## Swale Main Channel (with underdrain)

A swale main channel with an underdrain behaves similar to a bioretention BMP with an underdrain. Volume retention is achieved through infiltration of water stored in the pore spaces of engineered media between the invert of an elevated underdrain and the native soils. If the underdrain is not elevated above the native soils then volume reduction is achieved through infiltration below the underdrain. Volume retention also occurs by evapotranspiration through the vegetation in the swale. If runoff to the main channel flows over a side slope through sheet flow, a swale side slope BMP should be used in combination with the swale main channel BMP. All pollutants in infiltrated water are removed, while pollutants are removed through filtration for the water that flows through an underdrain.

### MIDS calculator user inputs for swale main channel (with underdrain)

For a swale main channel with underdrain system, the user must input the following parameters to calculate the volume and pollutant load reductions associated with the BMP.

* **Watershed tab**
	+ **BMP Name:** this cell is auto-filled but can be changed by the user.
	+ **Routing/downstream BMP**: if this BMP is part of a treatment train and water is being routed from this BMP to another BMP, the user selects the name of the BMP from the dropdown box to which water is being routed. All water must be routed to a single downstream BMP. Note that the user must include the BMP receiving the routed water in the Schematic tab or the BMP will not appear in the dropdown box.
	+ **BMP Watershed Area:** BMP watershed areas are the areas draining directly to the BMP. Values can be added for four soil types (Hydrologic Soil Groups (HSG) A, B, C, D) and for three Land Cover types (Forest/Open Space, Managed Turf and impervious). The surface area of the BMP should be included as a managed turf land cover under the hydrologic soils group of the native soils located under the BMP. Units are in acres.

If a swale side slope is routed to this BMP, do not include the side slope watershed areas for the swale main channel since this would be double counting the contributing area.

