



**INTERNATIONAL
STORMWATER BMP
DATABASE**
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International Stormwater Best Management Practices (BMP) Database

Manufactured Devices Performance Summary

Prepared by

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1 INTRODUCTION

“Manufactured devices” is an all-encompassing category of proprietary BMP data in the International Stormwater BMP Database (BMPDB). These devices include a wide variety of configurations and components designed to provide various treatment processes such as sedimentation, skimming, straining, filtration, sorption, and disinfection. The treatability of particular stormwater pollutants by a device is directly related to the treatment processes it provides (as well as its sizing relative to inflows.) For example, sediment and particulate-bound pollutants may be removed by sedimentation, but dissolved constituents may require adsorptive filtration or some type of biochemical process to be effectively removed.

The purpose of this paper is to provide a performance summary of manufactured devices contained in the BMP Database after subdividing this broad BMP category based on their dominant treatment process. This analysis does not provide summaries of manufactured device performance by manufacturer and does not provide endorsement for any particular manufactured device. Many different vendor technologies are commercially available for which there are no data currently included in the BMP Database. To be included in the BMP Database, proprietary manufactured devices must meet the conditions of the BMP Database Proprietary Device Policy (see <http://www.bmpdatabase.org/Policies.htm>).

The analyses presented here is similar to what the BMPDB Project Team has published for the technical papers on categorical BMP performance for solids, metals, and nutrients (<http://www.bmpdatabase.org/BMPPerformance.htm>). In all of these papers, Manufactured Devices are included as a single BMP type (i.e., not sub-divided by dominant unit treatment processes). This report is a companion paper to the technical papers on categorical BMP performance with performance of these devices now summarized based upon treatment process categories. Only statistical summaries of BMP performance are provided here. Background information on regulatory context, pollutant sources, fate and transport, and removal mechanisms can be found in the previously referenced technical papers presented by pollutant category.

Manufactured devices contained in the BMPDB were divided into seven treatment process subcategories. Out of the 78 manufactured devices in the BMP Database, 61 had adequate data sets suitable for sub-category-level water quality analysis. A description of these subcategories and the number of studies analyzed in each subcategory are listed in Table 1.

Table 1. Treatment Process Subcategories for Manufactured Devices.

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

Table 2 lists the water quality constituents that have been analyzed for the various manufactured device subcategories and that are summarized in the main body of this report. Some additional constituents are provided in the statistical attachments to this data summary. For some studies, either nitrate plus nitrite is reported or only nitrate is reported. Very few studies report both quantities; presumably because nitrite is typically found in low concentrations relative to nitrate in surface waters. Consequently, NO₃/NO₂ and NO₃ were combined prior to data analysis (referred to as NO_x). Only NO₃/NO₂ concentrations were used in the analysis for studies that reported both quantities. In addition to the constituents in Table 2, a limited fecal indicator bacteria data set is available for some of the manufactured device categories, but was not included in this summary due to the paucity of data. Also, note that volume control was not analyzed because with the exception of the subcategory Physical w/Volume Control these BMPs are not designed to reduce runoff volumes.

Table 2. Constituents Summarized by Pollutant Category.

Pollutant Category	Summarized Constituent
Solids	Total suspended solids (TSS)
Metals	Copper (total and dissolved) Lead (total and dissolved) Zinc (total and dissolved)
Nutrients	Total phosphorus Dissolved phosphorus Total Kjeldahl nitrogen (TKN) Nitrate plus nitrite (NO _x)

2 PROCESS CATEGORY MANUFACTURED DEVICE ANALYSIS

An overview of the performance for the analyzed constituents is provided below. The analyses are based upon the distributions of effluent EMCs for individual events by BMP category, thereby providing greater weight to those BMPs for which there are a larger number of data points reported. In other words, the performance analysis presented in this technical summary is “storm-weighted” (EMC weighted) as opposed to “BMP weighted” (site median weighted).² This update does not include BMP-weighted analyses.

The data were analyzed utilizing the same general procedures as the previously published technical papers. In the subsections below, side-by-side box plots have been generated using the influent and effluent concentrations from the manufactured device studies. For each treatment process category, the influent box plots are provided on the left and the effluent box plots are provided on the right. A key to the box plots is provided in Figure 1.

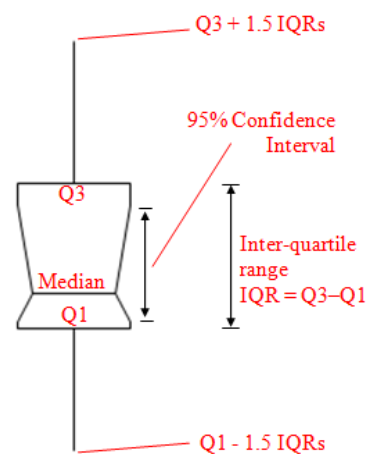
In addition to the box plots, tables of influent/effluent medians, 25th and 75th percentiles, and number of studies and data points for each manufactured device process category are provided, along with 95% confidence intervals about the medians. As per the previous technical papers, the median and interquartile ranges were selected as descriptive statistics for BMP performance because they are non-parametric (do not require distributional assumptions for the underlying data set) and are less affected by extreme values than means and standard deviations. Additionally, the median is less affected by assumptions regarding values below detection limits and varying detection limits for studies conducted by independent parties over many years. However, confidence intervals about the median can still be affected by outliers if simple substitution is used. Therefore, a robust regression-on-order statistics (ROS) method as described by Helsel and Cohn (1988) was utilized to provide probabilistic estimates of non-detects before computing descriptive statistics.

² There are several viable approaches to evaluating data in the BMP Database. Two general approaches that have been presented in the past (Geosyntec Consultants and Wright Water Engineers, 2008) are the “BMP-weighted” and “storm-weighted” approaches. The BMP-weighted approach represents each BMP with one value representing the central tendency and variability of each individual BMP study, whereas the storm-weighted approach combines all of the storm events for the BMPs in each category and analyzes the overall storm-based data set. The storm-weighted approach has been selected for this memorandum as it provides a much larger data set for analysis and preserves the storm-to-storm variability of the data.

Confidence intervals in the figures and tables were generated using the bias corrected and accelerated (BCa) bootstrap method described by Efron and Tibishirani (1993). This method is a robust approach for computing confidence intervals that is resistant to outliers and does not require any restrictive distributional assumptions. Due to random sampling that is conducted as part of this method, insignificant variations in the results may occur and is the cause of any inconsistencies between the values in the attachments and the tables presented below. Comparison of the confidence intervals about the influent and effluent medians can be used to roughly identify statistically significant differences between the central tendencies of the data. However, non-parametric hypothesis tests, such as the Mann-Whitney rank sum test or the Wilcoxon signed-rank test, can provide additional and more robust results for evaluating significant differences between medians. The Mann-Whitney test applies to independent data sets, whereas the Wilcoxon test applies to paired data sets (Helsel and Hirsch, 1992). Results of these tests are provided in the attached statistical summary reports for TSS, metals, and nutrients.

