Page Content

Calculating credits for permeable pavement

Download pdf (https://stormwater.pca.state.mn.us/index.php?title=File:Calculating_credits_for_permeable_pavement_-_Minnesota_Stormwater_Manual.pdf)

Warning: Models are often selected to calculate credits. The model selected depends on your objectives. For compliance with the Construction Stormwater permit, the model must be based on the assumption that an instantaneous volume is captured by the BMP.

Green Infrastructure: Permeable pavement can be an important tool for retention and detention of stormwater runoff. Permeable pavement may provide additional benefits, including reducing the need for de-icing chemicals, and providing a durable and aesthetically pleasing surface.

Recommended pollutant removal efficiencies, in percent, for permeable pavement with an underdrain. Sources (http://stormwater.pca.state.mn.us/index.php/Information_on_pollutant_removal_by_BMPs#References). NOTE: removal efficiencies are 100 percent of captured water for systems with no underdrain.

TSS=total suspended solids; TP=total phosphorus; PP=particulate phosphorus; DP=dissolved phosphorus; TN=total nitrogen

TSS	TP	PP	DP	TN	Metals	Bacteria	Hydrocarbons
74	41	74	0	insufficient data	insufficient data	insufficient data	insufficient data

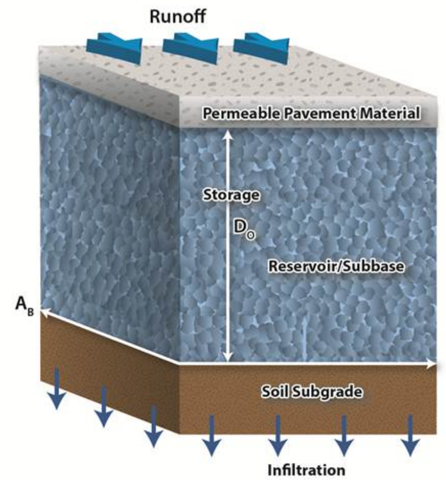
Credit (http://stormwater.pca.state.mn.us/index.php/Overview_of_stormwater_credits) refers to the quantity of stormwater or pollutant reduction achieved either by an individual **best management practice** (BMP) or cumulatively with multiple BMPs. Stormwater credits are a tool for local stormwater authorities who are interested in

- providing incentives to site developers to encourage the preservation of natural areas and the reduction of the volume of stormwater runoff being conveyed to a best management practice (BMP);
- complying with permit requirements, including antidegradation (see Construction permit (https://stormwater.pca.state.mn.us/index.php?title=Construction_stormwater_program); Municipal (MS4) permit (https://stormwater.pca.state.mn.us/index.php?title=Stormwater_Program_for_Municipal_Separate_Storm_Sewer_Systems_(MS4)));
- meeting the MIDS performance goal (http://stormwater.pca.state.mn.us/index.php/Performance_goals_for_new_development,_re-development_and_linear_projects); or

This page provides technical information

meeting or complying with water quality objectives, including **total maximum daily load** (https://stormwater.pca.state.mn.us/index.php?title=Total_Maximum_Daily_Loads_(TMDLs)) (TMDL) **wasteload allocations** (WLAs).

This page provides a discussion of how permeable pavement practices can achieve stormwater credits. Permeable pavement systems with and without underdrains are both discussed, with separate sections for each type of system as appropriate.

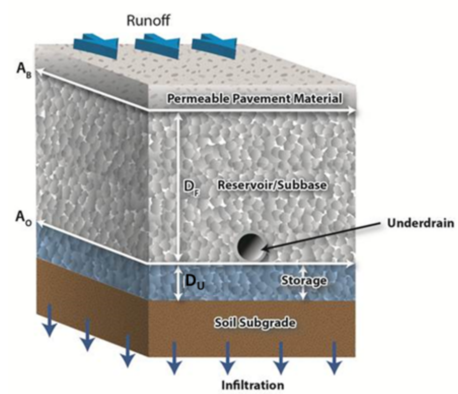


Schematic of a permeable pavement system with no underdrain. Water infiltrating through the pavement is stored in the reservoir/subbase and infiltrates into the underlying soil subgrade within a specified drawdown time, usually 48 hours.

Contents

Overview

Permeable pavements are a stormwater quality practice that allows runoff to pass through surface voids into an underlying stone reservoir/subbase for temporary storage before being discharged to an underdrain and/or underlying soil via infiltration. The most commonly used types of permeable pavement are pervious concrete, porous asphalt, and permeable interlocking concrete pavers.



Schematic of a permeable pavement system with an underdrain. Water infiltrating through the pavement is either captured by the underdrain or stored below the underdrain in the reservoir/subbase, where it infiltrates into the underlying soil subgrade within a specified drawdown time, usually 48 hours.

Pollutant removal mechanisms

Permeable pavement systems with no underdrains provide stormwater pollutant removal by reducing the volume of runoff from a site and the pollutant mass associated with that volume when infiltration is allowed (Water Environment Federation, 2012). In systems with underdrains most of the water is captured by the underdrain after passing through the subbase. If the underdrain is raised above the underlying soil subgrade, water stored in the reservoir/subbase below the underdrain will infiltrate into the underlying soil. If the underdrain is at the bottom of the reservoir/subbase, a small amount of infiltration may occur. Thus, pollutant removal in a permeable pavement system with an underdrain occurs through filtering of water captured by the underdrain and infiltration for water infiltrating into the underlying soil subgrade.

Location in the treatment train

Stormwater Treatment Trains are comprised of multiple Best Management Practices that work together to minimize the volume of stormwater runoff, remove pollutants, and reduce the rate of stormwater runoff being discharged to Minnesota wetlands, lakes and streams. Permeable pavements are installed near the start of the treatment train as a method that directs the stormwater runoff to a subgrade storage area in order to minimize the volume and pollutant mass of stormwater runoff .

Methodology for calculating credits

This section describes the basic concepts and equations used to calculate credits for volume, Total Suspended Solids (TSS) and Total Phosphorus (TP). Specific methods for calculating credits are discussed later in this article. Permeable pavement is also effective at reducing concentrations of other pollutants including nitrogen, metals, bacteria, and hydrocarbons. This article does not provide information on calculating credits for pollutants other than TSS and TP, but references are provided that may be useful for calculating credits for other pollutants.

Assumptions and approach

In developing the credit calculations, it is assumed the permeable pavement practice is properly designed, constructed, and maintained in accordance with the Minnesota Stormwater Manual. If any of these assumptions is not valid, the BMP may not qualify for credits or credits should be reduced based on reduced ability of the BMP to achieve volume or pollutant reductions. For guidance on design, construction, and maintenance, see the appropriate article within the permeable pavement section of the Manual.