* **BMP Parameters tab**
	+ **Is the underdrain elevated above native soils?:** This is a YES/NO question. Answering YES means that the underdrain is elevated within the media with storage capacity between the underdrain and the native soils. Answering NO means that the underdrain is not elevated within the media and is directly above the native soils with no storage capacity.
* **Channel length (LC):** This is the length of the swale channel from the farthest upstream point to the farthest downstream point. Units are in feet.
* **Swale bottom width (W**B**):** This is the bottom width of the swale main channel. Units are in feet. Based on design restrictions the bottom width cannot be less than 2 feet.
* **Channel slope (S):** This is the slope of the channel. Units are in percent. The slope is calculated by taking the difference between vertical elevations at the upstream and downstream points of the swale and dividing by the horizontal distance between the two locations. The slope therefore represents an average slope over the length of the swale. If the slope varies over the length of a swale, the user should take an average slope over the entire length rather than break the swale into separate smaller lengths. Based on design restrictions, the channel slope cannot be less than 0.5 percent or greater than 4 percent.
* **Total media depth (DM):** This the total depth of the bioretention base from the surface of the engineered media to the native soils. Units are in feet.
* **Depth below underdrain (DU):** This is the depth of the bioretention base from the underdrain invert elevation to the native soils. If the input to “Is the underdrain elevated above native soils” is set to NO, then this value will default to 0 and will become inactive. Units are in feet.
* **Media field capacity minus wilting point (FC-WP):** This is the amount of water between [field capacity](http://stormwater.pca.state.mn.us/index.php/Glossary#F) and the [permanent wilting point](http://stormwater.pca.state.mn.us/index.php/Glossary#W) stored in the media above the underdrain. This is water often considered to be available for uptake by plants. If multiple types of media are used in the BMP, this value should be an average of the media installed above the underdrain. Values for field capacity and wilting point based on soil type can be found [here](http://stormwater.pca.state.mn.us/index.php/Soil_water_storage_properties). The user inputs this value in cubic feet of water per cubic feet of media. The recommended range for this value is 0.05 to 0.17.
* **Media porosity minus filed capacity (*n* - FC)** - This is the ratio of media pore space to the total media volume between the underdrain invert and the bottom of the media (top of native soil). If multiple types of media are used in the BMP, this value should be an average of the media installed between the underdrain and the native soils. Values for porosity and field capacity based on soil type can be found [here](http://stormwater.pca.state.mn.us/index.php/Soil_water_storage_properties). The user inputs this value in cubic feet of pore space per cubic feet of media. The recommended range for this value is 0.15 to 0.35.
* **Planting media mix:** The user selects the type of media mix installed for planting from a predefined list of [Media mixes](http://stormwater.pca.state.mn.us/index.php/Design_criteria_for_bioretention#Materials_specifications_-_filter_media): Media mix A (water quality blend), Media mix B (enhanced filtration blend), Media mix C (North Carolina State University water quality blend), Media mix D, or Other. This value is used to determine the annual phosphorus load reduction credit.
* **Is the P content of the media less than 30 mg/kg?:** This is a YES/NO question. The P content of the planting media should be tested using the [Mehlich 3 test](http://soiltesting.tamu.edu/files/mehlich3.pdf) or an acceptable alternative method. Select YES if the P content of the planting media is less than 30 milligrams per kilogram and NO if it is greater. P content testing is not needed for planting media C or D; therefore, this item will automatically populate to YES if one of those two media types are selected. This value is used to determine the annual phosphorus load reduction credit.
* **Is a soil amendment used to attenuate phosphorus?:** This is a YES/NO question. Answer YES if the bioretention filter media contains [soils amendments to enhance phosphorus sorption](http://stormwater.pca.state.mn.us/index.php/Soil_amendments_to_enhance_phosphorus_sorption) and NO if amendments are not used. This value is used to determine the annual phosphorus load reduction credit.
* **Underlying soil - Hydrologic Soil Group**: The user selects the most restrictive soil (lowest hydraulic conductivity) within 3 feet of the media/soil interface of the swale main channel. There are 14 soil options that fall into 4 different Hydrologic Soil Groups ([Hydrologic Soil Group](http://stormwater.pca.state.mn.us/index.php/Glossary#H) (HSG) A, B, C, or D) for the user. These correspond with soils and infiltration rates contained in [this Manual](http://stormwater.pca.state.mn.us/index.php/Design_infiltration_rates). Once a soil type is selected, the corresponding infiltration rate will populate the “Infiltration rate of underlying soils” field. The user may also select “User Defined.” This selection will activate the “User Defined Infiltration Rate” cell, allowing the user to enter a different value from the values in the predefined selection list. The maximum allowable infiltration rate is 1.63 inches per hour.
* **Required drawdown time**: This is the time in which the stormwater captured by the BMP must drain into the underlying soil. The user may select from predefined values of 48 or 24 hours. The MPCA [Construction Stormwater General Permit](http://www.pca.state.mn.us/index.php/water/water-types-and-programs/stormwater/construction-stormwater/index.html) requires drawdown within 48 hours, but 24 hours is *Highly recommended* when discharges are to a trout stream. The calculator uses the underlying soil infiltration rate and the “Depth below underdrain” to check if the BMP is meeting the drawdown time requirement. The user will encounter an error and be required to enter a new “Depth below underdrain” if the water stored in the BMP cannot drawdown in the required time.
* **BMP Summary Tab:** *The BMP Summary tab* summarizes the volume and pollutant reductions provided by the specific BMP. It details the performance goal volume reductions and annual average volume, dissolved P, particulate P, and TSS load reductions. Included in the summary are the total volume and pollutant loads received by the BMP from its direct watershed, from upstream BMPs and a combined value of the two. Also included in the summary, are the volume and pollutant load reductions provided by the BMP, in addition to the volume and pollutant loads that exit the BMP through the outflow. This outflow load and volume is what is routed to the downstream BMP if one is defined in *the Watershed tab. Finally*, percent reductions are provided for the percent of the performance goal achieved, percent annual runoff volume retained, total percent annual particulate phosphorus reduction, total percent annual dissolved phosphorus reduction, total percent annual TP reduction, and total percent annual TSS reduction.

### Model input requirements and recommendations

The following are requirements for inputs into the MIDS calculator. If the following are not meet an error message will inform the user to change the input to meet the requirement.

