MICHIGAN STATE UNIVERSITY

STORM WATER DESIGN STANDARDS

STORM WATER DESIGN PROCEDURE

I. PURPOSE

It is the purpose of these storm water design standards to establish minimum storm water management requirements for all projects that are completed on the Michigan State University (MSU) campus to meet the following objectives:

- Ensure that storm water drainage systems and BMPs are adequate to address storm water management needs within a proposed project area and protect the campus from flooding and degradation of water quality.
- Minimize the degradation of the Red Cedar River.
- Maintain to the greatest extent practicable, balanced pre-development site hydrology in terms of the ratio of storm water runoff, groundwater recharge and evapo-transpiration.
- Keep MSU in compliance with their storm water discharge permit.

Further documentation of the impacts of development on land and water resources and the importance of storm water management can be found in Chapter 2 of the *Low Impact Development Manual for Michigan* (SEMCOG, 2008).

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II. DESIGN PROCESS

The storm water site design process is summarized in ***Table 1***. This process requires definition of the following:

- Sensitive Areas
- Volume Control Criteria
- Storm Water Management Zones
- Adequate Outlet
- Special Cases
- Selection of Best Management Practices

Table 1 – Design Process Flow Chart

Step	Description	Check	Tools
1	Locate site in campus watershed and determine storm water management zones and special cases.		Campus Watershed Map (***Figures 1 – 6***)
2	Designate "disturbance" areas and identify sensitive areas on site.		
3	Identify soil types, pre-development and existing land uses for curve number calculations.		Stormwater Calculator
4	Identify existing flow paths to determine time of concentration.		Stormwater Calculator
5	Layout site, protecting sensitive areas and leaving room for BMPs.		
6	Identify developed land uses for curve number calculations including **non-structural BMPs**.		Stormwater Calculator
7	Calculate time-of-concentration for developed site.		Stormwater Calculator
8	Select and size **structural BMPs** to meet required stream protection volume.	If calculated stream protection volume is not sufficient then return to Step 5. If site constraints preclude meeting the required volume, apply for approval of extended detention approach or consider using storm water credits from regional project.	Stormwater Calculator ED Curves
9	Check peak flows for 10-year and 25-year event (flood control). Check adequate outlet.	If peak developed discharge exceeds allowable peak discharge, calculate required detention storage volume, select **structural BMPs**.	Worksheet 1 Stormwater Calculator Rational Spreadsheet
10	Check safe passage of 100-year flood.		
11	Check that minimum water quality volumes are met.	If not already met through stream protection and flood control measures, select and size **structural BMPs** to meet.	Stormwater Calculator
12	Select and size **structural BMPs** for pre-treatment and spill containment (where necessary).		
13	Complete MSU Stormwater Design Summary Sheet and submit along with detailed design calculations to Stormwater Committee		Stormwater Design Summary Sheet

A. Sensitive Areas

Steps 1 and 2 of the design process require that the site be assessed in regard to its location in the watershed, and inventoried for existing on-site resources and/or special conditions (sensitive areas) that may pose a challenge and/or opportunity for storm water management. Campus Watershed Maps are included as ***Figures 1 – 6***. For the purpose of these rules, sensitive areas include:

1. Floodplains (and floodprone areas)
2. Wetlands
3. Lakes, ponds, rivers, streams and natural drainage ways
4. Soils and topography (steep, erodible)
5. Groundwater supplies (springs, wellhead protection areas)
6. Vegetation (woodlands, other sensitive ecosystems)

Identification of sensitive areas and "disturbance areas" on the site plan is required in Part 1 of this manual. "Disturbance Areas" are categorized as:

- No disturbance area
- Minimal disturbed area
- Construction traffic area
- Topsoil stockpiling and storage area

The watershed-scale assessment is completed by identifying the Storm Water Management Zones and Special Cases that may modify the required storm water volume controls as discussed in the following sections.

B. Volume Control Criteria

Volume-based criteria is essential to mitigate the impacts of urban runoff. Adequate controls are required to reduce channel erosion, maintain groundwater recharge, prevent overbank flooding and meet pollutant removal goals through the use of:

- Stream Protection Volume
- Flood Control Volume
- Water Quality Volume
- Pre-treatment Volume

A summary of sizing criteria is provided in ***Table 2***.

Table 2 – Summary of Standard Sizing Criteria

Volume Control	Minimum Sizing Criteria
Stream Protection *(volume and peak rate control)*	**(1) Onsite Retention:** No net increase in the pre-development runoff volume and rate from the disturbed portion of the site for the 2-year, 24-hour rainfall event. **OR** if site constraints preclude (1): Determine Volume Control Requirement and apply for storm water credit from a regional project.
Flood Control *(peak rate control)*	**If Stream Protection (1) is provided:** Detention of the 25-year, 24-hour rainfall event with a maximum release rate not to exceed the pre-developed 25-year peak runoff rate. **OR** **If Stream Protection (2) is provided:** Detention of the 25-year, 24-hour rainfall event with a 0.10 cfs/acre maximum release rate.
Extreme Flood	Overland flow paths must assure safe passage of 100-year flood events.
Water Quality	Treat runoff from the first 1.0-inch of rain from the directly connected impervious area and disturbed pervious area through settling (permanent pool or extended detention), infiltration, or filtration.
Pre-treatment	Settling basins (forebay): Provide 15% of the water quality volume. **OR** Vegetated Filter Strips and Grassed Swales meeting minimum length, slope and vegetated cover requirements. **OR** Proprietary Treatment Systems (Nutrient box, cyclone separator or bay separator)

1. Red Cedar Hydrology

Evaluation of USGS gage records for the Red Cedar River and hydrologic modeling of the river highlighted factors important to evaluating the impact of new campus development on stormwater runoff. All of the developed areas on campus drain directly into the Red Cedar River; therefore protection efforts are focused entirely on how changes impact the river.

Hydrologic modeling and gage data show that runoff from the urban area (including the MSU campus) occurs about two days before the flood peak on the Red Cedar River. Detention storage that significantly delays stormwater runoff from campus in most cases will increase the peak flow on the river.

The analysis of the river also shows that a significant portion of runoff that occurs at Quick Return Flow (water that infiltrates into the soil and is intercepted by tile drains and storm sewers). This reflects the high water table in the basin and that much of the agricultural land is tile-drained and the urban areas have intense drainage networks. Soil borings throughout campus show a high water table in many areas. When evaluating the change in runoff volume from new development it is important to recognize that many times under existing conditions most of the water that infiltrates is returned to the river quickly through the drainage system. In those cases there may not be significant change in runoff volume.

In conclusion, stormwater protection efforts on campus need to focus on improving the water quality of the Red Cedar River. When addressing the water quantity (volume) standard on campus it is important to recognize the unique hydrologic circumstances of the area.

2. Stream Protection Volume

Retention of a stream protection volume is required to control urban storm water runoff for the smaller, more frequent 1- to 2-year rainfall events (bankfull flood) that have a greater impact on the stability of headwater (or low-order) streams. Retention of the increase in volume for a 2-year storm between pre-developed and post-development conditions is required. Volume control for stream protection may also provide additional benefits by promoting groundwater recharge (that can provide for more stable stream base flows and cooler water temperatures), sustaining wetland hydrology and maintaining floodplain boundaries.

The 2-year storm was selected since 95% or more of the annual average runoff volume will be controlled, including all storms of a lesser frequency (encompassing the bankfull event). A pre-development condition is defined as a maximum runoff condition associated with the existing conditions as of July 1, 2010. The storage provided by the selected criteria will also serve to reduce peak flow rates for larger rainfall events.

Where retention and/or infiltration is not possible due to site constraints, the project design may pursue to offset with the regional project or bank after review by the stormwater committee of the site restraints.

3. Flood Control Volume

Although site-based storm water runoff rate control may help protect the area immediately downstream from a campus project site, the increased volume of runoff and the prolonged duration of runoff from multiple campus project sites can actually increase peak flow rates and duration of flood flows in downstream watercourses. Replicating 2010 runoff volumes for small (2-year) storms will substantially reduce the problem of frequent flooding. When 2-year volume control is provided, detention of storm water runoff for the 25-year flood event with a corresponding 2010 release rate is required to maintain peak flow rates and floodplain levels in downstream watercourses.

Where 2-year volume control is not provided, detention of the 25-year event with an allowable release rate of 0.10 cfs/acre is required. This approach is overly conservative with the allowable release rate to prevent the increase in peak flow rates further downstream as explained in the previous paragraph.

The peak discharge for the extreme flood event must be checked to verify that either infrastructure, overland flow routes and/or floodplains are present to safely convey the storm water runoff.

4. Water Quality Volume

Water quality volume is required to treat the “first flush” of storm water runoff that typically carries with it the highest concentration of pollutants. Capturing the runoff from the 90-percent annual non-exceedance storm is required to effectively treat all runoff from a majority (90%) of storms in a given year. In East Lansing (Michigan Climatic Zone 9), the 90-percent storm is equivalent to 0.91 inches of rain (per MDEQ memo *90 Percent Annual Non-exceedance Storms* dated March 24, 2006).

Capturing and treating runoff from the 90-percent annual non-exceedance storm has been found to generally meet pollutant load targets of:

> 80% decrease in total suspended solids (TSS); or
> discharge concentrations of TSS less than 80 mg/L

A majority of these pollutants build up on the surface of roadways and parking areas. Directly connected disturbed pervious surfaces (primarily lawns) can also contribute pollutant load (i.e. nutrients due to overuse of fertilizer; nutrients and bacteria due to overuse by wild/domestic animals). Impervious surfaces that meet the definition of “disconnected” (see Storm Water Disconnection BMP in Part 3) can be omitted from water quality calculations.

Water quality volume can be provided through one of the following methods:

- Permanent pool
- Extended detention
- Infiltration
- Filtration

The volume of a permanent pool incorporated into a storm water BMP can be counted as water quality volume. This is the volume below the ordinary static water level (also known as dead storage).

Extended detention is defined as holding the storm water runoff volume and releasing it gradually over a longer period of time than provided by conventional detention basins. The minimum extended detention time is 24 hours, and is defined as the time between the centroids of the inflow and outflow hydrographs. The storage volume provided by extended detention can be counted as water quality volume.

The volume of storm water runoff infiltrated into the ground through a storm water BMP can be counted as water quality volume. Guidelines for determining this volume are specified in the calculation credits for each structural infiltration BMP.

The volume of storm water runoff routed through a BMP that provides filtration (i.e. an underdrained BMP) can be counted as water quality volume. In the case of a vegetated filter strip or grassed swale, the filtering area must meet minimum standards for slope, length and vegetative cover for a maximum allowable drainage area to filter strip ratio of 6:1.

