# Design criteria for bioretention

**Green Infrastructure:** Bioretention practices can be an important tool for retention and detention of stormwater runoff. Because they utilize vegetation, bioretention practices provide additional benefits, including cleaner air, carbon sequestration, improved biological habitat, and aesthetic value.


The following terminology is used throughout this "Design Section":

**Warning:** *REQUIRED* - Indicates design standards stipulated by the MPCA Construction General Permit (https://stormwater.pca.state.mn.us/index.php/Construction_stormwater_permit) (CGP) or other consistently applicable regulations

*HIGHLY RECOMMENDED* - Indicates design guidance that is extremely beneficial or necessary for proper functioning of the bioretention practice, but not specifically required by the MPCA CGP.

*RECOMMENDED* - Indicates design guidance that is helpful for bioretention practice performance but not critical to the design.

## Contents

# Design phase maintenance considerations

**Caution:** Maintenance considerations are an important component of design

Implicit in the design guidance is the fact that many design elements of infiltration and filtration systems can minimize the maintenance burden and maintain pollutant removal efficiency. Key examples include

- limiting drainage area;
- providing easy site access (*REQUIRED*);
- providing pretreatment (*REQUIRED*); and
- utilizing native plantings (see Plants for Stormwater Design (http://www.pca.state.mn.us/publications/manuals/stormwaterplants.html)).

For more information on design information for individual infiltration and filtration practices, link here (http://stormwater.pca.state.mn.us/index.php/Category:Design_criteria).

# Major design elements

## Physical feasibility initial check

Before deciding to use a **bioretention practice** for stormwater management, it is helpful to consider several items that bear on the feasibility of using such a device at a given location. The following list of considerations will help in making an initial judgment as to whether or not a bioretention practice is the appropriate BMP for the site.

- **Drainage Area**: The *RECOMMENDED* maximum drainage area is typically 5 acres, but can be greater if the discharge to the basin has received adequate **pretreatment** (https://stormwater.pca.state.mn.us/index.php?title=Pretreatment) and the basin is properly designed, constructed, and maintained. For larger sites, multiple bioretention areas can be used to treat site runoff provided appropriate grading is present to convey flows. For more information on contributing area, see **Contributing drainage area to stormwater BMPs** (https://stormwater.pca.state.mn.us/index.php?title=Contributing_drainage_area_to_stormwater_BMPs).
- Site Topography and Slopes: It is *RECOMMENDED* that sloped areas immediately adjacent to the bioretention practice be less than 33 percent but greater than 1 percent to promote positive flow towards the practice.
- Soils: No restrictions; **engineered media** (https://stormwater.pca.state.mn.us/index.php?title=Design_criteria_for_bioretention#Materials_specifications_-_filter_media) *HIGHLY RECOMMENDED*; underdrain is *HIGHLY RECOMMENDED* where parent soils are HSG C or D.
- **Shallow soils** (https://stormwater.pca.state.mn.us/index.php?title=Shallow_groundwater) and **shallow depth to bedrock** (https://stormwater.pca.state.mn.us/index.php?title=Shallow_soils_and_shallow_depth_to_bedrock):

**Warning:** A separation distance of 3 feet is REQUIRED between the bottom of the bioretention practice and the elevation of the seasonally high water table (saturated soil) or top of bedrock (i.e. there must be a minimum of 3 feet of undisturbed soil beneath the infiltration practice and the seasonally high water table or top of bedrock). Note that if underlying soils are ripped to alleviate compaction, the requirement is a 2 foot minimum between the bottom of the ripped zone and a 3 foot minimum from the bottom of the infiltration practice. If there is only a 3 foot separation distance between the bottom of the infiltration practice and the elevation of the seasonally high water table or bedrock, limit ripping depth to 12 inches.

- **Karst** (https://stormwater.pca.state.mn.us/index.php?title=Karst): It is *HIGHLY RECOMMENDED* that **bioinfiltration** practices not be used in active karst formations without adequate geotechnical assessment. Underdrains and an impermeable liner (http://stormwater.pca.state.mn.us/index.php/Liners_for_stormwater_management) may be desirable in some karst areas.

- **Wellhead Protection Areas** (https://stormwater.pca.state.mn.us/index.php?title=Stormwater_and_wellhead_protection): It is HIGHLY RECOMMENDED to review the Stormwater and wellhead protection regarding stormwater infiltration in Wellhead Protection Areas.

- **Site Location / Minimum Setbacks** (https://stormwater.pca.state.mn.us/index.php?title=Stormwater_infiltration_and_setback_(separation)_distances):

**Warning:** The minimum setback distance from a stormwater infiltration system to a community public water-supply well is 50 feet as *REQUIRED* by the Minnesota Department of Health. The setback is 35 feet to all other water-supply wells.
**Caution:** The minimum setbacks in the table below are *HIGHLY RECOMMENDED* for the design and location of infiltration practices. It will be necessary to consult local ordinances for further guidance on siting infiltration practices.

It is *HIGHLY RECOMMENDED* that bioinfiltration practices not be hydraulically connected to structure foundations or pavement to avoid seepage and frost heave concerns, respectively. If groundwater contamination is a concern, it is *RECOMMENDED* that groundwater mapping be conducted to determine possible connections to adjacent groundwater wells. The table below provides the minimum recommended setbacks for the design and location of bioretention practices.

**Recommended minimum setback requirements. This represents the minimum distance from the infiltration practice to the structure of concern. If the structure is aboveground, the distance is measured from the edge of the permeable pavement to the structure. If the structure is underground, the setback distance represents the distance from the point of infiltration through the bottom of the permeable pavement system to the structure.**
Link to this table

| Setback from | Minimum Distance [feet] |
|---|---|
| Property Line | 10 |
| Building Foundation* | 10 |
| Private Well | 50 |
| Septic System Tank/Leach Field | 35 |

* Minimum with slopes directed away from the building.

## Conveyance

It is *Highly Recommended* that the designer provides non-erosive flow velocities at the outlet point to reduce downstream erosion. During the 10-year or 25-year storm (depending on local drainage criteria), discharge velocity should be kept below 4 feet per second for established grassed channels. Erosion control matting or rock should be specified if higher velocities are expected.

Common overflow systems within the structure consist of a yard drain inlet, where the top of the yard drain inlet is placed at the elevation of the shallow ponding area. A stone drop of about 12 inches or small stilling basin could be provided at the inlet of bioretention areas where flow enters the practice through curb cuts or other concentrated flow inlets. In cases with significant drop in grade this erosion protection should be extended to the bottom of the facility.

## Underdrains

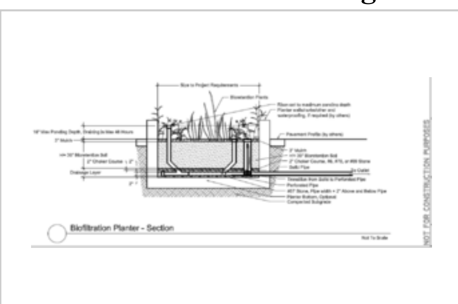
The following are *RECOMMENDED* for infiltration practices with underdrains.

- The minimum pipe diameter is 4 inches.
- Install 2 or more underdrains for each infiltration system in case one clogs. At a minimum provide one underdrain for every 1,000 square feet of surface area.
- Include at least 2 observation /cleanouts for each underdrain, one at the upstream end and one at the downstream end. Cleanouts should be at least 4 inches diameter vertical non-perforated schedule 40 PVC pipe, and extend to the surface. Cap cleanouts with a watertight removable cap.
- Construct underdrains with Schedule 40 or SDR 35 smooth wall PVC pipe.
- Install underdrains with a minimum slope of 0.5 percent, particularly in HSG D soils (Note: to utilize Manning’s equation the slope must be greater than 0).
- Include a utility trace wire for all buried piping.
- For underdrains that daylight on grade, include a marking stake and animal guard;
- For each underdrain have an accessible knife gate valve on its outlet to allow the option of operating the system as either an infiltration system, filtration system, or both. The valve should enable the ability to make adjustments to the discharge flow so the sum of the infiltration rate plus the under-drain discharge rate equal a 48 hour draw-down time.
- Perforations should be 3/8 inches. Use solid sections of non-perforated PVC piping and watertight joints wherever the underdrain system passes below berms, down steep slopes, makes a connection to a drainage structure, or daylights on grade.

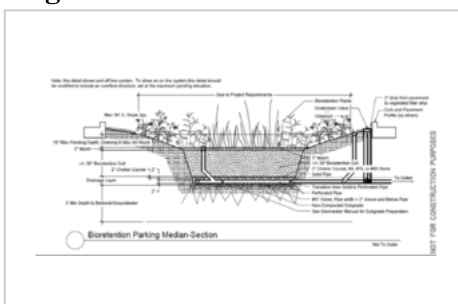
- Spacing of collection laterals should be less than 25 feet.
- Underdrain pipes should have a minimum of 3 inches of washed #57 stone above and on each side of the pipe (stone is not required below the pipe). Above the stone, two inches of choking stone is needed to protect the underdrain from blockage.
- Avoid filter fabric.
- Pipe socks may be needed for underdrains imbedded in sand. If pipe socks are used, then use circular knit fabric.

The procedure to size underdrains is typically determined by the project engineer. An example for sizing underdrains is found in Section 5.7 of the North Carolina Department of Environment and Natural Resources Stormwater BMP Manual (https://ncdenr.s3.amazonaws.com/s3fs-public/Water%20Quality/Surface%20Water%20Protection/SPU/SPU%20-%20BMP%20Manual%20Documents/BMPMan-Ch05-BMPDesignElem-20090716-DWQ-SPU.pdf). Underdrain spacing can be calculated using the following spreadsheet, which utilizes the vanSchilfgaarde Equation. The spradsheet includes an example calculation. File:Underdrain spacing calculation.xlsx

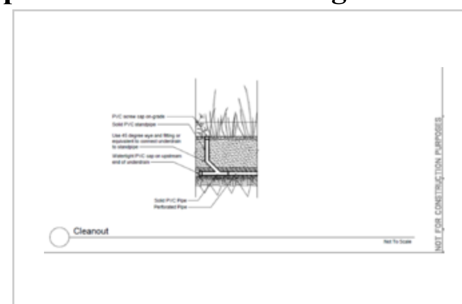
**Section drawings for different bioretention devices showing several underdrain features discussed above. Click on an image for enlarged view. Also see Bioretention plan and section drawings.**



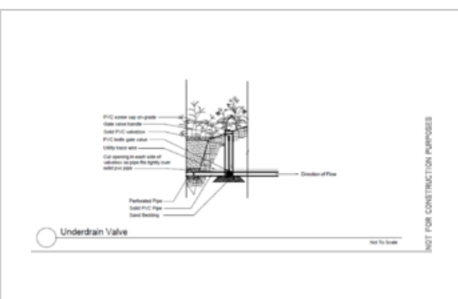

Biofiltration planter section




Bioretention parking median section




Bioretention cleanout




Bioretention underdrain valve

## Pretreatment

Pretreatment refers to features of a bioretention area that capture and remove coarse sediment particles.

**Warning:** To prevent clogging of the infiltration or filtration system with trash, gross solids, and particulate matter, use of a pretreatment device such as a vegetated filter strip, vegetated swale, small sedimentation basin (forebay), or water quality inlet (e.g., grit chamber) to settle particulates before the stormwater discharges into the infiltration or filtration system is REQUIRED.

For applications where runoff enters the bioretention system through sheet flow, such as from parking lots, or residential back yards, a grass filter strip with a pea gravel diaphragm is the preferred pre-treatment method. The width of the filter strip depends on the drainage area, imperviousness and the filter strip slope. The minimum RECOMMENDED vegetated filter strip width is 3 feet. The width should increase with increasing slope of the filter strip. Slopes should not exceed 8 percent. Pretreatment filter strips greater than 15 feet in width will provide diminishing marginal utility on the installation cost.

Pre-treatment concept developed by the City of Eagan, modified and implemented by the City of St. Cloud. Two 5 inch by 40 inch channel drains bolted to the back of the curb. Construction adhesive used where concrete and drains meet; weep holes drilled in bottom of drains. Maintenance completed by removing screws with cordless drill, then the grates and scooping out sediment/debris. Hex head screws required. this is a cost-effective BMP for small surface infiltration practices and can be easily used for retrofits. Photo courtesy of the City of St. Cloud.

For retrofit projects and sites with tight green space constraints, it may not be possible to include a grass buffer strip. For example, parking lot island retrofits may not have adequate space to provide a grass buffer. For applications where concentrated (or channelized) runoff enters the bioretention system, such as through a slotted curb opening, a grassed channel with a pea gravel diaphragm is the preferred pre-treatment method.

The bioretention practice should be inspected semi-annually to determine if accumulated sediment needs to be removed. Accumulated sediment should be removed from the gravel verge (if applicable) and vegetated filter strip as needed. If the watershed runoff is especially dirty, this frequency may need to be monthly or quarterly. Trash removal should occur in conjunction with removal of debris from the bioretention cell. During maintenance, check for erosion in the filter strip. If it is visible, it should be repaired with topsoil and re-planted. Vegetation of the filter strip should be designed at least 2 inches below the contributing impervious surface. If, over time, the grade of the vegetated filter strip rises above the adjacent impervious surface draining into it, the grade of the vegetated filter strip needs to be lowered to ensure proper drainage.

