Page Content

Calculating credits for stormwater ponds

Page video summary (https://stormwater.pca.state.mn.us/index.php?title=File:Credit_page_descriptions.mp4)

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.

Information: The discussion of credits applies only to wet ponds. Dry ponds do not receive credit for volume or pollutant removal

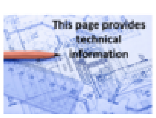
Recommended pollutant removal efficiencies, in percent, for constructed ponds. Sources (http://stormwater.pca.state.mn.us/index.php/Information_on_pollutant_removal_by_BMPs#References).

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

Design level	TSS	TP	PP	DP	TN	Metals	Bacteria	Hydrocarbons
1	60	34	60	0 or 40[1]	30	70	60	80
2	84	50	84	0 or 40[1]	30	70	60	80
3	90	60	90	0 or 40[1]	30	70	60	80

[1] If iron or another amendment to retain phosphorus has been incorporated into the design, the dissolved phosphorus removal is 40 percent. With no amendment, removal is 0 percent. Note that only iron enhanced pond benches are discussed in this manual as a mechanism for retaining dissolved phosphorus. -

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

- 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 constructed basins (**wet pond** (https://stormwater.pca.state.mn.us/index.php?title=Stormwater_ponds) and **stormwater wetland (https://stormwater.pca.state.mn.us/index.php?title=Stormwater_wetlands)**) can achieve stormwater credits.

Contents

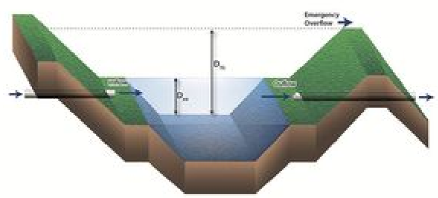
Overview

Information: The discussion of credits applies only to wet ponds. Dry ponds do not receive credit for volume or pollutant removal

Recommended pollutant removal efficiencies, in percent, for constructed wetlands. Sources (http://stormwater.pca.state.mn.us/index.php/Information_on_pollutant_removal_by_BMPs#References).

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

TSS	TP	PP	DP	TN	Metals	Bacteria	Hydrocarbons
73	38	69	0	30	70	60	80



Schematic showing characteristics of a constructed pond or constructed wetland.

Stormwater ponds **(wet pond)** (https://stormwater.pca.state.mn.us/index.php?title=Stormwater_ponds) and **stormwater wetlands (https://stormwater.pca.state.mn.us/index.php?title=Stormwater_wetlands)** are the most common types of constructed basins. Constructed basins have a **permanent pool** of water and are built for the purpose of capturing and storing stormwater runoff. These basins are constructed, either temporarily or in a permanent installation, to prevent or mitigate downstream water quantity and/or quality impacts. Several types of constructed basins and wetlands (stormwater basins, constructed stormwater ponds, wet detention ponds, **forebays (https://stormwater.pca.state.mn.us/index.php?title=Pretreatment_-_Screening_and_straining_devices,_including_forebays)**, wet sedimentation basins, **wet ponds** (https://stormwater.pca.state.mn.us/index.php?title=Stormwater_ponds), constructed wetlands, **stormwater wetlands (https://stormwater.pca.state.mn.us/index.php?title=Stormwater_wetlands)**, etc) are included in this general category. Generally stormwater ponds do not have a significant area of vegetation. Stormwater wetlands do have significant vegetation that enhances the nutrient removal of the basin. Not included in this BMP category are dry basins without a permanent pool. Also not included are **pretreatment** (https://stormwater.pca.state.mn.us/index.php?title=Pretreatment) practices, such as oil/water separators, swirl concentrators, and other manufactured devices, that have a permanent pool of water in the device.

Pollutant Removal Mechanisms

Constructed basins rely on physical, biological, and chemical processes to remove pollutants from incoming stormwater runoff. The primary treatment mechanism is gravitational settling of particulates and their associated pollutants as stormwater runoff resides in the **permanent pool**. Stormwater wetlands provide an additional mechanism for the removal of nutrient and other pollutants through the uptake by algae and aquatic vegetation. **Volatilization** and chemical activity can also occur in both ponds and wetlands, breaking down and assimilating a number of other stormwater contaminants such as hydrocarbons (WEF, ASCE/EWRI, 2012).

