0.0819 | 0.1308 | -29.30 | 1974.68 | 70% |
| 1200 | 0.0820 | 49.17 | 10290.31 | 0.0820 | 0.1308 | -29.30 | 1945.38 | 69% |
| 1210 | 0.0820 | 49.17 | 10339.48 | 0.0820 | 0.1308 | -29.30 | 1916.08 | 68% |
| 1220 | 0.0820 | 49.17 | 10388.66 | 0.0820 | 0.1308 | -29.30 | 1886.78 | 67% |
| 1230 | 0.0820 | 49.18 | 10437.83 | 0.0820 | 0.1308 | -29.30 | 1857.48 | 66% |
| 1240 | 0.0820 | 49.18 | 10487.01 | 0.0820 | 0.1308 | -29.30 | 1828.19 | 65% |
| 1250 | 0.0820 | 49.18 | 10536.19 | 0.0820 | 0.1308 | -29.29 | 1798.89 | 64% |
| 1260 | 0.0820 | 49.18 | 10585.37 | 0.0820 | 0.1308 | -29.29 | 1769.60 | 63% |
| 1270 | 0.0820 | 49.18 | 10634.55 | 0.0820 | 0.1308 | -29.29 | 1740.31 | 62% |
| 1280 | 0.0820 | 49.18 | 10683.73 | 0.0820 | 0.1308 | -29.29 | 1711.02 | 61% |
| 1290 | 0.0820 | 49.18 | 10732.91 | 0.0820 | 0.1308 | -29.29 | 1681.73 | 60% |
| 1300 | 0.0820 | 49.19 | 10782.10 | 0.0820 | 0.1308 | -29.29 | 1652.44 | 58% |
| 1310 | 0.0820 | 49.19 | 10831.29 | 0.0820 | 0.1308 | -29.28 | 1623.16 | 57% |
| 1320 | 0.0820 | 49.19 | 10880.48 | 0.0820 | 0.1308 | -29.28 | 1593.88 | 56% |
| 1330 | 0.0820 | 49.19 | 10929.67 | 0.0820 | 0.1308 | -29.28 | 1564.59 | 55% |
| 1340 | 0.0820 | 49.19 | 10978.86 | 0.0820 | 0.1308 | -29.28 | 1535.31 | 54% |
| 1350 | 0.0820 | 49.19 | 11028.05 | 0.0820 | 0.1308 | -29.28 | 1506.03 | 53% |
| 1360 | 0.0820 | 49.19 | 11077.24 | 0.0820 | 0.1308 | -29.28 | 1476.76 | 52% |
| 1370 | 0.0820 | 49.20 | 11126.44 | 0.0820 | 0.1308 | -29.28 | 1447.48 | 51% |
| 1380 | 0.0820 | 49.20 | 11175.64 | 0.0820 | 0.1308 | -29.28 | 1418.20 | 50% |
| 1390 | 0.0820 | 49.20 | 11224.84 | 0.0820 | 0.1308 | -29.27 | 1388.93 | 49% |
| 1400 | 0.0820 | 49.20 | 11274.04 | 0.0820 | 0.1308 | -29.27 | 1359.66 | 48% |
| 1410 | 0.0820 | 49.20 | 11323.24 | 0.0820 | 0.1308 | -29.27 | 1330.39 | 47% |
| 1420 | 0.0820 | 49.20 | 11372.44 | 0.0820 | 0.1308 | -29.27 | 1301.12 | 46% |
| 1430 | 0.0820 | 49.20 | 11421.64 | 0.0820 | 0.1308 | -29.27 | 1271.85 | 45% |
| 1440 | 0.0820 | 49.20 | 11470.85 | 0.0820 | 0.1308 | -29.27 | 1242.58 | 44% |
| 1450 | 0.0410 | 24.60 | 11495.45 | 0.0410 | 0.1308 | -53.87 | 1188.71 | 42% |

# A.3 Stormwater Pollution Reduction Storm

**POLLUTION REDUCTION STORM**

This methodology was originally developed in 2004. References and analysis has not been updated.

The development of design storms for the sizing of stormwater pollution reduction (treatment) facilities generally involves a statistical analysis of local rainfall data, whereas a certain storm volume, duration, and peak intensity (or rainfall distribution) is identified to achieve a predetermined treatment volume goal. This treatment volume goal will vary from jurisdiction to jurisdiction, but is generally 80 to 95% of the average annual runoff (Table A-8). It can be linked to a jurisdiction's municipal stormwater discharge permit (MS4 permit) definition of MEP (maximum extent practicable) as it relates to the removal of pollutants from stormwater.

### TREATMENT VOLUME GOAL

Portland has used a single treatment storm methodology (0.83 inches over 24 hours; NRCS Type 1A rainfall distribution) since 1994. The original intent of this design storm was to: 1) treat the "first-flush" or first 0.5 inches of runoff from all storm events and 2) pass 100% of 95% of all storm events through the treatment facility.

The City of Eugene uses a treatment goal of 80% of the average annual runoff; Gresham also uses 80% of the average annual runoff. The Washington State Department of Ecology (and thus many other jurisdictions in Washington) uses 91%.

A continuous simulation analysis, summarized as Figure A-4, was performed on multiple years of rainfall data to determine the percentage of average annual rainfall that should be treated to maximize treatment efficiency. This analysis indicates a knee in the curve somewhere between 80 and 85 percent of the average annual volume. It may not be desirable to set the treatment goal directly at the economically optimal point, as stormwater treatment facilities do not always operate at their optimal design flow rates. A margin of safety should be incorporated into the treatment volume goal. For these reasons, the City of Portland has chosen to set its treatment volume goal at 90% of the average annual rainfall volume.

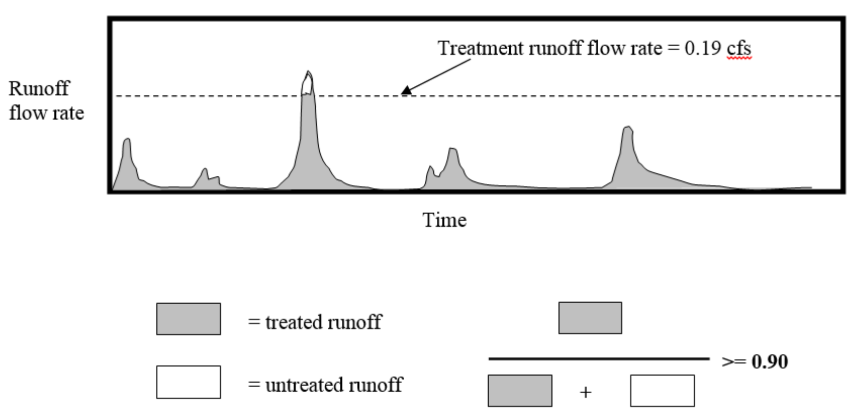
## RATE BASED TREATMENT SYSTEMS

Stormwater treatment systems can be divided into two categories based on the methods used to size them: rate (or flow) and volume (or detention) based systems. Rate based systems remove pollutants with physical processes that settle or filter particulates as the flow passes through the system. The actual volume of the facility doesn't play a major role in the pollutant removal process, as there isn't a significant detention period for the water to remain in the system for any length of time.

A continuous simulation model can easily be used to determine the average annual runoff volume percentage treated by a rate based system (Figure A-2). An assumption is that 100% of the runoff less than or equal to the peak treatment flow rate is fully treated, while the flows that exceed the peak treatment flow rate receive no treatment. Different assumptions can be made for on and off-line treatment systems. Likewise, an analysis of continuous rainfall intensity data can determine the average annual rainfall volume that is associated with a particular range of rainfall intensities. This type of analysis was completed for four different rain gages representing the different quadrants of Portland, and is summarized in Table A-9. Pollution Reduction Storm Analysis (2004). Five, ten and 20-minute intensities were analyzed to determine the intensities associated with the 90% rainfall volume goal. For 5-minute intensities, rainfall intensities of 0.19 inches per hour or less were determined to account for 90% of the average annual rainfall volume.

Eugene performed an analysis on 50 years of Eugene Airport rainfall data and also concluded that a rainfall intensity of 0.19"/hr would be needed to treat 90% of the average annual runoff volume.

**Figure A-2. Continuous simulation determination of 90% treatment flow rate**



## VOLUME BASED TREATMENT SYSTEMS

Unlike rate based systems, volume (or detention) based systems provide a significant storage volume for water to accumulate and be detained for a period of time. Pollutants are removed through physical (settlement) and/or biological processes. Unlike rate based systems, it is not easy to model volume based systems with continuous simulation models or rainfall analysis. Storm detention time needs to be factored into the model, and the mixing of water within the facility from one storm to the next creates a complex process that cannot be simulated accurately at this time. The currently accepted methodology used to size volume based treatment facilities is to set the wet portion of the pond or wetland (permanent pool) equal to the full volume of runoff generated by the predetermined water quality storm, and apply a safety factor (Vb/Vr ratio) (Figure A-3).

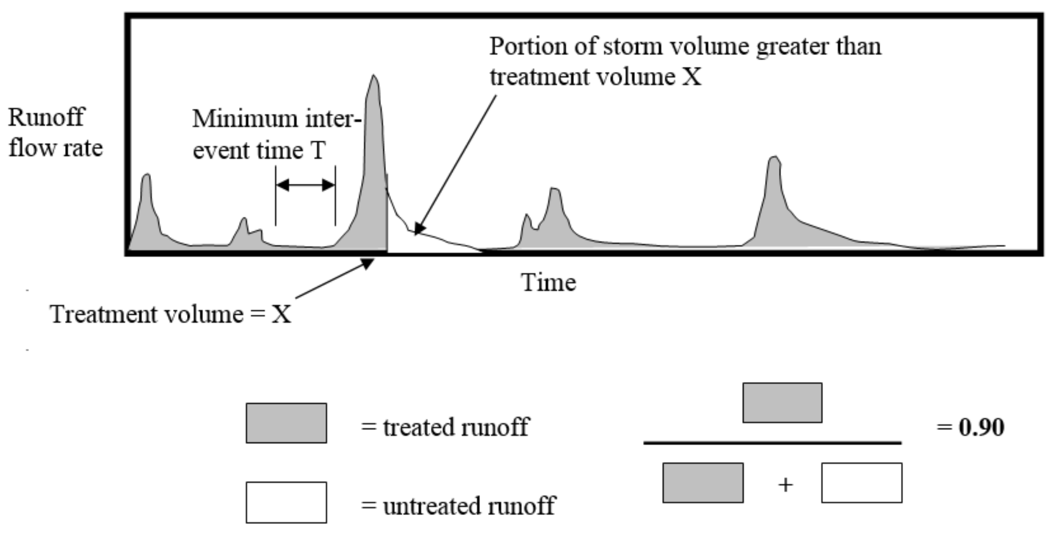
The volumes of most jurisdictions' water quality storms are set at their average annual treatment volume goal. For example, if the goal is to treat 80% of the average annual flow volume, the treatment storm depth is set to the 80% percentile storm. Eugene's goal is to treat 80% of the average annual volume. Their water quality storm is 1.4"/24 hours, which is equal to the 80th percentile storm. 80% of their storm events have a depth of 1.4 inches or less. In Portland's case, the 0.83" storm is not equal to the 90th percentile storm. An estimate would put it somewhere between the 60th and 65th percentile storm. This had been compensated for in the September 2002 Stormwater Management Manual by requiring volume-based facilities to use twice the volume of runoff generated by the 0.83" storm, or a Vb/Vr ratio of 2, but this factor should most likely be a function of soil type. In a recent version of Stormwater Treatment Northwest (Vol 9, No 4), Gary Minton and Roger Sutherland suggest that Pacific Northwest monitoring data indicates that a Vb/Vr ration of 1 may be adequate to achieve a TSS removal of 80%.