The type of vegetation in the bioretention cell determines the appropriate flow velocity for which the pre-treatment device should be designed. For tree-shrub-mulch bioretention cells, velocity through the pre-treatment device should not exceed 1 foot per second, which is the velocity that causes incipient motion of mulch. For grassed bioretention cells, flow velocity through the pre-treatment device should not exceed 3 feet per second. In all cases, appropriate maintenance access should be provided to pre-treatment devices.

In lieu of grass buffer strips, pre-treatment may be accomplished by other methods such as sediment capture in the curb-line entrance areas. Additionally, the parking lot spaces may be used for a temporary storage and pre-treatment area in lieu of a grass buffer strip. If bioretention is used to treat runoff from a parking lot or roadway that is frequently sanded during snow events, there is a high potential for clogging from sand in runoff. Local requirements may allow a street sweeping program as an acceptable pre-treatment practice. It is *HIGHLY RECOMMENDED* that pre-treatment incorporate as many of the following as are feasible:

- grass filter strip;
- vegetated swale;
- gravel diaphragm;
- mulch layer;
- forebay;
- flow-through structures; and
- up flow inlet for storm drain inflow.

## Treatment

The following guidelines are applicable to the actual treatment area of a bioretention practice:

- **Space Required:** It is *RECOMMENDED* that approximately 5 to 10 percent of the tributary impervious area be dedicated to the practice footprint; with a minimum 200 square foot area for small sites (equivalent to 10 feet x 20 feet). The surface area of all infiltration designed bioretention practices is a function of MPCA's 48-hour drawdown requirement and the infiltration capacity of the underlying soils.
- **Practice Slope:** It is *RECOMMENDED* that the slope of the surface of the bioretention practice not exceed 1 percent, to promote even distribution of flow throughout.
- **Side Slopes:** It is *HIGHLY RECOMMENDED* that the maximum side slopes for an infiltration practice is 3:1 (h:v).
- **Depth:** Ponding design depths have been kept to a minimum to
  - limit depth and duration of submergence of plants improve plant survivability;
  - reduce mosquito habitat;
  - minimize compaction of in-situ soils;
  - minimize clogging;
  - maximize contact time;
  - enhance safety by preventing drowning; and
  - maintain aesthetic value of the bioretention system

When the drawdown time for a bioinfiltration system is 48 hours, the maximum ponding depth is

- 18 inches for Hydrologic Soil Group (HSG) A soils;
- 18 inches for SM (HSG B) soils;
- 14.4 inches for loam, silt loam and MH (HSG B) soils; and
- 9.6 inches for HSG C soils.

If field tested rates for any soil exceed the rate for A soils in the manual (1.63 inches per hour), the maximum ponding depth is 18 inches. When the drawdown time is 24 hours, the above maximum ponding depths are reduced by a factor of 2.

**Warning:** Permittees must provide at least one soil boring, test pit or infiltrometer test in the location of the infiltration practice for determining infiltration rates.

The Construction Stormwater General Permit (https://stormwater.pca.state.mn.us/index.php/Construction_stormwater_permit) requires that on-site soil testing be consistent with the Minnesota Stormwater Manual. If the permit requirement is not applicable and the recommended number of soil tests have not been taken within the boundary of the SCM, it is *Highly Recommended* the maximum ponding depth be 6 inches. Drawdown time is the time from the high water level in the practice to 1 to 2 inches above the bottom of the facility at the lowest part of the bioretention system. It is *RECOMMENDED* that the elevation difference from the inflow to the outflow be approximately 4 to 6 feet when an underdrain is used.

**Warning:** The *REQUIRED* drawdown time for bioretention practices is 48 hours or less from the peak water level in the practice.

**Caution:** It is *HIGHLY RECOMMENDED* that the drawdown time for bioretention practices is 24 hours or less from the peak water level in the practice when discharges are to a trout stream.
**Warning:** It is *REQUIRED* that the design permeability rate through the planting soil bed be high enough to fully drain the stormwater quality design storm runoff volume within 48 hrs.

It is *HIGHLY RECOMMENDED* that the soil permeability rate be determined by field testing.

- **Groundwater Protection:** Infiltration of unfiltered PSH runoff into groundwater should never occur; the CGP specifically prohibits inflow from "designed infiltration systems from industrial areas with exposed significant materials or from vehicle fueling and maintenance areas".

It is *HIGHLY RECOMMENDED* that bioretention not be used on sites with a continuous flow from groundwater, sump pumps, or other sources so that constant saturated conditions do not occur.

**Warning:** It is *REQUIRED* that impervious area construction is completed and pervious areas established with dense and healthy vegetation prior to introduction of stormwater into a bioretention practice.

It is *HIGHLY RECOMMENDED* that soils meet the design criteria outlined later in this section and contain less than 5 percent clay by volume. Elevations must be carefully worked out to ensure that the desired runoff flow enters the facility with no more than the maximum design depth. The bioretention area ($A_f$) should be sized based on the principles discussed below.

## Landscaping

**Warning:** It is *REQUIRED* that impervious area construction is completed and pervious areas established with dense and healthy vegetation prior to introduction of stormwater into a vegetated infiltration practice.

Landscaping is critical to the performance and function of vegetated areas of infiltration practices. Therefore, a landscaping plan is *HIGHLY RECOMMENDED* for vegetated infiltration practices. *RECOMMENDED* planting guidelines for vegetated practices are as follows:

- Vegetation should be selected based on a specified zone of hydric tolerance. *Plants for Stormwater Design - Species selection for the Upper Midwest* (http://www.pca.state.mn.us/index.php/water/water-types-and-programs/stormwater/stormwater-management/plants-for-stormwater-design.html) is a good resource.
- Native plant species should be specified over non-native species. Hardy native species that thrive in our ecosystem without chemical fertilizers and pesticides are the best choices.
- Many vegetated practices feature wild flowers and grasses as well as shrubs and some trees.
- If woody vegetation is placed near inflow locations, it should be kept out of pretreatment devices and be far enough away to not hamper maintenance of pretreatment devices.
- Trees should not be planted directly overtop of under-drains and may be best located along the perimeter of the practice.
- Salt resistant vegetation should be used in locations with probable adjacent salt application, i.e. roadside, parking lot, etc.
- Plugs, bare root plants or potted plants are RECOMMENDED over seed for herbaceous plants, shrubs, and trees. Erosion control mats pre-vegetated with herbaceous plants are also acceptable. For turf, sod is recommended over seed. (NOTE: Fluctuating water levels following seeding (prior to germination) can cause seed to float and be transported, resulting in bare areas that are more prone to erosion and weed invasion than vegetated areas. Seed is also difficult to establish through mulch, a common surface component of vegetated practices. It may take more than two growing seasons to establish the function and desired aesthetic of mature vegetation via seeding.)
- Vegetated practices should be operated off-line for 1 year or, within the first year, until vegetation is established.

- Example target plant coverage includes
  - at least 50 percent of specified vegetation cover at end of the first growing season;
  - at least 90 percent of specified vegetation cover at end of the third growing season;
  - supplement plantings to meet project specifications if cover targets are not met; and
  - tailoring percent coverage targets to project goals and vegetation. For example, percent cover required for turf after 1 growing season would likely be 100 percent, whereas it would likely be lower for other vegetation types.
- Vegetated areas should be integrated into the site planning process, and aesthetic considerations should be taken into account in their siting and design.

Operation and maintenance of vegetated practices is critical to meeting these landscape recommendations and targets. For more information on operation and maintenance, see the section on operation and maintenance of stormwater infiltration practices.

## Safety

Bioretention practices do not pose any major safety hazards. Trees and the screening they provide may be the most significant consideration of a designer and landscape architect. Where inlets exist, they should have grates that either have locks or are sufficiently heavy that they cannot be removed easily. Standard inlets and grates used by Mn/DOT and local jurisdictions should be adequate. Fencing of bioretention facilities is generally not desirable.

## Maximum flow path

Flow path length is important only if high flows are not bypassed. Below are recommendations from other states or localities.

- North Carolina: The geometry of the cell shall be such that width, length, or radius are not less than 10 feet. This is to provide sufficient space for plants.
- Virginia (http://vwrrc.vt.edu/swc/april_22_2010_update/DCR_BMP_Spec_No_9_BIORETENTION_FinalDraft_v1-8_04132010.htm): Length of shortest flow path to overall length is 0.3 for Level 1 Design and 0.8 for Level 2 Design
- Dakota County Soil and Water Conservation District (http://www.dakotacountyswcd.org/pdfs/Dakota%20LID%20Standards%20Revised%2002-09-12.pdf): Where off-line designs are not achievable, bioretention practices shall be designed to route high flows on the shortest flow path across the cell to provide the least disturbance and displacement of the Water Quality Volume to be treated. Energy dissipation to avoid high flow velocity turbulence is required.

## Use of multiple cells

In comparison to multiple cells, one large bioretention or infiltration cell will often perform just as well as multiple smaller cells if sized and designed appropriately. One large cell is generally less costly than multiple smaller cells. This is due to the simpler geometry and grading requirements of one large cell, as well as a reduction in piping and outlet structures. Multiple smaller cells do however provide greater redundancy, i.e. if one large cell fails, more function is lost than if just one of multiple cells fail. Multiple cells are also more feasible than one large cell in steep terrain (slopes greater than 5 percent), where they can be terraced to match the existing grade. Provided access is maintained to each cell, multiple cells typically results in less and easier maintenance.

## Snow considerations

Considering management of snow, the following are recommended.

- Plan a plow path during design phase and tell snowplow operators where to push the snow. Plan trees around (not in) plow path, with a 16 foot minimum between trees.
- Plan for snow storage (both temporary during construction and permanent). Don’t plow into raingardens routinely. Raingardens should be last resort for snow storage (ie only for during very large snowevents as “emergency overflow”.
- Snow storage could be, for example, a pretreatment moat around a raingarden, i.e. a forebay for snow melt.

# Materials specifications - filter media

## Filter media depth

Research has shown that minimum bioretention soil media depth needed varies depending on the target pollutant(s). The table below summarizes the relationship between media depth and pollutant attenuation. In general, the *Recommended* filter media depth is 2.5 feet or more to allow adequate filtration processes to occur.

**Information:** The Recommended filter media depth is 2.5 feet or more to allow adequate filtration processes to occur
**Warning:** NOTE: Section 16.12 of the Construction Stormwater permit requires a 3 foot separation from the bottom of an infiltration practice and bedrock or seasonally saturated soils.

**Minimum bioretention soil media depths recommended to target specific stormwater pollutants. From Hunt et al. (2012) and Hathaway et al., (2011). NOTE: The Construction Stormwater permit (https://stormwater.pca.state.mn.us/index.php?title=MN_CSW_Permit_Section_16_Infiltration_Systems#16.12) requires a 3 foot separation from the bottom of an infiltration practice and bedrock or seasonally saturated soils.**
Link to this table

| Pollutant | Depth of Treatment with upturned elbow or elevated underdrain | Depth of Treatment without underdrain or with underdrain at bottom | Minimum depth |
|---|---|---|---|
| Total suspended solids (TSS) | Top 2 to 3 inches of bioretention soil media | Top 2 to 3 inches of bioretention soil media | Not applicable for TSS because minimum depth needed for plant survival and growth is greater than minimum depth needed for TSS reduction |
| Metals | Top 8 inches of bioretention soil media | Top 8 inches of bioretention soil media | Not applicable for metals because minimum depth needed for plant survival and growth is greater than minimum depth needed for metals reduction |
| Hydrocarbons | 3 to 4 inch Mulch layer, top 1 inch of bioretention soil media | 3 to 4 inches Mulch layer, top 1 inch of bioretention soil media | Not applicable for hydrocarbons because minimum depth needed for plant survival and growth is greater than minimum depth needed for hydrocarbons reduction |

| Pollutant | Depth of Treatment with upturned elbow or elevated underdrain | Depth of Treatment without underdrain or with underdrain at bottom | Minimum depth |
|---|---|---|---|
| Nitrogen | From top to bottom of bioretention soil media; Internal Water Storage Zone (IWS) improves exfiltration, thereby reducing pollutant load to the receiving stream, and also improves nitrogen removal because the longer retention time allows denitrification to occur underanoxic conditions. | From top to bottom of bioretention soil media | Retention time is important, so deeper media is preferred (3 foot minimum) |
| Particulate phosphorus | Top 2 to 3 inches of bioretention soil media. | Top 2 to 3 inches of bioretention soil media. | Not applicable for particulate phosphorus because minimum depth needed for plant survival and growth is greater than minimum depth needed for particulate phosphorus reduction |
| Dissolved phosphorus | From top of media to top of submerged zone. Saturated conditions cause P to not be effectively stored in submerged zone. | From top to bottom of bioretention soil media | Minimum 2 feet, but 3 feet recommended as a conservative value; if IWS is included, keep top of submerged zone at least 1.5 to 2 feet from surface of media |
| Pathogens | From top of soil to top of submerged zone. | From top to bottom of bioretention soil media | Minimum 2 feet; if IWS is included, keep top of submerged zone at least 2 feet from surface of media |
| Temperature | From top to bottom of bioretention soil media; Internal Water Storage Zone (IWS) improves exfiltration, thereby reducing volume of warm runoff discharged to the receiving stream, and also improves thermal pollution abatement because the longer retention time allows runoff to cool more before discharge. | From top to bottom of bioretention soil media | Minimum 3 feet, with 4 feet preferred |

## Performance specifications

The following performance specifications are applicable to all bioretention media.