The longer stormwater runoff remains in the permanent pool, the more settling (and associated pollutant removal) and other treatment will occur. After the particulates settle to the bottom of a pond, a permanent pool provides protection from re-suspension when additional runoff enters the pond during and after a rain event (WEF, ASCE/EWRI, 2012).

Location in the Treatment Train

Stormwater **treatment trains** (https://stormwater.pca.state.mn.us/index.php?title=Using_the_treatment_train_approach_to_BMP_selection) are comprised of multiple **best management practices** (BMPs) 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. Constructed basins are typically located at the end of the stormwater treatment train, capturing all the runoff from the site.

Methodology for calculating credits

This section describes the basic concepts used to calculate credits for volume, **total suspended solids (https://stormwater.pca.state.mn.us/index.php?title=Total_Suspended_Solids_(TSS)_in_stormwater)** (TSS) and **total phosphorus** (TP). Specific methods for calculating credits (http://stormwater.pca.state.mn.us/index.php/Calculating_credits_for_stormwater_ponds#Methods_for_calculating_credits) are discussed later in this article.

Constructed basins generate credits for TSS and TP. They do not substantially reduce the volume of runoff. Constructed basins are effective at reducing concentrations of other pollutants associated with sediment, including metals 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 (http://stormwater.pca.state.mn.us/index.php/Calculating_credits_for_stormwater_ponds#Other_Pollutants).

Wet pond design levels

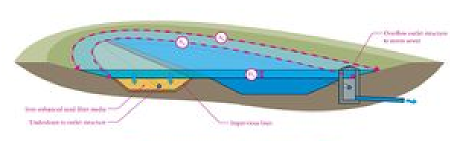
Wet ponds have many potential designs. Credits vary with design. Below are minimum requirements for three design levels used to credit constructed wet ponds.

- Design Level 1: must meet the following criteria
  - Dead (or permanent) storage of at least 1800 cubic feet per acre (=1/2 inch of impervious area) that drains to the pond
  - The pond's permanent storage volume must reach a minimum depth of at least 3 feet and must have no depth greater than 10 feet. The basin must be configured such that scour or resuspension of solids is minimized.
  - **Flow path** length to pond width ratio less than 1:1 or greater than 10:1 (scouring occurs at ratios greater than 10:1)
- Design Level 2: Meets all of the requirements for Design Levels 1 and 2 (except flow path) and does not meet all design requirements for Design Level 3
  - **Water Quality Volume** (https://stormwater.pca.state.mn.us/index.php?title=Water_quality_criteria) (flood pool volume) >= 1 inch of impervious area
  - Discharge rate of water quality volume does not exceed 5.66 cubic feet per second per acre of surface area of the pond.
  - Flow path length to pond width ratio = 1:1 to 3:1. A ratio of 3:1 is recommended.
- Design Level 3: Must meet all of the following design requirements
  - Discharge rate of water quality volume does not exceed 5.66 cubic feet per second per acre of surface area of the pond
  - Water quality volume (flood pool volume) > 1.5 inch of impervious area
  - Wet extended detention or multi-cell system
  - Sediment forebay at all major inflows
  - Flow path length to pond width ratio 3:1 to 10:1

Iron-enhanced sand filtration bench in wet ponds

An iron-enhanced sand filtration bench in a wet pond is essentially a wet extended detention pond with a permanent pool and a flood pool. The outlet structure of the pond is designed such that the water in the flood pool during and after a storm event is held above the elevation of the iron-enhanced sand filter bench, thereby allowing water to filter through the bench. The basic design elements of an iron-enhanced sand filter basin include the following.

Iron enhanced sand bench, Prior Lake, MN. Photo courtesy of Ross Bintner.



Iron-enhanced sand filter bench schematic.

