# CITY OF HASTINGS, MICHIGAN

# STORMWATER STANDARDS

**Procedures and Design Criteria for Stormwater Management**

**City of Hastings**
**Department of Public Services**
**201 E State Street**
**Hastings, MI 49058**

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## List of Abbreviations

### Acronyms

| | |
|---|---|
| ASTM | American Society for Testing and Materials |
| BMP | Best Management Practice |
| CN | Curve Number |
| EGLE | Michigan Department of Environment, Great Lakes and Energy (formerly Department of Environmental Quality (DEQ) prior to April 7, 2019). |
| EPA | United States Environmental Protection Agency |
| HSG | Hydrologic Soil Group |
| MCL | Michigan Compiled Laws |
| MDOT | Michigan Department of Transportation |
| NAICS | North American Industry Classification System |
| NOAA | National Oceanic and Atmospheric Administration |
| NPDES | National Pollutant Discharge Elimination System |
| NPS | Nonpoint Source |
| NRCS | Natural Resources Conservation Service |
| PA | Public Acts of Michigan |
| RRD | Remediation and Redevelopment Division |
| SEMCOG | Southeast Michigan Council of Governments |
| TR-55 | Technical Release 55 |
| USDA | United States Department of Agriculture |
| USGS | United States Geological Survey |

### List of Units

| | |
|---|---|
| ft ( ’ ) | feet |
| in ( ” ) | inches |
| cfs | cubic feet per second |
| H:V | horizontal to vertical |
| in/hr | inches per hour |

## Definitions

City — City of Hastings, Barry County, Michigan

Developer — Any person, landowner, firm, association, partnership, corporation, or combination of any of them that holds an ownership interest in land, and who submits a Drainage Plan for review; also referred to as the Proprietor in the Land Division Act (Act 288, PA 1967).

# I. PURPOSE

The City maintains a storm sewer infrastructure that serves a majority of its 5.29 square mile jurisdictional area. As the City continues to grow and redevelop, stormwater drainage systems will be necessary to provide for public safety, convenience, and the protection of property. The future of the City's surface water and groundwater resources also depends to a great extent on the management of storm water runoff. The City takes an active role in protecting these resources through effective stormwater management planning and practices.

It is the purpose of these published Stormwater Standards to meet the following objectives in the City:

1. Ensure stormwater drainage systems are adequate to address stormwater management needs within a proposed development, and protect the drainage, property, and water rights of landowners outside of the proposed development.
2. Reduce flood damage due to development.
3. Minimize degradation of watercourses due to development.
4. Prevent an increase in nonpoint source pollution.
5. Encourage water recharge into the ground where favorable conditions exist.

# II. AUTHORITY

## A. State law and Code of City Ordinances

Under the Home Rule City Act, PA 279 of 1909 (MCL 117.1 et seq), the City Commission has the power to enact, amend and repeal all ordinances that may be necessary or proper for carrying out the powers conferred and the duties imposed upon the City by the charter and by the laws of the State.

The Code of City Ordinances, Chapter 46 Land Division and Chapter 90 Zoning, establish the site plan review procedure under the Land Division Act, PA 288 of 1967 (MCL 560.101 et seq.); Condominium Act, PA 59 of 1978 (MCL 559.101 et seq.) and local regulation of condominiums (MCL 559.241); the Mobile Home Commission Act, PA 96 of 1987 (MCL 125.2301 et seq.); and the Michigan Zoning Enabling Act, PA 110 of 2006 (MCL 125.3101 et seq.), including Planned Unit Development (MCL 125.3503 et seq.); as amended.

## B. Provisions for Requirements in Addition to Minimum Standards

This manual provides minimum stormwater standards to be complied with by Developers and in no way limit the authority of the City to adopt or publish and enforce higher standards as a condition of approval of the final plat or site plan. The City reserves the right to determine site specific requirements other than those herein, based upon review of the plans. Any deviations from these Stormwater Standards shall be subject to approval by the City.

If any part of these Stormwater Standards is found to be invalid, such invalidity shall not affect the remaining portions of the standards which can be given effect without the invalid portion, and to this end the rules are declared to be severable.

# III. APPLICABILITY

## A. Review Required

These Stormwater Standards apply to all private and public development and redevelopment projects within the City that:

1. Require planning commission or staff approval under Chapter 46 Land Division; and Chapter 90 Zoning, Article 90-IV Site Plan Review of the City Code of Ordinances;
2. Will alter stormwater drainage characteristics of the site.

These standards also apply to City-owned facilities and City public works projects, including road projects.

## B. Exemptions

The following development activities are exempt from stormwater review:

1. Land and lot divisions (under Article 46-III City Code of Ordinances).
2. Construction, addition, extension or modification to an individual single or two-family residential dwelling.
3. Relocation of an existing driveway.
4. Non-motorized improvements (sidewalk, pathway) within public rights-of-way that disturb less than 5,445 square feet or 1/8 acre.

## C. Redevelopment

Redevelopment and additions requiring stormwater review shall comply with the current standards for the redeveloped or newly constructed portion of the site, except that the City reserves the right to require the entire site be brought up to the current standards.

The last land use prior to the redevelopment shall be the condition of the site prior to vacancy. The City reserves the right to define the last land use for the redevelopment site as the interim vacant condition.

# IV. FEES

The fees for stormwater permit review under the provisions of these Stormwater Standards are set forth in City Resolution 2020-09 to Revise Fees for Various Services, or a subsequent resolution when fees are updated by City Council.

# V. ADOPTION AND REVISION

The City Council has adopted these Stormwater Standards at the May 8, 2023 City Council meeting. The effective date of these standards is May 8, 2023. Revisions to the standards or fees will be subject to review and approval by City Council.

# I. SUMMARY OF REQUIREMENTS AND DESIGN PROCESS

The following stormwater management requirements shall apply to all new and redevelopments in the City of Hastings requiring stormwater review (refer to Part 1 section "Applicability"). The design process is summarized in the steps below.

1. Protection. The design process shall begin by identifying and prioritizing environmentally sensitive areas located on the site and laying out the site to maximize protection of the sensitive areas.
2. Drainage Plan. A drainage plan shall be prepared to meet the drainage and discharge requirements both internal and external to the site. An adequate outlet must always be identified downstream of the development to receive the post-development discharge.
3. Source Controls. Source controls reduce the volume of runoff generated from the site. Non-structural BMPs shall be maximized to protect sensitive areas and reduce the volume of runoff.
4. Runoff Controls. Runoff controls are typically needed to manage the additional post-development runoff. Structural BMPs shall be used for this purpose.
5. Standards. BMPs shall be selected and sized to meet the minimum stormwater standards summarized in **Table 1**, or higher standards, if required.
6. BMP Design. BMPs shall be designed in accordance with the calculation methodology and design criteria provided in this manual. A list of common BMPs and their treatment ability is given in **Table 2**.
7. Soils Investigation. Test pits or soil borings are required for most structural BMPs to determine soil classification, depth to groundwater and the presence of other site constraints. Field permeability testing is not generally required, but may be requested for questionable soils or conducted to allow the use of a higher design infiltration rate.
8. Groundwater. The highest known groundwater elevation and extent of mounding from infiltration BMPs shall be determined to ensure no adverse impacts internal and external to the site.
9. Operation and Maintenance. BMPs shall be designed to allow for operation and maintenance, demonstrated in the review submittals. Specific requirements are included on individual BMP design criteria sheets. A maintenance agreement with the City is not required at this time.

**Table 1 – Minimum Required Stormwater Standards**

| Standard/Where Required | Criteria |
|---|---|
| **Water Quality** "first flush"<br>All sites. | Treat the runoff generated from 1 inch of rain over the project site. |
| **Channel Protection**<br>Surface water discharge. | Retain the runoff volume increase between pre-development and post-development conditions for the 2-year, 24-hour storm, where site conditions are conducive to infiltration.<br><br>Where site conditions preclude infiltration the City requires extended detention of the 2-year runoff volume increase with a drawdown time of 48 hours. |
| **Flood Control**<br>All sites; unless exception is allowed. | Collection and Conveyance: Design storm sewers and swales for the 10-year storm, and open channels for the 25-year storm.<br><br>Detention and Retention: Store runoff from the 25-year storm with a maximum release rate of 0.13 cfs per acre.<br><br>Overflow Routes for Extreme Flood: Identify overflow routes and the extent of high water levels for the 100-year flood to ensure no adverse impacts to structures offsite or internal to the site. Where overland flow routes do not exist:<br>1. Protect buildings with redundant storm sewer system sized for the 100-year storm; and<br>2. Increase size of detention and retention basins to store two (2) times the flood control volume. |
| **Pretreatment** | Pretreatment volume equal to 15% of water quality volume. |
| **Hotspot**<br>Industrial and commercial land uses in **Table 3;**<br>Part 201 and Part 213 sites (Brownfields). | Isolate transfer and storage areas to minimize need for treatment.<br><br>Pretreatment BMP with impermeable barrier above groundwater and provisions for the capture of oil, grease, and sediments.<br><br>Minimum spill containment volume: 400 gallons. |

**Table 2 – Stormwater BMP Matrix**

| Stormwater BMP | Treatment | | | |
|---|---|---|---|---|
| | Requires Pretreatment | TSS Removal Efficiency | Provides Pretreatment | Provides Spill Containment |
| **Non-Structural BMPs** | | | | |
| Protect Sensitive Areas | | | | |
| Minimal Disturbance Area | | | | |
| Native Revegetation | | | ✓ | |
| Stormwater Disconnect | | | | |
| **Structural BMPs – Conveyance and Storage** | | | | |
| Storm Sewer | | | | ✓ |
| Culvert or Bridge | | | | |
| Open Channel | | | | |
| Detention Basin | ✓ | | | |
| Retention Basin | ✓ | | | |
| **Structural BMPs – Treatment and Small Site** | | | | |
| Sediment Forebay | | | ✓ | |
| Spill Containment Cell | | | ✓ | ✓ |
| Infiltration Practices | ✓ | | | |
| Constructed Filter | ✓ | | ✓ | |
| Bioretention/Rain Garden | ✓ | | | |
| Planter Box | | | ✓ | |
| Pervious Pavement | | | | |
| Vegetated Roof | | | ✓ | |
| Capture Reuse | ✓ | | | ✓ |
| Water Quality Device | | | ✓ | ✓ |
| Water Quality Swale | | | ✓ | ✓ |
| Bioswale | | | ✓ | |
| Vegetated Swale | | | ✓ | |
| Vegetated Filter Strip | | | ✓ | |
| Level Spreader | | | ✓ | |

✓ = Yes

TSS Removal Efficiency is not used at this time.

# II. DRAINAGE PLAN

The Drainage Plan consists of written narratives, drawings, maps, sketches, supporting calculations, reports, procedures, or any combination of these, which contain information pursuant to these Stormwater Standards.

### Drainage Patterns

Proposed drainage for the development shall conform to existing watershed boundaries, natural drainage patterns within the site, or any established county drainage districts.

### Staged Development

Each phase shall be self-sufficient from the standpoint of drainage.

### Location of Stormwater Management Facilities

Stormwater management facilities (detention and retention basins) within a development planned to have multiple lot owners shall be located on dedicated outlots, or have separate easements granted to the entity responsible for operation and maintenance of the stormwater management system.

Parking lots, roadways, and walkways shall not be flooded for use as stormwater detention.

### Offsite Stormwater

Surface water flows from offsite land shall be routed around the development's onsite stormwater system whenever possible. If water from offsite is directed through a private onsite detention basin, the basin must be sized to include the existing offsite area under current land use.

### Stormwater Discharge

The rate, volume, concentration, or constitution of stormwater discharged from a site for the specified design storms shall not create adverse impacts to downstream property owners and watercourses. To that end, the following stormwater discharge requirements must be met for all sites:

1. Post-development discharge shall not exceed the capacity of existing infrastructure or the existing discharge rate from the site. An adequate outlet must always be identified downstream of the development to receive the post-development discharge.
2. Post-development discharge shall not cause adverse impact to offsite property due to concentrated runoff or ponded water of greater height, area, and duration.
3. Discharge shall not cause downstream erosion or sedimentation.
4. Discharge to groundwater shall not cause groundwater mounding sufficient to adversely impact structures or adjacent property.
5. Post-development discharge shall not cause impairments by the contribution of pollutants to surface water or groundwater.
6. For a downstream drainage system that is inadequate to handle any increase to the existing design discharge from the site development, it is the Developer's responsibility to:
    a. Stabilize, cleanout or upsize the existing conveyance system, or establish a county drain to provide the needed design level of flood protection.
    b. Obtain flooding easements for increases in water levels determined to cause an adverse impact.
    c. Provide additional onsite stormwater controls.

It is the Developer's obligation to meet these requirements. Should a stormwater system, as built, fail to comply, it is the Developer's responsibility to have constructed at their expense, any necessary additional and/or alternative stormwater management facilities, subject to City review and approval.

# III. STANDARDS

## A. Water Quality

### Where Required

Treatment of the water quality volume is required for all sites to capture and treat the "first flush" of stormwater runoff that typically carries with it the highest concentration of pollutants.[1]

### Standard

Capture and treatment of the runoff from the 90% annual nonexceedance storm is required for the project site. This storm is approximately equivalent to 1 inch of rain (0.90 inch for Michigan Climatic Zone 9 per EGLE memo "90 Percent Annual Nonexceedance Storms" dated March 24, 2006).

Runoff is calculated from the disturbed portion of the site including both pervious and impervious surfaces.

Non-structural BMPs may be used to reduce the area requiring treatment.

### Treatment BMPs

Treatment can be provided through one of the following methods:

1. Settling (Permanent Pool or Detention)
2. Filtration
3. Infiltration
4. Absorption
5. Chemical/Mechanical Treatment

Permanent Pool. The volume of a permanent pool incorporated into a stormwater BMP and sized at 2.5 times the water quality volume.[2] This is the volume below the ordinary static water level (also known as dead storage).

Detention. The storage volume provided by detention of stormwater.

Filtration. The volume of stormwater runoff routed through a BMP that provides filtration (i.e. an underdrained BMP). In the case of a vegetated filter strip or vegetated swale, the filtering area must meet minimum standards for slope, length, drainage area and vegetative cover.

Infiltration. The volume of stormwater runoff infiltrated into the ground through a stormwater BMP.

Absorption and Chemical/Mechanical Treatment. The volume of stormwater runoff routed through a water quality device, or natural or engineered system.

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[1] Stenstrom, Michael K. and Kayhanian, Masoud (2005). *First Flush Phenomenon Characterization*. California Department of Transportation, Sacramento, California.

[2] Barrett, Michael (2005). *BMP Performance Comparisons: Examples from the International Stormwater BMP Database*, Center for Research in Water Resources, PRC#119, University of Texas, 2005 Water Environment Federation.

## B. Channel Protection

### Where Required

Channel protection is required for surface water discharges.

### Standard

Retain the runoff volume increase between pre-development and post-development conditions for the 2-year, 24-hour storm, where site conditions are conducive to infiltration.

Pre-development is defined as the last land use prior to the planned new development or redevelopment.

Retention can be provided through infiltration or reuse.

*Note:* Volume control for channel protection is required to mitigate increases in runoff rates and volumes for the more frequent (bankfull) rainfall events that have the greatest influence on shaping stream channels. An increase in runoff volume can expose channels to critical erosive velocities for a longer duration, causing accelerated channel adjustments to occur.

### Extended Detention

Where site constraints limit infiltration, extended detention of the 2-year volume increase is required.

Site constraints that limit the use of infiltration may include:

1. Poorly draining soils (<0.24 inches per hour; typically hydrologic soil groups C and D).
2. Bedrock.
3. High groundwater, or the potential of mounded groundwater to impair other uses.
4. Well head protection areas.
5. Stormwater hot spots.
6. Part 201 and Part 213 sites, and areas of soil or groundwater contamination.

Extended detention is defined as holding the stormwater runoff volume and releasing it gradually so the maximum storage volume will drawdown (drain) in 48 hours.

*Note:* The intent is to release stormwater runoff in such a gradual manner that critical erosive velocities during the bankfull event will seldom be exceeded in downstream channels.

If the minimum orifice size results in a detention time of less than 24 hours, the extended detention requirement may be waived by the City.

## C. Flood Control

### Where Required

Flood control is required for all sites.

### Standard

Detention or retention of the 25-year storm with a maximum release rate of no greater than 0.13 cfs per acre is required.

A pipe outlet (detention) shall be provided whenever possible.

An alternate maximum release rate may be allowed under certain conditions, including, but not limited to:

1. City Storm Sewer. Redevelopment sites discharging to a municipal storm sewer where the municipality has determined the sewer has adequate capacity for the existing peak discharge rate from the site. Detention need only be provided for any increase in impervious area.
2. Grandfathered Detention Sites. A site expansion with a previously approved discharge rate higher than the current standard may be “grandfathered in” and need only provide the additional storage volume for any increase in impervious area over that previously approved.
3. Direct Discharge. Direct discharges to waterbodies or watercourses where the Developer demonstrates that the receiving waters possess capacity to convey a post-development discharge no greater than the pre-development 10-year peak discharge rate safely and with no negative downstream impacts. In addition, the peak flow of the receiving waters cannot be increased by the proposed development (i.e. there is a sufficient difference in the timing of the two hydrographs).
4. Floodplain. When the site is located adjacent to or within a floodplain, excavation of new floodplain in lieu of standard stormwater detention may be required. The excavated volume shall be equal to the standard detention basin storage volume. Only the volume above the 2-year and below the 100-year floodplain elevation can be counted to meet the volume requirement.

### Overflow Routes for Extreme Flood

Overflow routes and the extent of high-water levels for the 100-year flood shall be identified for the site and for downstream areas between the site and the nearest acceptable floodway or outlet. Provisions shall be made to ensure no adverse impacts offsite or internal to the site.

Acceptable overflow routes are defined as available flow paths that do not flood structures including buildings, parking garages and the like. Where acceptable overflow routes do not exist:

1. Buildings shall be protected from flooding by two separate enclosed drainage systems, a primary and a redundant system, each independently protecting the building from flooding during the 100-year storm. Runoff shall be directed to the inlets of the primary system for up to a 10-year storm, to minimize the accumulation of debris over the redundant inlets; and
2. Detention and retention basins shall be increased in size to store two (2) times the flood control volume.

*Note:* The intent of the extreme flood criteria is to prevent flood damage from large but infrequent storm events by identifying and/or designing overland flow paths that are clear of structures and have grades below the lowest openings of structures. Overflow routes may include floodplains along open channels, overbank areas along vegetated swales, curb jumps in drives and parking lots, and other flow paths flood waters will take to reach an outlet, whether overland or underground.

## D. Pretreatment

### Where Required

Pretreatment is required prior to discharging stormwater runoff to the following structural BMPs to preserve the longevity and function of the BMP:

1. Detention Basin
2. Retention Basin
3. Infiltration Practices
4. Constructed Filter
5. Bioretention/Rain Garden
6. Capture Reuse

### Treatment BMPs

Pretreatment provides for the removal of courser sediments, trash, debris and other pollutants. Methods of pretreatment include:

1. Sediment Forebay
2. Water Quality Device
3. Vegetated Swale
4. Vegetated Filter Strip

### Standard

<u>Sediment Forebay</u>

A minimum pretreatment volume equivalent to 15% of the water quality volume is required for sediment forebays using gravity.

*Note:* This is a conservative approximation of results given by the Hazen equation for sediment basin sizing using a 50% settling efficiency for a 50-micron particle (silt) at a maximum 4-foot settling depth with a 1-year peak inflow at a rainfall intensity of 1 inch per hour, consistent with recommendations in the *Low Impact Development Manual for Michigan* (SEMCOG, 2008).

*Note:* For properly sized pretreatment BMPs, the entire contributing drainage area must be used to calculate the water quality volume if the disturbed portion is only a small percentage of the area.

<u>Water Quality Device</u>

Configured to trap sediment, oils and floatables in an integral unit.

<u>Vegetated Swale</u>

Minimum length shall be 20 feet with a minimum 1-foot-high check dam and wedge storage sized as a sediment forebay.

<u>Vegetated Filter Strip</u>

Minimum sheet flow length shall be 10 feet at a maximum slope of 2% with an impervious approach length no greater than 3.5 times the filter strip length, up to a maximum approach length of 75 feet.

Minimum sheet flow length shall be 15 feet for slopes between 2% and 6% with an impervious approach length no greater than 3 times the filter strip length, up to a maximum approach length of 75 feet.

*Note*: Vegetated filter strip sizing for pretreatment from Design of Stormwater Filtering Systems (Center for Watershed Protection, 1996).

## E. Hot Spots

### Where Required

Sites considered to be stormwater hot spots are identified in **Table 3**. These include activities with a high potential to cause contamination, and sites that have existing contamination. More specifically:

1. Commercial, industrial, institutional, municipal or transportation-related operations (i.e. high risk operations) involving the production, transfer, storage, and/or use of hazardous materials in quantities that pose a high risk to surface and groundwater quality as defined in Part 5 Rules: Spillage of Oil and Polluting Materials, Water Resources Protection (Part 31, Act 451, PA 1994).
2. "Brownfield" sites with soil or groundwater contamination under Part 201 Environmental Remediation and Part 213 Leaking Underground Storage Tanks (Act 451, PA 1994).

### Standard

Pretreatment volume with a minimum of 400 gallons required for spill containment from hot spot land use activities.

*Note:* The minimum spill containment volume provides a reasonable capture size (e.g. a small fuel truck can have a hauling capacity of 500 to 1,000 gallons) that can be accommodated with a 6-foot diameter water quality device.

Pretreatment BMPs must have an impermeable barrier between the treated material and the groundwater and have provisions for the capture of oil, grease, and sediments.

### Treatment BMPs

Specific stormwater management strategies for hotspots include the following:

1. Isolate transfer and storage areas from permeable surfaces and reduce exposure to stormwater.
2. Identify opportunities for use of infiltration BMPs in other areas of the site.
3. Where storage and transfer areas exposed to stormwater cannot be avoided:
   a. Infiltration of runoff from pavement surfaces is discouraged in favor of a surface water discharge.
   b. Pervious pavements that infiltrate into the groundwater are not permitted because they do not allow for any pretreatment or spill containment.
   c. Perforated pipes for infiltration are not permitted due to the difficulty in isolating an accidental spill.
   d. A standard catchbasin and outlet pipe with a downturned end is not permitted because the area of the permanent pool is insufficient to prevent the captured low-density fluids from becoming entrained in the water when surface inflow enters the structure.

### Evaluation Procedure

High-risk Operations

Sites meeting the classifications in **Table 3** must be evaluated to see if operations classify the site as a stormwater hotspot when it is not clear from the descriptions in the table. Evaluation is based on six categories of operations using the EPA form "Hotspot Site Investigation" as a guide:

1. Vehicle Operations
2. Outdoor Materials
3. Waste Management
4. Physical Plant Maintenance
5. Turf and Landscaping
6. Stormwater Infrastructure

The site is considered a stormwater hotspot unless scoring indicates "not a hotspot."

Brownfield Sites

Brownfield sites must be evaluated before an infiltration approach can be approved so as not to exacerbate existing conditions. The following steps must be followed for sites with known contamination:

1. Include a qualified environmental consultant on the design team.
2. Show areas of known contamination on the site map.
3. Specify on the drawings how contractor is to address any contamination which may be found during construction.
4. The site evaluation process must follow the document entitled *Implementing Stormwater Infiltration Practices at Vacant Parcels and Brownfield Sites* (EPA, 2013).
5. Submit supporting documentation of the site evaluation process with the stormwater review package.
6. Contact EGLE Remediation and Redevelopment Division (RRD) staff for consultation as necessary.

**Table 3 – Stormwater Hot Spots**

| 2017 North American Industry Classification System (NAICS) | |
|---|---|
| 31 – 33 | Manufacturing. |
| 44 – 45 | Retail Trade (441 Motor Vehicle and Parts Dealers, 444 Building Material and Garden Equipment and Supplies Dealers, 447 Gasoline Stations, 454 Non-store Retailers (e.g. fuel dealers)). |
| 48 – 49 | Transportation and Warehousing. |
| 71 | Arts, Entertainment, and Recreation (79393 Marinas). |
| 81 | Other Services (8111 Automotive Repair and Maintenance, 8113 Commercial and Industrial Machinery and Equipment Repair and Maintenance, 8123 Dry Cleaning and Laundry Services, 8129 Other Personal Services (e.g. photofinishing laboratory)). |
| 42, 56 | Salvage Yards (423930 Recyclable Material Merchant Wholesalers) and Recycling Facilities (562 Waste Management and Remediation Services). |
| | Brownfield Sites classified under Part 201 Environmental Remediation and Part 213 Leaking Underground Storage Tanks (Act 451, PA 1994) of the Michigan compiled laws. |
| | Areas with the potential for contaminating public water supply intakes. |
| | Other land uses and activities where petroleum products, chemicals or other polluting materials have a high probability of polluting surface or groundwater due to quantity of use, storage or waste products generated, as determined by the City. |
| Many of these sites will also be regulated under the EPA NPDES Industrial Stormwater Program.<br>A detailed list of NAICS industries can be found at: https://www.census.gov/naics/ | |

# I. SOILS INVESTIGATION

## A. Qualifications

Soils investigation by a qualified geotechnical consultant is required for BMPs that rely on infiltration. The geotechnical consultant shall be a professional engineer, soil scientist, or professional geologist.

## B. Feasibility Evaluation

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

1. County Soil Survey prepared by the NRCS and USDA Hydrologic Soil Group (HSG) classifications.
2. Existing soil borings, wells, or geotechnical report on the site.
3. Onsite septic percolation testing.
4. Cyclical groundwater levels http://waterdata.usgs.gov/mi/nwis/gw

## C. Test Pit/Soil Boring Requirements

A test pit (excavated trench) or soil boring shall be used for geotechnical investigation. Test pits may typically be selected for shallower investigations in locations where groundwater is sufficiently low.

The minimum number of test pits or soil borings shall be determined from **Table 4**. The City reserves the right to request additional test pits or soil borings based on local conditions and initial findings (e.g. large variability in soil type, high groundwater table).

**Table 4 – Minimum Number of Soil Tests Required**

| Type of BMP | Test Pit/Soil Boring | Depth of Test Pit/ Soil Boring | Field Permeability Test |
|---|---|---|---|
| Retention Basin<br>Infiltration Bed<br>Pervious Pavement | 1 per 5,000 square feet of bottom area; 1 minimum | 10 feet below proposed bottom | 1 per change in soil class; 1 minimum |
| Infiltration Trench<br>Bioswale | 1 per 500 to 1,000 linear feet of BMP; 1 minimum | 5 feet below proposed bottom | 1 per change in soil class; 1 minimum |
| Dry Well<br>Leaching Basin<br>Bioretention/Rain Garden<br>Planter Box | 1 minimum | 5 feet below proposed bottom | 1 per change in soil class; 1 minimum |
| Detention Basin | 1 per 10,000 square feet of bottom area; 1 minimum | 5 feet below proposed bottom | No |

Excavate a test pit or soil boring in the location of the proposed BMP. The following conditions shall be noted and described, referenced from a top-of-ground elevation:

1. Depth to groundwater recorded during initial digging or drilling, and again upon completion of the excavation.
2. Depth to bedrock or hardpan.
3. Depth and thickness of each soil horizon including the presence of mottling.
4. Unified Soil Classification System for all soil horizons. USDA soil texture classification when required.

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

## D. Highest Known Groundwater Elevation

The highest known groundwater elevation shall be determined by adjusting the measured groundwater elevation using indicators such as soil mottling and regional water level data. It should also take into consideration local conditions that may be temporarily altering water levels at the time of measurement. Such conditions could include, but not be limited to: dewatering, irrigation well or large quantity withdrawals in the area, or areas of groundwater infiltration (such as a nearby retention basin).

## E. Field Permeability Testing

Field permeability testing is generally not required, but may be performed to determine a design infiltration rate. The City reserves the right to request that field permeability testing be performed.

Acceptable field tests include:

1. Infiltration Rate of Soils in Field Using Double-Ring Infiltrometers (ASTM D3385).
2. Modified double-ring infiltration testing, using smaller diameter metal or plastic casings, where bore hole is required to reach design depth. The "Methodology for Double-Ring Infiltrometer Field Test" outlined on page 440 in Appendix E of the *Low Impact Development Manual for Michigan* (SEMCOG, 2008) shall be followed for each test.