Warning: Pre-treatment is required for all filtration and infiltration practices

In the following discussion, the water quality volume (V_{WQ}) is assumed to be delivered instantaneously to the BMP. The V_{WQ} is stored within the reservoir/subbase below the bottom of the pavement and above the soil subgrade. The V_{WQ} can vary depending on the stormwater management objective(s). For construction stormwater, the water quality volume is 1 inch times the new impervious surface area. For MIDS, the V_{WQ} is 1.1 inches times the impervious surface area. In reality, some water will infiltrate through the bottom and sidewalls of the BMP as a rain event proceeds. The instantaneous method therefore may underestimate actual volume and pollutant losses.

The approach in the following sections is based on the following general design considerations.

- Credit calculations presented in this article are for both event and annual volume and pollutant load removals.
- Stormwater volume credit for permeable pavements equates to the volume of runoff that is fully contained within the stone reservoir/subbase that will ultimately be infiltrated into the soil subgrade.
- TSS and TP credits for permeable pavements are achieved for the volume of runoff that is filtered and captured by an underdrain and the volume of water that is ultimately infiltrated.

Volume credit calculations - no underdrain

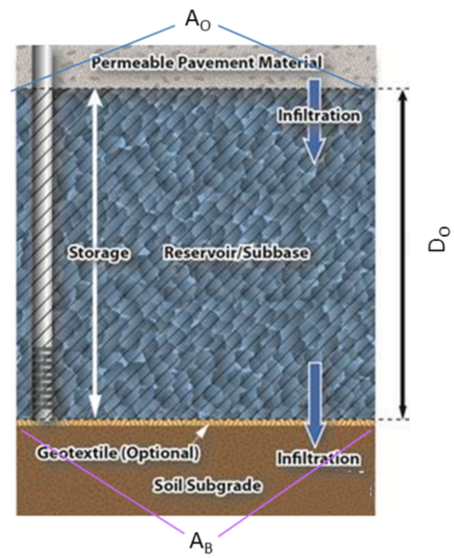
Volume credits are calculated based on the capacity of the BMP and its ability to permanently remove stormwater runoff via infiltration into the underlying soil from the existing stormwater collection system. These credits are assumed to be instantaneous values entirely based on the capacity of the BMP to capture, store, and transmit water in any storm event.

Volume credits for a permeable pavement system are based on the porosity of the subbase and system dimensions, specifically the depth of the reservoir/ subbase, the area of permeable pavement, and the bottom surface area. The volume credit (V_{inf_b}) for infiltration through the bottom of the BMP into the underlying soil, in cubic feet, is given by

$$V_{inf_b} = D_o\ n\ (A_O + A_B)\ /2$$

where

A_O is the overflow surface area of the permeable pavement system, in square feet;
A_B is the depth at the bottom of the permeable pavement system, in square feet;
D_O is the depth of the reservoir/subbase layer (engineered media), equal to the distance from the bottom of the permeable pavement material to the underlying soil subgrade, in feet; and
n is the **porosity (f)** of the reservoir/subbase, in cubic feet per cubic foot.



Schematic showing terminology for calculating volume credits for permeable pavement. A_O is the area at the bottom of the pavement, A_B the area at the reservoir/soil subgrade interface, and D_O the depth or thickness of the reservoir.

The subbase depth should be limited to the **drawdown time**. The construction stormwater general permit (https://stormwater.pca.state.mn.us/index.php?title=Construction_stormwater_program) requires a maximum 48 hour drawdown time (24 hours is recommended for discharges to trout streams). For example, using a **hydrologic soil group (https://stormwater.pca.state.mn.us/index.php?title=Design_infiltration_rates)** B (SM) soil with an infiltration rate of 0.45 inches per hour, the maximum depth is 1.8 feet.

Note that that entire porosity of the subbase layer is used to calculate the volume credit. This slightly overestimates the actual volume infiltrated since some water is held by the media after the runoff infiltrates. The water content after gravity drainage, called **field capacity**, is less than 5 percent of total porosity for a permeable pavement system.

The annual volume captured and infiltrated by the BMP can be determined with appropriate modeling tools, including the MIDS calculator. Example values are shown below for a scenario using the MIDS calculator. For example, a permeable pavement system designed to capture 1 inch of runoff from impervious surfaces will capture 89 percent of annual runoff from a site with B (SM) soils.

Annual volume, expressed as a percent of annual runoff, treated by a BMP as a function of soil and (https://stormwater.pca.state.mn.us/index.php?title=Water_quality_criteria) Water Quality Volume (https://stormwater.pca.state.mn.us/index.php?title=Water_quality_criteria)**. See footnote[1] for how these were determined.**
Link to this table

Soil	Water quality volume (V_{WQ}) (inches)				
	0.5	0.75	1.00	1.25	1.50

Soil	Water quality volume (V_{WQ}) (inches)				
	0.5	0.75	1.00	1.25	1.50
A (GW)	84	92	96	98	99
A (SP)	75	86	92	95	97
B (SM)	68	81	89	93	95
B (MH)	65	78	86	91	94
C	63	76	85	90	93

[1]Values were determined using the MIDS calculator. BMPs were sized to exactly meet the water quality volume for a 2 acre site with 1 acre of impervious, 1 acre of forested land, and annual rainfall of 31.9 inches.

Volume calculations - underdrain

The volume credit (V) for permeable pavement systems with **underdrains**, in cubic feet, is given by

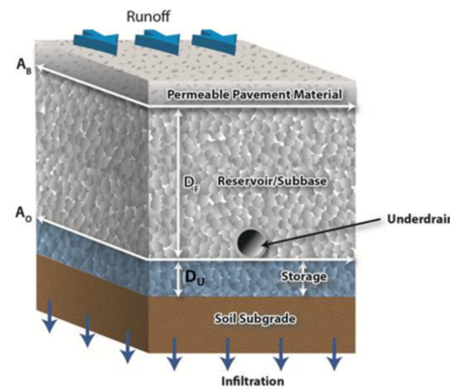
$$V = V_{inf_b} + V_U$$

The infiltrating volume (V_{inf_b}), in cubic feet, is given by

$$V_{inf_b} = A_B DDT I_R / 12$$

where

> A_B is the surface area at the bottom of the underdrain, in square feet;
> DDT is the drawdown time for water stored below the underdrain, in hours; and
> I_R is the **design infiltration rate (https://stormwater.pca.state.mn.us/index.php?title=Design_infiltration_rate_as_a_function_of_soil_texture_for_bioretention_in_Minnesota)** of underlying soil, in inches per hour.



Schematic of a permeable pavement system with an underdrain. Water infiltrating through the pavement is either captured by the underdrain or stored below the underdrain in the reservoir/subbase, where it infiltrates into the underlying soil subgrade within a specified drawdown time, usually 48 hours.

