Analysis of Treatment System Performance

International Stormwater Best Management Practices (BMP) Database [1999-2005]

Prepared by:

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Prepared for:

Water Environment Research Foundation
American Society of Civil Engineers (Environmental and Water Resources Institute/Urban Water Resources Research Council)
U.S. Environmental Protection Agency
Federal Highway Administration
American Public Works Association

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Analysis of Treatment System Performance
Disclaimer

The BMP Database ("Database") was developed as an account of work sponsored by the Water Environment Research Foundation (WERF), the American Society of Civil Engineers (ASCE) / Environmental and Water Resources Institute (EWRI), the American Public Works Association (APWA), the Federal Highway Administration (FHWA), and U.S. Environmental Protection Agency (EPA)(collectively, the "Sponsors"). The Database is intended to provide a consistent and scientifically defensible set of data on Best Management Practice ("BMP") designs and related performance. Although the individuals who completed the work on behalf of the Sponsors ("Project Team") made an extensive effort to assess the quality of the data entered for consistency and accuracy, the Database information and/or any analysis results are provided on an "AS-IS" basis and use of the Database, the data information, or any apparatus, method, or process disclosed in the Database is at the user's sole risk. The Sponsors and the Project Team disclaim all warranties and/or conditions of any kind, express or implied, including, but not limited to any warranties or conditions of title, non-infringement of a third party's intellectual property, merchantability, satisfactory quality, or fitness for a particular purpose. The Project Team does not warrant that the functions contained in the Database will meet the user's requirements or that the operation of the Database will be uninterrupted or error-free, or that any defects in the Database will be corrected.

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The Project Team's tasks have not included, and will not include in the future, recommendations of one BMP type over another. However, the Project Team's tasks have included reporting on the performance characteristics of BMPs based upon the entered data and information in the Database, including peer reviewed performance assessment techniques. Use of this information by the public or private sector is beyond the Project Team's influence or control. The intended purpose of the Database is to provide a data exchange tool that permits characterization of BMPs solely upon their measured performance using consistent protocols for measurements and reporting information.

The Project Team does not endorse any BMP over another and any assessments of performance by others should not be interpreted or reported as the recommendations of the Project Team or the Sponsors.

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Analysis of Treatment System Performance
Introduction

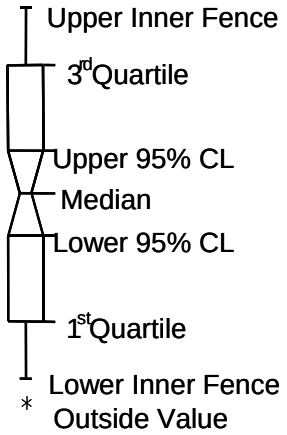
The following summaries analyze available monitoring data drawn from the International Stormwater Best Management Practices (BMP) Database to determine whether any differences in treatment performance may be determined based on BMP category (e.g. detention basin, media filter, wetland basin, etc). These summaries focus on two separate data analyses:

- A data set composed of each BMP study's average effluent event mean concentrations (EMCs) over the entire respective monitoring period, grouped by BMP category.
- A data set comprised of all of the individual effluent EMCs, grouped by BMP category.

For each water quality constituent examined, only those BMP studies reporting at least 3 influent and effluent EMCs were included in either data set. While this minimum threshold permits the actual calculation of the reported statistics (mean, median, percentiles, etc.), the robustness of such statistics is limited for these smallest samples.

The first data set (averaged EMCs) "weighs" the water quality data for each individual BMP study equally (one average EMC value per BMP study) no matter the number of events monitored, thereby placing the emphasis of the evaluation on whether similar types of BMPs at a variety of different sites achieve comparable average effluent quality. This analysis mutes the influence of individual events, and does not favor BMP studies that report a relatively large number of EMCs. The second analysis compares the distribution of effluent water quality from individual events by BMP category, thereby providing greater weight to those BMPs for which there are a larger number of EMCs reported. This represents an important distinction between the two analyses, and it is essential that interpretation of the performance summaries reflect how the data has been compiled and presented.

Notched box-and-whisker plots are used to graphically display the categorized distributions from both datasets. The notches encompass the 95% confidence interval of the median (averaged EMCs or individual EMCs, depending on the analysis) and provide a graphical, nonparametric means of assessing the difference between the centers of multiple distributions. A logarithmic scale was determined to be best suited for plotting the data. The log-scale boxplots were created utilizing the following method to calculate the upper and lower confidence levels:



1) The natural logs of the effluent values (averaged EMCs or individual EMCs, depending on the analysis) for a given BMP category are sorted in ascending order.
2) The upper and lower quantiles (i.e. the 75th and 25th percentiles) are calculated, following Tukey (1977).
3) The confidence interval of the median is calculated based on the upper and lower quantiles, following McGill et al (1978).
4) The median and confidence interval is translated back to arithmetic space. These values are used to delineate the upper and lower bounds of the notch on the boxplots.

For both the distributions of averaged EMCs by BMP category and the distributions of individual EMCs by BMP category, the arithmetic values of the median and associated upper confidence level (UCL) and lower confidence level (LCL) are provided in the table that accompanies each summary.

An assessment was also made of the difference between the median effluent values and the corresponding influent values for both data sets. This assessment is critical, because it provides a measure of whether or not the data indicate a statistically significant difference in pollutant levels between the influent and effluent. To perform this test, the median, UCL and LCL for influent values were calculated in the same manner as for the effluent. A significant difference between the median influent and effluent values is assumed if their respective confidence intervals do not overlap; otherwise, the difference is not considered statistically significant. The same test may be performed graphically by plotting influent and effluent notched boxplots side-by-side and comparing the confidence limits visually.

In many instances, no significant difference between influent and effluent medians was determined. Therefore, it is not possible to determine with any certainty whether the BMP had an effect or simply that the characteristics of the runoff treated (for example, low influent concentrations) govern the distribution of effluent values. Where the analysis of significant difference indicates that effluent levels are *greater* than influent, this is noted in the text and as a footnote to the tabulated values.

References

McGill, R., J.W. Tukey, and W.A. Larsen, "Variations of Boxplots," *The American Statistician*, Vol. 32, pp.12-16, 1978.

Tukey, J. W. (1977). *Exploratory data analysis.* Reading, MA: Addison-Wesley Publishing Company.

Analysis of Treatment System Performance - Solids

SEE INTRODUCTION FOR INTERPRETATION OF THESE FIGURES

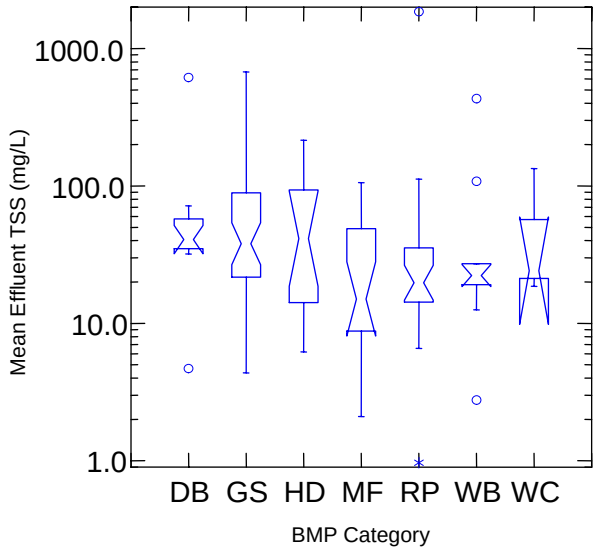


Figure 1. Mean effluent TSS concentration by BMP category

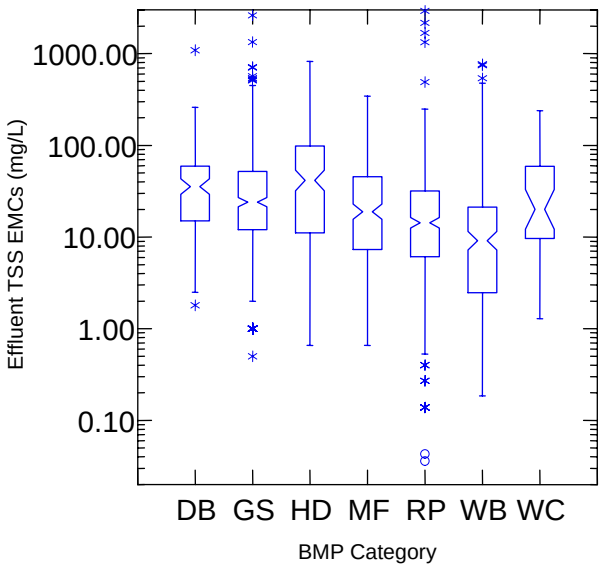


Figure 2. Individual effluent TSS EMCs by BMP category

Total Suspended Solids (mg/L)

Total suspended solids (TSS) represents the most widely reported stormwater constituent in the International Stormwater Best Management Practices (BMP) Database. Information regarding particle size distributions or settling velocities among the studies included in the database is very limited, and no distinction based on these factors is made between BMP studies analyzed.