5. Pre-Treatment Volume

Pretreatment provides for the removal of fine sediment, trash and debris, and is required to preserve the longevity and function of storm water best management practices, particularly infiltration practices. A minimum pre-treatment volume equivalent to 15% of the water quality volume is required for sediment forebays using gravity. This approximates results given by the Hazen Equation for sediment basin sizing using a 50% settling efficiency for a 50 micron particle (silt) and a 1-year peak inflow. Other methods of pre-treatment including the use of water quality devices and vegetated filter strips or grassed swales are allowed.

Pre-treatment is required for all infiltration BMPs (except pervious pavement), filters and detention basins, and may be necessary for some storm water reuse systems.

C. Adequate Outlet

1. In general, the existing storm sewer pipe network has adequate capacity to accept new storm water flows. The following requirements must be met to avoid adverse impacts to downstream facilities. An adequate outlet worksheet is provided as Worksheet 1.

2. **Existing infrastructure (storm sewer, culverts and ditches)**

   Post-development discharge shall not exceed the capacity of the existing drainage system. The adequate outlet standard is generally considered to be met by the following measures:

   a. Provide 2-year volume control with 10-year peak rates no greater than existing condition.

   b. Provide 25-year detention requirements.

   c. For a downstream drainage system that is inadequate to handle the proposed discharge from the site development, it is the project's responsibility to upsize the existing conveyance system, or establish a drain to provide the needed design level of flood protection.

3. **Offsite ponds, wetlands and depressions**

   Discharge rate and volume shall not cause adverse impact to offsite property due to water levels of greater height, area and duration. The no net increase of storm water standard is generally considered to be met by the following measures:

   a. Provide 2-year volume control and check that any rise in 100-year level causes no adverse impact.

Worksheet 1
ADEQUATE OUTLET WORKSHEET

Project Name and CP#: ____________________________________ Date: _____________

Location:____ By: _______________

Watershed Sub Basin: _____________________________________

Discharge to	**Control Provided** *(Check all that apply)*	**Certificate**
Direct discharge to Red Cedar River	___Minimum storm water discharge standards met.	**Adequate Outlet**
Existing infrastructure (storm sewer, culverts and ditches)	___2-year volume control and 10-year peak rate no greater than pre-developed. ___25-year detention requirements. ___Approval for alternative peak discharge rate of______cfs/acre	**Adequate Outlet**
	___Project will improve downstream county drainage system.	
Offsite ponds, wetlands and depressions	___Volume standards met and no adverse impact from any increase in 100-year level.	**No Net Increase of Storm Water**
	___Proprietor will obtain flooding easements.	

D. Special Cases

The standard criteria outlined above may not be necessary or suitable for certain sites. In addition, some types of BMPs may be totally unsuitable for consideration in special land use areas and should be excluded from application. A worksheet to document the special cases that apply to the proposed project is included as ***Worksheet 2***. The special cases most frequently encountered are additions to existing buildings that have very limited greenspace or the new building site does not have adequate greenspace footprint to develop BMPs.

1. Site Constraints

Site constraints may inhibit the ability of the project to provide full retention of the 2-year volume difference onsite. In many cases, infiltration will likely be used as the primary means of retention. Site constraints that limit the use of infiltration may include:

- Poorly draining soils
- High groundwater or the potential to mound groundwater around buildings
- Well-head protection areas

a. Additional Criteria

A waiver of the required retention volume (stream protection criterion 1) may be granted due to site constraints and be deemed eligible for credit from a regional project. The project must show the following to use the extended detention stream protection criterion (2):

- The LID design process (***Table 1***) was followed.
- Volume reduction is maximized to the greatest extent practicable.
- The cost to implement additional volume reduction BMPs is prohibitive, or would force noncompliance with local zoning ordinances.

b. Required Strategies

It should be noted that the presence of poorly draining soils on a site does not automatically preclude meeting the 2-year retention criteria since required volumes will be smaller, and BMPs that do not rely on infiltration such as tree planting (evapotranspiration) and storm water reuse can be employed.

2. Redevelopment

a. Additional Criteria

A stream protection volume “credit” is available for redevelopment sites. Stream protection volume criterion (1) may be modified for redevelopment sites as follows:

- No net increase in the existing runoff volume and rate from the disturbed portion of the site for the 2-year, 24-hour rainfall event.

Existing runoff volume and rate shall be the volume and rate after routing through all existing storm water controls.

F. Selection of Best Management Practices

Select appropriate storm water BMPs from the Storm Water BMP Summary Matrix. The BMP or combination of BMPs selected must meet required volume and peak rate criteria. The need for pre-treatment is indicated for each type of BMP. Those BMPs that can be selected to provide water quality volume control, pre-treatment and spill containment are also indicated. Operation and maintenance requirements are summarized for each BMP in terms of the need for a maintenance plan, easement and/or restrictive covenant.

Finally, each best management practice is designed in accordance with the guidelines provided in the BMP Fact Sheets comprising Chapters 6 and 7 of the *Low Impact Development Manual for Michigan* (SEMCOG, 2008) and supplementary design criteria provided in Part 3 of this manual.

G. Consideration of Offset by Regional Project

The design professional should determine the cost for meeting the storm water quality requirements and volume control requirements for the project. (See example project calculations table.) After the cost is determined, the storm water steering committee will determine if the project should proceed with an onsite solution, or if it would be more cost effective to offset the parameters with a regional project. In general, the committee will look at an onsite solution cost that is at least two times more expensive as the regional cost before considering using the offset criteria.

Storm Water BMP Application Matrix

Storm Water BMP	Storm Water Benefits			Application		Location	
	Runoff Volume Reduction	Peak Rate Reduction	Provides Water Quality	Retrofit Existing Facility	New Development	Regional Facility	Site Specific
Structural BMP's							
Bioretention (Raingarden)	X	X	(86)	X	X		X
Capture/Reuse	X	X	(*)	X	X	X	X
Catch Basin Inlet Device			(*)	X	X		X
Constructed Filter			(86)	X	X		X
Constructed Wetland	X	X	(72)	X	X	X	
Dry Detention Pond		X	(49)		X	X	X
Hydrodynamic Separator			(*)	X	X		X
Infiltration Basin	X	X	(89)		X	X	X
Infiltration Trench	X	X	(89)		X		X
Native Re-vegetation	X		(50)	X	X		X
Parking Structure	X	X			X	X	
Pervious Pavement	X	X	(84)		X		X
Planter Boxes*	X		(59)	X	X		X
Riparian Buffer Restoration	X		(50)	X	X		X
Sediment Basin			(50)	X	X		X
Soil Restoration	X			X	X		X
Subsurface Infiltration Bed	X	X	(89)	X	X		X
Tree Planting	X		(50)	X	X		X
Underground Detention		X		X	X		X
Vegetated Filter Strip			(81)	X	X		X
Vegetated Roof	X	X	(*)		X		X
Vegetated Swale			(81)	X	X		X
Wet Detention Pond		X	(80)		X	X	X
Non-Structural BMP's							
Catch Basin Cleaning			(22)	X	X	X	X
Storm Sewer Inspection			(22)	X	X	X	X

Blank Cell	BMP does not provide water quality treatment.
X	BMP requires pretreatment of stormwater, or BMP may be used to meet treatment criteria.
()	BMP may be used to meet water quality treatment criteria. Number in parenthesis is median TSS Removal Efficiency in percent. Source: Fraley-McNeal, L. (September 2007). *National Pollutant Removal performance Daabase, Verision 3,* Center for Watershed Protection. **Bioretention** same as **Constructed Filter**. **Pervious Pavement** number in parenthesis is average TSS Removal. Source: Rowe, Amy A., Borst, Michael, and O'Connor, Thomas P. (2007). *Pervious pavement System Evaluation,* EPA, Office of Research and Development. **Catch Basin Cleaning** number in parenthesis is average TSS removal for standard catch basin. Source: Pitt, R. and Field, R. (1998). *An Evaluation of Storm Drainage Inlet Devices for Stormwtaer Quality Treatment,*

		WEFTEC'98 Water Environment Federation 71st Annual Conference & Exposition, Proceeding Volume 6, Facility Operations I&II.
		Sediment basin, vegetative swale and filter strip (sized for pretreatment): 50% settling efficiency used in calculations.
	(*)	Submit manufacturer's certified test results.
	*	TSS removal efficiency assumes under drained BMP, use value for Infiltration Basin, if applicable.

STORM WATER DESIGN CRITERIA

I. SOILS INVESTIGATION

A. Qualifications

Soils investigation by a qualified geotechnical consultant is required when it is necessary to determine the site soil infiltration characteristics and groundwater table. The geotechnical consultant shall be either a registered professional engineer, soil scientist, or geologist licensed in the State of Michigan.

B. Background Evaluation

An initial feasibility investigation shall be conducted to screen proposed BMP sites. The investigation involves review of the following resources:

- County Soil Survey prepared by the NRCS and USDA Hydrologic Soil Group classifications.
- Existing soil borings or geotechnical report on the site prepared by a qualified geotechnical consultant.
- Onsite septic percolation testing within 200 feet of the proposed BMP location and on the same contour.
- Cyclical groundwater levels http://waterdatea.usgus.gov/mi/nwis/gw

C. Test Pit / Soil Boring Requirements

A test pit (excavated hole) or soil boring (minimum 2-inch diameter drilled hole using a bucket auger, probe, split-spoon sampler or Shelby tube) is allowed for geotechnical investigation. Test pits may typically be selected for shallower investigations in locations where groundwater is sufficiently low, and must comply with applicable OSHA safety standards. The minimum number of test pits or soil borings shall be determined from ***Table 6***.

Table 6 – Minimum Number of Soil Tests Required

Type of BMP	Test Pit / Soil Boring	Depth of Test Pit / Soil Boring	Field Permeability Test
Linear infiltration BMP	1 soil boring per 100 linear feet of BMP; 2 minimum	10 feet below proposed bottom	1 test per soil boring
Linear infiltration BMP (> 500 feet)	1 soil boring per 500 linear feet of BMP; 4 minimum	10 feet below proposed bottom	1 test per soil boring
Infiltration BMP	1 soil boring per 5,000 square feet of BMP bottom area; 2 minimum	10 feet below proposed bottom	1 test per soil boring
Detention BMP	1 soil boring per 10,000 square feet of BMP bottom area; 1 minimum	5 feet below proposed bottom	Not Applicable

Excavate a test pit or soil boring in the location of the proposed BMP.

At each test pit or soil boring, the following conditions shall be noted and described, referenced from a top-of-ground elevation:

- Depth to groundwater. The groundwater elevation shall be recorded during initial digging or drilling, and again upon completion of drilling.
- Depth to bedrock or hardpan.
- Depth and thickness of each soil horizon, including the presence of mottling.
- USDA soil texture classification for all soil horizons.

Test pit reports and soil boring logs shall include the date(s) data was collected and the location referenced to a site plan.