Laboratory tests are not allowed.

The minimum number of field permeability tests shall be determined from **Table 4**. The City reserves the right to request additional field permeability tests be performed.

Tests shall be conducted in the location of the proposed BMP at the proposed bottom elevation. An alternate testing depth may be allowed if material is identical and groundwater is not an issue.

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

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

## F. Design Infiltration Rates

The procedure used to determine a design infiltration rate is summarized in **Table 5**. The resulting design infiltration rate shall be the limiting value of the underlying soil or top dressing.

**Table 5 – Determination of a Design Infiltration Rate**

| Description | Value | Maximum Design Infiltration Rate |
|---|---|---|
| Underlying soil<br>Field permeability testing conducted<br>No testing | <br>Test value divided by 2<br>Table 6 | <br>10 in/hr<br>3.6 in/hr |
| Top dressing<br>Sand/compost/topsoil mix<br>Topsoil | Table 6<br>1.63 in/hr<br>0.50 in/hr | 3.6 in/hr |

The infiltration rate determined from field permeability testing shall be divided by 2 to calculate the design infiltration rate, up to a maximum design infiltration rate of 10 inches per hour.

Where field permeability testing is not performed, the design infiltration rates provided in Table 6 shall be used to calculate the storage volume and minimum infiltration area of the BMP necessary to drain in the allotted drawdown time.

**Table 6 – 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) | HSG |
|---|---|---|---|
| Gravel | 0.40 | 3.60 | 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 6 provides design values of the infiltration rate and effective water capacity (void ratio) for soils based on their textural classification. Soil textural classes correspond to the USDA Soil Textural Triangle shown in **Figure 1**.

*Note*: Infiltration is the process by which water on the ground surface enters the soil. Infiltration rate is a measure of the rate at which soil is able to absorb rainfall or irrigation in inches per hour. The rate decreases as the soil becomes saturated. The design infiltration rate assumes saturated conditions and closely approximates the hydraulic conductivity (typically given in feet per day) of the near-surface soil.

*Note*: The effective water capacity of a soil is the fraction of the void spaces available for water storage measured in inches per inch.

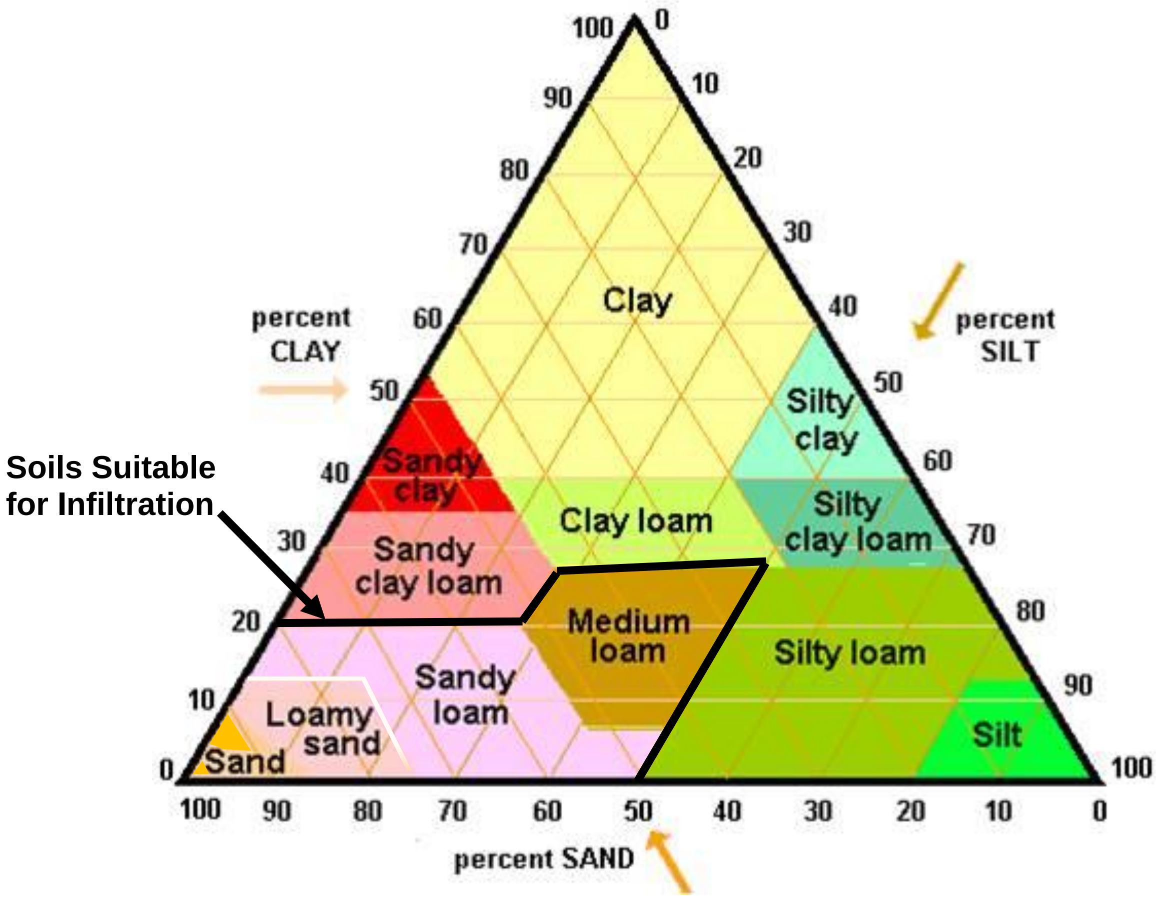
## G. Minimum Allowable Infiltration Rate

Soil textures with design infiltration rates less than 0.24 inches per hour are deemed not suitable for infiltration BMPs.

Soils with design infiltration rates between 0.24 and 0.50 inches per hour may be used if suitable supplemental measures are included in the design. Supplemental measures may include subsoil amendment, underdrain placed at the top of the storage bed layer, or placement of wick drains.

The design infiltration rate of the underlying soil must be no less than 3.6 inches per hour for infiltration BMPs designed for flood control.

**Figure 1 – USDA Soil Textural Triangle**



# II. CALCULATION METHODOLOGY

The Rational Method and the NRCS Runoff Curve Number Method (Curve Number Method) are typically used to calculate stormwater runoff, peak discharges and runoff volumes to design stormwater conveyance and storage systems.

The Curve Number Method is presently the only acceptable method to calculate the channel protection volume.

The Small Storm Hydrology Method is used to calculate runoff volumes from the smaller rainfall amounts used for water quality treatment.

## A. Calculating Runoff

### 1. Rational Method

The Rational Method may be used to calculate stormwater runoff volumes and peak discharges to size conveyance and storage systems for contributing drainage areas of 40 acres or less. The peak runoff rate is given by the equation:

$$Q = CIA \tag{3.1}$$

where:

*Q* = peak runoff rate (cubic feet per second).
*C* = weighted runoff coefficient of the drainage area.
*I* = average rainfall intensity for a storm with a duration equal to the time of-concentration of the drainage area (inches per hour). Use rainfall amounts from **Table 11** and divide by the duration in hours to obtain the average rainfall intensity (I).
*A* = drainage area (acres).

Runoff coefficients shall be selected from **Table 7**. Use 10-year coefficients to calculate peak discharges. Lawns and Open reflect average slopes (2% to 7%). Subtract 0.05 for flat slopes (0% to 2%). Add 0.05 for steep slopes (over 7%).[3]

**Table 7 – Rational Method Runoff Coefficients (10- to 100-year rainfall frequencies)**

| Character of Surface | Return Period (years) | | |
|---|---|---|---|
| | 10[1] | 25[2] | 100[2] |
| Asphalt and Concrete Pavement/Roofs | 0.95 | 0.97 | 0.98 |
| Brick Pavement and Gravel Surface | 0.85 | 0.88 | 0.91 |
| Lawns and Open (HSG A) | 0.10 | 0.17 | 0.20 |
| Lawns and Open (HSG B) | 0.15 | 0.27 | 0.38 |
| Lawns and Open (HSG C) | 0.20 | 0.45 | 0.55 |
| Lawns and Open (HSG D) | 0.30 | 0.57 | 0.67 |
| Water | 1.00 | 1.00 | 1.00 |

[1]The 10-year runoff coefficients are consistent with American Society of Civil Engineers and the Water Pollution Control Federation (1969). *Design and Construction of Sanitary and Storm Sewers*.

[2]The 25- and 100-year runoff coefficients are back-calculated to match 24-hour runoff volumes by the Curve Number Method and result in comparable storage volumes for detention and retention basins.

[3] C.T. Hann, B.J. Barfield, J.C. Hayes (1994). *Design Hydrology & Sedimentology for Small Catchments*.

Time-of-concentration for the Rational Method is the sum of overland flow and channel flow. A minimum of 15 minutes shall be used.

Overland flow time may be calculated using the following formula:

$$t_o = \left(\frac{2Ln}{3\sqrt{s}}\right)^{0.4673} \quad (3.2)$$

where:

$t_o$ = time of overland flow (minutes)

$L$ = length (feet); the distance from the extremity of the subcatchment area in a direction parallel to the slope until a defined channel is reached. Overland flow will become channel flow within 1,200 feet in almost all cases.

$n$ = surface retardants coefficient from **Table 8**

$s$ = slope (feet per foot); the difference in elevation between the extremity of the subcatchment area and the point in question divided by the horizontal distance

**Table 8 – Surface Retardants Coefficients**

| Type of Surface | Coefficient (n) |
|---|---|
| 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 |
| Source: Formula, coefficients and empirical observations from W.S. Kerby, J.M. Asce. Servis, Van Doren & Hazard Engineers, Topeka, Kansas. "Time of Concentration for Overland Flow" ENGINEER'S NOTEBOOK. | |

Channel flow shall be calculated using Manning's equation arranged as:

$$V = \frac{An}{1.49R^{\frac{2}{3}}S^{\frac{1}{2}}} \quad (3.3)$$

where:

$V$ = velocity (feet per second)

$A$ = wetted area (square feet)

$n$ = Manning's roughness coefficient from **Table 12**

$R$ = hydraulic radius (feet)

$S$ = slope (feet per foot)

The time-of-concentration is then:

$$Tc = t_o + \frac{L_c}{60V} \quad (3.4)$$

where:

$Tc$ = time-of-concentration (minutes)

$t_o$ = time of overland flow (minutes)

$L_c$ = length of channelized flow (feet)

$V$ = velocity of channelized flow (feet per second)

$60$ = factor to convert seconds to minutes

## 2. Curve Number Method

The Runoff Curve Number Method developed by the NRCS may be used to calculate stormwater runoff volumes and peak discharges to size conveyance and storage systems. This method must be used when it is necessary to calculate runoff volumes for channel protection. The formulas are as follows:

$$Qv = \frac{(P-0.2S)^2}{(P+0.8S)} \tag{3.5}$$

where:
$Q_v$ = surface runoff (inches). *Note*: Qv=0 if P ≤ 0.2S
$P$ = rainfall (inches)
$S$ = potential maximum retention after runoff begins (inches)
and where:

$$S = \frac{1000}{CN} - 10 \tag{3.6}$$

Surface runoff (Qv) is calculated separately for each land use and soil type combination. Total runoff volume can then be calculated by the formula:

$$Vt = \left(\textstyle\sum_i Q_{vi}\, A_i\right) \times 3630 \tag{3.7}$$

where:
*Vt* = total runoff volume of the design storm (cubic feet)
*Qv* = surface runoff for the $i^{th}$ land use (inches)
*A* = contributing area associated with the $i^{th}$ land use (acres)
*3630* = factor to convert acre-inches to cubic feet

Curve Number (CN) values are taken from NRCS TR-55, and provided in **Table 9**.

Peak Discharge

The EGLE procedure outlined in the paper "Computing Flood Discharges for Small Ungaged Watersheds" by Richard Sorrell, or computer software such as NRCS WinTR-55 may be used to calculate peak stormwater runoff rates.

A Michigan Unit Hydrograph is used in the EGLE small ungaged watershed spreadsheet and can be input into WinTR-55. The ordinates for the Michigan Unit Hydrograph for TR-55 are: [0.0, 0.5, 1.0, 0.8, 0.6, 0.4, 0.2 and 0.0].

*Note:* Using the standard NRCS unit hydrograph will overestimate peak runoff rates by 30 to 50 percent or more.

**Table 9 – Curve Numbers (CNs) from TR-55**

| Land Use Description | | Curve Number[1] | | | |
|---|---|---|---|---|---|
| | | Hydrologic Soil Group | | | |
| Cover Type | Hydrologic Condition[2] | A | B | C | D |
| Cultivated land | Good | 64 | 75 | 82 | 85 |
| Meadow | | 30 | 58 | 71 | 78 |
| Orchard or tree farm[3] | Poor | 57 | 73 | 82 | 86 |
| | Fair | 43 | 65 | 76 | 82 |
| | Good | 32 | 58 | 72 | 79 |
| Woods | Poor | 45 | 66 | 77 | 83 |
| | Fair | 36 | 60 | 73 | 79 |
| | Good | 30[4] | 55 | 70 | 77 |
| Open spaces (grass cover)[5] | Poor | 68 | 79 | 86 | 89 |
| | Fair | 49 | 69 | 79 | 84 |
| | Good | 39 | 61 | 74 | 80 |
| Paved parking lot, roof, driveway | | 98 | 98 | 98 | 98 |
| Gravel[6] | | 88 | 93 | 94 | 95 |
| Bare soil | | 77 | 86 | 91 | 94 |
| Water[7] | | 100 | 100 | 100 | 100 |

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

[1]Antecedent moisture condition II and initial abstract ($I_a$) = 0.2S

[2]Poor Condition: pasture or open space with less than 50% ground cover or heavily grazed with no mulch; woods - forest litter, small trees, and brush are destroyed by heavy grazing or regular burning.

Fair Condition: pasture or open space with 50% to 75% grass cover and not heavily grazed; woods are grazed but not burned, and some forest litter covers the soil.

Good Condition: cultivated land (row crops, straight row) with conservation treatment (crop residue cover), also small grain; pasture or open space with 75% or more ground cover and lightly or only occasionally grazed; woods are protected from grazing, and litter and brush adequately cover the soil.

[3]CN's shown were computed for areas with 50% woods and 50% open spaces (grass cover).

[4]Actual curve number is less than 30; use CN = 30 for runoff computations.

[5]CN's shown are equivalent to those for pasture.

[6]Surface only; not including right-of-way.

[7]Water added.

Time-of-concentration

Time-of-concentration for the Runoff Curve Number Method shall be calculated using NRCS TR-55 methodology as outlined below. A minimum of 0.1 hour (6 minutes) shall be used.

The flow path is split into three sections – sheet flow, shallow concentrated flow, and open channel flow. The travel time is computed for each flow regime. The time-of-concentration is then the sum of the travel times:

$$Tc = t_1 + t_2 + t_3 \tag{3.8}$$

(1) For sheet flow the travel time ($t_1$) in hours is given as:

$$t_1 = \frac{0.007(nL)^{0.8}}{P_2^{0.5} s^{0.4}} \tag{3.9}$$

where:

*n* = Manning's roughness coefficient from TR-55 Table 3-1
*L* = flow length (feet)
$P_2$ = 2-year, 24-hour precipitation depth (inches) from **Table 11**
*s* = slope (feet/foot)

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

$$v = \begin{matrix} 16.1345 s^{0.5} & Unpaved \\ 20.3282 s^{0.5} & Paved \end{matrix} \tag{3.10}$$

where:

*s* = slope (feet/foot)
*v* = velocity (feet per second)

The flow length (feet) is then divided by the velocity (feet per second) and a conversion factor of 3600 to obtain travel time ($t_2$) in hours:

$$t_2 = \frac{L}{3600\, v} \tag{3.11}$$

(3) Open channel flow uses Manning's equation to calculate the velocity based on slope, flow area, and wetted perimeter (refer to Equation 3.3). The flow length (feet) is then divided by the velocity (feet per second) to obtain travel time ($t_3$) in hours (refer to Equation 3.11).

BMP Residence Time

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

### 3. Small Storm Hydrology Method

The Small Storm Hydrology Method is used to calculate the water quality treatment volume. The method was developed to estimate the runoff volume from urban land uses for relatively small storm events where the Rational and NRCS Methods prove less accurate. Water quality volume is calculated by the formula:

$$Vwq = ARv(1)(3630) \quad (3.12)$$

where:

*Vwq* = minimum required water quality volume (cubic feet)
*A* = area (acres); the developed portion of the site, both impervious and pervious, not receiving treatment with a non-structural BMP
*Rv* = area-weighted volumetric runoff coefficient from **Table 10**
*1* = 90% non-exceedance storm rainfall amount (inches)
*3630* = factor to convert acre-inches to cubic feet

*Note:* The Volumetric Runoff Coefficients (Rv) provided in **Table 10** are similar to the Rational runoff coefficient, but are exclusive to the rainfall amount (1-inch).

**Table 10 – Runoff Coefficients for Small Storm Hydrology Method**

| Rainfall Amount (inches) | Volumetric Runoff Coefficient, Rv | | | | | |
|---|---|---|---|---|---|---|
| | 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 | 0.2015 |
| Source: Adapted from SEMCOG (2008). *Low Impact Development Manual for Michigan*, Table 9.3. (R. Pitt (2003). *The Source Loading and Management Model (WinSLAMM): Introduction and Basic Uses)*. | | | | | | |

The area-weighted volumetric runoff coefficient, Rv, is calculated as:

$$Rv = \frac{A_1 Rv_1 + A_2 Rv_2 + \cdots A_n Rv_n}{A} \quad (3.13)$$

where:

$Rv_n$ = runoff coefficient for sub-area n
$A_n$ = area of sub-area n (acres)
*A* = sum of the areas of all sub-areas (acres)

## B. Rainfall

The rainfall duration-frequency table provided in **Table 11** shall be used with the Rational Method to determine rainfall intensity for rainfall duration equal to the time-of-concentration. Divide the rainfall amount by the duration in hours to obtain the rainfall intensity.

The 24-hour rainfall amounts provided in **Table 11** shall be used with the Runoff Curve Number Method.

An MSE4 rainfall distribution shall be used when a unit hydrograph approach is used (e.g. WinTR-55 computer program).

**Table 11 – Rainfall Amounts (inches)**

| Duration | 1-Year | 2-Year | 5-Year | 10-Year | 25-Year | 50-Year | 100-Year |
|---|---|---|---|---|---|---|---|
| 24-hr | 2.22 | 2.52 | 3.08 | 3.59 | 4.39 | 5.08 | 5.83 |
| 12-hr | 1.92 | 2.19 | 2.70 | 3.17 | 3.92 | 4.57 | 5.28 |
| 6-hr | 1.61 | 1.89 | 2.40 | 2.87 | 3.57 | 4.17 | 4.82 |
| 3-hr | 1.37 | 1.63 | 2.09 | 2.50 | 3.11 | 3.62 | 4.16 |
| 2-hr | 1.25 | 1.48 | 1.89 | 2.25 | 2.78 | 3.22 | 3.69 |
| 1-hr | 1.02 | 1.21 | 1.53 | 1.81 | 2.23 | 2.57 | 2.93 |
| 30-min | 0.80 | 0.94 | 1.17 | 1.38 | 1.67 | 1.91 | 2.17 |
| 15-min | 0.56 | 0.65 | 0.81 | 0.95 | 1.15 | 1.32 | 1.49 |
| 10-min | 0.46 | 0.53 | 0.66 | 0.78 | 0.95 | 1.08 | 1.22 |
| 5-min | 0.31 | 0.36 | 0.45 | 0.53 | 0.65 | 0.74 | 0.83 |

Source: NOAA (2013). *Atlas 14, Precipitation-Frequency Atlas of the United States, Volume 8, Version 2.0*. Rainfall amounts from: HASTINGS. Station ID 20-3661.

# C. Calculating Storage Volumes and Release Rates

## 1. Water Quality

Treatment of the runoff generated from 1 inch of rain (the 90% annual nonexceedance storm) over the disturbed portion of the site is required. Water quality volume is calculated using the Small Storm Hydrology Method.

A 1-year frequency rainfall may be used with the time-of-concentration of the contributing drainage area to calculate the peak flow rate for sizing diversion structures and treatment BMPs.

*Note:* A 1-inch, 1-hour rainfall has approximately a 1-year frequency of occurrence. The use of a constant rainfall frequency allows for reasonable sizing of infrastructure for drainage areas with times-of-concentration less than 1 hour, since 1-inch of rain over these shorter durations results in high intensities and rainfall frequencies on the order of those used for flood control.

## 2. Pretreatment

Pretreatment volume may be included in the total water quality volume, and is calculated as:

$$Vpt = 0.15(Vwq) \tag{3.14}$$

where:
*Vpt* = minimum required pretreatment volume (cubic feet)
*Vwq* = water quality volume (cubic feet)

## 3. Channel Protection

### a. Retention

Channel protection consists of retaining onsite the net increase in runoff volume between pre-development and post-development conditions for a 2-year, 24-hour storm using the Runoff Curve Number Method. Channel protection volume is calculated with the following equation:

$$Vcp = Vt_{post} - Vt_{pre} \tag{3.15}$$

where:
*Vcp* = minimum required channel protection volume (cubic feet)
$Vt_{post}$ = total runoff volume for 2-year storm, post-development (cubic feet)
$Vt_{pre}$ = total runoff volume for 2-year storm, pre-development (cubic feet)

EGLE provides a NPS Storm Water Runoff Calculator to compute channel protection volume.

### b. Extended Detention

The storage volume of an extended detention basin shall be sized for that part of the 2-year runoff volume increase not met by retention, with a maximum release rate that results in a 48-hour drawdown time. The maximum release rate is computed with the following equation:

$$Q_{ED} = (Vcp - Vret)/(24 * 3600) \tag{3.16}$$

where:
$Q_{ED}$ = maximum extended detention release rate (cubic feet per second)
*Vcp* = total channel protection volume required (cubic feet)
*Vret* = channel protection volume met by retention (cubic feet)
*24*3600* = half of the drawdown time of outflow hydrograph (seconds)

## 4. Flood Control

### a. Detention

Detention of the 25-year rainfall event with a maximum allowable release rate of 0.13 cfs per acre is required, unless an exception is allowed.

The storage volume of any upstream retentive BMPs may be subtracted from the required flood control storage volume (Vfc).

#### (1) Rational Method for Detention

If the Rational Method is used, the required storage volume shall be calculated by the "Modified Chicago" Method using the 25-year runoff coefficients from **Table 7**.

The calculated storage volume shall be multiplied by 1.25 to obtain the required storage volume.

*Note:* This adjustment is necessary since the Modified Chicago Method tends to underestimate the storage volume when compared to pond routing, because it uses a constant maximum outflow. This is particularly evident for short times-of-concentrations (15 to 30 minutes)[4].

#### (2) Curve Number Method for Detention

If the Curve Number Method is used, the required storage volume shall be calculated by the formula:

$$V_{fc} = 0.75\left(\frac{(Qp - Qout)}{Qp}Vt\right) \qquad (3.17)$$

where:

$V_{fc}$ = minimum required storage volume for flood control (cubic feet)
*0.75* = adjustment factor to approximate results obtained by routing
*Qp* = peak runoff rate (cubic feet per second)
*Qout* = maximum allowable peak discharge (cubic feet per second)
*Vt* = total runoff volume for 25-year, 24-hour storm (cubic feet)

[4] Stahre, Peter and Urbonas, Ben (1990). Stormwater Detention For Drainage, Water Quality and CSO Management, pp. 268 274.

**b. Retention**

Retention basins shall be sized for the 25-year rainfall event.

The storage volume of any upstream retentive BMPs may be subtracted from the required flood control storage volume (Vfc).

**(1) Rational Method for Retention**

If the Rational Method is used, the required storage volume shall be calculated by the "Modified Chicago" Method using the 25-year runoff coefficients from **Table 7**.

The calculated storage volume shall be multiplied by 1.12 to obtain the required storage volume.

*Note:* This adjustment is necessary to match routing results.

The discharge or exfiltration rate into the soil from the retention basin shall be calculated as:

$$Qout = Ai/(12 \times 3600) \tag{3.18}$$

where:

$Q_{out}$ = discharge rate (cubic feet per second)
$A$ = infiltration area (square feet)
$i$ = design infiltration rate (inches per hour) from **Table 5**
*12* = factor to convert inches to feet
*3600* = factor to convert hours to seconds

**(2) Curve Number Method for Retention**

If the Curve Number Method is used, the required storage volume shall be calculated by the formula:

$$V_{fc} = Rs \times Vt \tag{3.19}$$

where:

$V_{fc}$ = minimum required storage volume for flood control (cubic feet)
$Rs$ = storage volume ratio coefficient
$Vt$ = total runoff volume for 25-year, 24-hour storm (cubic feet)

The storage volume ratio coefficient (Rs) is the ratio of required storage volume to total runoff volume. Values of Rs as a function of design high water depth are given in the table below. Linear interpolation may be used for design infiltration rates (i) between those shown in the table.

| i [in/hr] | Rs | | | | | |
|---|---|---|---|---|---|---|
| | 6-ft | 5-ft | 4-ft | 3-ft | 2-ft | 1-ft |
| 0.50 | -- | -- | -- | 0.80 | 0.74 | 0.64 |
| 1.00 | 0.80 | 0.77 | 0.74 | 0.70 | 0.64 | 0.55 |
| 1.36 | 0.75 | 0.72 | 0.69 | 0.65 | 0.60 | 0.52 |
| 2.00 | 0.70 | 0.67 | 0.64 | 0.60 | 0.55 | 0.47 |
| 3.60 | 0.62 | 0.59 | 0.57 | 0.53 | 0.48 | 0.39 |
| 6.00 | 0.55 | 0.53 | 0.50 | 0.47 | 0.42 | 0.33 |
| 10.00 | 0.50 | 0.47 | 0.44 | 0.40 | 0.35 | 0.26 |

-- drawdown time exceeds 72 hours

*Note:* The storage volume ratio coefficients were determined by formulating a curve to the results of routing multiple runoff scenarios for a range of design infiltration rates. The coefficient is dependent on design high water depth (as an indicator of drawdown time).

### 5. Retentive BMPs Sized for Channel Protection or Water Quality

The BMP volume (Vbmp) credited towards meeting the channel protection or water quality volume is the storage volume of the BMP plus the volume infiltrated by the BMP during the infiltration period.

The minimum required storage volume (Vs) shall be calculated by subtracting the volume infiltrated during the infiltration period (Vi) from the channel protection volume (Vcp) or water quality volume (Vwq) by the formula:

$$Vs = Vcp - Vi \tag{3.20}$$

The infiltrating volume is calculated as:

$$Vi = \frac{6iA}{12} \tag{3.21}$$

where:

| | | |
|---|---|---|
| *Vi* | = | volume infiltrated (cubic feet) |
| *6* | = | infiltration period (hours); time when the bed is receiving runoff and is capable of infiltrating at the design rate, conservatively estimated as 6 hours |
| *i* | = | design infiltration rate (inches per hour) |
| *A* | = | infiltration area (square feet) |
| *12* | = | factor to convert inches to feet |

*Note:* This method is recommended in the *Low Impact Development Manual for Michigan* (SEMCOG, 2008) as a straightforward way to approximate and credit the infiltrating volume to meet the treatment standards. It should be noted that the 6-hour assumption tends to underestimate BMP storage volume for high infiltration rates and overestimate BMP storage volume for low infiltration rates as compared to routing. This approximation is acceptable because only the storage volume provided by an upstream retentive BMP is allowed to be subtracted from the required flood control volume.

## D. Groundwater Mounding

A spreadsheet developed by the USGS is recommended to calculate the extent of groundwater mounding beneath infiltration BMPs. The USGS Scientific Investigations Report 2010–5102 *"Simulation of Groundwater Mounding Beneath Hypothetical Stormwater Infiltration Basins,"* may be used with the accompanying spreadsheet, which solves the Hantush (1967) equation to predict the extent of groundwater mounding based on user-specified site conditions. Other finite-difference groundwater flow models such as USGS MODFLOW are also acceptable.

## E. Computing Tools

Hydrologic and hydraulic calculations can be performed using a variety of customized spreadsheets and computer software. Results of computer models that use detailed routing methods to optimize storage volumes may be needed for more complex situations. Accompanying design calculations may include hand calculations or spreadsheets using the formulas specified in this manual, and computer models with submittal of clear and complete input and output.