- An iron-enhanced sand filter of desired width and length sited along the perimeter of the wet pond (iron-enhanced sands filters should be no less than 5 percent but no greater than 8 percent iron by weight to prevent clogging, see Erickson et al., 2010 (http://purl.umn.edu/115602) and Erickson et al., 2012 (https://www.researchgate.net/publication/223963903_Capturing_phosphates_with_iron_enhanced_sand_filtration). The 5 to 8 percent range is based upon iron filing material that is approximately 90 percent elemental iron with a size distribution approximately equal to that of **C-33 sand (https://www.google.com/search?q=astm+c33+pdf&sxsrf=ALiCzsZbiP07RhAm7slFtquulY-VE-7w1A%3A1652959846603&ei=ZiqGYqSyJJu6tQa6xrqYBg&oq=c33+sand&gs_lcp=Cgdnd3Mtd2l6EAEYBjIHCAAQRxCwAzIHCAAQRxCwAzIHCAAQRxCwAzIHCAAQRxCwAzIHCAAQRxCwAzIKCAAQRxCwAxDJAzIHCAAQRxCwAzIHCAAQRxCwAzIHCAAQRxCwAzIHCAAQsAMQQ0oECEEYAEoECEYYAFAAWABguS5oAXABeACAAQCIAQCSAQCYAQDIAQnAAQE&sclient=gws-wiz)** sand.
- An outlet structure that controls the flood pool elevation and can receive the filter bed drain.
- Subsurface drains at the filter bed bottom to drain the bed. The outlet of these subsurface drains should be exposed to the atmosphere and above the downstream high water level to allow the filter to fully drain.
- An impervious barrier (typically geotextile liner (http://stormwater.pca.state.mn.us/index.php/Liners_for_stormwater_management), for example HDPE) between the pond and the trench to minimize seepage from the pond into the trench.

- Filter draw down within 48 hours of storm completion to avoid filter fouling and to prepare the filter for next storm event.
- An **underdrain** that consists of corrugated polyethylene pipe with slits not holes to prevent loss of sand and minimize clogging. If holes are used, the pipe should be covered with pea gravel.

Assumptions and approach

In developing the credit calculations, it is assumed the constructed basin 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 pollutant reductions. For guidance on design, construction, and maintenance, see the appropriate article within the Manual (pond design (http://stormwater.pca.state.mn.us/index.php/Design_criteria_for_stormwater_ponds), construction (http://stormwater.pca.state.mn.us/index.php/Construction_specifications_for_stormwater_ponds), maintenance (http://stormwater.pca.state.mn.us/index.php/Operation_and_maintenance_of_stormwater_ponds); wetland design (http://stormwater.pca.state.mn.us/index.php/Design_criteria_for_stormwater_wetlands), construction (http://stormwater.pca.state.mn.us/index.php/Construction_specifications_for_stormwater_wetlands), maintenance (https://stormwater.pca.state.mn.us/index.php?title=Operation_and_maintenance_(O%26M)_of_stormwater_treatment_wetland_practices)).

Ponds constructed under the Construction Stormwater General Permit (http://stormwater.pca.state.mn.us/index.php/Construction_stormwater_permit) (CGP) must meet the following conditions.

- It is REQUIRED in the CGP (http://www.pca.state.mn.us/index.php/water/water-types-and-programs/stormwater/construction-stormwater/index.html) that the water quality volume (V_{wq}) is discharged at no more than 5.66 cubic feet per second per acre surface area of the pond.
- The REQUIRED total storage volume (V_{ts}) equals the sum of the volume in the permanent pool (V_{pp} below the outlet elevation) plus live storage allocation for water quality volume (V_{wq}). V_{wq} equals 1.0 inch of runoff per impervious acre.
- If the pond is being designed as a wet detention pond for new construction under the MPCA CGP Permit, then a permanent pool volume (V_{pp}) equal to 1,800 cubic feet for each acre draining to the pond is REQUIRED.
- It is REQUIRED in the CGP (http://www.pca.state.mn.us/index.php/water/water-types-and-programs/stormwater/construction-stormwater/index.htm) that permanent pool depths be a minimum of 3 feet and maximum of 10 feet at the deepest points.
- It is REQUIRED in the CGP (http://www.pca.state.mn.us/index.php/water/water-types-and-programs/stormwater/construction-stormwater/index.htm) that the riser be located so that short-circuiting between inflow points and the riser does not occur.
- The constructed basin must be situated outside of surface waters and any buffer required under Appendix A, Part C.3 (http://stormwater.pca.state.mn.us/index.php/APPENDIX_A#C._ADDITIONAL_BMPS_FOR_SPECIAL_WATERS_AND_IMPAIRED_WATERS)

If any of these assumptions are not valid, the credit will be reduced.