Figure 1. Box Plot Key

+ Possible outlier (> 1.5 IQRs from Q3)



In the summary tables which follow, effluent values in **bold green** indicate the upper 95% confidence interval of the effluent median is less than the lower 95% confidence interval of the influent median. Effluent values in **red bold italics** indicate the lower 95% confidence interval of the effluent median is greater than the upper 95% confidence interval of the influent median. Values with no color italic emphasis indicate the influent and effluent intervals overlap. Statistically significant differences based on the Mann-Whitney hypothesis test results are identified by asterisks (*) in the tables. Process categories with less than three studies with effluent data available were omitted from this summary.

Be aware that for some treatment process subcategories, a statistically significant difference between influent and effluent concentrations may not be present, but the effluent concentrations achieved 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. However this does not necessarily imply that the device type would not have been effective at higher influent concentrations.

In addition to the above caveats on the performance summaries, the following aspects of the data set may affect observations drawn from the statistical analysis:

- **Subcategory Representation:** As shown in Table 1, several subcategories of manufactured devices have relatively limited data sets; therefore, observations related to performance may change over time as more data are collected for these.

- **Inlet Insert Subcategory:** Hypothesis testing results related to statistically significant differences between inflow and outflow for the inlet insert subcategory should be used with caution due to the imbalance of inflow/outflow data points. Users may prefer to rely on the Wilcoxon signed rank test for paired data sets (inflow and outflow paired by event) provided in the statistical attachments. The inlet insert category is limited to two research efforts monitoring multiple manufactured device installations: one conducted by the Delaware Department of Transportation at a park-and-ride facility and the second conducted by Caltrans as part of a BMP Retrofit Pilot Program in 2004. All of the paired data for the inlet insert subcategory are limited to the Delaware study BMPs. The Caltrans study focused on effluent characterization, so there are no paired inflow-outflow samples for the Caltrans inlet inserts.
- **Manufactured Device-Physical Subcategory:** The median TSS inflow concentration for this subcategory is relatively low (33.6 mg/L) compared to several other subcategories. As a result, hypothesis testing used to assess whether statistically significant reductions in TSS occur with this subcategory has some limitations (i.e., it appears that this subcategory was installed at generally cleaner locations, so it is unknown how this subcategory would perform at “dirtier” locations). Relatively low influent concentrations for total lead were also observed for this subcategory.
- **Filtration Subcategory:** Influent concentrations for the filtration subcategory were much lower than other subcategories for most constituents. This is particularly notable for total copper, dissolved and total zinc, total and dissolved phosphorus, TKN, and NO_x. As a result, relative comparisons between effluent concentrations for this constituent are not informative and hypothesis testing for these constituents may be inconclusive regarding the ability of this manufactured device subcategory to provide statistically significant reductions of various pollutants.
- **Dissolved metals data sets** are generally limited for most manufactured device subcategories. Additionally, large percentages of non-detects in the influent for several dissolved metals limit conclusions that can be drawn regarding statistically significant differences between influent and effluent concentrations.

Performance analysis results by manufactured device treatment process subcategory are provided below and in the statistical attachments. Sections 2.1 through 2.3 include side-by-side box plots followed by tabular influent/effluent summary statistics for the constituents listed in Table 2. Key observations of this statistical summary are provided in Section 3.

2.1 Total Suspended Solids

Figure 2. Box Plots of Influent/Effluent TSS Concentrations

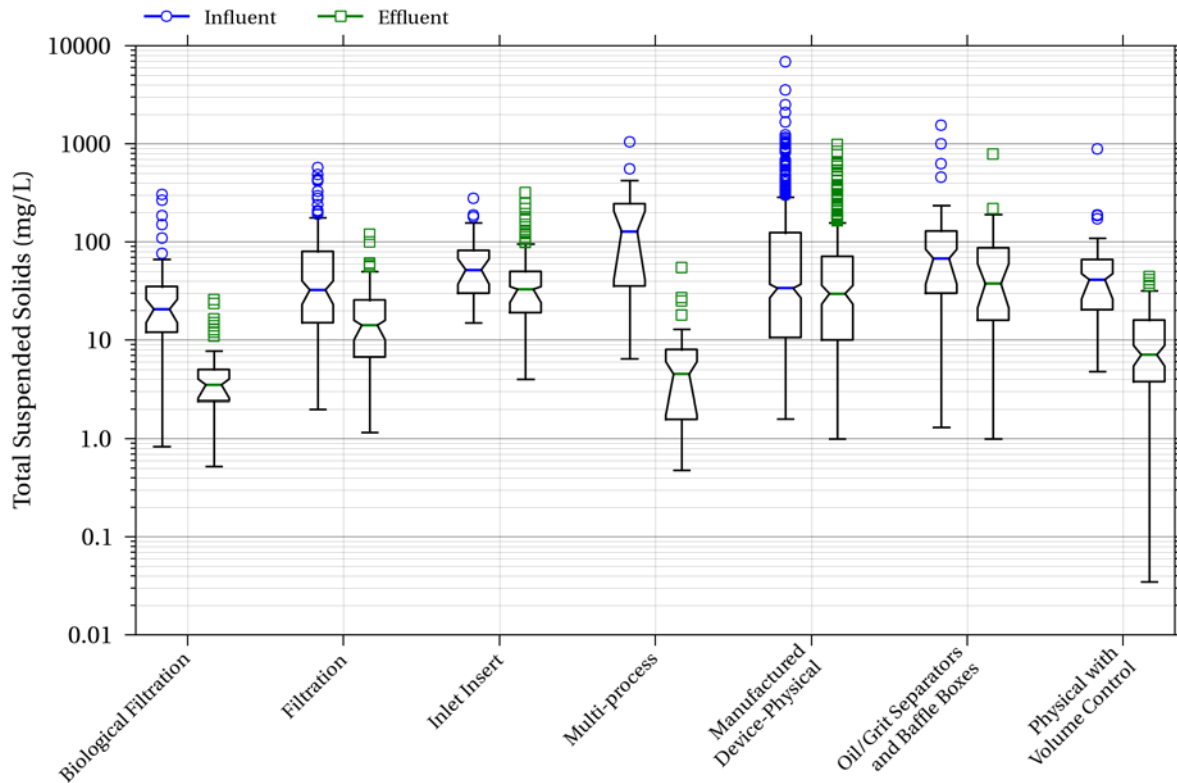


Table 3. Influent/Effluent Summary Statistics for TSS (mg/L)

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, 72	4, 72	12.0	2.4	20.5 (15.5, 25.9)	3.5 (2.5, 4.0)**	35.1	5.0
Filtration	7, 125	7, 125	15.0	6.7	32.3 (23.0, 40.0)	14.2 (10.0, 15.0)**	80.0	25.6
Inlet Insert	5, 53	11, 141	30.0	19.0	51.7 (37.0, 67.0)	32.9 (24.0, 35.0)**	82.0	50.0
Multi-process	4, 41	4, 36	35.5	1.6	127.4 (41.0, 206.0)	4.5 (1.7, 6.0)**	245.0	8.0
Manufactured Device-Physical	22, 487	22, 376	10.6	10.0	33.6 (26.8, 37.0)	29.7 (23.4, 36.0)	124.2	71.3
Oil/Grit Separators and Baffle Boxes	7, 51	8, 53	30.0	15.9	67.6 (35.2, 84.0)	37.3 (21.2, 59.8)**	129.1	87.0
Physical with Volume Control	5, 62	5, 62	20.4	3.8	41.2 (26.8, 47.6)	7.1 (5.4, 8.8)**	66.1	16.0

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

**Hypothesis testing using the Mann-Whitney test in Attachment 1 shows statistically significant decreases for this BMP category.