D. Field Permeability Testing

Field permeability testing is generally not required, but may be performed to determine if a design infiltration rate higher than indicated in ***Table 7*** may be used.

- Infiltration Rate of Soils in Field Using Double-Ring Infiltrometers (ASTM D-3385)
- Percolation Tests

The methodologies and procedures outlined on pages 440-441 in Appendix E of the *Low Impact Development Manual for Michigan* (SEMCOG 2008) shall be followed for each test.

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An additional factor of safety of two (2) shall be applied to the permeability test results by the following equation:

Permeability-test infiltration rate (inches/hour) / 2 = Design infiltration rate (inches/hour)

The minimum number of field permeability tests shall be determined from ***Table 6.***

Tests shall be conducted in the location of the proposed BMP at the proposed bottom elevation.

Tests shall not be conducted in the rain or within 24 hours of significant rainfall events (>0.5 inch), or when the temperature is below freezing.

Field permeability testing reports shall include the date(s) data was collected and the location referenced to a site plan.

E. Design Infiltration Rates

Where field permeability testing is not performed, the design infiltration rates provided in ***Table 7*** shall be used to size BMPs.

Table 7 – Design Infiltration Rates by USDA Soil Texture Class

Soil Texture Class	Effective Water Capacity[1] (inches per inch)	Design Infiltration Rate[2] (inches per hour)	Hydrologic Soil Group[1]
Gravel	0.40	3	A
Sand	0.35	3.60	A
Loamy Sand	0.31	1.63	A
Sandy Loam	0.25	0.50	A
(Medium) Loam	0.19	0.24	B
Silty Loam / (Silt)	0.17	0.13	B
Sandy Clay Loam	0.14	0.11	C
Clay Loam	0.14	0.03	D
Silty Clay Loam	0.11	0.04	D
Sandy Clay	0.09	0.04	D
Silty Clay	0.09	0.07	D
Clay	0.08	0.07	D

[1]Source: Maryland Department of Environment, 2000, *Maryland Stormwater Design Manual*, Appendix D.13, Table D.13.1 (Rawls, Brakensiek and Saxton, 1982).
[2]Source: Wisconsin Department of Natural Resources (2004). *Site Evaluation for Stormwater Infiltration (1002),* Table 2 (Rawls, 1998). *Note:* Values are reduced by approximately a factor of 2 from those given in Table D.13.1.

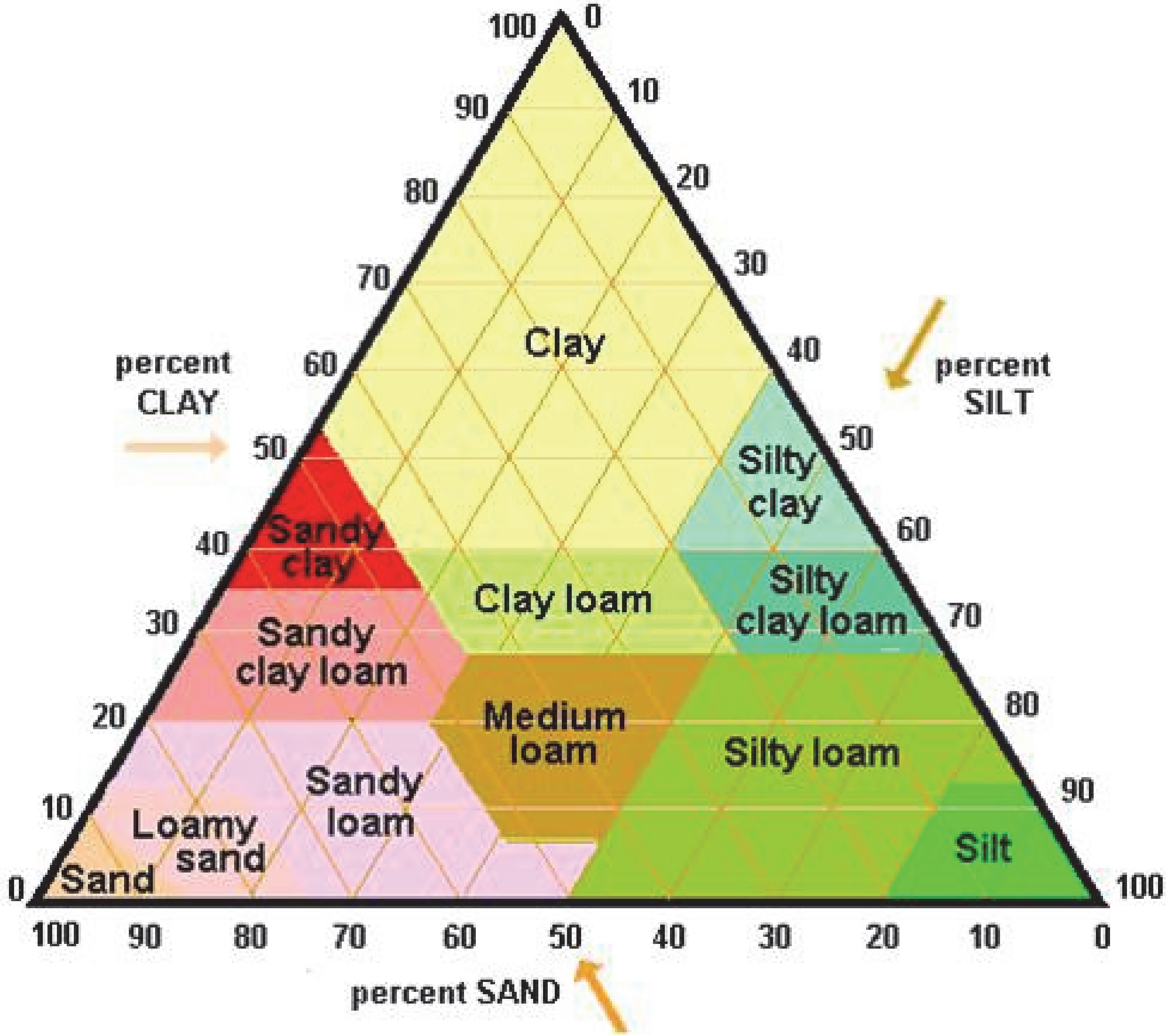
Table 7 provides design values of the effective water capacity (Cw) and the minimum infiltration rate (i) of the specific soil textural groups. The effective water capacity of a soil is the fraction of the void spaces available for water storage, measured in inches per inch. The minimum infiltration rate is the final rate that water passes through the soil profile during saturated conditions, measured in inches per hour. The soil textures presented in ***Table 7*** correspond to the soil textures of the USDA Textural Triangle at the end of this section. The values for design infiltration rate are modified from the original Table D.13.1 in the *Maryland Stormwater Manual* based on design values recommended by other sources (Massman, 2003 and WDNR, 2004) to be more reflective of long-term infiltration rates.

The least permeable soil horizon within four (4) feet below the proposed BMP bottom elevation shall be used to select the design infiltration rate.

F. Minimum Allowable Infiltration Rate

Soil textures with design infiltration rates less than 0.24 inches per hour are deemed not suitable for infiltration BMPs. Modifications to the BMP design through the use of underdrains or subsoil amendment, or selection of an alternative BMP shall be required.

For design infiltration rates between 0.10 and 0.24 inches per hour, BMP design may include an underdrain placed at the top of the storage bed layer.



USDA SOIL TEXTURAL TRIANGLE

II. CALCULATION METHODOLOGY

A. Calculating Runoff

1. Rainfall Loss Equations and Runoff Coefficients

a. The Runoff Curve Number Method, developed by the NRCS, shall be used to calculate storm water runoff. The resulting formulas are as follows:

$$Q_v = \frac{(P - 0.2S)^2}{(P + 0.8S)}$$

where:
Q_V = surface runoff volume (inches)
P = rainfall (inches)
S = potential maximum retention after runoff begins (inches)

and where:

$$S = \frac{1000}{CN} - 10$$

Surface runoff volumes are calculated separately for impervious and pervious areas.

b. Curve Number (CN) values shall be taken from Technical Release No. 55 (TR-55). Standard values are summarized in ***Table 8*** for convenience.

Table 8 – Curve Numbers (CNs) from TR-55

Cover Description		**Curve Number**			
Cover Type	**Hydrologic Condition**	**A**	**B**	**C**	**D**
Woods	Fair	36	60	73	79
	Good	30	55	70	77
Meadow		30	58	71	78
Open spaces (grass cover)	Fair	49	69	79	84
	Good	39	61	74	80
Paved parking lot, roof, driveway, etc.		98	98	98	98

Source: *Urban Hydrology for Small Watersheds*, *Technical Release No. 55*, U.S. Department of Agriculture Soil Conservation Service, 1986.

(1) Pre-development conditions shall consist of a “Meadow” cover type for all existing land covers other than woods. For existing woods use the “Woods” cover types for “good” hydrologic conditions.

(2) Open space in “fair” condition shall be used for post-development pervious areas that are <u>not</u> receiving non-structural and restorative structural BMP credits.

c. A Unit Hydrograph-based Method shall be used to generate peak storm water runoff rates.

d. An antecedent moisture condition of II, reflective of normal soil moisture, shall be used with the NRCS or Modified Michigan Unit Hydrograph Method.

e. Other methodologies and computer models listed in Chapter 9 of the *Low Impact Development Manual for Michigan* (SEMCOG, 2008) may also be accepted with the following limitations.

(1) The Rational Method shall only be used to generate peak discharges to size conveyance systems for sites less than 40 acres where it is not necessary to calculate volume reduction of flows entering the conveyance system. The peak runoff rate is given by the equation:

$$Q = CIA$$

where:
Q = peak runoff rate (cubic feet per second)
C = the runoff coefficient of the drainage area
I = the average rainfall intensity for a storm with a duration equal to the time of concentration of the drainage area (inches per hour)
A = the drainage area (acres)

(2) Runoff coefficients for various land uses and surface types are included in ***Table 9***.

Table 9 – Rational Method Runoff Coefficients

Type of Development	Runoff Coefficients
Business	
Downtown	0.70 to 0.95
Neighborhood	0.50 to 0.70
Residential	
Single family	0.30 to 0.50
Multi-units (detached)	0.40 to 0.60
Multi-units (attached)	0.60 to 0.75
Residential (suburban)	0.25 to 0.40
Apartment	0.50 to 0.70
Industrial	
Light	0.50 to 0.80
Heavy	0.60 to 0.90
Park, Cemeteries	0.10 to 0.25
Playgrounds	0.20 to 0.35
Railroad Yard	0.20 to 0.35
Unimproved	0.10 to 0.30
Character of Surface	
Pavement	
Asphalt and Concrete	0.70 to 0.95
Brick	0.70 to 0.85
Roofs	0.75 to 0.95
Lawns, Sandy Soil	
Flat 2%	0.05 to 0.10
Average 2% to 7%	0.10 to 0.15
Steep 7%	0.15 to 0.20
Lawns, Heavy Soil	
Flat 2%	0.13 to 0.17
Average 2% to 7%	0.18 to 0.22
Steep 7%	0.25 to 0.35

Source: *Design and Construction of Sanitary and Storm Sewers*, American Society of Civil Engineers and the Water Pollution Control Federation, 1969.