* Swale bottom width cannot be less than 2 feet.
* Channel slope cannot be greater than 4 percent or less than 0.5 percent.
* Infiltration rates of the underlying soils are restricted to a maximum of 1.63 inches/hour.
* The water underneath the underdrain must meet the drawdown time requirement specified. The drawdown time requirement is checked by comparing the user defined drawdown time with the calculated drawdown time(DDTcalc) calculated using the following:

$$DDT\_{calc}=\frac{D\_{U}}{I\_{R}/ 12}$$

Where

 DU is the depth below the underdrain (ft); and

 IR is the infiltration rate of the native soils (inches/hr).

If the DDTcalc is greater than the user defined required drawdown time then the user will be prompted to enter a new depth below the underdrain or infiltration rate of the native soils.

### Methodology

#### Required Treatment Volume

“Required treatment volume,” or the volume of stormwater runoff delivered to the BMP, equals the performance goal (1.1 inches or user-specified performance goal) times the impervious area draining to the BMP. This stormwater is delivered to the BMP instantaneously following the [Kerplunk method](http://www.stormh2o.com/SW/Articles/Kerplunk_15253.aspx).

#### Volume Reduction

The volume reduction achieved by a BMP compares the capacity of the BMP to the required treatment volume. The “Volume reduction capacity of BMP [V]” is calculated using BMP inputs provided by the user. For this BMP, the volume reduction credit methodology is determined by the location of the underdrain.

**Underdrain located at BMP bottom**: If the underdrain is located at the bottom of the BMP, then the “Volume reduction capacity of BMP [V]” is determined based on infiltration into the bottom of the BMP (Vinf\_b) and evapotranspiration in the planting media above the underdrain (VET).

Even with an underdrain present, under saturated media conditions some water will infiltrate through the bottom soils as water in the basin draws down. The volume of water lost through the bottom (Vinf\_b) of the BMP equals the following:

$$V\_{Inf\\_B}=I\_{R}\*\left(DDT\right)\*W\_{B}\*L\_{C}/(\frac{12in}{ft})$$

Where

IR is an infiltration rate into the native soils of 0.06 inches per hour;

WB is the width of the main channel (ft);

LC is the channel length(ft); and

DDT is the drawdown time in hours.

The default infiltration rate is set at 0.06 inches per hour to represent a D soil. This rate was selected because it is assumed most of the stormwater will pass through the underdrain before it can infiltrate through the bottom of the BMP. This may be a conservative assumption if underdrains are small, spaced far apart, and the underlying soil has an infiltration rate greater than 0.06 inches per hour. Conversely, more closely spaced or larger underdrains may allow the basin to drain in less than the required drawdown time, resulting in a slight overestimation of infiltration loss through the basin bottom. If the user specifies that an impermeable liner is present at the bottom of the BMP, then no credit is given for infiltration into the bottom soils.

In addition to the credit given for the infiltration below the underdrain, a swale main channel BMP can also achieve stormwater volume reduction through evapotranspiration (VET). The volume of water lost through evapotranspiration (VET) is the smaller of two calculated values, potential ET and measured ET.

* Potential ET (ETpot) is equal to the amount of water stored between [field capacity](http://stormwater.pca.state.mn.us/index.php/Glossary#F) and the [wilting point](http://stormwater.pca.state.mn.us/index.php/Glossary#W) in the media above the underdrain. ETpot is given by

$$ET\_{pot}=\left(\left(D\_{M}-D\_{U}\right)\*(L\_{C}\*W\_{B})\*\left(FC-WP\right)\right)$$

where DM is the total media depth in feet, DU is the depth under the underdrain in feet, LC is the channel length, WB is the channel width, and (FC – WP) is the difference between field capacity and wilting point.