2.2 Metals

2.2.1 Copper

Figure 3. Box Plots of Influent/Effluent Total Copper Concentrations

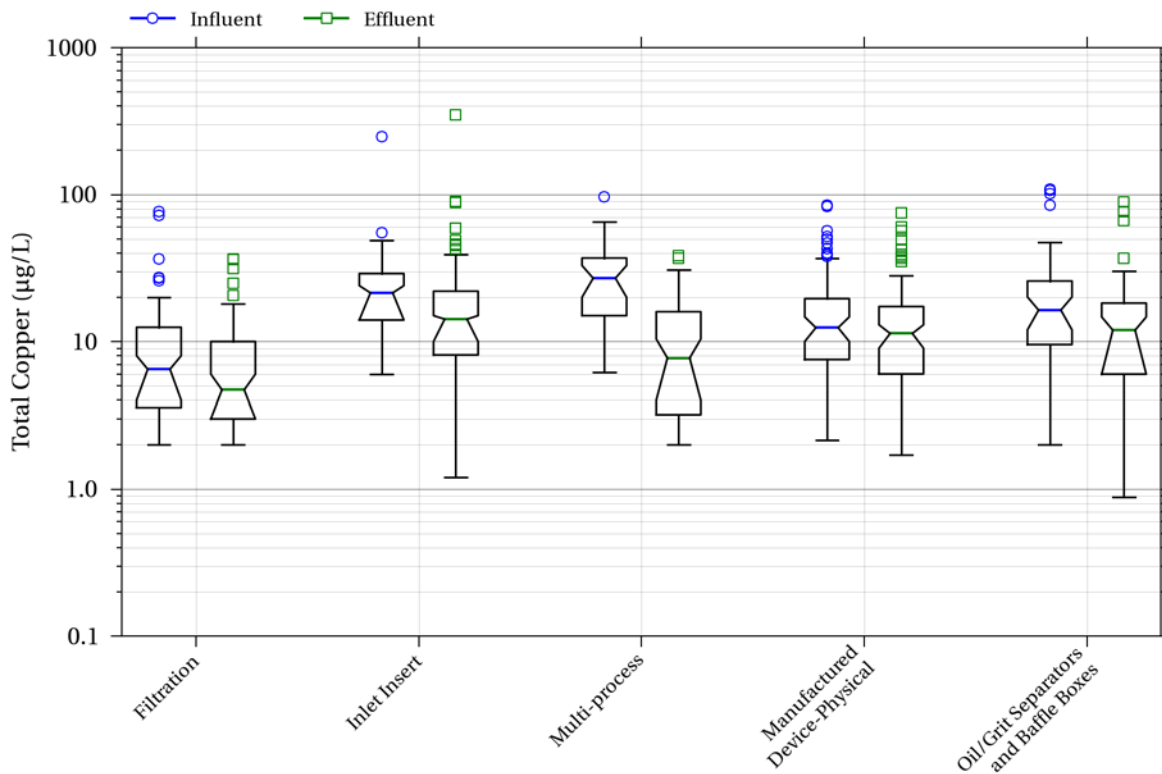


Table 4. Influent/Effluent Summary Statistics for Total Copper (µg/L)

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	3, 55	3, 55	3.58	3.00	6.48 (4.00, 8.00)	4.70 (3.00, 6.00)	12.50	10.00
Inlet Insert	5, 53	11, 141	14.00	8.10	21.43 (14.00, 24.00)	14.20 (10.42, 15.00)**	29.00	22.00
Multi-process	4, 41	4, 38	15.00	3.20	27.01 (20.00, 32.90)	7.74 (4.00, 10.40)**	37.00	15.95
Manufactured Device-Physical	8, 139	8, 133	7.54	6.01	12.41 (10.00, 14.70)	11.35 (9.00, 13.00)	19.58	17.30
Oil/Grit Separators and Baffle Boxes	4, 32	4, 31	9.53	6.00	16.33 (12.00, 20.10)	11.95 (6.00, 14.69)	25.80	18.26
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)

**Hypothesis testing in Attachment 2 using the Mann-Whitney test shows statistically significant decreases for this BMP category.

