

Appendix B

Stormwater Control Performance for Phosphorus as Described in the International BMP Database

Contents

Stormwater Control Performance for Phosphorus as Described in the International BMP Database	1
Overall Summary for Phosphorus Stormwater Controls.....	1
Manufactured Treatment Devices	7
Stormwater Control Volume Reductions	10
Phosphorus Reductions by Stormwater Controls in Chesapeake Bay Region.....	11
Performance Summary of Phosphorus Stormwater Controls as Shown in the International BMP Database	16

The most comprehensive compilation of stormwater control performance is the International BMP Database (<http://bmpdatabase.org/>) which contains data and descriptions for more than 530 control practice installations throughout the US. The International BMP Database website also contains several reports analyzing the performance of stormwater controls, in addition to containing the actual database. Users can download the database focusing on specific criteria, such as constituents of interest and location. This summary, focuses on the control of stormwater phosphorus.

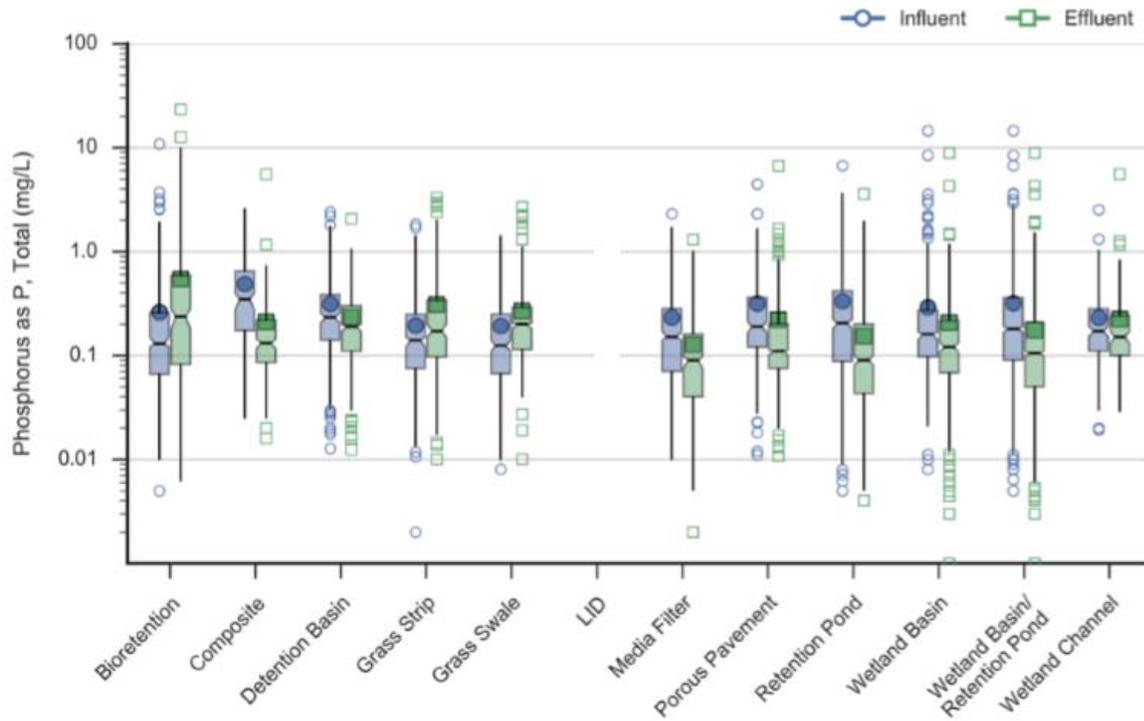
Overall Summary for Phosphorus Stormwater Controls

Periodically, the International BMP Database team prepares data summaries for specific categories of stormwater controls and/or for specific groups of pollutants. For example, they prepared a Statistical Summary Report for Solids, Bacteria, Nutrients, and Metals in 2017 (www.bmpdatabase.org/BMPPerformance.htm). This appendix excerpts sections of the 2017 report that focused on phosphorus.

The stormwater control categories included in this 2017 report are bioretention, composite/ treatment trains using multiple unit treatment processes, detention basins (surface/grass-lined), grass strips, grass swales, media filters (mostly sand filters), porous pavement, retention ponds (surface pond with a permanent pool), wetland basins (basins with open water surface), a combined category including both retention ponds and wetland basins, and wetland channels (swales and channels with wetland vegetation). Figure 1 and Table 1 summarize the influent and effluent total phosphorus concentrations associated with stormwater treatment using these different controls. Figure 2 and

Table 2 show similar information for dissolved phosphorus, while Figure 3 and Table 3 are for orthophosphate.

Figure 1. Box Plots of Influent/Effluent Total Phosphorus Concentrations (International BMP Database, 2017)



Note that the International BMP Database constructs the notched box and whisker plots as follows:

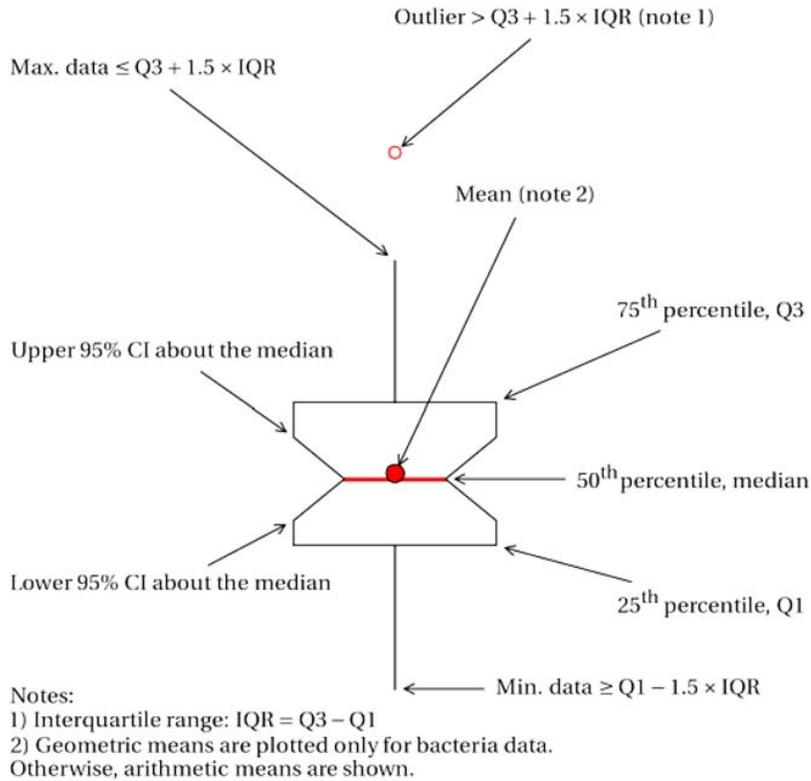


Table 1. Influent/Effluent Summary Statistics for Total Phosphorus (mg/L) (International BMP Database, 2017)