2. Time of Concentration

a. Travel time for use with a unit hydrograph-based method shall be calculated using NRCS TR-55 methodology.

(1) The flow path is split into three sections – sheet flow, shallow concentrated flow, and open channels. In each flow regime the velocity and/or travel time are computed. The time-of-concentration is then the sum of the travel times.

(a) For sheet flow the travel time (in hours) is given as:

$$\frac{0.007(nL)^{0.8}}{P_2^{0.5} s^{0.4}}$$

where *n* is Manning's factor, *L* is the flow length (feet), P_2 is the 2-year precipitation depth, and *s* is the slope (feet/foot). Multiply this value by 60 minutes per hour to obtain travel time in minutes.

(b) Shallow concentrated flow velocities are calculated for paved and unpaved surfaces. The velocities are given as:

$$v = \begin{matrix} 16.1345 s^{0.5} & Unpaved \\ 20.3282 s^{0.5} & Paved \end{matrix}$$

where *s* is the slope (feet/foot) and *v* is the velocity in feet per second. The flow length (feet) is then divided by the velocity (feet per second) and a conversion factor of 60 seconds per minute to obtain travel time in minutes.

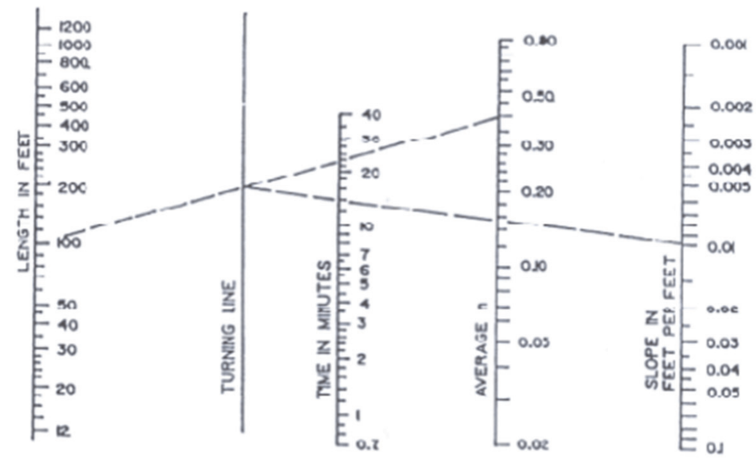
(c) Open channel flow uses Manning's equation to calculate the velocity based on slope, flow area, and wetted perimeter. The flow length (feet) is then divided by the velocity (feet per second) and a conversion factor of 60 seconds per minute to obtain travel time in minutes.

b. BMP residence time shall be calculated as the storage volume divided by the 10-year peak flow rate.

c. Overland flow time for use with the Rational Method may be calculated using the nomograph below. A minimum of 15 minutes shall be used.

The following is a table used for determining n

TYPE OF SURFACE	n VALUE
Smooth impervious Surface	0.02
Smooth bare packed soil	0.10
Poor grass, cultivated row crops or moderately rough bare surface	0.20
Pasture or average grass	0.40
Deciduous Timberland	0.60
Conifer Timberland, Deciduous Timberland with deep forest litter or dense grass	0.80



Example: N=0.40, L=100', S=0.01 feet/foot and tc=13.6 minutes

Chart is printed from the following equation.

$$tc = \left(\frac{2\,Ln}{3\sqrt{S}}\right)^{X} \qquad X = \frac{1}{2.14}$$

Taken from ENGINEER'S NOTEBOOK

"Time of concentration for overland flow" W.S. Kerby, J.M Asce, Hydrologist, Servis, Van Doren & Hazard, Engineers, Topeka, Kansas.

The variables needed to compute time of concentration for a proposed development are its length, slope, and surface retardants. These variables can be computed from field survey notes.

The length L is the distance from the extremity of the development area in a direction parallel to the slope until a defined channel is reached. The units are in feet. Overland flow will become channel flow within 1,200 feet in almost all cases. Time of concentration is the sum of overland flow and channel flow.

The slope S is the difference in elevation between the extremity of the drainage area and the point in question divided by the horizontal distance. The units are in feet/foot.

The surface retardants coefficient, n, is the average surface retardants value of the overland flow.

3. Rainfall

a. The 24-hour rainfall amounts from *NOAA Atlas 14* at station East Lansing 4S (20-2395) provided in ***Table 10*** shall be used the Unit Hydrograph Method.

b. The rainfall duration-frequency table from *NOAA Atlas 14* at station East Lansing 4S (20-395) provided in ***Table 10*** shall be used the Rational Method to determine a rainfall intensity for a rainfall duration equal to the time of concentration.

c. An MSE3 rainfall distribution shall be used with the Unit Hydrograph Method (e.g. WinTR-55 computer program).

Table 10 – Rainfall Amounts

Duration	1-year	2-year	5-year	10-year	25-year	50-year	100-year
24-hr	2.15	2.41	2.90	3.36	4.08	4.71	5.40
12-hr	1.81	2.06	2.54	2.98	3.67	4.27	4.91
6-hr	1.46	1.75	2.26	2.72	3.40	3.96	4.56
3-hr	1.22	1.49	1.96	2.36	2.95	3.43	3.93
2-hr	1.12	1.36	1.76	2.11	2.62	3.03	3.46
1-hr	0.93	1.11	1.42	1.69	2.08	2.40	2.72
30-min	0.74	0.87	1.08	1.27	1.54	1.76	1.99
15-min	0.52	0.61	0.76	0.89	1.08	1.23	1.39
10-min	0.43	0.50	0.62	0.73	0.88	1.01	1.14
5-min	0.29	0.34	0.42	0.50	0.60	0.69	0.78

Source: *NOAA (2013) Atlas 14, Precipitation-Frequency Atlas of the United States, Volume 8, Version 2.0.*
Rainfall amounts from: East Lansing 4S Station ID 20-2395

B. Calculating Storage Volumes and Release Rates

1. Stream Protection using Onsite Retention (1)

$$Vsp = V2dev - V2pre$$

where:
Vsp = minimum required stream protection volume (cubic feet)

and

$$V2dev = A(Qv_{dev\text{-}perv} + Qv_{dev\text{-}imp})1/12$$

$$V2pre = A(Qv_{pre\text{-}perv} + Qv_{pre\text{-}imp})1/12$$

where:
V2dev = runoff volume of the 2-year, 24 hour storm for proposed development conditions
V2pre = runoff volume of the 2-year, 24-hour storm under pre-development conditions
A = contributing disturbed site area (acres)
Qv = surface runoff volume (inches) by Runoff Curve Number Method
1/12 = factor to convert inches to feet

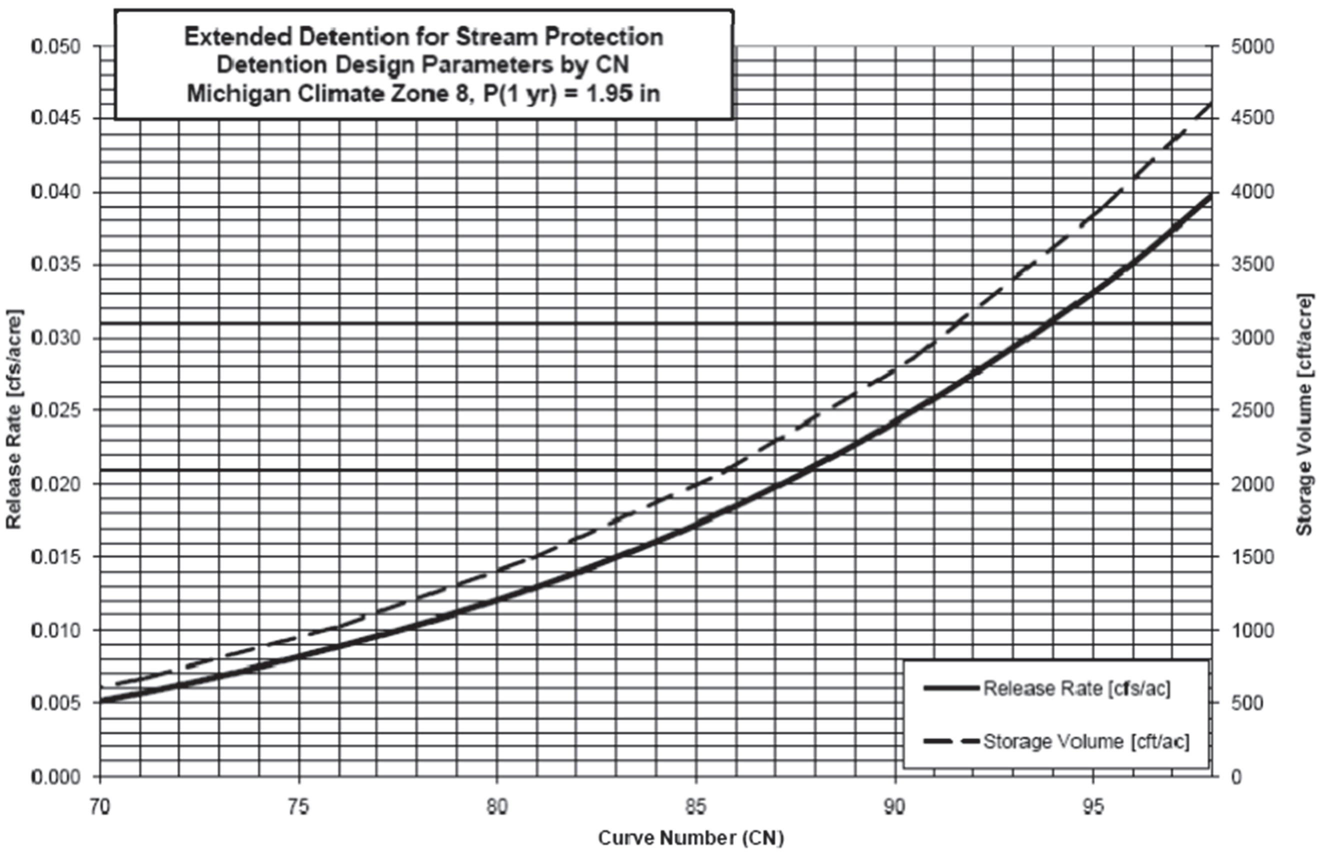
The stream protection volume must be retained onsite. This may be accomplished through infiltration, storm water reuse, interception and/or evapotranspiration.