# I. BEST MANAGEMENT PRACTICES

A Best Management Practice (BMP) is defined as a structural or non-structural practice or technique that mitigates the adverse impacts caused by land development on water quality and/or water quantity (SEMCOG, 2008).

Non-structural BMPs are source controls including protection measures that reduce the volume of stormwater runoff from the site.

Structural BMPs are runoff controls and consist of constructed measures that convey, store and treat stormwater in a site-specific location. Structural BMPs are further categorized as those used primarily for conveyance and flood storage, and those used primarily for treatment and/or for small sites.

BMPs shall be designed in accordance with the design criteria in this manual. BMPs proposed for use that are not included in this manual will be evaluated on an individual basis. Further information and examples are provided in the BMP Fact Sheets in Chapter 6 and Chapter 7 of the *Low Impact Development Manual for Michigan* (SEMCOG, 2008).

*Note:* Design criteria for BMPs used primarily for soil erosion and sedimentation control and channel stabilization (i.e. riprap, in stream structures, natural channel design), and technical specifications for construction are beyond the scope of this manual.

# II. NON-STRUCTURAL BEST MANAGEMENT PRACTICES

Design criteria is provided for the following BMPs:

- Protect Sensitive Areas
- Minimal Disturbance Area
- Native Revegetation
- Stormwater Disconnect

# Protect Sensitive Areas

## 1. Summary

| | |
|---|---|
| Description: | Identify, map and prioritize environmentally sensitive areas on the site to be preserved and protected. |
| Application: | Plats; condominiums; more difficult to implement as development density increases. |
| Pretreatment Required: | No. |
| Maintenance Plan: | No. |
| Calculation Credits: | Remove protected sensitive areas not affecting stormwater calculations, or select an appropriate existing land use.<br><br>For small sites, individual trees can receive a credit of 800 square feet per tree, counted as woods in “good” condition.[1] |
| Volume Reduction: | Exempt from channel protection criteria. |
| Rate Reduction: | Exempt from flood control criteria. |
| Water Quality: | Exempt from water quality criteria. |

[1]Source: *Low Impact Development Manual for Michigan* (SEMCOG, 2008).

## 2. Criteria

This BMP includes identification and protection of environmentally sensitive areas on the development property. For the purpose of these Stormwater Standards, sensitive areas include:

- Waterbodies (lakes and ponds)
- Rivers and streams
- Floodplains (and flood prone areas)
- Riparian buffers
- Wetlands
- Woodlands
- Sand dunes
- Natural flow pathways
- Soils and topography (erodible, steep, karst)
- Susceptible groundwater supplies
- Susceptible surface drinking water intakes
- Threatened and endangered species habitat

a. Sensitive areas are determined on a site-specific basis by survey, delineation, aerial photographs, or maps. Natural resources in sensitive areas may be regulated by federal, state, or local laws.

b. Identify all sensitive areas on the site plan and prioritize areas to be protected.

c. Sensitive areas to be protected must have a regulatory or other legal mechanism to ensure protection and preservation with uses consistent with stormwater management objectives (e.g. statute; ordinance; designation of separate out lots or set-asides with language in the master deed, restrictive covenants or bylaws; easement; conservation easement).

d. Identify sensitive areas and areas to be protected on the construction drawings.

e. Sensitive areas to be protected must have the limits delineated/flagged/fenced in the field during construction. Visible permanent boundary markers may be required to minimize encroachment. Notes to this effect must be included on the construction drawings.

f. Floodplains

Demonstrate that any activity proposed within a 100-year floodplain will not diminish the flood storage capacity. Compensatory storage will be required at a minimum ratio of one-to-one (1:1) for all lost floodplain storage.

(1) The compensating cut must be available during a flood event.

(2) Water must be able to move freely from stream to storage.

(3) Excavation must be adjacent to the floodplain.

(4) Flood storage must be between the 2-year flood elevation and the 100-year flood elevation.

(5) Compensating storage shall not be provided through channel widening.

g. Riparian buffers

Identify municipal ordinance requirements. In the absence of a local ordinance, standards for riparian buffers shall consist of:

(1) Trees, shrubs and herbaceous vegetation that is maintained in a condition that effectively filters stormwater runoff.

(2) Minimum 25-foot width (Zone 1). Variable widths may be allowed where a consistent minimum width would result in a hardship loss of buildable area, with the goal of maintaining an overall equivalent buffer area.

# Minimal Disturbance Area

## 1. Summary

| | |
|---|---|
| Description: | Identify and avoid disturbance to existing pervious areas during construction to reduce potential for erosion and increased runoff. |
| Application: | Larger sites with pervious areas; difficult to implement on small, high-density developments. |
| Pretreatment Required: | No. |
| Maintenance Plan: | No. |
| Calculation Credits: | |
| Volume Reduction: | Assign a CN reflecting open spaces (grass cover) in "good" condition for minimally disturbed pervious areas. Remove undeveloped areas not affecting stormwater calculations, or select an appropriate existing land use. |
| Rate Reduction: | None. |
| Water Quality: | Exempt from water quality criteria. |

## 2. Criteria

This BMP applies to those portions of buildable lots located outside of building zones and construction traffic areas; also undeveloped areas of the site and sensitive areas (e.g. steep topography or erodible soils) that can be adequately protected during construction, but are not protected in perpetuity.

Minimal disturbance area – Construction disturbance is limited to clearing of brush and minor grading. No clear-cutting, excavation, filling, stockpiling of material, or construction traffic is allowed. Area is vegetated after disturbance (if any).

a. Identify minimal disturbance areas on site plan and construction drawings.

b. Minimal 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.

c. Minimize soil compaction. Minimal disturbance areas must not be subject to excessive equipment movement, vehicle traffic and storage of equipment and/or materials.

d. Pruning or other required maintenance of vegetation is permitted. Additional planting with site-appropriate plants including turf grass is permitted.

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

# Native Revegetation

## 1. Summary

| | |
|---|---|
| Description: | Restoration of disturbed pervious areas with deeper-rooted native plants or trees in lieu of conventional turf grass to reduce runoff volume. |
| Application: | All development types; Limitations where rapid establishment of dense turf grass is needed to prevent erosion in concentrated flow situations. |
| Pretreatment Required: | No. This BMP can provide pretreatment. |
| Maintenance Plan: | Yes. |
| Calculation Credits: | |
| Volume Reduction: | Assign a CN reflecting meadow or woods.<br>For small sites, individual trees can receive a credit of 200 square feet per tree, counted as woods in "good" condition.[1] |
| Rate Reduction: | By virtue of lower CN. |
| Water Quality: | Exempt from water quality criteria. |

[1]Source: *Low Impact Development Manual for Michigan* (SEMCOG, 2008).

## 2. Criteria

a. Identify native revegetation areas on the construction drawings.

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

c. Native vegetation shall be selected from Appendix C of the *Low Impact Development Manual for Michigan* (SEMCOG, 2008).

d. Riparian Buffers: As specified in "Protect Sensitive Areas."

e. Areas receiving credit must be located on the development property.

# Stormwater Disconnect

## 1. Summary

<table>
<tr><td>Description:</td><td>Minimize runoff volume by disconnecting impervious areas from the stormwater conveyance system.</td></tr>
<tr><td>Application:</td><td>Rooftops; driveways; walkways; patio areas; minor roads.</td></tr>
<tr><td>Pretreatment Required:</td><td>No.</td></tr>
<tr><td>Maintenance Plan:</td><td>No.</td></tr>
<tr><td>Calculation Credits:</td><td></td></tr>
<tr><td>Volume Reduction:</td><td>Weight impervious CN with pervious CN for open spaces (grass cover) in “good” condition.<br><br>The following weighted CNs can be assigned to the disconnected impervious area. They assume a pervious area twice the size of the impervious area.<table><tr><td>A</td><td>B</td><td>C</td><td>D</td></tr><tr><td>59</td><td>73</td><td>82</td><td>86</td></tr></table></td></tr>
<tr><td>Rate Reduction:</td><td>By virtue of weighted CN.</td></tr>
<tr><td>Water Quality:</td><td>Exempt from water quality criteria.</td></tr>
</table>

## 2. Criteria

a. Stormwater from rooftops and other impervious areas is considered disconnected if it is routed to a stabilized vegetated area or an onsite depression storage area that meets the following criteria:

(1) Pervious area is not a structural BMP that must be designed to treat the runoff from the impervious surface. Pervious area may be a “Minimal Disturbance Area” or “Native Revegetation.”

(2) Impervious area must be limited to 1,000 square feet per discharge point.

(3) Roof downspouts and curb cuts must be at least 10 feet away from the nearest connected impervious surface to discourage “re-connections.”

(4) 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.

(5) For disconnects to stabilized vegetated areas:

(a.) Size of disconnect area shall be twice the size of the contributing impervious area.
(b.) Length of disconnect area must be at least the length of the flow path of the contributing impervious area (maximum 75 feet).
(c.) Slope of disconnect area must be no greater than 5%.

(6) Disconnection must ensure no basement seepage.

b. Identify disconnect areas on the construction drawings.

# III. STRUCTURAL BEST MANAGEMENT PRACTICES

Design criteria is provided for the following BMPs:

Conveyance and Storage

- Storm Sewer
- Culvert or Bridge
- Open Channel
- Detention Basin
- Retention Basin

Treatment and Small Site

- Sediment Forebay
- Spill Containment Cell
- Infiltration Practices
- Constructed Filter
- Bioretention/Rain Garden
- Planter Box
- Pervious Pavement
- Vegetated Roof
- Capture Reuse
- Water Quality Device
- Water Quality Swale
- Bioswale
- Vegetated Swale
- Vegetated Filter Strip
- Level Spreader

# Storm Sewer

## 1. Summary

| | |
|---|---|
| Description: | Provides stormwater conveyance in an enclosed system. |
| Application: | Urban areas; Where above-ground conveyance is not desirable. |
| Types: | Pipe (solid wall, perforated). |
| Pretreatment Required: | No. This BMP can provide spill containment. |
| Maintenance Plan: | Yes. |
| Calculation Credits: | |
| Volume Reduction: | Solid wall pipe: None.<br>Perforated pipe (with slope): None. |
| Rate Reduction: | None. |
| Water Quality: | Count volume routed through catch basin. |

## 2. Design Requirements

a. Sizing and Configuration

(1) Storm sewer shall be designed to convey the 10-year peak discharge.

(2) A dual or redundant storm sewer may be required to convey the 100-year peak discharge if acceptable overland flow routes do not exist.

(3) Design velocities, capacities, and friction losses shall be based on Manning's equation:

$$Q = \frac{1.49AR^{\frac{2}{3}}S^{\frac{1}{2}}}{n} \tag{4.1}$$

where:

*Q* = discharge (cubic feet per second)
*A* = wetted area (square feet)
*R* = hydraulic radius (feet)
*S* = slope (feet per foot)
*n* = Manning's roughness coefficient

(4) Manning's coefficients for closed conduit are included in **Table 12**.

(5) Acceptable slopes for circular pipe ("n" = 0.013) are included in **Table 13**. Minimum and maximum grade for other Manning's n values must be calculated based on allowable minimum and maximum velocities (V).

(6) As a general rule, the storm sewer system shall be designed without surcharging. Where this is not possible, surcharging may be allowed to 1 foot below the top of casting. However, minor losses must be considered in hydraulic grade line calculations.

(7) Storm sewer pipe shall have a minimum diameter of 12 inches. Smaller pipe may be approved for private systems.

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

(9) Restricted conveyance systems designed to create backflow into stormwater storage facilities are not permitted. A storm sewer line shall not be used as both an inlet and outlet line to a stormwater storage facility.

**Table 12 – Manning's Roughness Coefficients**

| Conduit | 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 corrugated) | 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 (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: American Society of Civil Engineers and the Water Pollution Control Federation (1969). *Design and Construction of Sanitary and Storm Sewers*. | |

**Table 13 – Minimum and Maximum Slopes for Storm Sewers**

| Pipe Size (inches) | Minimum % of Grade (Velocity = 2.5 feet per second) | Maximum % of Grade (Velocity = 12 feet per second) |
|---|---|---|
| 12 | 0.32 | 7.00 |
| 15 | 0.24 | 5.20 |
| 18 | 0.20 | 4.07 |
| 21 | 0.16 | 3.32 |
| 24 | 0.14 | 2.78 |
| 27 | 0.12 | 2.37 |
| 30 | 0.10 | 2.06 |
| 36 | 0.08 | 1.62 |
| 42 | 0.06 | 1.32 |
| 48 | 0.06 | 1.10 |
| 54 | 0.04 | 0.94 |
| 60 | 0.04 | 0.82 |
| 66 | 0.04 | 0.72 |
| Manning's "n" = 0.013 | | |

b. End Treatment

(1) Outlet pipes shall require energy dissipation. Riprap protection or equivalent erosion control measures shall be used where the velocity exceeds 4 feet per second, up to maximum allowable design velocity of 8 feet per second.
(2) Outlets into open channels or grassed swales shall enter at an angle of 90 degrees or less with the direction of flow.

c. Manholes and Catch Basins

(1) Manhole spacing shall not exceed 400 feet for sewers less than 42 inches in diameter and 600 feet for larger sewers.
(2) Manholes shall be placed at all changes in pipe direction, slope, pipe size, all inlet connection locations, and at the upper end of the storm sewer.
(3) Where possible, pipe inverts at junctions shall be designed to minimize junction losses (match 0.8 points of pipe diameters).
(4) Minimum inside diameter of all manholes, catch basins, and inlet structures shall be 48 inches, except that a 24-inch diameter structure may be allowed with a single 12-inch outlet pipe.
(5) All structures receiving direct surface water runoff shall have a sump not less than 24 inches deep.
(6) Catch basins shall be placed at low points of streets and yards. 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, and the following additional stipulations:
(a.) No more than 300 feet of pavement surface drainage will be allowed. No more than 200 feet of surface drainage will be allowed for grades exceeding 4%.
(b.) Consideration shall be given to pedestrian crossings when siting catch basins in intersections. Catch basins shall be placed upstream of pedestrian crossings when practical.
(c.) No more than 150 feet of street drainage will be allowed to flow around a corner.
(d.) No flow will be allowed across a public street intersection.

d. Sump Discharge

(1) Sump discharge outlets for individual lots shall be a catch basin (minimum 4-foot diameter) with lead (6-inch minimum diameter); manufactured tees; or cored and booted lead.

e. Yard Drainage

(1) Lots provided with yard drainage shall have an underdrain.
(2) Minimum diameter of yard catch basin shall be 2 feet.
(3) Minimum pipe diameter and slope by drainage area:

| Drainage Area (acre) | Minimum Pipe Diameter (inches) | Slope |
|---|---|---|
| ≤ 0.5 acre | 6 | 0.5% |
| ≥ 0.5 acre; ≤ 1 acre | 8 | 0.3% |
| > 1 acre | mainline storm sewer | Table 13 |

f. Materials

(1) All materials must comply with the authority having jurisdiction over the storm sewer system.
(2) Storm sewer pipe within the influence of a public road shall be reinforced concrete pipe. All other storm sewer pipe shall be reinforced concrete or smooth interior wall polyethylene in accordance with MDOT Standard Specifications. Other materials shall be subject to approval.
(3) Pipe joints shall be designed to prevent excessive infiltration or exfiltration.
(4) Manholes and catch basins shall be in accordance with MDOT Standard Specifications.

# Culvert or Bridge

## 1. Summary

| | |
|---|---|
| Description: | Provides stormwater conveyance through a crossing structure. |
| Application: | Where crossing of open channels, wetlands, waterbodies, and grassed swales is required. Culverts can also provide equalization and outlet control. |
| Types: | Pipe Culvert; Box Culvert; Bridge. |
| Pretreatment Required: | No. |
| Maintenance Plan: | Yes. |
| Calculation Credits: | |
| Volume Reduction: | None. |
| Rate Reduction: | None. |
| Water Quality: | None. |

## 2. Design Requirements

a. Sizing and Configuration

(1) Bridges shall be designed to provide a 4.3-foot minimum underclearance at normal flow for canoe traffic on navigable waterways, and a 2-foot minimum freeboard to the underside (low chord) of the bridge for a 100-year flood where conditions allow.
(2) Footings shall extend at least 4 feet below the bottom of the channel.
(3) Culverts serving a drainage area of less than 2 square miles shall be designed for the 25-year peak discharge in the developed watershed with a maximum outlet velocity of 8 feet per second. A maximum of 1 foot of inlet submergence may be permitted if this does not backup water out of the easement.
(4) The effect of the 100-year storm shall be reviewed to ensure no adverse increase in water elevation off of the development property or flooding of structures within the development.
(5) Sizing of culverts and bridges shall be performed using the Bernouli equation and include consideration of inlet and outlet control, entrance and exit losses, and tailwater condition. Published culvert nomographs and other computer software may be used.
(6) Minimum diameter of a drive culvert shall be 12 inches.
(7) Minimum diameter of a road crossing culvert shall be 18 inches or equivalent pipe arch.

b. End Treatment

(1) Headwalls, wingwalls, and all other end treatments shall be designed to ensure the stability of the surrounding soil. MDOT or manufacturer's designs may be used.
(2) Riprap protection or equivalent erosion control measures shall be used where the velocity exceeds 4 feet per second, up to maximum allowable design velocity of 8 feet per second.

c. Materials

(1) All materials must comply with the authority having jurisdiction over the roadway.
(2) Culverts may be reinforced concrete pipe, corrugated steel pipe, or pipe arch in accordance with MDOT Standard Specifications. Smooth interior wall polyethylene may also be allowed.

# Open Channel

## 1. Summary

| | |
|---|---|
| Description: | Stormwater conveyance in an excavated channel. |
| Application: | Larger drainage areas with concentrated runoff. |
| Types: | Channel; Ditch. |
| Pretreatment Required: | No. |
| Maintenance Plan: | Yes. |
| Calculation Credits: | |
| Volume Reduction: | None. |
| Rate Reduction: | None. |
| Water Quality: | None. |

## 2. Design Requirements

a. Sizing and Configuration

(1) The open channel shall be designed to convey the 25-year peak discharge.

(2) Open channel design velocity, capacity, and friction loss shall be based on Manning's equation:

$$Q = \frac{1.49 A R^{\frac{2}{3}} S^{\frac{1}{2}}}{n} \quad (4.1)$$

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

(3) Manning's coefficients shall be determined from **Table 12**. A minimum Manning's coefficient of 0.035 shall be used for open channels, unless special treatment is given to the bottom and sides (riprap, paving, mown sod, etc.).

(4) Minimum bottom width shall be 2 feet.

(5) Minimum longitudinal slope shall be 0.10%.

(6) Side slopes shall be no steeper than 2:1 (horizontal to vertical).

(7) The minimum velocity for open channels during the design event shall be 1.5 feet per second.

(8) The maximum velocity shall be 4 feet per second. Riprap protection or equivalent shall be used where the velocity exceeds 4 feet per second, up to maximum allowable design velocity of 8 feet per second.

b. Connections and Crossings

(1) Outlets into the open channel shall enter at an angle of 90 degrees or less with the direction of flow.

(2) A minimum clearance of 5 feet is required between open channel inverts and underground utilities unless special provisions are approved.

# Detention Basin

## 1. Summary

| | |
|---|---|
| Description: | Provides stormwater storage and slow release through a pipe outlet. |
| Application: | Practical for a wide range of applications including large sites. |
| Types: | Dry Basin; Underground Vault; Extended Detention Basin[1]; Wet Pond; Constructed Wetland. |
| Pretreatment Required: | Yes, if needed to facilitate maintenance, or preserve intended aesthetics of basin. |
| Maintenance Plan: | Yes. |
| Calculation Credits: | |
| Volume Reduction: | None. |
| Rate Reduction: | Calculated release rate. |
| Water Quality: | Count volume routed through BMP. |

[1] *Extended detention basins, by their nature, will typically develop the characteristics of a wetland.*

## 2. Sizing Calculations

a. Detention basins shall be sized for flood control.

b. Calculate the allowable release rate and required storage volume. Refer to Part 3 section "Calculating Storage Volumes and Release Rates, Flood Control, Detention" for calculation methods and credit allowed from upstream retentive BMPs.

c. Extended detention volume for water quality and/or channel protection may be included in the flood control volume <u>if it comprises no more than 30% of the flood control volume</u>. Any extended detention volume above that is additive.

d. If retention storage is provided below the orifice within the detention basin, only the storage volume and infiltration area below the orifice may be counted as the retentive BMP.

e. Detention basins without an acceptable surface water overflow route shall be designed for 2 times the required flood control volume.

## 3. Design Requirements

a. Siting

(1) Soil borings are required. Refer to Part 3 section "Soils Investigation."

(a.) A minimum of 2 feet is required between the bottom of dry detention basins and the highest known groundwater elevation.

(b.) Wet ponds and constructed wetlands shall be constructed in clay soils or have a reliable supply of baseflow or groundwater to support a permanent pool. Wet ponds and constructed wetlands proposed in sandy soils above the groundwater table shall have a clay or synthetic liner to minimize infiltration.

(c.) A constructed wetland must have a minimum contributing drainage area of 10 acres (5 acres for a pocket wetland).

(2) Setbacks shall be as follows:
  (a.) Public and private sidewalk/non-motorized pathway: 5 feet
  (b.) Adjacent property line: 10 feet
  (c.) Building foundation: 30 feet
  (d.) Private well: 50 feet
  (e.) Public well: 200 feet from Type I or Type IIa wells, 75 feet from Type IIb or Type III wells (Safe Drinking Water Act, Act 399, PA 1976)
  (f.) Septic system drainfield: 100 feet
  (g.) Airport: Per Federal Aviation Administration guidelines (wet pond; constructed wetland)

b. Configuration

(1) General
  (a.) Distances of flow paths between inlets and outlets shall be maximized. A minimum basin length-to-width ratio of 2 to 1 is required.
  (b.) If site constraints preclude placing pipes at opposite ends of the basin or meeting the length-to-width ratio, baffles (berms) may be used to lengthen the flow path.
  (c.) Where steeper side slopes than those specified are unavoidable, safety railing, fencing, or other access barriers may be approved.

(2) Dry Basin
  (a.) The design high water depth should generally not exceed 10 feet above the bottom of the basin.
  (b.) Side slopes shall not be steeper than 3:1 (H:V). Where basins are to be maintained as a mown lawn, side slopes shall be no steeper than 4:1 (H:V) to facilitate mowing.
  (c.) The bottom of dry detention basins shall be graded to provide positive flow to the pipe outlet. A minimum longitudinal bottom slope of 1% shall be provided. Cross slopes shall be 2% minimum. If continuous flow is anticipated, a low-flow channel shall be provided, with necessary crossings, and sloped to eliminate standing water. If site grades prohibit achieving these minimum slopes, the use of an underdrain with flatter slopes may be approved.

(3) Wet Pond
  (a.) At a minimum, the volume of the permanent pool for wet ponds shall be 2.5 times the water quality volume to account for reduced settling efficiency due to turbulence caused by wind.
  (b.) Wet ponds shall generally be wedge-shaped with inflow at the narrow end to prevent short-circuiting and stagnation. However, other shapes meeting the design intent may be approved.
  (c.) Permanent pools shall have a minimum depth of 3 feet across the deepest part of the basin to discourage aquatic plant infill and provide open water.
  (d.) The design high water depth should generally not exceed 10 feet above the permanent pool elevation.
  (e.) Side slopes shall not be steeper than 3:1 (H:V). Where basins are to be maintained as a mown lawn to the water’s edge, side slopes shall be no steeper than 4:1 (H:V) to facilitate mowing.
  (f.) A minimum 8-foot wide safety bench shall be constructed on the slopes of wet ponds with a permanent pool 3 feet or deeper. The safety bench shall have a maximum slope of 6:1 (H:V) and extend a minimum of 8 inches below the permanent pool level and a minimum of 8 inches above the permanent pool level.
  (g.) Warning signs prohibiting swimming and skating shall be posted for wet ponds.

(4) Constructed Wetland
   (a.) The emergent vegetation zone shall comprise 60 to 65% of the total surface area. Half shall be high marsh with a normal water depth of 6 inches or less, and half shall be low marsh with a normal water depth between 6 and 18 inches.
   (b.) The open water zone shall comprise 35% to 40% of the total surface area with a normal water depth of between 18 inches and 6 feet.
   (c.) At a minimum, the volume of the permanent pool for the open water zone shall be 2.5 times the water quality volume to account for reduced settling efficiency due to turbulence caused by wind.
   (d.) The design high water surface elevation shall not exceed the normal water surface elevation by more than 4 feet.
   (e.) Side slopes shall be 4:1 to 5:1 (H:V) wherever possible. Side slopes shall not be steeper than 3:1 (H:V).
   (f.) A minimum 8-foot wide safety bench shall be constructed on the slopes of constructed wetlands with a permanent pool 3 feet or deeper. The safety bench shall have a maximum slope of 6:1 (H:V) and extend a minimum of 8 inches below the permanent pool level and a minimum of 8 inches above the permanent pool level.
   (g.) A micro pool shall be located at the outlet of the stormwater wetland to protect the low flow pipe from clogging and prevent sediment resuspension. The micro pool shall be 3 to 6 feet deep and have a minimum surface area equivalent to the forebay.
   (h.) A pocket wetland shall consist of a forebay and micropool with safety benches.

c. Inlet Design

(1) Inlet pipes shall not be fully submerged at normal pool elevations.

(2) Inlet pipes shall require energy dissipation. Riprap protection or equivalent erosion control measures shall be used where the velocity exceeds 4 feet per second up to maximum allowable design velocity of 8 feet per second.

(3) Pretreatment shall be provided in a sediment forebay, spill containment cell, or water quality swale. For small sites, a water quality device may be used prior to the basin. Pretreatment for overland sheet flow entering the basin can be provided through a vegetated filter strip.

(4) When spill containment is required, all pipes contributing runoff from the high-risk area must enter the pretreatment BMP.

d. Outlet Design

(1) The outlet shall consist of a multi-stage outlet and include a low flow outlet, a primary overflow (typically provided through the top of a grated riser pipe), and a secondary emergency overflow spillway.

(2) Staged low flow outlet: When required, the lowest stage openings shall be sized for the water quality and/or channel protection volume. The flood control opening shall be placed at the water quality and/or channel protection high water level and sized so that the cumulative discharge from all openings is limited to the allowable design discharge at the design high water level.

(3) Low Flow Outlet

(a.) The low flow outlet shall be designed using the orifice equation, rearranged to solve for area:

$$A = \frac{Q}{c\sqrt{2gH}} \qquad (4.2)$$

where:

*A* = required area (square feet)
*Q* = required outflow (cubic feet per second)
*c* = orifice coefficient (approximately 0.6)
*2g* = 2 times the gravitation constant (g = 32.2 feet per second squared)
*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.) The outlet shall be designed to prevent clogging and be accessible for maintenance. The largest single orifice diameter shall be used in lieu of multiple smaller holes.

(d.) The minimum inlet and outlet pipe diameter from the control structure shall be 12 inches.

(e.) The minimum pipe or hole diameter cored through a weir wall shall be 6 inches. Smaller openings shall be provided using an orifice plate, drilled end cap, or reducer. The minimum orifice diameter shall be 2 inches.

(f.) Protection against clogging.

i. <u>Openings 6 inches and larger</u>: Sump; AND exterior pipe end grate set on an angle, consisting of parallel longitudinal bars spaced 4-inches on center for 12- through 30-inch pipe diameters, and 6-inches on center for pipe diameters 36 inch and larger.

ii. <u>Openings less than 6 inches</u>: Sump; AND exterior pipe end grate; AND baffle and/or screening around orifice plate. Screening shall have a surface area at least 10 times larger than the orifice area and openings equal to half the width of the orifice. Bends or tees used to form any downturned ends shall be 6-inch diameter.

iii. A gravel filter over minimum 4-inch underdrain or around a perforated riser may be used in lieu of an open exterior pipe. If a gravel filter is used, it shall consist of 3-inch washed stone placed around the riser with 1-inch washed stone covering the larger stone.

(g.) Orifices used to maintain a permanent pool shall be designed to withdraw water a minimum of 2 feet below the normal water surface.

(4) Primary Overflow

(a.) All detention basins must have a primary overflow at the design high water level.

(b.) The primary overflow and downstream pipe shall be designed to convey the 10-year undetained peak inflow at the maximum design high water level. Exceptions may be made where it is not practical to meet the 10-year criteria. The crest of the secondary emergency spillway shall be set at the maximum design high water level, but no less than 0.5 foot above the primary overflow.