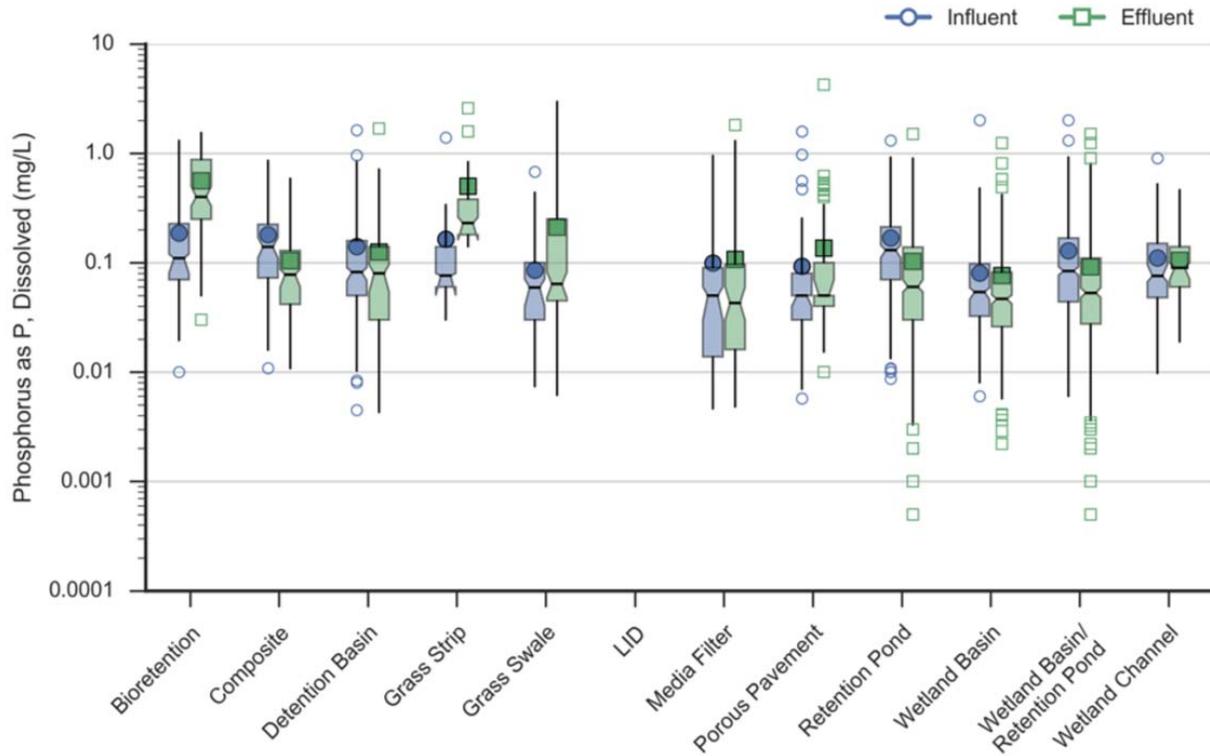
	BMP Category	BMPs		EMCs		25th		Median		75th		
		In	Out	In	Out	In	Out	In	Out	Difference	In	Out
Phosphorus as P, Total (mg/L)	Bioretention	30	30	583	505	0.07	0.08	0.13 (0.12, 0.15)	0.24 (0.18, 0.28)	◆◆◆◆	0.26	0.59
	Composite	10	10	184	166	0.17	0.09	0.35 (0.28, 0.40)	0.13 (0.12, 0.14)	◆◆◆◆	0.65	0.22
	Detention Basin	31	31	397	412	0.14	0.11	0.23 (0.21, 0.26)	0.19 (0.17, 0.20)	◆◆◆◆	0.38	0.30
	Grass Strip	19	19	360	276	0.08	0.10	0.14 (0.12, 0.15)	0.17 (0.15, 0.20)	◇◆◆◆	0.25	0.34
	Grass Swale	23	23	436	445	0.07	0.11	0.12 (0.11, 0.14)	0.20 (0.18, 0.21)	◆◆◆◆	0.25	0.29
	Media Filter	23	22	372	349	0.07	0.04	0.15 (0.13, 0.15)	0.09 (0.07, 0.10)	◆◆◆◆	0.28	0.16
	Porous Pavement	8	8	373	219	0.12	0.07	0.19 (0.16, 0.21)	0.11 (0.10, 0.11)	◆◆◆◆	0.36	0.20
	Retention Pond	55	55	891	873	0.09	0.04	0.20 (0.18, 0.22)	0.09 (0.08, 0.10)	◆◆◆◆	0.42	0.20
	Wetland Basin	20	20	595	574	0.10	0.07	0.16 (0.14, 0.17)	0.12 (0.11, 0.13)	◆◆◆◆	0.27	0.22
	Wetland Basin/Retention Pond	75	75	1486	1447	0.09	0.05	0.18 (0.17, 0.19)	0.10 (0.10, 0.11)	◆◆◆◆	0.36	0.21
	Wetland Channel	12	12	193	172	0.11	0.10	0.17 (0.15, 0.19)	0.15 (0.13, 0.17)	◇◇◆◆	0.28	0.24

Note: the following describes the notations under the difference column in the tables:

Inflow-Outflow Concentration Differences	Interpretation
◆◇◇	95% confidence intervals around influent/effluent medians do not overlap.
◇◆◇	P-value of the Mann-Whitney test is less than 0.05.
◇◇◆	P-value of the Wilcoxon test is less than 0.05.

Also note that these differences do not always indicate removals (lower effluent concentrations compared to influent concentrations); they can also signify significant differences with increased effluent concentrations (as occurs for several control practices in the above table. Overlapping confidence intervals assists visual interpretation of data plots. In most cases, lack of overlap indicates a significant difference in the data sets. However, this interpretation is sensitive to the number of data pairs: some overlap can be tolerated with large data sets, while small numbers of data pairs may still not be significantly different even with no overlap. The Mann-Whitney test is for independent data (not paired data) and is useful if there are large amounts of missing data for the paired (influent vs. effluent) observations. The Wilcoxon test is the most suitable statistical test for paired data, but missing information results in loss of data. If missing data are associated with non-detectable observations, both the Mann-Whitney and the Wilcoxon test will ignore that data pair. In that case, the sign test would be best. Therefore, the most robust statistical test for these paired observations (especially considering the large number of observations available) would be the Wilcoxon test.

Figure 2. Box Plots of Influent/Effluent Dissolved Phosphorus Concentrations (International BMP Database, 2017)



**Table 2. Influent/Effluent Summary Statistics for Dissolved Phosphorus (mg/L)
(International BMP Database, 2017)**

BMP Category	BMPs		EMCs		25th		Median			75th	
	In	Out	In	Out	In	Out	In	Out	Difference	In	Out
Bioretention	4	4	66	62	0.07	0.25	0.11 (0.08, 0.12)	0.40 (0.33, 0.50)	◆◆◆	0.23	0.88
Composite	8	8	167	153	0.07	0.04	0.14 (0.11, 0.17)	0.08 (0.06, 0.09)	◆◆◆	0.22	0.13
Detention Basin	10	10	137	137	0.05	0.03	0.08 (0.07, 0.09)	0.08 (0.05, 0.10)	◇◇◇	0.16	0.14
Grass Strip	3	3	21	17	0.06	0.18	0.08 (0.05, 0.08)	0.23 (0.15, 0.26)	◆◆◇	0.14	0.38
Grass Swale	7	6	71	53	0.03	0.04	0.06 (0.04, 0.07)	0.06 (0.05, 0.08)	◇◆◆	0.10	0.25
Media Filter	11	10	118	100	0.01	0.02	0.05 (0.03, 0.06)	0.04 (0.03, 0.06)	◇◇◆	0.09	0.10
Porous Pavement	4	4	244	119	0.03	0.04	0.05 (0.04, 0.05)	0.05 (0.05, 0.07)	◇◆◆	0.08	0.10
Retention Pond	18	19	373	394	0.07	0.03	0.13 (0.11, 0.14)	0.06 (0.05, 0.07)	◆◆◆	0.21	0.14
Wetland Basin	7	7	311	298	0.03	0.03	0.05 (0.05, 0.06)	0.05 (0.04, 0.05)	◇◆◆	0.10	0.08
Wetland Basin/ Retention Pond	25	26	684	692	0.04	0.03	0.08 (0.08, 0.09)	0.05 (0.05, 0.06)	◆◆◆	0.17	0.11
Wetland Channel	5	5	92	89	0.05	0.06	0.08 (0.07, 0.10)	0.09 (0.07, 0.10)	◇◇◇	0.15	0.14