Analysis of Mean Effluent TSS Concentration by BMP Category (one value per BMP Study)

Average effluent TSS concentrations are significantly lower than average influent for all BMP categories analyzed except hydrodynamic devices and wetland basins. Note that the limited number of wetland channel BMPs analyzed reduces the ability to statistically determine results for this category.

Median averaged effluent concentrations for detention basins, biofilters and hydrodynamic devices are above 35 mg/L, while those for media filters, retention ponds, wetland basins and wetland channels range between approximately 15 to 24 mg/L.

Media filters, biofilters and hydrodynamic devices are all primarily flow-through systems (i.e. no significant detention of flows). Of these, media filters exhibit the lowest averaged effluent. Of the storage-type categories, those which include some kind of permanent pool (retention ponds, wetland basins and wetland channels) exhibit lower effluent levels (only retention ponds achieves a strongly significant difference between influent and effluent).

Analysis of Effluent TSS Concentrations by BMP Category (all individual EMCs included in dataset)

Median effluent TSS EMCs for detention basins and hydrodynamic devices are notably higher than for the other BMP categories analyzed. In general, lower effluent TSS concentrations are observed for those categories that provide extended storage of stormwater flows (retention ponds, wetland basins).

BMP Category		Number of BMPs	Median of Avg. Effluent (95% Confidence Interval)[1]			Significant Difference Between Average Influent and Effluent[2]	Median of Effluent EMCs (95% Confidence Interval)[1]			Significant Difference Between Influent and Effluent EMCs[2]
			Median	LCL	UCL		Median	LCL	UCL	
DB	Detention Basin	11	40.72	32.11	51.64	YES	32.98	26.84	40.54	YES
GS	Biofilter	40	37.99	26.71	54.03	YES	24	21.34	26.99	NO
HD	Hydrodynamic Device	14	41.38	18.65	91.82	NO	36	27.58	46.99	YES
MF	Media Filter	19	15.05	8.09	28.02	YES	14.97	12.23	18.31	YES
RP	Retention Pond	24	19.77	14.74	26.51	YES	12	10.46	13.76	YES
WB	Wetland Basin	9	22.29	18.51	26.85	NO	7.55	5.93	9.6	YES
WC	Wetland Channel	3	24.18	9.83	59.45	YES	17	10.16	28.45	YES

1. Calculation of confidence interval based on McGill et al (1978), from the natural log of the quantiles.
2. Based on non-parametric analysis of difference in median values.

SEE INTRODUCTION FOR INTERPRETATION OF THESE FIGURES

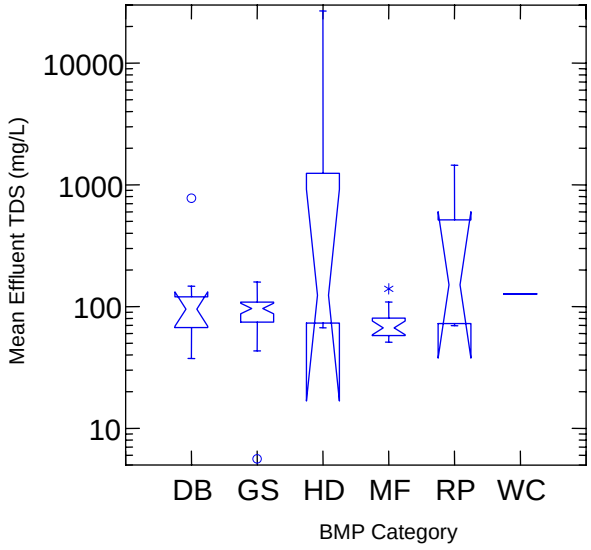


Figure 1. Mean effluent TDS concentration by BMP category

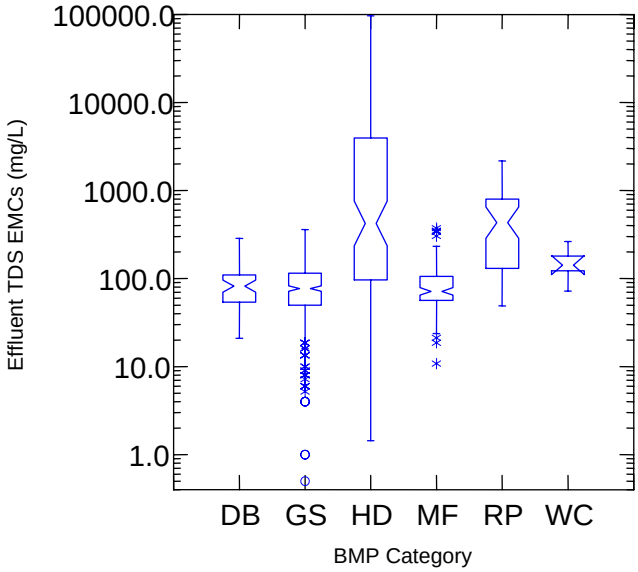


Figure 2. Individual effluent TDS EMCs by BMP category

Total Dissolved Solids (mg/L)

Total dissolved solids (TDS) is a gross index for solids less than approximately 1 micron. The effectiveness of standard BMP technologies in treating TDS is limited, based on those studies available in the International Stormwater BMP Database.

Analysis of Mean Effluent TDS Concentration by BMP Category (one value per BMP Study)

No significant difference between average influent and effluent TDS concentrations are exhibited for those BMP categories with sufficient number of individual sites to permit useful analysis.

Analysis of Effluent TDS Concentrations by BMP Category (all individual EMCs included in dataset)

A significant increase between influent and effluent TDS EMCs is exhibited for biofilters, media filters and retention ponds. The remaining categories exhibit no significant difference between median influent and effluent EMCs.

BMP Category		Number of BMPs	Median of Avg. Effluent (95% Confidence Interval)[1]			Significant Difference Between Average Influent and Effluent[2]	Median of Effluent EMCs (95% Confidence Interval)[1]			Significant Difference Between Influent and Effluent EMCs[2]
			Median	LCL	UCL		Median	LCL	UCL	
DB	Detention Basin	8	64.39	33.07	125.39	NO	82	69.83	96.29	NO
GS	Biofilter	36	55.56	37.23	82.91	NO	77	71.67	82.72	YES[3]
HD	Hydrodynamic Device	5	63.75	9.3	437.24	NO	350.93	191.55	642.92	NO
MF	Media Filter	16	55.76	50.32	61.78	NO	56	50.59	61.99	YES[3]
RP	Retention Pond	5	142.31	36.65	552.62	NO	359.09	235.57	547.39	YES[3]
WC	Wetland Channel	1	Insufficient sample size for analysis.				113.98	95.07	136.66	NO

1. Calculation of confidence interval based on McGill et al (1978), from the natural log of the quantiles.
2. Based on non-parametric analysis of difference in median values.
3. Indicates that effluent is significantly greater than influent.

Analysis of Treatment System Performance - Phosphorus

SEE INTRODUCTION FOR INTERPRETATION OF THESE FIGURES

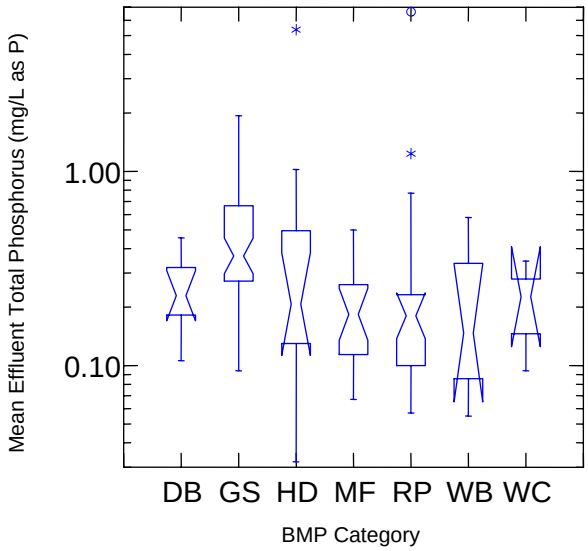


Figure 1. Mean effluent TP concentrations by BMP category

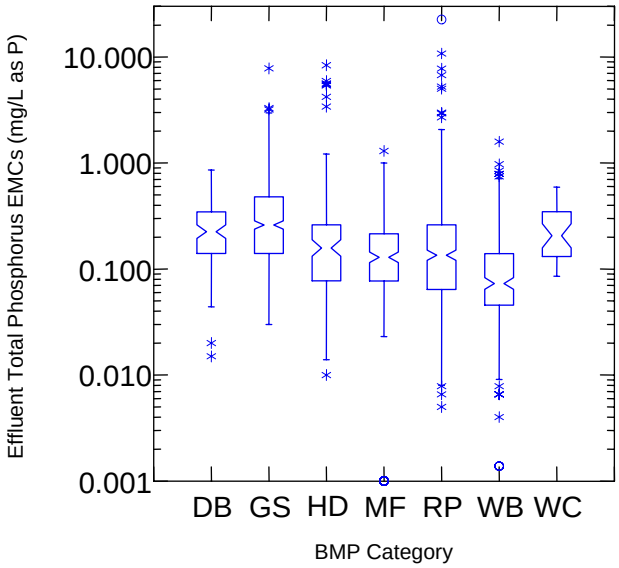


Figure 2. Individual effluent TP EMCs by BMP category

Total Phosphorus (mg/L as P)

Total Phosphorus (TP) is the second most-reported constituent in the International Stormwater Best Management Practices (BMP) Database, after Total Suspended Solids (TSS).