(c.) Hoods and trash racks shall be placed on riser pipes. Grate openings shall be a maximum of 3 inches on center. A vertical flow area must be provided where leaves and debris are prone to clog a horizontally seated grate.

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

(e.) Riser pipes shall be constructed of reinforced concrete or corrugated metal and be set in a concrete base designed to prevent buoyancy. Plastic is not acceptable as a material unless riser is buried, due to lack of durability.

(f.) The riser must be placed near or within the embankment to provide for maintenance access.

(g.) When possible, a drain for completely dewatering the detention basin shall be installed for maintenance purposes.

(h.) Pipes placed through embankments shall have anti-seep collars.

(i.) Outlet pipes shall require energy dissipation. Riprap protection or equivalent erosion control measures shall be used where the velocity exceeds 4 feet per second up to maximum allowable design velocity of 8 feet per second.

(5) Secondary Emergency Spillway

(a.) All detention basins must have a provision for an emergency spillway through the berm.

(b.) The spillway shall be designed for the 10-year undetained peak inflow with a maximum flow depth of 1 foot. The spillway shall be sized using the weir equation:

Rectangular weir: $$Q = CLH^{\frac{3}{2}} \quad (4.3)$$

Trapezoidal weir: $$Q = 0.75CmH^{2.5} + CLH^{\frac{3}{2}} \quad (4.4)$$

Triangular weir: $$Q = 0.75CmH^{2.5} \quad (4.5)$$

where:

*Q* = discharge (cubic feet per second)
*C* = coefficient of discharge (varies from 2.6 to 3.3)
*m* = horizontal component of side slope
*L* = length of spillway crest (feet)
*H* = total head measured above spillway crest (feet)

(c.) Freeboard.

i. Primary overflow provided: The top of berm elevation shall be equal to or greater than the design flow depth, and in no case shall the spillway depth be less than 0.5 foot.

ii. No primary overflow: The top of berm elevation shall be a minimum of 0.5 foot above the design flow depth, and in no case shall the spillway depth be less than 1 foot.

iii. Additional freeboard may be required based on risk.

(d.) Overflow spillways shall be protected with concrete, riprap, or a permanent erosion control blanket to prevent erosion of the structure. Protection shall extend across the entire spillway up to the top of berm, starting on the basin side a minimum of 3 feet below the crest and extending down the spillway to an apron a minimum of 6 feet beyond the toe of the spillway.

e. Access

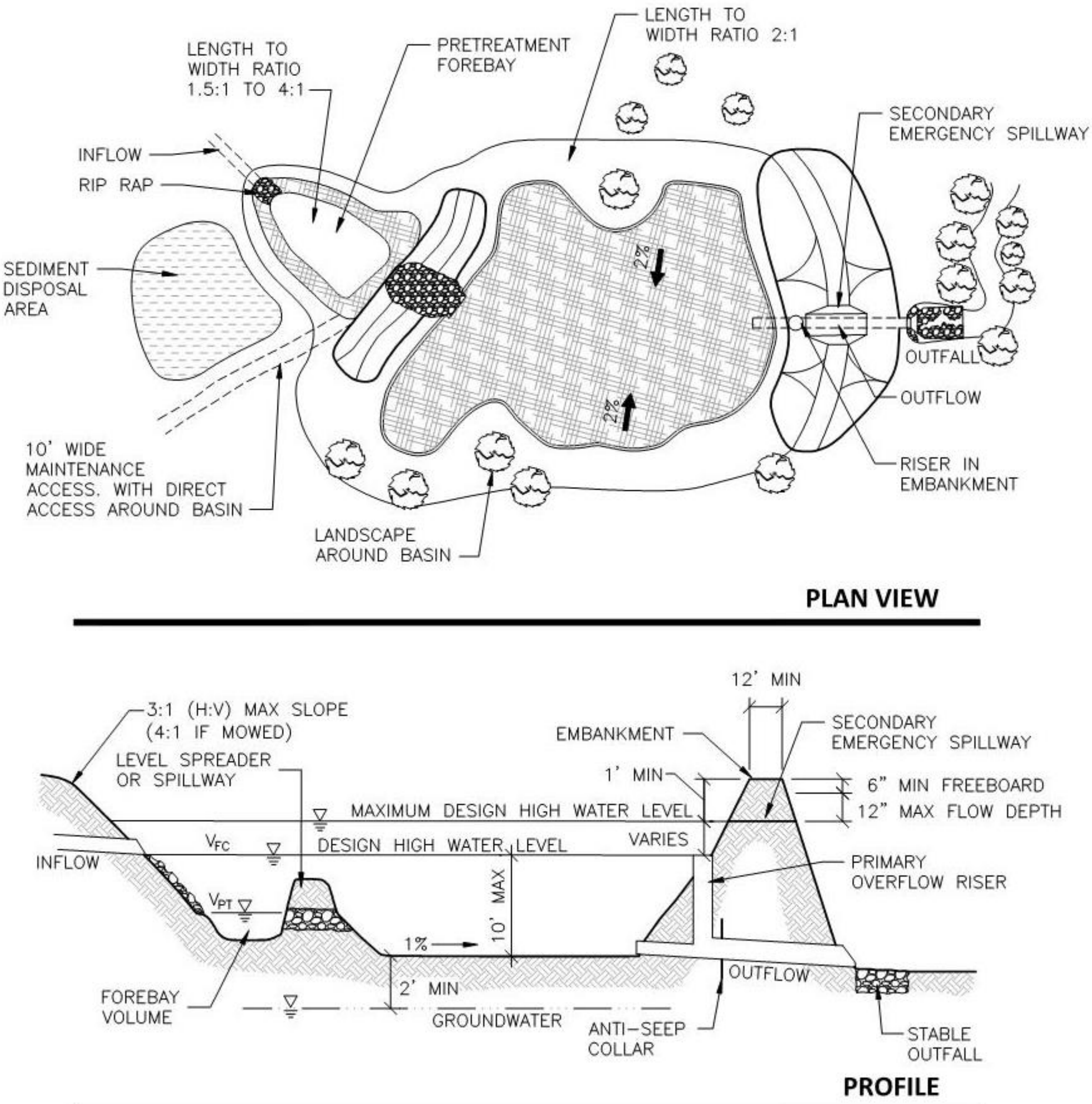
(1) Outlet control structures shall be placed near or within the embankment to facilitate maintenance access.

(2) Berm top width shall be a minimum of 4 feet, or 12 feet where vehicle access is required for maintenance.

(3) A minimum 10-foot wide maintenance access route from a public or private right-of-way shall be provided to the basin. The access way (including side slopes on trapezoidal and triangular spillways) shall have a vertical grade of no greater than 20% (5:1 H:V slope) and shall be stabilized to withstand the passage of heavy equipment. Direct access to the forebay, control structures and the outlet shall be provided.

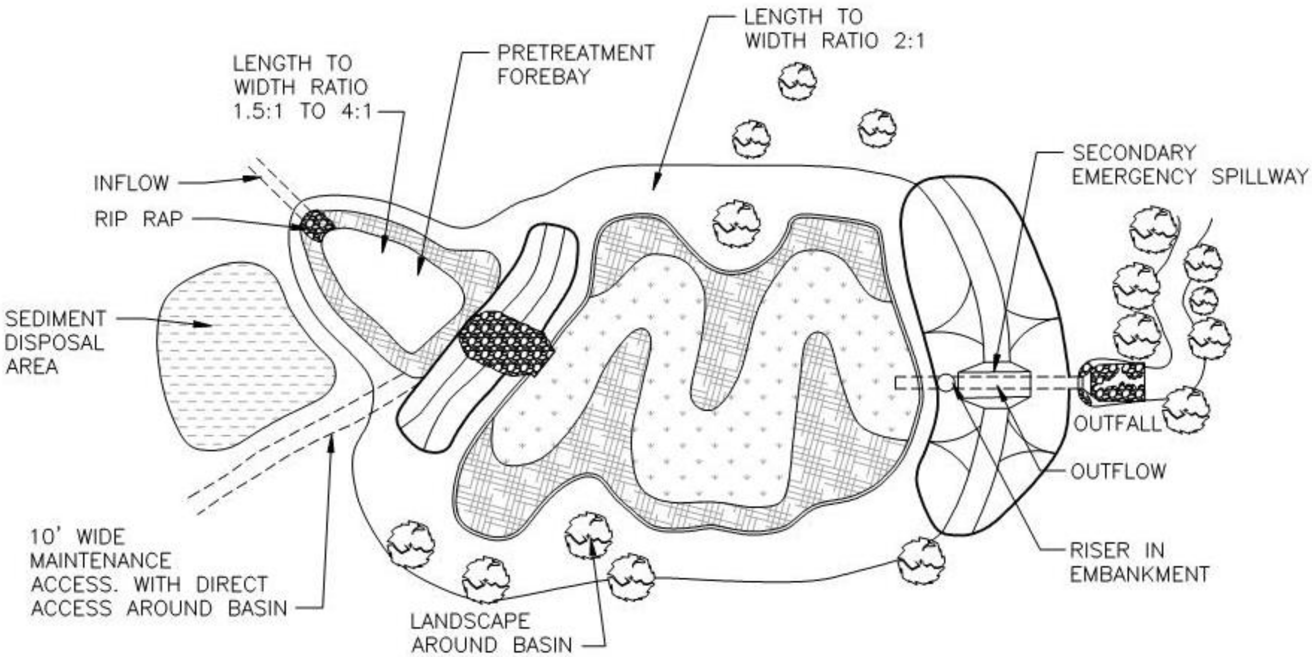
## 4. Design Schematics

# DRY DETENTION BASIN

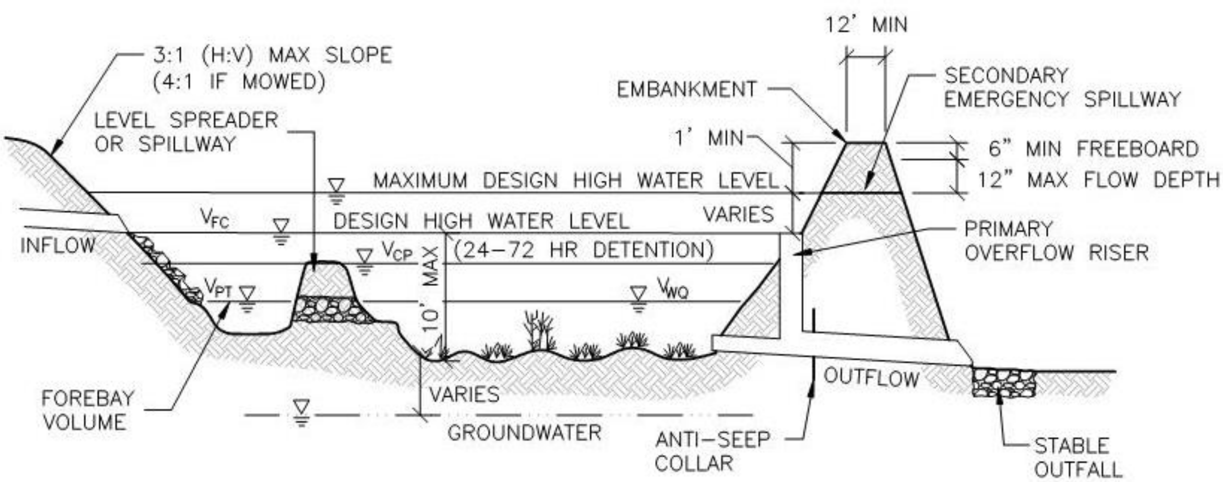



FINAL OUTLET CONFIGURATION MUST BE DESIGNED TO PREVENT CLOGGING

# EXTENDED DETENTION BASIN



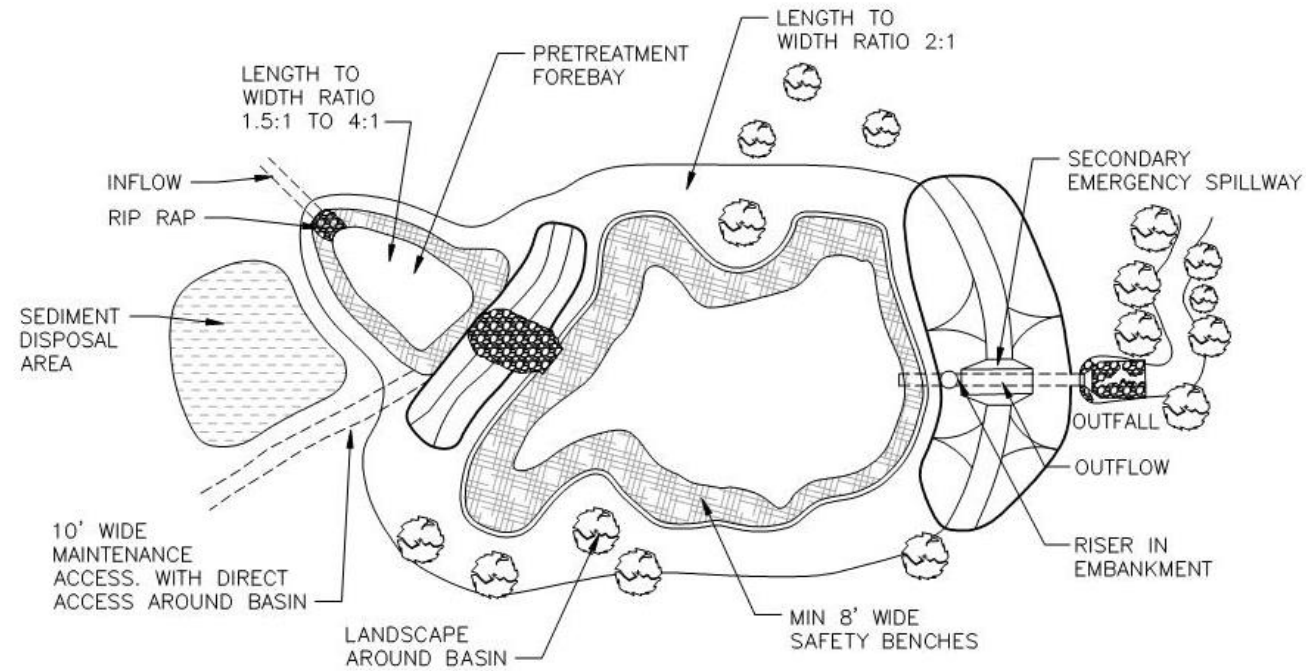

**PLAN VIEW**



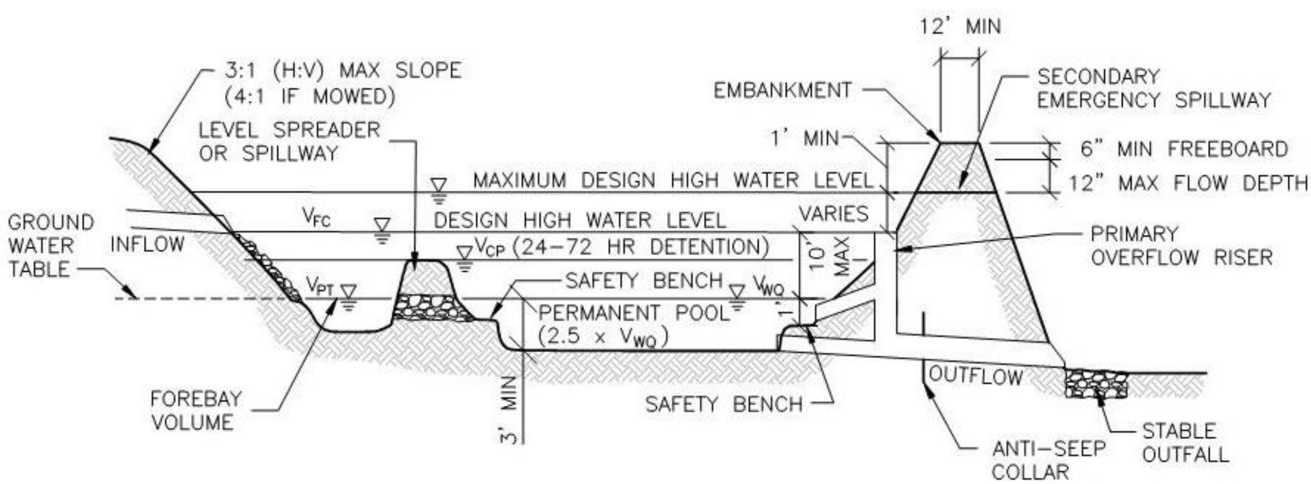

**PROFILE**

FINAL OUTLET CONFIGURATION MUST BE DESIGNED TO PREVENT CLOGGING

# WET DETENTION BASIN (WET POND)



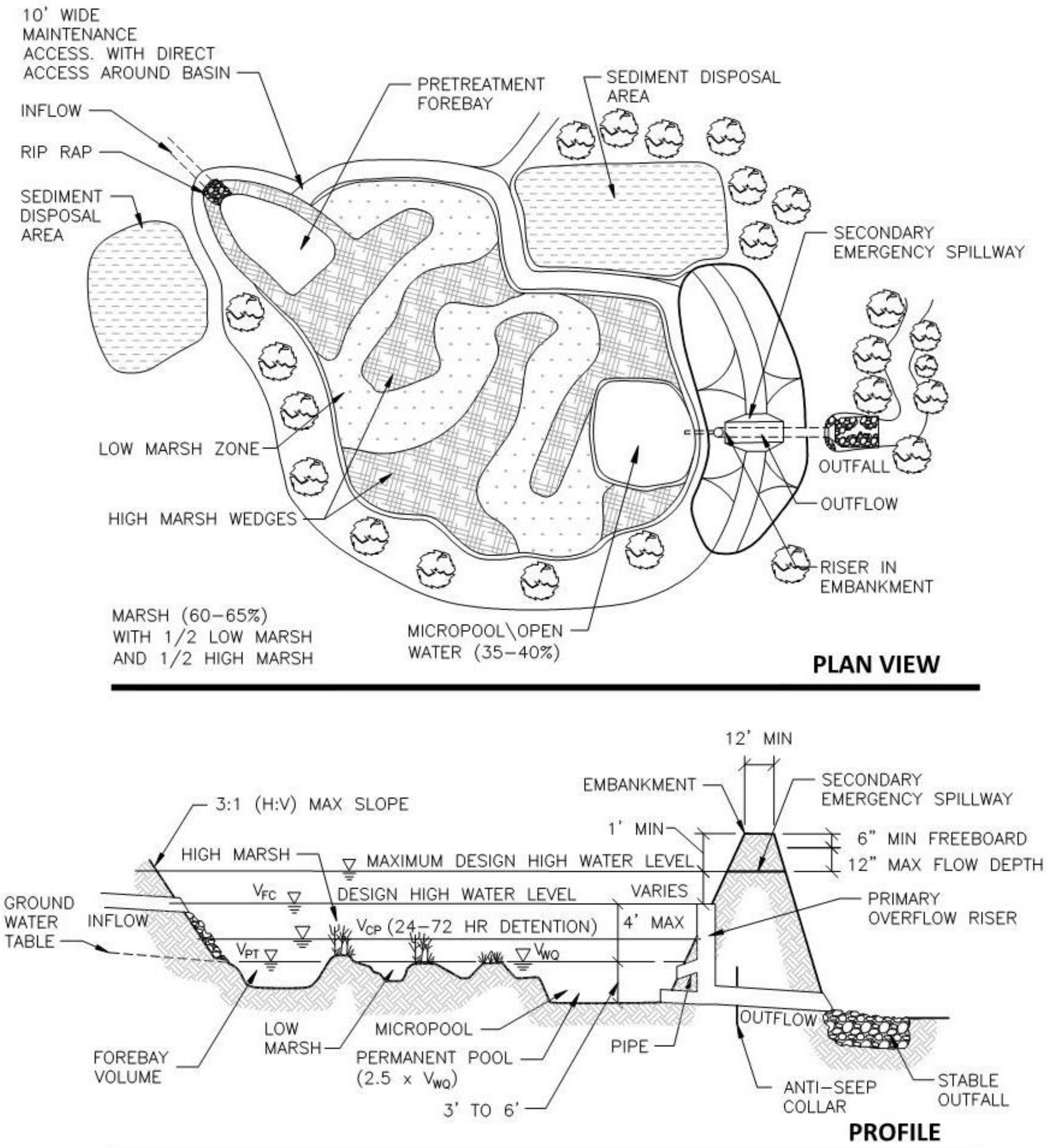

**PLAN VIEW**




**PROFILE**

FINAL OUTLET CONFIGURATION MUST BE DESIGNED TO PREVENT CLOGGING

# CONSTRUCTED WETLAND




FINAL OUTLET CONFIGURATION MUST BE DESIGNED TO PREVENT CLOGGING

# Retention Basin

## 1. Summary

| | |
|---|---|
| Description: | Provides stormwater storage without a pipe outlet, relying instead on infiltration into the ground. |
| Application: | Practical in sandy soils.<br>Not recommended for regional use. |
| Types: | Dry Basin; Wet Pond. |
| Pretreatment Required: | Yes. |
| Maintenance Plan: | Yes. |
| Calculation Credits: | |
| Volume Reduction: | Count volume stored and infiltrated. |
| Rate Reduction: | Designed for flood control: 100%. |
| Water Quality: | Count volume stored and infiltrated. |

## 2. Sizing Calculations

a. Retention basins shall be sized for flood control.

b. Calculate the required storage volume. Refer to Part 3 section "Calculating Storage Volumes and Release Rates, Flood Control, Retention" for calculation methods and credit allowed from upstream retentive BMPs.

c. Water quality and channel protection volumes may be included in the flood control volume.

d. Calculate the minimum infiltration area required to drain the required storage volume in the specified drawdown time using the design infiltration rate. Refer to Part 3 section "Design Infiltration Rates" to determine the design infiltration rate.

$$A = \frac{12Vs}{i(t_d)} \tag{4.6}$$

where:
$A$ = minimum infiltration area (square feet)
$Vs$ = storage volume (cubic feet)
$i$ = design infiltration rate (inches per hour)
$t_d$ = maximum allowable drawdown time (hours)
*12* factor to convert inches to feet

e. Drawdown time shall be no more than 72 hours.

f. The infiltration area shall be defined as the bottom of the basin, or the horizontal projection of the side slopes up to half of the design water depth above a permanent pool.

g. When possible, retention basins must have a primary overflow at the design high water level.

h. Retention basins without an acceptable surface water overflow route shall be designed for 2 times the required flood control volume.

i. Regional retention basins are strongly discouraged. If accepted for use, a regional retention basin shall be sized for the 100-year flood control volume and require spill containment, forebays sized for the full water quality volume, and may require other measures to reduce the potential for groundwater contamination and protect the infiltration capacity of the BMP.

## 3. Design Requirements

a. Siting

(1) Soil borings are required. Refer to Part 3 section “Soils Investigation.”

(a.) A minimum of 3 feet is required between the bottom of dry retention basins and the highest known groundwater elevation.

(2) Setbacks shall be as follows:

(a.) Public and private sidewalk/non-motorized pathway: 5 feet
(b.) Adjacent property line: 10 feet
(c.) Building foundation: 30 feet
(d.) Private well: 50 feet
(e.) Public well: 200 feet from Type I or Type IIa wells, 75 feet from Type IIb or Type III wells (Safe Drinking Water Act, Act 399, PA 1976)
(f.) Septic system drainfield: 100 feet
(g.) Airports: Per Federal Aviation Administration guidelines (wet pond)

(3) Groundwater mounding calculations may be required to ensure no adverse impacts to adjacent structures.

b. Configuration

(1) General

(a.) Where steeper side slopes than those specified are unavoidable, safety railing, fencing or other access barriers may be approved.

(2) Dry Basin

(a.) The design high water depth should generally not exceed 6 feet above the basin bottom.
(b.) Side slopes shall not be steeper than 3:1 (H:V). Where basins are to be maintained as a mown lawn, side slopes shall be no steeper than 4:1 (H:V) to facilitate mowing.
(c.) The bottom of dry retention basins shall generally be flat to encourage uniform ponding and infiltration.

(3) Wet Pond (no surface water outlet)

(a.) The design high water depth should generally not exceed 7 feet above the permanent pool elevation.
(b.) Where excavation and reshaping of the retention area is necessary, side slopes shall not be steeper than 3:1 (H:V). Where basins are to be maintained as a mown lawn to the water’s edge, side slopes shall be no steeper than 4:1 (H:V) to facilitate mowing.
(c.) A minimum 8-foot wide safety bench shall be constructed on the slopes of wet ponds with a permanent pool 3 feet or deeper. The safety bench shall have a maximum slope of 6:1 (H:V) and extend a minimum of 8 inches below the permanent pool level and a minimum of 8 inches above the permanent pool level.
(d.) Warning signs prohibiting swimming and skating shall be posted for wet ponds.

c. Inlet Design

(1) Inlet pipes shall not be fully submerged at normal pool elevations.

(2) Inlet pipes shall require energy dissipation. Riprap protection or equivalent erosion control measures shall be used where the velocity exceeds 4 feet per second, up to maximum allowable design velocity of 8 feet per second.

(3) Pretreatment is required for each inlet and shall be provided in a sediment forebay, spill containment cell, or water quality swale. For small sites, a water quality device may be used prior to the basin. Pretreatment for overland sheet flow entering the basin can be provided through a vegetated filter strip.

(4) When spill containment is required, all pipes contributing runoff from the high-risk area must enter the pretreatment BMP.

d. Overflow

(1) Primary Overflow

(a.) The primary overflow and downstream pipe shall be designed to convey the 10-year peak inflow at the maximum design high water level. The crest of the secondary emergency spillway shall be set at the maximum design high water level, but no less than 0.5 foot above the primary overflow.
(b.) Hoods and trash racks shall be placed on riser pipes. Grate openings shall be a maximum of 3 inches on center. A vertical flow area must be provided where leaves and debris are prone to clog a horizontally seated grate.
(c.) Riser pipes shall have a minimum diameter of 24 inches. Riser pipes greater than 4 feet in height shall be a minimum of 48 inches in diameter.
(d.) Riser pipes shall be constructed of reinforced concrete or corrugated metal and be set in a concrete base designed to prevent buoyancy. Plastic is not acceptable as a material unless riser is buried, due to lack of durability.
(e.) When possible, a drain for completely dewatering the retention basin shall be installed for maintenance purposes.
(f.) Pipes placed through embankments shall have anti-seep collars.
(g.) Outlet pipes shall require energy dissipation. Riprap protection or equivalent erosion control measures shall be used where the velocity exceeds 4 feet per second up to maximum allowable design velocity of 8 feet per second.

(2) Secondary Emergency Spillway

(a.) All retention basins must have a provision for an emergency spillway through the berm.
(b.) The spillway shall be designed for the 10-year peak inflow with a maximum flow depth of 1 foot. The spillway shall be sized using the weir equation:

Rectangular weir: $$Q = CLH^{\frac{3}{2}} \quad (4.3)$$

Trapezoidal weir: $$Q = 0.75CmH^{2.5} + CLH^{\frac{3}{2}} \quad (4.4)$$

Triangular weir: $$Q = 0.75CmH^{2.5} \quad (4.5)$$

where:
*Q* = discharge (cubic feet per second)
*C* = coefficient of discharge (varies from 2.6 to 3.3)
*m* = horizontal component of side slope
*L* = length of spillway crest (feet)
*H* = total head measured above spillway crest (feet)

(c.) Freeboard.
   i. Primary overflow provided: The top of berm elevation shall be equal to or greater than the design flow depth, and in no case shall the spillway depth be less than 0.5 foot.
   ii. No primary overflow: The top of berm elevation shall be a minimum of 0.5 foot above the design flow depth, and in no case shall the spillway depth be less than 1 foot.
   iii. Additional freeboard may be required based on risk.