The City of Eugene has performed an analysis on 50 years of Eugene Airport rainfall data, and concluded that 90% of rainfall events are less than 2.4 inches in depth. Hourly rainfall intensity data was used in the analysis, storm depths of 0.01 inches or less were eliminated from the analysis, and a minimum inter-event time of 6 hours was used. A slight change in the modeling assumptions has a significant impact on the outcome. In the December 2003 issue of Stormwater Treatment Northwest, Gary Minton stated that an analysis he did of 24-hour rainfall data from the Seattle-Tacoma International Airport indicated that with a storm depth of about 1.35 inches, 90% of the runoff would be treated over time. The specific assumptions that were used in Dr. Minton's analysis are not known, but he was not using the 90th percentile Seattle-Tacoma storm. The Washington State Department of Ecology's

Western Washington Stormwater Manual targets the capture of 91% of the average annual runoff for water quality, which they equate to two-thirds of a 2-year storm event (roughly 1.65 inches). Again, this storm event is not equivalent to the 91st percentile Western Washington storm.

A way of modeling the rainfall that could result in a clearer link to the treatment goal may be to determine the volume of a wet basin that will result in an average storm detention time of 24, 36, or 48 hours, depending on the anticipated TSS settling velocity in the vicinity of the site. The assumed inter-event time could be adjusted to ensure that enough detention time is provided between each storm event. An assumption could be made that storms with total volumes less than the "90% treatment storm" would receive 100% treatment. Storms with total volumes greater than the "90% treatment storm" would receive partial treatment: 100% treatment for the volume equal to the 90% storm volume, and 0% treatment for the volume greater than the 90% storm volume. This may be overly conservative, as some very long, drawn-out storms (>24 hours) with total volumes greater than the designated treatment volume, may in fact receive greater than 24 hours of detention time for the entire storm, or 100% effective treatment.

**Figure A-3. Continuous Simulation Determination of 90% Treatment Volume**



## CONCLUSION

The Portland water quality design storm shall be stated as a volume treatment goal- e.g. "90% of the average annual runoff shall be treated", and will be clarified by stating the peak rainfall intensity, and total volume components.  This achieves two things:

- Volume based facilities and rate based facilities will be theoretically sized to achieve treatment of the same percentage of average annual runoff volume.
- With the treatment rainfall intensity already given, the SBUH or other hydrograph based hydrologic analysis method won't be needed to size rate based treatment facilities, simplifying the design process.  Rather, the Rational Method can be used to calculate the runoff treatment flow rate, based on the site's time of concentration.

To achieve the treatment of 90% of the average annual rainfall volume, rate based facilities must be sized to treat rainfall at 0.19 inches per hour for sites with 5-minute time of concentration or less, 0.16 inches per hour for sites with a 10-minute time of concentration, and 0.13 inches per hour for sites with a 20-minute time of concentration.

For volume based facilities, Portland shall continue to size wet basins using 0.83 inches of rainfall over 24 hours (NRCS Type 1A rainfall distribution), with a Vb/Vr ratio of 2.

## Table A-8. Comparison of Pacific Northwest Water Quality Design Storms (2004)

| Jurisdiction | Average Annual Runoff (in) | Treatment Goal (average annual runoff %) | Water Quality Storm Volume (in) | Volume Based Facility Sizing Factors | WQ Storm Duration (hrs) | WQ Storm Intensity for off-line facilities (in/hr) | WQ storm intensity for on-line facilities (in/hr) |
|---|---|---|---|---|---|---|---|
| **Gresham** | 37.4 | 80 | 1.2 | 1 | 12 | 0.11 | 0.20 |
| **Eugene** | 46.6 | 80 | 1.4 | 1 | 24 | 0.13 | 0.22 |
| **Corvallis** | 43.2 | 90 | 0.90, 0.3 mean ann. for wet ponds | 3 | 24 | Not Specified: 0.90” storm peak 10 min intensity (per NRCS 1A distribution) = 0.29 in/hr | |
| **Clean Water Services** | 36 | 85 | 0.36 | 1 | 4 | WQ Volume / 4 hours = 0.09 in/hr | |
| **Department of Environmental Quality (OR)** | varies 37 avg. | | 2-year storm: 2.4” | 1 | 24 | Not Specified: 2.4” storm peak 10 min Intensity (per NRCS 1A distribution) = 0.78 in/hr | |
| **Tacoma, WA** | 37.6 | 91 | 6-mo storm volume | 1 | 24 | 91% treatment, HSPF continuous simulation, different on & off-line | |
| **Seattle, WA** | 38.6 | | Mean annual storm = 0.47 | 1 | 24 | 6-month storm (64% of 2-year storm or 1.08 inches) peak 10-min intensity using SBUH = 0.35 in/hr | |
| **King County (WA)** | 38.6 | 95 | Mean annual storm = 0.47-0.65 | 3 | 24 | 60% of 2-yr storm flow rate using KCRTS continuous simulation, or 64% of 2-yr storm flow rate using SBUH | |

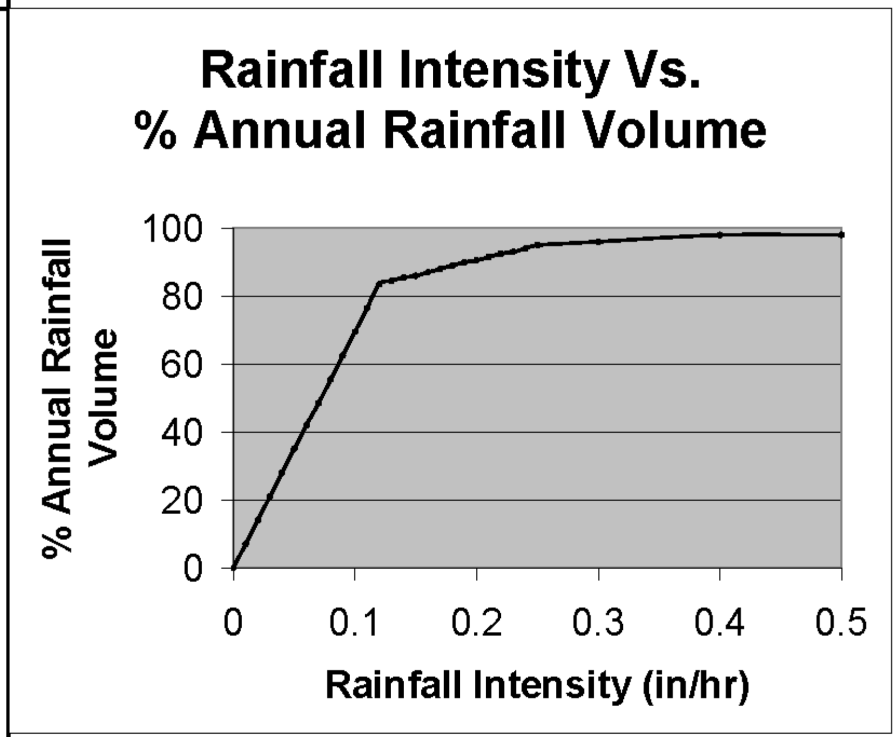
**Table A-8, continued**

| Jurisdiction | Average Annual Runoff (in) | Treatment Goal (average annual runoff %) | Water Quality Storm Volume (in) | Volume Based Facility Sizing Factors | WQ Storm Duration (hrs) | WQ Storm Intensity for off-line facilities (in/hr) | WQ storm intensity for on-line facilities (in/hr) |
|---|---|---|---|---|---|---|---|
| **Department of Ecology (WA) (Western WA)** | varies 36-46 | 91 | 6-month storm volume: Varies | 1 | 24 | 91% treatment: varies by jurisdiction, HSPF continuous simulation, different on & off-line | |
| **Portland** | 36 | 90 | 90% ave. annual treatm't volume* | 1 if $V_r$ = 1.7<br>2 if $V_r$=.83 | 24 | 90% treatment as shown by continuous simulation (see Table A-9) = 0.19 to 0.13 in/hr, depending on site's TofC | |

*As defined by the recommended analysis of 24 years of Portland rainfall data, assuming a minimum inter-event time of 12 hours and minimum rainfall amount of 0.01 inches (see Table A-10Table A-10. Volumes Resulting in Treatment of 90% of Rainfall Volume (2004) ). Portion of storm volume below specified treatment volume receives 100% treatment, portion of storm volume above specified treatment volume receives 0% treatment.

## Figure A-4. Rainfall Intensity vs. Percentage of Annual Rainfall Volume (2004)

| 5-minute intensity in/hr | % Annual Rainfall Volume |
|---|---|
| 0 | 0 |
| 0.01 | 7 |
| 0.02 | 14 |
| 0.03 | 21 |
| 0.04 | 28 |
| 0.05 | 35 |
| 0.06 | 42 |
| 0.07 | 48.5 |
| 0.08 | 55.5 |
| 0.09 | 62.5 |
| 0.1 | 69.5 |
| 0.11 | 76.5 |
| 0.12 | 83.5 |
| 0.13 | 84.5 |
| 0.14 | 85.5 |
| 0.15 | 86 |
| 0.16 | 87 |
| 0.17 | 88 |
| 0.18 | 89 |
| 0.19 | 90 |
| 0.2 | 90.5 |
| 0.21 | 91.5 |
| 0.22 | 92.5 |
| 0.23 | 93 |
| 0.24 | 94 |
| 0.25 | 95 |
| 0.3 | 96 |
| 0.4 | 98 |
| 0.5 | 98 |




Rainfall data taken from each of the four Portland quadrants, then averaged.

## Table A-9. Pollution Reduction Storm Analysis (2004)

| Intensity by Quadrant | Rainfall Depth (in) | Average |
|---|---|---|
| **5 min (NW)** | 0.19 | 0.19 in/hr |
| **5 min (SW)** | 0.19 | |
| **5 min (SE)** | 0.20 | |
| **5 min (NE)** | 0.19 | |
| **10 min (NW)** | 0.15 | 0.16 in/hr |
| **10 min (SW)** | 0.15 | |
| **10 min (SE)** | 0.165 | |
| **10 min (NE)** | 0.16 | |
| **20 min (NW)** | 0.13 | 0.13 in/hr |
| **20 min (SW)** | 0.12 | |
| **20 min (SE)** | 0.14 | |
| **20 min (NE)** | 0.135 | |

Assumption: Percentage of rainfall less intense than specified intensity receives 100% treatment, percentage of rainfall more intense than specified intensity receives 0 treatment.