Analysis of Mean Effluent Total Phosphorus Concentration by BMP Category (one value per BMP Study)

Media filters, retention ponds and wetland basins report the lowest median averaged effluent Total Phosphorus concentrations, although none of them report a statistically significant difference between median influent and effluent values. Biofilters exhibit a statistically significant increase in mean TP from influent to effluent.

Analysis of Effluent Total Phosphorus Concentrations by BMP Category (all individual EMCs included in dataset)

Median effluent Total Phosphorus EMCs are lowest for media filters, retention ponds and wetland basins. There is significant difference between median influent and effluent EMCs for most of the BMP categories analyzed, and nearly so for detention basins. Only biofilters exhibit no clear difference between influent and effluent Total Phosphorus EMCs, as a category.

BMP Category		Number of BMPs	Median of Avg. Effluent (95% Confidence Interval)[1]			Significant Difference Between Average Influent and Effluent[2]	Median of Effluent EMCs (95% Confidence Interval)[1]			Significant Difference Between Influent and Effluent EMCs[2]
			Median	LCL	UCL		Median	LCL	UCL	
DB	Detention Basin	9	0.23	0.17	0.31	NO	0.22	0.19	0.26	NO
GS	Biofilter	45	0.37	0.3	0.45	YES[3]	0.26	0.24	0.28	NO
HD	Hydrodynamic Device	12	0.21	0.11	0.38	NO	0.16	0.13	0.19	YES
MF	Media Filter	18	0.18	0.13	0.25	NO	0.13	0.12	0.14	YES
RP	Retention Pond	24	0.18	0.14	0.24	NO	0.13	0.12	0.15	YES
WB	Wetland Basin	7	0.15	0.06	0.33	NO	0.06	0.05	0.07	YES
WC	Wetland Channel	3	0.23	0.12	0.41	NO	0.17	0.13	0.23	YES

1. Calculation of confidence interval based on McGill et al (1978), from the natural log of the quantiles.
2. Based on non-parametric analysis of difference in median values.
3. Indicates that effluent is significantly greater than influent.

SEE INTRODUCTION FOR INTERPRETATION OF THESE FIGURES

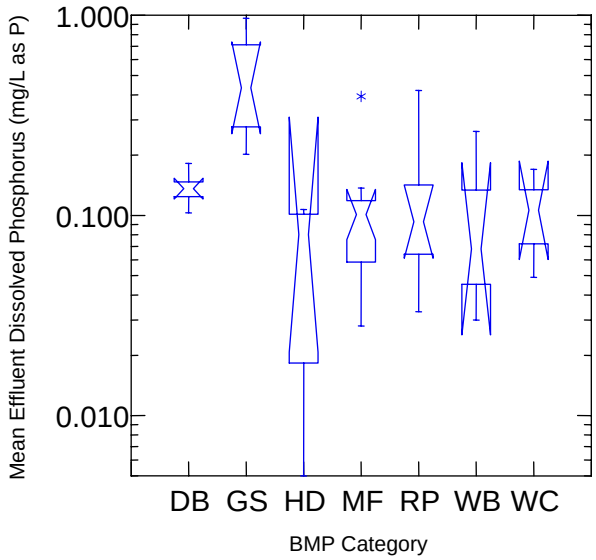


Figure 3. Mean effluent Dissolved Phosphorus concentrations by BMP category

Dissolved Phosphorus (mg/L as P)

Much fewer BMPs report Dissolved Phosphorus (DP) compared to TP.

Analysis of Mean Effluent Dissolved Phosphorus Concentration by BMP Category (one value per BMP Study)

Hydrodynamic devices, retention ponds and wetland basins exhibit the lowest mean effluent Dissolved Phosphorus, although the limited number of BMPs included in these categories (particularly hydrodynamic devices and wetland basins) prevents a statistical determination of their treatment performance. Results for biofilters yield a significant increase in mean DS from influent to effluent, while the remaining categories do not exhibit a significant difference.

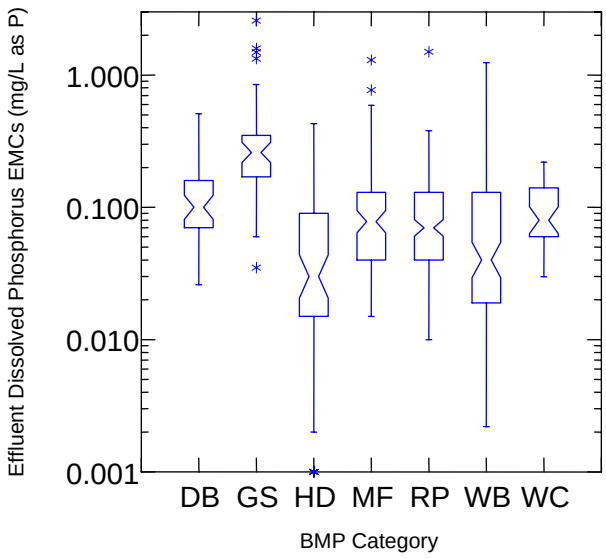


Figure 4. Individual effluent Dissolved Phosphorus EMCs by BMP category

Analysis of Effluent Dissolved Phosphorus Concentrations by BMP Category (all individual EMCs included in dataset)

Median effluent Dissolved Phosphorus EMCs are significantly lower for hydrodynamic devices and wetland basins (although the former exhibits no significant difference between influent and effluent EMCs, and the latter is limited to three BMPs in the category).

Biofilters exhibit a significant increase in Dissolved Phosphorus EMCs between influent and effluent. Among those categories with at least five BMPs in the dataset, only retention ponds exhibit a significant decrease in Dissolved Phosphorus EMCs.

BMP Category		Number of BMPs	Median of Avg. Effluent (95% Confidence Interval)[1]			Significant Difference Between Average Influent and Effluent[2]	Median of Effluent EMCs (95% Confidence Interval)[1]			Significant Difference Between Influent and Effluent EMCs[2]
			Median	LCL	UCL		Median	LCL	UCL	
DB	Detention Basin	5	0.14	0.12	0.15	NO	0.1	0.08	0.12	NO
GS	Biofilter	8	0.43	0.26	0.74	YES[3]	0.26	0.22	0.31	YES[3]
HD	Hydrodynamic Device	4	0.08	0.02	0.31	NO	0.03	0.02	0.04	NO
MF	Media Filter	15	0.1	0.08	0.13	NO	0.08	0.06	0.09	NO
RP	Retention Pond	9	0.09	0.06	0.14	NO	0.07	0.06	0.08	YES
WB	Wetland Basin	3	0.07	0.03	0.18	NO	0.04	0.03	0.05	YES
WC	Wetland Channel	3	0.11	0.06	0.19	NO	0.08	0.06	0.1	YES

1. Calculation of confidence interval based on McGill et al (1978), from the natural log of the quantiles.
2. Based on non-parametric analysis of difference in median values.
3. Indicates that effluent is significantly greater than influent.

Analysis of Treatment System Performance - Nitrogen

SEE INTRODUCTION FOR INTERPRETATION OF THESE FIGURES

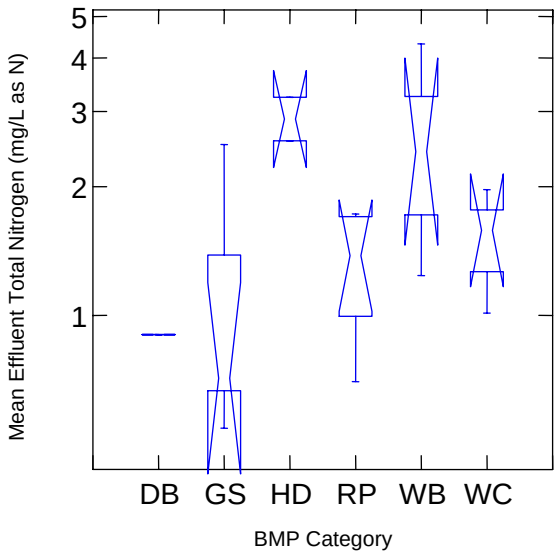


Figure 1. Mean effluent TN concentrations by BMP category

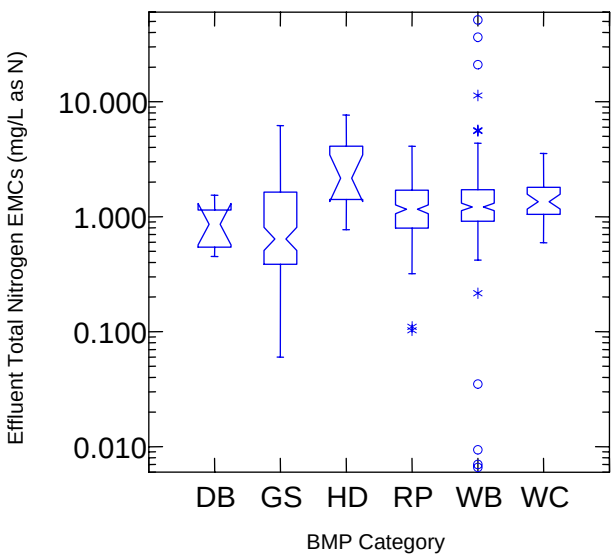


Figure 2. Individual effluent TN EMCs by BMP category

Total Nitrogen (mg/L as N)

Total Nitrogen (TN) includes the total organic and inorganic forms of nitrogen detected. Among the six categories in the International Stormwater Best Management Practices (BMP) Database which include sufficient data for analysis, the number of individual BMPs reporting Total Nitrogen is small (eight or less). This reduces the ability to observe statistically significant differences between the BMP types.