Figure 3. Box Plots of Influent/Effluent Orthophosphate Concentrations (International BMP Database, 2017)

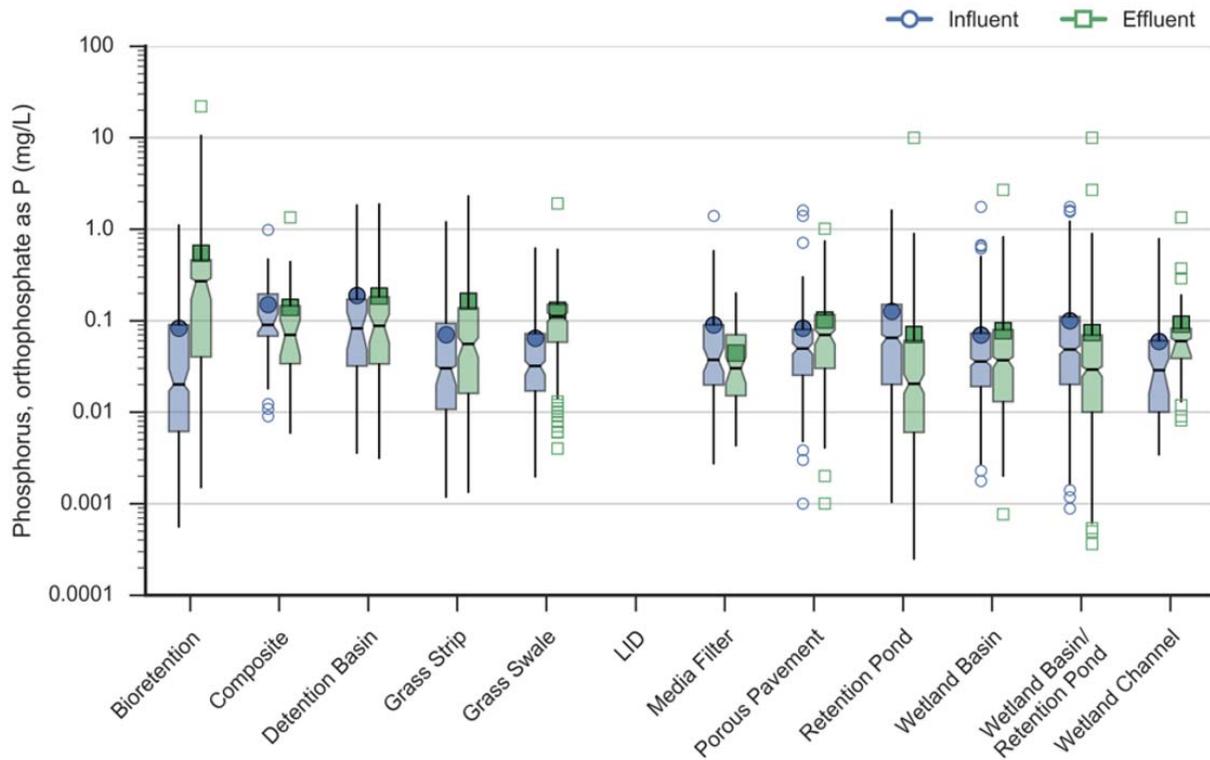


Table 3. Influent/Effluent Summary Statistics for Orthophosphate (mg/L) (International BMP Database, 2017)

BMP Category	BMPs		EMCs		25th		Median			75th		
	In	Out	In	Out	In	Out	In	Out	Difference	In	Out	
Bioretention	20	19	316	269	0.01	0.04	0.02 (0.02, 0.03)		0.27 (0.18, 0.29)	◆◆◆	0.09	0.46
Composite	4	3	54	42	0.07	0.03	0.09 (0.07, 0.12)		0.07 (0.04, 0.10)	◇◇◇	0.20	0.14
Detention Basin	8	8	72	75	0.03	0.03	0.08 (0.05, 0.12)		0.09 (0.06, 0.12)	◇◇◇	0.17	0.18
Grass Strip	13	13	275	218	0.01	0.02	0.03 (0.02, 0.03)		0.06 (0.04, 0.06)	◆◆◆	0.09	0.14
Grass Swale	7	7	218	217	0.02	0.06	0.03 (0.03, 0.04)		0.11 (0.10, 0.12)	◆◆◆	0.07	0.15
Media Filter	7	7	116	115	0.02	0.02	0.04 (0.03, 0.05)		0.03 (0.02, 0.04)	◇◇◆	0.09	0.07
Porous Pavement	6	6	174	114	0.03	0.03	0.05 (0.04, 0.06)		0.07 (0.05, 0.08)	◇◆◆	0.08	0.12
Retention Pond	33	33	524	508	0.02	0.01	0.06 (0.05, 0.07)		0.02 (0.02, 0.03)	◆◆◆	0.15	0.06
Wetland Basin	11	12	452	436	0.02	0.01	0.04 (0.03, 0.04)		0.04 (0.03, 0.04)	◇◇◆	0.07	0.08
Wetland Basin/ Retention Pond	44	45	976	944	0.02	0.01	0.05 (0.04, 0.05)		0.03 (0.02, 0.03)	◆◆◆	0.11	0.07
Wetland Channel	3	3	84	63	0.01	0.04	0.03 (0.02, 0.04)		0.06 (0.04, 0.06)	◆◆◆	0.06	0.08

Another summary report prepared by the International BMP Database team is: Categorical Summary of BMP Performance for Stormwater Nutrients Report Data Contained in the International Stormwater BMP Database (December 23, 2014). This report examines several categories of controls in detail for each constituent, beyond the summary tables and figures shown above.

Manufactured Treatment Devices

The International BMP Database team also prepared a summary of stormwater control effectiveness for manufactured treatment devices (Manufactured Devices Performance Summary July 2012). This special report was prepared because the information it contains is generally not included in the other data analysis reports.

These treatment devices include a wide range of subcategories designed to provide or enhance various treatment processes including sedimentation, skimming, straining, filtration, sorption, and disinfection. Out of the 78 manufactured devices in the BMP Database, 61 provided adequate documentation for data analyses. A description of these treatment subcategories and the number of studies are listed in Table 4. Figures 4 and 5 and Tables 5 and 6 show the performance information for total and filterable phosphorus.