The Stormwater Calculator is a Microsoft Excel spreadsheet application that uses a unit hydrograph-based storm water runoff method with NRCS Curve Numbers (CN) and time-of-concentration formulas. It calculates required treatment volumes and detention release rates for individual site drainage areas and allows the user to select non-structural and structural BMPs to meet required runoff rates and volumes. Output is graphed as hydrographs and summarized in tabular form for a range of rainfall frequencies (2, 5, 10, 25, 50 and 100-year). A copy is provided with this manual.

2. **Stream Protection using Extended Detention (2)**

Extended detention of the total runoff from the 1-year, 24-hour rainfall event to achieve a 24-hour lag between the centroid of the outflow hydrograph and the inflow hydrograph is required when the second stream protection approach is used. The resulting storage volume and maximum allowable release rate are determined from reservoir routing. Multiple simulations were performed for the "Curve Number Method" as described in *Lower Grand River Watershed, Stormwater Management for Stream Protection: Development of Michigan Statewide Rating Curves for Extended Detention Control of the Stream Protection Volume*, FTC&H, 2009.

Required release rates and storage volumes per acre are calculated for CN values of 70 to 98 and can be selected from the curves provided below.



Source: *Lower Grand River Watershed, Stormwater Management for Stream Protection: Development of Michigan Statewide Rating Curves for Extended Detention Control of the Stream Protection Volume*, FTC&H, 2009.

3. Flood Control using Detention Basins

The standard flood control criteria consists of detention of the 25-year, 24-hour rainfall event. Maximum allowable release rates are dependent upon which stream protection criteria is selected. If 2-year onsite retention is used, 25-year peak discharge rates must not exceed pre-development peak runoff rates. If 1-year extended detention is used, a 25-year maximum allowable release rate of 0.10 cfs/acre is required. The required storage volume is determined by reservoir routing with the Runoff Curve Number Method. The Stormwater Calculator will compute the required 25-year detention storage volume for the calculated inflow hydrograph given a user-specified release rate.

The Rational Method may be used to determine the volume of detention storage in areas where the standard flood control criteria is not required (Zone C). A Microsoft Excel spreadsheet application calculates the volume of inflow for a range of times and subtracts from that the volume of outflow, assumed to be at a constant rate, over the same time duration. The required storage volume is selected from the cell with the greatest difference between "volume in" minus "volume out." A factor of safety of 1.25 is applied because this method tends to underestimate the storage volume when compared to pond routing. An example is provided on the following page, and a copy of the spreadsheet is provided with this manual.

4. Flood Control using Retention Basins

The detention function of the Stormwater Calculator can be used to calculate the 25-year storage volume required when retention basins are used to provide flood control. The user-specified release rate would be the infiltration rate provided by the soil over the basin bottom as given the following equation:

$$Qout = i(A)(3600)(12)$$

where:
Qout = Average outflow from basin bottom (cubic feet per second)
i = design infiltration rate of soil (inches per hour)
A = Bottom area of basin (square feet)
3600 = factor to convert hours to seconds
12 = factor to convert inches to feet

The Rational Method spreadsheet may be used in the same manner, with the allowable release rate replaced with the average outflow from the basin bottom.

CAUTION: The Stormwater Calculator assumes that the resulting outflow volume is routed offsite when it is really infiltrated. When the detention function is used in this way, the user must be aware that this volume will be wrongly reflected in the discharge hydrographs.

DETENTION BASIN SIZING
(RATIONAL METHOD)

PROJECT:
JOB NO.:

DATE:
BY:

LOCATION:

CONTRIB. AREA (acres) =
RUNOFF "C" VALUE =
ALLOWABLE CFS/ACRE =
RAINFALL FREQUENCY = 100 YEAR

ALLOWABLE
RELEASE RATE (cfs) = 0

TIME (hrs)	(1) RAINFALL INTENSITY (in/hr)	(2) RAINFALL RUNOFF (cft)	(3) DISCHARGE VOLUME (cft)	(4) STORAGE VOLUME (cft)	(5) STORAGE VOLUME (ac-ft)	(6) TIME TO EMPTY (hrs)
0.17		0	0	0	0.00	0.0
0.25		0	0	0	0.00	0.0
0.33		0	0	0	0.00	0.0
0.5		0	0	0	0.00	0.0
0.67		0	0	0	0.00	0.0
0.75		0	0	0	0.00	0.0
0.83		0	0	0	0.00	0.0
1		0	0	0	0.00	0.0
2		0	0	0	0.00	0.0
3		0	0	0	0.00	0.0
4		0	0	0	0.00	0.0
5		0	0	0	0.00	0.0
6		0	0	0	0.00	0.0
7		0	0	0	0.00	0.0
8		0	0	0	0.00	0.0
9		0	0	0	0.00	0.0
10		0	0	0	0.00	0.0
12		0	0	0	0.00	0.0

NOTES:

(1) Input rainfall intensity, I, in in/hr for the specified design rainfall at each duration (time, t). I = P/t where P is the rainfall in inches.
(2) Rainfall runoff volume is calculated by multiplying the Rational Formula, Q = CIA, by the time, t : V = (It)CA
(3) Discharge volume is calculated by multiplying the discharge rate by the time: Vo = Qo t
(4) Storage volume is calculated by subtracting the discharge volume from the runoff volume.
(5) Storage volume is converted to acre-feet by dividing by 43,560 sft/acre
(6) Time to empty is calculated by dividing the storage volume by the discharge rate.

5. **Water Quality**

Treatment of runoff by settling (permanent pool or extended detention), infiltration or filtration is required from directly connected impervious areas and disturbed pervious areas (i.e. lawns). The minimum required water quality volume shall be calculated using the Small Storm Hydrology Method by the following formula:

$$Q = P \times Rv$$

where:
Q = runoff (inches)
P = rainfall (inches)
R_v = area-weighted volumetric runoff coefficient (individual runoff coefficients are given in ***Table 11***.)

Table 11 – Runoff Coefficients for Small Storm Hydrology Method

Rainfall, P (inches)	**Volumetric Runoff Coefficient, R_v**					
	Directly Connected Impervious Area			**Disturbed Pervious Area**		
	Flat Roofs / Unpaved	Pitched Roofs	Paved	Sandy Soils (HSG A)	Silty Soils (HSG B)	Clayey Soils (HSG C&D)
1.0	0.815	0.965	0.980	0.035	0.120	0.205

Source: Adapted from Table 9.3, *Low Impact Development Manual for Michigan,* SEMCOG, 2008 (Adapted from *The Source Loading and Management Model (WinSLAMM): Introduction and Basic Uses,* R. Pitt, 2003)

and

$$Vwq = QA(3630)$$

where:
Vwq = minimum required water quality volume (cubic feet)
Q = runoff (inches)
A = contributing area (acres)
3630 = factor to convert acre-inches to cubic feet

If a vegetated filter strip or grassed swale is used, the filtering area must meet minimum standards for slope, length and vegetative cover for a maximum allowable drainage area to filter strip ratio of 6:1.

6. **Pre-treatment**

a. Settling Basins (forebay):

$$Vpt = 0.15(Vwq)$$

where:
Vpt = minimum required pre-treatment volume (cubic feet)
Vwq = water quality volume (cubic feet)

b. Vegetated Filter Strips:

Provide a 5-foot minimum sheet-flow length at a maximum slope of 2%.

c. Grassed Swales:

Provide a 15-foot minimum sheet-flow length at a maximum slope of 2%.

d. Proprietary Treatment Systems:

Follow manufacturer’s guidelines.

7. Stormwater Calculator

The Stormwater Calculator is a Microsoft Excel spreadsheet application that uses the Runoff Curve Number Method with a Michigan Unit Hydrograph to compute required water quality and stream protection volumes, detention release rates and storage volumes for a single treatment train on the site. (A single treatment train consists of one or more water quality and/or channel protection BMPs in series. A site with multiple treatment trains requires one spreadsheet for each treatment train.

The 24-hour rainfall amounts and rainfall distribution specified in Part 4 section “Rainfall” are incorporated into the spreadsheet. Time-of-concentration formulas from NRCS TR-55 are also incorporated into the spreadsheet to calculate peak discharges.

The spreadsheet allows the user to select non-structural and structural BMPs to meet required runoff rates and volumes, and accounts for protected areas on the site. The Stormwater Calculator can also be used to calculate the TSS reduction.

Output is graphed as hydrographs and summarized in tabular form for a range of rainfall frequencies.

A copy of the spreadsheet is provided on the campus website.

TSS Reduction

The median and average TSS removal efficiencies for the BMPs provided in the BMP Application Matrix are used to demonstrate a TSS reduction of 80% or more. When BMPs are used in series (i.e. in a treatment train) to achieve the 80% reduction, the TSS removal efficiency of the tgreatment train is calculated as:

$$e_{TSS} = 1 - (1 - e_1)(1 - e_2) \ldots (1 - e_n)$$

where e_{TSS} is the removal efficiency of the treatment train, and e_n is the removal efficiency for the n^{th} BMP in the chain of n BMPs.

Pond Routing

Flood control volume is computed by numerically routing the hydrograph for the developed site through a detention basin (pond). The steps in the process are as follows:

1. The inflow hydrograph is interpolated from a collection of scaled hydrographs computed using TR-20 for various times-of-concentration and the ratio of initial abstract to total rainfall (Ia/P) values. This is similar to the tabular TR-55 approach. The hydrograph collection was generated using the Michigan specific dimensionless unit hydrograph.

2. Structural BMP volumes are removed from the front of the hydrograph, effectively reducing the required flood control volume. The resulting hydrograph does not start until all retention volume is satisfied.

3. The inflow hydrograph adjusted for structural BMPs is routed through a detention pond model using the Modified Puls Method (see Section 8.4.8 of the MDOT Drainage Manual). The pond is assumed to be prismatic and defined by a bottom area, side slope, and orifice diameter. Pond routing is the calculation of the outflow hydrograph given the inflow hydrograph and pond characteristics. This calculation is based on the continuity equation written in differential form:

$$\frac{dV}{dt} = I - Q$$

where *V* is the volume of water in storage in the pond at time *t*, *I* is the inflow at time t, and Q is the outflow at time t. To calculate the outflow hydrograph, a finite difference mthod approximation of the continuity equation is used. This allows Q to be calculated as a time series:

$$\left(V_{i+1} + Q_{i+1}\,\frac{\Delta t}{2}\right) = \left(I_{i+1} + I_i - Q_1\right)\frac{\Delta t}{2} + V_1$$

where Δt is the time step, $i + 1$ refers to the present time and i refers to a time Δt earlier. At time $i + 1$ everything on the right hand side of the equation is known, allowing the value of the left hand side to be determined. Since V and Q are both functions of the pond depth, H, given the pond characteristics a table that relates values of pond depth, H, to values of can be constructed. This table is then used to find the pond depth at time $i + 1$. Given this pond depth, the storage volume, V, and outflow, Q, can be computed at time $i + 1$. The calculation can then proceed to the remaining time steps resulting in the outflow hydrograph.