Information: The MIDS calculator assigns a default value of 0.06 inches per hour, equivalent to a D soil, to I_R. This is based on the assumption that most water will drain to the underdrain, but that some loss to underlying soil will occur. A conservative approach assuming a D soil was thus chosen.

The construction stormwater general permit (https://stormwater.pca.state.mn.us/index.php?title=Construction_stormwater_program) requires a maximum 48 hour drawdown time (24 hours is recommended for discharges to trout streams). Note the MIDS calculator (http://stormwater.pca.state.mn.us/index.php/MIDS_calculator) does not provide a volume credit for a permeable pavement system with an underdrain at the bottom.

If the underdrain is raised above the bottom of the BMP (i.e. above the interface between the reservoir/subbase and underlying soil subgrade), water stored below the underdrain will infiltrate. The infiltrating volume (V_U), in cubic feet, is given by

$$V_U = D_u \ n \ (A_U + A_B) \ /2$$

where

> D_u is the depth of the reservoir layer below the underdrain, in feet;
> A_B is the surface area at the bottom of the underdrain, in square feet;
> A_U is the surface area at the bottom of the reservoir layer/subbase, in square feet; and
> n is the porosity of the reservoir/subbase layer, in cubic feet per cubic foot.

The depth below the underdrain should be limited to the **drawdown time**. The construction stormwater general permit (https://stormwater.pca.state.mn.us/index.php?title=Construction_stormwater_program) requires a maximum 48 hour drawdown time (24 hours is recommended for discharges to trout streams). For example, using a **hydrologic soil group (https://stormwater.pca.state.mn.us/index.php?title=Design_infiltration_rates)** C soil with an infiltration rate of 0.2 inches per hour, the maximum depth below the underdrain is 0.8 feet.

Total Suspended Solids (TSS)

The TSS credits available for installation of permeable pavement depend on the design of the storage volume below the pavement and whether the runoff is filtered (through an underdrain), infiltrated, or both. Designs that filter runoff with an underdrain at the bottom of the storage layer are less effective in removing pollutants than infiltration designs. Runoff is filtered while flowing through the permeable pavement and the storage layer and out the underdrain. TSS removal credit of 100 percent is assumed for the infiltrated water. The recommended removal rate for filtered water is 74 percent, based on review of literature.

Removal of TSS by permeable pavement (M_{TSS}), in pounds per event or pounds per year, is given by

$$M_{TSS} = M_{TSS_I} + M_{TSS_F}$$

where

M_{TSS_I} = mass of TSS removed by infiltration (pounds per event or pounds per year); and
M_{TSS_F} = mass of TSS removed by filtration (pounds per event or pounds per year).

The annual TSS credit (M_{TSS_I}) for infiltrated runoff is given by

$$M_{TSS_I} = 2.72\ V_{Annual}\ F_I\ EMC_{TSS}$$

where

V_{Annual} is the annual volume treated by the BMP, in acre-feet;
F_I is the fraction of the total annual volume treated by the BMP that is infiltrated;
EMC_{TSS} = **event mean concentration** of TSS in the runoff, in mg/L; and
Factor of 2.72 used for conversion to pounds.

In a permeable pavement system with an underdrain, some of the water captured by the BMP will enter the underdrain while some will infiltrate below the underdrain. The amount infiltrating depends on several factors, including whether the underdrain is raised above the soil subgrade, the infiltration rate of the underlying soil, and size and spacing of the underdrains. Pollutants in water that enters the underdrain are filtered. The Annual TSS credit for filtered runoff (M_{TSS_F}) is given by

$$M_{TSS_F} = 2.72\ R_{TSS}\ V_{Annual}\ (F_F)\ EMC_{TSS}$$

where

F_F is the fraction of the total volume treated by the BMP that is filtered; and
R_{TSS} is the pollutant removal fraction for filtered water. A value of 0.74 is recommended.

If the permeable pavement is not the upstream most BMP in the treatment train, EMC_{TSS} should be dependent on the M_{TSS} effluent (mg/L) from the next upstream tributary BMP.

The annual volume treated by the BMP can be determined with appropriate modeling tools, including the MIDS calculator. Example values are shown below for a scenario using the MIDS calculator. For example, a permeable pavement system designed to capture 1 inch of runoff from impervious surfaces will capture 89 percent of annual runoff from a site with B (SM) soils. If an underdrain is in the system, this volume will have to be divided into the portion that infiltrates and the portion that is captured by the underdrain. The MIDS calculator can be used to determine these values.

Annual volume, expressed as a percent of annual runoff, treated by a BMP as a function of soil and (https://stormwater.pca.state.mn.us/index.php?title=Water_quality_criteria) Water Quality Volume (https://stormwater.pca.state.mn.us/index.php?title=Water_quality_criteria)**. See footnote[1] for how these were determined.**
Link to this table

Soil	**Water quality volume (V_{WQ}) (inches)**				
	0.5	**0.75**	**1.00**	**1.25**	**1.50**
A (GW)	84	92	96	98	99
A (SP)	75	86	92	95	97
B (SM)	68	81	89	93	95
B (MH)	65	78	86	91	94
C	63	76	85	90	93

[1]Values were determined using the MIDS calculator. BMPs were sized to exactly meet the water quality volume for a 2 acre site with 1 acre of impervious, 1 acre of forested land, and annual rainfall of 31.9 inches.

The event (storm) based TSS credit (M_{TSS_I}) for infiltrated runoff is given by

$$M_{TSS_I} = 2.72\ V_I\ EMC_{TSS}\ /43,560$$

where

V_I is the event-based volume infiltrated by the BMP, in cubic feet, and
a factor of 43,560 is used for conversion of volume from cubic feet to acre-ft.

The storm event based TSS credit (M_{TSS-F}) for filtered runoff is given by

$M_{TSS_F} = R_{TSS}\ 2.72\ V_F\ EMC_{TSS}\ /43560$

where

V_F is the event-based volume filtrated by the BMP, in cubic feet.

Total phosphorus (TP) credit calculations

Similar to TSS, TP reduction credits correspond directly with volume reduction through infiltration and filtration of captured stormwater. The water quality credits available for a permeable pavement system depend on the design of the storage volume below the pavement and whether or not the runoff is filtered (through underdrain) or infiltrated. TP credit is divided into particulate phosphorus (PP) and dissolved phosphorus (DP) removal, respectively making up 55 percent and 45 percent of the total TP credit. Because the volume of infiltrated water (calculated above) is completely removed from the existing system, 100 percent TP credit is assumed for all infiltrated stormwater. Filtered stormwater only receives credit for PP credit, and no credit is given for DP. This approach is consistent with the approach used in the MIDS calculator.