Table 4. Treatment Process Subcategories for Manufactured Devices (International BMP Database, 2012)

Treatment Process Subcategory	Description	# Studies
Biological Filtration	Media filtration devices that support plants or bacterial biofilms.	4
Filtration	Media filtration devices with a variety of media types and configurations (e.g., cartridge filters, vertical bed filters, etc.)	7
Inlet Insert	Catch basin insert devices designed primarily for gross solids capture and oil & grease absorption	11
Multi-process	Multiple treatment processes in series, such as sedimentation followed by filtration.	4
Manufactured Device-Physical	Gravitational settling with hydrodynamic devices	22
Oil/Grit Separators and Baffle Boxes	Oil/grit separators and baffle boxes designed for removing floatables and coarse solids.	8
Physical w/Volume Control	Detention vaults, pipes, or other structures with open bottoms that allow infiltration of stored water.	5
TOTAL		61

Figure 4. Box Plots of Influent/Effluent Total Phosphorus Concentrations (International BMP Database, 2012)

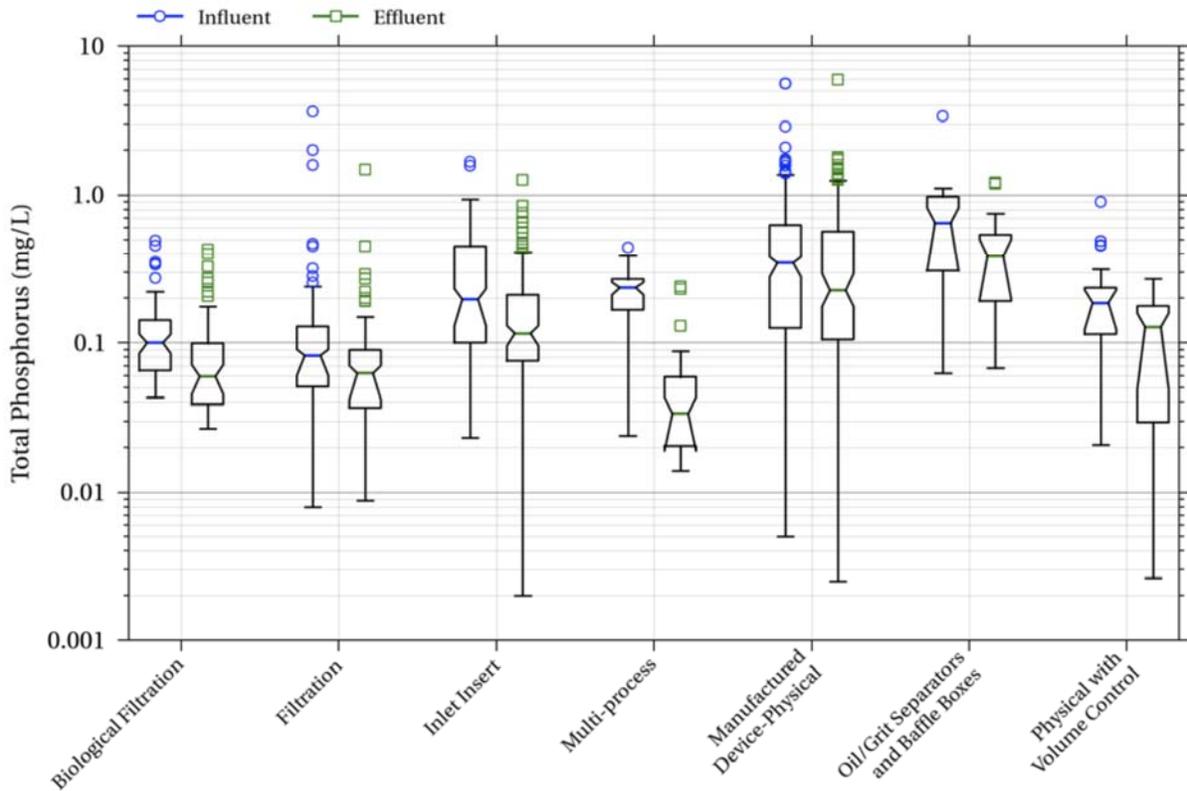


Table 5. Influent/Effluent Summary Statistics for Total Phosphorus (mg/L) (International BMP Database, 2012) (attachment 3 is in the BMP Database report and not included in this appendix)

BMP Type	Count of Studies and EMCs		25th Percentile		Median (95% Conf. Interval)*		75th Percentile	
	In	Out	In	Out	In	Out	In	Out
Biological Filtration	4, 64	4, 64	0.06	0.04	0.10 (0.08, 0.11)	0.06 (0.05, 0.07)**	0.14	0.10
Filtration	7, 98	7, 98	0.05	0.04	0.08 (0.06, 0.09)	0.06 (0.04, 0.07)**	0.13	0.09
Inlet Insert	5, 53	11, 130	0.10	0.08	0.20 (0.13, 0.23)	0.12 (0.09, 0.13)**	0.45	0.21
Multi-process	3, 28	3, 27	0.17	0.02	0.23 (0.21, 0.25)	0.03 (0.02, 0.04)**	0.27	0.06
Manufactured Device-Physical	18, 300	18, 257	0.13	0.10	0.35 (0.28, 0.38)	0.22 (0.17, 0.29)**	0.63	0.57
Oil/Grit Separators and Baffle Boxes	4, 23	4, 22	0.31	0.19	0.65 (0.28, 0.82)	0.39 (0.20, 0.50)	0.97	0.54
Physical with Volume Control	4, 36	4, 36	0.11	0.03	0.19 (0.12, 0.23)	0.13 (0.05, 0.16)**	0.23	0.18

*Computed using the BCa bootstrap method described by Efron and Tibishirani (1993)

**Hypothesis testing using the Mann-Whitney test in Attachment 3 shows statistically significant decreases for this BMP category.

Figure 5. Box Plots of Influent/Effluent Dissolved Phosphorus Concentrations (International BMP Database, 2012)