- Growing media must be suitable for supporting vigorous growth of selected plant species.
- The pH range (soil/water 1:1) is 6.0 to 8.5
- Soluble salts (soil/water 1:2) should not to exceed 500 parts per million
- All bioretention growing media must have a field tested infiltration rate between 1 and 8 inches per hour. Growing media with slower infiltration rates could clog over time and may not meet drawdown requirements. Target infiltration rates should be no more than 8 inches per hour to allow for adequate water

retention for vegetation as well as adequate retention time for pollutant removal. The following infiltration rates should be achieved if specific pollutants are targeted in a watershed.
- Total suspended solids: Any rate is sufficient, 2 to 6 inches recommended
- Pathogens: Any rate is sufficient, 2 to 6 inches recommended
- Metals: Any rate is sufficient, 2 to 6 inches recommended
- Temperature: slower rates are preferable (less than 2 inches per hour)
- Total nitrogen (TN): 1 to 2 inches per hour, with 1 inch per hour recommended
- Total phosphorus (TP): 2 inches per hour

The following additional bioretention growing media performance specifications are required to receive P reduction credit.

- Option A - use bioretention soil with phosphorus content between 12 and 36 mg/kg (ppm)
- Option B - use bioretention soil with a soil amendment that facilitates adsorption of phosphorus

In general, Bioretention Mixes A and B will not be suitable for achieving reductions in phosphorus loading for bioretention systems having an underdrain unless an amendment is added to the bioretention soil. For guidance on adding an amendment to a bioretention soil, see Soil amendments to enhance phosphorus sorption.

**Caution:** When considering potential impacts of phosphorus to surface waters, it is necessary to select the proper engineered media

Iron-enhanced sand media, Maplewood, Minnesota. Photo courtesy of Plaisted Companies.

This page provides a summary of engineered media mixes. The mixes are divided into those applicable for filtration practices and those applicable for infiltration practices. The page includes links to other pages in this manual and information on engineered media and media mixes used in locations other than Minnesota.

# Media mixes for filtration practices

**Caution:** When phosphorus is a surface water quality concern, mixes A, B, E, and F should not be used in BMPs having an underdrain unless the mix is amended to retain phosphorus.

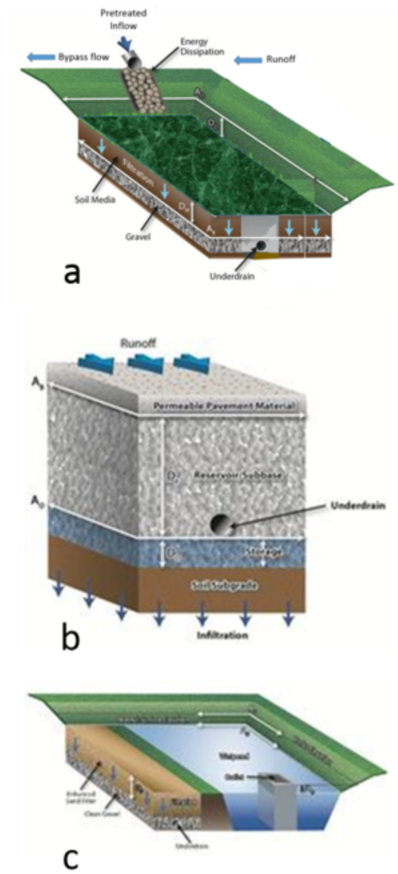
Mixes C and D are acceptable for filtration practices (https://stormwater.pca.state.mn.us/index.php?title=Stormwater_filtration_Best_Management_Practices) (e.g. BMPs with an underdrain). Mixes A, B, E, and F, discussed in the next section (https://stormwater.pca.state.mn.us/index.php?title=Engineered_(bioretention)_media_mixes_for_stormwater_applications#Media_mixes_for_infiltration_practices_or_modified_infiltration_practices), should be avoided when phosphorus is a surface water quality concern unless amended to retain phosphorus. Amendments include substituting a source of organic matter less prone to leaching phosphorus (e.g. coir (https://stormwater.pca.state.mn.us/index.php?title=Coir_and_applications_of_coir_in_stormwater_management), biochar (https://stormwater.pca.state.mn.us/index.php?title=Biochar_and_applications_of_biochar_in_stormwater_management)), or chemicals that attenuate phosphorus (https://stormwater.pca.state.mn.us/index.php?title=Soil_amendments_to_enhance_phosphorus_sorption) (e.g. iron, aluminum).

### Mix C: North Carolina State University water quality blend

Source: North Carolina Department of Environment and Natural Resources, 2009. See Section 12.3.4 (http://portal.ncdenr.org/c/document_library/get_file?uuid=199a62d4-3066-4e24-a3f1-088c6932483a&groupId=38364)

This mix (http://portal.ncdenr.org/c/document_library/get_file?uuid=199a62d4-3066-4e24-a3f1-088c6932483a&groupId=38364) is a homogenous soil mix of

- 85 to 88 percent by volume sand (USDA Soil Textural Classification);
- 8 to 12 percent fines by volume (silt and clay, with a maximum clay content of 5% recommended); and
- 3 to 5 percent organic matter by volume (ASTM D 2974 Method C) MnDOT Grade 2 compost (http://www.dot.state.mn.us/pre-letting/spec/2016/2016specbook.pdf) (**See Specification 3890, page 685**) is recommended.




Example filtration practices: a) biofiltration; b) permeable pavement; c) sand filter. (Source: CDM Smith).

A higher concentration of fines (12 percent) should be reserved for areas where nitrogen is the target pollutant. In areas where phosphorus is the target pollutant, a lower concentration of fines (8 percent) should be used. A soil phosphorus test using the Mehlich-3 (or equivalent) method is recommended but not required to receive water quality credits. The phosphorus index (P-index) for the soil must be low, between 10 and 30 milligrams per kilogram. This is enough phosphorus to support plant growth without exporting phosphorus from the cell. It is assumed this mix will not exceed the upper range of recommended values (30 milligrams per kilogram), although at lower concentrations of organic matter a soil test may be needed to confirm there is adequate phosphorus for plant growth.

## Mix D

**Caution:** If phosphorus is a water quality concern for receiving waters, Bioretention Mix D (as well as Mix C) is recommended when using infiltration systems having an underdrain. The following discussion provides general guidelines for Bioretention Mix D. If using or considering Bioretention Mix D, please see specific guidelines (http://stormwater.pca.state.mn.us/index.php/Design_guidelines_for_soil_characteristics_-_tree_trenches_and_tree_boxes#Product_guidelines) for this mix to avoid confusion with Mixes A, B, and C.

Bioretention Soil Mix D soil shall be a mixture of coarse sand, compost and topsoil in proportions which meet the following:

- silt plus clay (combined): 25 to 40 percent, by dry weight
- total sand: 60 to 75 percent, by dry weight
- total coarse and medium sand: minimum of 55 percent of total sand, by dry weight
- fine gravel less than 5 millimeters: up to 12 percent by dry weight (calculated separately from sand/silt/ clay total)
- organic matter content: 2 to 5 percent, percent loss on ignition by dry weight; MnDOT Grade 2 compost (http://www.dot.state.mn.us/pre-letting/spec/2016/2016specbook.pdf) (**See Specification 3890, page 685**) is recommended.
- saturated hydraulic conductivity: 1 to 4 inches per hour ASTM F1815. Note that although this infiltration rate is generally applicable at 85 percent compaction, Standard Proctor ASTM (http://www.astm.org/) D968, this is an infiltration rate standard and not a compaction standard. Therefore, this infiltration rate may be met at lower levels of compaction.

Suggested mix ratio ranges, by volume, are

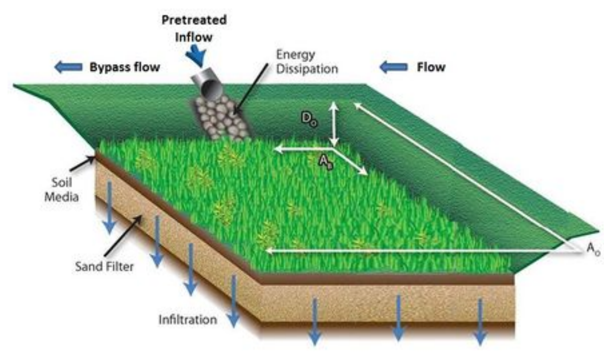
- Coarse sand (http://stormwater.pca.state.mn.us/index.php/Design_guidelines_for_soil_characteristics_-_tree_trenches_and_tree_boxes#Coarse_sand): 50 to 65 percent
- Topsoil (http://stormwater.pca.state.mn.us/index.php/Design_guidelines_for_soil_characteristics_-_tree_trenches_and_tree_boxes#Topsoil): 25 to 35 percent
- Compost (http://stormwater.pca.state.mn.us/index.php/Design_guidelines_for_soil_characteristics_-_tree_trenches_and_tree_boxes#Compost) (assuming MnDOT Grade 2 compost is being used): 10 to 15 percent. Note this yields an organic matter content of approximately 2 to 5 percent.

Note that the above mix ratios are on a volume basis rather than a weight basis. See specific guidance (http://stormwater.pca.state.mn.us/index.php/Design_guidelines_for_soil_characteristics_-_tree_trenches_and_tree_boxes#Product_guidelines) on these.

A soil phosphorus test using the Mehlich-3 (or equivalent) method is recommended but not required to receive water quality credits. The phosphorus index (P-index) for the soil must be low, between 10 and 30 milligrams per kilogram. This is enough phosphorus to support plant growth without exporting phosphorus from the cell. It is assumed this mix will not exceed the upper range of recommended values (30 milligrams per kilogram), although at lower concentrations of organic matter a soil test may be needed to confirm there is adequate phosphorus for plant growth.

# Media mixes for infiltration practices or modified infiltration practices

The following mixes are acceptable for infiltration practices (https://stormwater.pca.state.mn.us/index.php?title=Stormwater_infiltration_Best_Management_Practices).




Schematic showing an infiltration basin, which is one of several stormwater control practices designed to infiltrate stormwater runoff. Infiltration practices capture stormwater runoff and allow it to infiltrate into the underlying soil. Pollutant removal occurs through a variety of mechanisms, including adsorption, absorption, plant uptake, and degradation.

## Mix A: Water quality blend

A well blended, homogenous mixture of

- 60 to 70 percent construction sand;
- 15 to 25 percent top soil; and
- 15 to 25 percent organic matter.

  **Sand**: Provide clean construction sand, free of deleterious materials. AASHTO M-6 (http://www.transportation.org/) or ASTM C-33 (http://www.astm.org/) washed sand.

  **Top Soil**: Sandy loam, loamy sand, or loam texture per USDA textural triangle with less than 5 percent clay content

  **Organic Matter**: MnDOT Grade 2 compost (http://www.dot.state.mn.us/pre-letting/spec/2016/2016specbook.pdf) (**See Specification 3890, page 685**) is recommended.

It is assumed this mix will leach phosphorus. When an underdrain is utilized a soil phosphorus test is needed to receive water quality credits for the portion of stormwater captured by the underdrain. The phosphorus index (P-index) for the soil must be low, between 10 and 30 milligrams per kilogram when using the Mehlich-3 (or equivalent) test. This is enough phosphorus to support plant growth without exporting phosphorus from the cell.

## Mix B: Enhanced filtration blend

A well-blended, homogenous mixture of

- 70 to 85 percent construction sand; and
- 15 to 30 percent organic matter.

**Sand**: Provide clean construction sand, free of deleterious materials. AASHTO M-6 or ASTM C-33 washed sand.

**Top Soil** in the mix will help with some nutrient removal, especially nutrients, but extra care must be taken during construction to inspect the soils before installation and to avoid compaction.

**Organic Matter**: MnDOT Grade 2 compost (http://www.dot.state.mn.us/pre-letting/spec/2016/2016specbook.pdf) (**See Specification 3890, page 685**) is recommended.

It is assumed this mix will leach phosphorus. When an underdrain is utilized a soil phosphorus test is needed to receive water quality credits for the portion of stormwater captured by the underdrain. The phosphorus index (P-index) for the soil must be low, between 10 and 30 milligrams per kilogram when using the Mehlich-3 (or equivalent) test. This is enough phosphorus to support plant growth without exporting phosphorus from the cell.

