PENNSYLVANIA HOUSING RESEARCH CENTER

The International Stormwater BMP Database
Part 2: Data Summary for the Design of Residential BMPs

PHRC Land Development Brief

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INTRODUCTION

This brief is the second in a two-part series on the International Stormwater BMP Database. The Database, a repository of data collected from over 500 Best Management Practices (BMPs), was designed to allow researchers and designers access to continually updated data on the performance of stormwater BMPs. The Database is sponsored and supported by the Water Environment Research Foundation (WERF), the U.S. Environmental Protection Agency (USEPA), ASCE Environmental and Water Resources Institute (EWRI), Federal Highway Administration (FHWA) and the American Public Works Association (APWA).

This brief provides water quality and flow findings based on data submitted to the BMP Database by other researchers. The parameters selected for discussion are based on possible application to residential developments in Pennsylvania. This brief provides stormwater design professionals with recent research findings on pollutant removal efficiencies of BMPs to address various stormwater management challenges. Because there are only a few study sites in Pennsylvania, data from all projects are included in this analysis. Part 1 of this series (*The International Stormwater BMP Database Part 1: Summary of Database*) provides a briefer summary of the Database and some general suggestions on selecting BMPs to achieve sediment, nitrogen, and phosphorus removal, as well as volume reduction. Brief 2 is intended for stormwater design professionals and provides more technical data for use in BMP design and permit documentation.

BMP DATABASE PROJECTS IN PA

While there are over 500 projects in the BMP database, there are only three project locations in Pennsylvania listed in the database. These projects are located on Penn State's University Park campus, the Villanova University campus, and the Harrisburg Public Works Yard.

The project located on the University Park campus is a green roof and only has flow data reported for five events during 2005 and 2006. There are no water quality data for this BMP and very few design parameters provided; thus the University Park project provides little value in terms of evaluating BMP performance.

The BMP located at the Harrisburg Public Works Yard is a manufactured device. It is a two-chamber sediment trap with a baffle and screen to remove debris and large sediment and then finer particles. Suspended sediment concentration (SSC) and total suspended solids (TSS) were analyzed for 15 events during 2005 and 2006. The BMP decreased the median event mean concentration (EMC) of the effluent, but the decrease was not statically significant. This BMP is located in an industrial setting so both the application and results are not valid for comparison to residential installations.

Although the Villanova Urban Stormwater Partnership studies many different BMPs located on the Villanova University campus, an infiltration trench and pervious concrete are the only BMPs with data reports in the Database. Villanova's infiltration trench has a capture volume of 300 cubic feet and receives runoff from a 0.47 acre parking lot. The infiltration trench was monitored for a long list of constituents shown in Table 1. The reported median influent and effluent concentrations along with the calculated percent reduction are shown for each constituent. The number of events sampled for each constituent varied from 8 to 40. Statistical significance of percent reduction has not been determined. There is no report of the volume of runoff infiltrated for this BMP.

The location of the infiltration trench has a depth to groundwater of 15 feet and a depth to impermeable layer of 10 feet. These limiting layers are much deeper than many areas of the state which have soils with higher clay content or shallower depths to bedrock; therefore, design professionals should not necessarily expect to find similar results in an area with different constraints.

Villanova's porous concrete BMP has a surface area of 0.30 acres and an underground storage volume of approximately 14,000 cubic feet. The drainage area to the porous concrete BMP is 1.33 acres, of which 46 percent is impervious. The reported data indicates that the primary land use of the watershed is low-density residential, and the depth to groundwater is 25 feet with sandy soils for at least 10 feet. The infiltration trench under the porous surface was monitored for chloride, dissolved copper, nitrogen, nitrate, nitrite, phosphorus as PO_4, pH, specific conductance, total dissolved solids, and total suspended solids. The number of events sampled for each constituent varied from 2 to 20 at different monitoring stations. The results for 3 inflow and 6 subsurface monitoring stations are reported in the Database, but the locations of these monitoring stations are not noted in the BMP schematics so it is not possible to determine the removal efficiencies. There is no report of the volume of runoff infiltrated for this BMP.