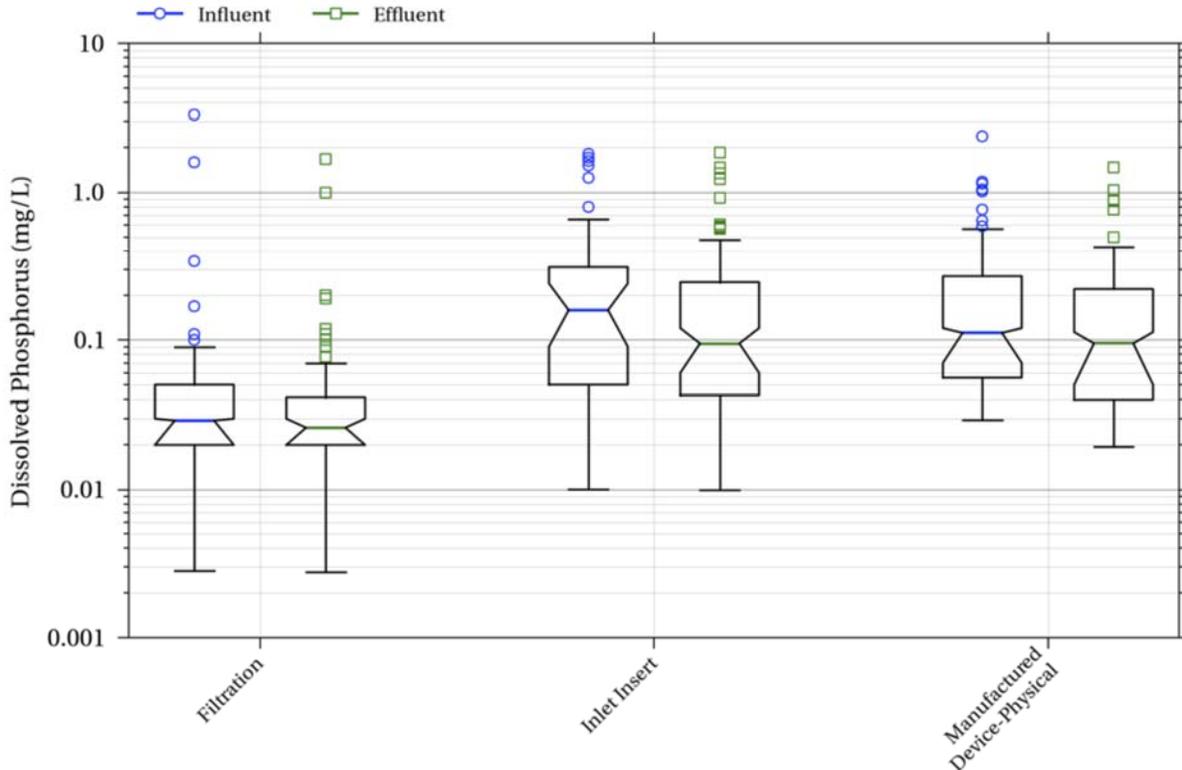


Table 6. Influent/Effluent Summary Statistics for Dissolved Phosphorus (mg/L) (International BMP Database, 2012)

BMP Type	Count of Studies and EMCs		25th Percentile		Median (95% Conf. Interval)*		75th Percentile	
	In	Out	In	Out	In	Out	In	Out
Biological Filtration	NA	NA	NA	NA	NA	NA	NA	NA
Filtration	4, 71	4, 71	0.02	0.02	0.03 (0.02, 0.03)	0.03 (0.02, 0.03)	0.05	0.04
Inlet Insert	5, 53	11, 80	0.05	0.04	0.16 (0.09, 0.25)	0.09 (0.06, 0.12)	0.31	0.24
Multi-process	NA	NA	NA	NA	NA	NA	NA	NA
Manufactured Device-Physical	5, 89	5, 84	0.06	0.04	0.11 (0.07, 0.12)	0.09 (0.05, 0.11)	0.27	0.22
Oil/Grit Separators and Baffle Boxes	NA	NA	NA	NA	NA	NA	NA	NA
Physical with Volume Control	NA	NA	NA	NA	NA	NA	NA	NA

NA – not available or less than 3 studies for BMP/constituent.

*Computed using the BCa bootstrap method described by Efron and Tibishirani (1993)

Stormwater Control Volume Reductions

The International BMP Database team also prepared a special report investigating volume reduction associated with stormwater controls (Expanded Analysis of Volume Reduction in Bioretention BMPs, May 2012). Table 7 reports the calculated volume reductions as a percentage of the inflow water volume for all of these studies, with or without underdrains.

Table 7. Relative Volume Reduction Statistics for Bioretention Studies (International BMP Database, 2012)

Analysis Group	# Studies	25 th Pctl.	Median	75 th Pctl.	Avg.
All Studies	20	42%	66%	98%	66%
No Underdrains	6	85%	99%	100%	89%
With Underdrains	14	33%	52%	73%	56%

Figure 6 below shows average relative percent volume reductions plotted against the ratio of the drainage area to the bioretention surface areas. These data illustrate that the use of underdrains substantially reduce the amount of runoff infiltrated, as the underdrains deliver treated runoff to the stormwater collection system when the water accumulates in the device to the level of the underdrain, substantially reducing the time available for infiltration. Obviously, there are situations when standing water would occur for prolonged periods (usually a three day limit in most areas to prevent mosquito problems), or if infiltration to the groundwater would cause potential adverse contamination. In those cases, underdrains are needed. The use of underdrains should therefore be carefully evaluated before their use and properly placed in the device (elevated in the storage layer and not along the bottom of the device).

Figure 6. Study Average Relative Percent Volume Reduction versus The Ratio Of BMP Surface Area to Tributary Area (International BMP Database, 2012).

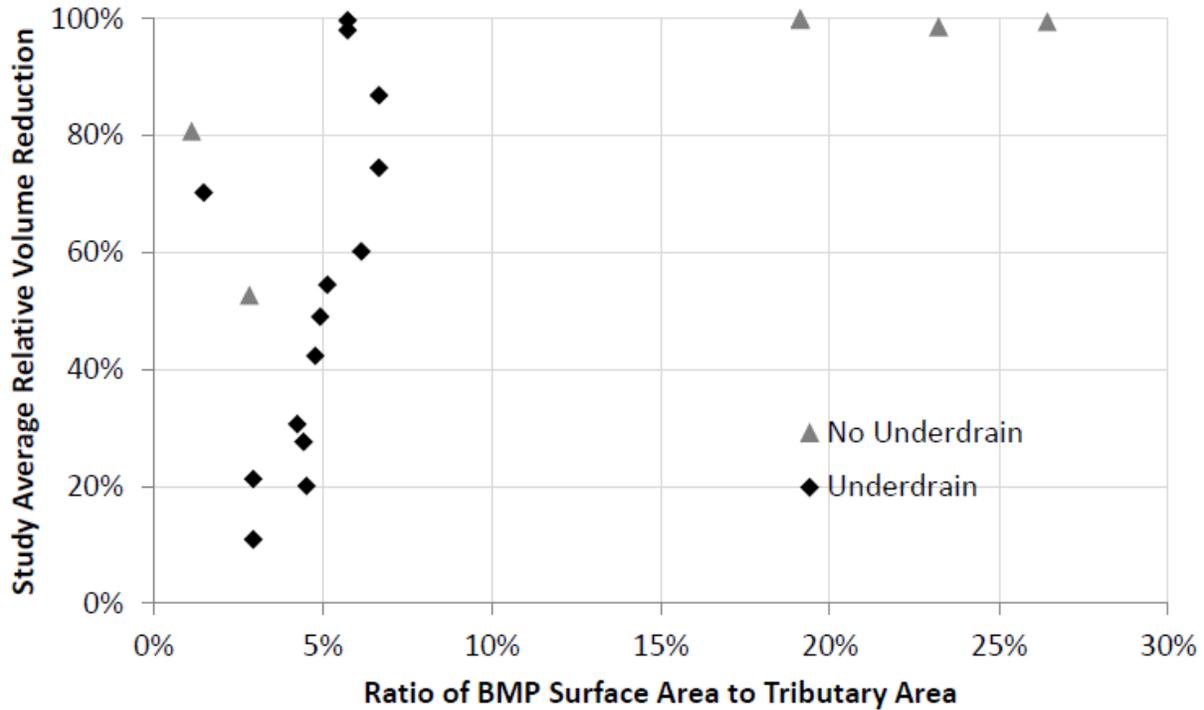


Figure 6 indicates that performance is strongly influenced by the ratio of the surface area of the device to the tributary area. With small controls in large areas (relative), more of the stormwater would bypass treatment by overflowing the device and enter the stormwater collection system with little treatment.

