

# RECOMMENDATIONS TO OPTIMIZE HYDROLOGIC BIORETENTION PERFORMANCE FOR COLD CLIMATES



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*Water Environment Research Foundation*

*Dakota County Soil and Water Conservation District*

*Emmons & Olivier Resources, Inc.*

*Washington Conservation District*

*Ramsey Washington Metro Watershed District*

## **October 2008**

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# **RECOMMENDATIONS TO OPTIMIZE HYDROLOGIC BIORETENTION PERFORMANCE FOR COLD CLIMATES**

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***October 2008***

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This research was made possible by Water Environment Research Foundation funding and the collective efforts of many dedicated stormwater professionals whose technical expertise guided this study. Our thanks go out to each of them for their special contribution. This study introduced many technical and physical challenges that required extraordinary effort to overcome. Special recognition is given to the members of the project team whose passion to protect and conserve our water resources was demonstrated by meeting those challenges; and cheerfully enduring three years of harsh winter conditions without complaint to further our knowledge of how bioretention systems work under cold climate conditions.

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# RECOMMENDATIONS TO OPTIMIZE HYDROLOGIC BIORETENTION PERFORMANCE FOR COLD CLIMATES



## BACKGROUND

One of the primary tools used in the decentralized approach to urban stormwater management is routing runoff to bioretention systems (rain gardens) integrated into the urban landscape. While the use of bioretention systems as a component of stormwater management is rapidly increasing, the understanding of how these systems perform in the winter has not kept pace, even though cold climate conditions occur in a significant portion of the United States and the world.

Completed in October 2008, the *Hydrologic Bioretention Performance and Design Criteria for Cold Climates* was a three year (2005-2008) Water Environment Research Foundation (WERF) hydrologic research project that explored the movement of water into and through the soil profile of four existing bioretention cells located in the Twin Cities metropolitan area of Minnesota during cold climate conditions. The study collected air temperature, soil temperature, and soil moisture data and conducted simulated snowmelt events to measure the cells individual performance responses under full scale winter conditions.



**Crystal Lake Bioretention Cell  
Burnsville, MN**



**Cottage Grove Bioretention Cell  
Cottage Grove, MN**



**Thompson Lake Bioretention Cell  
St. Paul, MN**



**Stillwater Bioretention Cell  
Stillwater, MN**

# RECOMMENDATIONS TO OPTIMIZE HYDROLOGIC BIORETENTION PERFORMANCE FOR COLD CLIMATES



## BACKGROUND (CONTINUED)

The following summarizes the conclusions of the study:

- 1. Three of the four studied bioretention cells remained hydrologically active during cold climate conditions most of the time. The fourth cell, although infiltrating some water, appeared limited in both warm and cold weather due to its poor draining soils.***

With the exception of the Stillwater cell, which has inherently poor soils, the data indicated the hydrologic performance of the studied cells was characteristically reliable throughout the study. At the Crystal, Thompson and Cottage Grove cells, the entire amount of Direct volume Discharge (DVD) test water used to simulate a snowmelt event was absorbed into the cell within the test period 16 out of 25 tests (64%) clearly indicating these cells were capable of infiltrating water during cold climate conditions most of the time. The Stillwater cell only absorbed the test water volume within the test period 1 out of 7 tests (14%) indicating limited performance most of the time.

- 2. The observed infiltration rates within each cell varied widely during the testing season.***

In the largest sense, the observed performance responses of the bioretention cells were products of the natural cold climate conditions and soil conditions encountered during the study. Winter conditions consist of an ever changing variety of unpredictable weather events that set into motion a complex, interactive relationship between the various factors that drive the hydrologic functions within the bioretention cells. While the overall study data clearly showed the range of observed performance was reflective of the wide range of climate driven influences, the data did not show strong correlations between hydrologic performance and individually measured factors.