**Table A-10. Volumes Resulting in Treatment of 90% of Rainfall Volume (2004)**

| Place and Time | Total Rainfall (in) | Number of 12-hr storms | Average storm size (in) | 90% Treatment Storm Size (in) | Average 90% Treatment Storm Size (in) |
|---|---|---|---|---|---|
| **NW 97-98** | 80.15 | 169 | 0.47 | 1.6 | 1.7 |
| **NW 90-91** | 65.5 | 163 | 0.40 | 1.3 | |
| **NW 83-84** | 83.9 | 202 | 0.42 | 1.9 | |
| **NW 80-81** | 95.37 | 247 | 0.39 | 2.1 | |
| **SW 97-98** | 73.85 | 176 | 0.42 | 1.4 | 1.7 |
| **SW 90-91** | 61.83 | 180 | 0.34 | 1.25 | |
| **SW 83-84** | 82.37 | 201 | 0.41 | 1.9 | |
| **SW 80-81** | 67.45 | 160 | 0.42 | 2.1 | |
| **SE 97-98** | 74.41 | 185 | 0.40 | 1.6 | 1.8 |
| **SE 90-91** | 63.71 | 184 | 0.35 | 1.3 | |
| **SE 83-84** | 82.75 | 192 | 0.43 | 2.0 | |
| **SE 80-81** | 65.41 | 163 | 0.40 | 2.3 | |
| **NE 97-98** | 74.00 | 180 | 0.41 | 1.4 | 1.7 |
| **NE 90-91** | 64.62 | 176 | 0.37 | 1.2 | |
| **NE 83-84** | 72.27 | 217 | 0.33 | 1.7 | |
| **NE 80-81** | 65.37 | 188 | 0.35 | 2.3 | |

Assumptions: Percentage of storm volume less than specified volume receives 100% treatment, percentage of storm volume greater than specified volume receives 0 treatment. Storm event is defined by a minimum of 0.01 inches of rainfall with a minimum inter-event period of 12 hours.

## A.4 Presumptive Approach Calculator Technical Framework

The Presumptive Approach Calculator (PAC) was developed to provide design professionals a standard tool for sizing vegetated stormwater facilities in accordance with the Stormwater Infiltration and Discharge Hierarchy (Section 1.3) and the Presumptive Sizing Approach (Section 2.2.2) of the Stormwater Management Manual (SWMM). The capability of the PAC includes sizing of stormwater facilities based on native soil infiltration rates, a standard growing medium infiltration rate, and above and below grade storage volumes.

The PAC allows a designer to use the native soil infiltration rates and test different vegetated stormwater facility configurations to find a design that meets the appropriate Stormwater Hierarchy goals for the site. Design parameters that influence results are the three facility types (swale, planter and basin), longitudinal slopes for swales, three facility shapes (rectangle, amoeba, or user defined), surface area, above ground capacity, below ground capacity, side slopes, depth to overflow and native infiltration rates.

The following are example scenarios that a design engineer can achieve and optimize using the PAC:

- Size surface infiltration facilities with or without an underground rock storage layer.
- Quickly evaluate various alternatives for facilities of different shapes, sizes and depths.
- Balance the facility size with underground rock storage layer depth and footprint area when sizing a facility to minimize the extent of excavation and placement of rock.
- Size facilities with Configuration E or F under Stormwater Hierarchy Category 2 as a self-contained UIC, providing a minimum sizing to support surface infiltration of the Pollution Reduction storm event, but allowing larger flows to bypass the growing medium and utilize additional below grade storage and/or access higher infiltration rates through the native soils.
- Size facilities to meet flow control requirements for Stormwater Hierarchy Categories 3 or 4.
- Overflow of runoff data discharging from a surface stormwater facility for 2, 5, 10 and 25-year storm events can be exported for further analysis to meet flow control requirements.

Although the sizing methodology has been standardized for the PAC, professional judgment is still required when evaluating the results and verifying the performance of a particular stormwater facility. A model run may achieve a successful design result for the requirements of the chosen Stormwater Hierarchy, but have to contend with site design challenges and constraints in addition to all other relevant code, project or development proposal requirements. If a project designer proposes to deviate from the recommended ranges, the City may require that the project to be designed under the Performance Approach.

The PAC is not intended to:

- Size multiple facilities at once or in sequence. A separate calculation is required for each paired facility and catchment.
- Calculate conveyance or analyze discharge point or emergency overflow pathway.
- Size drywells or other underground injection devices.
- Serve as an Operations and Maintenance Plan.
- Size detention ponds for flow control requirements.

## Overview of the PAC

This technical framework provides an overview of the calculations used in the PAC. It assumes general knowledge of Stormwater Management Manual requirements, including the Stormwater Hierarchy. The PAC uses standard terminology common to sizing of stormwater facilities throughout, but if there are any questions, refer to Glossary for definitions of terms used throughout the PAC. Additionally, the PAC was developed as a standard sizing tool, which required developing an optimal set of ranges for input variables. Refer to Allowed and Recommended Ranges for design data criteria and supplemental information on error or warning messages. Values outside the recommended range do not prevent the PAC from running the calculations, but additional documentation may be required with the submittal and design or review of the facility may fall under the Performance Approach. The PAC will not function using values outside of the allowable range.

Project designers begin a PAC project by entering in basic project information, such as address and contact information. For each catchment, the designer will need to enter impervious area and native soil infiltration testing results and then select the appropriate stormwater hierarchy category. The PAC will develop a SBUH hydrograph that will serve as the stormwater facility input hydrograph. The designer will then enter stormwater facility information for each catchment. Any number of catchments, each with a single stormwater facility, can be added to a project. Design data can be modified until it meets the desired project goals as required by the selected stormwater hierarchy category. The PAC will calculate results based on selected Stormwater Hierarchy Category and will indicate whether the facility achieves a “pass” or “fail” for the modeled storm events to meet pollution reduction and flow control requirements for the selected stormwater hierarchy.

At the completion of design, a PAC generates a PDF report that summarizes the project, catchment, and facility information. The PAC report will include relevant Pollution Reduction Sizing, 10-year storm sizing, and peak output for 2, 5, 10 and 25-year design storms. In addition, the report will include the sizing ratio, the overflow volume and the percentage of surface and rock storage capacity for each facility.

The following sections describe the qualitative and quantitative options that will influence stormwater facility sizing.

## Stormwater Infiltration and Discharge Hierarchy

The selection of the intended Stormwater Hierarchy Category (1 through 4) will determine the required results of the PAC (Figure A-5). If the PAC results do not meet the requirements, the project designer will need to adjust the catchment or facility design in an iterative process until the required results are met.

Only the two Facility Configurations A & B are eligible to meet the requirements of Stormwater Hierarchy Category 1. All Facility Configurations A through F are available for Hierarchy Category 2. Facility Configurations A through D are available for Hierarchy Category 3 and 4.

## A-5. Stormwater Management Requirements by Stormwater Hierarchy Category

| Hierarchy Category | SWMM Requirement | Meets Pollution Reduction Requirements | Flow Control Requirement |
|---|---|---|---|
| **1** | Onsite infiltration with a surface infiltration facility | Yes | Infiltration the 10-year design storm |
| **2** | Onsite infiltration with a surface infiltration facility with overflow to an approved UIC facility | Yes | Infiltration the 10-year design storm or use UIC |
| **3.a** | Off-site flow to Willamette River, Columbia River, or Columbia Slough, or discharge to a storm-only piping system or Multnomah County Drainage District system (with capacity) that directly discharges to one of the above water bodies | Yes | None |
| **3.b** | Discharge to overland storm drainage system, including streams, drainageways, ditches or other storm pipe system that discharges to an overland drainage system | Yes | Limit 2-year post-development peak flow rates to one-half of the 2-year pre-development peak rate and maintain post-development peak flow rates at the pre-development levels for the 5-, 10- , and 25-year events. |
| **3.c** | Base requirement for all other discharge points | Yes | Maintain peak flow rates at the predevelopment levels for the 2-, 5-, and 10-year, 24-hour runoff events |
| **4** | Discharge to a combined sewer | Yes | Limit 25-year post-development peak runoff rate to 10-year predevelopment peak rate |

## Stormwater Facility Shapes

The PAC offers three facility shapes to for Basin facility types, each with a different calculation to estimate the storage capacity. The different shapes allow flexibility in sizing to calculate storage volumes.

The Rectangle/Square facility shape is aptly named and can be simply defined. The proposed bottom area, the side slopes and depth are used to calculate available volume.

The Amoeba calculates volumes for organically shaped facilities with both convex and concave curves and uses the perimeter length around the proposed bottom area, the side slope and depth to calculate available volume. If the proposed facility will be more oval or round shaped with minimal or no concave curves, then the calculation would underestimate the storage volume and the User Defined shape may provide a more accurate calculation.

The User Defined shape can calculate available storage for any shape using the average end area method to calculate volumes. The designer needs to lay out the facility on paper or CAD when taking surface area measurements to consider side slopes between the bottom and top surface areas.

To simplify the sizing iterations, a designer may use the Rectangle/Square Facility shape to roughly size the facility and then select a different shape to fine tune the design and more accurately represent the proposed condition. Using the Amoeba or User Defined shape requires new perimeter length and area measurements for each iteration that can be time consuming for preliminary sizing.

## Stormwater Facility Configurations

The PAC allows for up to six different facility configurations. The following is a brief overview of the different configurations and applicability.

## Stormwater Facility Configurations A and B

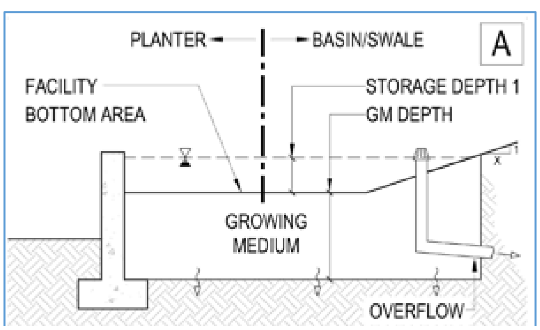
These facilities are the only two that can satisfy the requirements of Stormwater Hierarchy Category 1. These facilities use two-stage calculations to model the configuration. These facilities can also be selected for any other Stormwater Hierarchy Category. These facilities are sized so that at a minimum, the Pollution Reduction event infiltrates through the growing medium, but to meet Stormwater Hierarchy Category 1, the facility must be sized to infiltrate the 10-yr storm without overtopping. Where the surface storage is exceeded, overflow is to the approved discharge. Configurations A and B are limited by the surface infiltration capacity through the growing medium even if there are higher infiltration rates through the native soils.

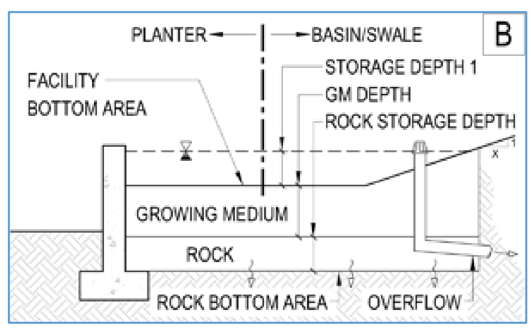
*Configuration A: Infiltration*

- No rock storage provided below grade. This configuration is best applied when the design infiltration rate for the native soil is greater than the design infiltration rate for the growing medium of 2 inches per hour.
- If the below grade infiltration capacity is less than the above grade infiltration capacity, the PAC uses the lower native soil infiltration capacity for the Stage I calculations.

*Configuration B: Infiltration with rock storage*

- Rock storage is provided below grade. This configuration is best applied when the design infiltration rate for the native soil is less than the design infiltration rate for the growing medium of 2 inches per hour.
- The rock storage provides additional contact area with the native soils than with configuration A and increases the potential for infiltration.