Analysis of Mean Effluent Total Nitrogen Concentration by BMP Category (one value per BMP Study)

Only detention basins exhibit a significant difference between the median of average influent and effluent concentrations. The small number of available studies yields a large degree of variability in the results, as evidenced by the large confidence intervals shown on the accompanying notched boxplot (Figure 1).

Analysis of Effluent Total Nitrogen Concentrations by BMP Category (all individual EMCs included in dataset)

Effluent EMCs for wetland channels are significantly less than influent, although only three BMPs are included in this dataset. Effluent concentrations for biofilters and hydrodynamic devices tend to be greater than influent, although overall the differences are not significant.

BMP Category		Number of BMPs	Median of Avg. Effluent (95% Confidence Interval)[1]			Significant Difference Between Average Influent and Effluent[2]	Median of Effluent EMCs (95% Confidence Interval)[1]			Significant Difference Between Influent and Effluent EMCs[2]
			Median	LCL	UCL		Median	LCL	UCL	
DB	Detention Basin	1	Insufficient sample size for analysis.				0.86	0.57	1.3	NO
GS	Biofilter	5	0.71	0.42	1.19	NO	0.64	0.51	0.81	NO
HD	Hydrodynamic Device	2	2.88	2.22	3.74	NO	2.16	1.35	3.45	NO
RP	Retention Pond	8	1.38	1.02	1.86	NO	1.16	1.06	1.27	NO
WB	Wetland Basin	4	2.42	1.46	4	NO	1.22	1.13	1.31	NO
WC	Wetland Channel	3	1.58	1.17	2.14	NO	1.35	1.17	1.57	YES

1. Calculation of confidence interval based on McGill et al (1978), from the natural log of the quantiles.
2. Based on non-parametric analysis of difference in median values.

SEE INTRODUCTION FOR INTERPRETATION OF THESE FIGURES

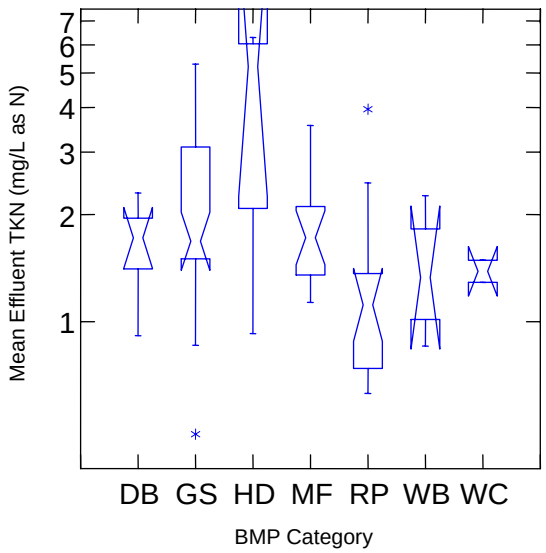


Figure 3. Mean effluent TKN concentrations by BMP category

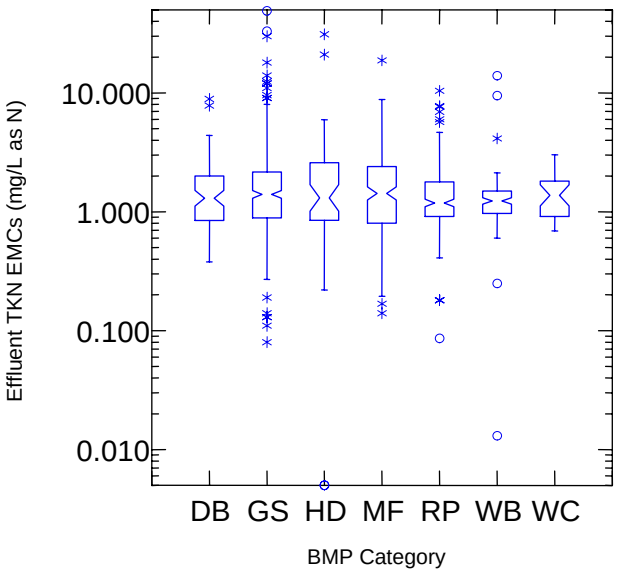


Figure 4. Individual effluent TKN EMCs by BMP category

Total Kjeldahl Nitrogen (mg/L as N)

Total Kjeldahl Nitrogen (TKN) represents the sum of organic nitrogen and ammonia. As a measure of available oxidizable nitrogen, it serves as an indicator of the oxygen that could be consumed through nitrification. It is the most widely reported form of nitrogen in the International Stormwater Best Management Practices (BMP) Database.

For most BMPs in the dataset, the average influent and effluent TKN data exhibit low varability (Cv < 1). Smaller sample sizes for detention basins, hydrodynamic devices, wetland basins and wetland channels reduces the utility of the analysis for these BMP types.

Analysis of Mean Effluent TKN Concentration by BMP Category (one value per BMP Study)

The lowest average effluent values are reported for retention ponds. Among the different types of media filters analyzed, those designated as sand filters generally reported lower effluent TKN levels. However, the lack of significant difference between average influent and effluent TKN across all BMP types hampers any effort to draw distinctions in performance between BMP categories based on averaged effluent concentrations.

Analysis of Effluent TKN Concentrations by BMP Category (all individual EMCs included in dataset)

The median effluent TKN EMCs for RP are significantly less than median influent concentrations, while the median effluent TKN EMC for wetland basins is significantly greater than median influent levels (note that this dataset is drawn from just four studies).

BMP Category		Number of BMPs	Median of Avg. Effluent (95% Confidence Interval)[1]			Significant Difference Between Average Influent and Effluent[2]	Median of Effluent EMCs (95% Confidence Interval)[1]			Significant Difference Between Influent and Effluent EMCs[2]
			Median	LCL	UCL		Median	LCL	UCL	
DB	Detention Basin	7	1.72	1.41	2.09	NO	1.3	1.12	1.51	NO
GS	Biofilter	37	1.68	1.39	2.03	NO	1.4	1.3	1.51	NO
HD	Hydrodynamic Device	4	5.21	2.25	12.1	NO	1.31	1.01	1.69	NO
MF	Media Filter	16	1.72	1.45	2.05	NO	1.42	1.26	1.62	NO
RP	Retention Pond	17	1.12	0.88	1.41	NO	1.05	0.97	1.13	YES
WB	Wetland Basin	4	1.33	0.84	2.11	NO	1.09	1.03	1.17	YES[3]
WC	Wetland Channel	2	1.39	1.18	1.63	NO	1.22	0.99	1.51	NO

1. Calculation of confidence interval based on McGill et al (1978), from the natural log of the quantiles.
2. Based on non-parametric analysis of difference in median values.
3. Indicates that effluent is significantly greater than influent.