## Mix C: North Carolina State University water quality blend

Source: North Carolina Department of Environment and Natural Resources, 2009. See Section 12.3.4 (http://portal.ncdenr.org/c/document_library/get_file?uuid=199a62d4-3066-4e24-a3f1-088c6932483a&groupId=38364)

This mix (http://portal.ncdenr.org/c/document_library/get_file?uuid=199a62d4-3066-4e24-a3f1-088c6932483a&groupId=38364) is a homogenous soil mix of

- 85 to 88 percent by volume sand (USDA Soil Textural Classification);
- 8 to 12 percent fines by volume (silt and clay, with a maximum clay content of 5% recommended); and
- 3 to 5 percent organic matter by volume (ASTM D 2974 Method C) MnDOT Grade 2 compost (http://www.dot.state.mn.us/pre-letting/spec/2016/2016specbook.pdf) (**See Specification 3890, page 685**) is recommended.

A higher concentration of fines (12 percent) should be reserved for areas where nitrogen is the target pollutant. In areas where phosphorus is the target pollutant, a lower concentration of fines (8 percent) should be used. A soil phosphorus test using the Mehlich-3 (or equivalent) method is recommended but not required to receive water quality credits. The phosphorus index (P-index) for the soil must be low, between 10 and 30 milligrams per kilogram. This is enough phosphorus to support plant growth without exporting phosphorus from the cell. It is assumed this mix will not exceed the upper range of recommended values (30 milligrams per kilogram), although at lower concentrations of organic matter a soil test may be needed to confirm there is adequate phosphorus for plant growth.

## Mix D

**Caution:** If phosphorus is a water quality concern for receiving waters, Bioretention Mix D (as well as Mix C) is recommended when using infiltration systems having an underdrain. The following discussion provides general guidelines for Bioretention Mix D. If using or considering Bioretention Mix D, please see specific guidelines (http://stormwater.pca.state.mn.us/index.php/Design_guidelines_for_soil_characteristics_-_tree_trenches_and_tree_boxes#Product_guidelines) for this mix to avoid confusion with Mixes A, B, and C.

Bioretention Soil Mix D soil shall be a mixture of coarse sand, compost and topsoil in proportions which meet the following:

- silt plus clay (combined): 25 to 40 percent, by dry weight
- total sand: 60 to 75 percent, by dry weight
- total coarse and medium sand: minimum of 55 percent of total sand, by dry weight
- fine gravel less than 5 millimeters: up to 12 percent by dry weight (calculated separately from sand/silt/ clay total)
- organic matter content: 2 to 5 percent, percent loss on ignition by dry weight; MnDOT Grade 2 compost (http://www.dot.state.mn.us/pre-letting/spec/2016/2016specbook.pdf) (**See Specification 3890, page 685**) is recommended.
- saturated hydraulic conductivity: 1 to 4 inches per hour ASTM F1815. Note that although this infiltration rate is generally applicable at 85 percent compaction, Standard Proctor ASTM (http://www.astm.org/) D968, this is an infiltration rate standard and not a compaction standard. Therefore, this infiltration rate may be met at lower levels of compaction.

Suggested mix ratio ranges, by volume, are

- Coarse sand (http://stormwater.pca.state.mn.us/index.php/Design_guidelines_for_soil_characteristics_-_tree_trenches_and_tree_boxes#Coarse_sand): 50 to 65 percent
- Topsoil (http://stormwater.pca.state.mn.us/index.php/Design_guidelines_for_soil_characteristics_-_tree_trenches_and_tree_boxes#Topsoil): 25 to 35 percent
- Compost (http://stormwater.pca.state.mn.us/index.php/Design_guidelines_for_soil_characteristics_-_tree_trenches_and_tree_boxes#Compost) (assuming MnDOT Grade 2 compost is being used): 10 to 15 percent. Note this yields an organic matter content of approximately 2 to 5 percent.

Note that the above mix ratios are on a volume basis rather than a weight basis. See specific guidance (http://stormwater.pca.state.mn.us/index.php/Design_guidelines_for_soil_characteristics_-_tree_trenches_and_tree_boxes#Product_guidelines) on these.

A soil phosphorus test using the Mehlich-3 (or equivalent) method is recommended but not required to receive water quality credits. The phosphorus index (P-index) for the soil must be low, between 10 and 30 milligrams per kilogram. This is enough phosphorus to support plant growth without exporting phosphorus from the cell. It is assumed this mix will not exceed the upper range of recommended values (30 milligrams per kilogram), although at lower concentrations of organic matter a soil test may be needed to confirm there is adequate phosphorus for plant growth.

## Mix E: MnDOT 3877.2 Type G 'Filter Topsoil Borrow'

A well-blended, homogenous mixture of

- 60 to 80 percent sand meeting gradation requirements of 3126, “Fine Aggregate for Portland Cement Concrete”; and
- 20 to 40 percent compost meeting requirements 3890 Grade 2 Compost.

Provide topsoil borrow containing two blended components of sand and compost for water quality, plant growing medium, and filtration medium with a filtration rate of at least 4 inches per hour [10 centimeters per hour].

See page 672 of MnDOT Standard Specifications for Construction (http://www.dot.state.mn.us/pre-letting/spec/2016/2016-spec-book.pdf)

## Mix F: Custom Infiltration Basin Planting Soil

This mix is a homogenous soil mix of

- 75 percent by weight loamy sand (USDA Soil Textural Classification based on grain size); and

- 25 percent by weight MnDOT grade 2 compost (See page 687 of Standard Specifications for Construction (http://www.dot.state.mn.us/pre-letting/spec/2016/2016-spec-book.pdf), Specification 3890).

Loamy sand as determined by the USDA soil texture classification based on grain size. Loamy sand is defined as soil material that contains at the upper limit 85 to 90 percent sand, and the percentage of silt plus 1.5 times the percentage of clay is not less than 15. At the lower limit it contains not less than 70 to 85 percent sand, and the percentage of silt plus twice the percentage of clay does not exceed 30. In addition, the maximum particle size shall be less than 1-inch.

# Links to related pages

- Media
  - Overview of engineered (bioretention) media
  - Engineered (bioretention) media materials specifications
  - Engineered (bioretention) media mixes for stormwater applications
  - Engineered (bioretention) media applications for stormwater BMPs
  - Phosphorus leaching, export, and retention in engineered (bioretention) media
  - Review and summary of literature pertaining to engineered (bioretention) media
  - Engineered (bioretention) media selection tool
- Amendments
  - Compost and stormwater management
  - Biochar and applications of biochar in stormwater management
  - Coir and applications of coir in stormwater management
  - Wood chips and applications of wood chips in stormwater
  - Water treatment residuals, spent lime and application in stormwater
  - Peat and applications of peat in stormwater
  - Engineered (bioretention) media amendments material specifications
  - Soil amendments to enhance phosphorus sorption (https://stormwater.pca.state.mn.us/index.php?title=Soil_amendments_to_enhance_phosphorus_sorption)

# Links to information on engineered media mixes outside Minnesota

**Caution:** The following information is not intended as recommendations for engineered media applications in Minnesota.

Media mixes for locations outside Minnesota

- Wisconsin Bioretention for infiltration technical standard 1004 (https://dnr.wi.gov/news/input/documents/guidance/BioretentionGuidanceFinal.pdf) - see Section 6, page 3.
- Washington State (https://www.wastormwatercenter.org/4422-bioretention-components)
- North Carolina (https://files.nc.gov/ncdeq/Water%20Quality/Surface%20Water%20Protection/SPU/SPU%20-%20BMP%20Manual%20Documents/BMPMan-Ch12-Bioretention-20090724-DWQ-SPU.pdf) - see Section 12.3.4
- Bioretention soil media example specifications (https://www.sandiegocounty.gov/content/dam/sdc/dpw/WATERSHED_PROTECTION_PROGRAM/susmppdf/lid_appendix_g_bioretention_soil_specification.pdf) - San Diego County
- Specification of Soils for Biotreatment or Bioretention Facilities (https://www.countyofnapa.org/DocumentCenter/View/3035/Bioretention-Soil-Media-Specification-PDF) - Napa County
- BIORETENTION SYSTEM DESIGN SPECIFICATIONS & “PERFORMANCE ENHANCING DEVICES” (https://owl.cwp.org/mdocs-posts/bioretention-system-design-specifications-performance-enhancing-devices/) - Chesapeake Bay
- Virginia (https://www.swbmp.vwrrc.vt.edu/wp-content/uploads/BMP_Spec_No_9_BIORETENTION.pdf) - see Section 6.6

Links to information on engineered media mixes used outside Minnesota

- Designing with Our Bioretention Standard 1004 –Focus on the Engineered Soils (https://www.waukeshacounty.gov/globalassets/parks--land-use/land-conservation/stormwater/bannerman.pdf) - Wisconsin
- Bioretention Soils: How much can we engineer soils? (https://depts.washington.edu/uwbg/docs/stormwater/BioretentionSoilSpecs.pdf) - Seattle, Washington
- Evaluation and Optimization of Bioretention Design for Nitrogen and Phosphorus Removal (https://www.unh.edu/unhsc/sites/unh.edu.unhsc/files/20130614%20EPA%20Final%20Report%20Filter%20Study.pdf)
- Low Impact Development Technical Workshop Series - Bioretention soil mixes (https://na.eventscloud.com/file_uploads/f321367a396a82050c41519a6442fd09_BioretentionSoilMedia-CH1Slide.pdf)
- Biotreatment Soil Media and Specification: Current Research on Trees and Water Quality Treatment (http://basmaa.org/DesktopModules/EasyDNNNews/DocumentDownload.ashx?portalid=0&moduleid=524&articleid=16&documentid=66)
- Bioretention Media Mixtures – A Literature Review (https://erams.com/co-stormwater-center/wp-content/uploads/2017/08/Bioretention-Media-Mixtures-Literature-Review.pdf)

**Comparison of pros and cons of bioretention soil mixes**
Link to this table.

| Mix | Composition in original Manual | Proposed updated composition | Pros | Cons |
|---|---|---|---|---|
| A | • 55-65% construction sand<br>• 10-20% top soil<br>• 25-35% organic matter[2] | • 60-70% construction sand<br>• 15-25% top soil<br>• 15-25% organic matter[2]<br>• to receive P credit for water captured by underdrain the P content must be less than 30 mg/kg (ppm) per Mehlich III (or equivalent) test; NOTE a minimum P concentration of 12 mg/kg is recommended for plant growth. | Likely to sorb more dissolved P and metals than mix B because it contains some fines; best for growth of most plants | Likely to leach P; if topsoil exceeds maximum allowed clay content, higher fines content could result in poor hydraulic performance and long drawdown times |

| Mix | Composition in original Manual | Proposed updated composition | Pros | Cons |
|---|---|---|---|---|
| B | ▪ 50-70% construction sand<br>▪ 30-50% organic matter | ▪ 70-85% construction sand<br>▪ 15-30% organic matter<br>▪ to receive P credit for water captured by underdrain the P content must be less than 30 mg/kg per Mehlich III (or equivalent) test; NOTE a minimum P concentration of 12 mg/kg is recommended for plant growth. | Easy to mix; least likely to clog | Likely to leach P, lack of fines in mix results in less dissolved pollutant removal; harder on most plants than mix A because it dries out very quickly |
| C | Not in original MN Stormwater Manual | ▪ 85-88 percent by volume sand and<br>▪ 8 to 12 percent fines by volume,<br>▪ 3 to 5 percent organic matter by volume<br>▪ recommended P content between 12 and 30 mg/kg per Mehlich III (or equivalent) test | Likely to sorb more dissolved P and metals than mix B because it contains some fines; less likely to leach P than mix B because of low P content | Harder on most plants than mix A because it dries out very quickly. Research in Wisconsin indicates that in cold climates, excess of Na ions can promote displacement of Mg and Ca in the soil, which breaks down soil structure and decreases infiltration rate, and can also cause nutrient imbalances[1] |

| Mix | Composition in original Manual | Proposed updated composition | Pros | Cons |
|---|---|---|---|---|
| D | Not in original MN Stormwater Manual | ▪ All components below by dry weight:<br>▪ 60-75% sand<br>▪ Min. 55% total coarse and medium sand as a % of total sand<br>▪ Less than 12% fine gravel less than 5 mm (Calculated separately from sand/silt/ clay total)<br>▪ 2 to 5 % organic matter<br>▪ recommended P content between 12 and 30 mg/kg per Mehlich III (http://www.clemson.edu/sera6/M3%20Method%20SERA-6%2001_11-2010.doc) (or equivalent) test | Best for pollutant removal, moisture retention, and growth of most plants; less likely to leach P than mix B because of low P content | Harder to find. Research in Wisconsin indicates that in cold climates, excess of Na ions can promote displacement of Mg and Ca in the soil, which breaks down soil structure and decreases infiltration rate, and can also cause nutrient imbalances |
| E | Not in original manual | ▪ 60-80% sand meeting gradation requirements of MnDOT 3126, ―Fine Aggregate for Portland Cement Concrete<br>▪ 20-40% MnDOT 3890 Grade 2 Compost<br>▪ 30% organic leaf compost | High infiltration rates, relatively inexpensive | As compost breaks down, nutrients available for plants decreases |

| Mix | Composition in original Manual | Proposed updated composition | Pros | Cons |
|---|---|---|---|---|
| F | Not in original manual | ▪ 75% loamy sand by volume:<br>  ▪ Upper Limit: 85-90% sand with %Silt + 1.5 times %Clay > 15%.<br>  ▪ Lower Limit: 70-85% sand with %Silt + 2 times %Clay < 30%.<br>  ▪ Maximum particle size < 1-inch<br>▪ 25% MnDOT 3890 Grade 2 Compost | Finer particles in loamy sand holds moisture for better plant growth | Lower infiltration rates, requires careful soil placement to avoid compaction, requires custom mixing |

[1]This problem can be avoided by minimizing salt use. Sodium absorption ratio (SAR) can be tested; if the SAR becomes too high, additions of gypsum (calcium sulfate) can be added to the soil to free the Na and allow it to be leached from the soil (Pitt et al in press).