Phosphorus Reductions by Stormwater Controls in Chesapeake Bay Region

A summary report was prepared in May 2012 addressing stormwater controls in the Chesapeake Bay region (Geosyntec Consultants and Wright Water Engineers. International Stormwater Best Management Practices (BMP) Database: BMP Performance Summary: Chesapeake Bay and Related Areas, 150 pages), from which the following figures and tables originated. The following is quoted from this report:

“Figure 7 includes box plots of influent and effluent concentrations for total phosphorus for various BMP types for the CBay area, and summarizes the non-parametric summary statistics. As shown in the figure and table, detention basins, media filters, retention ponds, and wetland basins all appear to reduce median total phosphorus concentrations. Manufactured devices also appear capable of removing total phosphorus, but not consistently below about 0.16 mg/L. Grass strips show a tendency to increase total phosphorus; however with a paired influent/effluent analysis this increase is not significant at the 95% confidence level. Also, some of the influent/effluent data pairs for bioretention plotted in Attachment 2 indicate that export of phosphorus may occur, particularly when influent concentrations are low. Media filters, retention

ponds and wetland basins tend to achieve the most dramatic decreases in total phosphorus with median effluent concentrations around 0.1 mg/L.” Table 8 also summarizes the performance of the stormwater controls located in the Chesapeake Bay watershed.

Figure 7. Box Plots of Influent/Effluent Total Phosphorus Concentrations by BMP Type located in the Chesapeake Bay Watershed (International BMP Database, 2012).

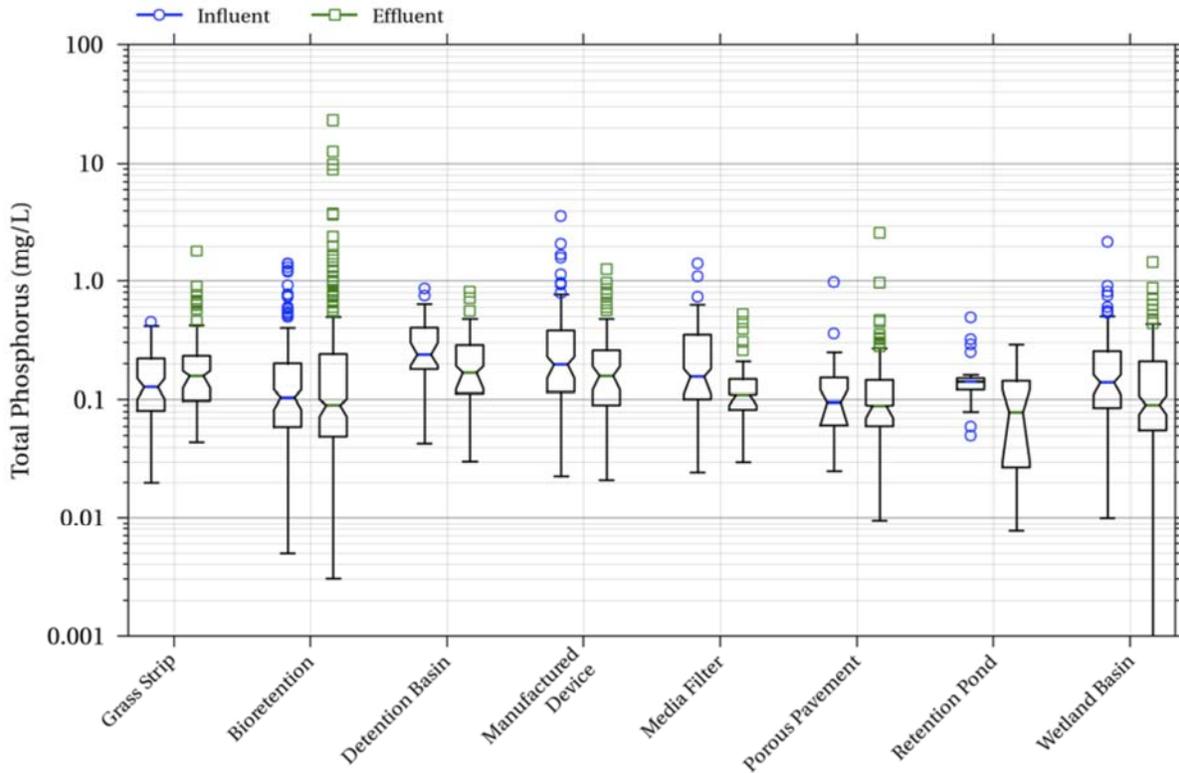


Table 8. Influent/Effluent Summary Statistics for Total Phosphorus for Stormwater Controls Located in the Chesapeake Bay Watershed (International BMP Database, 2012)

BMP Type	Count of Studies and EMCs		25th Percentile		Median (95% Conf. Interval)		75th Percentile	
	In	Out	In	Out	In	Out	In	Out
Grass Strip	8, 138	8, 122	0.08	0.10	0.13 (0.10, 0.15)	0.16 (0.12, 0.17)	0.22	0.23
Bioretention	15, 224	15, 205	0.06	0.05	0.10 (0.08, 0.12)	0.09 (0.07, 0.10)	0.20	0.24
Detention Basin	6, 55	6, 67	0.18	0.11	0.24 (0.19, 0.30)	0.17 (0.12, 0.19)	0.40	0.29
Manufactured Device	11, 107	11, 106	0.11	0.09	0.20 (0.15, 0.23)	0.16 (0.12, 0.19)	0.38	0.26
Media Filter	4, 57	5, 62	0.10	0.08	0.16 (0.11, 0.18)	0.11 (0.09, 0.11)	0.35	0.15
Porous Pavement	5, 50	11, 163	0.06	0.06	0.09 (0.06, 0.12)	0.09 (0.07, 0.09)	0.15	0.15
Retention Pond	3, 21	4, 32	0.12	0.03	0.14 (0.14, 0.14)	0.08 (0.03, 0.12)	0.15	0.14
Wetland Basin	4, 111	4, 112	0.09	0.06	0.14 (0.11, 0.16)	0.09 (0.07, 0.11)	0.25	0.21

The Chesapeake Bay Watershed (International BMP Database, 2012) report further describes the notations in the “BMP Type” column of Table 8, as follows:

“To identify the strength of the statistical differences as determined from comparisons of 1) confidence intervals about the medians, 2) results from the Mann-Whitney test, and 3) results from the Wilcoxon test, a key has been developed for use in summary tables below. A solid square next to a BMP type is used to indicate differences for each comparison method and an empty square is used to indicate the differences are not significant. The key to this symbology is as follows:

- • • 95% confidence intervals for the medians *do not overlap*, Mann-Whitney test has a p-value *less* than 0.05, Wilcoxon test has a p-value *less* than 0.05.
- • • 95% confidence intervals for the medians *overlap*, Mann-Whitney test has a p-value *less* than 0.05, Wilcoxon test has a p-value *less* than 0.05.
- ◦ • 95% confidence intervals for the medians *overlap*, Mann-Whitney test has a p-value *less* than 0.05, Wilcoxon test has a p-value *greater* than 0.05.
- ◦ ◦ 95% confidence intervals for the medians *overlap*, Mann-Whitney test has a p-value *greater* than 0.05, Wilcoxon test has a p-value *less* than 0.05.