Volume credit calculations

Constructed basins provide pollutant removal associated with settling of particulates normally present in stormwater runoff, and serve the purpose of reducing peak stormwater flows for channel protection and overbank flood control. Pollutant removal is accomplished by the maintenance of a **permanent pool** of water that serves to both settle and store the particulates. The necessity of the permanent pool negates the ability to infiltrate runoff; therefore ***no volume credit is obtained for basins and wetlands***.

Total suspended solids (TSS) calculations

Constructed basins provide pollutant removal associated with settling of particulates normally present in stormwater runoff. No credits associated with volume reduction are available.

The event-based TSS credit for constructed basins, M_{TSS} in pounds, is given by

$$M_{TSS} = 0.0000624\ R_{TSS}\ EMC_{TSS}\ V_{pp}$$

where

R_{TSS} is the TSS removal fraction for the constructed basin;
EMC_{TSS} is the **event mean concentration** of TSS in runoff, in milligrams per liter;
V_{pp} is the volume treated by the BMP, in cubic feet; and
0.0000624 is a conversion factor.

TSS removal for constructed ponds and wetlands varies with the design (https://stormwater.pca.state.mn.us/index.php?title=Calculating_credits_for_stormwater_ponds#Wet_pond_design_levels).

Constructed ponds

- Design Level 1 TSS removal = 60%
- Design Level 2 TSS removal = 84%
- Design Level 3 TSS removal = 90%

Design Level 2 is the most common design level, with a median removal of 84 percent

Constructed wetlands: median removal rate of 73 percent.

For a discussion of the principles of sedimentation, see Weiss et al. (https://stormwaterbook.safl.umn.edu/sedimentation-practices).

The **Water Quality Volume** (https://stormwater.pca.state.mn.us/index.php?title=Water_quality_criteria) (V_{WQ}), which is equivalent to V_{pp}, is delivered as an **instantaneous volume** to the BMP. 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 (https://stormwater.pca.state.mn.us/index.php?title=Minimal_Impact_Design_Standards), the V_{WQ} is 1.1 inches times the new impervious surface area.

The annual TSS credit, in pounds, is given by

$$M_{TSS} = 2.72\ R_{TSS}\ EMC_{TSS}\ F\ V_{annual}$$

where

F is the fraction of annual runoff treated by the BMP,
V_{annual} is annual runoff in acre-feet, and
2.72 is a conversion factor.

For a constructed pond or wetland, the fraction of annual runoff treated by the BMP is assumed to be 1, meaning all runoff from the **contributing drainage area (https://stormwater.pca.state.mn.us/index.php?title=Contributing_drainage_area_to_stormwater_BMPs)** passes through and is treated by the BMP.

Example calculation

Assume a constructed pond is designed to treat 5 acres of impervious surface and 5 acres of forested land on B (SM) soils. The TSS concentration in runoff is 54.5 milligrams per liter. Annual runoff, calculated using the MIDS calculator, is 11.72 acre-feet. The annual TSS reduction is 2.72 * 0.84 * 54.5 * 11.72 = 1459 pounds. If the BMP was a constructed wetland instead of a constructed pond, the removal efficiency would be 0.73 instead of 0.84 and the TSS reduction would be 1268 pounds.

Total phosphorus (TP) calculations

Constructed basins provide pollutant removal associated with settling of particulates normally present in stormwater runoff. No credits associated with volume reduction are available.

In the Minimal Impact Design Standards (MIDS) Calculator (https://stormwater.pca.state.mn.us/index.php?title=MIDS_calculator), phosphorus in runoff is assumed to be 55 percent **particulate phosphorus** (PP) and 45 percent **dissolved phosphorus** (DP). Using these values, the event-based TP removal, M_{TP} in pounds, is given by

$$M_{TP} = 0.0000624\ ((0.55\ R_{PP})\ + (0.45\ R_{DP}))\ EMC_{TP}\ V_{pp}$$

where

- R_{PP} is the removal fraction for particulate phosphorus;
- R_{DP} is the removal fraction for dissolved phosphorus; and
- EMC_{TP} is the event mean concentration for total phosphorus in runoff, in milligrams per liter.