The study used the term “observed infiltration rate” to describe the actual measured distance (in inches per hour) a pool of test water, covering a cell bottom, has receded after the cessation of test water being added during a DVD test. It was measured by observing water drawdown from a fixed reference mark versus time beginning when the addition of water ceased. In this fashion, it should be considered as part of the initial wetting stage rather than long-term or sustained infiltration. As used in this study, the observed infiltration rate accounts for the combined influences of surface hydraulic loading rate, filling of the interstitial area and the transmission rate occurring simultaneously across the test pool area. Most importantly, an “observed infiltration rate”, as used in this study, is not equivalent to (or should not be converted into) a “design infiltration rate” commonly used to size infiltration systems. Design infiltration rates are used to predict a sustainable rate of flow based factors such as the least permeable soil layer within five vertical feet of the bottom of an infiltration area. Design infiltration rates are intentionally conservative due to variable (and sometimes unknown) soil conditions and the need for sustainable performance throughout the lifetime of the bioretention facility. The *Minnesota Stormwater Manual* (Chapter 8, page 195) provides guidance for design infiltration rates (MN Stormwater Steering Committee, 2007).

# RECOMMENDATIONS TO OPTIMIZE HYDROLOGIC BIORETENTION PERFORMANCE FOR COLD CLIMATES



## BACKGROUND (CONTINUED)

The range of “observed infiltration rates” spanned from very fast to virtually zero depending on the influencing factors. The Crystal Lake cell recorded the widest range of observed infiltration rates (18.9 to 0.15 in/hr), followed by the Cottage Grove cell (13.2 to 0.30 in/hr), the Thompson Lake cell (4.2 to 1.4 in/hr) and the Stillwater cell (3.7 to 0.20 in/hr). Characteristically, the fastest rates occurred early winter in the testing season and progressively slowed as the tests were completed later in the season toward spring. The data also showed the fastest infiltration rates occur when the soils were warm and dry; the infiltration rates decreased as the soils became colder and wetter. The data indicate that each bioretention cell operated within its own performance range unique to its specific location; however the very fast infiltration rates observed during some tests could not be relied upon for consistency all winter.

Within each bioretention cell, the influencing factors of soil temperature, soil texture and soil moisture combined to affect the observed infiltration rate dramatically. Of the monitored factors, the data indicate that soil temperature had the strongest correlation to performance and soil moisture the weakest. Overall, the data suggest that hydrologic performance was most strongly influenced by the sum of the combined factors. Due to the complex and interrelated nature of those factors, this study was not able to further define or quantify the individual relationship ratios of these factors tied to hydrologic performance and many questions remain.

Anecdotal observations indicated a key component linking these factors is soil texture and the permeability of frost. For example, a combination of cold, wet, and fine textured soils at the Stillwater cell seemed to be more susceptible to concrete frost than the corresponding cold, wet and coarse textured soils at the Crystal cell. The combination of soil moisture and soil temperature was the leading antecedent condition that drove the presence and type of frost. Where cold temperatures met wet soils, concrete frost was most likely to develop. Where soils were frost-free, independent conditions at varying degrees drove hydrologic performance. For instance, bioretention cells with wet soils prior to a simulated runoff event did not perform as well as a cell with antecedent dry soils.

- 3. The bioretention cells that performed well under warm conditions were observed to perform well under cold conditions; and the cell that did not perform well in warm conditions, did not perform well under cold conditions.***

The Crystal, Thompson and Cottage Grove cells had the fastest observed infiltration rates and clearly demonstrated successful operations under cold climate conditions. While the factors which most influenced that success were not well defined by the study, it was apparent these three functioning cells share common characteristics such as free draining granular soils that were observed to perform well under warm climate conditions. Field observations concluded that expanding on the design components that optimize warm climate performance would likely optimize cold climate performance.

That simple finding suggested the best way to optimize performance for cold climate operations is to design, construct and maintain well performing warm climate systems. Further study effort was made to identify the design elements and functional characteristics of the cells that functioned well in both cold and warm conditions and forms the basis of this guidance document.



# RECOMMENDATIONS TO OPTIMIZE HYDROLOGIC BIORETENTION PERFORMANCE FOR COLD CLIMATES



## BACKGROUND (CONTINUED)

### Observed Cold Climate Operations

In comparing the design, construction, maintenance, and functional characteristics of the Crystal, Thompson and Cottage Grove cells, a pattern of common characteristics developed that established the core of the cold climate recommendations provided in this document. In contrast the fourth cell, Stillwater did not share these characteristics.