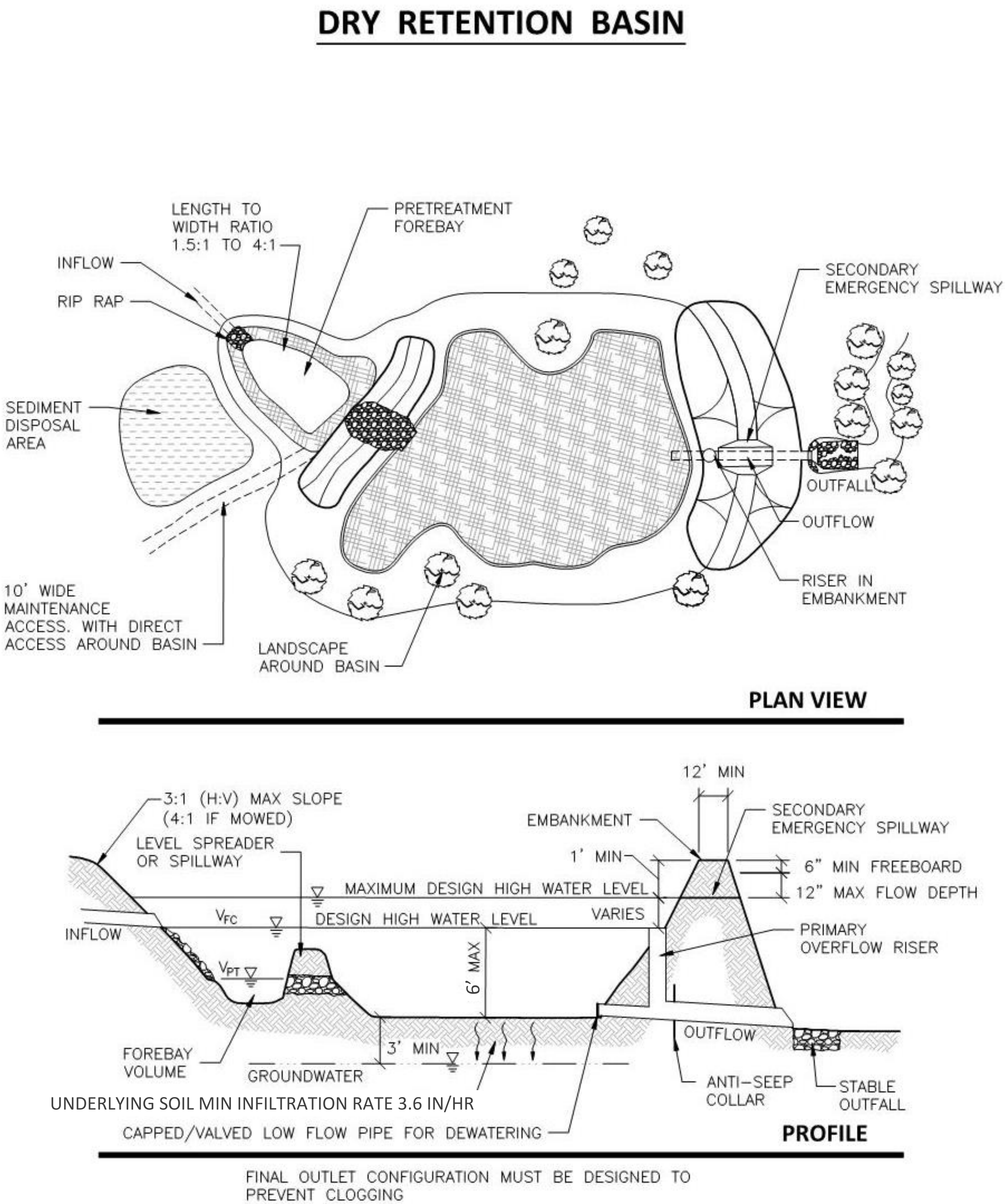
(d.) Overflow spillways shall be protected with concrete, riprap, or a permanent erosion control blanket to prevent erosion of the structure. Protection shall extend across the entire spillway up to the top of berm, starting on the basin side a minimum of 3 feet below the crest and extending down the spillway to an apron a minimum of 6 feet beyond the toe of the spillway.

e. Access
   (1) Berm top width shall be a minimum of 4 feet, or 12 feet where vehicle access is required.
   (2) A minimum 10-foot wide maintenance access route from a public or private right-of-way shall be provided to the basin. The access way (including side slopes on trapezoidal and triangular spillways) shall have a vertical grade of no greater than 20% (5:1 H:V slope) and shall be stabilized to withstand the passage of heavy equipment. Direct access to the forebay, control structures and the outlet shall be provided.

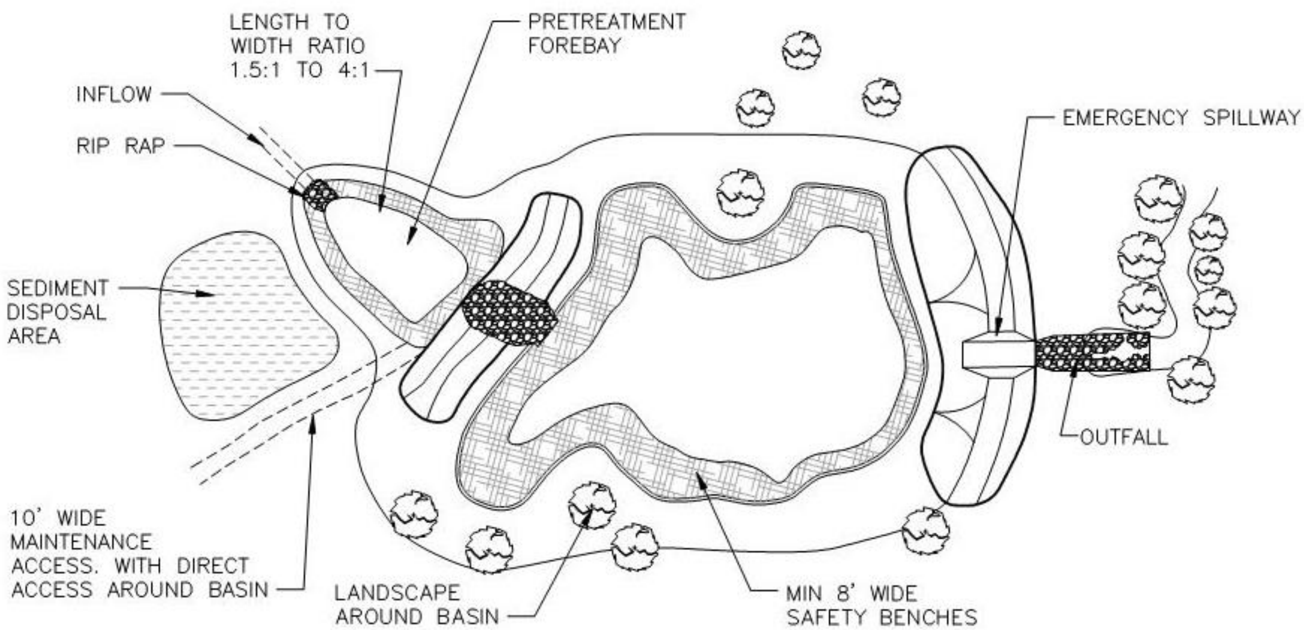
f. Finishing and Top Dressing
   (1) Care must be taken during the excavation and finishing process to make sure that soil compaction does not occur.
   (2) The bottom of dry retention basins shall be scarified or deep tilled to a depth of 6 to 12 inches after final grading has been established.
   (3) Top Dressing for basin bottom and side slopes:
      (a.) A permeable blend of sand, compost and/or topsoil with a pH between 5.5 and 7.5.
         i. 3-inches of compost tilled into the top 6-inches of native permeable soil (equivalent to a 9-inch homogenous mixture of 70% sand; 30% compost); or
         ii. 4-inches of topsoil tilled into the top 6-inches of native permeable soil (equivalent to a 10-inch homogenous mixture with maximum 20% silts, 4% clay, and 80% to 92% sand).
      (b.) Topsoil shall be sandy loam, loamy sand or loam per USDA Soil Textural Triangle with 20% to 50% fines by volume (silt and clay with <10% clay), and 2% to 8% organic matter by dry weight.
      (c.) Placement of a topsoil layer without tilling is generally not allowed due to the diminished infiltration rates observed.
      (d.) A bare sand bottom is not allowed, as it provides no cation exchange capacity or vegetative uptake for pollutant removal.

g. Supplemental Measures
   (1) Supplemental measures may be required to ensure that a retention basin drains sufficiently as the soil becomes less permeable with use. The need for supplemental measures may be based on a number of indicators including:
      (a.) Underlying soils with a design infiltration rate less than 3.6 inches per hour.
      (b.) High probability for sedimentation (particularly fines).
      (c.) Larger regional basin where there is less control over contributing area runoff.
      (d.) Probability of groundwater rising higher than minimum isolation distance.
   (2) Supplemental measures may include:
      (a.) Leaching basins, infiltration trench, or wick drains placed in the bottom of the basin.
      (b.) Valved outlet to drain basin.
      (c.) Conversion to a wet basin with sufficient storage volume provided above the permanent pool.

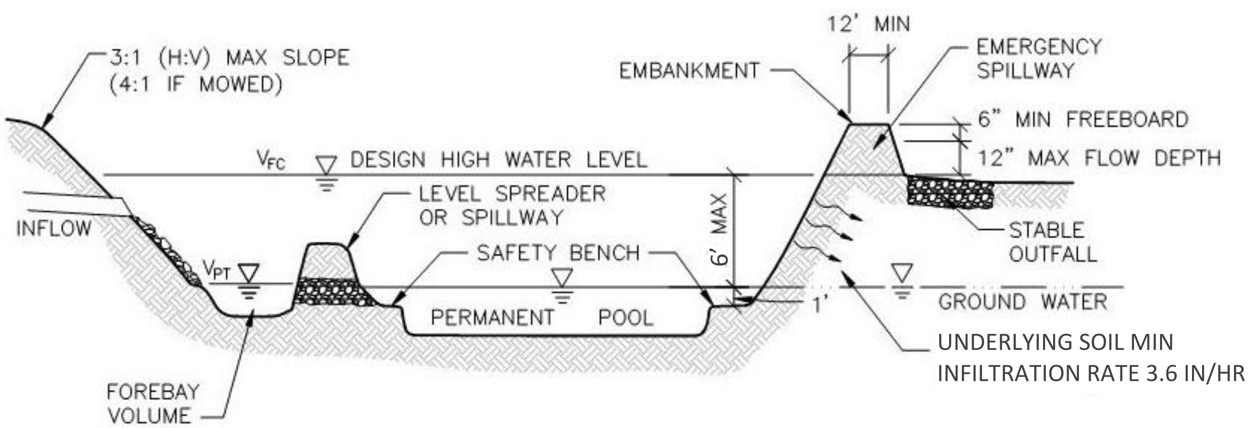
## 4. Design Schematics



# WET RETENTION BASIN




**PLAN VIEW**




**PROFILE**

# Sediment Forebay

## 1. Summary

| | |
|---|---|
| Description: | Stormwater pretreatment practice. |
| Application: | Typically used with a detention or retention basin. |
| Types: | Wet basin; Dry basin; Level spreader. |
| Pretreatment Required: | No. This BMP can provide pretreatment. |
| Maintenance Plan: | Yes. |
| Calculation Credits: | |
| Volume Reduction: | None. |
| Rate Reduction: | None. |
| Water Quality: | Count volume routed through BMP. |

## 2. Sizing Calculations

a. Sediment forebays shall be sized for pretreatment. Refer to Part 3 section “Calculating Storage Volumes and Release Rates, Pretreatment.”

b. The pretreatment volume is the volume of the forebay to the elevation of the level spreader or overflow spillway including any permanent pool.

## 3. Design Requirements

a. Siting

(1) Where more than one inlet pipe is required, the calculated forebay volume shall be pro-rated by flow contribution of each inlet.

b. Configuration

(1) The sediment forebay shall be a separate sump, which can be formed by grading.

(2) The minimum sump depth shall be 2 feet, and in any case no less than 1 foot.

(3) The forebay must be wider than it is deep. The minimum surface area shall be 25% of the pretreatment volume (this results in a maximum depth of 4 feet).

(4) The length-to-width ratio shall be a minimum of 1.5:1 and a maximum of 4:1 to allow for adequate hydraulic length yet minimize scour velocities.

(5) The top-of-berm elevation between the forebay and the basin shall be a minimum of 1 foot below the outer berm elevation.

(6) The overflow spillway shall be sized using Equations 4.3 through 4.5 and designed to prevent erosion.

## 4. Design Schematics

a. See “Detention Basin” and “Retention Basin” BMPs.

# Spill Containment Cell

## 1. Summary

| | |
|---|---|
| Description: | Lined stormwater pretreatment practice. |
| Application: | Typically used with a detention or retention basin. |
| Types: | Wet cell. |
| Pretreatment Required: | No. This BMP can provide pretreatment and spill containment. |
| Maintenance Plan: | Yes. |
| Calculation Credits: | |
| Volume Reduction: | None. |
| Rate Reduction: | None. |
| Water Quality: | Count volume routed through BMP. |

## 2. Sizing Calculations

a. Spill containment cells shall be sized for pretreatment. Refer to Part 3 section “Calculating Storage Volumes and Release Rates, Pretreatment”.

b. The pretreatment volume is the volume of the spill containment cell to the elevation of the level spreader or overflow spillway including any permanent pool.

c. The spill containment volume is the storage volume between the normal water level and the entrance of the outlet pipe. The minimum spill containment volume shall be provided to capture a slug pollutant load from an accidental spill of toxic materials.

## 3. Design Requirements

a. Siting

(1) All inlets shall enter the spill containment cell unless the inlet collects stormwater exclusively from non-hotspot areas (i.e. office parking, courtyard, roof.)

b. Configuration

(1) The spill containment cell must be wider than it is deep. The minimum surface area shall be 25% of the pretreatment volume (this results in a maximum depth of 4 feet).

(2) The length-to-width ratio shall be a minimum of 1.5:1, and a maximum of 4:1 to allow for adequate hydraulic length yet minimize scour velocities.

(3) The top-of-berm elevation between the spill containment cell and the basin shall be a minimum of 1 foot below the outer berm elevation.

(4) Side slopes shall not be steeper than 3:1 (H:V). Where basins are to be maintained as a mown lawn, side slopes shall be no steeper than 4:1 (H:V) to facilitate mowing.

(5) Minimum depth of the permanent pool shall be 3 feet.

(6) Unless protected by fencing, a minimum 4-foot wide safety bench shall be constructed around the permanent pool. The safety bench shall have a maximum slope of 6:1 (H:V) and extend a minimum of 4 inches below the permanent pool level and a minimum of 4 inches above the permanent pool level.

c. Outlet Design

(1) The outlet structure from the spill containment cell 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 of the transfer pipe shall be located a minimum of 1 foot below the normal water level, and a minimum of 1 foot above the bottom of the spill containment cell or manhole sump.

(2) The transfer pipe(s) between the spill containment cell and the basin shall be sized for the peak inflow from a 10-year rainfall event.

(3) Minimum pipe diameter shall be 12 inches.

d. Emergency Overflow

(1) The crest of the level spreader or overflow spillway from the spill containment cell shall be set at the elevation of the calculated 10-year hydraulic head.

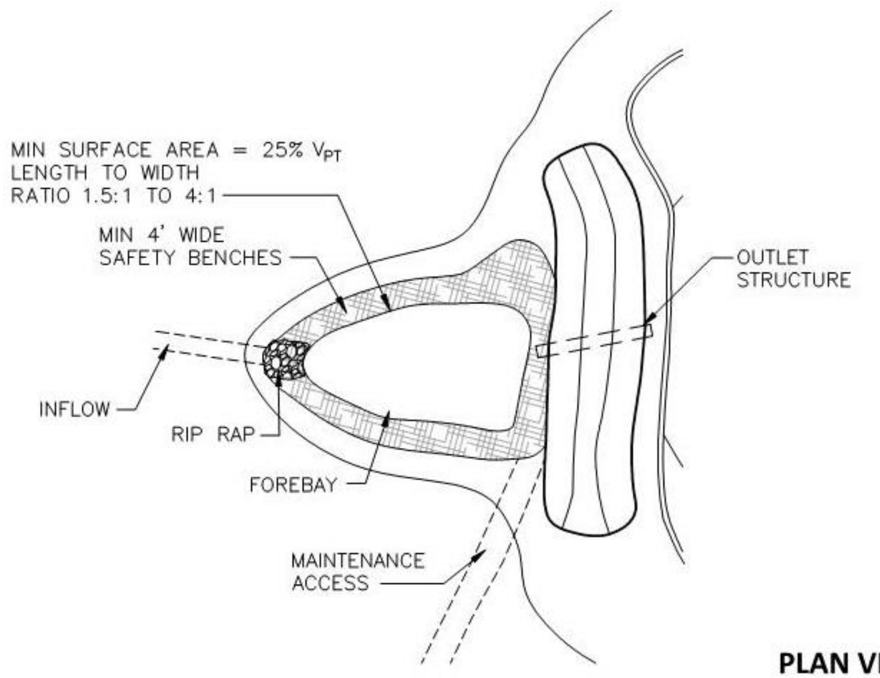
(2) The overflow spillway from the spill containment cell shall be sized using Equations 4.3 through 4.5 and designed to prevent erosion.

e. Materials

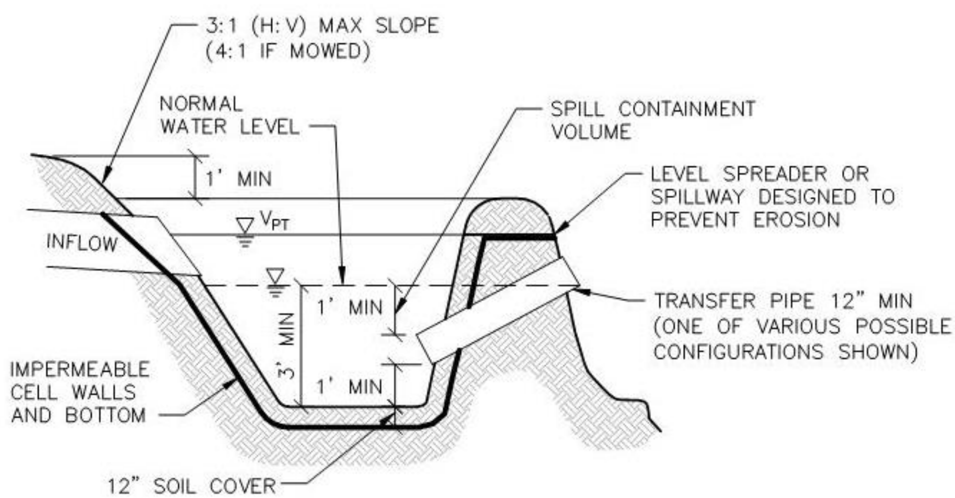
(1) The spill containment cell shall be lined with impermeable materials extending up to the design high water elevation. A minimum 18-inch-thick clay layer, or an impermeable liner protected with a minimum 12 inches of soil cover are acceptable alternatives. Maximum allowable permeability shall be $1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

## 4. Design Schematics

### SPILL CONTAINMENT CELL




PLAN VIEW




NOTE:
SPILL CONTAINMENT CELL
SHALL BE CONSTRUCTED IN
PLACE OF THE FOREBAY
WHERE REQUIRED

PROFILE

# Infiltration Practices

## 1. Summary

| | |
|---|---|
| Description: | Stormwater treatment and storage without a pipe outlet, relying instead on infiltration into the ground. |
| Application: | Practices are typically applicable to small sites and drainage areas in sandy soils. |
| Types: | Dry Well; Leaching Basin; Infiltration Trench; Infiltration Bed; Infiltration Berm. |
| Pretreatment Required: | Yes. |
| Maintenance Plan: | Yes. |
| Calculation Credits: | |
| Volume Reduction: | Count volume stored and infiltrated. |
| Rate Reduction: | Designed for flood control: 100%.<br>Designed for channel protection and/or water quality: Adjust time-of-concentration by dividing storage volume by 10-year peak flow rate. |
| Water Quality: | Count volume stored and infiltrated. |

## 2. Sizing Calculations

a. Infiltration practices may be sized for water quality, channel protection, or flood control.

b. Calculate the required water quality or channel protection volume. Refer to Part 3 section “Calculating Storage Volumes and Release Rates.”

c. Calculate the required storage volume. Refer to Part 3 section “Calculating Storage Volumes and Release Rates, Flood Control, Retention” and “Retentive BMPs.”

d. Calculate the minimum infiltration area required to drain the required storage volume in the specified drawdown time using the design infiltration rate. Refer to Part 3 section “Design Infiltration Rates” to determine the design infiltration rate.

$$A = \frac{12Vs}{i(t_d)} \tag{4.6}$$

where:

$A$ = minimum infiltration area (square feet)
$Vs$ = storage volume (cubic feet)
$i$ = design infiltration rate (inches per hour)
$t_d$ = maximum allowable drawdown time (hours)
$12$ = factor to convert inches to feet

e. Total drawdown time shall be no more than 72 hours. Depth of surface ponding shall be no more than 2 feet and drain within 24 hours.

f. Infiltration area shall be defined as:
   (1) Dry Well/Leaching Basin: Bottom of stone and ½ the height of the sides below the outlet elevation; omit bottom area when groundwater is less than 3 feet from the bottom.
   (2) Infiltration Trench: Bottom area of the trench.
   (3) Infiltration Bed: Bottom area of the bed.
   (4) Infiltration Berm: Ponding area (length of berm x average width of ponding behind berm).

g. 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*

   Where perforated pipe is used, the formula is modified:

   *Subsurface Storage Volume (cubic feet) = Volume of Pipe (cubic feet) + [Length (feet) x Width (feet) x Depth (feet) – Volume of Pipe (cubic feet)] x Void Ratio of Material*

   (2) Leaching basins:
   *Storage Volume (cubic feet) =* $\Pi r^2$ *(square feet) x Depth (feet)*

   where:
   r = radius of leaching basin (feet)
   $\Pi$ = *pi* (approximately 3.14)

   Volume of storage in stone envelope around leaching basin may also be counted.

   (3) Infiltration berm:
   *Surface Storage Volume (cubic feet) = Average Ponding Area (square feet) x Design High Water Depth (feet)*

## 3. Design Requirements

a. Siting

   (1) Soil borings are required. Refer to Part 3 section "Soils Investigation."
      (a.) A minimum of 3 feet is required between the bottom of infiltration practices and the highest known groundwater elevation.
      (b.) Void ratio for the imported material shall be based on the USDA soil textural class and effective water capacity in **Table 6**. A maximum design value of 0.40 shall be used for the void ratio of stone.

   (2) Setbacks shall be as follows:
      (a.) Adjacent property line: 10 feet
      (b.) Building foundation: 10 feet
      (c.) Private well: 50 feet
      (d.) Public well: 200 feet from Type I or Type IIa wells, 75 feet from Type IIb or Type III wells (Safe Drinking Water Act, Act 399, PA 1976)
      (e.) Septic system drainfield: 50 feet

   (3) Infiltration practices shall be located outside of the drip line of adjacent trees to avoid root intrusion.

b. Configuration

(1) General

(a.) A combination of surface and subsurface storage may be used to provide the required storage volume.

(2) Dry wells, infiltration trenches and infiltration beds

(a.) Infiltration trench width : 2-foot minimum to 6-foot maximum.

(b.) Coarse aggregates shall be uniformly graded, washed and wrapped in a non-woven geotextile to provide separation between the aggregate and the surrounding soil and prevent fines from clogging the infiltration surface.

(c.) An observation well shall be provided for each dry well, at each end of an infiltration trench, and at each corner of an infiltration bed with intermediate center wells added so as not to exceed maximum distance of 50 feet between wells.

(d.) Perforated pipes laid flat may be used to distribute runoff over the bottom of infiltration trenches and infiltration beds.

(e.) Cleanouts shall be provided at pipe ends.

(f.) Care must be taken during the excavation and finishing process to make sure that soil compaction does not occur.

(3) Leaching Basins

(a.) Leaching basins shall have a minimum diameter of 4 feet and meet the layout requirements for catchbasins (refer to “Storm Sewer”).

(b.) 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.

(c.) Bedding and backfill shall consist of clean stone with nonwoven geotextile fabric placed along the walls of the trench and wrapped around the stone and the basin.

(4) Infiltration Berms

(a.) Infiltration berms shall be constructed along (parallel to) contours at a constant level elevation.

(b.) Maximum berm height shall be 2 feet to prevent excessive ponding behind berm.

(c.) Berm top width shall be a minimum of 2 feet.

(d.) Side slopes shall not be steeper than 4:1 (H:V) to facilitate mowing and ensure stable side slopes.

(e.) Well compacted cohesive soil shall be used to construct the berm.

(f.) The berm shall be well vegetated to prevent erosion if overtopped.

c. Inlet Design

(1) Pretreatment is required for each inlet and for overland flow entering the infiltration practice. Exceptions may be allowed for small, paved drainage areas contributing directly to a leaching basin.

d. Emergency Overflow

(1) All infiltration practices must have a provision for overflow at the high water level.

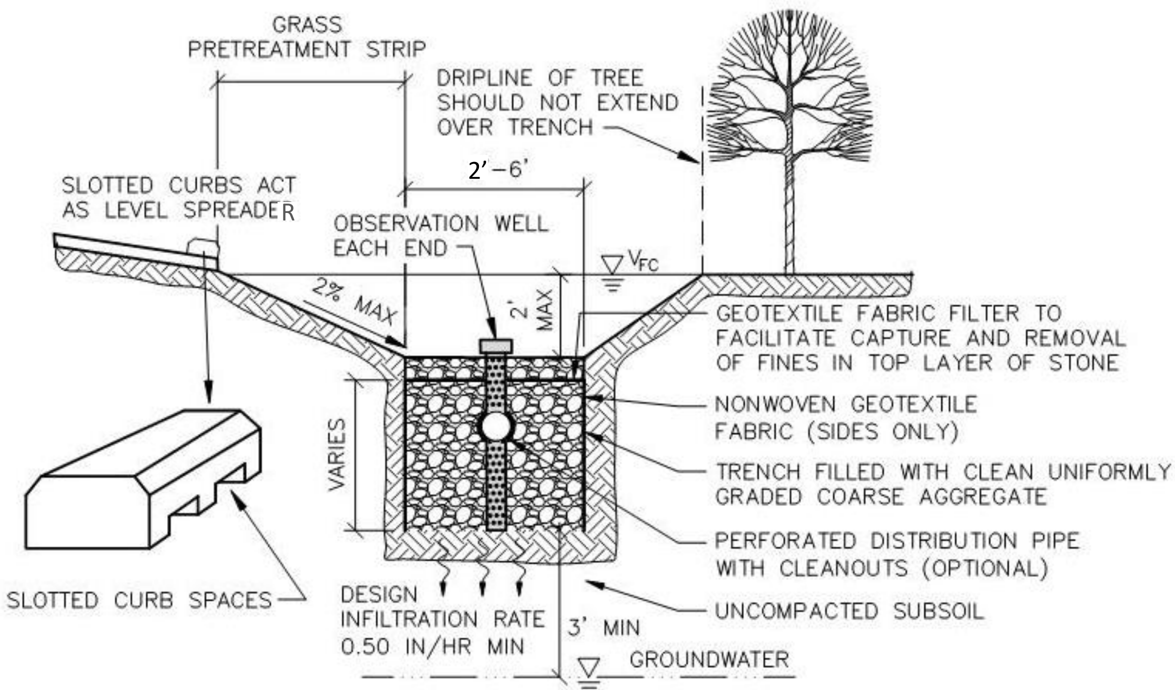
(2) Infiltration practices without an acceptable surface water overflow route shall be designed for 2 times the required flood control volume.

e. Access

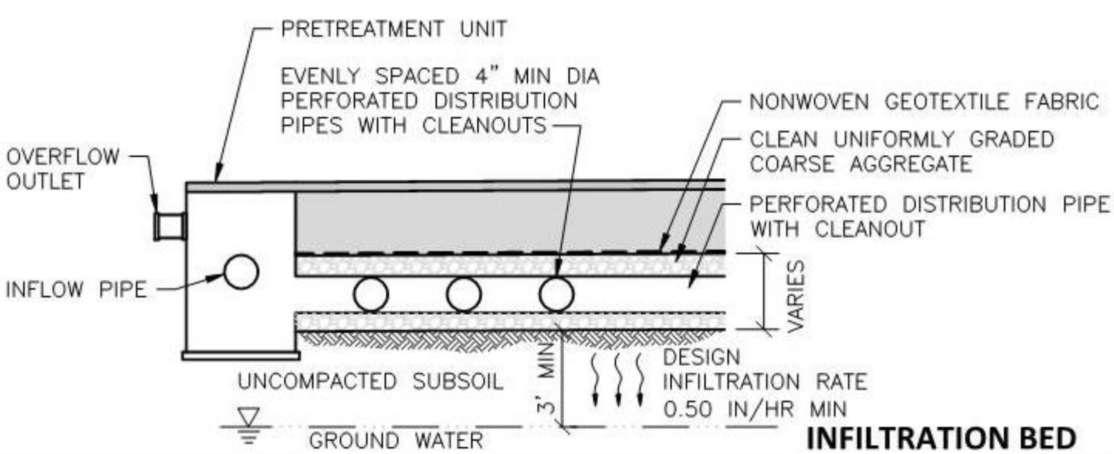
(1) Inspection and maintenance access to the infiltration practice shall be provided.