SEE INTRODUCTION FOR INTERPRETATION OF THESE FIGURES

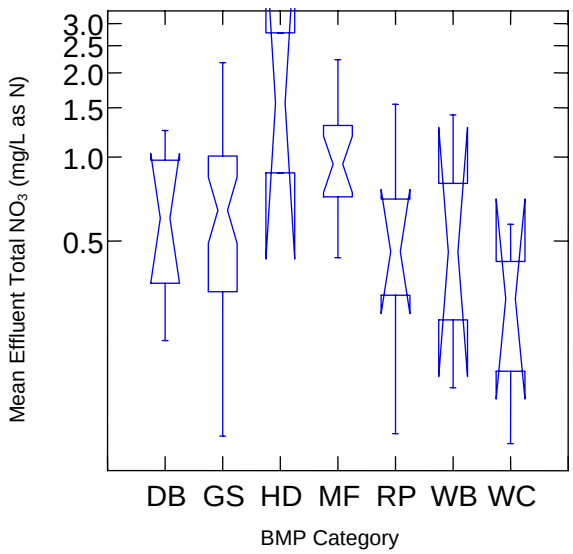


Figure 5. Mean effluent Nitrate Nitrogen concentrations by BMP category

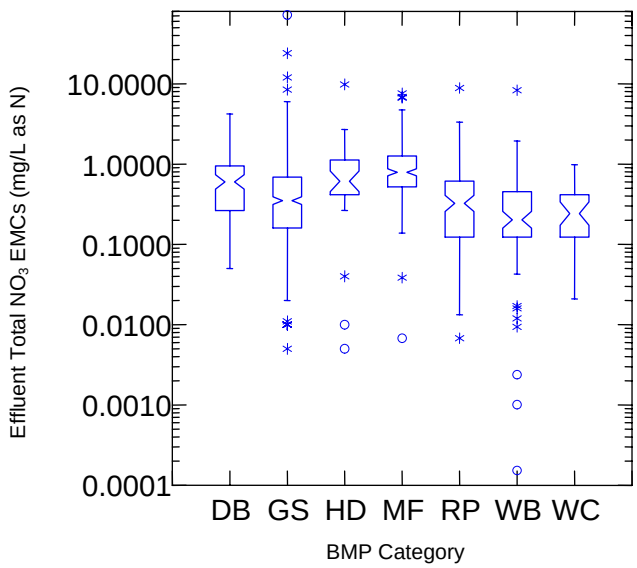


Figure 6. Individual effluent Nitrate Nitrogen EMCs by BMP category

Total Nitrate Nitrogen (mg/L as N)

Nitrogen concentrations in runoff often takes the form of Nitrate Nitrogen, either due to direct export of agricultural or lawn and garden fertilizers and other materials containing high levels of nitrate, or the oxidation of organic and ammonia nitrogen during transport through the watershed. Removal of nitrate nitrogen is primarily through denitrification, where anoxic conditions drive the conversion of oxidized nitrogen to nitrogen gas.

By far the largest number of studies reporting Nitrate Nitrogen are for biofilters, either grass strips or grass swales.

Analysis of Mean Effluent Total NO_3 Concentration by BMP Category (one value per BMP Study)

No significant difference between averaged influent and effluent is identified for any BMP categories except media filters, which exhibit a significant increase. The results for this analysis exhibit a high degree of variability, and no single category exhibits significantly lower average effluent values than the others.

Analysis of Effluent Total NO_3 Concentrations by BMP Category (all individual EMCs included in dataset)

Wetland basins and wetland channels exhibit the lowest effluent Total Nitrate EMCs, although both categories include only three BMPs each. Effluent EMCs are highest for detention basins, hydrodynamic devices and media filters. A significant reduction between influent and effluent EMCs is exhibited for retention ponds and wetland basins, while media filters exhibit a significant increase between influent and effluent EMCs, as a category.

BMP Category		Number of BMPs	Median of Avg. Effluent (95% Confidence Interval)[1]			Significant Difference Between Average Influent and Effluent[2]	Median of Effluent EMCs (95% Confidence Interval)[1]			Significant Difference Between Influent and Effluent EMCs[2]
			Median	LCL	UCL		Median	LCL	UCL	
DB	Detention Basin	9	0.6	0.35	1.03	NO	0.6	0.49	0.74	NO
GS	Biofilter	42	0.64	0.49	0.85	NO	0.35	0.31	0.39	NO
HD	Hydrodynamic Device	2	1.56	0.43	5.66	NO	0.61	0.45	0.82	NO
MF	Media Filter	16	0.94	0.75	1.19	YES[3]	0.68	0.61	0.75	YES[3]
RP	Retention Pond	6	0.46	0.27	0.76	NO	0.27	0.21	0.34	YES
WB	Wetland Basin	3	0.46	0.16	1.28	NO	0.17	0.13	0.21	YES
WC	Wetland Channel	3	0.31	0.14	0.71	NO	0.2	0.14	0.28	NO

1. Calculation of confidence interval based on McGill et al (1978), from the natural log of the quantiles.
2. Based on non-parametric analysis of difference in median values.
3. Indicates that effluent is significantly greater than influent.

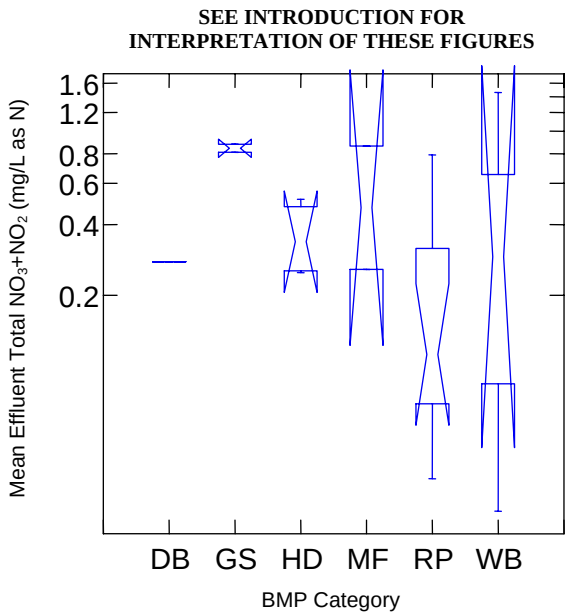


Figure 7. Mean effluent Nitrate+Nitrite Nitrogen concentrations by BMP category

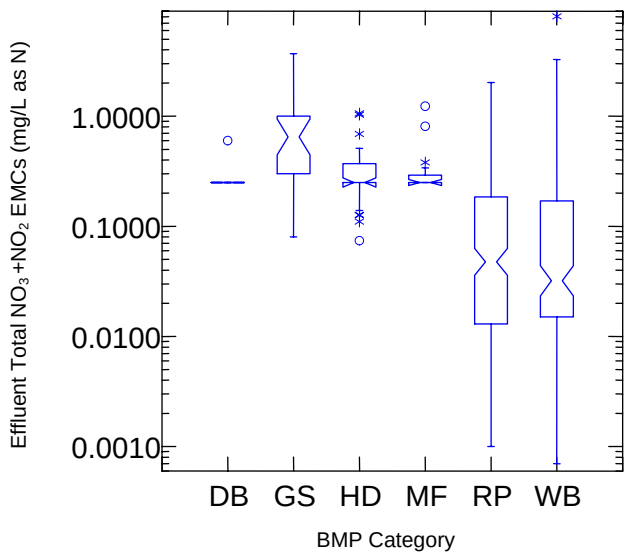


Figure 8. Individual effluent Nitrate+Nitrite Nitrogen EMCs by BMP category

Total Nitrate + Nitrite (mg/L as N)

Total Nitrate + Nitrite includes both the intermediate form of oxidized nitrogen, nitrite, as well as the completely oxidized nitrate. In oxygen-rich environments, nitrite rapidly reduces to nitrate (nitrification), while under anaerobic conditions it transforms to nitrogen gas (denitrification). The combined forms of oxidized nitrogen are not commonly reported in the International Stormwater Best Management Practices (BMP) Database. The category with the most BMPs reporting total nitrate + nitrite is retention ponds.

Analysis of Mean Effluent Total NO_3+NO_2 Concentration by BMP Category (one value per BMP Study)

No significant difference between the medians of averaged influent and effluent concentrations is exhibited for any BMP category analyzed. The lack of sufficient data for most BMP categories prevents any substantial comparative analysis.

Analysis of Effluent Total NO_3+NO_2 Concentrations by BMP Category (all individual EMCs included in dataset)

Median effluent EMCs for retention ponds and wetland basins are significantly less than median influent levels. Results for the other categories suggest little influence on Nitrate + Nitrite levels.

BMP Category		Number of BMPs	Median of Avg. Effluent (95% Confidence Interval)[1]			Significant Difference Between Average Influent and Effluent[2]	Median of Effluent EMCs (95% Confidence Interval)[1]			Significant Difference Between Influent and Effluent EMCs[2]
			Median	LCL	UCL		Median	LCL	UCL	
DB	Detention Basin	1	Insufficient sample size for analysis.				0.25	0.25	0.25	NO
GS	Biofilter	2	0.85	0.77	0.92	NO	0.65	0.45	0.94	NO
HD	Hydrodynamic Device	4	0.34	0.21	0.56	NO	0.25	0.23	0.28	NO
MF	Media Filter	2	0.47	0.12	1.82	NO	0.25	0.23	0.27	NO
RP	Retention Pond	12	0.11	0.06	0.22	NO	0.05	0.04	0.06	YES
WB	Wetland Basin	3	0.29	0.04	1.9	NO	0.03	0.02	0.04	YES

1. Calculation of confidence interval based on McGill et al (1978), from the natural log of the quantiles.
2. Based on non-parametric analysis of difference in median values.