Removal of TP by permeable pavement is given by

$M_{TP} = M_{TP_I}\ + M_{TP_F}$

where

M_{TP} is the annual or event TP removal (lb/yr or lb/event);
M_{TP_I} is the annual or event TP removal from infiltrated runoff (lb/yr or lb/event); and
M_{TP_F} is the annual or event TP removal from filtered water (lb/year or lb/event).

The total annual TP removal for infiltrated runoff is given by

$M_{TP_I} = 2.72\ V_{annual}\ F_I\ EMC_{TP}$

where

V_{annual} is the annual volume treated by the BMP, in acre-feet,
F_I is the fraction of the total annual volume treated by the BMP that is infiltrated,
EMC_{TP} = event mean concentration of TP in the runoff, in mg/L, and
a factor of 2.72 used for conversion to pounds.

In a permeable pavement system with an underdrain, some of the water captured by the BMP will enter the underdrain while some will infiltrate below the underdrain. The amount infiltrating depends on several factors, including whether the underdrain is raised above the soil subgrade, the infiltration rate of the underlying soil, and size and spacing of the underdrains. Pollutants in water that enters the underdrain are filtered. The Annual TP credit for filtered runoff (M_{TP_F}) is given by

$M_{TP_F} = 2.72\ R_{TP}\ V_{Annual}\ F_F\ EMC_{TP}$

where

F_F is the fraction of the total volume treated by the BMP that is filtered; and
R_{TP} is the pollutant removal fraction for filtered water.

The pollutant removal fraction applies only to particulate phosphorus (PP), which is assumed to be 55 percent of total phosphorus (TP). The recommended removal efficiency for PP is 74 percent. Thus, the recommended value for R_{TP} is 0.55 * 0.74 or 0.41. The assumption of 55 percent particulate phosphorus and 45 percent dissolved phosphorus is likely inaccurate for certain land uses, such as industrial, transportation, and some commercial areas. Studies indicate particulate phosphorus comprises a greater percent of total phosphorus in these land uses. It may therefore be appropriate to modify the above equation with locally derived ratios for particulate and dissolved phosphorus. For more information on fractionation of phosphorus in stormwater runoff, link here (https://stormwater.pca.state.mn.us/index.php?title=Event_mean_concentrations_of_total_and_dissolved_phosphorus_in_stormwater_runoff#Ratios_of_particulate_to_dissolved_phosphorus).

If the permeable pavement is not the upstream most BMP in the treatment train, EMC_{TP} should be dependent on the M_{TP} effluent (mg/L) from the next upstream tributary BMP.

The annual volume treated by the BMP can be determined with appropriate modeling tools, including the MIDS calculator. Example values are shown below for a scenario using the MIDS calculator. For example, a permeable pavement system designed to capture 1 inch of runoff from impervious surfaces will capture 89 percent of annual runoff from a site with B (SM) soils. If an underdrain is in the system, this volume will have to be divided into the portion that infiltrates and the portion that is captured by the underdrain. The MIDS calculator can be used to determine these values.

Annual volume, expressed as a percent of annual runoff, treated by a BMP as a function of soil and (https://stormwater.pca.state.mn.us/index.php?title=Water_quality_criteria) Water Quality Volume (https://stormwater.pca.state.mn.us/index.php?title=Water_quality_criteria)**. See footnote[1] for how these were determined.**
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[1]Values were determined using the MIDS calculator. BMPs were sized to exactly meet the water quality volume for a 2 acre site with 1 acre of impervious, 1 acre of forested land, and annual rainfall of 31.9 inches.

The event (storm) event based TP credit (M_{TP_I}) for infiltrated runoff is given by

$$M_{TP_I} = 2.72\ V_I\ EMC_{TP}\ /43,560$$

where

V_I is the event-based volume infiltrated by the BMP, in cubic feet; and
a factor of 43,560 is used for conversion of volume from cubic feet to acre-ft.

The storm event based TP credit (M_{TP-F}) for filtered runoff is given by

$$M_{TP-F} = R_{TP}\ 2.72\ V_F\ EMC_{TP}\ /43560$$

where

V_F is the event-based volume filtered by the BMP, in cubic feet

Example calculations for TSS and TP

NOTE: The MIDS calculator was used for the following examples. The performance goal was changed from the MIDS default of 1.1 inches to 1 inch.

Assume a permeable pavement system is designed to capture and treat 1 inch of runoff from a 1 acre impervious area. Note that in these calculations, the permeable pavement is considered part of the impermeable surface.

For this example, assume a 9000 square foot surface area at the top of the reservoir/subbase, a 9000 square foot area at the reservoir/soil subgrade, an underlying B soil with an infiltration rate of 0.45 inches per hour, a porosity of 0.4 cubic feet per cubic foot, a depth below the underdrain of 1 foot, a TSS EMC of 54.5 milligrams per liter, and a TP EMC of 0.3 milligrams per liter. With this depth below the underdrain, all the water can be infiltrated (3600 cubic feet per event; 2.3446 acre-feet per year). Annual TSS removal, in pounds, is given by

$$2.72(2.3446)(1)(54.5) = 347$$

Annual TP removal is given by

$$2.72(2.3446)(1)(0.3) = 1.91$$

If the depth below the underdrain was 0.5 feet instead of 1 foot, only half of the 1 inch performance goal is infiltrated, corresponding to an annual infiltration volume of 1.60 acre-feet. Note that the relationship between infiltration performance goal and annual volume infiltrated is not linear. The first step is to calculate the infiltration and filtered fractions of total volume captured by the BMP. The infiltrated fraction is 1.60/2.3446 or 0.68, leaving a filtered fraction of 0.32.

Annual TSS removal, in pounds, is given by

$$(2.72(2.3446)(0.68)(54.5)) + ((2.72(2.3446)(0.32)(0.74)(54.5)) = 319$$

The first term in parentheses corresponds with the infiltrated portion and equals about 236.3 pounds. The second term in parentheses corresponds with the filtered portion, having a removal efficiency of 0.74 (74 percent), for a total removal of about 82.3 pounds.

Annual TP removal, in pounds, is given by

$$(2.72(2.3446)(0.68)(0.3)) + ((2.72(2.3446)(0.32)(0.55)(0.74)(0.3)) = 1.55$$

The first term in parentheses corresponds with the infiltrated portion and equals about 1.30 pounds. The second term in parentheses corresponds with the filtered portion, having a particulate P fraction of 0.55, and a removal efficiency of 0.74 (74 percent) for the particulate fraction, for a total removal of about 0.25 pounds.