[2]MnDOT Grade 2 compost (http://www.dot.state.mn.us/pre-letting/spec/2005/3835-3973.pdf) is recommended.

## Other media

Several other media are currently being tested. A few examples are listed below.

### Wisconsin peat moss replacement (Bannerman, 2013)

The following mix utilizes peat moss instead of compost.

- 12 percent peat moss
- 2 percent Imbrium Sorptive®MEDIA
- 86 percent sand

This mix aims to maximize phosphorus removal in 2 ways:

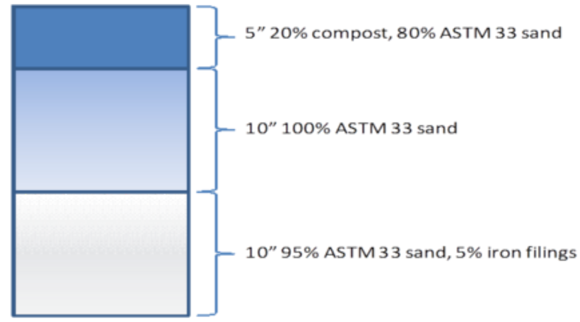
- substituting peat moss for compost, since peat moss has lower phosphorus content than compost and does not leach phosphorus; and
- including Sorptive®MEDIA to sorb phosphorus and minimize phosphorus in effluent

### Layered systems

**Information:** For information on use of iron amendments for phosphorus retention, see Soil amendments to enhance phosphorus sorption and Design criteria for iron enhanced sand filter

Several researchers are currently testing layered systems designed to minimize phosphorus in bioretention effluent. The Wisconsin layered system utilizes a 5 inch surface layer containing 20 percent compost, a 10 inch sand layer below the top layer, and a 10 inch lower layer containing 5 percent iron filings. Advantages of this system include

- compost is used only where it is needed for soil water retention for healthy plant growth. Using sand without compost below the top five inches of the soil profile, where vegetation does not need compost, minimizes total compost volume in the system, and thereby reduces potential for leaching of phosphorus from compost; and
- iron filings in bottom layers sorb phosphorus.



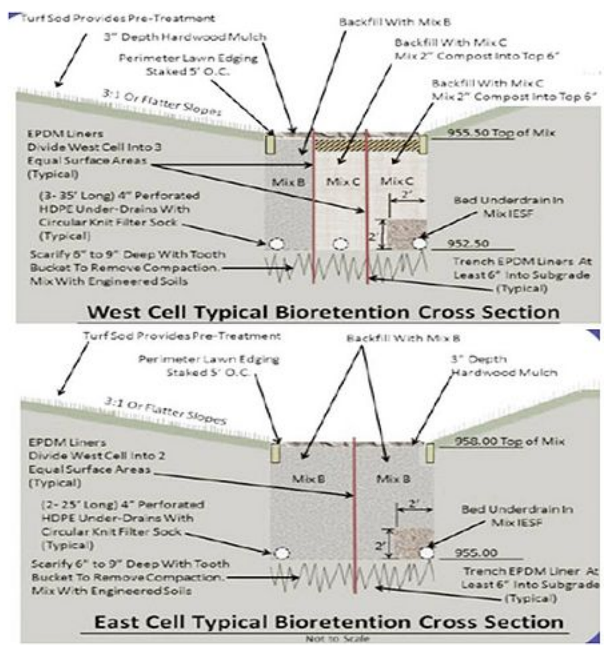
Section showing Wisconsin layered system with compost only in top 5 inches and iron filings in 10 inch deep layer at the bottom of the system

Disadvantages include

- higher cost due to layering;
- greater potential for installation error compared to a system that is not layered; and
- plants may not grow as vigorously because soil water holding capacity will be very low below the top 5 inches of soil, since there is no organic matter below that depth.

Dakota County developed a layered system with compost only in top six inches, 20 percent coir pith, and 5 percent iron filings in the bottom layer (Isensee 2013). Advantages of this mix include:

- compost is used only where it is needed for soil water retention for healthy plant growth. Using sand without compost below the top foot of the soil profile, where vegetation does not need compost, minimizes total compost volume in the system, and thereby reduces potential for leaching of P from compost.
- iron filings in bottom layers sorb P; and
- coir supplements organic matter provided by compost but does not leach P.



Sections showing Dakota County layered systems with compost only in top six inches, 20 percent coir pith, and 5 percent iron filings in bottom layer (From Dakota County Soil and Water Conservation District 2012). Mix B is 70 percent washed sand/30 percent compost; Mix C is 80 percent washed sand/20 percent coir pith; Mix IESF is 95 percent washed sand/5 percent iron filings. each cell is 3 feet deep.

Disadvantages include:

- higher cost due to layers; and
- greater potential for installation error compared to a system that is not layered.Dakota County is monitoring these bioretention systems, which were installed in fall of 2012.

## Addressing phosphorus leaching concerns with media mixes

**Caution:** Biofiltration practices can export phosphorus and contribute to water quality impairments

Biofiltration practices (bioretention systems with an underdrain) return treated water to the stormwater discharge system. Bioretention media with high concentrations of organic matter can export soluble phosphorus in higher concentrations than the incoming stormwater runoff, thus contributing to increased phosphorus loading to receiving waters. The International Stormwater BMP Database (http://www.bmpdatabase.org/Docs/03-SW-1COh%20BMP%20Database%202016%20Summary%20Stats.pdf) (2016), for example, shows statistically higher concentrations of dissolved phosphorus in effluent from bioretention systems compared to influent.

If biofiltration practices are implemented to reduce phosphorus loads to receiving waters, we recommend implementing one of the following recommendations.

- Test the mix for phosphorus (P) concentration. If the media phosphorus content exceeds 30 mg-P/kg-mix it is likely to export P. Consider amending the mix to lower the P content to less than 30 mg-P/kg-mix or adding a material (https://stormwater.pca.state.mn.us/index.php?title=Soil_amendments_to_enhance_phosphorus_sorption), such as iron, to attenuate P.
- Use mix C (https://stormwater.pca.state.mn.us/index.php?title=Design_criteria_for_bioretention#Mix_C:_North_Carolina_State_University_water_quality_blend), D (https://stormwater.pca.state.mn.us/index.php?title=Design_criteria_for_bioretention#Mix_D), or some other mix with an organic matter content less than 5 percent by dry weight.
- Use peat or some other low-P or slow release material as the source of organic matter instead of compost.
- Use an amendment (https://stormwater.pca.state.mn.us/index.php?title=Soil_amendments_to_enhance_phosphorus_sorption) that attenuates P, such as iron. Link here (https://stormwater.pca.state.mn.us/index.php?title=Design_criteria_for_bioretention#Layered_systems) to see example designs that utilize P-attenuating amendments.

**Notes about soil phosphorus testing: applicability and interpretation**

The Mehlich III phosphorus test is specified throughout the Manual, with the stipulation that other soil P tests may be acceptable. Other common P tests used by soil testing laboratories are the Bray and Olsen tests. These tests are acceptable substitutes for the Mehlich III test, with the exception that the Bray test should not be used in calcareous soils or those with a pH greater than 7.3. If in doubt, ask your soil testing laboratory to recommend the appropriate test.

If the pH and non-calcareous conditions are met, the numerical results of the Bray test can be considered equal to those of the Mehlich III test for the purposes of assessing bioretention mixes and other recommendations or requirements stated in the Manual (e.g., if less than 30 milligrams per kilogram by the Mehlich III test is specified to receive the P credit, then the Bray test result should be less than 30 milligrams per kilogram if the Bray test is substituted). The equivalent Olsen test result is lower, such that if 30 milligrams per kilogram or less by the Mehlich test is specified, then an Olsen test result of 20 milligrams per kilogram or less is necessary to receive the P credit. In general, most guidance interprets Olsen test results at a ratio of approximately 2:3 of those of Bray and Mehlich III, with Bray and Mehlich III being roughly equivalent to each other. For example, a Mehlich III result of 9 milligrams per kilogram would be equivalent to 9 milligrams per kilogram by Bray (as long as pH is less than 7.3) and equivalent to 6 milligrams per kilogram by Olsen.

For more information on the relationships between these P tests, see "Differentiating and Understanding the Mehlich 3, Bray, and Olsen Soil Phosphorus Tests" (http://www.agronext.iastate.edu/soilfertility/info/mnconf11_22_99.pdf), by Sawyer and Mallarino (1999).

# Design procedure - design steps

The following steps outline a recommended design procedure for bioretention practices in compliance with the MPCA Construction General Permit for new construction. Design recommendations beyond those specifically required by the permit are also included and marked accordingly.

## Step 1: Make a preliminary judgment

Make a preliminary judgment as to whether site conditions are appropriate for the use of an infiltration practice, and identify the function of the practice in the overall treatment system.

A. Consider basic issues for initial suitability screening, including:

- site drainage area (See the **Summary of infiltration practices for given drainage areas** table below);
- site topography and slopes;
- soil infiltration capacity;
- regional or local depth to groundwater and bedrock;
- site location/ minimum setbacks; and
- presence of active karst.

B. Determine how the infiltration practice will fit into the overall stormwater treatment system.

- Decide whether the infiltration practice is the only BMP to be employed, or if are there other BMPs addressing some of the treatment requirements.
- Decide where on the site the infiltration practice is most likely to be located.

**Stormwater infiltration BMPs - contributing drainage area**
Link to this table

| Stormwater BMP | Recommended contributing area | Notes |
|---|---|---|
| Infiltration Basin | 50 acres or less | A natural or constructed impoundment that captures, temporarily stores and infiltrates the design volume of water into the surrounding naturally permeable soil over several days. In the case of a constructed basin, the impoundment is created by excavation or embankment. |
| Bioinfiltration Basin | 5 acres or less | Bioinfiltration basins must meet the required 48 hour drawdown time and must be sized in order to allow for adequate maintenance. It is HIGHLY RECOMMENDED that bioinfiltration basins be designed to prevent high levels of bounce as submerging vegetation may inhibit plant growth. A maximum wet storage depth of 1.5 feet is HIGHLY RECOMMENDED. |
| Infiltration Trench | 5 acres or less | |
| Dry Well Synonym: Infiltration Tube, French Drain, Soak-Away Pits, Soak Holes | 1 acre or less (rooftop only) | |

| Stormwater BMP | Recommended contributing area | Notes |
|---|---|---|
| Underground Infiltration | 10 acres or less | Though feasible, larger underground infiltration systems may cause groundwater contamination as water is not able to infiltrate through a surface cover. In addition, wind flocculation, UV degradation, and bacterial degradation, which provide additional treatment in surface systems, do not occur in underground systems. Because performance research is lacking for larger features, it is HIGHLY RECOMMENDED that the contributing drainage area to a single device not exceed 10 acres. |
| Dry Swale with Check Dams | 5 acres or less | |
| Permeable Pavement | It is RECOMMENDED that external contributing drainage area not exceed the surface area of the permeable pavement. It is HIGHLY RECOMMENDED that external contributing drainage area not exceed twice the surface area of the permeable pavement | It is RECOMMENDED that external drainage area be as close to 100% impervious as possible. Field experience has shown that drainage area (pervious or impervious) can contribute particulates to the permeable pavement and lead to clogging. Therefore, sediment source control and/or pre-treatment should be used to control sediment run-on to the permeable pavement section. |
| Tree Trench/Tree Box | up to 0.25 acres per tree | |

References: Virginia (http://www.vwrrc.vt.edu/swc/april_22_2010_update/DCR_BMP_Spec_No_8_INFILTRATION_Final_Draft_v1-8_04132010.htm), North Carolina (https://deq.nc.gov/about/divisions/energy-mineral-land-resources/energy-mineral-land-permit-guidance/stormwater-bmp-manual), West Virginia (http://www.dep.wv.gov/WWE/Programs/stormwater/MS4/Pages/StormwaterManagementDesignandGuidanceManual.aspx), Maine (http://www.maine.gov/dep/land/stormwater/stormwaterbmps/), Lake Tahoe (http://tahoebmp.org/bmphandbook.aspx), Connecticut (http://www.ct.gov/deep/cwp/view.asp?a=2721&q=325704), Massachusetts (http://www.mass.gov/eea/agencies/massdep/water/regulations/massachusetts-stormwater-handbook.html), New York (http://www.dec.ny.gov/chemical/29072.html), Wisconsin (https://dnr.wi.gov/topic/Stormwater/standards/postconst_standards.html), Vermont (http://dec.vermont.gov/sites/dec/files/wsm/stormwater/docs/Resources/sw_manual-vol1.pdf), New Hampshire (http://des.nh.gov/organization/divisions/water/stormwater/manual.htm), Ontario (https://www.ontario.ca/document/stormwater-management-planning-and-design-manual), Pennsylvania (http://www.elibrary.dep.state.pa.us/dsweb/View/Collection-8305)

## Step 2: Confirm design criteria and applicability

Determine whether the infiltration practice must comply with the MPCA Construction Stormwater General (CSW) Permit (https://stormwater.pca.state.mn.us/index.php/Construction_stormwater_permit). Check with local officials, Watershed management Organizations (WMOs), and other agencies to determine if there are any additional restrictions and/or surface water or watershed requirements that may apply.