The solid squares are also colored to indicate whether the effluent median may be lower or higher than the influent. If the square is green, then the effluent median is less than the influent median and if the square is red, the effluent median is greater than the influent median. Be aware that for some BMP types, a statistically significant difference between influent and effluent concentrations may not be present, but the effluent concentrations achieved by the BMP are relatively low and may be comparable to the performance of other BMPs that have statistically significant differences between inflow and outflow. For example, data sets that have low influent concentrations and similarly low effluent concentration (i.e., clean water in = clean water out) may not show statistically significant differences.”

Summaries for dissolved phosphorus influent and effluent concentrations are shown in Figure 8 and Table 9. Only sufficient dissolved phosphorus data are available for manufactured devices and wetland basins. Manufactured devices do not demonstrate significant removals, but wetland basins are capable of reducing median effluent concentrations of dissolved phosphorus to 0.04 mg/L. However, the 75th percentile effluent concentration is still greater than 100 µg/L.

Figure 8. Box Plots of Influent/Effluent Dissolved Phosphorus Concentrations by BMP Type Located in the Chesapeake Bay Watershed (International BMP Database, 2012).

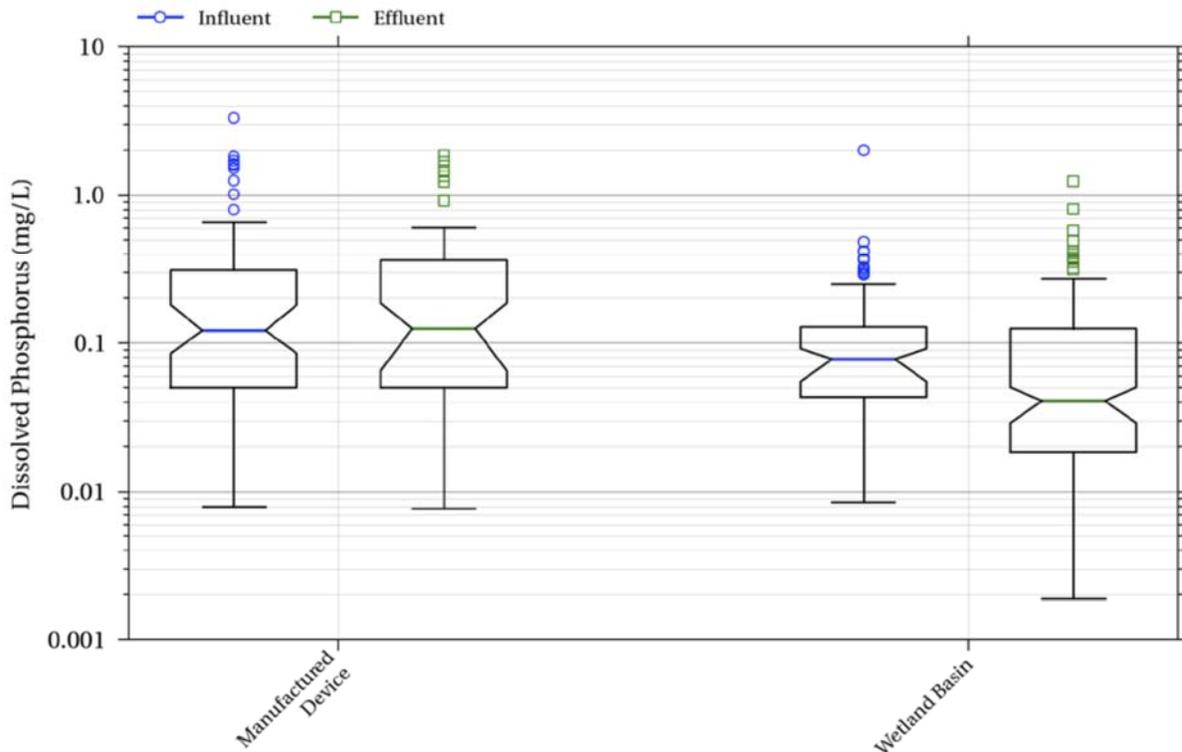


Table 9. Influent/Effluent Summary Statistics for Dissolved Phosphorus Associated with Stormwater Controls Located in the Chesapeake Bay Watershed (International BMP Database, 2012)

BMP Type		Count of Studies and EMCs		25th Percentile		Median (95% Conf. Interval)		75th Percentile	
		In	Out	In	Out	In	Out	In	Out
Manufactured Device	ooo	7, 74	7, 74	0.05	0.05	0.12 (0.08, 0.18)	0.13 (0.06, 0.19)	0.31	0.36
Wetland Basin	ooo	4, 104	4, 103	0.04	0.02	0.08 (0.06, 0.09)	0.04 (0.03, 0.05)	0.13	0.12

Performance summaries for orthophosphate are shown in Figure 9 and Table 10. Only media filters show statistically significant removals. Grass strips and bioretention practices tend to increase median orthophosphate concentrations, as they did for total phosphorus. However, it was pointed out that the studies in both of these categories had very low influent concentrations. Therefore, conclusions concerning the performance of manufactured devices for orthophosphate are unclear based on the data available (Mann-Whitney p-value = 0.256; Wilcoxon p-value = 0.001). The report also indicated that “subcategories of manufactured devices that include

adsorptive media may be more effective at reducing orthophosphate concentrations than the overall manufactured device category.”

Figure 9. Box Plots of Influent/Effluent Orthophosphate Concentrations by BMP Type Located in the Chesapeake Bay Watershed (International BMP Database, 2012).