1. All three cells had sufficient surface area to accommodate its entire design runoff treatment volume within a surface pool less than one foot deep.
2. All three cells were observed to have adequate capacity to infiltrate the volume of runoff received during the interim snowmelt events within a working pool depth between 0.3 feet to 0.6 feet. During the large spring melt event, the cells filled to capacity and bypassed the high flows.
3. Highly permeable, well-draining coarse granular materials (void of fine silts and clays) decreased the duration time of soil saturation to minimize freezing and to restore soil capacity to accommodate future melt events.
4. Investigation of installation methods indicated that efforts were made during the installations to protect the infiltration capacity of the soils, both under and within, the cells to avoid soil compaction, smearing and damage from construction sediment.
5. Regular maintenance was provided in the years following their installations to remove sediment buildup at the inlets, remove debris/weeds and sustain the health of the vegetation within the cells.



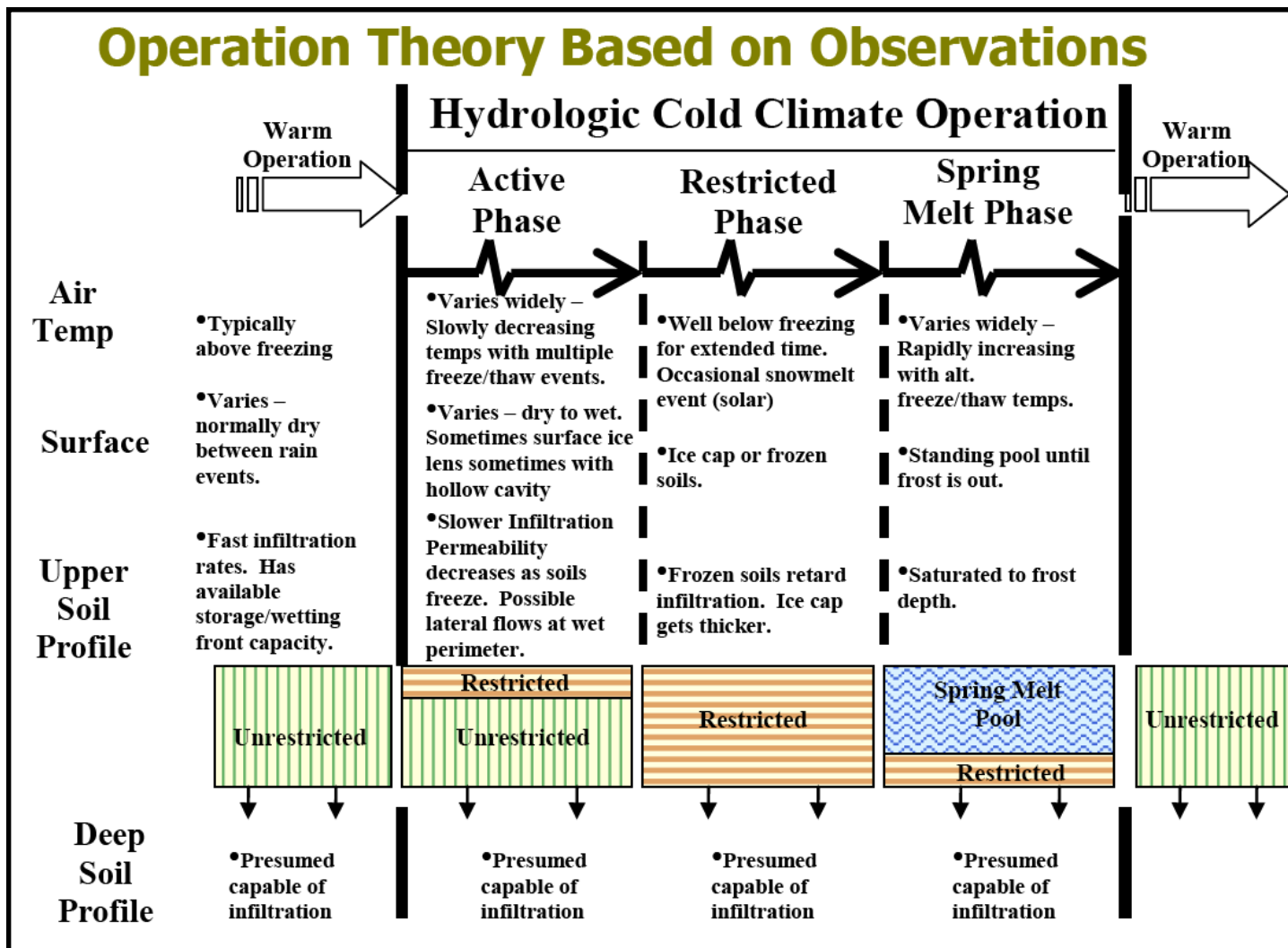
**Low flow during interim melt event**



# RECOMMENDATIONS TO OPTIMIZE HYDROLOGIC BIORETENTION PERFORMANCE FOR COLD CLIMATES



## BACKGROUND (CONTINUED)



Based on field observations, an operational theory of the basic manner in which the bioretention cells operate in cold climate was developed. The graphic represents hydrologic performance phases during cold climate operations and describes the changing factors thought to most influence hydrologic performance. Over the three year study, the Crystal, Thompson and Cottage Grove cells operated within the active phase, at various observed infiltration rates, approximately 84% of the time during the cold climate season. All three cells became occasionally hydrologically restricted during extended periods of air temperatures well below freezing; and all were flooded beyond capacity for brief time periods during large spring snowmelt events.