## 4. Design Schematics

# INFILTRATION PRACTICES

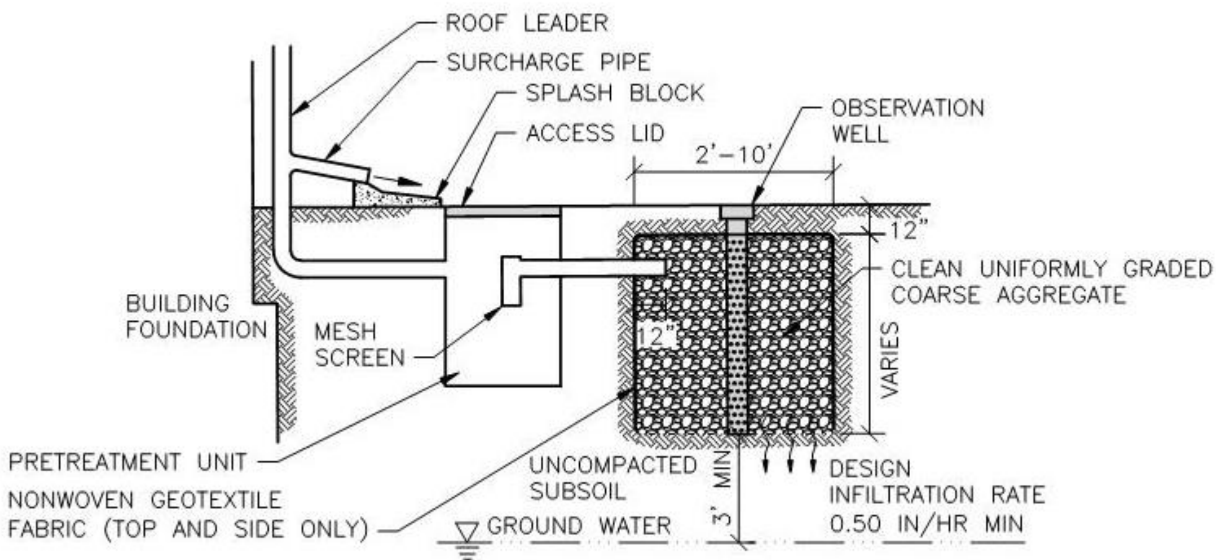



INFILTRATION TRENCH

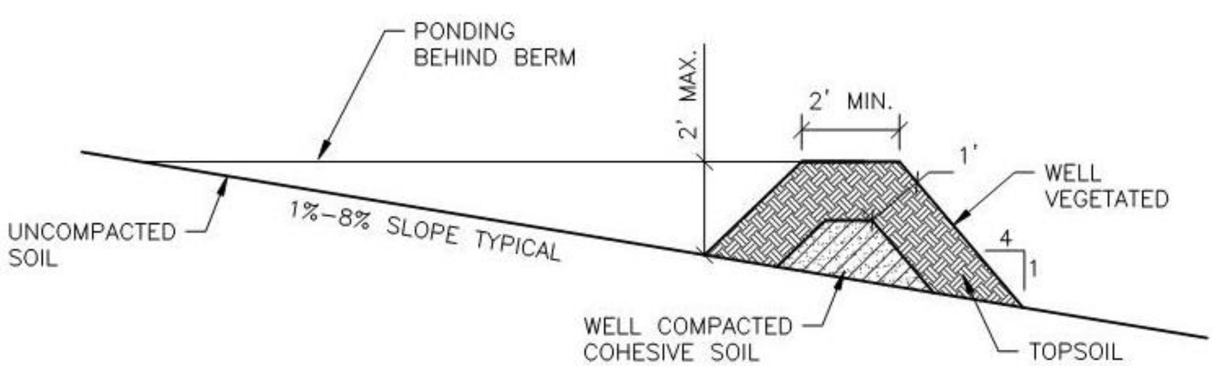



INFILTRATION BED

# INFILTRATION PRACTICES




**DRY WELL**




**INFILTRATION BERM**

# Constructed Filter

## 1. Summary

| | |
|---|---|
| Description: | Provides stormwater treatment and storage with a pipe outlet (underdrain). |
| Application: | Areas with high heavy metal pollutant loads. May be used on small sites to provide extended detention. |
| Types: | Sand; Gravel; Sand/compost mix; Other media.<br>Dry; Static water level within filter media. |
| Pretreatment Required: | Yes. This BMP can also provide pretreatment. |
| Maintenance Plan: | Yes. |
| Calculation Credits: | |
| Volume Reduction: | None. |
| Rate Reduction: | Adjust time-of-concentration by dividing storage volume by 10-year peak flow rate. |
| Water Quality: | Count volume routed through filter. |

## 2. Sizing Calculations

a. Constructed filters shall be sized for water quality or pretreatment.

b. Calculate the required water quality or pretreatment volume. Refer to Part 3 section "Calculating Storage Volumes and Release Rates."

c. The design volume of the BMP is the storage volume of the voids and underdrain within the filter media including any temporary surface storage volume to the elevation of the overflow.

d. Calculate the minimum filter surface area required to drain the design volume in the specified drawdown time using hydraulic conductivity of filter media:

$$A = \frac{V(d_f)}{K(t_d)(h_f+d_f)} \tag{4.7}$$

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 3-foot maximum)
$K$ = hydraulic conductivity (feet per day)
$t_d$ = maximum allowable drawdown time (days)
$h_f$ = average head; typically ½ of the maximum head on filter media (feet)

e. Total drawdown time shall be no more than 72 hours. Maximum depth of surface ponding above the filter bed shall be 24 inches and drain within 24 hours.

f. An orifice may be used at the downstream end of the underdrain to provide extended detention as long as drawdown times are met.

g. 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) = Volume of Pipe (cubic feet) + [Length (feet) x Width (feet) x Depth (feet) – Volume of Pipe (cubic feet)] x Void Ratio of Material*

h. Design values for hydraulic conductivity of the filter media shall be as specified in **Table 14**. Values for other types of filter media will be reviewed for use on an individual basis.

**Table 14 –Hydraulic Conductivities for Filter Media**

| Filter Media | Hydraulic Conductivity, K (feet per day) |
|---|---|
| Gravel | 14[1] |
| Compost (loose) | 8.7[2] |
| Coarse Sand | 3.5[2] |
| Peat | 2[2] |
| Topsoil (< 10% clay) | 1.3[3] |

[1] Adapted from William E. Sanford, et. al. (1995). *Hydraulic Conductivity of Gravel and Sand as Substrates in Rock-reed Filters,* Table 3 (using lowest initial conductivity for sand and gravel (0.25 cm/s) and correction factors from Source 2 (p. 5-18)).

[2] Center for Watershed Protection (1996). *Design of Stormwater Filtering Systems.*

[3] D. Carpenter and L. Hallam (2007). An *Investigation of Rain Garden Planting Mixtures and the Implications for Design.*

A composite value of hydraulic conductivity for mixture combinations shall be calculated as: K = (%xK1 + %xK2 +%xK3)/100

### 3. Design Requirements

a. Siting

(1) Soil borings are required. Refer to Part 3 section "Soils Investigation."

(a.) A minimum of 2 foot is required between the bottom of the constructed filter and the highest known groundwater elevation.

b. Configuration

(1) Filter media shall have a minimum depth of 18 inches and a maximum depth of 36 inches.

(2) Stone bedding shall consist of at least 2 inches under the pipe and 4 inches above the pipe. An aggregate window extending to the filter surface may also be provided as a factor-of-safety.

(3) A 4-inch minimum diameter underdrain shall be provided in the gravel layer with lateral spacing at 10 feet, and in any case no more than 25 feet.

(4) All underground pipes shall have cleanouts accessible from the surface.

(5) Pipes shall be sloped to prevent siltation.

(6) Constructed filters located in areas of existing soil contamination shall be lined to prevent infiltration.

c. Inlet Design

(1) A level spreader, distribution pipes or other flow dispersion measure shall be used for energy dissipation and to uniformly distribute the flow.

(2) Pretreatment is required for each inlet and for overland flow entering the constructed filter.

d. Emergency Overflow

(1) All constructed filters must be designed so that larger storms may safely overflow or bypass the filter. Flow splitters, multi-stage chambers or other devices may be used.

(2) Sufficient space must be provided between the top of the filtering bed and the overflow to allow the maximum design head to be stored for filtration.

e. Materials

(1) Stone bedding shall consist of clean, uniformly graded coarse aggregate (MDOT coarse or open-graded aggregate).

(2) A woven geotextile fabric, or an additional 2 inches of gravel choker course shall be placed between the filter media layer(s) and the stone layer.

(3) When used, impermeable liner shall have a maximum permeability of $1 \times 10^{-7}$ centimeters per second certified by the manufacturer.

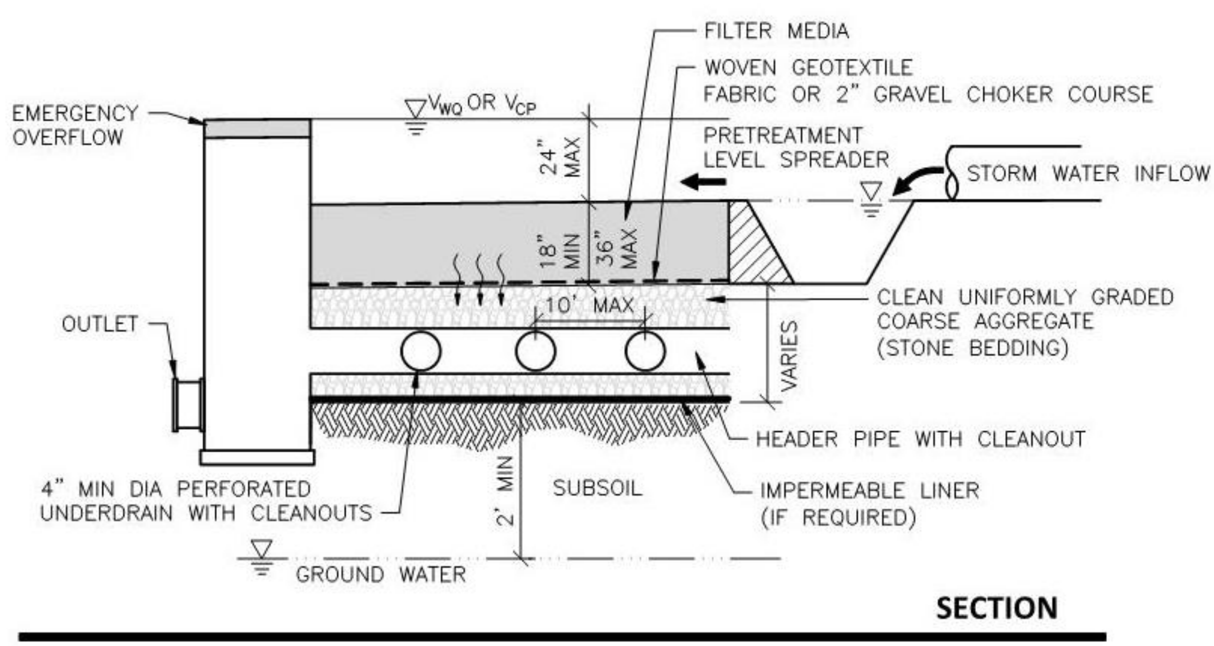
f. Access

(1) Inspection and maintenance access to the constructed filter shall be provided.

(2) For underground vault heights greater than 4 feet, ladder access shall be provided.

## 4. Design Schematics

CONSTRUCTED FILTER



# Bioretention/Rain Garden

## 1. Summary

| | |
|---|---|
| Description: | Incorporates amended soil and provides stormwater storage, treatment and uptake with or without a pipe outlet. |
| Application: | Small sites and drainage areas. |
| Types: | Bioretention: Natural-looking herbaceous.<br>Rain garden: Landscaped and manicured.<br>Retentive; Underdrain at top of storage layer; Underdrain at bottom of storage layer; Lined. |
| Pretreatment Required: | Yes. |
| Maintenance Plan: | Yes. |
| Calculation Credits: | |
| Volume Reduction: | Retentive: Count volume stored and infiltrated.<br>Underdrained: Count volume stored and infiltrated between bottom of BMP and invert of underdrain. |
| Rate Reduction: | Adjust time-of-concentration by dividing storage volume by 10-year peak flow rate. |
| Water Quality: | Count volume stored and infiltrated, or routed through filter. |

## 2. Sizing Calculations

a. Bioretention/rain gardens shall be sized for water quality or channel protection, and may be sized for flood control in small drainage areas.

b. Minimum surface area (loading ratio) shall be 5:1 contributing impervious area to BMP surface area, with a maximum impervious area of 1 acre (43,560 square feet) per bioretention cell.

c. Calculate the required water quality or channel protection volume. Refer to Part 3 section "Calculating Storage Volumes and Release Rates."

d. For underdrained BMP, follow sizing criteria for "Constructed Filter."

e. For retentive BMP, calculate the required storage volume. Refer to Part 3 section "Calculating Storage Volumes and Release Rates, Flood Control, Retention" and "Retentive BMPs."

f. Calculate the minimum infiltration area required to drain the storage volume in the specified drawdown time using the design infiltration rate. Refer to Part 3 section "Design Infiltration Rates" to determine the design infiltration rate. The bottom area of the BMP shall be used as the infiltration area.

$$A = \frac{12Vs}{i(t_d)} \tag{4.6}$$

where:

$A$ = minimum infiltration area (square feet)
$Vs$ = storage volume (cubic feet)
$i$ = design infiltration rate (inches per hour)
$t_d$ = maximum allowable drawdown time (hours)
$12$ = factor to convert inches to feet

g. Total drawdown time shall be no more than 72 hours. Depth of surface ponding shall be no more than 12 inches and drain within 12 hours. Surface ponding depth may be increased up to 24 inches for bioretention areas and drain within 24 hours.

h. 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*

*Note: Count subsurface storage volume only if permeability of media is greater than permeability of subsoil.*

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

## 3. Design Requirements

a. Siting

(1) Soil borings are required. Refer to Part 3 section "Soils Investigation."
- (a.) A minimum of 3 feet is required between the bottom of bioretention/rain gardens capable of infiltration and the highest known groundwater elevation.
- (b.) A minimum of 2 feet is required between the bottom of lined or underdrained bioretention/rain gardens and the highest known groundwater elevation.
- (c.) An underdrain shall be provided for design infiltration rates of the underlying native soil less than 0.50 inches per hour, or if bioretention/rain garden will be lined.
- (d.) Void ratio for the amended soil material shall be based on the USDA soil textural class and effective water capacity in **Table 6**. A maximum design value of 0.30 shall be used for the void ratio of the amended soil material. A maximum design value of 0.40 shall be used for the void ratio of stone.

(2) Setbacks shall be as follows:
- (a.) Adjacent property line: 10 feet
- (b.) Building foundation: 10 feet
- (c.) Private well: 50 feet
- (d.) Public well: 200 feet from Type I or Type IIa wells, 75 feet from Type IIb or Type III wells (Safe Drinking Water Act, Act 399, PA 1976)
- (e.) Septic system drainfield: 50 feet

b. Configuration

(1) General
- (a.) The bottom shall be flat to encourage uniform ponding and infiltration.
- (b.) Minimum bottom width shall be 3 feet.
- (c.) Bioretention/rain gardens located in areas with steep slopes shall be terraced to minimize earth disturbance and maximize infiltration area.
- (d.) Care must be taken during the excavation and finishing process to make sure that soil compaction does not occur.

(e.) Bioretention/rain gardens located in areas of existing soil contamination shall be lined to prevent infiltration.
(f.) Underdrains shall have a 4-inch minimum pipe diameter.
(g.) All underground pipes shall have cleanouts accessible from the surface.
(h.) Pipes shall be sloped to prevent siltation.
(i.) Side slopes shall not be steeper than 3:1 (H:V), unless landscape retaining walls are used.
(j.) An observation well shall be provided for each bioretention/rain garden without a bottom underdrain.

(2) Rain garden
(a.) A landscape plan shall be provided.

c. Inlet Design

(1) Inlet pipes shall require energy dissipation. Riprap protection or equivalent erosion control measures shall be used where the velocity exceeds 4 feet per second up to a maximum allowable design velocity of 8 feet per second.

(2) Pretreatment is required for each inlet and for overland flow entering the bioretention/ rain garden.

d. Emergency Overflow

(1) All bioretention/rain gardens must have a provision for overflow at the high water level.

e. Materials

(1) Amended soil material shall consist of 18 to 48 inches of the following materials, evenly mixed: Compost: minimum 20%; Sand: 20-80%; Topsoil: maximum 30%.
(a.) Alternative mix designs with ratios outside of the limits provided will be considered with justification.
(b.) The soil mix shall have a pH between 5.5 and 7.5.

(2) Topsoil shall be sandy loam, loamy sand or loam per USDA Soil Textural Triangle with 20% to 50% fines by volume (silt and clay with <10% clay), and 2% to 8% organic matter by dry weight.

(3) Stone shall consist of clean, uniformly graded coarse aggregate.

(4) A woven geotextile fabric shall be placed between the amended soil and the stone, when a stone layer is used.

(5) When used, impermeable liner shall have a maximum permeability of 1 x 10-7 centimeters per second certified by the manufacturer.

(6) Plant selection shall consider exposure and tolerance to salt, sediment and pollutants, and the design depth of surface storage. Native species are encouraged.
(a.) Bioretention: Plugs and seed.
(b.) Rain gardens: Container stock.

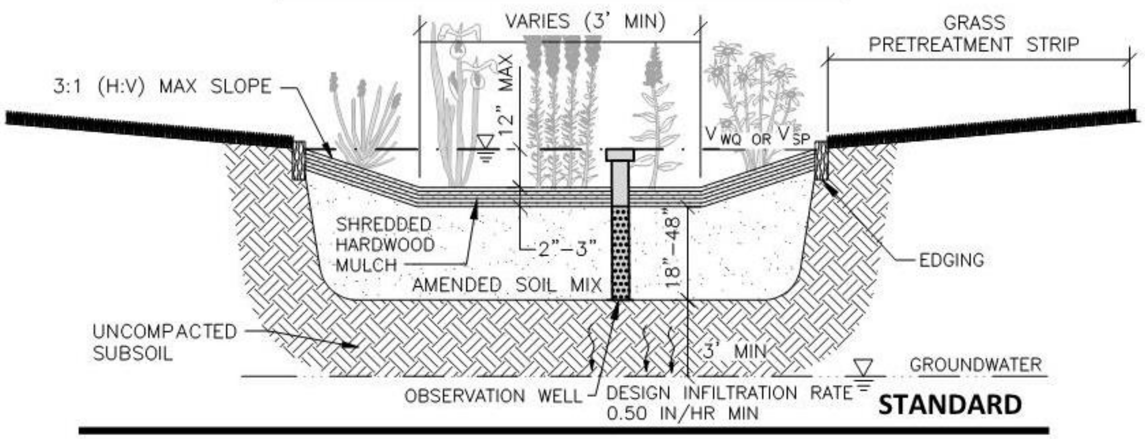
(7) Mulch shall be applied after planting.
(a.) Bioretention: Shredded hardwood mulch, straw mulch or mulch blanket shall be uniformly applied and tacked.
(b.) Rain gardens: Shredded hardwood mulch shall be uniformly applied to a depth of 2 to 3 inches.

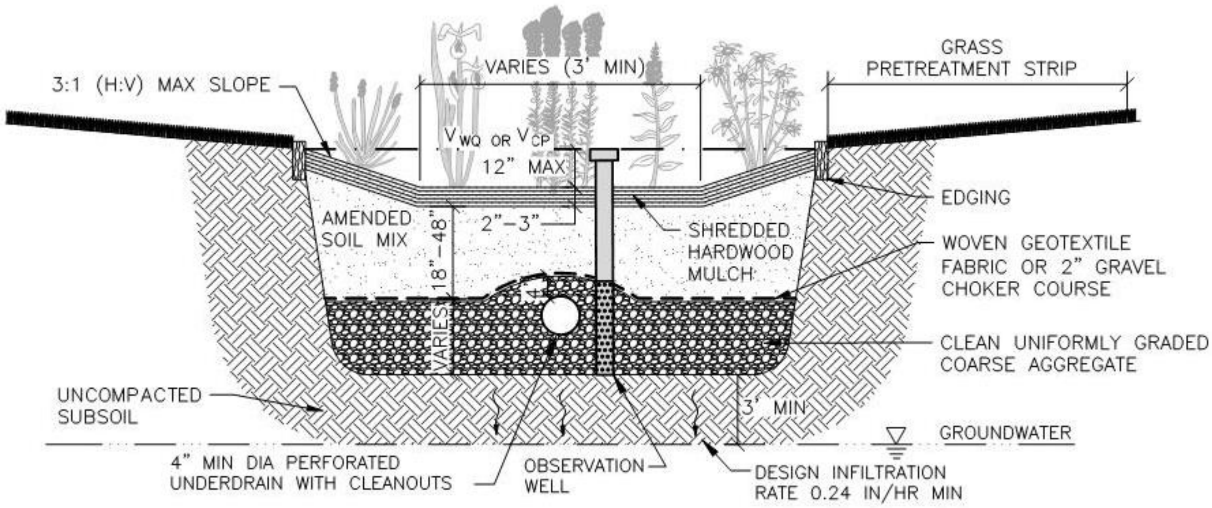
f. Access

(1) Inspection and maintenance access to the bioretention/rain garden shall be provided.

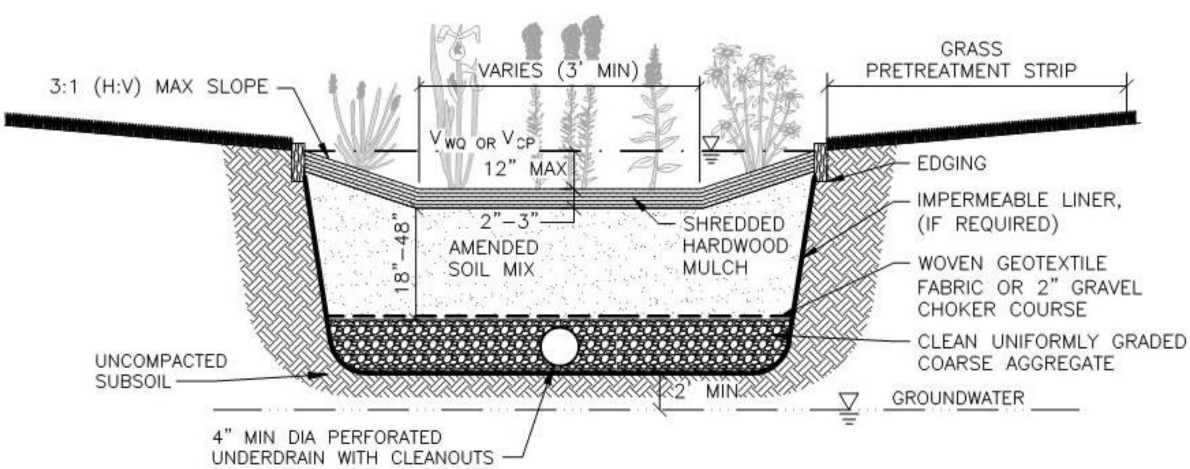
## 4. Design Schematics

# BIORETENTION/RAIN GARDEN




**BIORETENTION/RAIN GARDEN WITH STONE STORAGE LAYER**




**BIORETENTION/RAIN GARDEN WITH BOTTOM DRAIN**

# Planter Box

## 1. Summary

| | |
|---|---|
| Description: | A type of rain garden. |
| Application: | Small sites or highly urban areas. |
| Types: | Retentive; Underdrain at top of storage layer; Underdrain at bottom of storage layer; Lined. |
| Pretreatment Required: | No. This BMP can provide pretreatment. |
| Maintenance Plan: | Yes. |
| Calculation Credits: | |
| Volume Reduction: | Retentive: Count volume stored and infiltrated.<br>Underdrained: Count volume stored and infiltrated between bottom of BMP and invert of underdrain. |
| Rate Reduction: | Adjust time-of-concentration by dividing storage volume by 10-year peak flow rate. |
| Water Quality: | Count volume stored and infiltrated, or routed through filter. |

## 2. Sizing Calculations

a. Planter boxes shall be sized for water quality, pretreatment or channel protection.

b. Minimum surface area (loading ratio) shall be 5:1 contributing impervious area to BMP surface area, with a maximum impervious area of 15,000 square feet per planter box.

c. Calculate the required water quality, pretreatment or channel protection volume. Refer to Part 3 section “Calculating Storage Volumes and Release Rates.”

d. For underdrained BMP, follow sizing criteria for “Constructed Filter.”

e. For retentive BMP, calculate the required storage volume. Refer to Part 3 section “Calculating Storage Volumes and Release Rates, Flood Control, Retentive BMPs.”

f. Calculate the minimum infiltration area required to drain the storage volume in the specified drawdown time using the design infiltration rate. Refer to Part 3 section “Design Infiltration Rates” to determine the design infiltration rate. The bottom area of the BMP shall be used as the infiltration area.

$$A = \frac{12Vs}{i(t_d)} \qquad (4.6)$$

where:
*A* = minimum infiltration area (square feet)
*Vs* = storage volume (cubic feet)
*i* = design infiltration rate (inches per hour)
$t_d$ = maximum allowable drawdown time (hours)
*12* factor to convert inches to feet

g. Total drawdown time shall be no more than 12 hours. Depth of surface ponding shall be no more than 12 inches and drain within 4 hours.

h. 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*

*Note: Count subsurface storage volume only if permeability of media is greater than permeability of subsoil.*

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

### 3. Design Requirements

a. Siting

(1) Soil borings are required. Refer to Part 3 section "Soils Investigation."

(a.) A minimum of 3 feet is required between the bottom of the planter box and the highest known groundwater elevation.

(b.) A minimum of 2 foot is required between the bottom of a lined or underdrained planter box and the highest known groundwater elevation.

(c.) An underdrain shall be provided for design infiltration rates less than 0.50 inches per hour, or if planter box will be lined.

(d.) Void ratio for the amended soil material shall be based on the USDA soil textural class and effective water capacity in **Table 6**. A maximum design value of 0.30 shall be used for the void ratio of the amended soil material. A maximum design value of 0.40 shall be used for the void ratio of stone.

b. Configuration

(1) A combination of surface and subsurface storage may be used to provide the required storage volume.

(2) Minimum width of planter boxes shall be 30 inches, or 18 inches if flow-through.

(3) Care must be taken during the excavation and finishing process to make sure that soil compaction does not occur.

(4) Planter boxes located in areas of existing soil contamination shall be lined to prevent infiltration.

(5) Underdrains shall have a 4-inch minimum pipe diameter.

(6) All underground pipes shall have cleanouts accessible from the surface.

(7) Pipes shall be sloped to prevent siltation.

(8) A planting plan shall be provided.

c. Inlet Design

(1) Inlet pipes shall require energy dissipation. Riprap protection or equivalent erosion control measures shall be used where the velocity exceeds 4 feet per second, up to a maximum allowable design velocity of 8 feet per second.

d. Emergency Overflow

(1) All planter boxes must have a provision for overflow at the high-water level.

e. Materials

(1) Suggested structural elements of planter boxes are stone, concrete, brick or pressure-treated wood.

(2) Amended soil material shall consist of 12 to 36 inches of the following materials, evenly mixed: Compost: minimum 20%; Sand: 20-80% ; Topsoil: maximum 30%.

(a.) Alternative mix designs with ratios outside of the limits provided will be considered with justification.

(b.) The soil mix shall have a pH between 5.5 and 6.5.

(3) Topsoil shall be sandy loam, loamy sand or loam per USDA Soil Textural Triangle with 20% to 50% fines by volume (silt and clay with <10% clay), and 2% to 8% organic matter by dry weight.