Figure 4. Box Plots of Influent/Effluent Dissolved Copper Concentrations

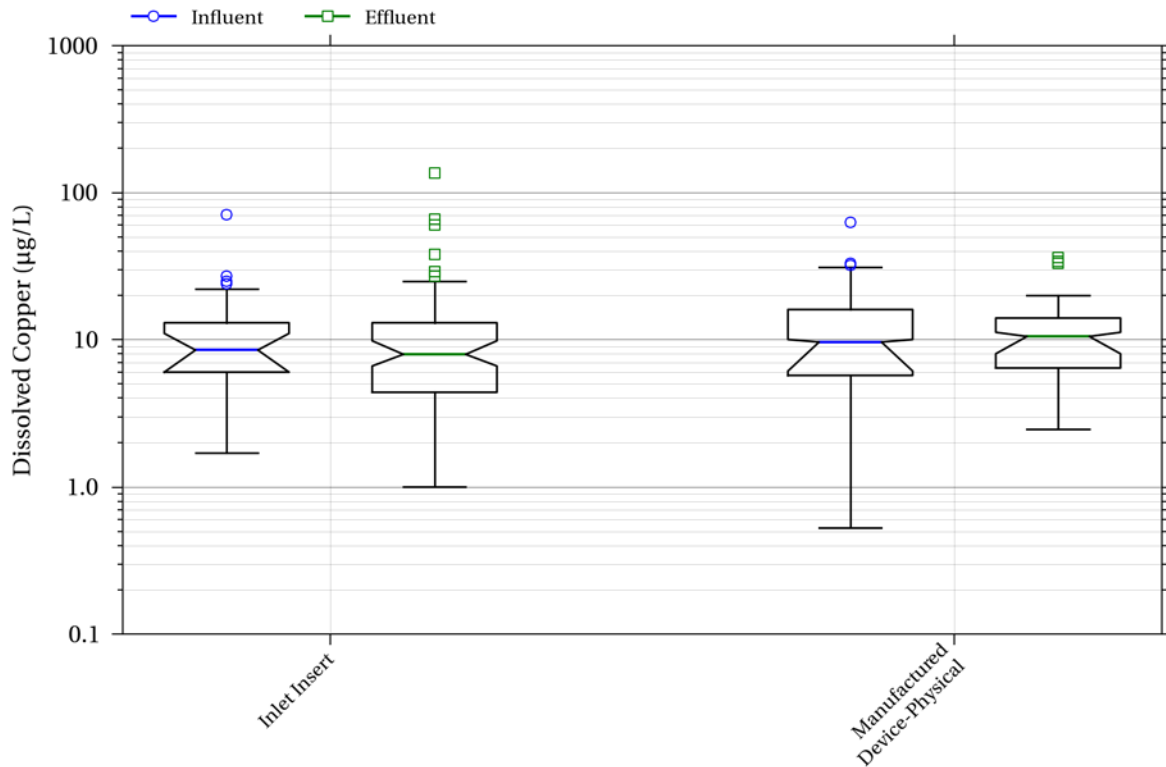


Table 5. Influent/Effluent Summary Statistics for Dissolved Copper (µg/L)

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	NA	NA	NA	NA	NA	NA	NA	NA
Inlet Insert	5, 53	11, 142	6.00	4.38	8.45 (6.00, 11.00)	7.95 (6.34, 9.80)	13.00	13.00
Multi-process	NA	NA	NA	NA	NA	NA	NA	NA
Manufactured Device-Physical	4, 51	4, 51	5.70	6.40	9.60 (6.30, 10.00)	10.48 (8.00, 12.00)	16.00	14.00
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)

2.2.2 Lead

Figure 5. Box Plots of Influent/Effluent Total Lead Concentrations

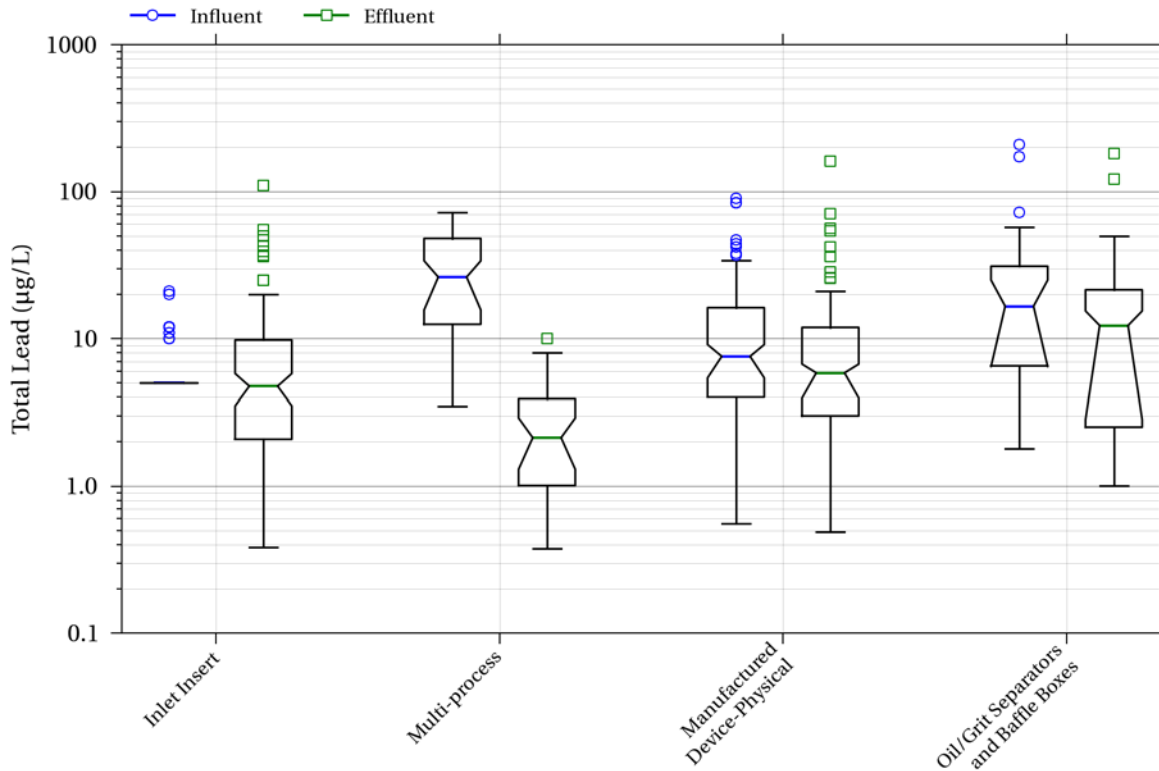


Table 6. Influent/Effluent Summary Statistics for Total Lead (µg/L)

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	NA	NA	NA	NA	NA	NA	NA	NA
Inlet Insert	5, 53	11, 141	5.00	2.08	5.00 (5.00, 5.00)	4.76 (3.50, 5.78)	5.00	9.77
Multi-process	4, 41	4, 39	12.50	1.01	26.27 (15.64, 33.80)	2.13 (1.30, 2.90)**	48.00	3.90
Manufactured Device-Physical	6, 102	6, 97	4.00	3.00	7.56 (5.52, 9.16)	5.84 (3.95, 6.70)	16.21	11.90
Oil/Grit Separators and Baffle Boxes	3, 27	3, 26	6.52	2.51	16.61 (6.44, 25.00)	12.30 (2.68, 15.40)	31.04	21.45
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)

**Hypothesis testing using the Mann-Whitney test in Attachment 2 shows statistically significant decreases for this BMP category.