# RECOMMENDATIONS TO OPTIMIZE HYDROLOGIC BIORETENTION PERFORMANCE FOR COLD CLIMATES



## BACKGROUND (CONTINUED)

Listed in the next section are practical recommendations and technical guidance that can be applied by stormwater professionals who design, construct and maintain bioretention systems operating under cold climate conditions. The list of recommendations are not all inclusive and many other best management practices may be applicable that also may improve performance. The recommendations are not meant to replace the design criteria already in use for warm climates, but rather to supplement those existing criteria with the knowledge gained by the cold climate study to optimize designs for operating in cold climate conditions.

This document presumes the design professionals utilizing the recommendations are proficient in hydrology, stormwater management, water quality issues and are current with low impact development technologies and concepts without further explanation. Therefore, the information supporting each recommendation is presented in a format that only lists brief self-evident statements which spotlight key criteria and design elements in terms easily recognizable by stormwater professionals. The recommendations are organized in the form of a checklist to help designers record which recommendations they implement and identify those they do not.

This document does not duplicate available published information or provide detailed explanation of warm climate bioretention design or operations. The user of this document is advised to refer to Chapter 12-6 Bioretention of the *Minnesota Stormwater Manual (2007)* for that information.

<http://www.pca.state.mn.us/water/stormwater/stormwater-manual.html>

# RECOMMENDATIONS TO OPTIMIZE HYDROLOGIC BIORETENTION PERFORMANCE FOR COLD CLIMATES

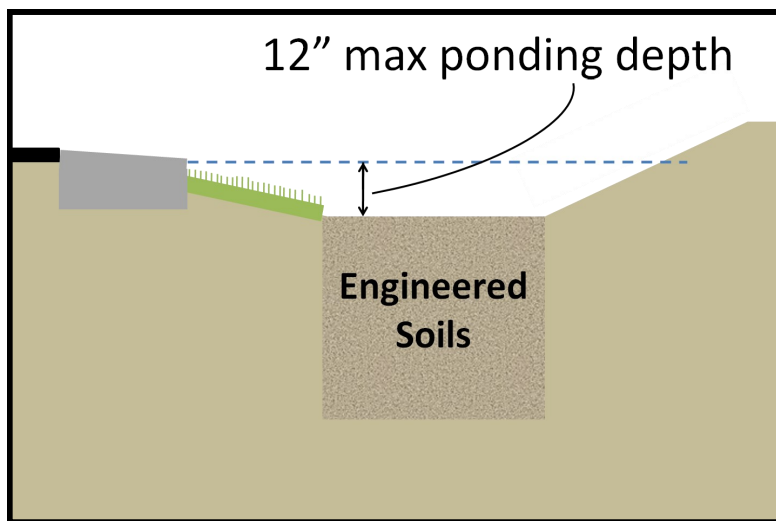


## CELL SIZING

Bioretention cells operating in cold climates should be designed to have sufficient surface area to accommodate its entire designed water quality treatment volume within a surface pool less than one foot deep.

- Bioretention cells should be designed for low flow water quality treatment for runoff resulting from small events. Bioretention cells are not a high flow rate control devices and pool depth should be limited to less than 1 foot.
- Bioretention cells must be sized in compliance with regulatory criteria to treat various applicable water quality treatment requirements.