Data on the additional BMPs on the Villanova University campus are available through the Villanova Urban Stormwater Partnership website at http://www3.villanova.edu/vusp/.

Table 1. Median influent and effluent concentrations of studied constituents with calculated percent reduction for the Villanova Infiltration Trench BMP

Constituent	Units	Median Influent Concentration	Median Effluent Concentration	Percent Reduction
Total suspended solids	mg/L	26.37	11.61	56%
Copper, Suspended	µg/L	29.35	15.47	47%
Nitrogen, Total	mg/L	2.17	1.2	45%
Phosphorus as P, Total	mg/L	0.74	0.44	41%
Chromium, Suspended	µg/L	13.86	8.32	40%
Kjeldahl nitrogen	mg/L	0.44	0.3	32%
Lead, Suspended	µg/L	2.94	2.16	27%
Specific conductance	µmhos/c m	96.44	70.3	27%
Chromium, Dissolved	µg/L	1.66	1.25	25%
Nitrogen, Nitrite as N	mg/L	0.04	0.03	25%
Nitrogen, Nitrate as N	mg/L	0.41	0.31	24%
Phosphorus, orthophosphate as P	mg/L	0.05	0.04	20%
Chloride, Total	mg/L	14.5	11.96	18%
Lead, Dissolved	µg/L	1.21	1.17	3%
Cadmium, Suspended	µg/L	1.25	1.25	0%
Cadmium, Dissolved	µg/L	0.88	0.9	-2%
Total dissolved solids	mg/L	68.1	74.01	-9%
Copper, Dissolved	µg/L	6.58	8.26	-26%

GENERAL RESULTS FROM THE BMP DATABASE

Because of the limited number of documented projects in Pennsylvania, it is helpful to look at the full dataset and summary reports in order to more accurately inform BMP design.

Water Quality

Over 3,000 different water quality constituents have been reported in the Database. Sediment, nitrogen and phosphorus have been selected for further examination in this brief because these constituents are the targets of the Chesapeake Bay TMDL Plan and the PA DEP NPDES Permit for Stormwater Discharges Associated with Construction Activities. Median influent and effluent concentrations for sediment and nutrients of interest will be presented in this section along with the calculated percent removal based on the median influent and effluent values (Eq 1).

$$\begin{matrix}\textbf{percent}\\\textbf{removal}\end{matrix} = \frac{(\textbf{influent conc.} - \textbf{effluent conc.})}{\textbf{influent conc.}} * \mathbf{100} \qquad \text{(Eq 1)}$$

This brief presents percent removal data despite concerns about the appropriateness of percent removal as a metric for BMP performance because this is the approach taken by the PA DEP for the calculation of water quality values for *PA DEP NPDES Permits for Stormwater Discharges Associated with Construction Activities*, and the TMDL Strategy Plan as part of the *NPDES Permit for Stormwater Discharges from Small Municipal Separate Storm Sewer Systems (MS4s) (PAG-13)*.

Many researchers in the field of stormwater management, including the developers of the BMP Database, have advised against using percent removal values. Percent removal is frequently more a function of the influent water quality than of the effectiveness of the BMP. Dirtier influent water will generally yield a higher percent removal than cleaner water. A broader statistical analysis of influent and effluent data is preferable to obtain a robust assessment of BMP effectiveness. See Reference 12 for additional information regarding percent removal.

The summary tables in the following sections show the number of studies and number of samples for both influent and effluent Event Mean Concentrations. Note that in several cases the sample sizes were not large enough to produce statistically significant results. The International Stormwater BMP Database project team determined the median concentrations and statistical significance of the values presented in this brief. The statistical analysis performed by the Database project team has been summarized here to allow for easier presentation of the results impacting residential applications. The statements in this brief and Part 1 that refer to a particular category of BMP being more or less efficient at pollutant removal than other BMPs are based on the percent removals calculated from the median influent and effluent values as reported in the technical papers by the Database project team (References 4-7).