(4) Stone bedding shall consist of clean, uniformly graded coarse aggregate.

(5) A woven geotextile fabric shall be placed between the amended soil and the stone.

(6) Impermeable liner shall have a maximum permeability of 1 x 10-7 centimeters per second certified by the manufacturer.

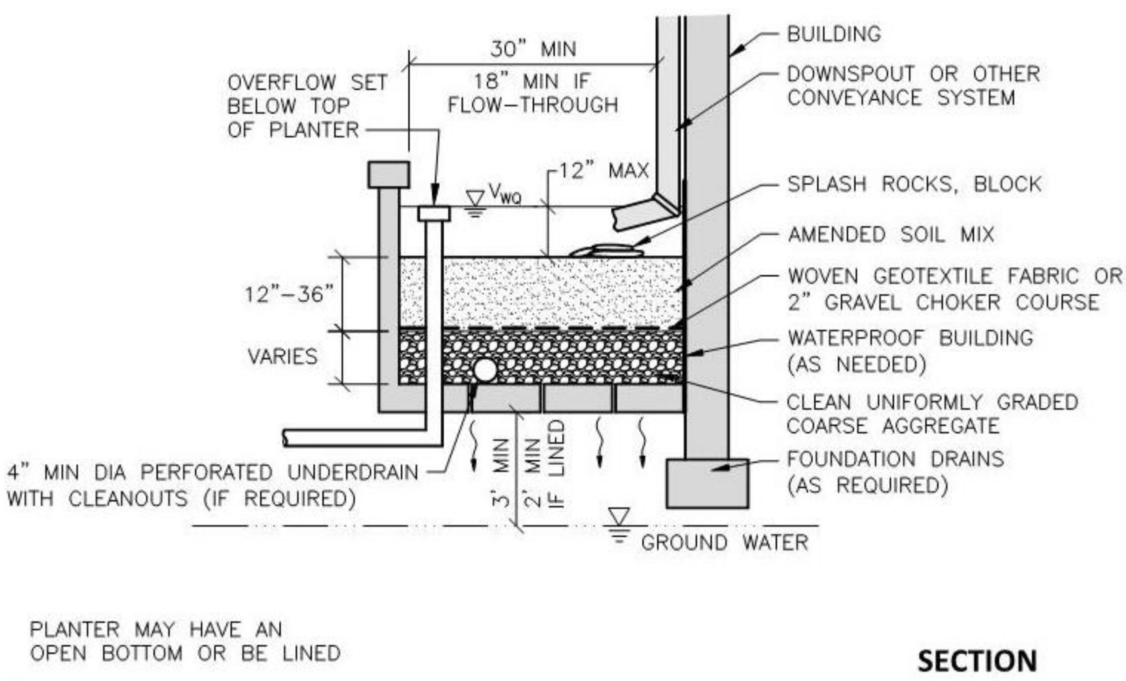
(7) Plant selection shall consider exposure and tolerance to salt, sediment and pollutants, and the design depth of surface storage. Native species are encouraged.

(8) Plants shall be container stock.

f. Access. Inspection and maintenance access to the planter box shall be provided.

## 4. Design Schematics

**PLANTER BOX**



# Pervious Pavement

## 1. Summary

| | |
|---|---|
| Description: | Permeable pavement surface with storage layer underneath. Provides stormwater storage and treatment with or without a pipe outlet. |
| Application: | Parking lots, alleys and roads and drives with low-volume vehicular traffic and minimal turning motions. |
| Types: | Retentive; Underdrain at top of storage layer; Underdrain at bottom of storage layer; Lined. |
| Pretreatment Required: | No. |
| Maintenance Plan: | Yes. |
| Calculation Credits: | |
| Volume Reduction: | Retentive: Count volume stored and infiltrated (limited by design rainfall on pavement and roof).<br>Underdrained: Count volume stored and volume infiltrated between bottom of BMP and invert of underdrain (limited by design rainfall on pavement and roof). |
| Rate Reduction: | Retentive: 100%. |
| Water Quality: | Count volume stored and infiltrated, or volume filtered. |

## 2. Sizing Calculations

a. Pervious pavement shall be sized for flood control.

b. Calculate the runoff volume from the flood control rainfall event assuming impervious pavement. Refer to Part 3 section "Calculating Runoff."

c. The design volume of the BMP is the storage volume of the voids and underdrain within the stone to the elevation of the overflow.

d. Water quality volume may be included in the flood control volume. Channel protection volume may be included in the flood control volume for retentive BMP (no underdrain).

e. For retentive BMP, the bottom area of the stone shall be used as the infiltration area.

f. Maximum allowable drawdown time shall be 24 hours.

g. 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*

## 3. Design Requirements

a. Siting

(1) Soil borings are required. Refer to Part 3 section "Soils Investigation."

(a.) A minimum of 3 feet is required between the bottom of pervious pavement capable of infiltration and the highest known groundwater elevation.

(b.) A minimum of 2 foot is required between the bottom of lined or underdrained pervious pavement and the highest known groundwater elevation.

(c.) An underdrain shall be provided for design infiltration rates less than 0.50 inches per hour, or if stone bed will be lined.

(d.) A maximum design value of 0.40 shall be used for the void ratio of stone.

(2) Runoff from offsite areas shall not be directed onto pervious pavement surface.

b. Configuration

(1) The stone bed shall be flat to encourage uniform ponding and infiltration.

(2) For pervious pavements located in areas with steep slopes, stone beds shall be terraced to maximize infiltration area.

(3) Pervious pavements located in areas of existing soil contamination shall be lined to prevent infiltration.

(4) Underdrains shall have a 4-inch minimum pipe diameter with lateral spacing at 10 feet, and in any case no more than 25 feet.

(5) All underground pipes shall have cleanouts accessible from the surface.

(6) Pipes shall be sloped to prevent siltation.

c. Inlet Design

(1) Pervious pavements shall have a backup method for water to enter the storage bed. Backup drainage may consist of an unpaved 1- to 2-foot wide stone edge or inlets with sediment traps.

d. Emergency Overflow

(1) Stone beds must have a provision for overflow below the level of the pavement surface when an underdrain is not already provided.

e. Materials

(1) Stone bed shall consist of 8 to 36 inches of clean, uniformly graded coarse aggregate.

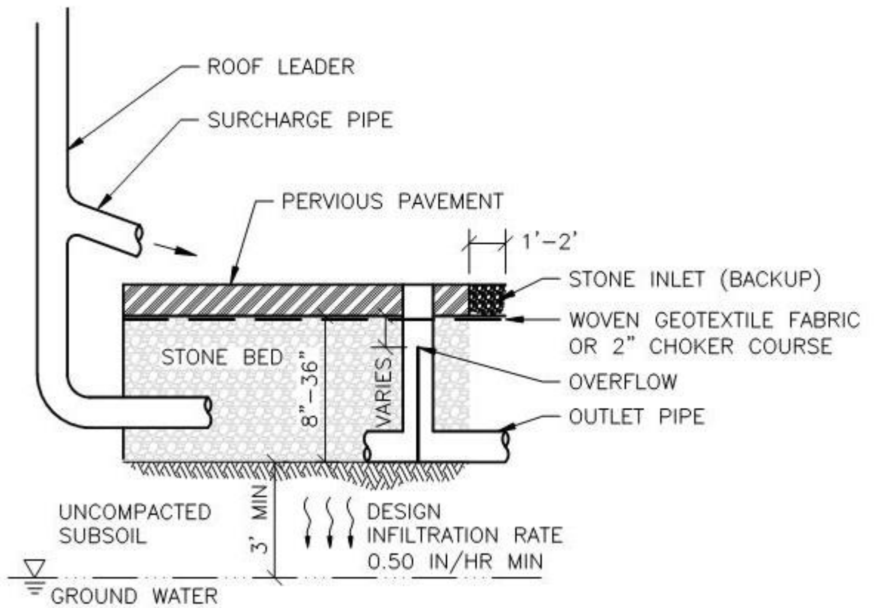
(2) A woven geotextile fabric or 2-inch gravel choker course shall be placed between the pervious pavement and stone bed.

(3) A nonwoven geotextile fabric or liner shall be placed between the stone bed and the subsoil for underdrained pavements.

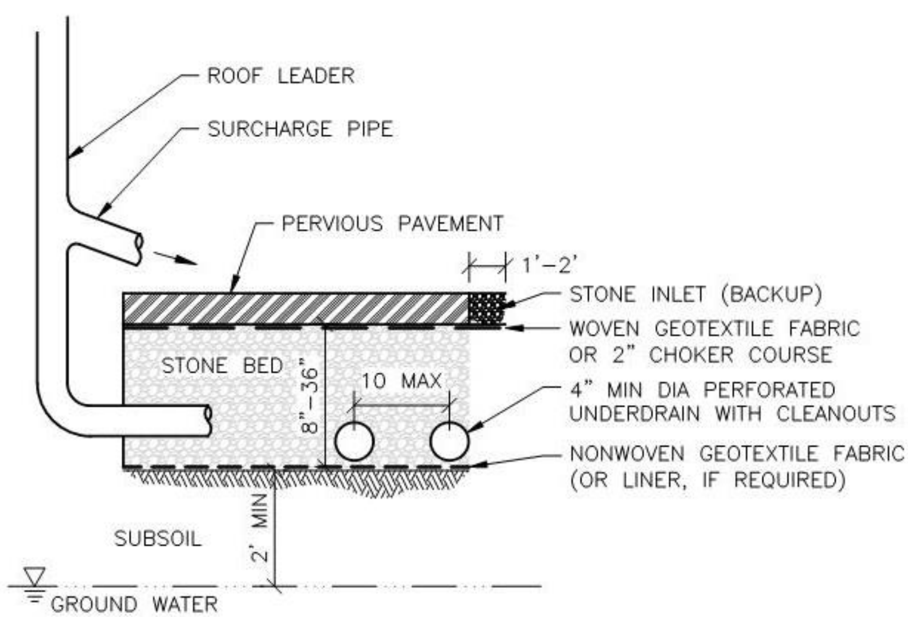
(4) Impermeable liner shall have a maximum permeability of 1 x 10-7 centimeters per second certified by the manufacturer.

## 4. Design Schematics

# PERVIOUS PAVEMENT




**STANDARD**




**PERVIOUS PAVEMENT WITH BOTTOM DRAIN**

# Vegetated Roof

## 1. Summary

| | |
|---|---|
| Description: | Liner, soil media and vegetation placed on roof surface. Provides stormwater storage and treatment with a surface overflow. |
| Application: | Most practical for flat rooftops. |
| Types: | Intensive (> 4 inches, wide variety of plants, public use); Extensive (≤ 4 inches, plants are herbs, mosses, succulents and grasses). |
| Pretreatment Required: | No. This BMP can provide pretreatment. |
| Maintenance Plan: | Yes. |
| Calculation Credits: | |
| Volume Reduction: | Count subsurface storage volume below the overflow (limited by design rainfall on roof). |
| Rate Reduction: | Adjust time-of-concentration. |
| Water Quality: | Count subsurface storage volume. |

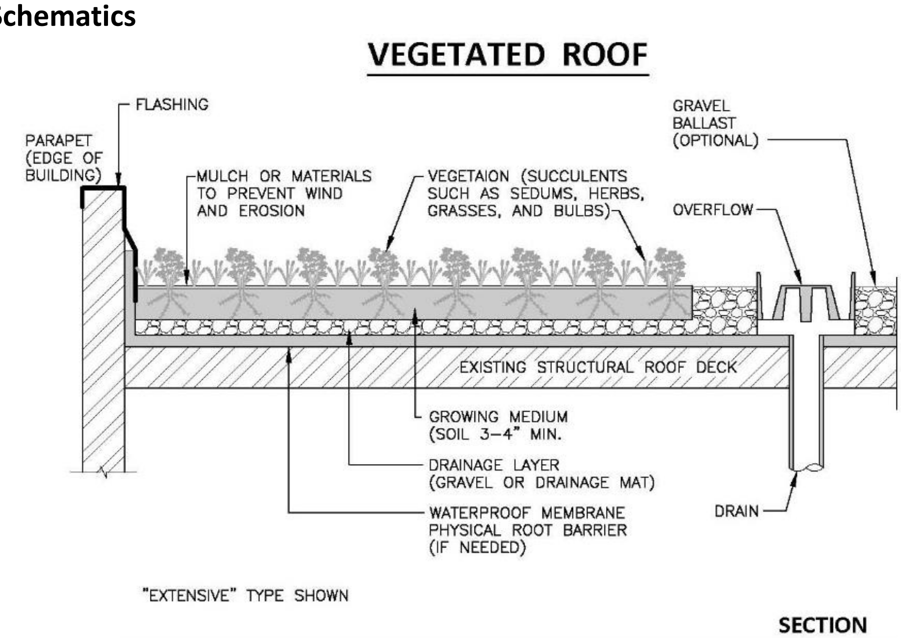
## 2. Sizing Calculations

a. Vegetated roofs shall be sized for water quality, pretreatment, or channel protection.
b. The minimum subsurface storage volume shall be equal to the volume from 1-inch of rain falling on the roof area.
c. The subsurface storage volume below the overflow may be counted as retention.
d. 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.*

## 3. Design Requirements

a. Configuration: Follow manufacturer’s and structural engineer’s guidelines.
b. Emergency Overflow: A positive outlet for overflow shall be provided.

## 4. Design Schematics



# Capture Reuse

## 1. Summary

| | |
|---|---|
| Description: | Stormwater capture, storage and removal from storm flow by reuse for irrigation or as greywater. |
| Application: | Most practical for roof runoff. Other collection areas may require pumping for reuse. |
| Types: | Rain barrels; Cisterns (both above ground and underground); Tanks; Ponds. |
| Pretreatment Required: | Yes. This BMP can provide spill containment. |
| Maintenance Plan: | Yes. |
| Calculation Credits: | |
| Volume Reduction: | Count storage volume provided. |
| Rate Reduction: | Adjust time-of-concentration by dividing storage volume by 10-year peak inflow rate. |
| Water Quality: | Count volume stored. |

## 2. Sizing Calculations

a. Capture reuse may be sized for water quality or channel protection.

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

c. Obtain average monthly precipitation (inches) and evapotranspiration (ET) in inches. www.enviroweather.msu.edu

d. Multiply average monthly precipitation by contributing area and area-weighted Small Storm Hydrology Method runoff coefficient (assuming 90% of the storms produce 1 inch of rain or less) to obtain volume of recharge. A modified equation for the Small Storm Hydrology Method is given below:

$$V = PR_v A(3630) \quad (4.8)$$

where:

*V* = recharge volume (cubic feet)
*P* = rainfall (inches)
*Rv* = area-weighted volumetric runoff coefficient (individual runoff coefficients are given in **Table 10**)
*A* = contributing area (acres)
*3630* = factor to convert acre-inches to cubic feet

e. Multiply recharge volume by 7.48 gallons per cubic foot to convert to gallons.

f. Calculate ET for open water surfaces. 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.

g. Select trial size container or pond volume.

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

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

*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. | | | | | | |

### 3. Design Requirements

a. Siting

(1) Storage units shall be positioned to receive rooftop runoff.

(2) Protect storage units from direct sunlight to minimize algae growth.

(3) Discharge points and storage units shall be clearly marked "Caution: Untreated Rainwater. Do Not Drink."

b. Configuration

(1) If storage units are used to supplement greywater needs, a parallel conveyance system must be installed to separate greywater from other potable water piping systems.

(2) Storage units shall be watertight with a smooth interior surface.

(3) Covers and lids shall have a tight fit to keep out surface water, insects, animals, dust and light.

(4) Observation risers shall be provided for buried storage units.

(5) Pumps and pressure tanks may be used to add pressure (most irrigation systems require at least 15 pounds per square inch).

c. Inlet Design

(1) Screens shall be used to filter debris from runoff flowing into the storage unit.

d. Emergency Overflow

(1) A positive outlet for overflow shall be provided a few inches from the top of the storage unit and sized to safely discharge the peak flow from the 10-year design storm when the storage unit is full.

(2) Above-ground storage units shall have a release mechanism to drain and empty the unit between storm events.

# Water Quality Device

## 1. Summary

| | |
|---|---|
| Description: | Stormwater treatment provided in a prefabricated unit, also known as a Manufactured Treatment Device (MTD). |
| Application: | Practical for small sites and drainage areas. |
| Types: | Oil and grit separator; Hydrodynamic separator; Baffle box. |
| Pretreatment Required: | No. This BMP can provide pretreatment and spill containment |
| Maintenance Plan: | Yes. |
| Calculation Credits: | |
| Volume Reduction: | None. |
| Rate Reduction: | None. |
| Water Quality: | Count volume routed through BMP. |

## 2. Sizing Calculations

a. Water quality devices shall be sized for water quality and pretreatment.

b. Calculate the design water quality flow rate. Refer to Part 3 section "Calculating Storage Volumes and Release Rates, Water Quality."

c. Select water quality device unit/model based on manufacturer's recommendations.

d. When the device is used to provide spill containment, the minimum spill containment volume shall be provided between the normal water level and the entrance of the outlet pipe to capture a slug pollutant load from an accidental spill of toxic materials.

## 3. Design Requirements

a. Configuration

(1) The geometry of the water quality device shall promote the trapping of sediment, oils and floatables.

(2) The water quality device shall be designed to prevent surcharging in pipes upstream of the device.

b. Emergency Overflow

(1) A bypass overflow shall be designed to convey the 10-year peak discharge to prevent release of trapped sediments and pollutants.

(2) The outlet from the overflow shall not be submerged under normal conditions.

c. Materials

(1) Catch basin inserts (inlet filters) are not accepted as a post-construction BMP.

# Water Quality Swale

## 1. Summary

| | |
|---|---|
| Description: | Lined swale designed to provide spill containment. |
| Application: | Small sites in lieu of a spill containment cell when a permanent pool is not desirable. |
| Types: | Dry swale. |
| Pretreatment Required: | No. This BMP can provide pretreatment and spill containment. |
| Maintenance Plan: | Yes. |
| Calculation Credits: | |
| Volume Reduction: | None. |
| Rate Reduction: | Adjust time-of-concentration by dividing storage volume by 10-year peak flow rate. |
| Water Quality: | Count volume routed through filter. |

## 2. Sizing Calculations

a. Water quality swales shall be sized for water quality or pretreatment.

b. Calculate the required water quality or pretreatment volume. Refer to Part 3 section "Calculating Storage Volumes and Release Rates."

c. The design volume of the BMP is the storage volume of the voids and underdrain within the filter media including any temporary surface storage volume to the elevation of the overflow, and including any permanent pool within the outlet structure.

d. The spill containment volume provided is the storage volume between the normal water level in the water quality swale and the entrance of the outlet pipe. The minimum spill containment volume shall be provided to capture a slug pollutant load from an accidental spill of toxic materials.

e. Follow sizing criteria for "Constructed Filter."

f. The swale shall be designed to pass the 10-year peak discharge. Refer to "Vegetated Swale" for sizing calculations.

## 3. Design Requirements

a. Siting

(1) All inlets shall enter the water quality swale unless the inlet collects stormwater exclusively from non-hotspot areas (i.e. office parking, courtyard, roof).

b. Configuration

(1) The bottom of the water quality swale shall be flat to encourage uniform ponding and filtration.
(2) The swale shall have a minimum bottom width of 2 feet and a maximum bottom width of 10 feet.
(3) Side slopes shall be 3:1 (H:V) or flatter.
(4) Sand filter shall have a minimum depth of 18 inches and a maximum depth of 36 inches.
(5) Stone bedding shall consist of at least 2 inches under the pipe and 4 inches above the pipe. An aggregate window extending to the filter surface may also be provided as a factor-of-safety.
(6) Underdrains shall have a 4-inch minimum pipe diameter.
(7) All underground pipes shall have cleanouts accessible from the surface.
(8) Pipes shall be sloped to prevent siltation.

c. Inlet Design

(1) Inlet pipes shall require energy dissipation. Riprap protection or equivalent erosion control measures shall be used where the velocity exceeds 4 feet per second up to a maximum allowable design velocity of 8 feet per second.

d. Outlet Design

(1) The containment structure shall be constructed within a manhole and be designed to draw water from the central portion of the water column within the manhole to trap floatables and contain sediments in a minimum 3-foot sump.

e. Emergency Overflow

(1) A positive outlet for overflow shall be provided.

(2) A catch basin and outlet pipe may be used to convey the 10-year peak discharge. This must be a separate structure or chamber within the containment manhole to prevent the captured low-density fluids from becoming entrained in the water when surface inflow enters the structure.

f. Materials

(1) Top Dressing for bottom and side slopes:

(a.) A permeable blend of sand, compost and/or topsoil with a pH between 5.5 and 7.5.

i. 3-inches of compost tilled into the top 6-inches of native permeable soil (equivalent to a 9-inch homogenous mixture of 70% sand; 30% compost); or

ii. 4-inches of topsoil tilled into the top 6-inches of native permeable soil (equivalent to a 10-inch homogenous mixture with maximum 20% silts, 4% clay, and 80% to 92% sand).

(b.) Topsoil shall be sandy loam, loamy sand or loam per USDA Soil Textural Triangle with 20% to 50% fines by volume (silt and clay with <10% clay), and 2% to 8% organic matter by dry weight.

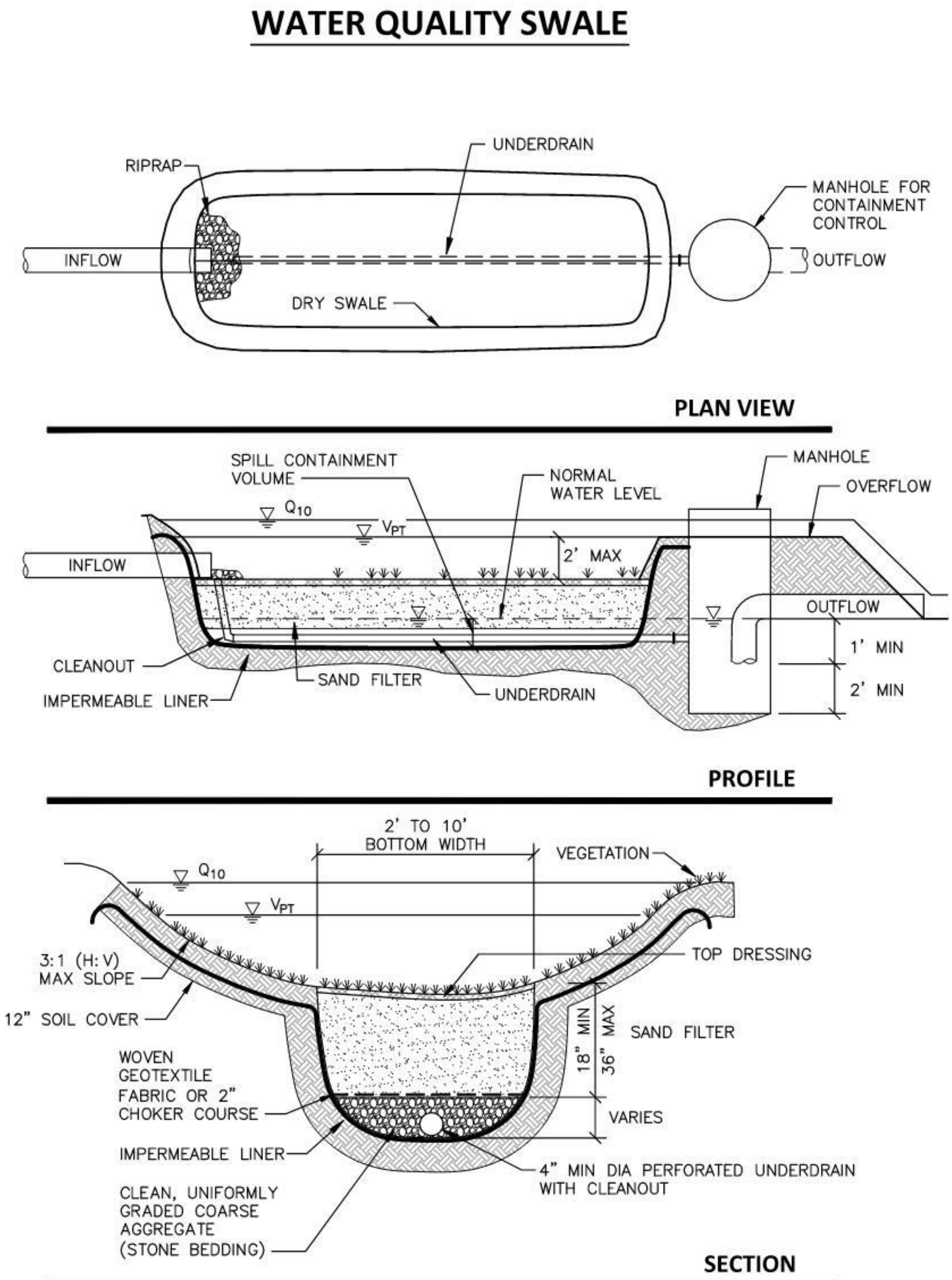
(c.) Placement of a topsoil layer without tilling is generally not allowed due to the diminished infiltration rates observed.

(2) Stone bedding shall consist of clean, uniformly graded coarse aggregate.

(3) A woven geotextile fabric or 2-inch gravel choker course shall be placed between the sand and the stone bedding.

(4) The water quality swale shall be lined with impermeable materials extending up to the design high water elevation. A minimum 18-inch-thick clay layer, 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.