**Design infiltration rates should not be applied to predict cold climate hydrologic performance. Under cold climate conditions bioretention cells operate within a wide range of infiltration rates that are unpredictable and may reduce to near zero at any time during cold climate conditions.**



**Surface pool depth should be 12" or less and should recede in 12 hours or less to minimize the potential for freezing**

- The range of observed infiltration rates may vary from very fast to nearly zero depending on unpredictable climate conditions.
- Very high rates of infiltration may be observed, particularly during early winter events, but should not be relied upon for consistency all winter.



# RECOMMENDATIONS TO OPTIMIZE HYDROLOGIC BIORETENTION PERFORMANCE FOR COLD CLIMATES



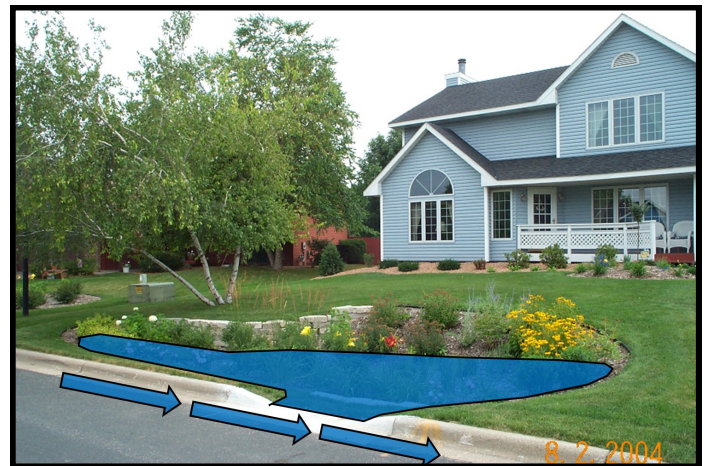
## OFF LINE DESIGN

Cell design should be off-line to bypass high flows.

- Cells that utilize the same entrance and exist flow path upon reaching pooling capacity are considered to be an off-line cell design.
- Cells should be off-line designs that only allow low flow to enter the cell during interim snowmelt events to create a shallow working pool depth that effectively infiltrates into the soils before freezing.
- Cells should be designed to fill to overflow capacity during the large spring melt event and allow the high flows to bypass the cell. High flows should not cross the cell.



Off-line cell design during low flow

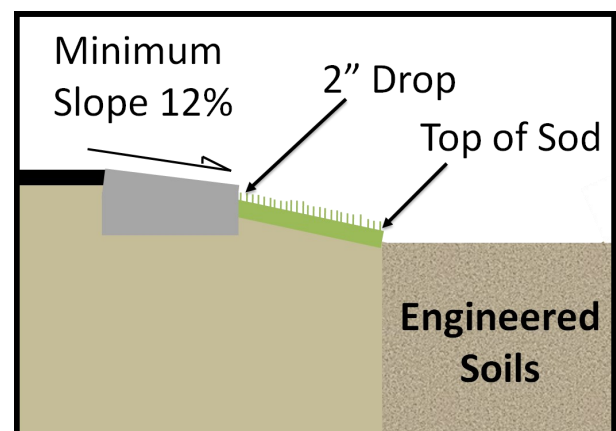


Off-line cell design during high flow

## INLETS

Design the curb-cuts opening to be a least five feet wide and back sloped at least 12% to avoid run by. Adjacent curb inlet castings should be raised at least one inch higher than the gutter flow lines.

- Install grass turf at curb-cuts to filter sediment. Sediment accumulated in turf grass filters can easily be raked out. Avoid difficult to maintain rock inlets.
- The top of sod should be two inches below the lowest point of the curb-cut to minimize ice and debris blockage.
- Stabilize the down-slope inflow path all the way to the lowest point in the cell to minimize erosion.