Figure 6. Box Plots of Influent/Effluent Dissolved Lead Concentrations

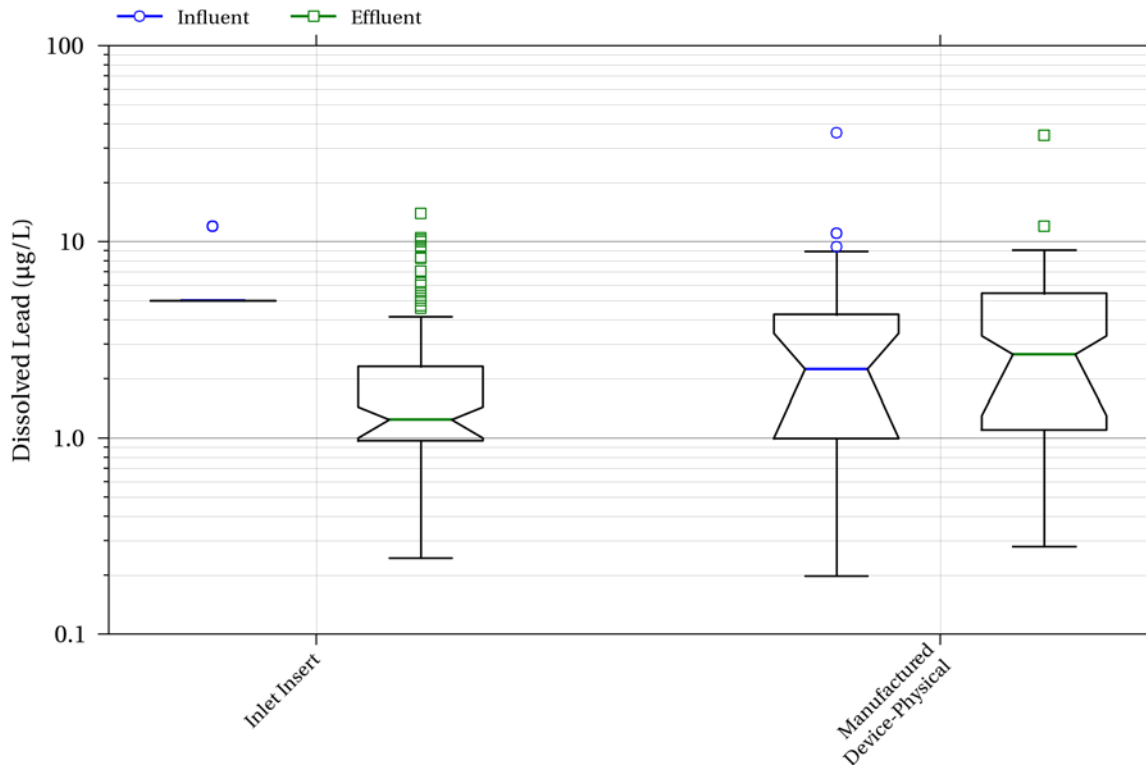


Table 7. Influent/Effluent Summary Statistics for Dissolved Lead (µg/L)

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	NA	NA	NA	NA	NA	NA	NA	NA
Inlet Insert	5, 53	11, 141	5.00	0.97	5.00 (5.00, 5.00)	1.24 (1.00, 1.44)****	5.00	2.31
Multi-process	NA	NA	NA	NA	NA	NA	NA	NA
Manufactured Device-Physical	4, 51	4, 51	0.99	1.10	2.24 (1.00, 3.40)	2.66 (1.37, 3.30)	4.25	5.45
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
Biological Filtration	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)

****Conclusions are limited for this BMP category due to a large percentage of non-detects in the influent.

2.2.3 Zinc

Figure 7. Box Plots of Influent/Effluent Total Zinc Concentrations

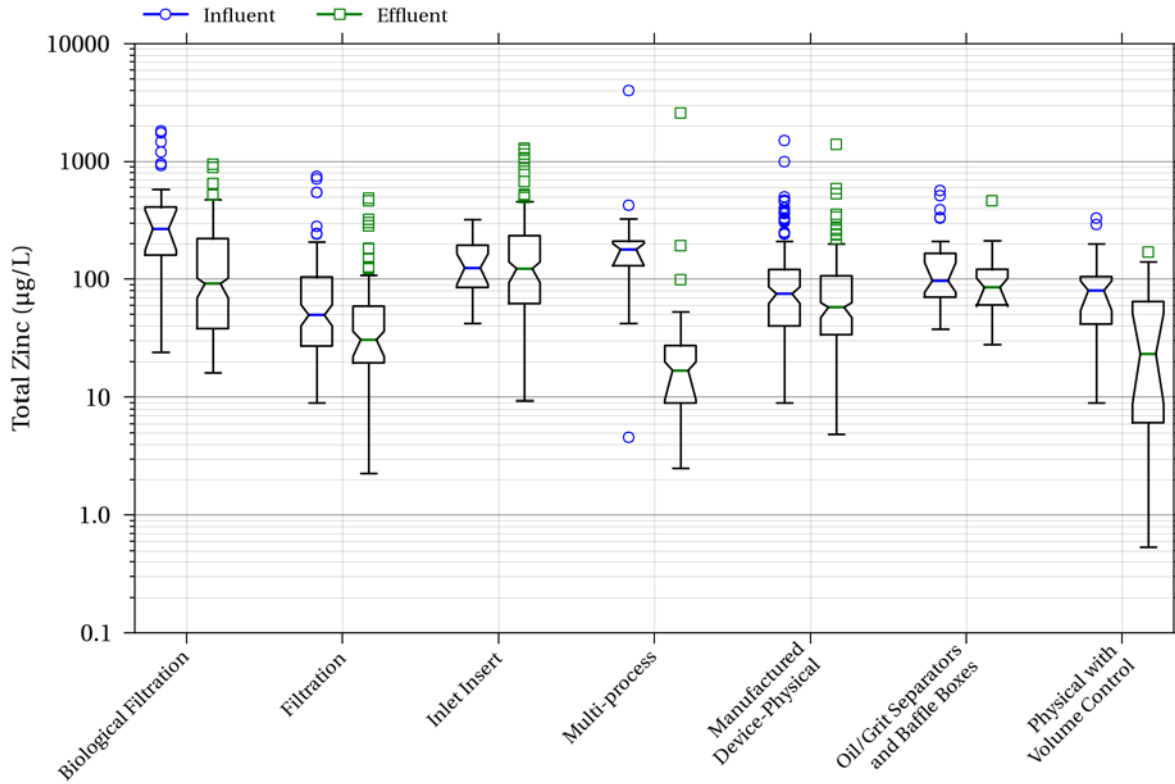


Table 8. Influent/Effluent Summary Statistics for Total Zinc (µg/L)

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	3, 37	3, 37	160.0	38.0	269.5 (175.0, 384.0)	91.4 (69.0, 102.0)**	410.0	221.0
Filtration	7, 108	7, 108	27.0	19.4	49.5 (40.0, 59.0)	30.6 (22.0, 36.0)**	104.3	58.9
Inlet Insert	5, 53	11, 141	85.0	62.0	124.6 (90.0, 164.0)	122.3 (93.0, 140.0)	194.0	234.0
Multi-process	4, 41	4, 38	130.0	9.0	178.8 (129.8, 200.0)	16.8 (9.0, 19.8)**	210.0	27.3
Manufactured Device-Physical	12, 190	12, 185	40.0	33.7	75.2 (62.0, 85.6)	57.60 (48.1, 63.1)**	120.8	106.6
Oil/Grit Separators and Baffle Boxes	4, 32	4, 31	70.3	60.3	96.5 (77.1, 138.1)	84.61 (62.0, 102.0)	165.5	121.1
Physical with Volume Control	4, 46	4, 46	41.5	6.1	80.1 (56.5, 96.5)	23.23 (8.8, 51.2)**	105.0	64.5

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

**Hypothesis testing using the Mann-Whitney test in Attachment 2 shows statistically significant decreases for analyzed BMPs for total zinc.