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).

For wet ponds, removal rates for PP and DP vary with design level. Assuming PP removal is 55% of TP, the removal rates are given below.

- Design Level 1 removal rates: DP = 0%, PP =60%, TP = 34%
- Design Level 2 removal rates: DP = 8%, PP = 84%, TP = 50%
- Design Level 3 removal rates: DP = 23%, PP = 90%, TP = 60%

The MIDS Calculator gives no credit for DP unless an amendment to retain phosphorus (https://stormwater.pca.state.mn.us/index.php?title=Soil_amendments_to_enhance_phosphorus_sorption) is incorporated into the pond design. Data from the International BMP Database (https://bmpdatabase.org/) indicates constructed basins with no P-retaining amendment typically provide no credit for DP. Information on phosphorus removal fractions (percentages) can be found here (http://stormwater.pca.state.mn.us/index.php/Information_on_pollutant_removal_by_BMPs). PP removal rates for pond Design Level 2, the most common design, are 0.84 for constructed ponds and 0.69 for constructed wetlands.

Assuming PP is 55 percent of TP, the annual TP credit, in pounds, is given by

$$M_{TP} = 2.72\ ((0.55\ R_{PP})\ + (0.45\ R_{DP}))\ EMC_{TSS}\ F\ V_{annual}$$

where

- F is the fraction of annual runoff treated by the BMP;

- V_{annual} is annual runoff in acre-feet; and
- 2.72 is a conversion factor.

For a constructed pond or wetland, the fraction of annual runoff treated by the BMP is assumed to be 1, meaning all runoff from the contributing area passes through and is treated by the BMP.

Example calculation

Assume a 10 acre site with 5 acres of impervious and 5 acres of forested land. Annual rainfall is 31.9 inches and the soil is B (SM) with an infiltration rate of 0.45 inches per hour. The TP EMC is 0.3 milligrams per liter and the removal efficiency of the BMP for particulate phosphorus is 0.85. No dissolved phosphorus is removed. The MIDS calculator was used to calculate an annual runoff of 11.72 acre-feet delivered to the BMP. The annual TP reduction is therefore

2.72 * ((0.55 * 0.84) + (0.45 * 0)) * 0.3 * 11.72 = 4.42 pounds

If the BMP was a constructed wetland the removal efficiency for particulate phosphorus would be 0.68 instead of 0.85 and the total phosphorus removed would be 3.58 pounds.

Methods for calculating credits

This section provides specific information on generating and calculating credits from constructed basins for total suspended solids (TSS) and total phosphorus (TP). Stormwater runoff pollution reductions ("credits") may be calculated using one of the following methods:

1. Quantifying volume and pollution reductions based on accepted hydrologic/hydraulic 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

The techniques described in this article assume that volume credit cannot be obtained for stormwater ponds and wetlands. This is based on an overall assumption that ponds and wetlands have insignificant losses related to seepage, evaporation, and transpiration. Stormwater pond and wetland designers that suspect significant volume losses from a specific BMP are encouraged to quantify these volume losses through field measurements.

Ponds and wetlands are also effective at reducing concentrations of other pollutants including nitrogen and metals. This article does not provide information on calculating credits for pollutants other than TSS and phosphorus, but references are provided that may be useful for calculating credits for other pollutants; see Other Pollutants and References for more information.

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 for stormwater ponds and wetlands. The available models described in this section are commonly used by water resource professionals, but are not explicitly endorsed or required by the Minnesota Pollution Control Agency.

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

- Model name and version
- Date of analysis
- Person or organization conducting analysis
- Detailed summary of input data
- Calibration and verification information
- 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 for constructed basin BMPs. In using this table to identify models appropriate for constructed ponds and wetlands, use the sort arrow on the table and sort by *Constructed Basin BMPs*. Models identified with an *X* may be appropriate for using with constructed basins.

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.

Model name	BMP Category						Assess TP removal?	Assess TSS removal?	Assess volume reduction?	Comments
	Constructed basin BMPs	Filter BMPs	Infiltrator BMPs	Swale or strip BMPs	Reuse	Manu-factured devices				
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.
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						Assess TP removal?	Assess TSS removal?	Assess volume reduction?	Comments
	Constructed basin BMPs	Filter BMPs	Infiltrator BMPs	Swale or strip BMPs	Reuse	Manu-factured devices				
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.