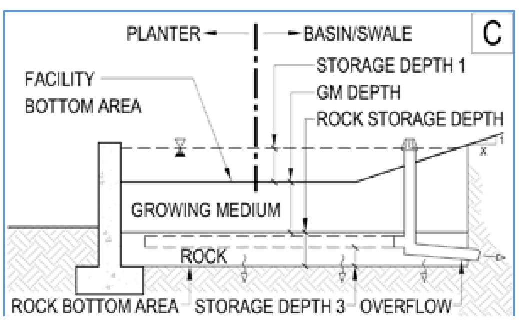



**Stormwater Facility Configurations C and D**

Under these two configurations, an assumption is made that no measurable runoff will infiltrate into the native subgrade. All the runoff that enters the facility is assumed to be discharged either as percolated runoff collected by the underdrain pipe or as overflow that is collected and conveyed to the same discharge pipe. This discharge through the underdrain pipe eliminates Stormwater Hierarchy Category 1 as a goal. Since it is assumed that there is no interface with the native subgrade, only the first stage of the two-stage calculation is required to model the configuration (see 3.4 for discussion of two-stage calculations). These facilities are sized so that at a minimum, the Pollution Reduction event infiltrates through the growing medium, but any larger storm events would overflow to the approved discharge.

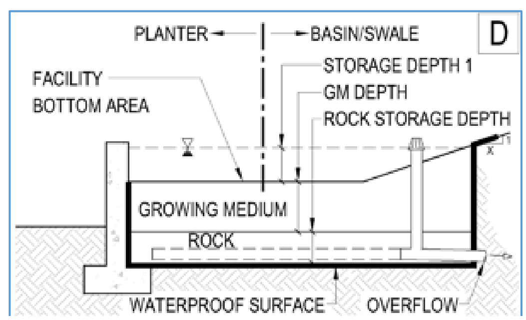
*Configuration C: Infiltration with rock storage and underdrain*

- No impermeable liner is placed around the facility
- The facility may allow some minor infiltration, but the PAC calculations do not estimate this volume.




*Configuration D: Lined facility with rock storage and underdrain*

- An impermeable liner is placed around the facility

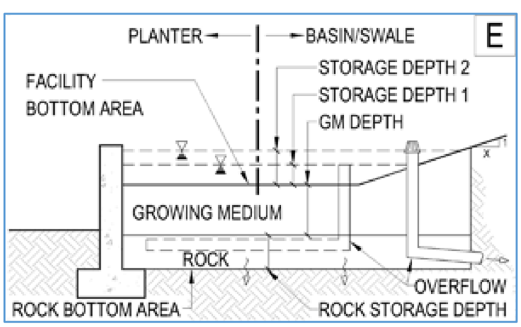


## Stormwater Facility Configurations E and F

These are the only facilities that allow overflow stormwater to bypass the growing medium to the rock storage, which requires them to be registered as an Underground Injection Control (UIC), similar to a soakage trench, sump or drywell. These facilities are sized so that at a minimum the Pollution Reduction event infiltrates through the growing medium, but larger storm events are allowed to overflow to the rock storage layer below. This overflow eliminates Stormwater Hierarchy Category 1 as a goal. These configurations can be especially useful on sites where there is not space available for configurations A or B (generally larger than E or F) or on sites were the native infiltration rate is greater than that of the growing medium. Providing a direct connection to the below grade rock storage allows the facility to take advantage of the higher native infiltration capacity or provide additional below grade storage to reduce the size of the facility. Because E & F allow minimum sizing of the surface component based on the Pollution Reduction event like Configurations C & D and allow a portion of larger events to bypass the growing medium like a UIC, they are considered a “hybrid” configuration design.

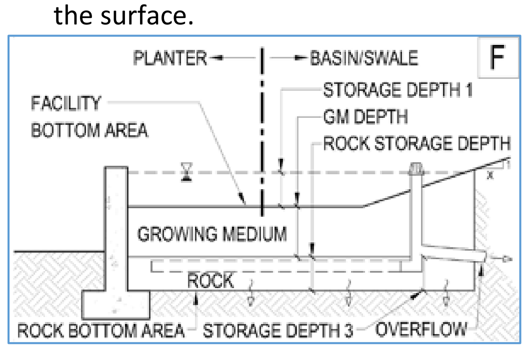
*Configuration E: Infiltration with bypass to rock storage*

- Can allow greater surface storage above what is needed for the Pollution Reduction event.
- In the condition where the below grade infiltration capacity is less than the surface infiltration capacity, and the rock storage becomes full, the below grade restriction will limit the infiltration rate on the surface and cause the water on the surface to remain longer through and after a storm event.




*Configuration F: Infiltration with underdrain and bypass to rock storage*

- For projects where minimal surface depth is important, this configuration allows maximum sub-surface storage while ensuring that the surface storage drains freely based on the surface infiltration capacity of the facility.
- Contrary to Configuration E, any limitation of below grade infiltration relative to surface percolation or overflow flows will accumulate in the rock storage and discharge through the below grade outflow pipe without restricting infiltration of the water on the surface.



## Interpreting the Results

There are up to four pieces of data generated for both the Pollution Reduction sizing and flow control results for each catchment/facility pairing. These are the "PASS" or "FAIL" text, the overflow volume, the maximum Percent Surface Capacity Used and the maximum Percent Rock Capacity Used. In general, the PAC generates a "PASS" if the above grade storage component does not overtop to the approved discharge. In contrast, the PAC generates a "FAIL" if the facility does overtop to the approved discharge during the respective storm event.

For a "FAIL" result, the overtopping volume can be compared to the total volume of the respective storm event shown on the SBUH hydrograph to gauge the extent of under-sizing of the facility. Knowing the percent or portion of above grade or below grade storage available during the Pollution Reduction or relevant storm event allows the project designer to refine the facility parameters and optimize the design without exceeding the capacity.

### Stormwater Hierarchy Category Goals

When Stormwater Hierarchy Category 1 is selected, it is required that both facility must be able to infiltrate the Pollution Reduction storm sizing and infiltrate a 10-yr storm event to achieve a "PASS" result. However, if Stormwater Hierarchy Category 2 is selected, then it is only required that the facility is sized to infiltrate the Pollution Reduction storm to achieve a "PASS" result. The project designer then has the option of indicating that a separate UIC facility will be used downstream to infiltrate the 10-yr storm event. Supplemental documentation supporting the design of the UIC will be required.

When Hierarchy Category 3 or 4 is selected, the facility is required to achieve a "PASS" result for being sized to treat the Pollution Reduction storm. The facility must also be sized to meet the specific stormwater hierarchy category requirements for flow control. Flow control requirements are met based on modeling peak discharge rates generated for the appropriate 2, 5, 10 & 25-year storm events and comparing those peak runoff rates for the same catchment area under pre-existing conditions for modeled storm events.

### Graphs and Tables

The PAC produces summary information and graphs to illustrate the performance of the facility throughout the duration of various storm events and up to 48 hours (2,880 minutes). The longer duration allows the graph to show the flows that lag past the 24-hour storm event as the water passes through the growing medium or infiltrates into the native soils. The tables that support the graphs can be viewed and exported.

The calculations can be performed without viewing the graphs or supporting tables, but the graphs can sometimes provide clues to the facility performance to more quickly determine an optimally sized design. For example, a line that is reverse-scaled from the top of the graph per a second axis on the right side of the graph indicates the amount of storage being used (% full) for the surface and rock storage as applicable. This "real-time" graphing of the storage capacity during a modeled storm event allows the project designer to identify when the peak storage or overtopping condition occurs and see the influence that the native infiltration capacity and rock storage might have on the surface storage performance. This is of particular interest when the below grade infiltration capacity is less than the above grade infiltration capacity for Facility Configurations A & B or anytime when flows beyond the Pollution Reduction storm event are allowed to bypass the growing medium to the rock storage for Facility Configurations E & F.

As the project designer becomes familiar with the PAC, additional applications may be identified to model variations in design. However, in order to reflect the conditions in the field, there are some guidelines for sizing and design:

- Design criteria are defined in Allowed and Recommended Ranges. The data entry can be outside recommended parameters, but additional documentation may be required at time of review to support the design. For example, greater porosity can be justified for the below grade storage component where additional void space is provided with chambers or perforated pipes. Entering data outside recommended parameters may result with the facility being reviewed under the Performance Approach.
- The PAC calculates the infiltration capacity by multiplying the respective design infiltration rate with the Bottom Area of the surface facility for planters, Infiltration Area at 75% Depth 1 for swales and basins, or Rock Storage Bottom Area for the below grade storage. The calculations do not track the wetted area as the flows enter and exit the facility to iterate an estimated variable infiltration rate, nor do they account for increased infiltration with increased head. Therefore, consideration should be given to expected performance when running the calculations with an oversized facility. In a model condition where the facility is oversized, the PAC will overestimate the performance by allowing the higher infiltration capacity whether the inflow has fully wetted the allocated infiltration area or not. The results will reflect smaller values for percent capacity used than might be observed. A facility with more optimized sizing will function more closely with the calculations.

- When designing with Facility Configuration E, two different “risers” are defined with the data entry as Storage Depth 1 and Storage Depth 2. The lower overflow “riser” at Depth 1 provides a direct connection to the rock storage reservoir, while the higher “riser” at Depth 2 represents the overflow elevation to the offsite discharge point. The lower “riser” has the capacity to collect and convey stormwater to the rock storage reservoir without overtopping the second “riser” to the discharge point.

## Overview of PAC Calculations

This section describes the methodology used in the Presumptive Approach Calculator (PAC) for the calculations of hydrographs and facility routing. The intent of this section is to provide a summary of the concepts used by the PAC. The PAC uses a similar reservoir routing process as most hydrologic analysis software packages to size detention or infiltration facilities. However, the primary difference is that the PAC has the capability of running a Two-Stage Calculation. Two reservoir routing models run concurrently so the performance of the second stage calculation (below grade) can influence the performance of the first stage calculations (above grade). The output hydrograph from the first stage calculation serves as the inflow hydrograph for the second.

### Hydrologic Methods

The PAC uses the Santa Barbara Urban Hydrograph (SBUH) method for all hydrologic calculations. This method is approved by the Bureau of Environmental Services (BES) for determining runoff when performing flow control calculations.

The SBUH method is based on the Soil Conservation Service (SCS) method, except that the SBUH method directly computes a runoff hydrograph without going through an intermediate process (unit hydrograph). Although the Soil Conservation Service is now called the Natural Resources Conservation Service (NRCS), the method is still commonly referred to as the SCS method. The SBUH method predicts a peak runoff rate and rainfall-runoff distribution based on the catchment characteristics including catchment area, curve number (CN) of the ground surface, and Time of Concentration (Tc). Further discussion of the SBUH method is provided in SWMM Santa Barbara Urban Hydrograph Method as well as guidance for determining a Tc for each of the catchments. The default CN value for impervious surfaces is 98.

The PAC uses the NRCS Type 1A, 24-hour storm distribution with a fixed 10-minute interval per SWMM. When using the PAC, the SBUH calculations will account for impervious areas entered by the project designer in accordance with the SWMM guidelines. However, the PAC can also be utilized under the Performance Approach provided that supplemental support documentation is provided. Accordingly, the CN data entry will allow some flexibility in the modeling to reflect a weighted CN (of each catchment) for numerous conditions. Precipitation values for each modeled storm event are described in Stormwater Pollution Reduction Storm. The Pollution Reduction (PR) storm event is representative of 90% of the average annual rainfall and is used to size pollution reduction facilities. Refer to Stormwater Pollution Reduction Storm for additional discussion of the PR storm precipitation.

The PAC will generate a hydrograph for each of the five modeled storm events based on the data entered for each catchment. This data is then used by the PAC to evaluate the performance of the surface infiltration facilities.