**Warning:** If the infiltration practice must comply with the CSW permit, the following prohibitions apply:

- areas that receive discharges from vehicle fueling and maintenance;
- areas with less than three (3) feet of separation distance from the bottom of the infiltration system to the elevation of the seasonally saturated soils or the top of bedrock;
- areas that receive discharges from industrial facilities which are not authorized to infiltrate industrial stormwater under an NPDES/SDS Industrial Stormwater Permit issued by the MPCA;
- areas where high levels of contaminants in soil or groundwater will be mobilized by the infiltrating stormwater;

- areas of predominately Hydrologic Soil Group D (clay) soils;
- areas within 1,000 feet up-gradient, or 100 feet down-gradient of active karst features;
- areas within a Drinking Water Supply Management Area (DWSMA) as defined in Minn. R. 4720.5100, subp. 13., if the system will be located:
  - in an Emergency Response Area (ERA) within a DWSMA classified as having high or very high vulnerability as defined by the Minnesota Department of Health; or
  - in an ERA within a DWSMA classified as moderate vulnerability unless a regulated MS4 Permittee performed or approved a higher level of engineering review sufficient to provide a functioning treatment system and to prevent adverse impacts to groundwater; or
  - outside of an ERA within a DWSMA classified as having high or very high vulnerability, unless a regulated MS4 Permittee performed or approved a higher level of engineering review sufficient to provide a functioning treatment system and to prevent adverse impacts to groundwater; and
- areas where soil infiltration rates are more than 8.3 inches per hour unless soils are amended to slow the infiltration rate below 8.3 inches per hour.

## Step 3: Perform field verification of site suitability

**Warning:** The Construction Stormwater permit includes the following requirements.

16.10. Permittees must provide at least one soil boring, test pit or infiltrometer test in the location of the infiltration practice for determining infiltration rates.

16.11. For design purposes, permittees must divide field measured infiltration rates by 2 as a safety factor or permittees can use soil-boring results with the infiltration rate chart in the Minnesota Stormwater Manual to determine design infiltration rates. When soil borings indicate type A soils, permittees should perform field measurements to verify the rate is not above 8.3 inches per hour. This permit prohibits infiltration if the field measured infiltration rate is above 8.3 inches per hour.

Designers should evaluate soil properties during preliminary site layout with the intent of installing infiltration practices on soils with the highest infiltration rates (HSG A and B). Preliminary planning for the location of an infiltration device may be completed using a county soil survey or the NRCS Web Soil Survey (http://websoilsurvey.nrcs.usda.gov/app/HomePage.htm). These publications provide HSG information for soils across Minnesota. To ensure long-term performance, however, field soil measurements (https://stormwater.pca.state.mn.us/index.php?title=Determining_soil_infiltration_rates) are desired to provide site-specific data.

If the initial evaluation indicates that an infiltration practice would be a good BMP for the site, it is *RECOMMENDED* that soil borings or pits be dug within the proposed boundary of the infiltration practice to verify soil types and infiltration capacity characteristics and to determine the depth to groundwater and bedrock. Soil borings for building structural analysis are not acceptable. In all design scenarios, a minimum of one soil boring (two are recommended) shall be completed to a depth 5 feet below the bottom of the proposed infiltration Stormwater Control Measure (SCM or BMP) (Dakota County Soil and Water Conservation District, 2012) per ASTM D1586 (ASTM (http://www.astm.org/), 2011). For infiltration SCMs with surface area between 1000 and 5000 square feet, two borings shall be made. Between 5000 and 10000 square feet, three borings are needed, and for systems with greater than 10000 square feet in surface area, 4 or more borings are needed. For each additional 2500 square feet beyond 12,500 square feet, an additional soil boring should be made. Soil borings must be undertaken during the design phase (i.e. prior to the commencement of construction) to determine how extensive the soil testing will be during construction. Borings should be completed using continuous split spoon sampling, with blow counts being recorded to determine the level of compaction of the soil. Soil borings are needed to understand soil types, seasonally high groundwater table elevation, depth to karst, and bedrock elevations.

**Recommended number of soil borings, pits or permeameter tests for bioretention design. Designers select one of these methods.**
Link to this table

| Surface area of stormwater control measure (BMP)($ft^2$) | Borings | Pits | Permeameter tests |
|---|---|---|---|
| < 1000 | 1 | 1 | 5 |
| 1000 to 5000 | 2 | 2 | 10 |
| 5000 to 10000 | 3 | 3 | 15 |
| >10000 | 4[1] | 4[1] | 20[2] |

[1]an additional soil boring or pit should be completed for each additional 2,500 $ft^2$ above 12,500 $ft^2$

[2]an additional five permeameter tests should be completed for each additional 5,000 $ft^2$ above 15,000 $ft^2$

It is *HIGHLY RECOMMENDED* that soil profile descriptions be recorded and include the following information for each soil horizon or layer (Source: *Site Evaluation for Stormwater Infiltration* (https://dnr.wi.gov/topic/Stormwater/standards/postconst_standards.html), Wisconsin Department of Natural Resources Conservation Practice Standards 2004):

- thickness, in inches or decimal feet;
- Munsell soil color notation;
- soil mottle or redoximorphic feature color, abundance, size and contrast;
- USDA soil textural class with rock fragment modifiers;
- soil structure, grade size and shape;
- soil consistence, root abundance and size;
- soil boundary; and
- occurrence of saturated soil, impermeable layers/lenses, ground water, bedrock or disturbed soil.

It is RECOMMENDED that a standard soil boring form be used. A good example is File:Boring Pit Log form.docx. The NRCS Field Book for Describing and Sampling Soils (http://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/ref/?cid=nrcs142p2_054184) provide detailed information for identifying soil characteristics. Munsell color charts can be found at [1] (http://www.masterplan.southsuburbanairport.com/Environmental/pdf2/Part%204%20-%20References/Reference%2016%20Munsell%20Color%20Charts/MunsellColorChart.pdf).

**Warning:** A separation distance of 3 feet is REQUIRED between the bottom of the infiltration practice and the elevation of the seasonally high water table (saturated soil) or top of bedrock (i.e. there must be a minimum of 3 feet of undisturbed soil beneath the infiltration practice and the seasonally high water table or top of bedrock).

It is HIGHLY RECOMMENDED that the field verification be conducted by a qualified geotechnical professional.

## Step 4: Compute runoff control volumes

**Warning:** If the bioretention practice is being designed to meet the requirements of the MPCA Permit, the *REQUIRED* treatment volume is the water quality volume ($V_{wq}$) of 1 inch of runoff from the new impervious surfaces created from the project. If part of the overall $V_{wq}$ is to be treated by other BMPs, subtract that portion from the $V_{wq}$ to determine the part of the $V_{wq}$ to be treated by the bioretention practice.

The design techniques in this section are meant to maximize the volume of stormwater being infiltrated. If the site layout and underlying soil conditions permit, a portion of the Channel Protection Volume ($V_{cp}$), Overbank Flood Protection Volume ($V_{p10}$), and the Extreme Flood Volume ($V_{p100}$) may also be managed in the bioretention practice.

## Step 5: Determine bioretention type and size practice

(Note: Steps 5, 6, 7 and 8 are iterative)

**Select Design Variant**

After following the steps outlined above, the designer will presumably know the location of naturally occurring permeable soils, the depth to the water table, bedrock or other impermeable layers, and the contributing drainage area. While the first step in sizing a bioretention practice is selecting the type of design variant for the site, the basic design procedures for each type of bioretention practice are similar.

After determining the water quality volume for the entire site (Step 4), determine the portion of the total volume that will be treated by the bioretention practice. Based on the known $V_{wq}$, infiltration rates of the underlying soils and the known existing potential pollutant loading from proposed/existing landuse, select the appropriate bioretention practice from the table below. Note: the determination for underdrain is an iterative sizing process.

**Warning:** Bioretention practices shall discharge through the soil or filter media in 48 hours or less. Additional flows that cannot be infiltrated or filtered in 48 hours should be routed to bypass the system through a stabilized discharge point.

Experience has demonstrated that, although the drawdown period is 48 hours, there is often some residual water pooled in the infiltration practice after 48 hours. This residual water may be associated with reduced head, water gathered in depressions within the practice, water trapped by vegetation, and so on. The drawdown period is therefore defined as the time from the high water level in the practice to 1 to 2 inches above the bottom of the facility. This criterion was established to provide the following: wet-dry cycling between rainfall events; unsuitable mosquito breeding habitat; suitable habitat for vegetation; aerobic conditions; and storage for back-to-back precipitation events. This time period has also been called the period of inundation.

**Caution:** It is *HIGHLY RECOMMENDED* that the drawdown time for bioretention practices is 24 hours or less from the peak water level in the practice when discharges are to a trout stream.

**Summary of Bioretention Variants for Permeability of Native Soils and Potential Land use Pollutant Loading**
(Link to this table)

| Bioretention Type[1] | Variant | Underlying Soil Performance Criteria |
|---|---|---|
| Bioinfiltration<br>(Infiltration/Recharge Facility) | No underdrain | Higher recharge potential (facility drain time without underdrain is 48 hours or less) |
| Biofiltration with underdrain at the bottom<br>(Filtration/Partial Recharge Facility) | Underdrain | Lower recharge potential (facility drain time without underdrain is > 48 hours) |
| Biofiltration with internal water storage | Underdrain | Lower recharge potential (facility drain time without underdrain is >48 hours) |
| Biofiltration with elevated underdrain<br>(Infiltration/Filtration/Recharge Facility) | Elevated underdrain | Higher nutrient loadings and/or quantity control |
| Biofiltration with liner (http://stormwater.pca.state.mn.us/index.php/Liners_for_stormwater_management)<br>(Filtration Only Facility) | Underdrain with liner | Hot Spot Treatment |

[1]The terminology has been changed from the original manual. The original Manual terminology is shown in parenthesis. For more information, see Bioretention terminology

Information collected during the Physical Suitability Evaluation (see Step 3) should be used to explore the potential for multiple bioretention practices versus relying on a single bioretention practice. Bioretention is best employed close to the source of runoff generation and is often located in the upstream portion of the stormwater treatment train, with additional stormwater BMPs following downstream.

**Determine site infiltration rates (for facilities with infiltration and/or recharge)**

For design purposes, there are two ways of determining the soil infiltration rate. The first, and preferred method, is to field-test the soil infiltration rate using appropriate methods described below. The other method uses the typical infiltration rate of the most restrictive underlying soil (determined during soil borings).

If infiltration rate measurements are made, a minimum of one infiltration test in a soil pit must be completed at the elevation from which exfiltration would occur (i.e. interface of gravel drainage layer and in situ soil). When the SCM surface area is between 1000 and 5000 square feet, two soil pit measurements are needed. Between 5000 and 10000 square feet of surface area, a total of three soil pit infiltration measurements should be made. Each additional 5000 square feet of surface area triggers an additional soil pit.

**Recommended number of soil borings, pits or permeameter tests for bioretention design. Designers select one of these methods.**
Link to this table

| Surface area of stormwater control measure (BMP)($ft^2$) | Borings | Pits | Permeameter tests |
|---|---|---|---|
| < 1000 | 1 | 1 | 5 |
| 1000 to 5000 | 2 | 2 | 10 |
| 5000 to 10000 | 3 | 3 | 15 |
| >10000 | 4[1] | 4[1] | 20[2] |

[1]an additional soil boring or pit should be completed for each additional 2,500 $ft^2$ above 12,500 $ft^2$

[2]an additional five permeameter tests should be completed for each additional 5,000 $ft^2$ above 15,000 $ft^2$

The median measured infiltration rate should be utilized for design. Soil pits should be dug during the design phase and should be a minimum of two feet in diameter for measurement of infiltration rate. Infiltration testing in the soil pit can be completed with a double-ring infiltrometer or by filling the pit with water and measuring stage versus time. If the infiltration rate in the first pit is greater than 2 inches per hour, no additional pits shall be needed.

Alternatively, a Modified Philip-Dunne permeameter can be used to field test infiltration rate. Modified Philip-Dunne permeameter tests may be made in conjunction with soil borings or may be completed using a handheld soil auger. Borings should be lined with a plastic sleeve to prevent infiltration from the sides of the borehole (i.e. restrict flow to vertical infiltration). Soil borings should be filled with water. The time for the borehole to drain should be recorded and divided by the initial ponding depth in the borehole to provide an infiltration rate measurement. The design infiltration rate should be the lower of the median soil pit infiltration rate or the median borehole method infiltration rate.