	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**
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						Assess TP removal?	Assess TSS removal?	Assess volume reduction?	Comments
	Constructed basin BMPs	Filter BMPs	Infiltrator BMPs	Swale or strip BMPs	Reuse	Manu-factured devices				
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 General Permit TMDL annual reporting requirement (https://stormwater.pca.state.mn.us/index.php?title=Forms,_guidance,_and_resources_for_completing_the_TMDL_annual_report_form). 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 BMPs, including constructed ponds and constructed wetlands. 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.

Minimal Impact Design Standards
for enhancing stormwater management in Minnesota

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 has been developed for all BMPs in the calculator, including constructed ponds (http://stormwater.pca.state.mn.us/index.php/Requirements,_recommendations_and_information_for_using_stormwater_pond_as_a_BMP_in_the_MIDS_calculator) and constructed wetlands (http://stormwater.pca.state.mn.us/index.php/Requirements,_recommendations_and_information_for_using_stormwater_wetland_as_a_BMP_in_the_MIDS_calculator.). 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 constructed pond or constructed wetland device. A more detailed explanation of the differences between mass load reductions and concentration (EMC) reductions can be found on the pollutant removal page (http://stormwater.pca.state.mn.us/index.php/Information_on_pollutant_removal_by_BMPs#Recommended_Performance_Measures).

Designers may use the pollutant reduction values in the Minnesota Stormwater Manual 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 stormwater pond or wetland device with site characteristics and climate similar to the device being considered for credits;
- when using data from an individual study, review the article to determine that the design principles of the studied stormwater pond or wetland are close to the design recommendations (https://stormwater.pca.state.mn.us/index.php?title=Design_criteria_for_stormwater_ponds) for Minnesota

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 stormwater pond, considering such conditions as watershed characteristics, pond sizing, and climate factors.

- International Stormwater Best Management Practices (BMP) Database Pollutant Category Summary Statistical Addendum: TSS, Bacteria, Nutrients, and Metals (https://bmpdatabase.org/)
  - Compilation of BMP performance studies published through 2011
  - 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 (page 9) 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
- 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 Zn
  - Pollutant removal broken down according to land use
  - Applicable to infiltration trench, infiltration basin, bioretention, grass swale, wet pond, and porous pavement
- Watershed Protection Techniques, Technical Note #114. Pollutant Removal Dynamics of Three Wet Ponds in Canada (http://www.stormwatercenter.net/Practice/75-Pollutant%20Removal.pdf). 2000
  - Provides values for TSS, phosphorus, nitrogen, metals, bacteria, pentachlorophenol and oil/grease
  - Applicable to wet ponds
- 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
- Semadeni-Davies, Annette. "Winter performance of an urban stormwater pond in southern Sweden." Hydrological processes 20.1 (2006): 165-182
  - Provides removal efficiencies in cold-weather climates for TSS and metals, and reports influent/effluent vales of pH
  - Applicable to stormwater ponds

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)

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

In addition to TSS and phosphorus, constructed basins can reduce loading of other pollutants. According to the International Stormwater Database (https://bmpdatabase.org/), studies have shown that constructed basins are effective at reducing concentration of pollutants, including nutrients, metals, bacteria, cyanide, oils and grease, Volatile Organic Compounds (VOC), and Biological Oxygen Demand (BOD). A compilation of the pollutant removal capabilities from a review of literature are summarized below.

Other Pollutants Reduced by Constructed Basins: Stormwater Ponds
Link to this table

Pollutant Category	Constituent	Treatment Capabilities (Low = < 30%; Medium = 30-65%; High = 65 -100%)
Metals[1, 2]	Cd, Cr, Cu, Zn As, Fe, Ni, Pb	Medium/High
Nutrients	Total Nitrogen, TKN	Medium Low
Organics		High

[1] Results are for total metals only

[2] Information on As was found only in the International Stormwater Database where removal was found to be low