Figure 8. Box Plots of Influent/Effluent Dissolved Zinc Concentrations

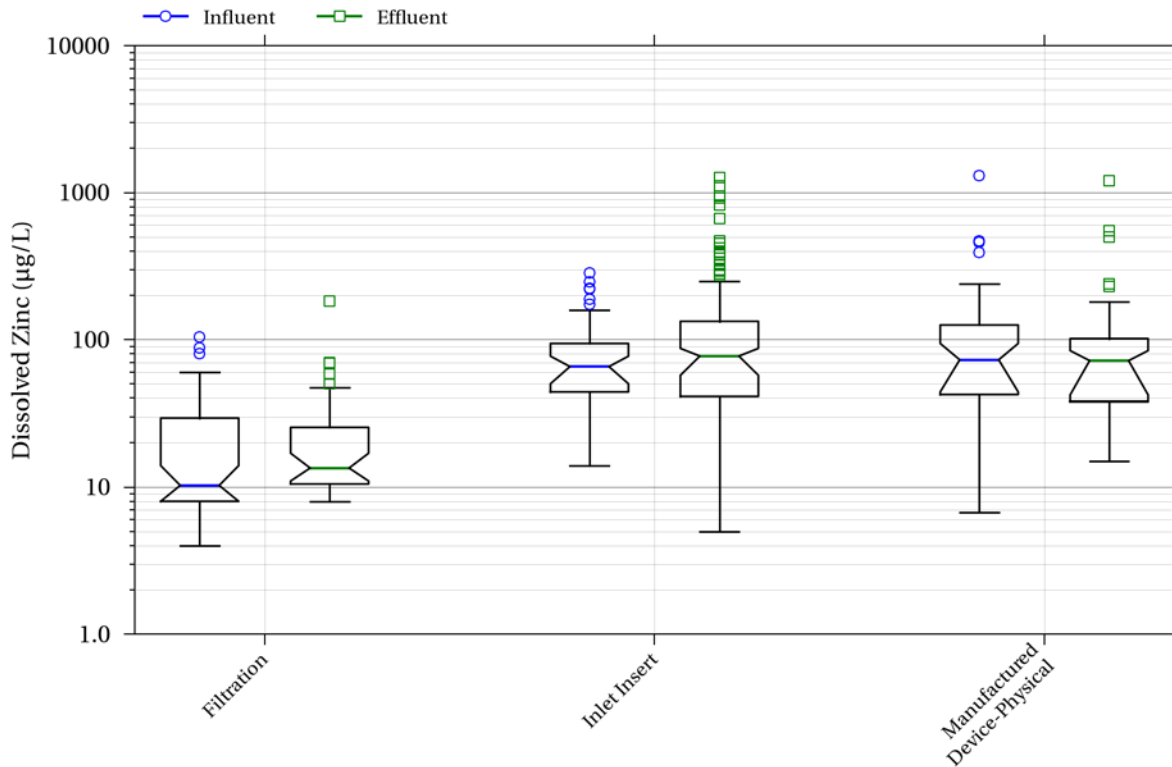


Table 9. Influent/Effluent Summary Statistics for Dissolved Zinc (µg/L)

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	3, 43	3, 43	8.0	10.5	10.3 (8.0, 14.0)	13.5 (11.0, 17.0)***	29.5	25.5
Inlet Insert	5, 53	11, 142	44.0	41.0	65.4 (50.0, 77.0)	77.0 (57.1, 87.0)	94.0	133.0
Multi-process	NA	NA	NA	NA	NA	NA	NA	NA
Manufactured Device-Physical	4, 50	4, 51	42.3	38.0	72.9 (44.0, 92.5)	71.8 (42.0, 84.0)	125.5	101.5
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)

***Hypothesis testing using the Mann-Whitney test in Attachment 2 shows statistically significant *increases* for this BMP category.

2.3 Nutrients

2.3.1 Phosphorus

Figure 9. Box Plots of Influent/Effluent Total Phosphorus Concentrations

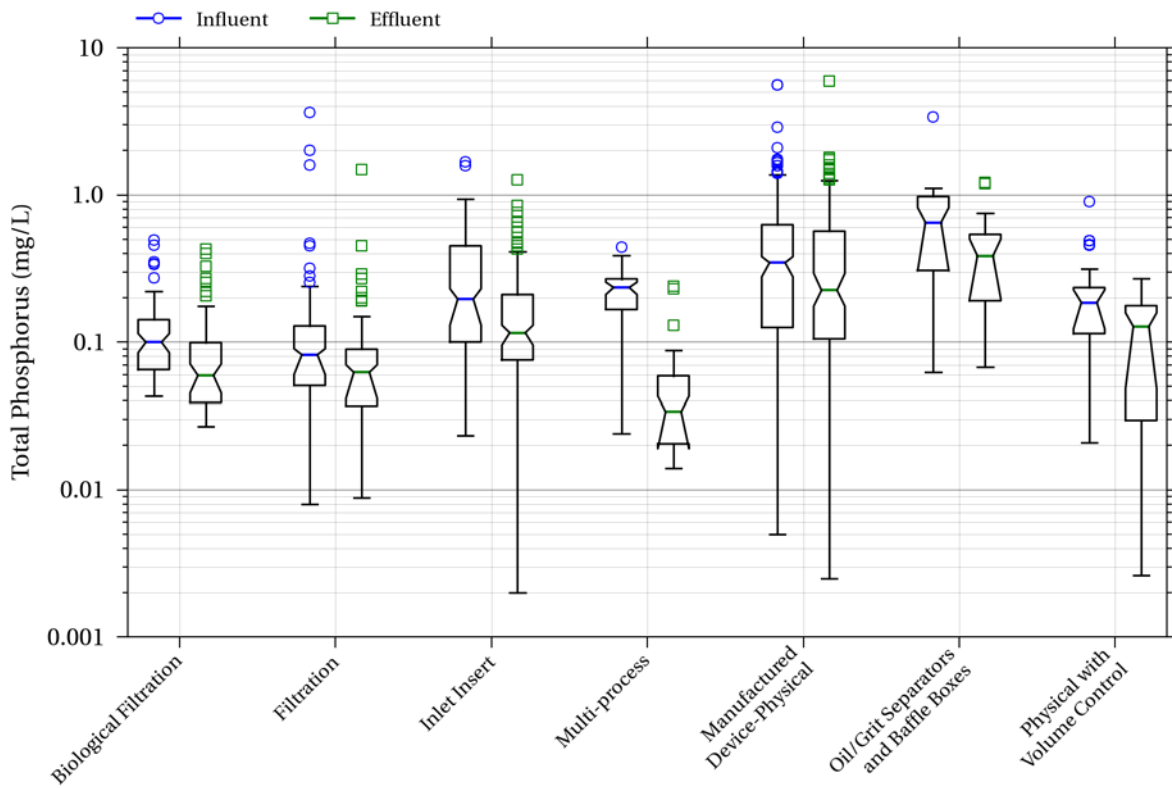


Table 10. Influent/Effluent Summary Statistics for Total Phosphorus (mg/L)