The percent reductions of various water constituents for a variety of BMP categories are shown in the right-hand column of Tables 2-8. BMPs are organized so those with the highest percent removals are at the top of the table and those with the lowest percent removals or increases in effluent concentration are at the bottom. Note that negative values indicate an *increase* in concentration between the influent and effluent. BMPs marked in bold with an asterisk indicate a statistically significant change in concentration. Some BMP categories had few samples or a high degree of variability for a particular pollutant; so, although a percent reduction can be calculated, it is not statistically significant.

Sediment

The researchers responsible for the BMP Database have taken a unit treatment process approach to defining BMP function. The unit processes for sediment removal are sedimentation and filtration. Researchers entering sediment removal data into the Database must define particle size distribution and particle density for the sediment, and BMP detention times.

Total suspended sediment (TSS), total dissolved sediment (TDS), and turbidity are the sediment parameters collected in the BMP Database.

Through analysis of the entire dataset, media filters, porous pavement, composite BMPs, retention ponds and bioretention were found to be the BMPs with the highest percent reduction of TSS (Table 2). All BMP categories except for green roofs were found to produce statistically significant reductions in TSS.

Table 2. Number of studies and samples with the median influent and effluent concentrations of *total suspended solids (TSS)* with calculated percent reduction

	# of studies, # of EMCs		Median concentrations (mg/L)		Percent reduction
	Inf.	Eff.	Inf.	Eff.	
Media Filter*	**28, 442**	**29, 409**	**52.7**	**8.7**	**83%**
Porous Pavement*	**14, 246**	**23, 406**	**65.3**	**13.2**	**80%**
Composite*	**10, 201**	**10, 163**	**94**	**17.4**	**81%**
Retention Pond*	**47, 725**	**48, 723**	**70.7**	**13.5**	**81%**
Bioretention*	**14, 202**	**14, 193**	**37.5**	**8.3**	**78%**
Detention Basin*	**20, 287**	**21, 299**	**66.8**	**24.2**	**64%**
Grass strip*	**19, 350**	**20, 286**	**43.1**	**19.1**	**56%**
Wetland Basin*	**15, 301**	**17, 305**	**20.4**	**9.06**	**56%**
Manufactured Device*	**55, 923**	**63, 904**	**34.5**	**18.4**	**47%**
Bioswale*	**21, 338**	**23, 354**	**21.7**	**13.6**	**37%**
Wetland Channel*	**8, 189**	**8, 154**	**20**	**14.3**	**29%**
Green Roof	2, 20	4, 51	10.5	2.9	72%

Note: Positive % reduction indicates a *decrease* from influent to effluent concentrations.
* and bold font indicates a statistically significant change in the effluent concentration compared to the influent concentration.

Overall, there was not a statistically significant reduction in TDS for any of the BMP categories. Filter strips, media filters, and retention ponds showed an increase in effluent concentrations of TDS.

In general, the results for turbidity were similar to those of TSS, but limited data prevents more detailed discussion of BMP effectiveness for this constituent.

Stormwater design professionals can increase the efficiency of BMPs designed for sediment removal by increasing the hydraulic residence time of BMPs. Increasing the hydraulic residence time increases the removal efficiency of total suspended sediment. The hydraulic residence time can be increased by:

1. lengthening flow paths in ponds or wetlands,
2. increasing bed thickness and creating evenly distributed flows through outlet control in media filters and bioretention BMPs; and
3. conducting regular maintenance to prevent clogging in filtration and infiltration BMPs.