## 4. Design Schematics



# Bioswale

## 1. Summary

| | |
|---|---|
| Description: | Vegetated swale designed to capture and treat stormwater with native (or imported) soils below the base of the channel. |
| Application: | Linear projects or areas; Sandy soils. |
| Types: | Dry swale; Swale with check dams. |
| Pretreatment Required: | No. This BMP can provide pretreatment. |
| Maintenance Plan: | Yes. |
| Calculation Credits: | |
| Volume Reduction: | Count volume stored and infiltrated. |
| Rate Reduction: | Adjust time-of-concentration by dividing storage volume by 10-year peak flow rate. |
| Water Quality: | Count volume stored and infiltrated, or routed through filter. |

## 2. Sizing Calculations

a. Bioswales shall be designed for water quality, pretreatment, or channel protection.

b. Calculate the required water quality, pretreatment or channel protection volume. Refer to Part 3 section "Calculating Storage Volumes and Release Rates."

c. For underdrained BMP, follow sizing criteria for "Constructed Filter."

d. For retentive BMP, calculate the required storage volume. Refer to Part 3 section "Calculating Storage Volumes and Release Rates, Flood Control, Retentive BMPs."

e. Calculate the minimum infiltration area required to drain the required storage volume in the specified drawdown time using the design infiltration rate. Refer to Part 3 section "Design Infiltration Rates" to determine the design infiltration rate. The bottom area of the BMP shall be used as the infiltration area.

$$A = \frac{12Vs}{i(t_d)} \tag{4.6}$$

where:
$A$ = minimum infiltration area (square feet)
$Vs$ = storage volume (cubic feet)
$i$ = design infiltration rate (inches per hour)
$t_d$ = maximum allowable drawdown time (hours)
$12$ = factor to convert inches to feet

f. Depth of surface ponding shall be no more than 12 inches and drain within 12 hours.

g. The swale shall be designed to pass the 10-year peak discharge. Refer to "Vegetated Swale" for sizing calculations.

h. Calculate the wedge-shaped storage volume behind each check dam (if used):

*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*

## 3. Design Requirements

a. Configuration

(1) Bioswales shall have a maximum longitudinal slope of 1%.
(2) The swale shall have a minimum bottom width of 2 feet and a maximum bottom width of 10 feet.
(3) Side slopes shall be 3:1 (H:V) or flatter.
(4) Underdrains shall have a 4-inch minimum pipe diameter.
(5) All underground pipes shall have cleanouts accessible from the surface.
(6) Pipes shall be sloped to prevent siltation.

b. Check Dam Design

(1) Check dams may be used along bioswales to encourage ponding and infiltration.
(2) Check dams shall be earthen or other impervious design. Rock check dams are not suitable for infiltration.
(3) Maximum ponding depth behind check dam shall be 24 inches. Minimum check dam height shall be 12 inches.
(4) Minimum top width of check dam shall be 2 feet.
(5) Check dams shall be keyed into the bottom and sides of the swale a minimum of 1-foot on all sides.
(6) The center of the check dam crest must be below the sides of the check dam by a minimum of 12 inches.
(7) The crest of a downstream check dam shall be no lower than the downstream toe of the upstream check dam.
(8) Erosion control measures (i.e. riprap, turf reinforcement mat) shall be used to protect the integrity of the check dam and downstream toe.

c. Inlet Design

(1) Inlet pipes shall require energy dissipation. Riprap protection or equivalent erosion control measures shall be used where the velocity exceeds 4 feet per second up to a maximum allowable design velocity of 8 feet per second.

d. Emergency Overflow

(1) A positive outlet for overflow shall be provided.
(2) A catch basin and outlet pipe may be used to convey the 10-year peak discharge.

e. Materials

(1) Top Dressing for bottom and side slopes:

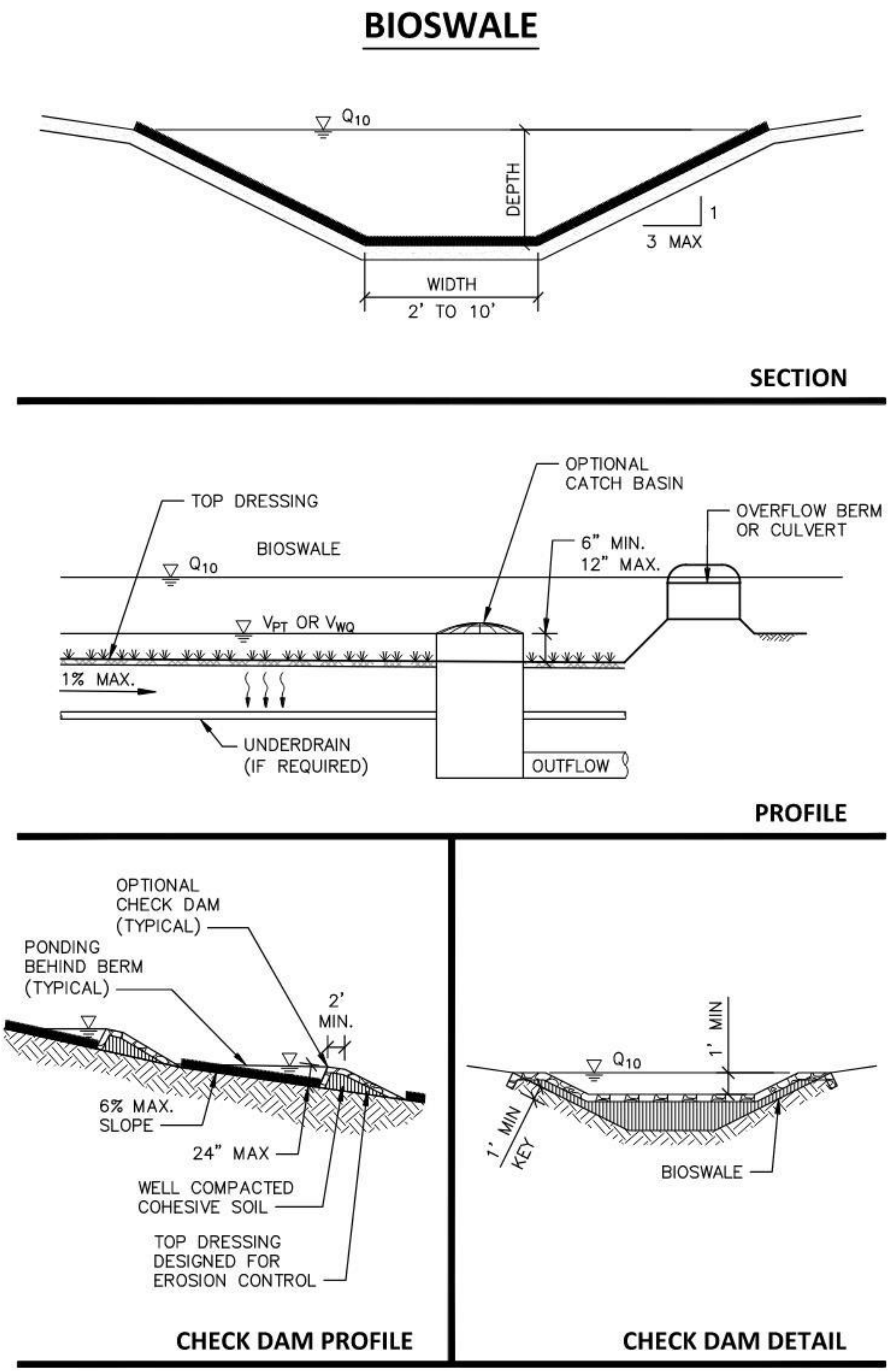
(a.) A permeable blend of sand, compost and/or topsoil with a pH between 5.5 and 7.5.

i. 3-inches of compost tilled into the top 6-inches of native permeable soil (equivalent to a 9-inch homogenous mixture of 70% sand; 30% compost); or
ii. 4-inches of topsoil tilled into the top 6-inches of native permeable soil (equivalent to a 10-inch homogenous mixture with maximum 20% silts, 4% clay, and 80% to 92% sand).

(b.) Topsoil shall be sandy loam, loamy sand or loam per USDA Soil Textural Triangle with 20% to 50% fines by volume (silt and clay with <10% clay), and 2% to 8% organic matter by dry weight.

(c.) Placement of a topsoil layer without tilling is generally not allowed due to the diminished infiltration rates observed.

## 4. Design Schematics



# Vegetated Swale

## 1. Summary

| | |
|---|---|
| Description: | Stormwater conveyance designed to slow and filter stormwater. |
| Application: | Small drainage areas with concentrated flow; yard drainage. |
| Types: | Dry swale; Swale with check dams (no infiltration). |
| Pretreatment Required: | No. This BMP provides pretreatment. |
| Maintenance Plan: | Yes. |
| Calculation Credits: | |
| Volume Reduction: | None. |
| Rate Reduction: | Due to longer time-of-concentration for swale. |
| Water Quality: | Count volume routed through BMP. |

## 2. Sizing Calculations

a. Vegetated swales shall be designed for water quality or pretreatment, and sized to pass the 10-year peak discharge.

b. Calculate 10-year peak flow rate. Refer to Part 3 section "Calculating Runoff."

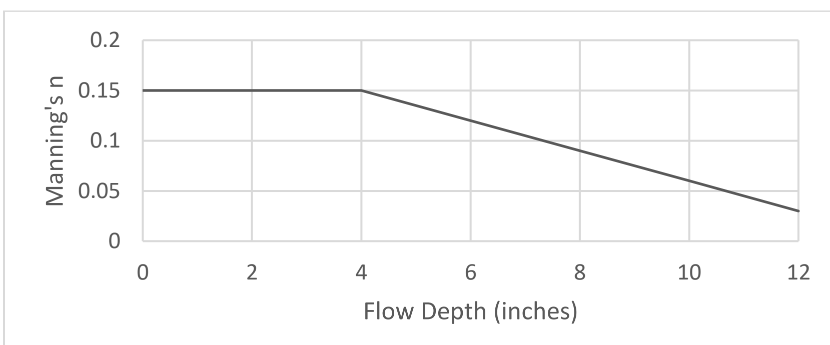
c. Size swale using Manning's equation:

$$Q = \frac{1.49AR^{\frac{2}{3}}S^{\frac{1}{2}}}{n} \tag{4.1}$$

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

d. Select the higher value of Manning's roughness coefficient from **Table 12** or **Figure 2** below.

**Figure 2 – Manning's Roughness Coefficients for Vegetated Swales**




Source: SEMCOG (2008). *Low Impact Development Manual for Michigan*, Figure 7.62.

e. Check that flow velocities are within acceptable limits. The minimum velocity for open channels shall be 1.5 feet per second. The maximum velocity shall be 4 feet per second.

f. Calculate the wedge-shaped storage volume behind each check dam (if used):

*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*

### 3. Design Requirements

a. Siting

(1) Vegetated swales can be used for drainage areas up to 5 acres. Drainage areas greater than this may require open channels.

b. Configuration

(1) Trapezoidal, with a minimum bottom width of 2 feet and a maximum bottom width of 8 feet.
(2) Side slopes shall be 3:1 (H:V) or flatter.
(3) Longitudinal slope shall be a minimum of 1% and a maximum of 6%. Flatter slopes may be allowed on permeable soils.
(4) <u>Design to meet water quality standard</u>:
(a.) Maximum design flow depth shall be 6 inches, or approximately equal to the grass height.
(b.) Minimum length shall be 50 feet for a point discharge at upstream end, and 100 feet for lateral inflow.
(5) <u>Design to meet pretreatment standard</u>:
(a.) Minimum length shall be 20 feet with a minimum 1-foot high check dam and wedge storage sized as a sediment forebay.

c. Check Dam Design

(1) Check dams may be used for energy dissipation along vegetated swales with longitudinal slopes greater than 3%.
(2) Maximum ponding depth behind check dam shall be 24 inches.
(3) Minimum check dam height shall be 12 inches.
(4) Check dams shall be keyed into the bottom and sides of the swale a minimum of 1-foot on all sides. The height of the key must exceed the 10-year water surface elevation by a minimum of 6 inches on both sides.
(5) The center of the check dam crest must be below the sides of the check dam by a minimum of 12 inches.
(6) The crest of a downstream check dam shall be no lower than the downstream toe of the upstream check dam.

d. Materials

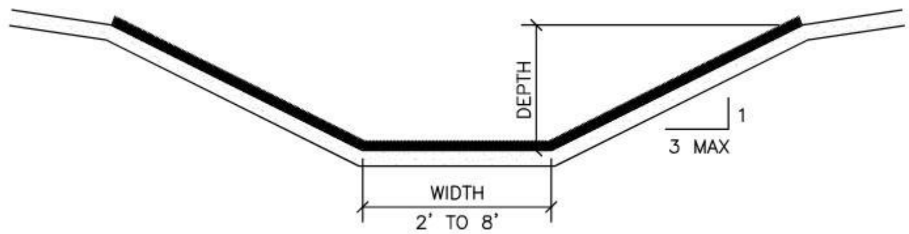
(1) Establishment of vegetation shall follow the guidelines outlined below.

| Swale Bottom Treatment | Swale Grade |
|---|---|
| Seed and Mulch | 0.3% to 0.5% |
| Standard Mulch Blanket | 0.5% to 1.5% |
| High Velocity Mulch Blanket or Sod | 1.5% to 3.0% |
| Turf Reinforcement Mat or Check Dams | 3.0% to 6.0% |
| Specific Design Required | > 6.0% |

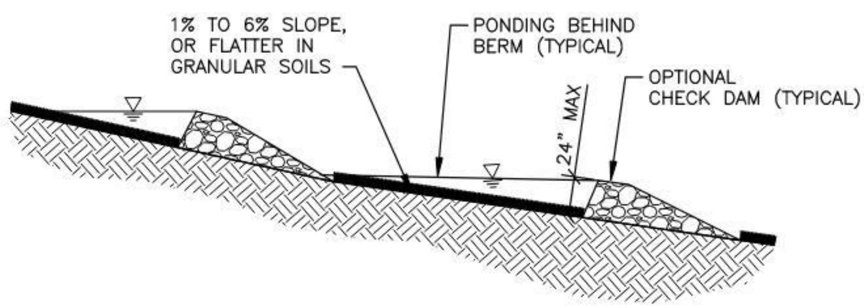
Source: *Michigan Department of Transportation Drainage Manual* (2006).

## 4. Design Schematics

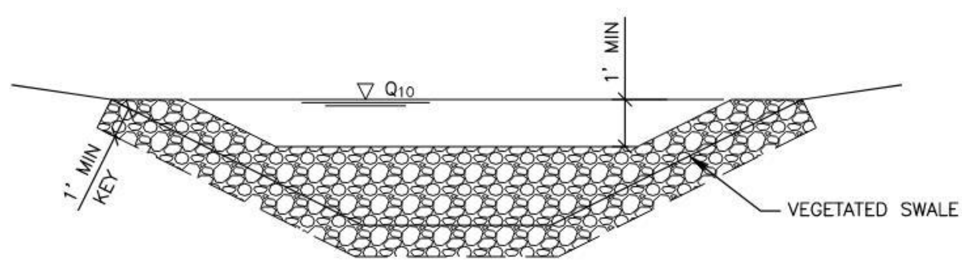
### VEGETATED SWALE




SECTION




PROFILE




CHECK DAM DETAIL

# Vegetated Filter Strip

## 1. Summary

| | |
|---|---|
| Description: | Overland flow path designed to slow and filter stormwater. |
| Application: | Contributing drainage areas with sheet flow surface runoff. |
| Types: | Turf grass; other dense herbaceous groundcover vegetation. |
| Pretreatment Required: | No. This BMP provides pretreatment. |
| Maintenance Plan: | Yes. |
| Calculation Credits: | |
| Volume Reduction: | None. |
| Rate Reduction: | Adjust time-of-concentration. |
| Water Quality: | Count volume routed through BMP. |

## 2. Sizing Calculations

a. Vegetated filter strips shall be designed for water quality or pretreatment.

b. Minimum surface area (loading ratio) shall be 6:1 contributing area to BMP surface area.

c. Determine minimum required longitudinal length based on slope and type of vegetation using the graphs in **Figures 3a** through **3d**.

## 3. Design Requirements

a. Siting

(1) Maximum upstream drainage length shall generally be 100 feet impervious or 200 feet pervious.

b. Configuration

(1) The upstream edge of the filter strip shall be level and at an elevation at least 1 inch below the adjacent pavement.

(2) A level spreader may also be required to evenly distribute flow across filter strip.

(3) Slopes shall range from 1% to 8%, with optimal slopes ranging from 2% to 6%.

(4) The maximum lateral slope shall be 1%.

(5) Berms and curbs may be installed along the sides of the filter strip parallel to the direction of flow to prohibit runoff from laterally bypassing the filter strip.

(6) Design to meet pretreatment standard:

(a.) Minimum sheet flow length shall be 10 feet at a maximum slope of 2% with an impervious approach length no greater than 3.5 times the filter strip length, up to a maximum approach length of 75 feet.

(b.) Minimum sheet flow length shall be 15 feet for slopes between 2% and 6% with an impervious approach length no greater than 3 times the filter strip length, up to a maximum approach length of 75 feet.

**Figure 3a – Filter Strip Length (Sandy soils with HSG A)**

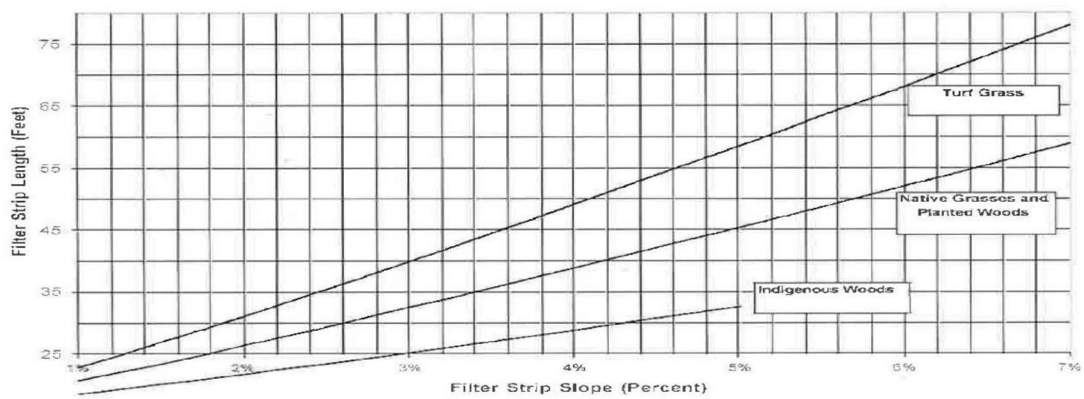



**Figure 3b1 – Filter Strip Length (Sandy Loam soils with HSG B)**

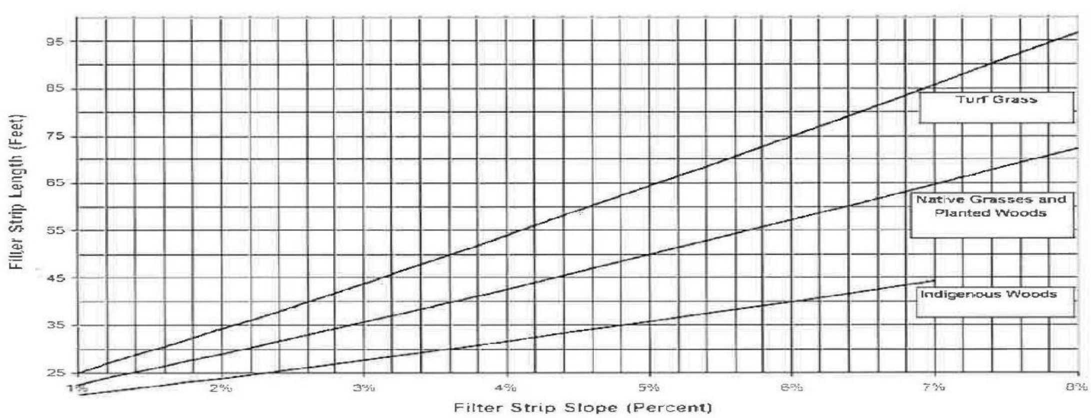
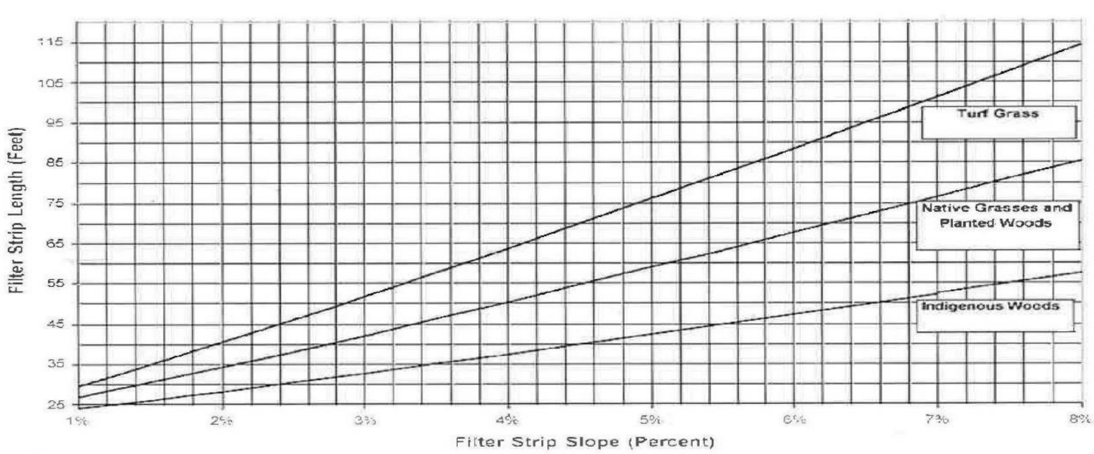



**Figure 3b2 – Filter Strip Length (Loam, Silt-Loam soils with HSG B)**




Source: SEMCOG (2008), *Low Impact Development Manual for Michigan,* Figures 7.52, 7.53 and 7.54
(New Jersey Stormwater Best Management Practices Manual, 2004)

**Figure 3c – Filter Strip Length (Sandy Clay Loam soils with HSG C)**

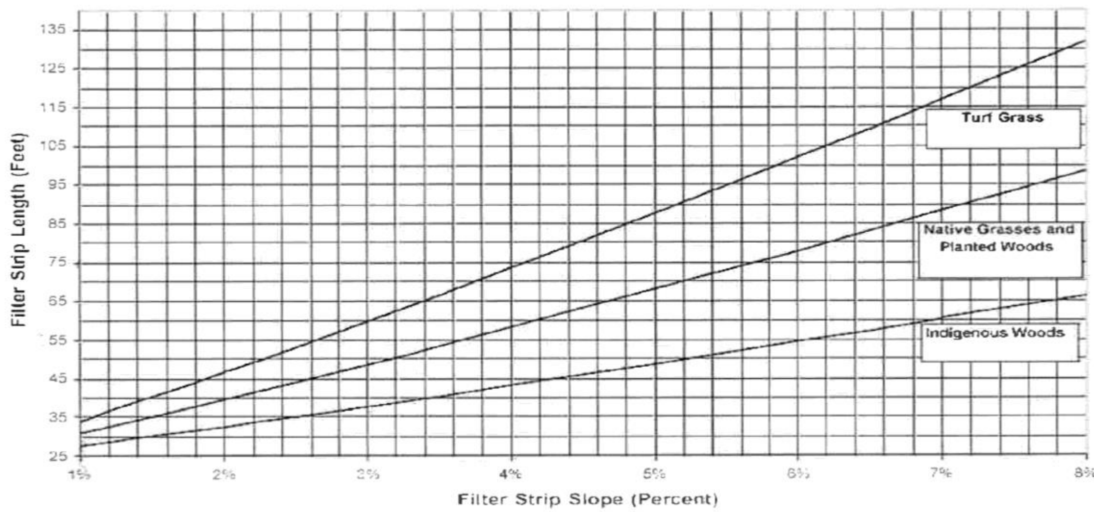
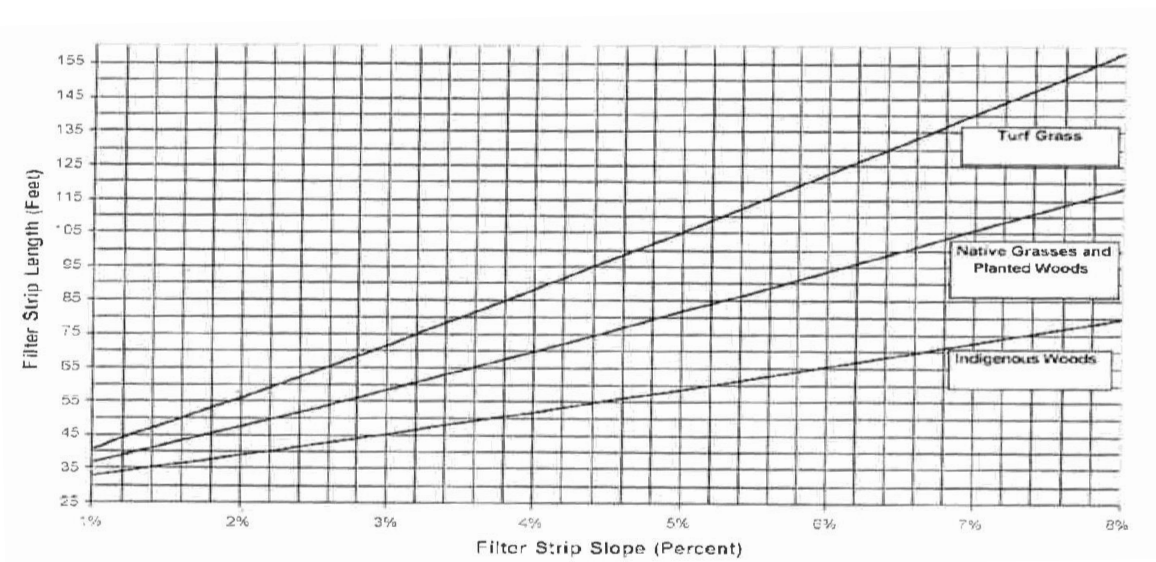
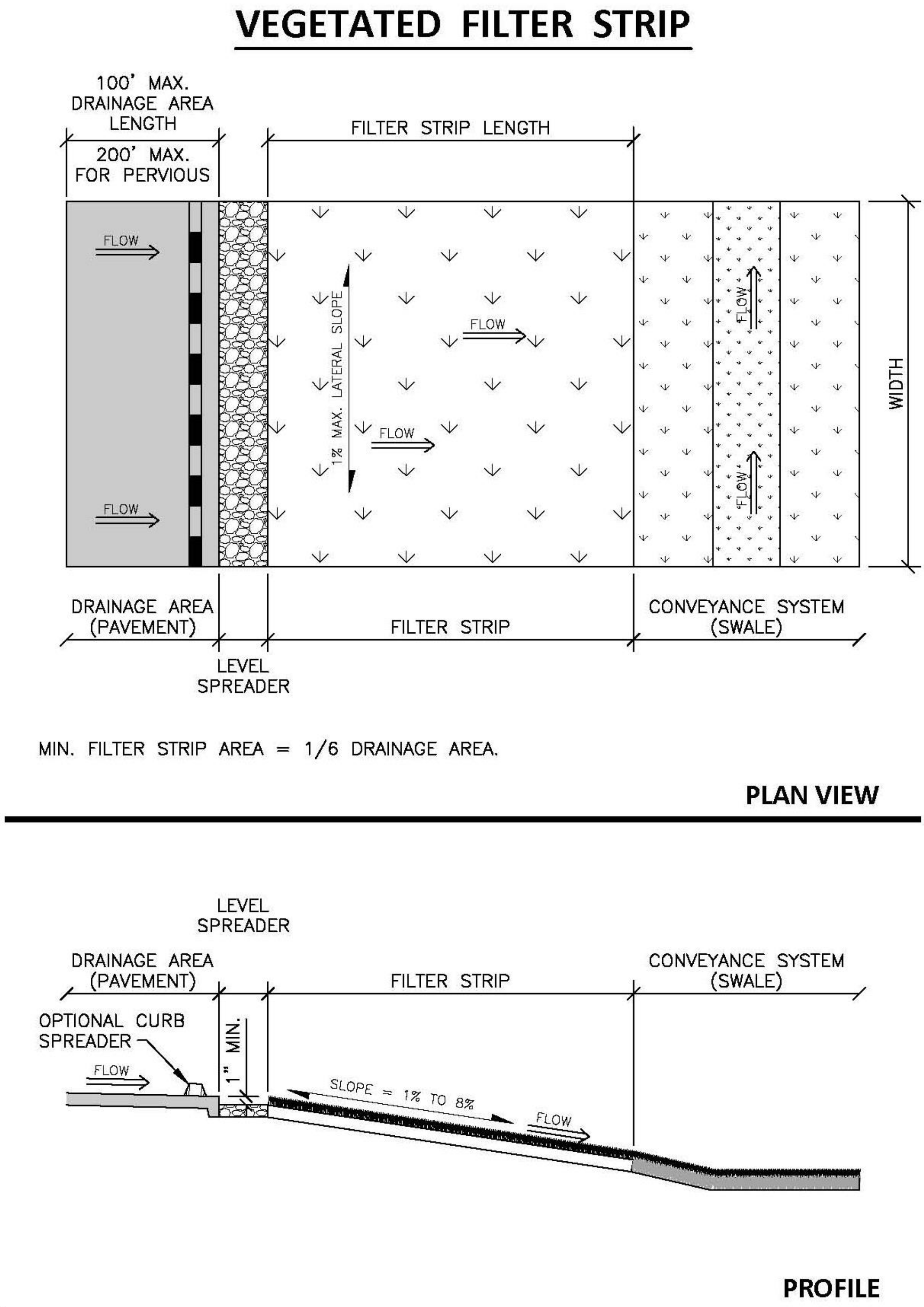



**Figure 3d – Filter Strip Length (Clay Loam, Silty Clay, Clay soils with HSG D)**




Source: SEMCOG (2008), *Low Impact Development Manual for Michigan,* Figures 7.55 and 7.56
(New Jersey Stormwater Best Management Practices Manual, 2004)

## 4. Design Schematics



# Level Spreader

## 1. Summary

| | |
|---|---|
| Description: | Shallow, level berm placed perpendicular to a flow path. |
| Application: | Used with other BMPs to disperse concentrated stormwater flows. |
| Types: | Inflow (prior to BMP); Outflow (at outlet of BMP). |
| Pretreatment Required: | No. This BMP provides pretreatment. |
| Maintenance Plan: | Yes. |
| Calculation Credits: | |
| Volume Reduction: | None. |
| Rate Reduction: | None. |
| Water Quality: | None. |

## 2. Sizing Calculations

a. Level spreaders shall be sized to pass the 10-year peak flow.

b. Calculate 10-year peak flow rate. Refer to Part 3 section “Calculating Runoff.”

## 3. Design Requirements

a. Siting

(1) Slopes below outflow level spreaders should be no greater than 8% in the direction of flow to discourage channelization.

b. Configuration

(1) Construct level spreaders in compacted fill or of other non-erodible material.

(2) Minimum length: 10 feet.

(3) A bypass may be required for higher flows.

c. Material

(1) Level spreaders may be constructed of compacted earth, rock, stone, concrete, treated timber or perforated pipe in stone.