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 10. Box Plots of Influent/Effluent Dissolved Phosphorus Concentrations

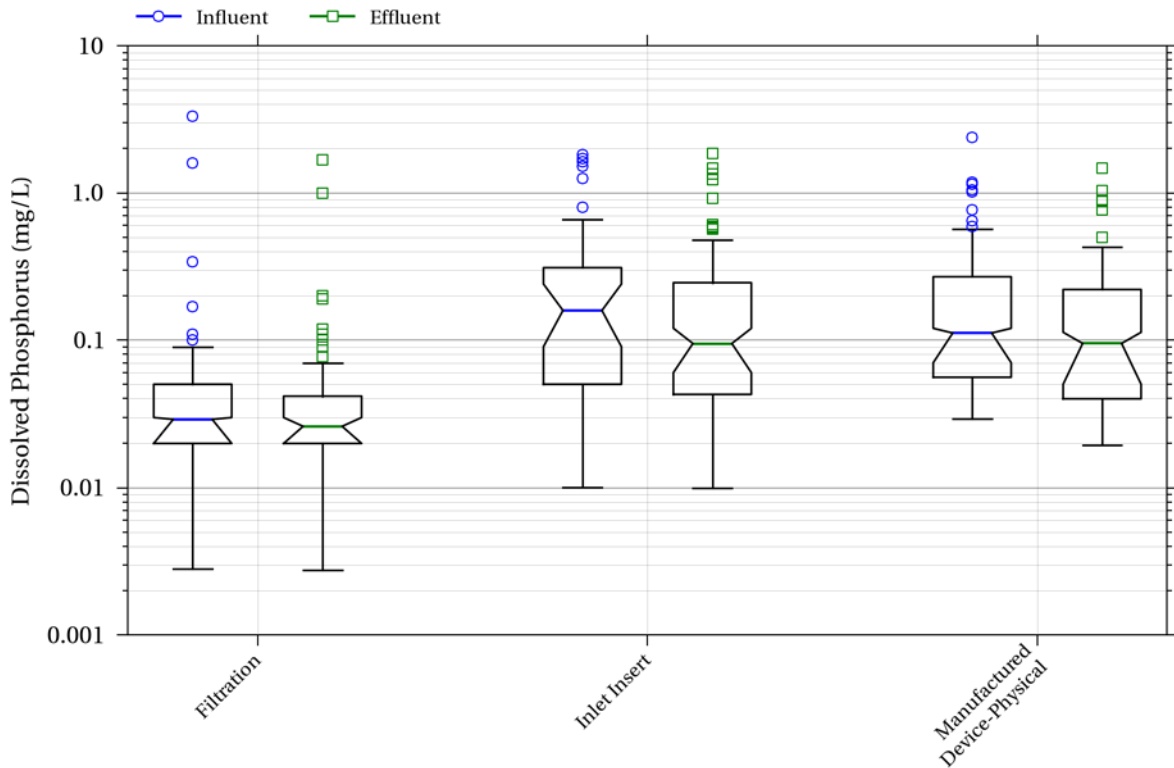


Table 11. Influent/Effluent Summary Statistics for Dissolved Phosphorus (mg/L)

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)

2.3.2 Nitrogen

Figure 11. Box Plots of Influent/Effluent Total Kjeldahl Nitrogen Concentrations

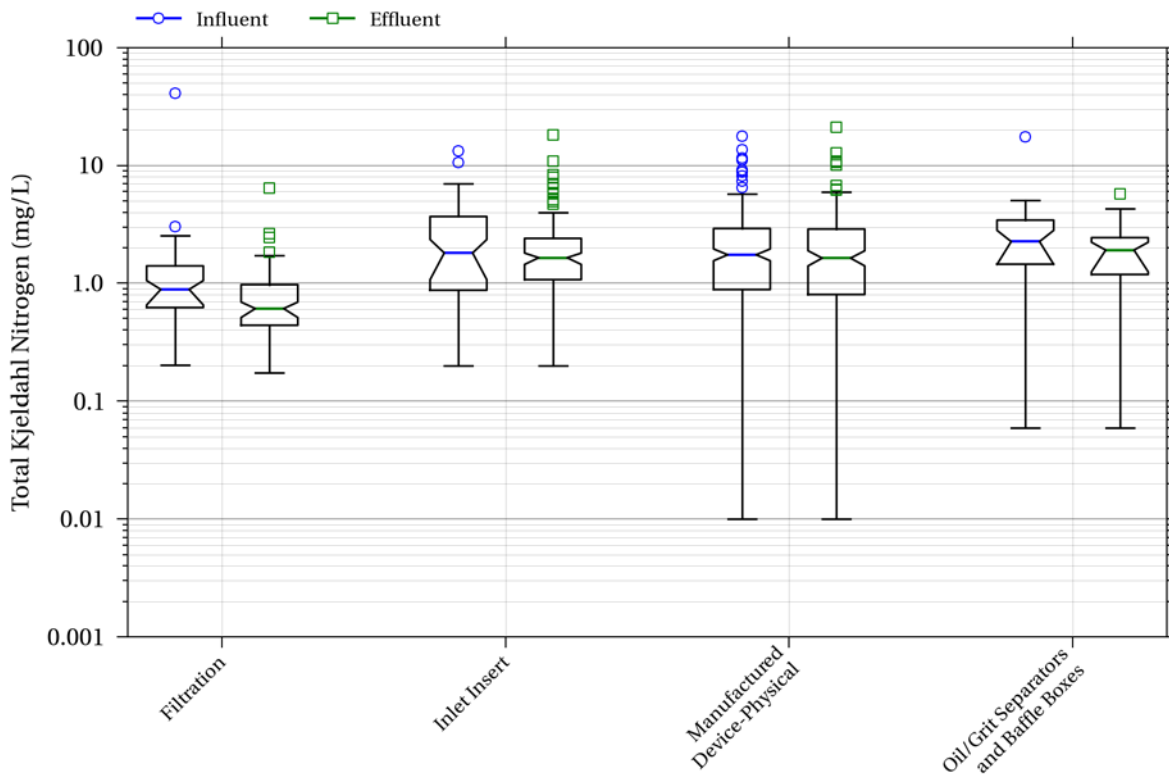


Table 12. Influent/Effluent Summary Statistics for Total Kjeldahl Nitrogen (mg/L)

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, 57	4, 57	0.62	0.44	0.89 (0.65, 1.05)	0.61 (0.51, 0.68)**	1.40	0.97
Inlet Insert	5, 53	11, 131	0.87	1.07	1.80 (1.07, 2.44)	1.64 (1.45, 1.78)	3.68	2.40
Multi-process	NA	NA	NA	NA	NA	NA	NA	NA
Manufactured Device-Physical	10, 242	10, 201	0.88	0.80	1.74 (1.55, 1.95)	1.63 (1.38, 1.88)	2.91	2.88
Oil/Grit Separators and Baffle Boxes	4, 28	4, 27	1.45	1.18	2.26 (1.44, 2.81)	1.91 (1.25, 2.22)	3.43	2.44
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)