Analysis of Treatment System Performance - Zinc

SEE INTRODUCTION FOR INTERPRETATION OF THESE FIGURES

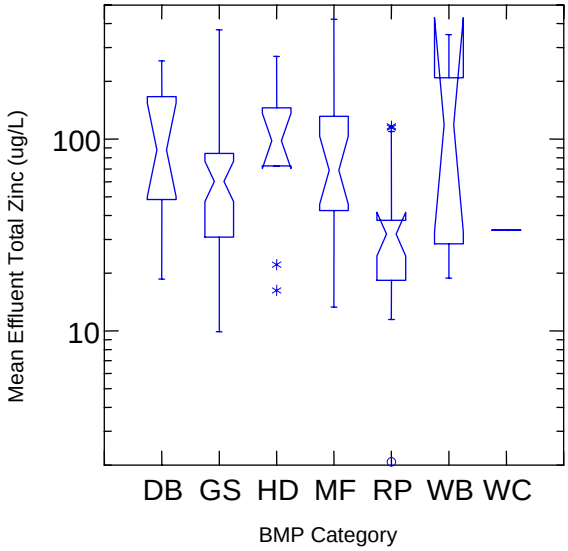


Figure 1. Mean effluent Total Zinc concentration by BMP category

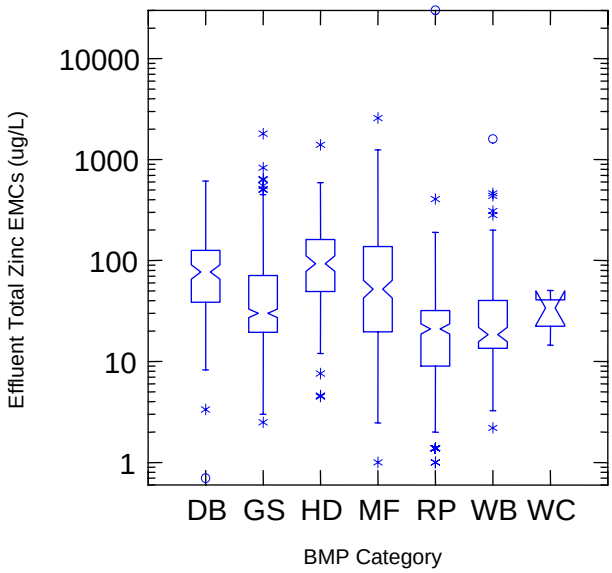


Figure 2. Individual effluent Total Zinc EMCs by BMP category

Total Zinc (µg/L)

Total Zinc, which encompasses both the particulate-borne and dissolved fraction, is one of the most commonly reported metals in the International Stormwater Best Management Practices (BMP) Database. Zinc is particularly prevalent in urban and highway environments, due to atmospheric, industrial and automobile-related sources and deposition. Tire wear and exposed zinc building materials are thought to be two of the larger sources.

Analysis of Mean Effluent Total Zinc Concentration by BMP Category (one value per BMP Study)

Among those categories with sufficient BMPs for analysis, a significant difference between the medians of average influent and average effluent concentrations is exhibited for biofilters. Overall, retention ponds report the lowest distribution of average effluent Total Zinc levels.

Analysis of Effluent Total Zinc Concentrations by BMP Category (all EMCs included in dataset)

All BMP categories except wetland channels report significantly lower median effluent EMCs than median influent EMCs for Total Zinc (note that the wetland channel dataset is limited to only one BMP). The distribution of effluent EMCs is lowest for retention ponds and wetland basins (note that the majority of Total Zinc EMCs for wetland basins are associated with a single study that reported relatively low effluent values). Detention basins and hydrodynamic devices represent the highest effluent values.

BMP Category		Number of BMPs	Median of Avg. Effluent (95% Confidence Interval)[1]			Significant Difference Between Average Influent and Effluent[2]	Median of Effluent EMCs (95% Confidence Interval)[1]			Significant Difference Between Influent and Effluent EMCs[2]
			Median	LCL	UCL		Median	LCL	UCL	
DB	Detention Basin	12	87.92	50.08	154.35	NO	73.48	62.33	86.64	YES
GS	Biofilter	43	60.23	47.26	76.75	YES	30	27.25	33.03	YES
HD	Hydrodynamic Device	11	97.98	70.32	136.51	NO	100	83.77	119.37	YES
MF	Media Filter	19	68.85	45.71	103.68	NO	50.5	41.03	62.15	YES
RP	Retention Pond	19	31.97	24.6	41.55	NO	21	18.69	23.6	YES
WB	Wetland Basin	6	118.74	32.82	429.62	NO	18	15.2	21.32	YES
WC	Wetland Channel	1	Insufficient sample size for analysis.				33.67	22.58	50.22	NO

1. Calculation of confidence interval based on McGill et al (1978), from the natural log of the quantiles.
2. Based on non-parametric analysis of difference in median values.

SEE INTRODUCTION FOR INTERPRETATION OF THESE FIGURES

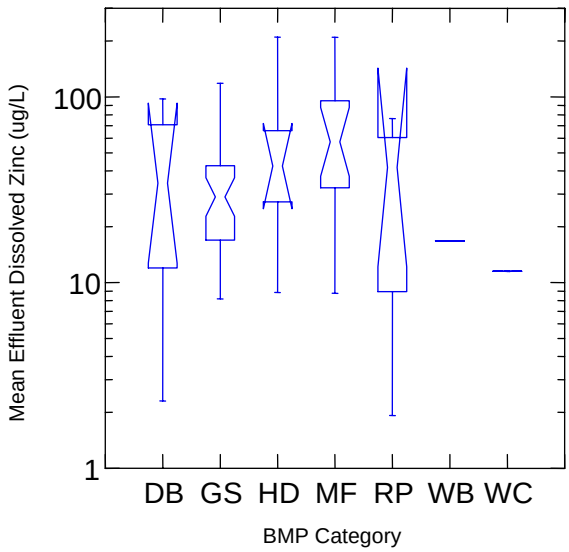


Figure 3. Mean effluent Dissolved Zinc concentration by BMP category

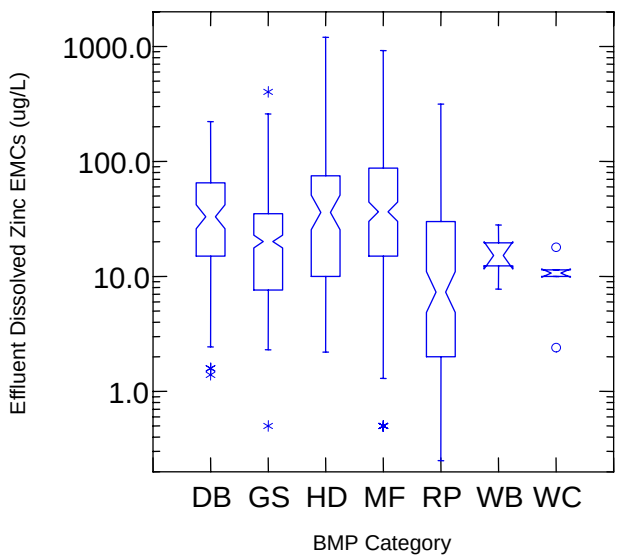


Figure 4. Individual effluent Dissolved Zinc EMCs by BMP category

Dissolved Zinc (µg/L)

Dissolved Zinc is reported most frequently in the International Stormwater BMP Database for biofilters and media filters. Most of the other BMP categories include less than 10 studies, reducing the ability to obtain statistically significant results.

Analysis of Mean Effluent Dissolved Zinc Concentration by BMP Category (one value per BMP Study)

A significant difference between averaged influent and effluent concentrations are exhibited for biofilters (there are insufficient BMPs to make a statistically significant determination for wetland channels). Among those categories with sufficient number of BMPs, biofilters also exhibit the lowest distribution of average effluent.

Analysis of Effluent Dissolved Zinc Concentrations by BMP Category (all individual EMCs included in dataset)

Among those BMP categories consisting of more than one study, all categories except detention ponds and hydrodynamic devices exhibit a significant difference in median influent and effluent EMCs. Of these, the distribution of effluent EMCs for retention ponds is significantly lower than the other valid BMP categories (i.e. excluding wetland basins and wetland channels). This result is strongly influenced by the large number of very low effluent values reported for a single retention pond.

BMP Category		Number of BMPs	Median of Avg. Effluent (95% Confidence Interval)[1]			Significant Difference Between Average Influent and Effluent[2]	Median of Effluent EMCs (95% Confidence Interval)[1]			Significant Difference Between Influent and Effluent EMCs[2]
			Median	LCL	UCL		Median	LCL	UCL	
DB	Detention Basin	8	34.34	12.73	92.68	NO	33	25.95	41.96	NO
GS	Biofilter	37	28.91	22.75	36.73	YES	20.1	17.68	22.85	YES
HD	Hydrodynamic Device	7	42.41	25.01	71.94	NO	36	25.49	50.85	NO
MF	Media Filter	16	57.31	37.39	87.83	NO	36.47	30.09	44.2	YES
RP	Retention Pond	6	41.68	12.15	142.95	NO	7.3	4.86	10.98	YES
WB	Wetland Basin	1	Insufficient sample size for analysis.				15.2	11.56	19.98	YES
WC	Wetland Channel	1	Insufficient sample size for analysis.				10.69	9.83	11.64	YES

1. Calculation of confidence interval based on McGill et al (1978), from the natural log of the quantiles.
2. Based on non-parametric analysis of difference in median values.