NOTE: In the table above, the recommended number of permeameter tests increases by 5 tests per each additional 5000 square feet of surface area. For larger sites, this can result in a very large number of samples. There may be situations where fewer permeameter tests may be used (5 is the minimum) . For example, in situations where the variability in saturated hydraulic conductivity between measurements is not great, fewer samples may be taken. One method for determining the number of samples is to plot standard deviation versus number of samples. Measurements may be halted when the standard deviation becomes relatively constant from one sample to the next. In the example to the right the standard deviation flattens at about 7 to 10 samples. Therefore, 7 to 10 samples would be an appropriate number of samples for this situation.

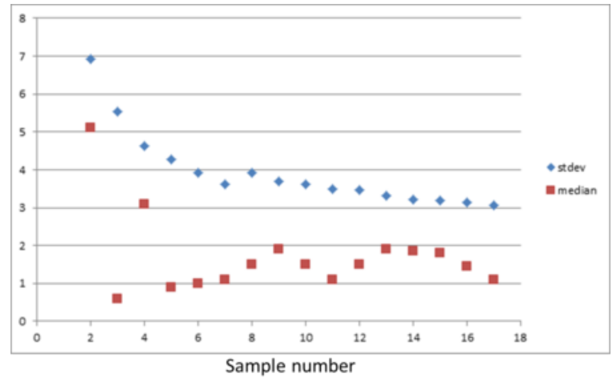



Illustration of how to determine the appropriate number of permeameter samples. The y-axis represents the standard deviation or median hydraulic conductivity. When the standard deviation for all measurements flattens out with successive measurements, collection of additional permeameter tests may be halted, provided a minimum of 5 samples have been collected.

For information on conducting soil infiltration rate measurements, see Determining soil infiltration rates.

If the infiltration rate is not measured, use the table below to estimate an infiltration rate for the design of infiltration practices. These infiltration rates represent the long-term infiltration capacity of a practice and are not meant to exhibit the capacity of the soils in the natural state.

**Caution:** Select the design infiltration rate from the table based on the least permeable soil horizon within the first 5 feet below the bottom elevation of the proposed infiltration practice

**Caution:** The table for design infiltration rates has been modified. Field testing is recommended for gravelly soils (HSG A; GW and GP soils; gravel and sandy gravel soils). If field-measured soil infiltration rates exceed 8.3 inches per hour, the Construction Stormwater permit requires the soils be amended. Guidance on amending these soils can be found here.

**Design infiltration rates, in inches per hour, for A, B, C, and D soil groups. Corresponding USDA soil classification and Unified soil Classifications are included. Note that A and B soils have two infiltration rates that are a function of soil texture.***
**The values shown in this table are for uncompacted soils. This table (https://stormwater.pca.state.mn.us/index.php?title=General_relationship_of_soil_bulk_density_to_root_growth_based_on_soil_texture) can be used as a guide to determine if a soil is compacted. For information on alleviating compacted soils, link here (https://stormwater.pca.state.mn.us/index.php/Alleviating_compaction_from_construction_activities). If a soil is compacted, reduce the soil infiltration rate by one level (e.g. for a compacted B(SM) use the infiltration rate for a B(MH) soil).**
Link to this table

| Hydrologic soil group | Infiltration rate (inches/hour) | Infiltration rate (centimeters/hour) | Soil textures | Corresponding Unified Soil Classification |
|---|---|---|---|---|

| Hydrologic soil group | Infiltration rate (inches/hour) | Infiltration rate (centimeters/hour) | Soil textures | Corresponding Unified Soil Classification |
|---|---|---|---|---|
| A | Although a value of 1.63 inches per hour (4.14 centimeters per hour) may be used, it is ***Highly recommended*** that you conduct field infiltration tests or amend soils.[b] See Guidance for amending soils with rapid or high infiltration rates and Determining soil infiltration rates (https://stormwater.pca.state.mn.us/index.php?title=Determining_soil_infiltration_rates). | | gravel<br>sandy gravel | GW - well-graded gravels, sandy gravels<br>GP - gap-graded or uniform gravels, sandy gravels |
| | 1.63[a] | 4.14 | silty gravels<br>gravelly sands<br>sand | GM - silty gravels, silty sandy gravels<br>SW - well-graded gravelly sands<br>SW - uniformly graded sands |
| | 0.8 | 2.03 | sand<br>loamy sand<br>sandy loam | SP - gap-graded or poorly graded sands |
| B | 0.45 | 1.14 | | SM - silty sands, silty gravelly sands |
| | 0.3 | 0.76 | loam, silt loam | MH - micaceous silts, diatomaceous silts, volcanic ash |
| C | 0.2 | 0.51 | Sandy clay loam | ML - silts, very fine sands, silty or clayey fine sands |

| Hydrologic soil group | Infiltration rate (inches/hour) | Infiltration rate (centimeters/hour) | Soil textures | Corresponding Unified Soil Classification |
|---|---|---|---|---|
| D | 0.06 | 0.15 | clay loam<br>silty clay loam<br>sandy clay<br>silty clay<br>clay | GC - clayey gravels, clayey sandy gravels<br>SC - clayey sands, clayey gravelly sands<br>CL - low plasticity clays, sandy or silty clays<br>OL - organic silts and clays of low plasticity<br>CH - highly plastic clays and sandy clays<br>OH - organic silts and clays of high plasticity |

*NOTE that this table has been updated from Version 2.X of the Minnesota Stormwater Manual. The higher infiltration rate for B soils was decreased from 0.6 inches per hour to 0.45 inches per hour and a value of 0.06 is used for D soils (instead of < 0.2 in/hr).

Source: Thirty guidance manuals and many other stormwater references were reviewed to compile recommended infiltration rates. All of these sources use the following studies as the basis for their recommended infiltration rates: (1) Rawls, Brakensiek and Saxton (1982); (2) Rawls, Gimenez and Grossman (1998); (3) Bouwer and Rice (1984); and (4) Urban Hydrology for Small Watersheds (NRCS). SWWD, 2005, provides field documented data that supports the proposed infiltration rates. (view reference list)

[a]This rate is consistent with the infiltration rate provided for the lower end of the Hydrologic Soil Group A soils in the Stormwater post-construction technical standards, Wisconsin Department of Natural Resources Conservation Practice Standards (https://dnr.wi.gov/topic/Stormwater/standards/postconst_standards.html).

[b]The infiltration rates in this table are recommended values for sizing stormwater practices based on information collected from soil borings or pits. A group of technical experts developed the table for the original Minnesota Stormwater Manual in 2005. Additional technical review resulted in an update to the table in 2011. Over the past 5 to 7 years, several government agencies revised or developed guidance for designing infiltration practices. Several states now require or strongly recommend field infiltration tests. Examples include North Carolina, New York, Georgia, and the City of Philadelphia. The states of Washington and Maine strongly recommend field testing for infiltration rates, but both states allow grain size analyses in the determination of infiltration rates. The Minnesota Stormwater Manual strongly recommends field testing for infiltration rate, but allows information from soil borings or pits to be used in determining infiltration rate. A literature review suggests the values in the design infiltration rate table (https://stormwater.pca.state.mn.us/index.php?title=Design_infiltration_rates) are not appropriate for soils with very high infiltration rates. This includes gravels, sandy gravels, and uniformly graded sands. Infiltration rates for these geologic materials are higher than indicated in the table.

References: Clapp, R. B., and George M. Hornberger. 1978. Empirical equations for some soil hydraulic properties. Water Resources Research. 14:4:601–604; Moynihan, K., and Vasconcelos, J. 2014. SWMM Modeling of a Rural Watershed in the Lower Coastal Plains of the United States (https://www.chijournal.org/Journals/PDF/C372). Journal of Water Management Modeling. C372; Rawls, W.J., D. Gimenez, and R. Grossman. 1998. Use of soil texture, bulk density and slope of the water retention curve to predict saturated hydraulic conductivity Transactions of the ASAE. VOL. 41(4): 983-988; Saxton, K.E., and W. J. Rawls. 2005. Soil Water Characteristic Estimates by Texture and Organic Matter for Hydrologic Solutions. Soil Science Society of America Journal. 70:5:1569-1578.

The infiltration capacity and existing hydrologic regime of natural basins are inherently different than constructed practices and may not meet MPCA Permit requirements for constructed practices. In the event that a natural depression is being proposed to be used as an infiltration system, the design engineer must demonstrate the following information:

- infiltration capacity of the system under existing conditions (inches per hour)
- existing drawdown time for the high water level (HWL) and a natural overflow elevation.

The design engineer should also demonstrate that operation of the natural depression under post-development conditions mimics the hydrology of the system under pre-development conditions.

If the infiltration rates are measured, the tests shall be conducted at the proposed bottom elevation of the infiltration practice. If the infiltration rate is measured with a double-ring infiltrometer the requirements of ASTM D3385 (http://www.astm.org) (Standard test method for infiltration rate of soils in field using double-ring infiltrometer) should be used for the field test.

**Warning:** The measured infiltration rate shall be divided by a safety factor of 2.

The safety factor of 2 adjusts the measured infiltration rates for the occurrence of less permeable soil horizons below the surface and the potential variability in the subsurface soil horizons throughout the infiltration site. This safety factor also accounts for the long-term infiltration capacity of the stormwater management facility.

## Size bioretention area

To meet requirements of the Stormwater General Permit (https://stormwater.pca.state.mn.us/index.php/Construction_stormwater_permit) (CSW permit), the surface area ($A_s$, in square feet) of a bioinfiltration practice is given by

$$A_s = V_w / D_o$$

Where:
$V_w$ = the water treatment volume of the area contributing runoff to the practice; and
$D_o$ = the storage depth of ponded water in the practice.

The water treatment volume is given by

$$V_w = 0.0833 A_c$$

Where
0.0833 = one inch of infiltration, as required by the permit; and
$A_c$ = the impervious surface area contributing to the practice.

The entire water quality treatment volume is assumed to be instantaneously ponded in the bioinfiltration practice.

For a bioretention BMP with sloped sides, the surface area ($A_s$) of an infiltration practice is the average area of the BMP, given by

$$A_s = (A_o + A_M)/2$$

Where
$A_o$ is the surface area at the overflow; and
$A_M$ is the surface area at the top of the bioretention media

The water treatment volume must drain with 48 hours (24 hours is RECOMMENDED if discharges from the practice are to a trout stream). The ponding depth can therefore be calculated knowing the infiltration rate of the soils underlying the practice. Field-measured infiltration rates are preferred. If the infiltration rate has not been measured, use the table below to determine the infiltration rate of the underlying soils. The ponded depth must not exceed 18 inches (1.5 feet) regardless of the soil infiltration rate. Note the numbers in the table are intentionally conservative based on experience gained from Minnesota infiltration sites. Two example calculations are provided below.

**Example 1** Assume a 5 acre watershed is 20 percent impervious. Runoff from this watershed will be routed to a bioinfiltration practice that has an underlying loam soil.

- The treatment volume = 5 acres * 0.20 * 43560 square feet per acre * 0.0833 inches = 3630 cubic feet
- The ponded depth = 48 hours * 0.30 inches per hour = 14.4 inches = 1.2 feet
- The surface area of the practice = 3025 square feet

The dimensions of the bioinfiltration practice can be determined to accommodate this area. For example, a square practice will be 55 feet wide by 55 feet long. Note that the depth of 1.2 feet meets the requirement that the ponded depth be 1.5 feet or less.

**Example 2** Assume a 7 acre watershed is 15 percent impervious. Runoff from this watershed will be routed to a bioinfiltration practice where the underlying soil has a field-measured infiltration rate of 2 inches per hour.

Note:

- The watershed acreage exceeds the RECOMMENDED 5 acre maximum size.
- The infiltration rate must be divided by a safety factor of 2 since a field-measure rate is being used. This gives an infiltration rate of 1 inch per hour.
- The ponded depth = 48 hours * 1 inch per hour = 48 inches = 4 feet. This exceeds the maximum depth of 1.5 feet. Thus the ponded depth is set equal to 1.5 feet.
- The treatment volume = 7 acres * 0.15 * 43560 square feet per acre * 0.0833 inches = 3811 cubic feet
- The surface area of the practice = $3811 ft^3$ / 1.5ft = 2541 square feet

The dimensions of the bioinfiltration practice can be determined to accommodate this volume. For example, a square practice will be 50.4 feet wide by 50.4 feet long.

If the bioinfiltration practice does not require meeting the Construction Stormwater General Permit, methods other than the instantaneous volume method may be used. For example, as a bioinfiltration basin fills during a rain event, water infiltrates the media. The bioinfiltration area could be sized as follows

$$A_s = V_{wq}/(D_o + (I_R * t))$$

Where:
$I_R$ = infiltration rate of underlying soils (feet per day);and
t = time during which the bioretention basin continues to capture runoff.

The time during which runoff continues to be delivered to the BMP varies with each event. As an example, for a 1 hour event on a B (SM) soil with an infiltration rate of 0.45 inches per hour, 1 acre of contributing impervious area, and a 1.5 foot ponding depth, $A_s$ is 2361 square feet, compared to 2420 square feet considering only an instantaneous volume, or a decrease of 2.4 percent in the size of the basin. On an A soil with and infiltration rate of 1.6 inches per hour, $A_s$ is 2222 square feet, or a decrease of 8.2 percent in the needed size of the basin. The area of the basin can also be decreased by increasing the ponded depth to greater than the 1.5 foot recommended. However, increased ponding depths increase the inundation time for plants in the bioretention basin.