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

Figure 12. Box Plots of Influent/Effluent NO_x as Nitrogen Concentrations

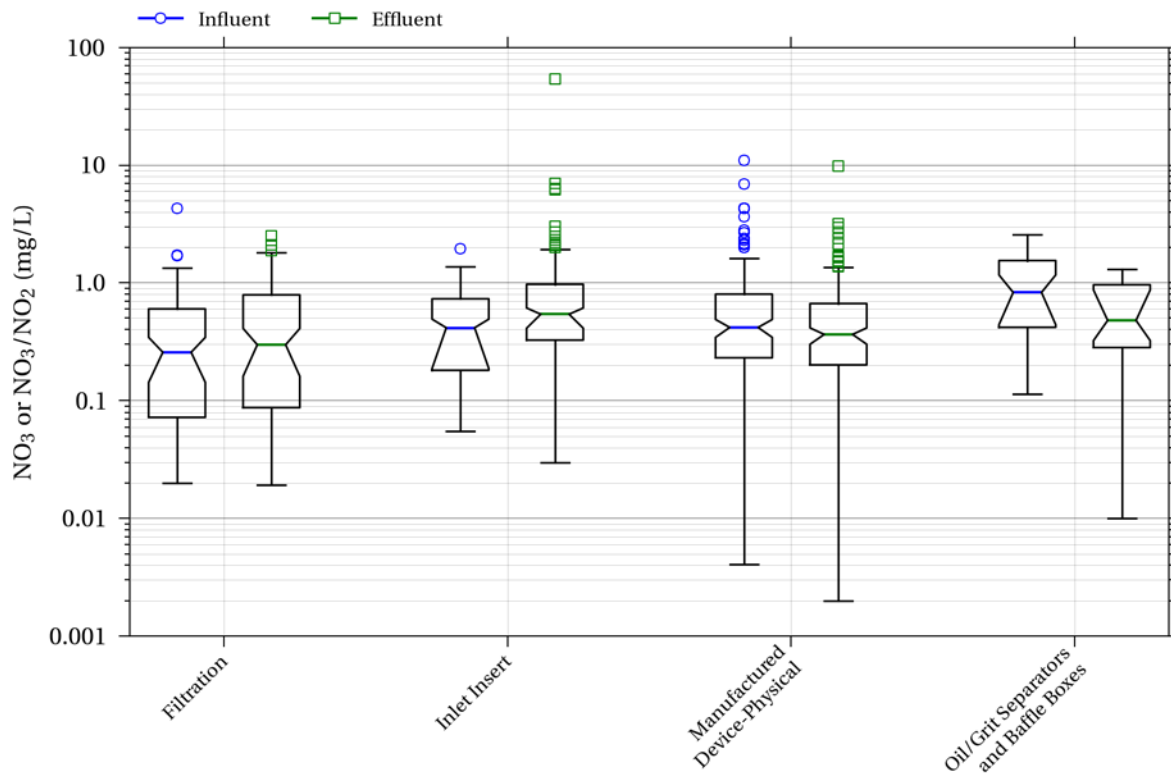


Table 13. Influent/Effluent Summary Statistics for NO_x as Nitrogen (mg/L)

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	5, 73	5, 73	0.07	0.09	0.26 (0.14, 0.34)	0.29 (0.17, 0.41)	0.60	0.79
Inlet Insert	5, 53	11, 131	0.18	0.33	0.42 (0.19, 0.49)	0.54 (0.41, 0.61)	0.73	0.97
Multi-process	NA	NA	NA	NA	NA	NA	NA	NA
Manufactured Device-Physical	15, 295	15, 254	0.23	0.20	0.42 (0.34, 0.49)	0.36 (0.30, 0.41)**	0.80	0.67
Oil/Grit Separators and Baffle Boxes	4, 28	4, 27	0.42	0.28	0.83 (0.44, 1.14)	0.48 (0.32, 0.87)	1.54	0.96
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)

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

3 OBSERVATIONS

General observations related to pollutant removal for the manufactured device subcategories analyzed include:

- TSS: All subcategories except Manufactured Device-Physical demonstrated statistically significant reductions in TSS. Particularly lower effluent TSS concentrations were observed for Biological Filtration, Filtration, Multi-process, and Physical with Volume Control subcategories. Hypothesis test results for Manufactured Device-Physical may be affected by unusually low influent TSS concentrations, as noted in Section 2.0. Hypothesis test results for Inlet Inserts are also limited due to underlying data set characteristics, as discussed in Section 2.0.
- Total Copper, Lead and Zinc: The Multi-process subcategory showed statistically significant reductions for all three metals, with particularly low concentrations achieved for total zinc. Biological Filtration, Filtration, Manufactured Device-Physical and Physical with Volume Control also showed statistically significant reductions for total zinc.
- Dissolved Copper, Lead and Zinc: The data set for these constituents was limited. Hypothesis test results did not show statistically significant reductions for dissolved metals for any of the manufactured device subcategories.
- Total Phosphorus: All subcategories showed statistically significant reduction for total phosphorus, with the exception of the Oil/Grit Separator and Baffle Boxes subcategory. The Oil/Grit Separator and Baffle Box subcategory had influent concentrations several times higher than most of the other categories. Conversely, Biological Filtration and Filtration subcategories had unusually low influent concentrations. The Multi-process subcategory had the greatest reductions and particularly low total phosphorus effluent concentrations.
- Dissolved Phosphorus: The dissolved phosphorus data set was limited to three manufactured device subcategories, none of which showed statistically significant reductions.
- TKN: The TKN data set was limited to four subcategories. Only Filtration showed statistically significant reductions. Influent concentrations for the Filtration subcategory were also about half the concentration of the other subcategories with data.
- NO_x: The NO_x data set was also limited to four subcategories. Only Manufactured Device-Physical showed statistically significant reduction in NO_x based on hypothesis testing. However, overlap of 95% confidence limits for the medians was observed for NO_x for this subcategory, and the NO₃/NO₂-only sub-analysis in Attachment 3 did not show statistically significant reductions. This additional information, combined with unit process theory, results in a recommendation that Manufactured Device-Physical performance for NO_x should be viewed as inconclusive for purposes of this summary paper.

The observations provided above are based on general subcategories of manufactured devices; however, it is recognized that proprietary designs may vary substantially. Those researching

manufactured device performance are also encouraged to review individual BMP performance summaries for specific BMP installations, which may perform better or worse than the general subcategories analyzed in this summary paper. If comparisons to other BMP types are desired, the reader is encouraged to review previously completed technical papers accessible at <http://www.bmpdatabase.org/BMPPerformance.htm>.

4 ATTACHMENTS

- Attachment 1. TSS Statistical Summary Report
- Attachment 2. Metals Statistical Summary Report
- Attachment 3. Nutrients Statistical Summary Report