Analysis of Treatment System Performance - Lead

SEE INTRODUCTION FOR INTERPRETATION OF THESE FIGURES

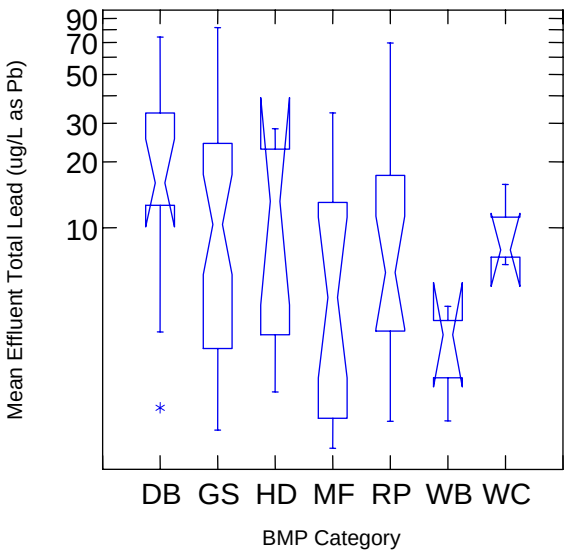


Figure 1. Mean effluent Total Lead concentrations by BMP category

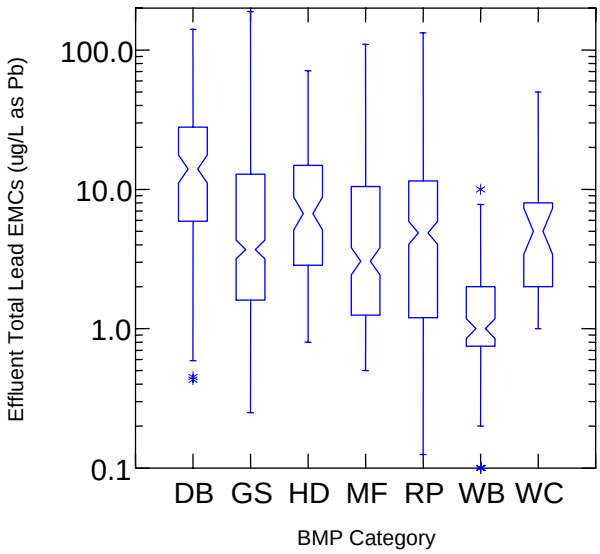


Figure 2. Individual effluent Total Lead EMCs by BMP category

Total Lead (µg/L as Pb)

Total Lead is the second-most reported metal constituent in the International Stormwater Best Management Practices (BMP) Database after Total Zinc.

Analysis of Mean Effluent Total Lead Concentration by BMP Category (one value per BMP Study)

A statistically significant difference between the median of averaged influent and median of averaged effluent lead concentrations is only exhibited for wetland channels, which is limited to three sites. Of the categories with a sufficient number of studies, media filters report the lowest averaged effluent concentrations.

Analysis of Effluent Total Lead Concentrations by BMP Category (all individual EMCs included in dataset)

In terms of EMCs, all seven BMP categories examined exhibited significantly lower median effluent EMCs than influent. Distribution of effluent EMCs are the lowest for media filters and biofilters, both of which employ a filtration as a primary unit process.

Interpretation of results is hindered by the presence of a large number of non-detects. Several EMCs for biofilters, hydrodynamic devices, retention ponds and wetland basins fall below the typical detection threshold – over 60% of one retention pond's EMCs are non-detects.

BMP Category		Number of BMPs	Median of Avg. Effluent (95% Confidence Interval)[1]			Significant Difference Between Average Influent and Effluent[2]	Median of Effluent EMCs (95% Confidence Interval)[1]			Significant Difference Between Influent and Effluent EMCs[2]
			Median	LCL	UCL		Median	LCL	UCL	
DB	Detention Basin	11	16.01	10.08	25.43	NO	14	11.12	17.63	YES
GS	Biofilter	42	10.35	6.12	17.51	NO	3.7	3.16	4.33	YES
HD	Hydrodynamic Device	8	13.2	4.44	39.28	NO	6.7	5.1	8.81	YES
MF	Media Filter	18	4.8	2.06	11.18	NO	3.05	2.44	3.82	YES
RP	Retention Pond	19	6.24	3.45	11.29	NO	4.87	4.03	5.88	YES
WB	Wetland Basin	3	3.25	1.87	5.63	NO	1	0.85	1.18	YES
WC	Wetland Channel	3	7.93	5.4	11.64	YES	5	3.41	7.32	YES

1. Calculation of confidence interval based on McGill et al (1978), from the natural log of the quantiles.
2. Based on non-parametric analysis of difference in median values.

SEE INTRODUCTION FOR INTERPRETATION OF THESE FIGURES

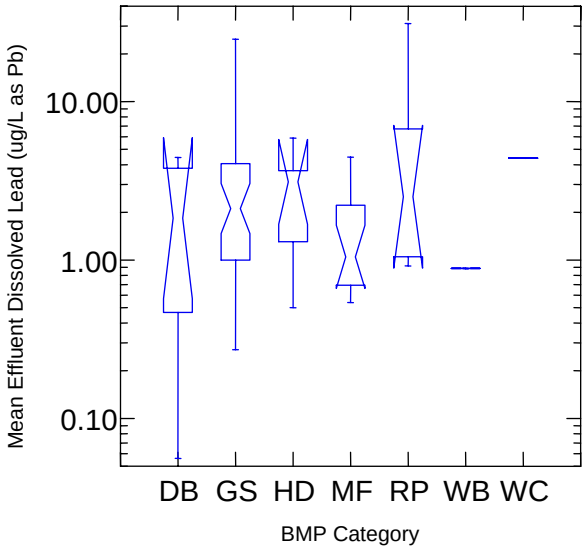


Figure 3. Mean effluent Dissolved Lead concentrations by BMP category

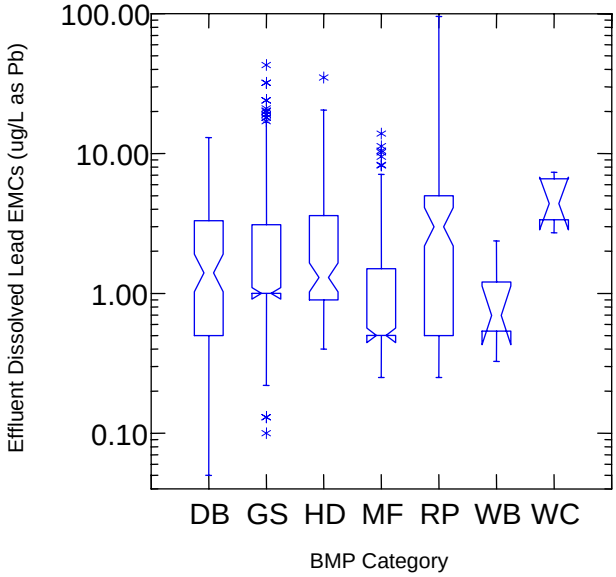


Figure 4. Individual effluent Dissolved Lead EMCs by BMP category

Dissolved Lead (µg/L as Pb)

USEPA recommended freshwater criterion (acute levels) for Dissolved Lead is 65 µg/L*. With the exception of a single EMC reported for a retention pond, effluent concentrations in this dataset were well below the freshwater criterion.

In contrast to the results for Total Lead, the results for Dissolved Lead largely indicate no significant impact on water quality concentrations. Of those BMP categories with more than one study in the dataset, the only significant difference exhibited is between influent and effluent EMCs for media filters.

Analysis of Dissolved Lead is strongly impacted by associated minimum detection limits. Known non-detects in the Database are analyzed by substituting ½ the detection limit, which is 0.5 µg/L for most studies in this dataset; a small number of EMCs are reported below this value.

* Based on 2002 National Recommended Water Quality Criteria. Value is expressed as a function of the hardness in the water column, corresponding here to 100 mg/L of hardness.

BMP Category		Number of BMPs	Median of Avg. Effluent (95% Confidence Interval)[1]			Significant Difference Between Average Influent and Effluent[2]	Median of Effluent EMCs (95% Confidence Interval)[1]			Significant Difference Between Influent and Effluent EMCs[2]
			Median	LCL	UCL		Median	LCL	UCL	
DB	Detention Basin	8	1.84	0.57	5.92	NO	1.4	1.03	1.91	NO
GS	Biofilter	37	2.11	1.47	3.04	NO	1	0.91	1.1	NO
HD	Hydrodynamic Device	7	3.11	1.68	5.76	NO	1.3	1.03	1.65	NO
MF	Media Filter	16	1.05	0.66	1.66	NO	0.5	0.44	0.56	YES
RP	Retention Pond	8	2.51	0.89	7.08	NO	3	2.19	4.12	NO
WB	Wetland Basin	1	Insufficient sample size for analysis.				0.59	0.36	0.97	NO
WC	Wetland Channel	1	Insufficient sample size for analysis.				3.95	2.52	6.17	YES

1. Calculation of confidence interval based on McGill et al (1978), from the natural log of the quantiles.
2. Based on non-parametric analysis of difference in median values.
3. Indicates that effluent is significantly greater than influent.