4. The pond model characteristics include bottom area, side slope, and orifice diameter. The calculator computes the required orifice diameter to produce the desired peak discharge at an arbitrary depth of 5 feet. The sides are conservatively assumed to be vertical.

5. The spreadsheet runs a macro that iteratively adjusts to bottom area until the desired peak discharge and storage depth are met.

Advantages

The Stormwater Calculator can assist the Design Engineer in applying the correct land uses and Curve Numbers in calculating channel protection volume, accounting for travel time through BMPs, accounting for total TSS reduction from a series of BMPs, and evaluating a variety of stormwater management options quickly.

Design calculations submitted using the Stormwater Calculator will help to expedite the review process because reviewing engineers are familiar with the spreadsheet and can more quickly check that sizing requirements are being met.

III. NON-STRUCTURAL BEST MANAGEMENT PRACTICES

MSU has adopted standards for the following non-structural BMPs as defined in Chapter 6 of the *Low Impact Development Manual for Michigan* (SEMCOG 2008):

http://www.semcog.org

- Minimize Soil Compaction and Total Disturbed Area
- Protect Natural Flow Pathways (including Riparian Buffers)
- Protect Sensitive Areas
- Storm Water Disconnection

Design requirements are provided in BMP Fact Sheets from the *Low Impact Development Manual for Michigan* (SEMCOG 2008). All of the following criteria must be met to receive credit for each non-structural BMP selected for use.

Minimize Soil Compaction and Total Disturbed Area

This BMP applies to those portions of buildable lots located outside of construction traffic and staging areas and lot building zones that can be maintained as "minimal disturbance areas" or "no disturbance areas" during construction. This BMP does not require a maintenance plan or permanent easement.

1. Identify "minimal disturbance areas" and "no disturbance areas" on site plan and construction drawings.
2. "Minimal" and "no disturbance" areas must be protected by having the limits delineated/flagged/fenced in the field. Notes to this effect must be included on construction drawings.
3. "No disturbance areas" must not be subject to grading or movement of existing soils. Existing vegetation must be present in a healthy condition. Invasive vegetation may be removed.
4. "Minimal disturbance areas" must not be subject to excessive equipment movement. Vehicle traffic and storage of equipment and/or materials is not permitted.
5. Pruning or other required maintenance of vegetation is permitted. Additional planting with site-appropriate plants, including turf grass is permitted.
6. Areas receiving credit must be located on the development project.

Calculation Credits: Assign a CN reflecting open space in "good" condition, or woods in "fair" condition, instead of open space in "fair" condition as required for disturbed pervious areas. For small sites, individual trees can receive a credit of 800 square feet per tree, counted as woods in "fair" condition. Woods in "good" condition may be used if trees are protected by a local tree ordinance. Exempt from water quality criteria.

Protect Natural Flow Pathways

1. Identify all existing natural flow pathways on site plan.
2. Identify natural flow pathways to be protected on site plan and construction drawings.
3. Natural flow pathways to be protected must have the limits delineated/flagged/ fenced in the field. Notes to this effect must be included on construction drawings.
4. Identify flow pathways designed as part of the storm water management system including strategies such as:
   a. increased length
   b. increased roughness
   c. decreased slope
5. Ensure adequacy of flow pathway for post-development flows.
6. Include natural flow pathways in maintenance plan.
7. Protected natural flow paths on multiple individual private lots must have an easement in accordance with the requirements in Part 1 of this manual.

Calculation Credits: Adjust time-of-concentration. Exempt from water quality criteria.

Storm Water Disconnection

1. Storm water from rooftops and other impervious areas is considered disconnected if it is routed to a stabilized vegetated area including onsite swales and bioretention areas, or an onsite depression storage area that meets the following criteria:
   a. Disconnection must ensure no basement seepage.
   b. Disconnection in less permeable soils (HSGs C and D) may require the use of dry wells, french drains or other temporary storage device to compensate for poor infiltration capability if ponding of water for extended period of time becomes problematic.
   c. Maximum contributing impervious area flow path length shall be 75 feet.
   d. Maximum contributing impervious area shall be 1,000 square feet per discharge point.
   e. Size of disconnect area shall be twice the size of the contributing impervious area.
   f. Length of disconnect area must be at least the length of the contributing impervious area.
   g. Roof downspouts and curb cuts must be at least 10 feet away from the nearest connected impervious surface to discourage "re-connections."
   h. Slope of disconnect area must be no greater than 5%.
   i. Disconnect area must be a "no disturbance" or "minimal disturbance" area.
2. Identify disconnect areas on site plan and construction drawings.
3. Include storm water disconnect areas in maintenance plan.

Calculation Credits: Weight CN with pervious area. Adjust time-of-concentration, including a 1.25 factor for paved areas flowing onto pervious areas. Exempt from water quality criteria.

IV. STRUCTURAL BEST MANAGEMENT PRACTICES

MSU has adopted standards for the following structural BMPs as defined in Chapter 7 of the *Low Impact Development Manual for Michigan* (SEMCOG 2008):

http://www.semcog.org/uploadedfiles/Programs_and_Projects/Water/Stormwater/LID/LID_Manual_chapter7.pdf

- Bio-retention / Rain Garden
- Capture Reuse
- Constructed Filter
- Detention Basins
- Infiltration Practices
- Level Spreader
- Native Re-vegetation
- Pervious Pavement
- Planter Box
- Riparian Buffer Restoration
- Soil Restoration
- Vegetated Filter Strip
- Vegetated Roof
- Vegetated Swale / Bio-swale
- Water Quality Devices

MSU has also adopted standards for the following additional structural BMPs as defined in this manual:

- Storm Sewer
- Culvert or Bridge
- Spill Containment Cell

BMPs shall be designed in accordance with BMP Fact Sheets from the *Low Impact Development Manual for Michigan* (SEMCOG 2008). Supplemental Design Requirements are provided here. Sizing Calculations and Calculation Credits provided in this manual replace direction given on individual BMP Fact Sheets.

Bioretention / Rain Garden

Supplemental Design Requirements

1. Siting

   a. Soils investigation is required.
   b. A minimum of 4 feet is required between the bottom of the BMP and the measured groundwater elevation to account for seasonal and cyclical variations in groundwater level.

2. Materials

   a. Void ratio for the amended soil material shall be based on the USDA soil textural class and Effective Water Capacity in ***Table 7***. A maximum void ratio of 0.30 shall be allowed for the amended soil material.

Sizing Calculations

1. Calculate design runoff volume routed to the BMP.

2. The required storage volume shall be equal to the design runoff volume.

3. The bottom area of the BMP shall be used as the infiltration area.

4. Calculate minimum infiltration area required to drain the required storage volume in the specified drawdown time (72 hours total for BMP, 24 hours for surface ponding) using the design infiltration rate of the soil. (This assumes that the actual infiltration rates of the amended/imported BMP materials are greater than or equal to the design rates allowed based on soil type.)

   $$A = [V / (i \times t)] \times 12$$

   where:
   A = minimum infiltration area (square feet)
   V = design runoff volume (cubic feet)
   12 = factor to convert inches to feet
   i = infiltration rate of soil (inches per hour)
   t = maximum allowable drawdown time

5. Calculate the storage volume of the BMP.

   Average Bed Area (square feet) = [Area at Design High Water Depth (square feet) + Bottom Area (square feet)] / 2

   Surface Storage Volume (cubic feet) = Average Bed Area (square feet) x Design High Water Depth (feet)

   Subsurface Storage Volume (cubic feet) = Length (feet) x Width (feet) x Depth (feet) x Void Ratio of Material

   Total Storage Volume (cubic feet) = Surface Storage Volume (cubic feet) + Subsurface Storage Volume (cubic feet)

6. The infiltration volume is counted in the volume credit, and is calculated as:

   Design Infiltration Rate (inches per hour) x 6 hours x Infiltration Area (square feet) x 1/12 unit conversion

   Note: The infiltration period is the time when the bed is receiving runoff and is capable of infiltrating at the design rate, which is conservatively estimated as 6 hours.

7. For underdrained BMP, follow criteria for filter.

Calculation Credits

Volume Reduction:

- Infiltration: Count storage volume and infiltration volume.
- Underdrained: Count storage and infiltration volume between BMP bottom and elevation of underdrain.

Peak Rate Reduction:

- Reduction in peak discharge due to an extended time of concentration through BMP (storage volume divided by 10-year peak flow rate). The overflow (both rate and volume) is conveyed downstream.

Water Quality:

- Provides through infiltration or filtration.

Capture Reuse

Sizing Calculations

1. Determine water use (gallons per day) and add up for each month of the year.

2. Obtain average monthly precipitation (inches) and evapo-transpiration (ET) in inches. www.enviroweather.msu.edu

3. Multiply average monthly precipitation by contributing area and area-weighted Small Storm Hydrology Method runoff coefficient to obtain volume of recharge. Multiply by 3630 to convert acre-inches to cubic feet. Multiply by 7.48 gallons per cubic foot to convert to gallons.

4. Multiply average monthly ET (inches) by surface area of pond (square feet) and divide by 12 to calculate the volume of water evaporated in cubic feet. Multiply by 7.48 gallons per cubic foot to convert to gallons.

5. Select trial size container or pond volume.

6. Calculate the water balance. A tabular method may be used similar to that illustrated below:

   Volume of Water in Storage at End of Month = Storage Volume at Start of Month + Recharge from Monthly Precipitation - ET - Monthly Water Use

Month	Vstart	+Recharge	- ET	- Use	= Vend*	Lost
1						
2	=Vend1					
Total	--				--	

   * Limited by total volume of the selected container or pond. If value is greater than container volume, surplus is lost to overflow. If value is negative, it means that amount must be supplemented.

7. Adjust size of container or pond to balance reuse efficiency and cost.

Calculation Credits

Volume Reduction:
- Count storage volume provided.

Peak Rate Reduction:
- Reduction in peak discharge due to an extended time of concentration through BMP (storage volume divided by 10-year peak flow rate). Outflow (rate and volume) conveyed downstream.

Water Quality:
- Provides through ultimate infiltration (irrigation), or discharge to wastewater system.

Constructed Filter

Supplemental Design Requirements

1. Siting

   a. Soils investigation is required.
   b. A minimum of 2 feet is required between the bottom of the BMP and the measured groundwater elevation to account for seasonal and cyclical variations in groundwater level.

Sizing Calculations

2. Calculate design runoff volume routed to the BMP.

3. Calculate filter surface area required to drain the design volume in the specified drawdown time (72 hours total for BMP; 24 hours for surface ponding) using design infiltration rate of filter media.

$$A = [V \times d_f / (i \times (h_f + d_f) \times t)] \times 12$$

   where:
   A = minimum surface area of filter (square feet)
   V = design runoff volume (cubic feet)
   d_f = depth of filter media (1.5-foot minimum to 2.5-foot maximum)
   i = infiltration rate of soil (inches per hour)
   h_f = average head; typically ½ of the maximum head on filter media (feet)
   t = maximum allowable drawdown time
   12 = factor to convert inches to feet

3. Check whether soil conductivity or hydraulics of underdrain governs.

Calculation Credits

Volume Reduction:
- None given.