Nitrogen (N)

The forms of nitrogen included in this analysis are total nitrogen (TN), total Kjeldahl nitrogen (TKN), and NO_x as nitrogen. TKN is the sum of organic nitrogen, ammonia (NH_3), and ammonium (NH_4^+). TN is the TKN plus nitrate (NO_3^-) and nitrite (NO_2^-). Nitrite readily converts to nitrate so it can be difficult to determine the concentration of nitrite at the time of sample collection as compared to the concentration at the time of sample analysis. NO_x, which is the sum of NO_3^- and NO_2^-, is often used instead of trying to report the constituents separately.

Bioretention and retention ponds were found to significantly reduce total N concentrations, while detention basins show an average increase in total nitrogen (Table 3).

Bioretention and retention ponds were also found to significantly reduce total Kjeldahl nitrogen concentrations; however, porous pavement and media filters were more effective at removing this form of nitrogen (Table 4).

Table 3. Number of studies and samples with the median influent and effluent concentrations of *total nitrogen (TN)* with calculated percent reduction

	# of studies, # of EMCs		Median concentrations (mg/L)		
	Inf.	Eff.	Inf.	Eff.	Percent reduction
Retention Pond*	**19, 259**	**19, 272**	**1.83**	**1.28**	**30%**
Bioretention*	**12, 218**	**12, 200**	**1.25**	**0.9**	**28%**
Composite*	**3, 53**	**4, 64**	**2.37**	**1.71**	**28%**
Media Filter*	**5, 100**	**5, 87**	**1.06**	**0.82**	**23%**
Grass strip	8, 138	8, 122	1.34	1.13	16%
Wetland Channel	5, 83	6, 88	1.59	1.33	16%
Bioswale	6, 181	8, 238	0.75	0.71	5%
Manufactured Device	8, 133	8, 117	2.27	2.22	2%
Green Roof	NA	NA	NA	NA	NA
Wetland Basin	6, 222	6, 223	1.14	1.19	-4%
Porous Pavement	1, 14	9, 136	1.26	1.49	-18%
Detention Basin*	**3, 52**	**3, 64**	**1.4**	**2.34**	**-67%**

Note: Positive % reduction indicates a *decrease* from influent to effluent concentrations. Negative % reduction indicates an *increase* from influent to effluent concentrations.
* and bold font indicates a statistically significant change in the effluent concentration compared to the influent concentration.

Porous pavement and media filters that are effective at reducing TKN concentrations (Table 4) have been found to actually increase the concentration of NO_x (Table 5).

Vegetated BMPs with permanent pools such as wetland basins and channels, and retention ponds are the most effective BMPs for reducing NO_x (Table 5).

Because BMP effectiveness varies depending on the constituent, to select the best BMPs for a specific location it is important to know what form or forms of nitrogen may be present in stormwater runoff from that particular site.

Table 4. Number of studies and samples with the median influent and effluent concentrations of *total Kjeldahl nitrogen (TKN)* with calculated percent reduction

	# of studies, # of EMCs		Median concentrations (mg/L)		Percent reduction
	Inf.	Eff.	Inf.	Eff.	
Porous Pavement*	**12, 224**	**23, 396**	**1.66**	**0.8**	**52%**
Media Filter*	**26, 411**	**25, 374**	**0.96**	**0.57**	**41%**
Composite*	**7, 130**	**9, 145**	**1.64**	**1.02**	**38%**
Bioretention*	**14, 214**	**14, 201**	**0.94**	**0.6**	**36%**
Retention Pond*	**36, 482**	**39, 496**	**1.28**	**1.05**	**18%**
Wetland Channel*	**6, 122**	**7, 139**	**1.45**	**1.23**	**15%**
Grass strip	19, 350	19, 272	1.29	1.09	16%
Bioswale	17, 288	19, 324	0.72	0.62	14%
Manufactured Device	24, 390	31, 433	1.59	1.48	7%
Wetland Basin	6, 72	8, 184	0.95	1.01	-6%
Detention Basin	11, 175	12, 185	1.49	1.61	-8%
Green Roof	1, 15	3, 32	1.51	1.75	-16%

Note: Positive % reduction indicates a *decrease* from influent to effluent concentrations. Negative % reduction indicates an *increase* from influent to effluent concentrations.
* and bold font indicates a statistically significant change in the effluent concentration compared to the influent concentration.