Bioinfiltration practices may also be sized using different treatment goals. For example, the performance goal for Minimal Impact Design Standards (MIDS) is 1.1 inches, compared to 1 inch for the CSW permit. The MIDS performance goal was also based on initial modeling (http://www.pca.state.mn.us/index.php/view-document.html?gid=15664) that included infiltration during the rain event.

**Warning:** 48 hours is the *REQUIRED* maximum $t_f$ for bioretention under the CGP

**Caution:** The table for design infiltration rates has been modified. Field testing is recommended for gravelly soils (HSG A; GW and GP soils; gravel and sandy gravel soils). If field-measured soil infiltration rates exceed 8.3 inches per hour, the Construction Stormwater permit requires the soils be amended. Guidance on amending these soils can be found here.

**Design infiltration rates, in inches per hour, for A, B, C, and D soil groups. Corresponding USDA soil classification and Unified soil Classifications are included. Note that A and B soils have two infiltration rates that are a function of soil texture.***
**The values shown in this table are for uncompacted soils. This table (https://stormwater.pca.state.mn.us/index.php?title=General_relationship_of_soil_bulk_density_to_root_growth_based_on_soil_texture) can be used as a guide to determine if a soil is compacted. For information on alleviating compacted soils, link here (https://stormwater.pca.state.mn.us/index.php/Alleviating_compaction_from_construction_activities). If a soil is compacted, reduce the soil infiltration rate by one level (e.g. for a compacted B(SM) use the infiltration rate for a B(MH) soil).**
Link to this table

| Hydrologic soil group | Infiltration rate (inches/hour) | Infiltration rate (centimeters/hour) | Soil textures | Corresponding Unified Soil Classification |
|---|---|---|---|---|
| | Although a value of 1.63 inches per hour (4.14 centimeters per hour) may be used, it is ***Highly recommended*** that you conduct field infiltration tests or amend soils.[b] See Guidance for amending soils with rapid or high infiltration rates and Determining soil infiltration rates (https://stormwater.pca.state.mn.us/index.php?title=Determining_soil_infiltration_rates). | | gravel<br>sandy gravel | GW - well-graded gravels, sandy gravels<br>GP - gap-graded or uniform gravels, sandy gravels |
| A | 1.63[a] | 4.14 | silty gravels<br>gravelly sands<br>sand | GM - silty gravels, silty sandy gravels<br>SW - well-graded gravelly sands<br>SW - uniformly graded sands |
| | 0.8 | 2.03 | sand<br>loamy sand<br>sandy loam | SP - gap-graded or poorly graded sands |

| Hydrologic soil group | Infiltration rate (inches/hour) | Infiltration rate (centimeters/hour) | Soil textures | Corresponding Unified Soil Classification |
|---|---|---|---|---|
| B | 0.45 | 1.14 | | SM - silty sands, silty gravelly sands |
| | 0.3 | 0.76 | loam, silt loam | MH - micaceous silts, diatomaceous silts, volcanic ash |
| C | 0.2 | 0.51 | Sandy clay loam | ML - silts, very fine sands, silty or clayey fine sands |
| D | 0.06 | 0.15 | clay loam<br>silty clay loam<br>sandy clay<br>silty clay<br>clay | GC - clayey gravels, clayey sandy gravels<br>SC - clayey sands, clayey gravelly sands<br>CL - low plasticity clays, sandy or silty clays<br>OL - organic silts and clays of low plasticity<br>CH - highly plastic clays and sandy clays<br>OH - organic silts and clays of high plasticity |

*NOTE that this table has been updated from Version 2.X of the Minnesota Stormwater Manual. The higher infiltration rate for B soils was decreased from 0.6 inches per hour to 0.45 inches per hour and a value of 0.06 is used for D soils (instead of < 0.2 in/hr).

Source: Thirty guidance manuals and many other stormwater references were reviewed to compile recommended infiltration rates. All of these sources use the following studies as the basis for their recommended infiltration rates: (1) Rawls, Brakensiek and Saxton (1982); (2) Rawls, Gimenez and Grossman (1998); (3) Bouwer and Rice (1984); and (4) Urban Hydrology for Small Watersheds (NRCS). SWWD, 2005, provides field documented data that supports the proposed infiltration rates. (view reference list)

[a]This rate is consistent with the infiltration rate provided for the lower end of the Hydrologic Soil Group A soils in the Stormwater post-construction technical standards, Wisconsin Department of Natural Resources Conservation Practice Standards (https://dnr.wi.gov/topic/Stormwater/standards/postconst_standards.html).

[b]The infiltration rates in this table are recommended values for sizing stormwater practices based on information collected from soil borings or pits. A group of technical experts developed the table for the original Minnesota Stormwater Manual in 2005. Additional technical review resulted in an update to the table in 2011. Over the past 5 to 7 years, several government agencies revised or developed guidance for designing infiltration practices. Several states now require or strongly recommend field infiltration tests. Examples include North Carolina, New York, Georgia, and the City of Philadelphia. The states of Washington and Maine strongly recommend field testing for infiltration rates, but both states allow grain size analyses in the determination of infiltration rates. The Minnesota Stormwater Manual strongly recommends field testing for infiltration rate, but allows information from soil borings or pits to be used in determining infiltration rate. A literature review suggests the values in the design infiltration rate table (https://stormwater.pca.state.mn.us/index.php?title=Design_infiltration_rates) are not appropriate for soils with very high infiltration rates. This includes gravels, sandy gravels, and uniformly graded sands. Infiltration rates for these geologic materials are higher than indicated in the table.

References: Clapp, R. B., and George M. Hornberger. 1978. Empirical equations for some soil hydraulic properties. Water Resources Research. 14:4:601–604; Moynihan, K., and Vasconcelos, J. 2014. SWMM Modeling of a Rural Watershed in the Lower Coastal Plains of the United States (https://www.chijournal.org/Journals/PDF/C372). Journal of Water

Management Modeling. C372; Rawls, W.J., D. Gimenez, and R. Grossman. 1998. Use of soil texture, bulk density and slope of the water retention curve to predict saturated hydraulic conductivity Transactions of the ASAE. VOL. 41(4): 983-988; Saxton, K.E., and W. J. Rawls. 2005. Soil Water Characteristic Estimates by Texture and Organic Matter for Hydrologic Solutions. Soil Science Society of America Journal. 70:5:1569-1578.

All bioretention growing media should have a field tested infiltration rate between 1 and 8 inches per hour. Growing media with slower infiltration rates could clog over time and may not meet drawdown requirements. Target infiltration rates should be no more than 8 inches per hour to allow for adequate water retention for vegetation as well as adequate retention time for pollutant removal. Slower rates (2 inches per hour or less) are recommended if the primary pollutant(s) of concern are temperature, total nitrogen or total phosphorus. If the infiltration rate of the growing media has not been field tested, the coefficients of permeability recommended for the Planting Medium / Filter Media Soil is 0.5 feet per day (Claytor and Schueler, 1996). Note: the value is conservative to account for clogging associated with accumulated sediment.

## Step 6. Size outlet structure and/or flow diversion structure, if needed

(Note: Steps 5, 6, 7 and 8 are iterative)

**Warning:** It is *REQUIRED* that an outlet be incorporated into the design of a bioretention practice to safely convey excess stormwater.

## Step 7. Perform groundwater mounding analysis

(Note: Steps 5, 6, 7 and 8 are iterative) Groundwater mounding, the process by which a mound forms on the water table as a result of recharge at the surface, can be a limiting factor in the design and performance of bioretention practices where infiltration is a major design component. A minimum of 3 feet of separation between the bottom of the bioretention practice and seasonally saturated soils (or from the top of bedrock) is *REQUIRED* (5 feet *RECOMMENDED*) to maintain the hydraulic capacity of the practice and provide adequate water quality treatment. A groundwater mounding analysis is *RECOMMENDED* to verify this separation for infiltration designed bioretention practices.

The most widely known and accepted analytical methods to solve for groundwater mounding is based on the work by Hantush (1967) and Glover (1960). The maximum groundwater mounding potential should be determined through the use of available analytical and numerical methods. Detailed groundwater mounding analysis should be conducted by a trained hydrogeologist or equivalent as part of the site design procedure.

## Step 8. Determine pre-treatment volume and design pre-treatment measures

**Warning:** Some form of dry or wet pre-treatment is *REQUIRED* prior to the discharge of stormwater into the bioretention practice, to remove any sediment and fines that may result in clogging of the soils in the sediment basin area.

If a grass filter strip is used, it is *HIGHLY RECOMMENDED* that it be sized using the guidelines in the table below.

**Guidelines for filter strip pre-treatment sizing**
Link to this table

| Parameter | Impervious Parking Lots | Residential Lawns |
|---|---|---|

| Parameter | Impervious Parking Lots | | | | Residential Lawns | | | |
|---|---|---|---|---|---|---|---|---|
| Maximum Inflow Approach Length (ft) | 35 | | 75 | | 75 | | 150 | |
| Filter Strip Slope | =<2% | >2% | =<2% | 2% | =<2% | 2% | =<2% | 2% |
| Filter Strip Minimum Length | 10' | 15' | 20' | 25' | 10' | 12' | 15' | 18' |

**Grass channel sizing**

It is *HIGHLY RECOMMENDED* that grass channel pre-treatment for bioretention be a minimum of 20 feet in length and be designed according to the following guidelines:

- parabolic or trapezoidal cross-section with bottom widths between 2 and 8 feet;
- channel side slopes no steeper than 3:1 (horizontal:vertical);
- flow velocities limited to 1 foot per second or less for peak flow associated with the water quality event storm (i.e., 0.5 or 1.0 inches depending on watershed designation); and
- flow depth of 4 inches or less for peak flow associated with the water quality event storm.

## Step 9. Check volume, peak discharge rates and period of inundation against State, local and watershed management organization requirements

(Note: Steps 5, 6, 7 and 8 are iterative)

Follow the design procedures identified in the Unified sizing criteria section to determine the volume control and peak discharge recommendations for water quality, recharge, channel protection, overbank flood and extreme storm.

Model the proposed development scenario using a surface water model appropriate for the hydrologic and hydraulic design considerations specific to the site (see also Introduction to stormwater modeling). This includes defining the parameters of the bioretention practice defined above: sedimentation basin elevation and area (defines the pond volume), infiltration/permeability rate, and outlet structure and/or flow diversion information. The results of this analysis can be used to determine whether or not the proposed design meets the applicable requirements. If not, the design will have to be re-evaluated (back to Step 5).

The following items are specifically REQUIRED by the MPCA Permit:

**Warning:**

- *Volume* - Infiltration or filtration systems shall be sufficient to infiltrate or filter a water quality volume of 1 inch of runoff from the new impervious surfaces created by the project. If this criterion is not met, increase the storage volume of the bioretention practice or treat excess water quality volume (Vwq) in an upstream or downstream BMP (see Step 5). Retrofit and supplemental systems do not need to meet this requirement, provided new impervious surfaces are not created.
- *Peak Discharge Rates* - Since most bioretention systems are not designed for quantity control they generally do not have peak discharge limits. However outflow must be limited such that erosion does not occur down gradient.
- *Drawdown period* - Bioretention practices shall discharge through the soil or filter media in 48 hours or less. Additional flows that cannot be infiltrated or filtered in 48 hours should be routed to bypass the system through a stabilized discharge point.

Experience has demonstrated that, although the drawdown period is 48 hours, there is often some residual water pooled in the infiltration practice after 48 hours. This residual water may be associated with reduced head, water gathered in depressions within the practice, water trapped by vegetation, and so on. The drawdown period is therefore defined as the time from the high water level in the practice to 1 to 2 inches above the bottom of the facility. This criterion was established to provide the following: wet-dry cycling between rainfall events; unsuitable mosquito breeding habitat; suitable habitat for vegetation; aerobic conditions; and storage for back-to-back precipitation events. This time period has also been called the period of inundation.

Other design requirements may apply to a particular site. The applicant should confirm local design criteria and applicability (see Step 2).

### Step 10. Prepare vegetation and landscaping plan

See Major Design Elements for guidance on preparing vegetation and landscaping management plan.

### Step 11. Prepare operations and maintenance (O&M) plan

See Operations and Maintenance for guidance on preparing an O&M plan.

### Step 12. Prepare cost estimate

See Cost Considerations section for guidance on preparing a cost estimate that includes both construction and maintenance costs.

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# Related pages

- Bioretention terminology (including types of bioretention)
- Overview for bioretention
- Design criteria for bioretention
- Construction specifications for bioretention
- Operation and maintenance of bioretention
- Assessing the performance of bioretention
- Cost-benefit considerations for bioretention
- Calculating credits for bioretention
- Soil amendments to enhance phosphorus sorption
- Summary of permit requirements for bioretention
- Supporting material for bioretention
- External resources for bioretention
- References for bioretention
- Requirements, recommendations and information for using bioretention with no underdrain BMPs in the MIDS calculator
- Requirements, recommendations and information for using bioretention with an underdrain BMPs in the MIDS calculator