Peak Rate Reduction:
- Reduction in peak discharge calculated by routing through BMP; outflow (rate and volume) conveyed downstream.

Water Quality:
- Provides through filtration.

Detention Basins

Supplemental Design Requirements

1. Siting

   a. Soils investigation is required.

2. Sizing and Configuration

   a. The bottom of dry detention basins shall be graded to provide positive flow to the pipe outlet. A minimum flow line bottom slope of 1% should be provided. Cross slopes should be 2% minimum. If continuous flow is anticipated, a low-flow channel shall be provided, with necessary crossings, and sloped to eliminate standing water.

   b. At a minimum, the volume of the permanent pool for wet detention basins shall be 2.5 times the water quality volume.

   c. Where water quality and stream protection are provided through detention, these volumes may be included in the flood control volume.

3. Outlet Design

   a. The outlet may be designed using the orifice equation, rearranged to solve for area.

$$A = \frac{Q}{c\sqrt{2gH}}$$

where:
A = required area (square feet)
Q = required outflow (cubic feet per second)
c = orifice coefficient (approximately 0.6)
2g = two times the gravitation constant (g = 32.2 feet per second)
H = height of design high water level above center of orifice outlet (feet)

   b. Other types of outlet devices shall have full design calculations provided for review.

   c. Pipes or orifice plates shall have a minimum diameter of 4 inches.

   d. Riser pipes with holes or slits less than 4 inches in diameter shall have a stone and gravel filter placed around the outside of the pipe.

   e. Hoods and trash racks shall be placed on riser pipes. Grate openings shall be a maximum of 3 inches on center.

   f. Riser pipes shall have a minimum diameter of 24 inches. Riser pipes greater than 4 feet in height shall be 48 inches in diameter.

g. Riser pipes shall be constructed of reinforced concrete or corrugated metal and be set in a concrete base. Plastic is not acceptable as a riser material.

h. Outlet control structures shall be placed near or within the embankment to facilitate maintenance access.

i. All detention facilities must have a provision for overflow at the high water level. A spillway shall be designed for the 10-year inflow with a maximum flow depth of 1 foot. The spillway shall be sized using the weir equation.

$$Q = 2.6LH^{\frac{3}{2}}$$

where:

Q = discharge (cubic feet per second)
2.6 = coefficient of discharge
L = length of spillway crest (feet)
H = total head measured above spillway crest (feet)

j. The top of berm elevation shall be a minimum of 1 foot above the design maximum water level.

k. Overflow spillways shall be protected with riprap or a permanent erosion control blanket to prevent erosion of the structure.

4. Sediment Forebay

a. The capacity of the forebay shall be equivalent to the pretreatment volume. Where more than one inlet pipe is required, the calculated forebay volume shall be pro-rated by flow contribution of each inlet.

b. The length-to-width ratio shall be a minimum of 1.5:1 and a maximum of 4:1.

Sizing Calculations

1. Calculate required design runoff volume and peak rate (inflow hydrograph).

2. Calculate allowable outflow(s).

3. Route inflow hydrograph through detention pond using stage-storage relation and outlet hydraulics. Storage volume may be calculated by:

    a. Stormwater Calculator
    b. Rational Method Spreadsheet
    c. Other Computer Routing Program

Calculation Credits

Volume Reduction:

- None given

Peak Rate Reduction:

- Reduction in peak discharge calculated by routing through BMP; outflow (rate and volume) conveyed downstream

Water Quality:

- Dry Pond: Does not provide sufficient treatment
- Wet Pond: Provides through permanent pool
- Underground Detention: Does not provide sufficient treatment
- Constructed Wetlands: Provides through permanent pool
- Extended Detention: Provides through sufficient particle settling time

Infiltration Practices

Supplemental Design Requirements

1. Siting

    a. Soils investigation is required.

    b. A minimum of 4 feet is required between the bottom of the BMP and the measured groundwater elevation to account for seasonal and cyclical variations in groundwater level.

2. Sizing and Configuration

    a. Infiltration basins with a permanent water level shall be sized based on the horizontal projection of the side slopes above the permanent water elevation to calculate the required infiltration area.

    b. Infiltration basins without an acceptable surface water overflow route shall include a factor of safety of an additional 3 feet of freeboard.

Sizing Calculations

1. Dry wells, leaching basins, infiltration trenches, infiltration beds, infiltration berms:

    a. Calculate design runoff volume routed to the BMP.

    b. The required storage volume shall be equal to the design runoff volume.

    c. Infiltration area shall be defined as:

BMP	Infiltration Area
Dry Well/Leaching Basin	Bottom and sides (lateral)
Infiltration Trench	Bottom of trench (length x width)
Infiltration Bed	Bottom area of the bed
Infiltration Berm	Ponding area (length of berm x average width of ponding behind berm)

    d. Calculate the minimum infiltration area required to drain the required storage volume in the specified drawdown time (72 hours total for BMP) using the design infiltration rate of the soil.

$$A = [V / (i \times t)] \times 12$$

where:

A = minimum infiltration area (square feet)
V = design runoff volume (cubic feet)
12 = factor to convert inches to feet
i = infiltration rate of soil (inches per hour)
t = maximum allowable drawdown time

e. Calculate the storage volume of the BMP.

(1) Dry wells, infiltration trenches, infiltration beds:

Subsurface Storage Volume (cubic feet) = Length (feet) x Width (feet) x Depth (feet) x Void Ratio of Material

(2) Leaching basins:

Storage Volume (cubic feet) = 2 Πr^2 *(square feet) x Depth (feet)*

where:
r = radius of leaching basin (feet)
Π = *pi* (approximately 3.14)

(3) Infiltration berm:

Surface Storage Volume (cubic feet) = Ponding Area (square feet) x Design High Water Depth (feet)

f. The infiltration volume is counted in the volume credit, and is calculated as:

Design Infiltration Rate (inches per hour) x 6 hours x Infiltration Area (square feet) x 1/12 unit conversion

Note: The infiltration period is the time when the bed is receiving runoff and is capable of infiltrating at the design rate, which is conservatively estimated as 6 hours.

2. Infiltration basins:

a. Calculate required design runoff volume and peak rate (inflow hydrograph).

b. The infiltration area shall be defined as the bottom of the basin.

c. Calculate minimum infiltration area required to drain design volume in specified drawdown time (72 hours for surface ponding) using estimated design infiltration rate of soil.

$$A = [V / (i \times t)] \times 12$$

where:
A = minimum infiltration area (square feet)
V = design runoff volume (cubic feet)
12 = factor to convert inches to feet
i = infiltration rate of soil (inches per hour)
t = maximum allowable drawdown time

d. Calculate storage volume based on minimum allowable infiltration area and allowable depths. Storage volume may be calculated by:

(1) Stormwater Calculator
(2) Rational Method Spreadsheet
(3) Other Computer Routing Program

Calculation Credits

Volume Reduction:

- Count storage volume and infiltration volume.

Peak Rate Reduction:

- Reduction in peak discharge due to an extended time of concentration through BMP (storage volume divided by 10-year peak flow rate).

Water Quality:

- Provides through infiltration.

Level Spreaders

Calculation Credits

Volume Retained:
- None given

Peak Rate Reduction:
- None given

Water Quality:
- Does not provide sufficient treatment

Native Revegetation

1. Identify native revegetation areas on site plan and construction drawings.

2. Native revegetation areas must be protected by having the limits delineated/flagged/fenced in the field. Notes to this effect must be included on construction drawings.

3. Areas receiving credit must be located on the development project.

4. Include native revegetation areas in maintenance plan.

Calculation Credits: Assign a CN reflecting a meadow instead of open space in "fair" condition as required for other disturbed pervious areas. For small sites, individual trees can receive a credit of 200 square feet per tree, counted as woods in "good" condition. Exempt from water quality criteria.

Pervious Pavement

Supplemental Design Requirements

1. Siting

   a. Soils investigation is required.

   b. A minimum of 4 feet is required between the bottom of the BMP and the measured groundwater elevation to account for seasonal and cyclical variations in groundwater level.

   c. Runoff from offsite areas shall not be directed onto porous pavement surface.

Sizing Calculations

1. Calculate required design rainfall volume.

2. The required storage volume shall be equal to the design rainfall volume from the contributing surface area (porous pavement, roof).

3. The bottom area of the BMP shall be used as the infiltration area.

4. Maximum allowable drawdown time shall be 72 hours.

5. Calculate the subsurface storage volume of the BMP.

   Subsurface Storage Volume (cubic feet) = Length (feet) x Width (feet) x Depth (feet) x Void Ratio of Material

6. The infiltration volume is counted in the volume credit, and is calculated as:

   Design Infiltration Rate (inches per hour) x 6 hours x Infiltration Area (square feet) x 1/12 unit conversion

   Note: The infiltration period is the time when the bed is receiving runoff and is capable of infiltrating at the design rate, which is conservatively estimated as 6 hours.

7. For underdrained BMP, follow criteria for filter.

Calculation Credits

Volume Reduction:

- Infiltration: Count storage volume and infiltration volume limited by 2-year rainfall volume on pavement.

Peak Rate Reduction:

- Reduction in peak discharge due to an extended time of concentration through BMP (storage volume divided by 10-year peak flow rate). The overflow (both rate and volume) is conveyed downstream.

Water Quality:

- Provides through infiltration or filtration.

Planter Box

Supplemental Design Requirements

1. Siting

    a. Soil infiltration testing is required.

    b. A minimum of 4 feet is required between the bottom of the BMP and the measured groundwater elevation to account for seasonal and cyclical variations in groundwater level.

2. Materials

    a. Void ratio for the amended soil material shall be based on the USDA soil textural class and Effective Water Capacity in ***Table 7***. A maximum void ratio of 0.30 shall be allowed for the amended soil material.