Methods for calculating credits

This section provides specific information on generating and calculating credits from permeable pavement for volume, Total Suspended Solids (TSS) and Total Phosphorus (TP). Stormwater runoff volume and pollution reductions ("credits") may be calculated using one of the following methods:

1. Quantifying volume and pollution reductions based on accepted hydrologic models
2. The Simple Method and MPCA Estimator
3. MIDS Calculator
4. Quantifying volume and pollution reductions based on values reported in literature
5. Quantifying volume and pollution reductions based on field monitoring

Credits based on models

Warning: The model selected depends on your objectives. For compliance with the Construction Stormwater permit, the model must be based on the assumption that an instantaneous volume is captured by the BMP.

Users may opt to use a water quality model or calculator to compute volume, TSS and/or TP pollutant removal for the purpose of determining credits. The available models described in the following sections are commonly used by water resource professionals, but are not explicitly endorsed or required by the Minnesota Pollution Control Agency. Furthermore, many of the models listed below cannot be used to determine compliance with the Construction Stormwater General permit (https://stormwater.pca.state.mn.us/index.php?title=Construction_stormwater_program) since the permit requires the water quality volume to be calculated as an instantaneous volume.

Use of models or calculators for the purpose of computing pollutant removal credits should be supported by detailed documentation, including:

1. Model name and version
2. Date of analysis
3. Person or organization conducting analysis
4. Detailed summary of input data
5. Calibration and verification information
6. Detailed summary of output data

The following table lists water quantity and water quality models that are commonly used by water resource professionals to predict the hydrologic, hydraulic, and/or pollutant removal capabilities of a single or multiple stormwater BMPs. The table can be used to guide a user in selecting the most appropriate model for computing volume, TSS, and/or TP removal by the BMP. In using this table to identify models appropriate for permeable pavement, use the sort arrow on the table to select Infiltrator BMPs or Filter BMPs, depending on the type of permeable pavement BMP and the terminology used in the model.

Comparison of stormwater models and calculators. Additional information and descriptions for some of the models listed in this table can be found at this link (http://stormwater.pca.state.mn.us/index.php/Available_stormwater_models_and_selecting_a_model). Note that the Construction Stormwater General Permit (https://stormwater.pca.state.mn.us/index.php?title=Construction_stormwater_program) requires the water quality volume to be calculated as an instantaneous volume, meaning several of these models cannot be used to determine compliance with the permit.
Link to this table
Access this table as a Microsoft Word document: File:Stormwater Model and Calculator Comparisons table.docx.

	BMP Category									
Model name	**Constructed basin BMPs**	**Filter BMPs**	**Infiltrator BMPs**	**Swale or strip BMPs**	**Reuse**	**Manu-factured devices**	**Assess TP removal?**	**Assess TSS removal?**	**Assess volume reduction?**	**Comments**
Center for Neighborhood Technology Green Values National Stormwater Management Calculator (https://cnt.org/tools/green-values-calculator)	X	X	X		X		No	No	Yes	Does not compute volume reduction for some BMPs, including cisterns and tree trenches.

	BMP Category									
Model name	**Constructed basin BMPs**	**Filter BMPs**	**Infiltrator BMPs**	**Swale or strip BMPs**	**Reuse**	**Manu-factured devices**	**Assess TP removal?**	**Assess TSS removal?**	**Assess volume reduction?**	**Comments**
CivilStorm (http://www.bentley.com/en-US/Products/CivilStorm/)							Yes	Yes	Yes	CivilStorm has an engineering library with many different types of BMPs to choose from. This list changes as new information becomes available.
EPA National Stormwater Calculator (http://www.epa.gov/nrmrl/wswrd/wq/models/swc/)	X		X		X		No	No	Yes	Primary purpose is to assess reductions in stormwater volume.
EPA SWMM (https://www.epa.gov/water-research/storm-water-management-model-swmm)	X		X		X		Yes	Yes	Yes	User defines parameter that can be used to simulate generalized constituents.
HydroCAD (http://www.hydrocad.net/)	X		X	X			No	No	Yes	Will assess hydraulics, volumes, and pollutant loading, but not pollutant reduction.
infoSWMM (http://www.innovyze.com/products/infoswmm/)	X		X		X		Yes	Yes	Yes	User defines parameter that can be used to simulate generalized constituents.
infoWorks ICM (http://www.innovyze.com/products/infoworks_icm/)	X	X	X	X			Yes	Yes	Yes	
i-Tree-Hydro (http://www.itreetools.org/hydro/index.php)			X				No	No	Yes	Includes simple calculator for rain gardens.
i-Tree-Streets (http://www.itreetools.org/streets/index.php)							No	No	Yes	Computes volume reduction for trees, only.

Model name	BMP Category: Constructed basin BMPs	Filter BMPs	Infiltrator BMPs	Swale or strip BMPs	Reuse	Manu-factured devices	Assess TP removal?	Assess TSS removal?	Assess volume reduction?	Comments
LSPC (https://cfpub.epa.gov/si/si_public_record_Report.cfm?Lab=NERL&dirEntryId=75860&CFID=22884508&CFTOKEN=98267566)	X		X	X			Yes	Yes	Yes	Though developed for HSPF, the USEPA BMP Web Toolkit can be used with LSPC to model structural BMPs such as detention basins, or infiltration BMPs that represent source control facilities, which capture runoff from small impervious areas (e.g., parking lots or rooftops).
MapShed (https://wikiwatershed.org/help/model-help/mapshed/)	X	X	X	X			Yes	Yes	Yes	Region-specific input data not available for Minnesota but user can create this data for any region.
MCWD/MWMO Stormwater Reuse Calculator (http://minnehahacreek.org/sites/minnehahacreek.org/files/Stormwater%20Harvesting%20and%20Reuse%20Model_v2.0.xlsx)					X		Yes	No	Yes	Computes storage volume for stormwater reuse systems
Metropolitan Council Stormwater Reuse Guide Excel Spreadsheet (http://www.metrocouncil.org/Wastewater-Water/Planning/Water-Supply-Planning.aspx)					X		No	No	Yes	Computes storage volume for stormwater reuse systems. Uses 30-year precipitation data specific to Twin Cites region of Minnesota.
MIDS Calculator (http://stormwater.pca.state.mn.us/index.php/MIDS_calculator)	X	X	X	X	X	X	Yes	Yes	Yes	Includes user-defined feature that can be used for manufactured devices and other BMPs.