Curb-cut inlet design

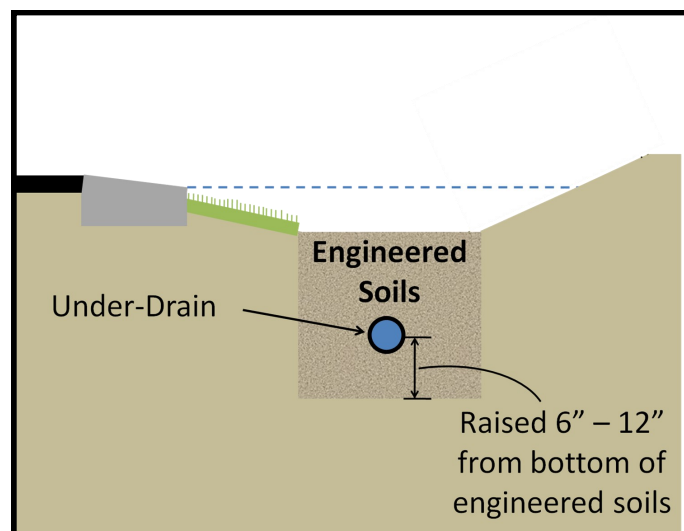
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## UNDER-DRAINS

The installation of an under-drain system with an accessible cap or valve at its outlet is recommended to allow the option of operating the bioretention cell as either an infiltration system (valve closed) or a filtration system (valve open). Residence time for water quality treatment can be managed by adjusting a partially open valve.

- Opening the subdrain valve may allow early-fall drawn down in preparation for freezing weather.
- In cold climate conditions, it is better to open the valve to have a functional filtration system than a non-functional (frozen) infiltration system.



**Design options include a raised under-drain to create a fluctuating aerobic/anaerobic zone to enhance the denitrification process and provide retention storage to reduce total volume discharge**



**Installation of an under-drain system in a bioretention system**



**Accessible under-drain outlet for a bioretention system to adjust residence time within the bioretention cell**



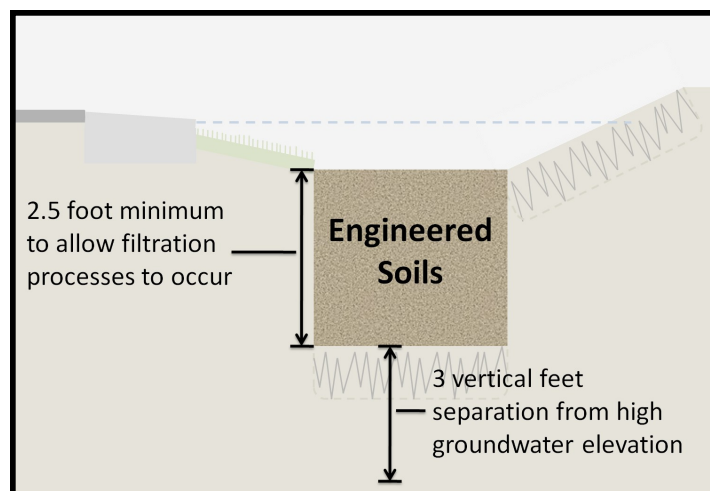
# RECOMMENDATIONS TO OPTIMIZE HYDROLOGIC BIORETENTION PERFORMANCE FOR COLD CLIMATES



## SOILS

Using engineered soils with known permeability and performance characteristics is recommended for cold climate operations. Highly permeable, free draining soil similar to Mix B: Enhanced Filtration Blend performed well. (*Minnesota Stormwater Manual*; <http://www.pca.state.mn.us/water/stormwater/stormwater-manual.html>) The use of existing onsite (in-situ) soils or topsoil blends should only be considered if controlled testing certifies the permeability and performance of those soils is equal to or greater than Mix B engineered soils.

- The use of soils with unknown performance should be avoided. Only a very small percentage of fines or clay has the potential to severely reduce soil performance and increase susceptibility to freezing.
- Engineered soils consisting of coarse wash sand and compost worked well. The *Minnesota Stormwater Manual* (MN Stormwater Steering Committee, 2007) went to great lengths to research soil mixes necessary for successful bioretention operation. The following recommendation resulted from that research:



Engineered soils placement

**Mix B Enhanced Filtration Blend:** A well blended, homogenous mixture of 20-70% construction sand: and 30-50% organic leaf compost is necessary to provide a soil medium with a high infiltration/ filtration capacity.

**Sand:** Provide clean construction sand, free of deleterious materials. AASHTO M-6 or ASTM C-33 with grain size of 0.02” - 0.04”

**Organic Leaf Compost:** Mn/DOT Grade 2

**Note:** Mix A: Water Quality Blend (*Minnesota Stormwater Manual*) is not recommended since its specification allows topsoil with a maximum of 5% clay (based on an ideal of zero clay content) to be used. In reality topsoil of that quality is not available and the field verification of the specification for clay content is difficult.