References and suggested reading

- Bureau of Environmental Services. 2006. Effectiveness Evaluation of Best Management Practices for Stormwater Management in Portland, Oregon (https://www.portlandoregon.gov/bes/article/133994). Bureau of Environmental Services, Portland, Oregon.
- California Stormwater Quality Association. 2003. California Stormwater BMP Handbook-New Development and Redevelopment (https://www.casqa.org/sites/default/files/BMPHandbooks/BMP_NewDevRedev_Complete.pdf). California Stormwater Quality Association, Menlo Park, CA.
- Caltrans. 2004. BMP Retrofit Pilot Program Final Report (https://dot.ca.gov/-/media/dot-media/programs/design/documents/ctsw-rt-01-050-001-a11y.pdf), Report No. CTSW-RT-01-050. Division of Environmental Analysis. California Dept. of Transportation, Sacramento, CA.
- CDM Smith. 2012. Omaha Regional Stormwater Design Manual (https://omahastormwater.org/orsdm/). Chapter 8 Stormwater Best Management Practices. Kansas City, MO.
- Caraco, Deborah, and Richard A. Claytor. 1997. Stormwater BMP Design: Supplement for Cold Climates (https://vermont4evolution.files.wordpress.com/2011/12/ulm-elc_coldclimates.pdf). US Environmental Protection Agency.
- Dorman, M. E., H. Hartigan, F. Johnson, and B. Maestri. 1988. Retention, detention, and overland flow for pollutant removal from highway stormwater runoff: interim guidelines for management measures (http://catalog.hathitrust.org/Record/012356026). Final report, September 1985-June 1987. No. PB-89-133292/XAB. Versar, Inc., Springfield, VA (USA).
- Geosyntec Consultants, and Wright Water Engineers. 2002. Urban stormwater BMP performance monitoring (https://www3.epa.gov/npdes/pubs/montcomplete.pdf).
- Gulliver, J. S., A. J. Erickson, and PTe Weiss. 2010. Stormwater treatment: Assessment and maintenance (http://stormwaterbook.safl.umn.edu/). University of Minnesota, St. Anthony Falls Laboratory. Minneapolis, MN.
- Hathaway, J. M., W. F. Hunt, and S. Jadlocki. 2009. Indicator bacteria removal in storm-water best management practices in Charlotte, North Carolina (http://lshs.tamu.edu/docs/lshs/end-notes/indicator%20bacteria%20removal%20in%20stormwater%20bmps%20in%20charlotte,%20nc-3678140698/indicator%20bacteria%20removal%20in%20stormwater%20bmps%20in%20charlotte,%20nc.pdf). Journal of Environmental Engineering 135, No. 12:1275-1285.
- Jaffe, et. al. 2010. The Illinois Green Infrastructure Study (http://www.epa.state.il.us/green-infrastructure/docs/draft-final-report.pdf). Prepared by the University of Illinois at Chicago, Chicago Metropolitan Agency for Planning, Center for Neighborhood Technology, Illinois-Indiana Sea Grant College Program.