Table 5. Number of studies and samples with the median influent and effluent concentrations of *nitrate and nitrite (NO_x)* with calculated percent reduction

	# of studies, # of EMCs		Median concentrations (mg/L)		Percent reduction
	Inf.	Eff.	Inf.	Eff.	
Wetland Basin*	**11, 245**	**11, 246**	**0.24**	**0.08**	**67%**
Retention Pond*	**43, 639**	**43, 626**	**0.43**	**0.18**	**58%**
Wetland Channel*	**8, 149**	**8, 132**	**0.34**	**0.19**	**44%**
Detention Basin*	**13, 201**	**14, 213**	**0.55**	**0.36**	**35%**
Composite*	**9, 157**	**10, 142**	**0.57**	**0.4**	**30%**
Grass strip*	**20, 360**	**20, 287**	**0.41**	**0.27**	**34%**
Bioretention*	**17, 278**	**17, 259**	**0.26**	**0.22**	**15%**
Green Roof	2, 21	4, 55	0.39	0.31	21%
Bioswale	20, 335	22, 372	0.3	0.25	17%
Manufactured Device	33, 504	40, 546	0.41	0.41	0%
Media Filter*	**27, 434**	**26, 391**	**0.33**	**0.51**	**-55%**
Porous Pavement*	**13, 229**	**23, 401**	**0.42**	**0.71**	**-69%**

Note: Positive % reduction indicates a *decrease* from influent to effluent concentrations. Negative % reduction indicates an *increase* from influent to effluent concentrations.
* and bold font indicates a statistically significant change in the effluent concentration compared to the influent concentration.

Phosphorus (P)

Like nitrogen, phosphorus is also present in the environment in different forms and is analyzed using different methods to characterize the different forms. The common forms of phosphorus that are discussed in this brief are total phosphorus (TP), orthophosphate (OP), and dissolved phosphorus (DP). Total phosphorus includes all forms of phosphorus, both the particulate form that is frequently adsorbed to soil particles and the phosphorus that is dissolved in the runoff. Dissolved phosphorus is the portion of phosphorus that is dissolved in the runoff and found by passing the sample through a 0.45 micron membrane to remove any sediment from the sample. Orthophosphate is the phosphate ion (PO_4^{3-}) and is often referred to as reactive phosphorus.

Composite BMPs (treatment trains), retention ponds, media filters, porous pavement, wetland basins, manufactured devices, and detention basins were all found to reduce total P (Table 6).

Table 6. Number of studies and samples with the median influent and effluent concentrations of *total phosphorus (TP)* with calculated percent reduction

	# of studies, # of EMCs		Median concentrations (mg/L)		Percent reduction
	Inf.	Eff.	Inf.	Eff.	
Composite*	**9, 176**	**10, 153**	**0.36**	**0.13**	**64%**
Retention Pond*	**46, 657**	**48, 654**	**0.3**	**0.13**	**57%**
Media Filter*	**28, 433**	**28, 403**	**0.18**	**0.09**	**50%**
Porous Pavement*	**13, 231**	**22, 389**	**0.15**	**0.09**	**40%**
Wetland Basin*	**13, 282**	**13, 278**	**0.13**	**0.08**	**38%**
Manufactured Device*	**45, 602**	**52, 641**	**0.19**	**0.12**	**37%**
Detention Basin*	**18, 250**	**19, 275**	**0.28**	**0.22**	**21%**
Bioretention	18, 271	18, 249	0.11	0.09	18%
Wetland Channel	8, 167	8, 147	0.15	0.14	7%
Grass strip*	**20, 358**	**20, 280**	**0.14**	**0.18**	**-29%**
Bioswale*	**20, 331**	**22, 364**	**0.11**	**0.19**	**-73%**
Green Roof*	**2, 22**	**5, 60**	**0.09**	**0.5**	**-456%**

Note: Positive % reduction indicates a *decrease* from influent to effluent concentrations. Negative % reduction indicates an *increase* from influent to effluent concentrations.
* and bold font indicates a statistically significant change in the effluent concentration compared to the influent concentration.