On site mixing of engineered soils



# RECOMMENDATIONS TO OPTIMIZE HYDROLOGIC BIORETENTION PERFORMANCE FOR COLD CLIMATES



## SOILS (CONTINUED)

Avoid use of fine textured soils containing silt or clay particles within the cell; they infiltrate slowly increasing their susceptibility to freezing. Over-excavation to remove slow draining soils and replacement with engineered soils is strongly recommended.



Example of well-draining, coarse granular material



Fine textured soils can dramatically decrease the rate of infiltration



Installation of engineered soil mixture into excavated bioretention cell.



Avoid construction compaction to protect soil permeability



Engineered soils placement on flat and level excavated cell bottom

### Specification Sources:

Minnesota Stormwater Manual (2007)

<http://www.pca.state.mn.us/water/stormwater/stormwater-manual.html>

MnDOT 2005 Standard Specifications for Construction

<http://www.dot.state.mn.us/pre-letting/spec/>

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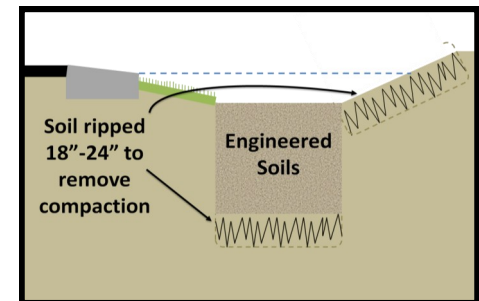
## INSTALLATION

**Avoid reducing the infiltration capability of the underlying soils during installation by avoiding compaction, smearing and damage from construction sediment.**

- Installation should only be done during periods of dry weather. Remove all standing water and mud to avoid mixing with the existing underlying (in-situ) soils. Prevent run-on into excavated cell. Engineered soil placement should be placed on dry soils and completed before the next precipitation event.
- Excavate with a backhoe equipped with a toothed bucket to avoid compacting or smearing the underlying soils.
- The existing underlying (in-situ) soils in the excavated bottom and side slope soils of bioinfiltration cells should be ripped 18 to 24 inches deep to remove compaction prior to placing engineered soil. The first lift of engineered soil should be gently mixed with the loosened in-situ soils to avoid layer stratification and promote permeability.
- The bottom of the excavated cell should be flat and level (not parabolic and/or sloped)
- Care must be taken to avoid contamination of engineered soils during excavation and backfilling operations.
- Construction equipment should not be allowed into the basin area; except that a tracked skid loader may be used for spreading the engineered soil mixture after the first 1.5 feet of engineered soil has been placed in the excavated bottom.
- All stormwater during construction must be diverted until all disturbed soils up gradient of the cell have been stabilized and impervious surfaces cleared of all construction sediments.



**Excess water and sediment should be removed prior to excavation**



**Compaction removed to improve underlying soil permeability**



**Non-functional bioretention cell due to construction sediment damage**



**Bioretention cell with sediment control and blocked inlet to keep the cell off line during establishment**



# RECOMMENDATIONS TO OPTIMIZE HYDROLOGIC BIORETENTION PERFORMANCE FOR COLD CLIMATES



## VEGETATION

- Nursery grown plant plugs or potted plant materials should be used. Basin seeding should be avoided unless the cell is offline for a minimum of 1 year to allow for seedling establishment.
- Plant selection should integrate deep rooted native plant materials to promote infiltration and evapotranspiration.
- Woody vegetation should be avoided near areas that are susceptible to salt spray from vehicular traffic.
- Avoid snow pile storage within the cell to minimize plant damages and depositing the sediment load within the snowpack directly into the cell. Pretreatment filtering to remove sediment is recommended.



## MAINTENANCE

For new bioretention cells, a minimum of one year maintenance should be specified to include watering plants during dry weather periods and control weed growth. After vegetation is well established, yearly maintenance is needed to replace/enhance mulch, replace unhealthy plants and remove accumulated sediment, trash and other debris at inlets.



**Street sweeping and grass turf filter at inlets are recommended to protect bioretention cell from sediment loads transported by snowmelt runoff**