Sizing Calculations

1. Calculate design runoff volume routed to BMP.

2. The required storage volume shall be equal to the design runoff volume.

3. The bottom area of the BMP shall be used as the infiltration area.

4. Calculate minimum infiltration area required to drain the required storage volume in specified drawdown time (12 hours total for BMP; 4 hours for surface ponding) using the design infiltration rate of the soil. (This assumes that the actual infiltration rates of the amended/imported BMP materials are greater than or equal to the design rates allowed based on soil type.)

$$A = [V / (i \times t)] \times 12$$

where:
A = minimum infiltration area (square feet)
V = design runoff volume (cubic feet)
12 = factor to convert inches to feet
i = infiltration rate of soil (inches per hour)
t = maximum allowable drawdown time

5. Calculate the storage volume of the BMP.

    Surface Storage Volume (cubic feet) = Bed Area (square feet) x Design High Water Depth (feet)

    Subsurface Storage Volume (cubic feet) = Length (feet) x Width (feet) x Depth (feet) x Void Ratio of Material

    Total Storage Volume (cubic feet) = Surface Storage Volume (cubic feet) + Subsurface Storage Volume (cubic feet)

6. The infiltration volume is counted in the volume credit, and is calculated as:

Design Infiltration Rate (inches per hour) x 6 hours x Infiltration Area (square feet) x 1/12 unit conversion

Note: The infiltration period is the time when the bed is receiving runoff and is capable of infiltrating at the design rate, which is conservatively estimated as 6 hours.

7. For underdrained BMP, follow criteria for filter.

Calculation Credits

Volume Reduction:

- Infiltration: Count storage volume and infiltration volume.
- Filtration: None given.

Peak Rate Reduction:

- Reduction in peak discharge due to an extended time of concentration through BMP (storage volume divided by 10-year peak flow rate). The overflow (both rate and volume) is conveyed downstream.

Water Quality:

- Provides through infiltration or filtration.

Soil Restoration

This BMP includes soil amendment and/or deep tilling to restore porosity to compacted soils and infiltration beds of other BMPs. However, due to the difficulty of ensuring implementation and longevity, this BMP provides no storm water credit.

Vegetated Filter Strip

Sizing Calculations

1. Calculate area contributing runoff.

2. Calculate minimum required filter strip area.

3. Calculate minimum required length based on slope and type of vegetation.

Calculation Credits

Volume Reduction:

- None given.

Peak Rate Reduction:

- Adjust time-of-concentration.

Water Quality:

- Provides through infiltration or filtration.

Vegetated Roof

Sizing Calculations

1. Calculate the subsurface storage volume of the BMP.

   Subsurface Storage Volume (cubic feet) = Length (feet) x Width (feet) x Depth (feet) x Void Ratio of Material

Calculation Credits

Volume Reduction:

- Count storage volume limited by 2-year rainfall volume on roof.

Peak Rate Reduction:

- Reduction in peak discharge due to an extended time of concentration through BMP (storage volume divided by 10-year peak flow rate). Outflow (rate and volume) conveyed downstream.

Water Quality:

- Exempt from water quality criteria.

Vegetated Swale / Bioswale

Sizing Calculations

1. Channel

    a. Calculate 10-year peak flow rate.

    b. Size channel based on Manning's Equation.

    c. Check that flow velocities are within acceptable limits.

2. Volume Behind Check Dam

    Calculate the wedge-shaped storage volume behind each check dam.

    Storage Volume (cubic feet) = 0.5 x Length of Swale Impoundment Area per Check Dam (feet) x Depth of Check Dam (feet) x [Top Width of Check Dam (feet) + Bottom Width of Check Dam (feet)] / 2

Calculation Credits

Volume Reduction:
- Vegetated Swale: None given
- Bioswale: Storage volume behind check dams.

Peak Rate Reduction:
- Adjust time-of-concentration.

Water Quality:
- Provides through infiltration or filtration of runoff if vegetated filter strip area, length and slope requirements are met.

Water Quality Device

Calculation Credits

Volume Reduction:
- None given.

Peak Rate Reduction:
- None given.

Water Quality:
- Does not provide sufficient treatment.

Storm Sewer

Design Requirements

1. Sizing and Configuration

   a. The storm sewer system shall be designed to convey runoff from a 10-year frequency rainfall event.

   b. Storm sewer design velocities, capacities, and friction losses shall be based on Manning's equation:

$$Q = \frac{1.49AR^{\frac{2}{3}}S^{\frac{1}{2}}}{n}$$

where:
Q = discharge (cubic feet per second)
A = wetted area (square feet)
R = hydraulic radius (feet)
S = slope (feet per foot)
N = Manning's Coefficient

   c. Acceptable slopes for circular pipe ("n" = 0.013) are included in ***Table 12***. Minimum and maximum grade for other Manning's n values must be calculated based on allowable minimum and maximum velocities (V).

Table 12- Minimum and Maximum Slopes for Storm Sewers
(Manning's "n" = 0.013)

Pipe Size	Minimum % of Grade (V = 2.5 feet/second)	Maximum % of Grade (V = 10 feet/second)
12"	0.32	4.88
15"	0.24	3.62
18"	0.20	2.84
21"	0.16	2.30
24"	0.14	1.94
27"	0.12	1.66
30"	0.10	1.44
36"	0.08	1.12
42"	0.06	0.92
48"	0.06	0.76
54"	0.04	0.60
60"	0.04	0.54
66"	0.04	0.48

d. Manning's coefficients for closed conduit are included ***Table 13***.

Table 13 - Manning's Roughness Coefficients

Conduit	Manning's Coefficients
Closed Conduits	
Asbestos-Cement Pipe	0.011 to 0.015
Brick	0.013 to 0.017
Cast Iron Pipe	
Cement-lined and seal-coated	0.011 to 0.015
Concrete (Monolithic)	
Smooth forms	0.012 to 0.014
Rough forms	0.015 to 0.017
Concrete Pipe	0.011 to 0.015
Corrugated-Metal Pipe (1/2-inch corrg.)	
Plain	0.022 to 0.026
Paved invert	0.018 to 0.022
Spun asphalt-lined	0.011 to 0.015
Plastic Pipe (Smooth)	0.011 to 0.015
Vitrified Clay	
Pipes	0.011 to 0.015
Liner channels	0.013 to 0.017
Open Channels	
Lined Channels	
Asphalt	0.013 to 0.017
Brick	0.012 to 0.018
Concrete	0.011 to 0.020
Rubble or riprap	0.020 to 0.035
Vegetal	0.030 to 0.040
Excavated or Dredged	
Earth, straight and uniform	0.020 to 0.030
Earth, winding, fairly uniform	0.025 to 0.040
Rock	0.030 to 0.045
Unmaintained	0.050 to 0.140
Natural Channels (minor streams, top width at flood state < 100 feet)	
Fairly regular section	0.030 to 0.070
Irregular section with pools	0.040 to 0.100

Source: *Design and Construction of Sanitary and Storm Sewers*, American Society of Civil Engineers and the Water Pollution Control Federation, 1969.

e. As a general rule, surcharging the pipe will be allowed to 1 foot below the top of casting. However, minor losses must be considered in hydraulic grade line calculations.

f. Storm sewer pipe shall have a minimum diameter of 12 inches.

g. The minimum depth of cover shall be 24 inches from grade to the top of pipe.

h. Restricted conveyance systems designed to create backflow into storm water storage facilities are not permitted.

2. End Treatment

Outlet protection shall be provided as necessary to prevent erosion, based on the maximum velocities specified under the Open Channel BMP.

3. Manholes and Catchbasins

   a. Manhole spacing shall not exceed 400 feet for sewers less than 42 inches in diameter and 600 feet for larger sewers.

   b. Manholes shall be placed at all changes in pipe direction, pipe size, all inlet connection locations, and at the end of the storm sewer.

   c. Pipe inverts at junctions shall be designed to minimize junction losses (match 0.8 points of pipe diameters).

   d. Minimum inside diameter of all manholes, catch basins, and inlet structures shall be 48 inches.

   e. Inlet structures shall be placed at low points of streets and yards, and be spaced a maximum of 400 feet apart. Spacing and/or number of inlet structures required to accommodate the design flows in streets, private drives, and parking areas shall be provided based on inlet capacity with no ponding occurring during a 10-year storm.

   f. No more than 150 feet of street drainage will be allowed to flow around a corner.

   g. No flow will be allowed across a street intersection.

   h. Perforated catchbasins (leaching basins) shall have an open bottom and perforations around the circumference of the structure at no greater than 12-inch intervals horizontally and vertically the entire depth of the sump.

4. Materials

    a. Storm sewer pipe shall be reinforced concrete or smooth interior wall polyethylene in accordance with MDOT Standard Specifications.

    b. Pipe joints shall be designed to prevent excessive infiltration or exfiltration.

    c. Manholes and catch basins shall be in accordance with MDOT Standard Specifications.

    d. Connections to manholes shall be made with a resilient connector for pipe diameters 24 inches or less.

Calculation Credits

Volume Reduction:

- Solid wall pipe: None given.
- Perforated pipe (meeting slopes for minimum velocity): None given.
- Perforated catchbasins (leaching basins): Count storage volume below outlet pipe invert.

Peak Rate Reduction:

- None given.

Water Quality:

- Does not provide sufficient treatment.

Spill Containment Cell

Design Requirements

1. General

    a. A spill containment cell or equivalent storm water filter shall be used to trap and localize incoming sediments, and to capture slug pollutant loads from accidental spills of toxic materials (spill containment volume).

    b. The spill containment cell can be a wet forebay or an under-drained storm water filter with an impermeable bottom and sides to the design high water level.

2. Sizing and Configuration

    a. The spill containment cell volume shall be equivalent to the pre-treatment volume.

    b. The minimum surface area shall be 25% of the required volume.

    c. The length-to-width ratio for wet forebays shall be a minimum of 3:1, and a maximum of 4:1 to allow for adequate hydraulic length, yet minimize scour velocities. The maximum length-to-width ratio for storm water filters may be as high as 20:1 to allow for incorporation into a swale.

    d. The minimum hydraulic length shall be equal to the length specified in the length-to-width ratio.

    e. The overflow structure from the spill containment cell shall be sized for the peak inflow from a 10-year rainfall event.

    f. The top-of-berm elevation between the spill containment cell and the downstream receiving BMP shall be a minimum of 1 foot below the outer berm elevation.

    g. The spill containment cell shall have a minimum 1-foot-deep sump below the inlet pipe for sediment accumulation.

    h. The outlet structure from a wet forebay shall be designed to draw water from the central portion of the water column within the cell to trap floatables and contain sediments. The inlet side of the structure shall be located a minimum of 1 foot below the normal water level, and a minimum of 1.5 feet from the bottom of the spill containment cell. Minimum depth of the permanent pool is 2.5 feet. The outlet structure from a storm water filter shall be designed within a manhole and be designed to draw water from the central portion of the water column to trap floatables and contain sediments in a sump.

3. Materials

The spill containment cell shall be lined with impermeable materials extending up to the design high water elevation. A minimum 18-inch-thick clay later, or an impermeable liner protected with a minimum 12 inches of soil cover are acceptable alternatives. Maximum allowable permeability shall be 1 x 10^{-7} centimeters per second as determined by the geotechnical consultant for clay placement, or manufacturer's certificate for liner products.

Calculation Credits

Volume Reduction:

- None given.

Peak Rate Reduction:

- None given.

Water Quality:

Used for pre-treatment, but could be sized to meet water quality volume standards