Phosphorus is generally transported through the adsorption to sediment particles rather than dissolved in water. Therefore, higher removal rates of phosphorus can often be achieved through better control of sediment. BMPs that utilize the unit processes of sedimentation and filtration generally result in an overall reduction of total P concentrations.

Retention ponds and wetland basins are also effective at reducing the concentration of orthophosphate and dissolved phosphorus (Tables 7 and 8).

Table 7. Number of studies and samples with the median influent and effluent concentrations of *total orthophosphate* with calculated percent reduction

	# of studies, # of EMCs		Median concentrations (mg/L)		Percent reduction
	Inf.	Eff.	Inf.	Eff.	
Retention Pond*	**27, 361**	**28, 357**	**0.1**	**0.04**	**60%**
Manufactured Device*	**14, 201**	**14, 185**	**0.21**	**0.1**	**52%**
Media Filter*	**9, 170**	**9, 157**	**0.05**	**0.03**	**40%**
Wetland Basin*	**5, 166**	**5, 161**	**0.03**	**0.02**	**33%**
Detention Basin	2, 31	2, 31	0.53	0.39	26%
Composite	4, 56	4, 47	0.09	0.07	22%
Porous Pavement	7, 87	9, 112	0.05	0.05	0%
Grass strip*	**14, 274**	**14, 223**	**0.03**	**0.06**	**-100%**
Wetland Channel*	**3, 84**	**3, 63**	**0.03**	**0.06**	**-100%**
Bioretention*	**13, 164**	**13, 164**	**0.01**	**0.04**	**-300%**
Bioswale*	**5, 140**	**7, 197**	**0.03**	**0.12**	**-300%**
Green Roof*	**2, 21**	**4, 55**	**0.02**	**0.46**	**-2200%**

Note: Positive % reduction indicates a *decrease* from influent to effluent concentrations. Negative % reduction indicates an *increase* from influent to effluent concentrations.
* and bold font indicates a statistically significant change in the effluent concentration compared to the influent concentration.

Table 8. Number of studies and samples with the median influent and effluent concentrations of *dissolved phosphorus (DP)* with calculated percent reduction

	# of studies, # of EMCs		Median concentrations (mg/L)		Percent reduction
	Inf.	Eff.	Inf.	Eff.	
Retention Pond*	**19, 379**	**20, 371**	**0.13**	**0.06**	**54%**
Wetland Basin*	**5, 114**	**5, 113**	**0.08**	**0.05**	**38%**
Composite	7, 143	8, 142	0.16	0.08	50%
Bioretention	1, 10	1, 10	0.25	0.13	48%
Manufactured Device	16, 239	23, 265	0.08	0.06	25%
Media Filter	13, 103	13, 96	0.08	0.08	0%
Green Roof			NA	NA	NA
Detention Basin	8, 91	9, 94	0.1	0.11	-10%
Wetland Channel	5, 92	5, 89	0.08	0.09	-13%
Porous Pavement	4, 114	5, 125	0.04	0.05	-25%
Grass strip	3, 21	3, 17	0.08	0.25	-213%
Bioswale*	**6, 66**	**6, 52**	**0.06**	**0.07**	**-17%**

Note: Positive % reduction indicates a *decrease* from influent to effluent concentrations. Negative % reduction indicates an *increase* from influent to effluent concentrations.
* and bold font indicates a statistically significant change in the effluent concentration compared to the influent concentration.