SBUH uses two steps to synthesize the runoff hydrograph:

1. Computing the instantaneous hydrograph
2. Computing the runoff hydrograph

The instantaneous hydrograph, $I_t$ (cfs), at each time step ($d_t$) is computed as follows:

$I_t = 60.5 R_t A / d_t$

Where

$R_t$ = Total runoff depth at time increment $d_t$ (inches)

A = Area in acres

$d_t$ = Time interval in minutes

The runoff hydrograph, $Q_t$, is then obtained by routing the instantaneous hydrograph $I_t$ through an imaginary reservoir with a time delay equal to the time of concentration, $T_c$ of the catchment basin. The following equation estimates the routed flow, Q:

$Q_t = Q_{(t-1)} + w[I_{(t-1)} + I_t - 2Q_{(t-1)}]$

Where

$w = d_t / (2T_c + d_t)$

$d_t$ = time interval in minutes

The tabulated values of $Q_t$ for each time step represent the runoff hydrograph that is utilized as the input hydrograph for the PAC.

## Storage Capacity Calculations

The PAC offers four options for facility shapes to size a surface storage capacity for basins. Each has a different calculation to estimate the storage capacity. The Amoeba and Rectangle/Square facility shapes use the side slope to calculate available volume, which allows the project designer to roughly size a facility without needing to recalculate an upper surface area with each iteration, as would be required with the User Defined shape. The Swale facility shape includes a number of calculations to estimate the storage capacity accounting for swale geometry, longitudinal slope, number of segments, and berm heights. To simplify the sizing iterations, a designer may use the Rectangle/Square Facility shape to roughly size the facility and then the project designer may select a different shape to fine tune the design and more accurately represent the proposed condition. The Rock Storage capacity is a more simple volume calculation that accounts for the porosity of the rock aggregate.

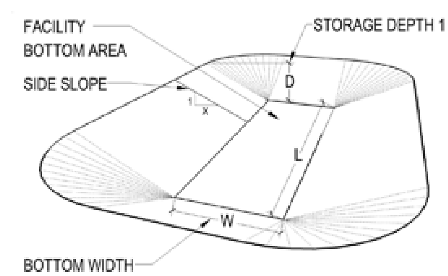
### *Rectangle/Square*

The PAC calculates volume by treating it as a trapezoidal basin where:

$$V = LWD + (L + W)XD^2 + \frac{1}{3}\pi X^2 D^3$$

$$A = A_{bottom} + A_{sides} + A_{corners}$$

$$A = LW + 2(L + W)XD + \pi(XD)^2$$




Where:

V = Storage in cubic ft

L = Bottom length of surface facility in ft

W = Bottom width of surface facility in ft

D = Depth of surface facility in ft

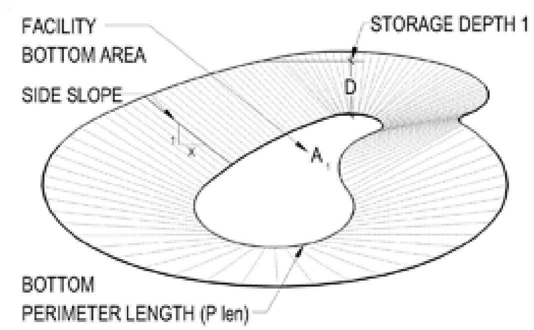
X = Side slope, (X:1) (H:V)

### *Amoeba*

The amoeba shape can be selected for an organically-shaped facility that has both convex and concave curves. The volume is greatly affected by the perimeter length, so care should be given when approximating this value for early iterations. If the proposed facility will be more oval or round shaped with minimal or no concave curves, then the calculation would underestimate the storage volume and the User Defined shape may provide a more accurate calculation. The PAC calculates the volume using the following equation:

$$V = \frac{1}{2} D X P_{len} + A_1 D$$

$$A = A_1 P_{len} D X$$




Where:

V = Storage in cubic ft

D = Depth of surface facility in ft

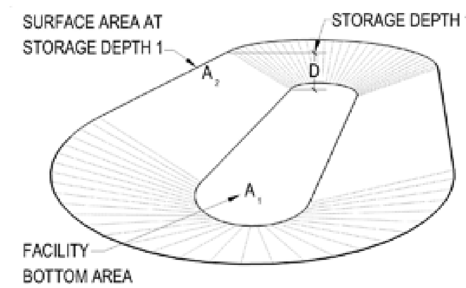
X = Side slope, (X:1) (H:V)

$P_{len}$ = Perimeter length of facility bottom area in ft

$A_1$ = Bottom surface area of surface facility in square ft

***User Defined***

The PAC calculates volume by the depth times the average of the top and bottom surface areas per the following equation:




$$V_{single-stage} = \frac{A_1 + A_2}{2}$$

$$V_{dual-stage} = \frac{A_1 + A_2}{2} + \frac{A_2 + A_3}{2}$$

Where:

V = Storage in cubic ft

D = Depth of surface facility in ft

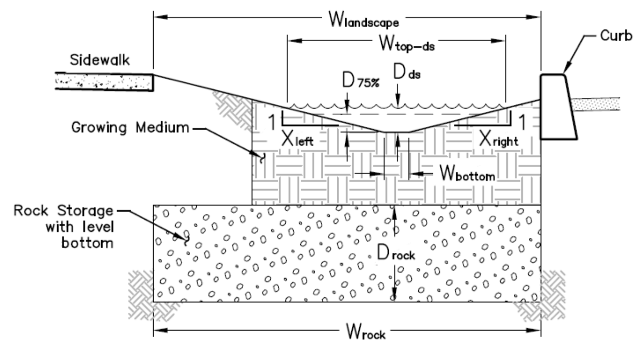
$A_1$ = Bottom surface area of surface facility in square ft

$A_2$ = Surface area of surface facility at depth D in square ft

$A_3$ = Surface area of surface facility at secondary overflow depth (Configuration E only)

***Swale***

The swale facility type requires a more complex calculation to accurately model the infiltration area and surface storage volume than the calculation methodologies for the different basin shapes. These values are greatly affected by the swale size, shape, depth, number of segments, check dams and slope of the adjacent grade as well as configuration type. The PAC automates the calculation of these values given specific customizable swale parameters.

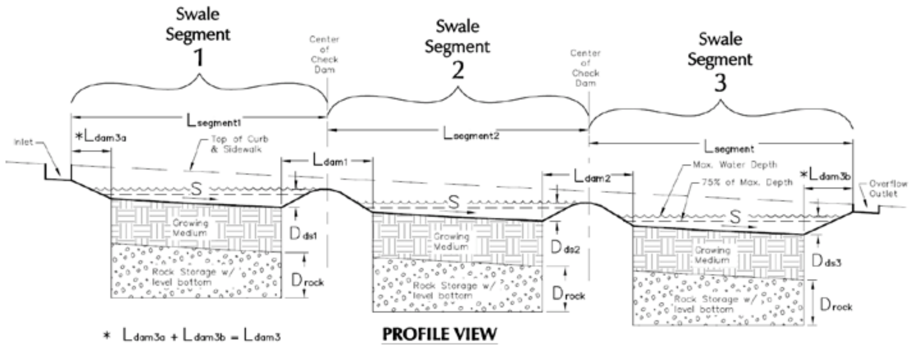


TYP. CROSS-SECTION

For Facility Configuration: A-D, E or F:

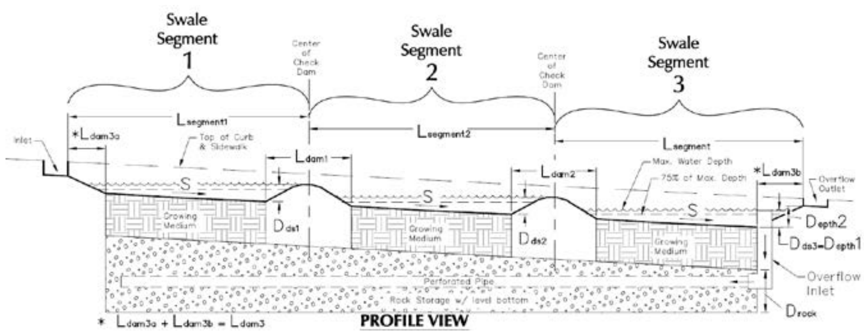
- # = Number of swale segments
- $L_{segment}$ = Length of swale segment
- $L_{dam}$ = Check Dam Length
- *S* = Longitudinal Swale Slope
- $W_{bottom}$ = Typical Bottom Width
- $X_{right}$ *:1* = Side Slope of right side of swale
- $X_{left}$ *:1* = Side Slope of left side of swale
- $D_{ds}$ *aka Depth 1 =* Downstream depth of swale created by a check dam or the overflow outlet
- $W_{landscape}$ = Width of landscape, usually measured from back of curb to sidewalk
- $W_{rock}$ = Width of rock storage layer
- $D_{rock}$ = Depth of rock storage
- *V* = Rock porosity
- *Depth 2* = Only used with configuration E. Maximum storage depth for above grade storage component before overtopping to the approved discharge. Refer to graphic of swale configuration E below.
- *Depth 3* = Only used with configurations C & F. Depth of rock storage available between the bottom of the facility and the invert of the outlet pipe. Refer to graphic of swale configuration F below.

For Facility Configurations A[1], B, C & D[2]

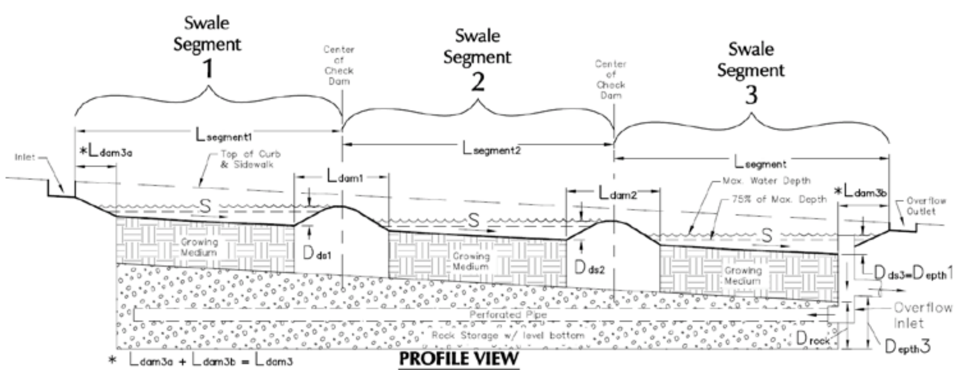



- [1] For Configuration A, rock storage is eliminated.
- [2] For Configurations C & D, all rock storage segments contain an underdrain that conveys filtered runoff to an approved discharge point.