Model name	BMP Category Constructed basin BMPs	Filter BMPs	Infiltrator BMPs	Swale or strip BMPs	Reuse	Manu-factured devices	Assess TP removal?	Assess TSS removal?	Assess volume reduction?	Comments
MIKE URBAN (SWMM or MOUSE) (http://www.mikebydhi.com/Products/Cities/MIKEURBAN.aspx)	X		X		X		Yes	Yes	Yes	User defines parameter that can be used to simulate generalized constituents.
P8 (http://wwwalker.net/p8/)	X		X	X		X	Yes	Yes	Yes	
PCSWMM (http://www.chiwater.com/Software/PCSWMM/)	X		X		X		Yes	Yes	Yes	User defines parameter that can be used to simulate generalized constituents.
PLOAD (http://water.epa.gov/scitech/datait/models/basins/framework.cfm#models)	X	X	X	X		X	Yes	Yes	No	User-defined practices with user-specified removal percentages.
PondNet (http://wwwalker.net/)	X						Yes	No	Yes	Flow and phosphorus routing in pond networks.
PondPack (http://www.bentley.com/en-US/Products/PondPack)	X		[				No	No	Yes	PondPack can calculate first-flush volume, but does not model pollutants. It can be used to calculate pond infiltration.
RECARGA (http://dnr.wi.gov/topic/stormwater/standards/recarga.html)			X				No	No	Yes	
SHSAM (https://shsam.barr.com/)						X	No	Yes	No	Several flow-through structures including standard sumps, and proprietary systems such as CDS, Stormceptors, and Vortechs systems
SUSTAIN (https://www.epa.gov/water-research/system-urban-stormwater-treatment-and-analysis-integration-sustain)	X	X	X	X	X		Yes	Yes	Yes	Categorizes BMPs into Point BMPs, Linear BMPs, and Area BMPs

Model name	BMP Category: Constructed basin BMPs	Filter BMPs	Infiltrator BMPs	Swale or strip BMPs	Reuse	Manu-factured devices	Assess TP removal?	Assess TSS removal?	Assess volume reduction?	Comments
SWAT (http://swat.tamu.edu/)	X	X	X				Yes	Yes	Yes	Model offers many agricultural BMPs and practices, but limited urban BMPs at this time.
Virginia Runoff Reduction Method (https://swbmp.vwrrc.vt.edu/vrrm/)	X	X	X	X	X	X	Yes	No	Yes	Users input Event Mean Concentration (EMC) pollutant removal percentages for manufactured devices.
WARMF (https://www.epri.com/research/products/3002011868)	X	X					Yes	Yes	Yes	Includes agriculture BMP assessment tools. Compatible with USEPA Basins
WinHSPF (https://www.researchgate.net/figure/The-WinHSPF-interface-available-through-BASINS_fig1_274344576)	X		X	X			Yes	Yes	Yes	USEPA BMP Web Toolkit available to assist with implementing structural BMPs such as detention basins, or infiltration BMPs that represent source control facilities, which capture runoff from small impervious areas (e.g., parking lots or rooftops).
WinSLAMM (http://www.winslamm.com/default.html)	X	X	X	X			Yes	Yes	Yes	
XPSWMM (https://www.innovyze.com/en-us/products/xpswmm)	X		X		X		Yes	Yes	Yes	User defines parameter that can be used to simulate generalized constituents.

The Simple Method and MPCA Estimator

The Simple Method is a technique used for estimating storm pollutant export delivered from urban development sites. Pollutant loads are estimated as the product of **event mean concentration** and runoff depths over specified periods of time (usually annual or seasonal). The method was developed to provide an easy yet reasonably accurate means of predicting the change in pollutant loadings in response to development. Ohrel (http://www.stormwatercenter.net/Library/Practice/13.pdf) (2000) states: "In general, the Simple Method is most appropriate for small watersheds (<640 acres) and when quick and reasonable stormwater pollutant load estimates are required". Rainfall data, land use (runoff coefficients), land area, and pollutant concentration are needed to use the Simple Method. For more information on the Simple Method, see The Simple method to Calculate Urban Stormwater Loads (http://www.stormwatercenter.net/monitoring%20and%20assessment/simple%20meth/simple.htm) or The Simple Method for estimating phosphorus export.

Some simple stormwater calculators utilize the Simple Method (EPA STEPL (https://www.epa.gov/nps/spreadsheet-tool-estimating-pollutant-loads-stepl), Watershed Treatment Model (https://www.stormwatercenter.net/monitoring%20and%20assessment/watershed_treatment_model.htm)). The MPCA developed a simple calculator for estimating load reductions for TSS, total phosphorus, and bacteria. Called the **MPCA Estimator** (http://stormwater.pca.state.mn.us/index.php/Guidance_and_examples_for_using_the_MPCA_Estimator), this tool was developed specifically for complying with the MS4 General Permit TMDL annual reporting requirement (https://stormwater.pca.state.mn.us/index.php?title=2020_MS4_General_Permit_Section_22_Discharges_to_Impaired_Waters_with_a_USEPA-Approved_TMDL_that_includes_an_Applicable_WLA). The MPCA Estimator provides default values for pollutant concentration, **runoff coefficients** (https://stormwater.pca.state.mn.us/index.php?title=Runoff_coefficients_for_5_to_10_year_storms) for different land uses, and precipitation, although the user can modify these and is encouraged to do so when local data exist. The user is required to enter area for different land uses and area treated by BMPs within each of the land uses. BMPs include infiltrators (e.g. bioinfiltration, infiltration basin, tree trench, permeable pavement, etc.), filters (biofiltration, sand filter, green roof), constructed ponds and wetlands, and swales/filters. The MPCA Estimator includes standard removal efficiencies for these BMPs, but the user can modify those values if better data are available. Output from the calculator is given as a load reduction (percent, mass, or number of bacteria) from the original estimated load. Default TSS removal fractions are 0.84 for wet basins and 0.73 for constructed wetlands. Default removal fractions for TP are 0.50 for wet basins and 0.38 for constructed wetlands.

Caution: The MPCA Estimator should not be used for modeling a stormwater system or selecting BMPs.

Because the MPCA Estimator does not consider BMPs in series, makes simplifying assumptions about runoff and pollutant removal processes, and uses generalized default information, it should only be used for estimating pollutant reductions from an estimated load. It is not intended as a decision-making tool.

Download MPCA Estimator here (https://stormwater.pca.state.mn.us/index.php?title=File:MPCA_simple_estimator_version_3.0_March_5_2021.xlsx)

MIDS Calculator

The Minimal Impact Design Standards (MIDS) best management practice (BMP) calculator is a tool used to determine stormwater runoff volume and pollutant reduction capabilities of various low impact development (LID) BMPs. The MIDS calculator estimates the stormwater runoff volume reductions for various BMPs and annual pollutant load reductions for total phosphorus (including a breakdown between particulate and dissolved phosphorus) and total suspended solids (TSS). The calculator was intended for use on individual development sites, though capable modelers could modify its use for larger applications.

Download the MIDS Calculator

The MIDS calculator is designed in Microsoft Excel with a graphical user interface (GUI), packaged as a windows application, used to organize input parameters. The Excel spreadsheet conducts the calculations and stores parameters, while the GUI provides a platform that allows the user to enter data and presents results in a user-friendly manner.