Some BMPs were found to increase the concentration of phosphorus. The composition of the media may be an important factor in determining whether phosphorus concentrations are increased or decreased as runoff passes through the BMP. BMPs like grass strips, bioretention, bioswales, and green roofs often include the use of engineered media. Some media were found to have high concentrations of phosphorus, which could dissolve in the stormwater that is being treated, especially if the water is being stored in the soil of an under-drained system. To help determine how the phosphorus levels of media are influencing the phosphorus concentration, the P index of soils or media used in BMPs will soon be included in the data collected in the Database.

Similar to the findings for nitrogen, different efficiencies were found for different forms of P (orthophosphate, total phosphorus, dissolved phosphorous). It may help a designer to determine what forms of phosphorus may be present on a site and select BMPs accordingly. When designing for phosphorus removal, the designer must carefully specify BMP media to ensure that a low phosphorus material is used. If site soils are being used in BMPs, the phosphorus content or P index should be determined.

Volume Reduction

In the early years of the BMP Database, performance analysis was based primarily on water quality parameters and not on volume control. Recently volume control has been an increasing concern in stormwater management and therefore was incorporated into sets of data collected in the BMP Database.

BMPs with normally dry conditions such as bioretention, filter strips, vegetated swales, and grass-lined detention basins yield the largest long-term volume reductions. These normally dry BMPs also provide the largest volume reductions for smaller storms, which occur more frequently than larger events. Controlling small events leads to a smaller number of discharges and a smaller impact on downstream channels. Table 9 summarizes the statistically significant median percent volume reduction for the normally dry BMPs.

Table 9. Median volume reduction for the normally-dry categories of BMPs

	# of Study Locations	Median % Reduction
Bioretention (with underdrain)	7	57%
Biofilter – grass swales	13	42%
Biofilter – grass strips	16	34%
Detention basins – surface, grass lined	11	33%

BMPs with a standing pool, such as wetland basins, are lined to retain runoff and provide very little volume reduction.

The design of volume reduction of BMPs is very sensitive to site soil conditions including soil textural classification, compaction, and depth to groundwater, bedrock or impermeable layer.

There is a wide range in the data used to determine the median volume reductions reported in Table 9. If a site has sandy soils, a large depth to confining layer and compaction is avoided during construction, volume reductions higher than those in Table 9 can be expected. On the other hand, if the site has soils with a high clay content, a shallow depth to a confining layer, or more compaction, a smaller volume reduction would be expected.

Load versus Concentration

Although some BMPs have been found to increase the concentration of nitrogen or phosphorus, this does not necessarily mean that nutrients will be exported from the BMP. The volume reduction of a BMP must be considered along with the pollutant concentration to determine if an additional amount of the nutrient is leaving the BMP.

For example, Figure 3 shows phosphorus removal with bioswales. The median influent concentration is 0.11 mg/L and the median effluent concentration is 0.19 mg/L. This is a 73 percent increase in phosphorus concentration. Assuming an influent volume of 10,000 L the influent load would be 11.0 g

$$(0.11\ mg/L) \times (10{,}000\ L) \times \left(\frac{1\ g}{1{,}000\ mg}\right) = 11.0\ g$$

Bioswales have a median volume reduction of 42 percent so in this example the effluent volume would be 5,800 L.

$$(10{,}000\ L) \times (1 - 0.42) = 5{,}800\ L$$

Even though the effluent concentration increased, the volume was reduced so the effluent load remained the same at 11.0 g.

$$(0.19\ mg/L) \times (5{,}800\ L) \times \left(\frac{1\ g}{1{,}000\ mg}\right) = 11.0\ g$$

In this example there is no change in the load of phosphorus through the BMP. With a larger volume reduction there could be an overall reduction in the effluent load of pollutant, but if the volume reduction is not as large, or the increase in effluent concentration is larger, there could be an increase in the nutrient load as a result of implementing some water quality BMPs.