* Measured ET (ETmea) is the amount of water lost to ET as measured using available data. Pan evaporation (PE) measurements collected at the University of Minnesota Southwest Experiment Station at Lamberton, Minnesota were used to estimate an average daily PE (*Source:* Climate of Minnesota Part XII- The Hydrologic Cycle and Soil Water, 1979). A rate of 0.2 inches per day was used, which is an intermediate value between the summertime maximum rate and the lowest rates in October. PE is converted to ET by multiplying by a correction factor of 0.5. Analysis of rainfall patterns indicates that a typical time period between precipitation events is 72 hours in Minnesota. Therefore, a volume loss from ET is calculated over a 3 day period to measure conformance to the MIDS performance goal. Therefore, the measured ET volume equals the media surface area (LC \* WB) in square feet times the daily ET rate in inches per day times 3 days.

$$ET\_{mea}=L\_{C}\*W\_{B}\*0.2\frac{in}{day}\*0.5\*3 days/12 in/ft $$

Measured ET and potential ET are compared and the volume lost to ET is the smaller of the two values.

**Elevated Underdrain:** If the underdrain is elevated above the bottom of the BMP, then the volume reduction credit is determined based on the storage capacity in the media between the underdrain and the native soils and evapotranspiration in the planting media above the underdrain (VET).

The volume captured below the underdrain equals the following:

$$V= L\_{C}\*W\_{B}\*n\*D\_{U}$$

Where

 LC is the channel length (ft);

 WB is the channel width (ft);

 (n-FC) is the media porosity minus the field capacity; and

 DU is the depth below the underdrain (ft).

The stored water must drain within the specified drawdown time. The underlying soil controls the infiltration rate. The user must input the soil with the most restrictive hydraulic conductivity in the 3 feet directly below the basin (i.e. below the bottom of the engineered media).

In addition to the credit given for the storage capacity below the underdrain, a swale main channel system with an elevated underdrain also receives volume reduction credit for evapotranspiration. Credit is given following the same methods described when the underdrain is located at the bottom of the BMP (see discussion above).

The “Volume of retention provided by BMP” is the amount of volume credit the BMP provides toward the performance goal. This value is equal to the “Volume reduction capacity of BMP [V]”, calculated using the above method, as long as the volume reduction capacity is less than or equal to the “Required treatment volume.” If “Volume reduction capacity of BMP [V]” is greater than “Required treatment volume”, then the BMP volume credit is equal to “Required treatment volume.” This check makes sure the BMP is not getting more credit than the amount of water it receives. For example, if the BMP is oversized the user will only receive credit for “Required treatment volume” routed to the BMP.

#### Pollutant Reduction

Pollutant load reductions are calculated on an annual basis. Therefore, the first step in calculating annual pollutant load reductions is converting “Volume reduction capacity of BMP,” which is an instantaneous volume reduction, to an annual volume reduction percentage. This is accomplished through the use of performance curves (add link to addendum) developed from multiple modeling scenarios. The performance curves use “Volume reduction capacity of BMP [V]”, the infiltration rate of the underlying soils, the contributing watershed percent impervious area, and the size of the contributing watershed to calculate a percent annual volume reduction. While oversizing a BMP above “Required treatment volume” will not provide additional credit towards the performance goal volume, it may provide additional pollutant reduction.

A 100 percent removal is credited for all pollutants associated with the reduced volume of stormwater. Stormwater captured by the swale system but not infiltrated or consumed through ET is assumed to flow through the filter media and out the underdrain. A constant 68 percent removal rate is applied to the filtered stormwater for TSS reduction. The removal rates of the filtered stormwater for annual particulate phosphorus and dissolved phosphorus depend on the answers given to the three user inputs: “Planting media mix”, “Is the P content of the media less than 30 mg/kg?” and “Is a soil amendment used to attenuate phosphorus?”

**Particulate Phosphorus:** The particulate phosphorus credit given is either 0 percent or 45 percent depending on the media mix used and the P content of the media.

* If [Media Mix](http://stormwater.pca.state.mn.us/index.php/Construction_specifications_for_bioretention#Materials_specifications_-_filter_media) C or D is used, the annual particulate phosphorus reduction credit is 45 percent of the filtered water volume.
* If a media mix other than C or D is used and the soil phosphorus as measured using the [Mehlich 3 test](http://soiltesting.tamu.edu/files/mehlich3.pdf) or a suitable alternative test is 30 milligrams per kilogram or less, the annual particulate phosphorus reduction credit is 45 percent of the filtered water volume.
* If a media mix other than C or D is used and the soil phosphorus as measured using the [Mehlich 3 test](http://soiltesting.tamu.edu/files/mehlich3.pdf) or a suitable alternative test is greater than 30 milligrams per kilogram, the annual pollutant phosphorus reduction credit is 0 percent of the filtered water volume.
* If a media mix other than C or D is used and the soil phosphorus has not been determined, the annual particulate phosphorus credit is 0 percent of the filtered water volume.