Detailed guidance and examples have been developed for all BMPs in the calculator, including permeable pavement. An overview of individual input parameters and workflows is presented in the MIDS Calculator User Documentation (http://stormwater.pca.state.mn.us/index.php/User%E2%80%99s_Guide).

Credits based on reported literature values

A simplified approach to computing a credit would be to apply a reduction value found in literature to the pollutant mass load or concentration (EMC) of the permeable pavement practice. Concentration reductions resulting from treatment can be converted to mass reductions if the volume of stormwater treated is known.

Designers may use the pollutant reduction values reported in this manual (http://stormwater.pca.state.mn.us/index.php/Information_on_pollutant_removal_by_BMPs) or may research values from other databases and published literature. Designers who opt for this approach should

- select the median value from pollutant reduction databases that report a range of reductions, such as from the International BMP Database (https://bmpdatabase.org/);
- select a pollutant removal reduction from literature that studied a permeable pavement practice with site characteristics and climate similar to the device being considered for credits;
- review the article to determine that the design principles of the studied permeable pavement are close to the design recommendations for Minnesota, as described in this manual (https://stormwater.pca.state.mn.us/index.php?title=Design_criteria_for_permeable_pavement) and/or by a local permitting agency; and
- give preference to literature that has been published in a peer-reviewed publication.

The following references summarize pollutant reduction values from multiple studies or sources that could be used to determine credits. Users should note that there is a wide range of monitored pollutant removal effectiveness in the literature. Before selecting a literature value, users should compare the characteristics of the monitored site in the literature against the characteristics of the proposed permeable pavement practice, considering such conditions as watershed characteristics, permeable pavement practice sizing, soil infiltration rates, and climate factors.

- International Stormwater Best Management Practices (BMP) Database (https://bmpdatabase.org/)
  - Compilation of BMP performance studies
  - Provides values for TSS, Bacteria, Nutrients, and Metals
  - Applicable to grass strips, bioretention, bioswales, detention basins, green roofs, manufactured devices, media filters, porous pavements, wetland basins, and wetland channels
- Updated BMP Removal Efficiencies from the National Pollutant Removal Database (2007) & Acceptable BMP Table for Virginia (http://lshs.tamu.edu/docs/lshs/end-notes/updated%20bmp%20removal%20efficiencies%20from%20the%20national%20pollutant%20re-2854375963/updated%20bmp%20removal%20efficiencies%20from%20the%20national%20pollutant%20removal%20database.pdf)
  - Provides data for several structural and non-structural BMP performance evaluations
- The Illinois Green Infrastructure Study (http://www.epa.state.il.us/green-infrastructure/docs/draft-final-report.pdf)
  - Figure ES-1 summarizes BMP effectiveness
  - Provides values for TN, TSS, peak flows / runoff volumes
  - Applicable to permeable pavements, constructed wetlands, infiltration, detention, filtration, and green roofs
- New Hampshire Stormwater Manual (https://www.des.nh.gov/sites/g/files/ehbemt341/files/documents/2020-01/wd-08-20b.pdf)
  - Volume 2, Appendix B summarizes BMP effectiveness
  - Provides values for TSS, TN, and TP removal
  - Applicable to basins and wetlands, stormwater wetlands, infiltration practices, filtering practices, treatment swales, vegetated buffers, and pre-treatment practices
- Design Guidelines for Stormwater Bioretention Facilities (https://www.wri.wisc.edu/wp-content/uploads/FinalWR03R001.pdf). University of Wisconsin, Madison
  - Table 2-1 summarizes typical removal rates
  - Provides values for TSS, metals, TP, TKN, ammonium, organics, and bacteria
  - Applicable for bioretention
- BMP Performance Analysis (https://www3.epa.gov/region1/npdes/stormwater/tools/BMP-Performance-Analysis-Report.pdf). Prepared for US EPA Region 1, Boston MA.
  - Appendix B provides pollutant removal performance curves
  - Provides values for TP, TSS, and zinc
  - Pollutant removal broken down according to land use
  - Applicable to infiltration trench, infiltration basin, bioretention, grass swale, wet pond, and porous pavement
- Weiss, P.T., J.S. Gulliver and A.J. Erickson. 2005. The Cost and Effectiveness of Stormwater Management Practices: Final Report (http://www.lrrb.org/media/reports/200523.pdf)
  - Table 8 and Appendix B provides pollutant removal efficiencies for TSS and P
  - Applicable to wet basins, stormwater wetlands, bioretention filter, sand filter, infiltration trench, and filter strips/grass swales

Credits based on field monitoring

Field monitoring may be made in lieu of desktop calculations or models/calculators as described. Careful planning is HIGHLY RECOMMENDED before commencing a program to monitor the performance of a BMP. The general steps involved in planning and implementing BMP monitoring include the following.

1. Establish the objectives and goals of the monitoring. When monitoring BMP performance, typical objectives may include the following.
   1. Which pollutants will be measured?
   2. Will the monitoring study the performance of a single BMP or multiple BMPs?
   3. Are there any variables that will affect the BMP performance? Variables could include design approaches, maintenance activities, rainfall events, rainfall intensity, etc.
   4. Will the results be compared to other BMP performance studies?
   5. What should be the duration of the monitoring period? Is there a need to look at the annual performance vs the performance during a single rain event? Is there a need to assess the seasonal variation of BMP performance?
2. Plan the field activities. Field considerations include
   1. equipment selection and placement;
   2. sampling protocols including selection, storage, and delivery to the laboratory;
   3. laboratory services;
   4. health and Safety plans for field personnel;
   5. record keeping protocols and forms; and
   6. quality control and quality assurance protocols
3. Execute the field monitoring
4. Analyze the results

This manual contains the following guidance for monitoring.

- Recommendations and guidance for utilizing monitoring to meet TMDL permit requirements
- Recommendations and guidance for utilizing lake monitoring to meet TMDL permit requirements
- Recommendations and guidance for utilizing stream monitoring to meet TMDL permit requirements
- Recommendations and guidance for utilizing major stormwater outfall monitoring to meet TMDL permit requirements
- Recommendations and guidance for utilizing stormwater best management practice monitoring to meet TMDL permit requirements

The following guidance manuals have been developed to assist BMP owners and operators on how to plan and implement BMP performance monitoring.