For Facility Configuration E




For Facility Configuration F



The below equations use the entered parameters to ultimately solve for:

- $V_{surface}$ = surface volume
- $A_{75\%}$ = Infiltration Area @ 75% Full
- $A_{rock}$ = Rock Storage Bottom Area
- $V_{rock}$ = Rock Storage Volume

***Swale Equations***

$L_{adjust} = L_{segment} - \frac{1}{2} L_{dam}$ If $D_{up\,=}$ 0, then calculate $L_{adjust2}$

$$L_{adjust2} = {D_{ds}}/{S}$$

$D_{us} = D_{ds} - SL_{adjust}$ If $D_{up}$ < 0, then $D_{us}$ is set to 0. If using configuration E, replace $D_{ds}$ with Depth 2

$$W_{top-ds} = W_{bottom} + D_{ds}X_{right} + D_{ds}X_{left}$$

$$W_{top-us} = W_{bottom} + D_{us}X_{right} + D_{us}X_{left}$$

$A_{ds} = \frac{1}{2}\left(W_{bottom} + W_{top-ds}\right)D_{ds}$ If using configuration E, replace $D_{ds}$ with Depth 2

$$A_{ds} = \frac{1}{2}\left(W_{bottom} + W_{top-us}\right)D_{us}$$

$V_{surface} = \frac{1}{2}(A_{ds} + A_{us})L_{adjust}$ If $D_{up}$ = 0 , replace $L_{adjust}$ with $L_{adjust2}$

$$D_{75\%ds} = \frac{3}{4} D_{ds}$$

$D_{75\%Us} = D_{75\%ds} - SL_{adjust}$ If value <0 , then $D_{75\%us}$ is set to 0

$L_{adjust3} = {D_{75\%ds}}/{S}$

$$W_{top-75\%ds} = W_{bottom} + D_{75\%ds}X_{right} + D_{75\%ds}X_{left}$$

$$W_{top-75\%us} = W_{bottom} + D_{75\%us}X_{right} + D_{75\%du}X_{left}$$

$A_{75\%} = \frac{1}{2}\left(W_{top-75\%ds} + W_{top-75\%us}\right)L_{adjust}$ If $D_{75\%us}$ = 0 , replace $L_{adjust}$ with $L_{adjust3}$

$$L_{rock} = L_{segment} - L_{dam}$$

If using configuration E or F, replace equation with…

$$L_{rock} = \sum_{i=1}^{n} L_{segment,i} - L_{dam,n}$$

$$A_{rock} = W_{rock} L_{adjust}$$

$$V_{rock} = W_{rock} L_{adjust} D_{rock} \varphi_{rock}$$

If using configurations C or F, replace $D_{rock}$ with Depth 3 where Depth 3 < $D_{rock}$

***Rock Storage***

The volume of the rock storage is calculated by treating it as a box with a given porosity where:

$V = A_1 D v$

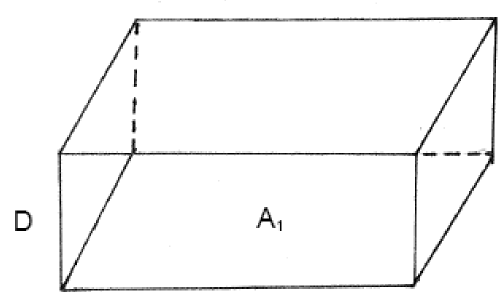
Where:

V = Storage in cubic ft

$A_1$ = Bottom surface area of rock storage in square ft

D = Depth of rock storage in ft

$v$ = Porosity of rock




## Reservoir Routing

Reservoir routing is a method for routing a modeled storm hydrograph through a modeled reservoir (in this case a surface infiltration facility) in order to determine the peak flow attenuation and flow storage that occurs. This process changes the pattern of flow with respect to time. The purpose of reservoir routing is usually to reduce and delay the peak flow. The routing procedure used by the PAC accounts for the infiltration through both the growing medium and the native soil with a two-stage calculation (with the exception of Facility Configurations C & D that use only the first of the two-stage calculation).

## Two-Stage Calculations

The PAC uses the methodology summarized above for both the above grade portion of the surface infiltration facility as the runoff passes through the growing medium, as well as the rock storage reservoir at the interface with the native subgrade. The routing process is similar to most hydrologic analysis software packages to size detention or infiltration facilities. However, the primary difference is that the PAC has the capability of running a two-stage calculation, or two reservoir routing models run concurrently so the performance of the second stage calculation (below grade) can influence the performance of the first stage calculations (above grade). The two stage calculations are performed for each modeled storm event, and the output hydrograph from the first stage calculation serves as the inflow hydrograph for the second.

### Stage I Calculations

The first stage of the two-stage calculation evaluates the performance of the above grade storage component. The percolation capacity of this component is a fixed rate based on the Facility Bottom Area for Planters or the infiltration area at 75% of Depth 1 for Swales and Basins times the infiltration rate of the growing medium (assumed to be 2 inches per hour). The PAC routes the storm event through the surface facility tracking the volume that percolates and the excess volume that is stored in the above grade storage component. As the modeled storm event subsides, the PAC continues to track the stored volume of runoff as it percolates through the growing medium. Runoff does not reach the below grade storage component until it has passed through the growing medium or overtopped the bypass pipe to the rock storage in Facility Configurations E or F. Any flows that overtop to the approved discharge under Facility Configurations A, B, C & D are tracked separately and are not rerouted to the below grade storage. Depending upon the Facility Configuration, the model will sometimes include a lag time based on the depth and infiltration rate of the growing medium. (See 3.6 for discussion of lag time.)

For Facility Configuration A where there is no below grade rock storage, the PAC uses the lesser infiltration capacity of the surface facility or below grade area. The PAC assumes a constant infiltration capacity for the surface storage that does not vary as the water level rises or falls and wets the side slopes. However, the PAC does track the rock storage capacity during the concurrent Stage II Calculations for Facility Configurations B & E. If the rock storage becomes full at a particular time step of the calculations, then the PAC compares the above grade and below grade infiltration capacity and uses the lesser of the two infiltration rates until the rock storage volume is less than full. This allows the model to limit the rate of percolating or overflowing water into the rock storage during the Stage I calculations that cannot be accommodated below grade.

This influence of the below grade capacity does not affect Facility Configuration D since the facility assume no infiltration and a free flowing rock subgrade; thus, the PAC does not perform the Stage II Calculations for Configuration D. For Facility Configurations C and F, the below grade capacity does not influence the infiltration capacity of the surface facility, since the below grade overflow to approved discharge will alleviate any backwater effect created by a full rock storage condition.

### Stage II Calculations

The second stage of the two-stage calculation evaluates the performance of the below grade storage component. The percolation capacity of this component is a fixed rate based on the Rock Storage Bottom Area and the design infiltration rate of the native soil at the bottom of the facility. The PAC does not account for any increased head or wetted side slopes to increase the infiltration capacity. The PAC routes flows that percolate through the growing medium, or that enter the bypass pipe to the rock storage with Facility Configurations E or F, that are generated by the Stage I calculations. The PAC assumes free vertical and lateral flow through the drain rock and tracks the volume of water that reaches the native subgrade and any excess volume that is stored in the below grade storage component. If the below grade storage capacity is exceeded at any particular time step for Facility Configurations B or E, the PAC will limit the amount of water that can pass through the growing medium or bypass pipe (Facility Configuration E only), and influence the outflow from the Stage I calculations. In some cases where there is a lag time modeled for the flows percolating through the growing medium, and the modeled percolating flows encounter a full rock storage condition, then under Facility Configurations B or E the PAC evaluates whether there is any available capacity in the above grade storage component and adds the incremental volume to the surface storage as available. (See 3.6 for discussion of lag time.) If the surface storage is also full, then the incremental flow is added to any overtopping flows to the approved discharge at that time step. The Stage II calculations are skipped for Facility Configuration D, as the rock subgrade is assumed to be free flowing to the underdrain pipe and no below grade infiltration calculations are necessary. The Stage II Calculations are performed for Facility Configuration F, but any flows that cause the rock storage to exceed capacity are routed to the overflow pipe without influencing the Stage I Calculations.

### *Facility Configuration A or B*

Facility configuration A uses only a single-stage calculation. Configuration B uses the two-stage calculation. In the first stage of the calculations, the flow that percolates through the growing medium is tracked at each time step. The flows follow the inflow hydrograph up to the surface facility infiltration capacity flow rate. Note that the surface infiltration capacity can be affected by the below grade storage capacity. Any inflow that exceeds this infiltration capacity will be stored in the above grade portion of the surface facility, rounded up to the next 10 cubic feet, and be tracked at each time step. If the surface capacity of the facility is exceeded, an overtopping flow at each time step is generated. Any overtopping flows generated during the first stage of the calculations are illustrated in the Stage I graph as "Flow Overtopping to Approved Discharge". For Configuration B, the PAC also generates a separate outflow hydrograph that is limited to the runoff that percolates through the growing medium with a lag time rounded up to the next 10 minutes.

This separate outflow hydrograph from the first stage is the inflow hydrograph for the second stage calculations. Just like the Stage I calculations, the flow that infiltrates to the native subgrade is tracked at each time step and any required storage volume in the below grade rock storage portion of the facility is also tracked at each time step. If the rock storage capacity is exceeded during any particular time step, the PAC compares the above grade and below grade infiltration capacity. Since the below grade and above grade storage are hydraulically connected, it is important to identify when the full condition occurs so that the Stage I infiltration capacity can be reduced if the Below Grade Infiltration Capacity is less than the Above Grade Infiltration Capacity. The model can account for this reduction in infiltration capacity because the Stage I and Stage II calculations are run concurrently.

Note that for Facility Configuration A there is no rock storage, and the below grade storage component is assumed to be 100% full. The calculations are still the same. As noted above, when the Stage II calculations indicate that the below grade storage is full, the PAC compares the above grade and below grade infiltration capacity and models the Stage 1 calculations with the lesser of the two. Since the flows reaching the native soil are limited to what can pass through the growing medium, then the below grade infiltration capacity should never be exceeded and the flows into the "rock storage" would equal the flow capacity out. Any overtopping flows from the Stage 1 calculations represent the output hydrograph for each modeled storm event.

A facility should not overtop during the first stage of the calculations for a modeled PR storm event to meet pollution reduction requirements. A facility with a hierarchy goal of category 1 should not overtop to during a modeled 10-yr storm event during first stage calculations.

***Facility Configurations C or D***

Two-stage calculations are used for these configurations. Configuration D assumes a zero-volume rock gallery, and an impervious native infiltration rate, effectively bypassing the stage-two calculation.

In the Stage I calculations, the flow that percolates through the growing medium is tracked at each time step. The flows follow the inflow hydrograph up to the surface facility infiltration capacity flow rate. Any inflow that exceeds this infiltration capacity will be stored in the above grade portion of the surface facility, rounded up to the next 10 cubic feet, and be tracked at each time step. If the surface capacity of the facility is exceeded, an overtopping flow at each time step is generated. The PAC also generates a separate outflow hydrograph that is limited to the runoff that percolates through the growing medium with a lag time. Since the overtopping “riser” and the underdrain are hydraulically connected the “Flow Overtopping to Approved Discharge” includes the overtopping hydrograph.

The percolation hydrograph from the Stage I calculations is the input hydrograph for the Stage II calculations. Just like the Stage I calculations, the flow that infiltrates to the native subgrade is tracked at each time step and any required storage volume in the below grade rock storage portion of the facility is also tracked at each time step. If the rock storage capacity is exceeded during any particular time step, the PAC immediately adds the excess to the overflow hydrograph, “Flow Overtopping to Approved Discharge”, with along with overflows from Stage I calculations.

A facility that overtops the modeled PR storm event does not meet the pollution reduction requirements.