**Dissolved Phosphorus:** The dissolved phosphorus credit given is between 0 percent and 60 percent depending on the media mix, the media P content, and if the media was amended to attenuate phosphorus.

* If Media Mix C or D is used, or if a media mix other than C or D is used and soil phosphorus as measured using the [Mehlich 3 test](http://soiltesting.tamu.edu/files/mehlich3.pdf) or a suitable alternative test is 30 milligrams per kilogram or less, the annual dissolved phosphorus credit applied to the filtered water volume is calculated by

$$credit=20\%\*\frac{(D\_{M}- D\_{U})}{2 ft}$$

where (DM - DU) represents the media depth above the underdrain. The credit is calculated as a percent reduction with a maximum value of 20 percent for media depths above the underdrain greater than 2 feet. If the media depth above the underdrain is less than 2 feet the credit is reduced equivalently.

* If a media mix other than C or D is used and the soil phosphorus as measured using the [Mehlich 3 test](http://soiltesting.tamu.edu/files/mehlich3.pdf) or a suitable alternative test is greater than 30 milligrams per kilogram, the annual dissolved phosphorus credit is 0 percent of the filtered water volume.
* If a media mix other than C or D is used and the soil phosphorus has not been determined, the annual dissolved phosphorus credit is 0 percent of the filtered water volume.
* An additional annual dissolved phosphorus credit of 40 percent of the filtered water volume may be received if [phosphorus-sorbing amendments](http://stormwater.pca.state.mn.us/index.php/Soil_amendments_to_enhance_phosphorus_sorption) are used. Acceptable amendments include the following:
	+ 5 percent by volume elemental iron filings above the internal water storage (IWS) layer or elevated underdrain;
	+ minimum 5 percent by volume sorptive media above IWS layer or elevated underdrain;
	+ minimum 5 percent by weight water treatment residuals (WTR) to a depth of at least 3.9 inches (10 centimeters);
* An additional annual dissolved phosphorus credit commensurate with the research results can be applied if other phosphorus-sorptive amendments are proposed that have supporting third party research results showing dissolved phosphorus reduction for at least a 20-year lifespan.

The removal rates of the filtered stormwater for annual particulate phosphorus and dissolved phosphorus is summarized in the following [table](http://stormwater.pca.state.mn.us/index.php/Phosphorus_credits_for_bioretention_systems_with_an_underdrain).

NOTE: The user can modify event mean concentrations (EMCs) on the ***Site Information*** tab in the calculator. Default concentrations are 54.5 milligrams per liter for total suspended solids (TSS) and 0.3 milligrams per liter for total phosphorus (particulate plus dissolved). The calculator will notify the user if the default is changed. Changing the default EMC will result in changes to the total pounds of pollutant reduced.

### Routing

Overflow from a swale main channel with an underdrain can be routed to any other BMP, except for a green roof and a swale side slope or any BMP in a stormwater treatment sequence that would cause stormwater to be rerouted back to the swale main channel already in the treatment sequence. All BMPs can be routed to the swale main channel

### Assumptions for swale main channel

The following general assumption applies in calculating the credit for a swale main channel with an underdrain. If this assumption is not followed the volume and pollutant reduction credits cannot be applied.

* The swale main channel has been properly [designed](http://stormwater.pca.state.mn.us/index.php/Design_criteria_for_filtration), [constructed](http://stormwater.pca.state.mn.us/index.php/Construction_specifications_for_filtration) and will be properly [maintained](http://stormwater.pca.state.mn.us/index.php/Operation_and_maintenance_of_filtration) according to specifications for filtration systems.

## Images



Symbol for Swale main channel with underdrain in MIDS calculator



BMP watershed area parameters



Screen shot from MIDS calculator showing user inputs needed for a swale main channel with an underdrain.



Schematic showing pollutant load reductions for infiltrated and overflow water