Urban Stormwater BMP Performance Monitoring (https://www3.epa.gov/npdes/pubs/montcomplete.pdf)

Geosyntec Consultants and Wright Water Engineers prepared this guide in 2009 with support from the USEPA, Water Environment Research Foundation, Federal Highway Administration, and the Environment and Water Resource Institute of the American Society of Civil Engineers. This guide was developed to improve and standardize the protocols for all BMP monitoring and to provide additional guidance for Low Impact Development (LID) BMP monitoring. Highlighted chapters in this manual include:

- Chapter 2: Developing a monitoring plan. Describes a seven-step approach for developing a monitoring plan for collection of data to evaluate BMP effectiveness.
- Chapter 3: Methods and Equipment for hydrologic and hydraulic monitoring
- Chapter 4: Methods and equipment for water quality monitoring
- Chapters 5 (Implementation) and 6 (Data Management, Evaluation and Reporting)
- Chapter 7: BMP Performance Analysis
- Chapters 8 (LID Monitoring), 9 (LID data interpretation]), and 10 (Case studies).

Evaluation of Best Management Practices for Highway Runoff Control (NCHRP Report 565) (http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rpt_565.pdf)

AASHTO (American Association of State Highway and Transportation Officials) and the FHWA (Federal Highway Administration) sponsored this 2006 research report, which was authored by Oregon State University, Geosyntec Consultants, the University of Florida, and the Low Impact Development Center. The primary purpose of this report is to advise on the selection and design of BMPs that are best suited for highway runoff. The document includes chapters on performance monitoring that may be a useful reference for BMP performance monitoring, especially for the performance assessment of a highway BMP.

- Chapter 4: Stormwater Characterization
  - 4.2: General Characteristics and Pollutant Sources
  - 4.3: Sources of Stormwater Quality data
- Chapter 8: Performance Evaluation
  - 8.1: Methodology Options
  - 8.5: Evaluation of Quality Performance for Individual BMPs
  - 8.6: Overall Hydrologic and Water Quality Performance Evaluation
- Chapter 10: Hydrologic Evaluation
  - 10.5: Performance Verification and Design Optimization

Investigation into the Feasibility of a National Testing and Evaluation Program for Stormwater Products and Practices (https://www.wef.org/globalassets/assets-wef/3---resources/topics/o-z/stormwater/stormwater-institute/wef-stepp-white-paper_final_02-06-14.pdf)

- In 2014 the Water Environment Federation released this White Paper that investigates the feasibility of a national program for the testing of stormwater products and practices. The report does not include any specific guidance on the monitoring of a BMP, but it does include a summary of the existing technical evaluation programs that could be consulted for testing results for specific products (see Table 1 on page 8).

Caltrans Stormwater Monitoring Guidance Manual (Document No. CTSW-OT-13-999.43.01) (http://citeseerx.ist.psu.edu/viewdoc/download;jsessionid=E443A824528FE7FBFF5A2C21D437C3C0?doi=10.1.1.434.8249&rep=rep1&type=pdf)

The most current version of this manual was released by the State of California, Department of Transportation in November 2013. As with the other monitoring manuals described, this manual does include guidance on planning a stormwater monitoring program. However, this manual is among the most thorough for field activities. Relevant chapters include.

- Chapter 4: Monitoring Methods and Equipment
- Chapter 5: Analytical Methods and Laboratory Selection
- Chapter 6: Monitoring Site Selection
- Chapter 8: Equipment Installation and Maintenance
- Chapter 10: Pre-Storm Preparation
- Chapter 11: Sample Collection and Handling
- Chapter 12: Quality Assurance / Quality Control
- Chapter 13: Laboratory Reports and Data Review
- Chapter 15: Gross Solids Monitoring

Optimizing Stormwater Treatment Practices: A Handbook of Assessment and Maintenance (http://stormwaterbook.safl.umn.edu/)

This online manual was developed in 2010 by Andrew Erickson, Peter Weiss, and John Gulliver from the University of Minnesota and St. Anthony Falls Hydraulic Laboratory with funding provided by the Minnesota Pollution Control Agency. The manual advises on a four-level process to assess the performance of a Best Management Practice.

- Level 1: Visual Inspection (https://stormwaterbook.safl.umn.edu/assessment-programs/visual-inspection)
- Level 2: Capacity Testing (https://stormwaterbook.safl.umn.edu/assessment-programs/capacity-testing)
- Level 3: Synthetic Runoff Testing (http://stormwaterbook.safl.umn.edu/assessment-programs/synthetic-runoff-testing)
- Level 4: Monitoring (https://stormwaterbook.safl.umn.edu/assessment-programs/monitoring)

Level 1 activities do not produce numerical performance data that could be used to obtain a stormwater management credit. BMP owners and operators who are interested in using data obtained from Levels 2 and 3 should consult with the MPCA or other regulatory agency to determine if the results are appropriate for credit calculations. Level 4, Monitoring, is the method most frequently used for assessment of the performance of a BMP.

Use these links to obtain detailed information on the following topics related to BMP performance monitoring:

- Water Budget Measurement (https://stormwaterbook.safl.umn.edu/water-budget-measurement)
- Sampling Methods (https://stormwaterbook.safl.umn.edu/sampling-methods)
- Analysis of Water and Soils (https://stormwaterbook.safl.umn.edu/analysis-water-and-soils)
- Data Analysis for Monitoring (https://stormwaterbook.safl.umn.edu/data-analysis)

Other pollutants

Permeable pavements provide removal of sediment (TSS), nutrients (phosphorus and nitrogen), and metals through filtration, infiltration, and soil adsorption. Temperature control occurs in the stone reservoir/subbase and soil subgrade. Phosphorus, metals, and hydrocarbons are adsorbed onto soils within the subgrade. In addition, nutrients such as phosphorus and nitrogen may be biologically degraded.

According to the International Stormwater Database (https://bmpdatabase.org/), studies have shown that permeable pavements are effective at reducing concentration of pollutants including solids, bacteria, metals, and nutrients. A compilation of the pollutant removal capabilities from a review of literature of permeable pavement studies are summarized in the table below.

Relative pollutant reduction from permeable pavement systems for metals, nitrogen, bacteria, and organics.
Link to this table

Pollutant	Constituent	Treatment capabilities[1]
Metals[2]	Cadmium, Chromium, Copper, Zinc, Lead, Nickel	Medium/High
Nitrogen	Total nitrogen, Total Kjeldahl nitrogen	Medium/High
Bacteria	Fecal coliform, e. coli	Insufficient data
Organics		Medium

[1] Low: < 30%; Medium: 30 to 65%; High: >65%

[2] Results are for total metals only

References and suggested reading

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- USEPA. Stormwater Menu of BMPs. Permeable Pavements (http://water.epa.gov/polwaste/npdes/swbmp/Pervious-Concrete-Pavement.cfm). 2009.

Related articles

- Overview for permeable pavement
- Types of permeable pavement
- Design criteria for permeable pavement
- Construction specifications for permeable pavement
- Assessing the performance of permeable pavement
- Operation and maintenance of permeable pavement
- Calculating credits for permeable pavement