***Facility Configuration E***

This facility configuration uses the two-stage calculations. In the first stage of the calculations, the flow that percolates through the growing medium is tracked at each time step. The flows follow the inflow hydrograph up to the surface facility infiltration capacity flow rate. Note that the surface infiltration capacity can be affected by the below grade storage capacity. Any inflow that exceeds this infiltration capacity will be stored in the above grade portion of the surface facility, rounded up 10 cubic feet, and be tracked at each time step. As the surface capacity of the facility at Depth 1 is exceeded, an overtopping flow at each time step is generated. The model assumes that all flow generated in this overtopping condition is directed to the rock storage. None of this flow is directed to the “riser” at Depth 2 at this point in the calculations. The combined flows of the runoff percolating through the growing medium with a lag time, and the flows overtopping the “riser” at Depth 1 represent the outflow hydrograph for each modeled storm event.

This combined outflow hydrograph from the first stage is the inflow hydrograph for the second stage calculations. Just like the Stage I calculations, the flow that infiltrates to the native subgrade is tracked at each time step and any required storage volume in the below grade rock storage portion of the facility is also tracked at each time step. If the rock storage capacity is exceeded during any particular time step, the PAC compares the above grade and below grade infiltration capacity. Since the below grade and above grade storage are hydraulically connected, it is important to identify when the full condition occurs so that the Stage I infiltration capacity can be potentially reduced to the Below Grade Infiltration Capacity in the event that it is less than the Above Grade Infiltration Capacity. The PAC can account for this reduction in infiltration capacity because the Stage I and Stage II calculations are run concurrently.

At some point in the model these flows overtopping the “riser” at Depth 1, or in some cases the percolating flows from the Stage I calculations when a lag time is applied, the model will try to add flows to the below grade storage when it is already full. When this occurs the PAC will take this excess volume at each time step and add it to the surface storage volume at the corresponding time step. The calculations then evaluate whether the surface storage volume exceeds the surface capacity at Depth 2. Any overtopping flows are illustrated in the Surface Facility Modeling graph as “Overflow to Approved Discharge”.

A facility should not overtop to the approved discharge during the first stage of the calculations for a modeled PR storm event to meet pollution reduction requirements. A facility with a hierarchy goal of Category 2 should not overflow to the approved discharge during a modeled 10-yr storm event.

***Facility Configuration F***

This facility configuration uses the two-stage calculations. In the first stage of the calculations, the flow that percolates through the growing medium is tracked at each time step. The flows follow the inflow hydrograph up to the surface facility infiltration capacity flow rate. Since the outflow pipe to the approved discharge is provided below grade, the surface infiltration capacity will not be affected by the below grade storage capacity. Any inflow that exceeds this infiltration capacity will be stored in the above grade portion of the surface facility, rounded to the next 10 cubic feet, and be tracked at each time step. As the surface capacity of the facility at Depth 1 is exceeded, an overtopping flow at each time step is generated. The model assumes that all flow generated in this overtopping condition is directed to the rock storage. None of this flow is directed to the “Overflow to Approved Discharge” at this point in the calculations. The combined flows of the runoff percolating through the growing medium with a lag time and the flows overtopping the “riser” at Depth 1 represent the outflow hydrograph for each modeled storm event.

This combined outflow hydrograph from the first stage is the inflow hydrograph for the second stage calculations. Just like the Stage I calculations, the flow that infiltrates to the native subgrade is tracked at each time step and any required storage volume in the below grade rock storage portion of the facility is also tracked at each time step. If the rock storage capacity is exceeded during any particular time step, an overtopping flow is generated. Any overtopping flows generated during the second stage of the calculations are illustrated in the Below Grade Modeling graph as “Overflow to Approved Discharge”.

A facility should not overtop to the approved discharge during the second stage of the calculations for a modeled PR storm event to meet pollution reduction requirements. A facility with a hierarchy goal of Category 2 should not overflow to the approved discharge during a modeled 10-yr storm event.

## Overflow Calculations

In the event that the project designer has selected a facility configuration that assumes no infiltration, the second stage calculation is not necessary and the outflow hydrograph from the first stage represents the outflow from the facility. When an infiltration facility is selected, both the first and second stage calculations are performed. Since these facilities are designed to infiltrate at least a portion of the storm event, the outflow from the facility is only the portion of the catchment runoff that overflows to the discharge point.

In addition, some facilities can be sized as Stormwater Hierarchy Category 2, and release to a downstream facility that is sized for infiltration, such as a drywell UIC. In these cases an overflowing condition is acceptable, and the PAC can track the outflow hydrograph that overflows the facility. The project designer can export the output hydrograph table from the PAC for use in a separate detention sizing software to gain “partial credit” for the flow attenuation provided by the facility.

### Lag Time

The PAC calculations account for a lag time or delay before reaching the below grade storage for water that percolates through the growing medium. In accordance with the SWMM guidelines, the presumed infiltration rate for the growing medium is 2 inches per hour. As the water passes through the growing medium it moves more quickly than 2 inches per hour. Similar to water passing through a funnel, the water from the surface must travel more quickly through the smaller voids in the growing medium per the continuity equation:

$$Q = \bar{V}A$$

Where:

$Q$ = Flow

$\bar{V}$ = Average Velocity

$A$ = Cross Sectional Area of Pore Space

As a unit of volume of water percolates from the surface, that same volume of water enters the growing medium. Within a square foot of soil, the cross-sectional area available to transmit water is equal to the porosity, or void fraction, $\varphi$

$$Q/_{ft^2} = \bar{V}\varphi$$

The growing medium is estimated to have 30% void space ( $\varphi_{GM}$ ) as opposed to the surface that has 100% void space ( $\varphi_{SURF}$ ). Instead of traveling 2 inches per hour through the growing medium, the water moves at $6.\overline{6}$ inches per hour, taking 2.7 hours to pass through an 18 inch depth of growing medium. These values are derived from the following equations:

$$Q_{surf} = Q_{gm}$$

$$\bar{V}_{surf}\varphi_{surf} = \bar{V}_{gm}\varphi_{gm}$$

$$\frac{2in}{hr} * 1 = \bar{V}_{gm} * 0.3$$

$$\bar{V}_{gm} = \frac{6.\overline{6}in}{hr}$$

$$t = \frac{\overline{D}_{gm}}{\overline{V}_{gm}} = \frac{18in}{\frac{6.\overline{6}in}{hr}} = 2.7hrs = 162min$$

The PAC model calculates hydrograph values on 10-minute intervals. The lag time is rounded up to the next 10-minute interval. Thus, a lag time of 0.1 minute would shift the outflow hydrograph one interval, or 10 minutes. A time lag of 162 minutes would shift the outflow hydrograph 17 intervals, or 170 minutes.

There are some conditions where the lag time is not applied to the calculations. The lag time is always applied to Facility Configurations C, D and F, but the lag time is reduced to zero under Facility Configurations A, B and E when the below grade infiltration capacity is less than the above grade infiltration capacity. The reason for this discrepancy is to minimize the potential for the model to allow surface flows to percolate through the growing medium with the Stage I calculations during a time step when the rock storage below is already full. When there is no lag time, the Stage I calculations recognize the full below grade condition immediately and limit the surface percolation rate during the same time step to the slower below grade infiltration capacity. There are instances where this can still occur, but the PAC calculations try to accommodate for this by adding the flows back to the surface storage at the corresponding time step.

## Sizing Methodology

The reservoir routing process of the PAC sizing tool is similar to the Storage Indication Method used in most hydrologic software.

The equation used to evaluate the facility at each time step without overtopping is:

$$V_{IN} - V_{OUT} = V_{STORAGE\_REQUIRED}$$

Where:

$$V_{STORAGE\_REQUIRED} < V_{STORAGE\_AVAILABLE}$$

Where:

$V_{IN}$ = Stormwater volume into the facility every 10 minute interval (runoff from site)
$V_{OUT}$ = Stormwater volume out of the facility every 10 minute interval (infiltration through growing medium)
$V_{STORAGE\_REQUIRED}$=Cumulative difference of $V_{IN}$ - $V_{OUT}$
$V_{STORAGE\_AVAILABLE}$ = Total reservoir volume available to store $V_{STORAGE\_REQUIRED}$

$V_{IN}$ is calculated using the Santa Barbara Urban Hydrograph method with a NRCS Type 1A storm distribution at a 10-minute interval with the following assumptions or project designer supplied data entry:
$P$ =24-hour model storm event precipitation per BES in inches (PR, 2-yr, 5-yr, 10-yr or 25-yr event)
$A$ = Impervious area of catchment draining to facility in acres
$CN$ = Weighted curve number for impervious area
$T_c$ = Time of concentration for catchment area in minutes (5 minutes minimum)

This yields a runoff flow rate ($Q_{IN}$) for every 10 minute interval ($T_{10min}$) throughout the storm event.

$V_{IN}$ at each time step can now be calculated from:

$$Q = \frac{V}{T}$$

$$\therefore V_{IN} = Q_{IN} * T_{10min}$$

$V_{OUT}$ at each time step is obtained by first calculating the infiltration flow rate ($Q_{OUT}$) through the growing medium or native subsoil, depending upon the stage being modeled, using the following:

$$I * A_{75\%} = Q_{OUT}$$

$$\therefore V_{OUT} = Q_{OUT} * T_{10min}$$

Where:

I = Soil infiltration rate = 2 inches/hour for growing medium or the design infiltration rate for the native soil (field tested rate with a correction factor applied). The soil infiltration rate is then converted from inches/hour to ft/sec.

$A_{75\%}$ = Vertically projected area of the facility at 75% of the maximum depth. Bottom area where infiltration occurs in square feet (bottom area of surface facility or bottom area of rock storage).

$V_{STORAGE\_AVAILABLE}$ at each time step is obtained by first calculating:

$$V_{IN} - V_{OUT} = V_{DIFF}$$

If: $V_{DIFF} \leq 0$ then $V_{OUT}$ exceeds $V_{IN}$ and the facility remains empty or empties by that amount if the facility had previously stored excess runoff during previous 10 minute intervals.

If: $V_{DIFF} > 0$ then $V_{IN}$ exceeds $V_{OUT}$ and the facility will need to store the excess

volume as well as any excess volume from previous 10 minute intervals where this was also true.
Therefore, cumulative required storage volume is calculated after each 10 minute interval at some time t+n by the following:

$$V_{DIFF,t} + V_{DIFF,t+1} + V_{DIFF,t+2} \dots V_{DIFF,t+n} = \sum_{i=t}^{n} V_{DIFF,i} = V_{STORAGE\_REQUIRED,t+n}$$

$V_{STORAGE\_AVAILABLE}$ at each time interval can then be obtained from the following:

$$V_{STORAGE} - V_{STORAGE\_REQUIRED} = V_{STORAGE\_AVAILABLE}$$

Where:
$V_{STORAGE}$ =Total reservoir volume below overflow or outflow structure (facility reservoir capacity)
If: $V_{STORAGE\_AVAILABLE} < 0$ then the facility will overflow, and conversely
If: $V_{STORAGE\_AVAILABLE} \geq 0$ then the facility will have capacity.

At some point in time during the storm, the inflow will be less than the infiltration capacity. Any water stored above grade will then be added to the inflow hydrograph until it is depleted.

If: $Q_{IN} < Q_{CAP}$ and $V_{STORED} > 0$, then $Q_{OUT} = Q_{IN} + Q_{STORAGE}$

where $Q_{STORAGE}$ is the lesser of $Q_{CAP} - Q_{IN}$ and $\frac{V_{STORED}}{\Delta t}$, rounded up to the next 10 cubic feet.

The PAC evaluates the results from the reservoir routing and identifies whether the facility is predicted to overtop during a particular storm event. A “PASS” or “FAIL” result is generated depending upon the hierarchy goals selected for the facility. The PAC further identifies the maximum % capacity of the above grade and below grade storage components to allow the designer to optimize the design. If the facility fails to infiltrate the entire modeled storm event, it will identify the volume of overflow. When Stormwater Hierarchy Category 3 or 4 is selected, the PAC will generate an output hydrograph for multiple modeled storm events.