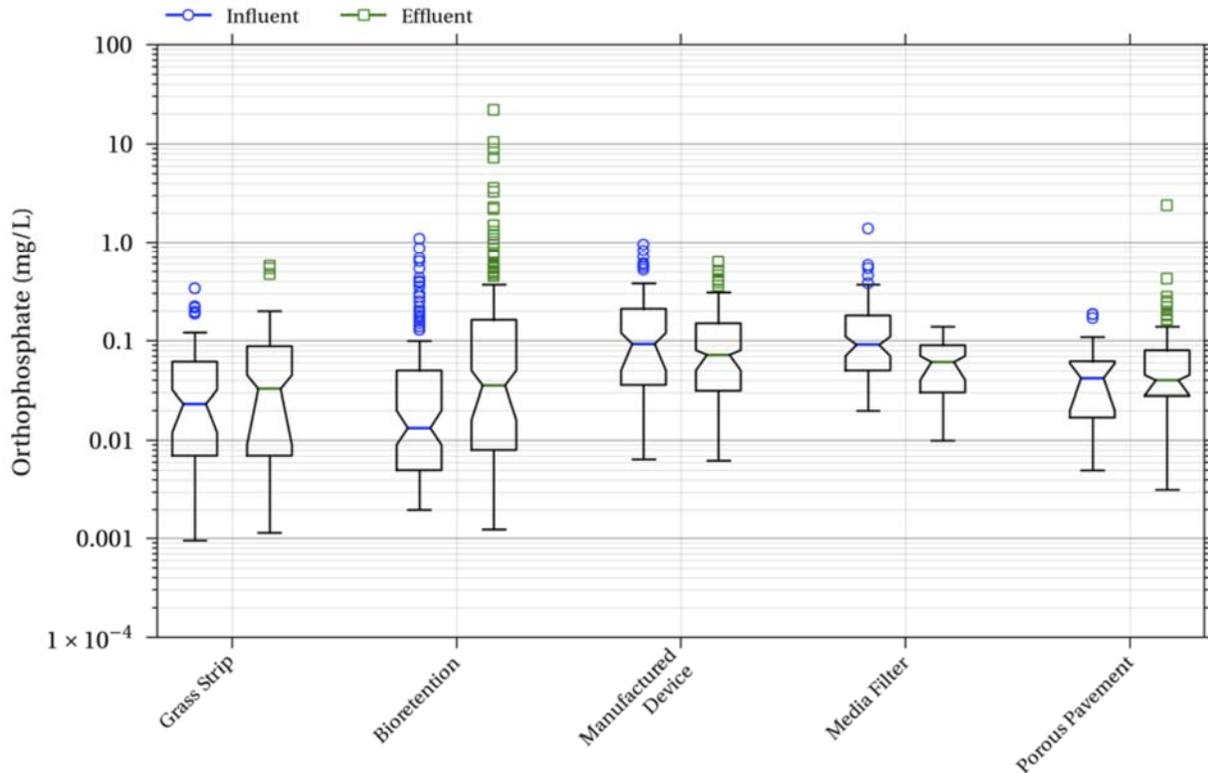


Table 10. Influent/Effluent Summary Statistics for Orthophosphate for Stormwater Controls Located in the Chesapeake Bay Watershed (International BMP Database, 2012)

BMP Type		Count of Studies and EMCs		25th Percentile		Median (95% Conf. Interval)		75th Percentile	
		In	Out	In	Out	In	Out	In	Out
Grass Strip	--■	5, 90	5, 89	0.01	0.01	0.02 (0.01, 0.03)	0.03 (0.01, 0.05)	0.06	0.09
Bioretention	---■	13, 164	13, 164	0.00	0.01	0.01 (0.01, 0.02)	0.04 (0.02, 0.05)	0.05	0.16
Manufactured Device	--■	7, 69	7, 69	0.04	0.03	0.09 (0.05, 0.12)	0.07 (0.05, 0.08)	0.21	0.15
Media Filter	---■	4, 57	4, 56	0.05	0.03	0.09 (0.07, 0.11)	0.06 (0.04, 0.07)	0.18	0.09
Porous Pavement	---■	5, 42	7, 69	0.02	0.03	0.04 (0.02, 0.06)	0.04 (0.03, 0.05)	0.06	0.08

This Chesapeake Bay summary report also contains detailed information for each category of these control practices for each constituent.

Performance Summary of Phosphorus Stormwater Controls as Shown in the International BMP Database

Tables 11 and 12 summarize the stormwater phosphorus control practices as reported by the International BMP Database in several of their reports.

Table 11. Treated Stormwater Phosphorus Concentrations (from 2017 International BMP Database report)

	Total Phosphorus (mg/L)		Dissolved Phosphorus (mg/L)		Orthophosphate (mg/L)	
	median effluent concentration	75 th percentile effluent concentration	median effluent concentration	75th percentile effluent concentration	median effluent concentration	75th percentile effluent concentration
Grass strips	0.17 (increase)	0.34 (increase)	0.23 (increase)	0.38 (increase)	0.06 (increase)	0.14 (increase)
Grass swales	0.20 (increase)	0.29 (increase)	0.06 (no change)	0.25 (increase)	0.11 (increase)	0.15 (increase)
Bioretention	0.24 (increase)	0.59 (increase)	0.40 (increase)	0.88 (increase)	0.27 (increase)	0.46 (increase)
Composite	0.13	0.22	0.08	0.13	no significant change	no significant change
Detention basins	0.19	0.30	no significant change	no significant change	no significant change	no significant change
Media filters	0.09	0.16	0.04 (Wilcoxon only significant test result)	0.10 (Wilcoxon only significant test result)	0.03 (Wilcoxon only significant test result)	0.07 (Wilcoxon only significant test result)
Porous pavement	0.11	0.20	0.05 (no change)	0.10 (increase)	0.07 (increase)	0.12 (increase)
Retention pond	0.09	0.20	0.06	0.14	0.02	0.06
Wetland basin	0.12	0.22	0.05 (no change)	0.08	0.04 (no change) (Wilcoxon only significant test result)	0.08 (increase) (Wilcoxon only significant test result)
Wetland basin/retention pond	0.10	0.21	0.05	0.11	0.03	0.07
Wetland channel	0.15 (Wilcoxon only significant test result)	0.24 (Wilcoxon only significant test result)	no significant change	no significant change	0.06 (increase)	0.08 (increase)

Table 12. Treated Stormwater Phosphorus Concentrations from Manufactured Treatment Devices (from 2012 International BMP Database report)

	Total Phosphorus (mg/L)		Dissolved Phosphorus (mg/L)	
	median effluent concentration	75 th percentile effluent concentration	median effluent concentration	75 th percentile effluent concentration
Biological filtration	0.06	0.10	NA	NA
Filtration	0.06	0.09	no significant change	no significant change
Inlet insert	0.12	0.21	no significant change	no significant change
Multi-process	0.03	0.06	NA	NA
Manufactured device – physical	0.22	0.57	no significant change	no significant change
Oil/Grit separators and baffle boxes	no significant change	no significant change	NA	NA
Physical with volume control	0.13	0.18	NA	NA

NA = not available

The final effluent phosphorus concentrations are seen to increase with the bioretention, grass filters, and grass swales stormwater controls. This has been commonly reported by researchers when the stormwater is exposed to media containing compost or some other organic material, fertilized landscaped surfaces, and even phosphorus enriched soils (as in the filters and swales). Media filters, porous pavement, retention ponds, wetland basins, and wetland basins with retention ponds all have median concentrations at 0.09 or 0.10 mg/L. However, the corresponding 75th percentile values were at, or greater than, 0.16 mg/L. The treatment trains (multi-process manufactured treatment device) had the lowest median total phosphorus effluent concentrations, reported as 0.03 mg/L. Sand filtration (no additional media) also had a relatively low total phosphorus effluent concentration at 0.06 mg/L. The 75th percentile values for these two controls were substantially greater at 0.06 and 0.09 mg/L, respectively. The maximum observed effluent concentrations are not summarized but can be seen on the grouped box and whisker plots to be substantially larger than the 75th percentile values. Dissolved phosphorus and orthophosphates are much more challenging to control, as they are not affected by sedimentation processes.

Some of these treatment controls, such as all of the manufactured treatment devices, bioretention, media filters, and porous pavement, are only suitable for small source areas. These controls only affect a portion of the stormwater from a site. The uncontrolled areas would not have their concentrations decreased unless treated at larger drainage system (swales) or outfall (detention and retention ponds, and wetlands) locations.

Besides concentration reductions, modern stormwater controls also emphasize runoff volume reductions. If an area is sensitive to mass discharges (such as lake receiving waters), then mass discharges are likely more important than concentration values.