Analysis of Treatment System Performance - Copper

SEE INTRODUCTION FOR INTERPRETATION OF THESE FIGURES

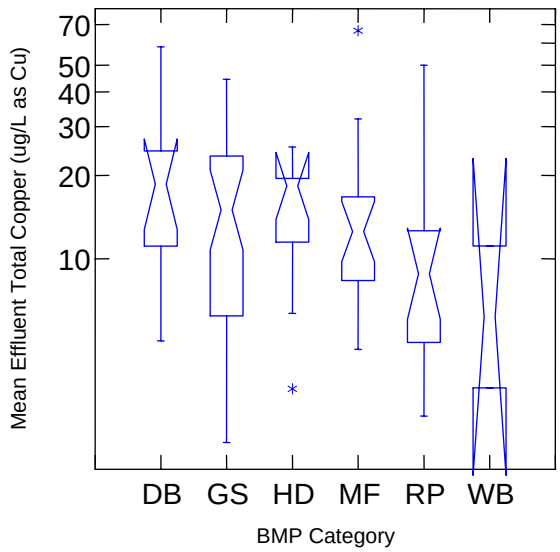


Figure 1. Mean effluent Total Copper concentration by BMP category

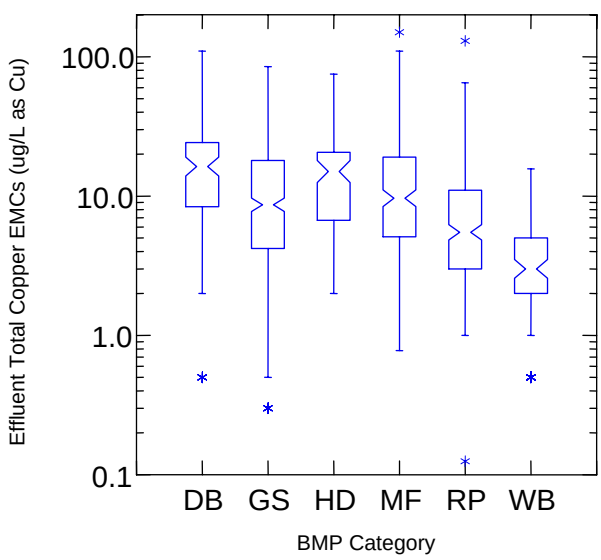


Figure 2. Individual effluent Total Copper EMCs by BMP category

Total Copper (µg/L as Cu)

Total Copper is well-reported in the International Stormwater Best Management Practices (BMP) Database. A majority of the studies reporting Total Copper are in the biofilter category.

Analysis of Mean Effluent Total Copper Concentration by BMP Category (one value per BMP Study)

A significant difference between the median influent and effluent means was identified for biofilters. Other BMP categories report lower averaged effluent values, but do not exhibit a significant change from influent concentrations. The wetland basin dataset is also hampered by the small number of available studies.

Analysis of Effluent Total Copper Concentrations by BMP Category (all individual EMCs included in dataset)

Of the BMP categories analyze, only hydrodynamic devices fail to exhibit a significant difference in median influent and effluent EMCs. The distribution of effluent EMCs for retention ponds and wetland basins are significantly lower than for other BMP categories, although the latter is based on a dataset from only three BMPs. One retention pond almost uniformly reported effluent Total Copper values of 50 µg/L – neglecting this potentially erroneous data, the distribution of effluent EMCs for retention ponds would be lower than shown here.

BMP Category		Number of BMPs	Median of Avg. Effluent (95% Confidence Interval)[1]			Significant Difference Between Average Influent and Effluent[2]	Median of Effluent EMCs (95% Confidence Interval)[1]			Significant Difference Between Influent and Effluent EMCs[2]
			Median	LCL	UCL		Median	LCL	UCL	
DB	Detention Basin	11	18.59	12.75	27.12	NO	16.3	13.94	19.06	YES
GS	Biofilter	40	15.01	10.76	20.92	YES	8.65	7.73	9.67	YES
HD	Hydrodynamic Device	9	18.31	13.86	24.19	NO	15	12.5	18	NO
MF	Media Filter	19	12.54	9.75	16.13	NO	9.65	8.41	11.07	YES
RP	Retention Pond	15	8.83	6.05	12.9	NO	5.5	4.85	6.24	YES
WB	Wetland Basin	2	6.16	1.65	23.03	NO	3	2.57	3.5	YES

1. Calculation of confidence interval based on McGill et al (1978), from the natural log of the quantiles.
2. Based on non-parametric analysis of difference in median values.

SEE INTRODUCTION FOR
INTERPRETATION OF THESE FIGURES

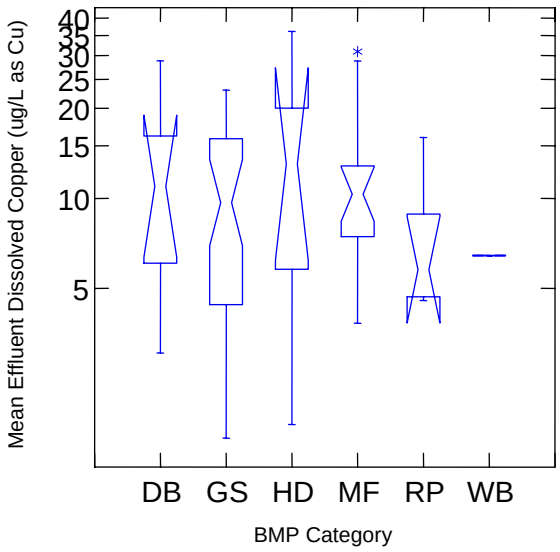


Figure 3. Mean effluent Dissolved Copper concentration by BMP category

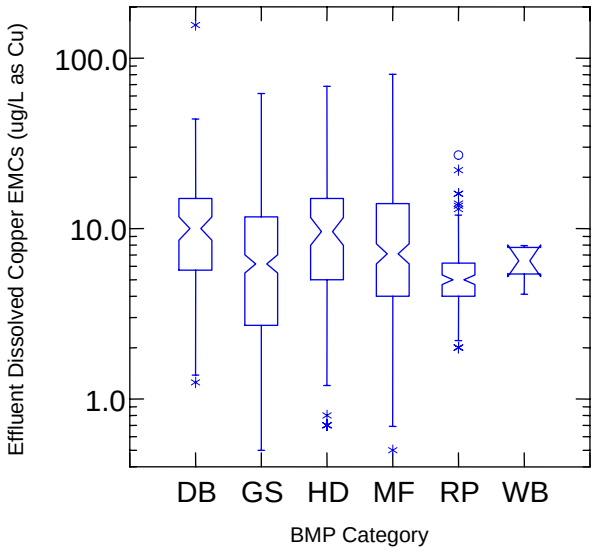


Figure 4. Individual effluent Dissolved Copper EMCs by BMP category

Dissolved Copper (µg/L as Cu)

Dissolved Copper is not as widely reported in the Database as Total Copper. The most studies reporting Dissolved Copper are for media filters and biofilters.

Analysis of Mean Effluent Dissolved Copper Concentration by BMP Category (one value per BMP Study)

No significant difference between median influent and effluent averaged EMCs was exhibited by any of the BMP categories consisting of more than one study.

Analysis of Effluent Dissolved Copper Concentrations by BMP Category (all individual EMCs included in dataset)

Biofilters and retention ponds exhibit a significant difference in median influent and effluent EMCs. The distribution of effluent EMCs for retention ponds is also significantly lower than for other BMP categories.

BMP Category		Number of BMPs	Median of Avg. Effluent (95% Confidence Interval)[1]			Significant Difference Between Average Influent and Effluent[2]	Median of Effluent EMCs (95% Confidence Interval)[1]			Significant Difference Between Influent and Effluent EMCs[2]
			Median	LCL	UCL		Median	LCL	UCL	
DB	Detention Basin	8	10.98	6.35	18.98	NO	10	8.53	11.72	NO
GS	Biofilter	37	9.68	6.95	13.49	NO	6.2	5.48	7.01	YES
HD	Hydrodynamic Device	7	13.02	6.21	27.3	NO	9.6	7.95	11.59	NO
MF	Media Filter	17	10.33	8.38	12.73	NO	7.1	6.2	8.14	NO
RP	Retention Pond	6	5.77	3.83	8.7	NO	5	4.69	5.33	YES
WB	Wetland Basin	1	Insufficient sample size for analysis.				6.46	5.21	8	NO

1. Calculation of confidence interval based on McGill et al (1978), from the natural log of the quantiles.
2. Based on non-parametric analysis of difference in median values.