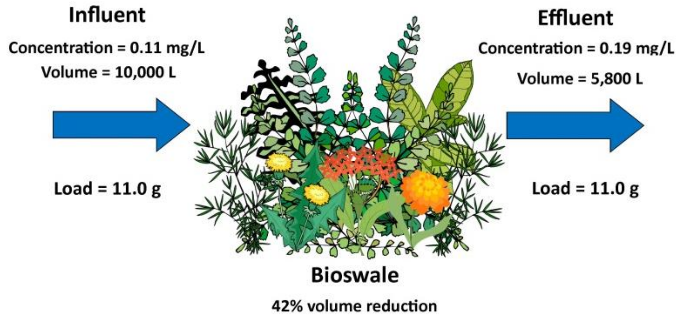

Figure 3. Schematic of a bioswale showing the difference between concentration and load.

GENERAL RECOMENDATIONS FOR BMP DESIGN BASED ON THE BMP DATABASE

Based on the reported data, there are no clear, easy-to-follow guidelines that can be applied in the selection and design of BMPs to meet all volume and water quality control parameters. There are a large number of variables that influence the effectiveness of each individual BMP, and the interactions among the variables are complex. These variables and their interactions can be modeled or simulated, but researchers are still gathering the necessary data to be able to accurately predict the outcome of various BMPs in various settings. Based on available data, it is impossible to create universal BMP design rules; however, it is possible to make general recommendations for BMPs and design parameter selection to achieve volume, sediment or nutrient reductions.

Because BMPs were found to have different removal efficiencies for the different forms of pollutants, determining which pollutants are present on a specific site may allow for the selection of the most appropriate BMPs.

Table 10 lists the BMPs that were found to have the highest percent removals for the selected stormwater management parameters, while Table 11 lists the BMPs that have been found to *increase* pollutant concentrations.

Table 10. Recommended BMPs for stormwater management parameters based on percent removal calculated using statistically significant median influent and effluent data from the Database.

Stormwater Management Parameters	Recommended BMPs
TSS	Media filters Porous pavement Retention ponds Bioretention Detention basins Grass strips Wetland basins Bioswales Manufactured devices Wetland channels
Total N	Retention ponds Bioretention ponds Media filter
TKN	Porous pavement Media filters Bioretention Retention pond Wetland channel
NO_x	Wetland basins Retention ponds Wetland channels Detention basin Grass strip Bioretention
Total P	Retention pond Media filters Porous pavement Wetland basins Manufactured devices Detention basin
Orthophosphate	Retention ponds Manufactured devices Media filters Wetland basins
Dissolved P	Retention ponds Wetland basins
Volume	Filter strips Vegetated swales Bioretention basins Detention basins (grass lined)

Table 11. BMPs that can increase pollutant concentrations based percent removal calculated using median influent and effluent data from the Database.

Stormwater Pollutant	BMPs Not Recommended for Specific Pollutant Removal
Total N	Detention basin
NOx	Porous pavement Media filters
TP	Grass strips Bioswales Green roofs
Orthophosphate	Grass strips Bioretention Bioswales Green roofs Wetland channels
Dissolved P	Bioswales

Note that the increases found for some pollutants may be controlled through better design such as specifying BMP media or soil composition.

Designing BMPs with longer residence times, such as bioretention or retention ponds, or permanent pools, such as wetland basins, will increase sediment removal, which will also increase the removal of phosphorus adsorbed to the sediment. Bioretention and retention ponds are also effective for removal of total nitrogen.

Based on the information contained in the BMP Database, it is recommended that stormwater professionals adopt a treatment train approach. While there is very little data on the measured effectiveness of composite BMPs (treatment trains), the conflicting percent reductions found for volume and different water quality parameters indicate that a single-type BMP approach will generally not work to meet all of the stormwater control requirements. To achieve maximum control of runoff volume, sediment, nitrogen, and phosphorus, designers should incorporate different types of BMPs into a site. Using a treatment train will also help to account for the inherent variability and uncertainties that are associated with BMP performance.

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