## Glossary

***BOTTOM OF FACILITY.*** Bottom of facility is where the facility interfaces with the native subgrade. This is either at the bottom of the rock storage or at the bottom of the growing medium where no below grade rock storage is provided.

***BOTTOM PERIMETER LENGTH.*** Dimension in feet of the perimeter measured at the toe of side slopes for basins with an amoeba shape.

***BOTTOM WIDTH.*** Dimension in feet (either length or width) between toe of side slopes for basins or between sidewalls for a planter at the bottom of the above grade storage component.

***CATCHMENT.*** The extent of a drainage basin that contributes to a specific stormwater facility. The area can be from one surface or a combination of impervious surfaces, such as roof area and hardscape.

***CORRECTION FACTOR COMPONENT.*** Variable correction factor applied to field tested native soil infiltration rate based on the infiltration testing procedure (See Section 2.3.6).

***DESIGN INFILTRATION RATE***. Infiltration rate used in PAC calculations for Native or Imported Growing Medium. Design infiltration rate for growing medium is fixed at 2 inches per hour per BES SWMM guidelines. Design infiltration rate for the native soils is the field-tested infiltration rate with a correction factor applied.

***FACILITY BOTTOM AREA.*** Surface area in square feet of the above grade storage component at stage zero. Area measurements limited to “level” area at toe of side slopes for basins or at the sidewall for a planter.

***FACILITY CONFIGURATION.*** Pipe and facility configuration applied to any of the three facility types. Selection determines the calculations performed when sizing the facility.

***FACILITY SHAPE.*** Various facility shapes with different volume calculations to more accurately estimate surface volumes. Amoeba shape is an organically-shaped facility that has both convex and concave curves. Rectangle/Square shape is a rectilinear facility. User Defined shape facilities allow data entry of surface areas at stage zero and at the defined Depth 1. The Amoeba or Rectangle/Square shapes use the side slope to calculate volumes and allow the project designer to vary the depth of the facility without having to recalculate a new surface area with each iteration.

***FACILITY SIDE SLOPE***. The horizontal component for the side slope on the above grade storage component of the facility based on the following X:1 (H:V).

***FACILITY TYPE.*** Type of surface infiltration facility including Swale, Planter or Basin. Different design criteria apply to each facility type. Refer to Section 2.3 for additional discussion of each facility type.

***FREEBOARD.*** The vertical distance between the overflow elevation (design water surface elevation) and the elevation at which overtopping of the structure or facility that contains the water would occur.

***GROWING MEDIUM DEPTH.*** Depth of imported growing medium in inches. A deeper section of growing medium can increase the lag time before the percolating runoff reaches the underdrain or below grade rock storage.

***HIERARCHY CATEGORY.*** Stormwater management requirement for discharge/infiltration. The Hierarchy was set up to protect the watershed health and mimic pre-developed hydrologic conditions to the maximum extent feasible. Refer to Section 1.3.1 for further discussion of Stormwater Hierarchy Categories 1 through 4.

***IMPERVIOUS AREA***. Projected area of impervious surfaces collected within the catchment in square feet.

***PRE-DEVELOPMENT CURVE NUMBER, CNpre***. Weighted curve number at pre-developed conditions (Lewis & Clark era) for the area requiring stormwater management. Refer to Santa Barbara Urban Hydrograph Method for CN values of different impervious surfaces.

***POST-DEVELOPMENT CURVE NUMBER, CNpost.*** Weighted curve number value for the post-development impervious area requiring stormwater management. Refer to SWMM Appendix C.1 for CN values of different impervious surfaces.

***INFILTRATION AREA @ 75% DEPTH 1.*** Calculated water surface area when surface facility is filled to 75% of maximum depth at Depth 1. This value is multiplied by the Growing Medium Design Infiltration Rate to determine the infiltration capacity for the above grade storage component.

***INFILTRATION CAPACITY.*** Calculated infiltration capacity for above grade and below grade storage components of the facility. The value is the product of the Design Infiltration Rate and the surface area allocated to infiltration.

***INFILTRATION TESTING PROCEDURE.*** Test procedure used to measure field infiltration rates of native subgrade. Refer to Section 2.3.6 for direction on number and locations of testing and how to report results for multiple infiltration tests.

***NATIVE SOIL FIELD TESTED INFILTRATION RATE (ITEST).*** Field tested infiltration rate of native subgrade. Refer to Section 2.3.6 for direction on number and locations of testing and how to report results for multiple infiltration tests.

***OVERFLOW VOLUME.*** Calculated volume of water that overflows to the downstream facility, the discharge point, or the escape route during the PAC calculations for the respective storm event.

***POLLUTION REDUCTION (PR).*** The Pollution Reduction (PR) storm event is representative of 90% of the average annual rainfall and is used to size pollution reduction facilities. Refer to Stormwater Pollution Reduction Storm for additional discussion of the PR storm precipitation.

***ROCK CAPACITY USED.*** The maximum calculated percentage of rock storage capacity used during the PAC calculations for the respective storm event.

***ROCK STORAGE BOTTOM AREA.*** Surface area in square feet of the below grade storage component at the bottom of facility. Side slopes for below grade storage are assumed to be vertical and area measurements are limited to “level” area at toe of side walls. Rock storage bottom area cannot exceed surface area at maximum above grade storage depth for basins, the landscape area for swales, or the limits of the sidewalls for planters.

***ROCK STORAGE CAPACITY.*** Storage capacity of below grade rock storage. This value is calculated by multiplying the total volume of the below grade rock available for storage by the porosity for the rock material.

***ROCK STORAGE DEPTH.*** Depth of below grade rock storage in inches.

***ROCK POROSITY.*** Void fraction of rock placed in below grade storage component. Porosity can vary for a variety of aggregate.

***SIZING RATIO.*** Ratio of total area of the facility to the impervious catchment area.

***STORAGE DEPTH 1.*** Maximum storage depth in inches for the above grade storage component before overtopping to the offsite discharge point/overflow riser.

***STORAGE DEPTH 2.*** Maximum storage depth in inches for above grade storage component before overtopping to the offsite discharge point.

***STORAGE DEPTH 3.*** Depth of rock storage available in inches between the Bottom of Facility and the invert of the outlet pipe.

***SURFACE AREA AT STORAGE DEPTH 1.*** Surface area in square feet of the above grade storage component at stage Depth 1 for User Defined Facility Shape.

***SURFACE AREA AT STORAGE DEPTH 2.*** Surface area in square feet of the above grade storage component at stage Depth 2 for User Defined Facility with Facility Configuration E.

***SURFACE CAPACITY USED.*** The maximum calculated percentage of surface storage capacity used during the PAC calculations for the respective storm event.

***SURFACE CAPACITY @ DEPTH 1.*** The calculated surface storage volume available at Depth 1 based on the dimensional data provided for the facility.

***SURFACE CAPACITY @ DEPTH 2.*** The calculated surface storage volume available at Depth 2 based on the dimensional data provided for the facility.

***TIME OF CONCENTRATION, Tc, MINUTES.*** The amount of time it takes stormwater runoff to travel from the most distant point (measured by travel time) on a particular site or drainage basin to a particular point of interest.

***TOTAL FACILITY AREA.*** Calculated top area in square feet of a facility based on the dimensional data entered on the PAC. For a basin, this includes the freeboard area of the facility and for a swale this includes the entire width of the landscape strip.

## Allowed and Recommended Ranges

| Data Field | Facility Types | Recommended Range | | Unacceptable values | Default Value |
|---|---|---|---|---|---|
| | | Minimum | Maximum | | |
| **Impervious Area** | n/a | 0 | 43,560 | ≤0 | 0 |
| **Pre-Development Curve Number** | n/a | 0 | 100 | ≤0, ≥100 | 72 |
| **Post-Development Curve Number** | n/a | 0 | 100 | ≤0, ≥100 | 98 |
| **Time of Concentration (min)** | n/a | 0 | 50 | ≤0 | 5 |
| **$I_{(test)}$ for Native Soil (in/hr)** | n/a | 0.5 | 20 | ≤0 | 0 |
| **Storage Depth 1 (in)** | Planter | 6 | 18 | ≤0 | - |
| **Storage Depth 2 (in)** | Planter | 6 | 18 | <Storage Depth 1 | - |
| **Facility Side Slope, h/v (ft/ft)** | Basin | 3 | 10 | <0 | 3 |
| **Storage Depth 1 (in)** | Basin | 6 | 36 | ≤0 | - |
| **Storage Depth 2 (in)** | Basin | 6 | 36 | <Storage Depth 1 | - |
| **Bottom Perimeter Length (ft)** | Basin | Circumference of a circle with the stated facility bottom area | n/a | <Circumference of a circle with the stated facility bottom area | - |
| **Surface Area at Storage Depth 1 ($ft^2$)** | Basin | Facility Bottom Area | n/a | ≤0 | - |
| **Surface Area at Storage Depth 2 ($ft^2$)** | Basin | Surface Area at Storage Depth 1 | n/a | <Surface Area at Storage Depth 1 | - |
| **Freeboard (in)** | Basin (Rectangular, Amoeba) | 0 | n/a | <0 | - |
| **Facility Bottom Area ($ft^2$)** | Planter/Basin | 10 | n/a | ≤0 (Flat Planter)<br><0 (Basin) | - |
| **Facility Bottom Width (ft)** | Planter/Basin | 2 | n/a | <0 (Basin, Planter)<br>≤0 (Flat planter) | - |
| **Growing Medium Depth (in)** | Planter/Swale/Basin | 18 | 36 | ≤0 | 18 |

| Data Field | Facility Types | Recommended Range | | Unacceptable | Default |
|---|---|---|---|---|---|
| **Rock Storage Bottom Area ($ft^2$)** | all | 0 | Facility Surface Area at Max Depth | <0 | - |
| **Rock Storage Depth (in)** | Planter/Basin | 6 | 48 | ≤0 | 12 |
| **Rock Porosity ($ft^3/ft^3$)** | all | 0.3 | 0.4 | ≤0, ≥1 | 0.3 |
| **Storage Depth 3 (in)** | all | 6 | Rock Depth + Growing Medium Depth | <0 | - |
| **Segment Length (ft)** | Swale | 5 | n/a | ≤0 | 6 |
| **Check Dam Length (ft)** | Swale | 2 | n/a | <0 | 1 |
| **Slope, v/h (ft/ft)** | Swale | 0 | n/a | <0 | 0.02 |
| **Swale Bottom Width (ft)** | Swale | 0 | n/a | <0 | 2 |
| **Right Side Slope, h/v (ft/ft)** | Swale | 3 | 10 | <0 | 3 |
| **Left Side Slope, h/v (ft/ft)** | Swale | 3 | 10 | <0 | 3 |
| **Downstream Depth (in)** | Swale | 6 | 12 | ≤0 | 9 |
| **Landscape Width (ft)** | Swale | 4 feet or bottom width and width from side slopes | n/a | ≤0 | 8 |
| **Rock Width (ft)** | Swale | 0 | Landscape Width | ≤0 | 8 |
| **Rock Depth (in)** | Swale | 0 | 48 | ≤0 | 12 |
| **Storage Depth 2 (in)** | Swale | 6 | 12 | ≤0 | - |