- Jurries, Dennis. 2003. Biofilters (Bioswales, Vegetative Buffers, & Constructed Wetlands) for Storm Water Discharge Pollution Removal (https://nacto.org/docs/usdg/biofilters_bioswales_vegetative_buffers_constructed_wetlands_jurries.pdf). State of Oregon Department of Environmental Quality.
- Kurz, R.C. 1998. Removal of Microbial Indicators from Stormwater using Sand Filtration, Wet Detention, and Alum Treatment Best Management Practices (https://www.swfwmd.state.fl.us/sites/default/files/medias/documents/removal_microbial_indicators.pdf). South West Florida Water Management District, Tampa, FL.
- Leisenring, M., J. Clary, and P. Hobson. 2012. International Stormwater Best Management Practices (BMP) Database Pollutant Category Summary Statistical Addendum: TSS, Bacteria, Nutrients, and Metals (https://www.waterrf.org/system/files/resource/2020-11/DRPT-4968_0.pdf).
- Muthukrishnan, Swarna. 2010. Treatment Of Heavy Metals In Stormwater Runoff Using Wet Pond And Wetland Mesocosms (http://scholarworks.umass.edu/cgi/viewcontent.cgi?article=1083&context=soilsproceedings). In Proceedings of the Annual International Conference on Soils, Sediments, Water and Energy, vol. 11, no. 1, p. 9.
- New Hampshire Department of Environmental Services. 2008. 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. Concord, NH.
- North Carolina Department of Environment and Natural Resources. 2007. Stormwater Best Management Practices Manual. North Carolina Department of Environment and Natural Resources, Raleigh, North Carolina. (https://deq.nc.gov/about/divisions/energy-mineral-and-land-resources/stormwater/stormwater-program/stormwater-design)
- Oregon State University, Geosyntec Consultants, University of Florida, the Low Impact Development Center, Inc. 2006. Evaluation of Best Management Practice for Highway Runoff Control (NCHRP Report 565) (http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rpt_565.pdf). Research sponsored by the American Association of State Highway and Transportation Officials in cooperation with the Federal Highway Administration.
- Scholes, L., R. B. E. Shutes, D. M. Revitt, M. Forshaw, and D. Purchase. 1998. *The treatment of metals in urban runoff by constructed wetlands*. Science of the Total Environment 214, no. 1: 211-219.
- Schueler, T.R., Kumble, P.A., and Heraty, M.A. 1992. *A Current Assessment of Urban Best Management Practices: Techniques for Reducing Non-Point Source Pollution in the Coastal Zone*. Metropolitan Washington Council of Governments, Washington, D.C.
- Semadeni-Davies, Annette. 2006. Winter performance of an urban stormwater pond in southern Sweden (http://onlinelibrary.wiley.com/doi/10.1002/hyp.5909/abstract). Hydrological processes 20, no. 1:165-182.
- State of California, Department of Transportation. 2013. Caltrans Stormwater Monitoring Guidance Manual (http://www.dot.ca.gov/hq/env/stormwater/pdf/CTSW_OT_13_999.pdf). Sacramento, CA.
- TetraTech. 2008. *BMP Performance Analysis*. Prepared for US EPA Region 1, Boston, MA.
- Water Environment Federation. 2014. 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). A White Paper by the National Stormwater Testing and Evaluation of Products and Practices (STEPP) Workgroup Steering Committee.
- Weng, Liang, and S. Meek. 2000. Pollutant Removal Dynamics of Three Wet Ponds in Canada (https://owl.cwp.org/mdocs-posts/elc_pwp75/). Watershed Protection Techniques 3, no. 3:721-728.
- WEF, ASCE/EWRI. 2012. *Design of Urban Stormwater Controls, WEF Manual of Practice No. 23*. ASCE/EWRI Manuals and Reports on Engineering Practice No. 87. Prepared by the Design of Urban Stormwater Controls Task Forces of the Water Environment Federation and the American Society of Civil Engineers/Environmental & Water Resources Institute.
- Weiss, Peter T., John S. Gulliver, and Andrew J. Erickson. 2005. The Cost and Effectiveness of Stormwater Management Practices Final Report (http://www.lrrb.org/media/reports/200523.pdf).
- Wossink, G. A. A., and Bill Hunt. 2003. The economics of structural stormwater BMPs in North Carolina (https://repository.lib.ncsu.edu/bitstream/handle/1840.4/1948/NC-WRRI-344.pdf?sequence=2). Water Resources Research Institute of the University of North Carolina.

Related pages

- Constructed stormwater ponds
  - Overview for stormwater ponds
  - Types of stormwater ponds
  - Design criteria for stormwater ponds
  - Design considerations for constructed stormwater ponds used for harvest and irrigation use/reuse
  - Construction specifications for stormwater ponds
  - Assessing the performance of stormwater ponds
  - Operation and maintenance of stormwater ponds
  - Cost-benefit considerations for stormwater ponds
  - Calculating credits for stormwater ponds
  - Stormwater wet pond fact sheet
  - References for stormwater ponds
  - Requirements, recommendations and information for using stormwater pond as a BMP in the MIDS calculator
- Calculating credits
  - Calculating credits for bioretention
  - Calculating credits for infiltration basin
  - Calculating credits for infiltration trench
  - Calculating credits for permeable pavement
  - Calculating credits for green roofs
  - Calculating credits for sand filter
  - Calculating credits for stormwater ponds
  - Calculating credits for stormwater wetlands

- Calculating credits for iron enhanced sand filter
- Calculating credits for swale
- Calculating credits for tree trenches and tree boxes
- Calculating credits for stormwater and rainwater harvest and use/reuse