Appendix D
Water Quality Results

National Pollutant Removal Performance Database

Version 3

September, 2007

Center for Watershed Protection

8390 Main Street, 2nd Floor
Ellicott City, MD 21043
410.461.8323
FAX 410.461.8324
www.cwp.org
www.stormwatercenter.net

The National Pollutant Removal Performance Database v. 2 was recently updated to include an additional 27 studies published through 2006. The updated database was statistically analyzed to derive the median and quartile removal values for each major group of stormwater BMPs. The data are presented as box and whisker plots for the various pollutants found in stormwater runoff.

1.0 Introduction

The National Pollutant Removal Performance Database, version 2 (Winer, 2000) consisted of 139 individual best management practice (BMP) performance studies published through 2000. An update of the database has since been conducted to include an additional 27 studies published through 2006. The source information for these additional studies is listed in the References section of this document. The updated database was statistically analyzed to derive the median and quartile removal values for each major group of stormwater BMPs (Figures 1-7).

All BMP studies considered for inclusion into the database were reviewed with respect to three target criteria:

1. Five or more storm samples were collected
2. Automated equipment that enabled flow or time-based composite samples were used
3. The method used to compute removal efficiency was documented

Pollutant removal efficiency, usually represented by a percentage, specifically refers to the pollutant reduction from the inflow to the outflow of a system. The two most common computation methods are event mean concentration (EMC) efficiency and mass or load efficiency. When more than one method was used to calculate pollutant removal in a specific BMP study, mass or load-based measurements of removal efficiency were entered into the database rather than concentration-based measurements.

While EMC efficiency averages the inflow and outflow concentrations for all storm events, it does not account for water volume. Mass efficiency, on the other hand, is influenced by the volume of water entering the BMP and water losses within the BMP (e.g., evapotranspiration and infiltration) (Winer, 2000). This method is based on the sum of incoming and outgoing loads and is considered a more accurate calculation than EMC efficiency, which gives equal weight to both small and large storm events. As a general rule, the concentration-based technique often results in slightly lower performance efficiencies than the mass-based technique.

2.0 Caveats

The statistical analysis results should be used to examine the general removal capability of various groups and design variations of BMPs. Several caveats should be understood for those using these data:

- *Limited Data* - BMP research is still a relatively young field and the number of studies is limited, especially for certain categories of BMPs. Users should understand that these performance results represent an analysis of currently available research; further research will likely lead to revised numbers. As the number of studies increase, so will the confidence with which BMP performance can be reported.

- *Range of Data* - Across the various categories of BMPs, the range of data for a particular pollutant can be quite high. That is, there is a large difference between the lowest and highest removal efficiency reported. The range is represented by the length of the bars in Figures 1 – 7. The greater the range, the less confidence there is in the median removal efficiency. Also, further work is necessary to identify the factors that lead to either poor or good performance.
- *Factors that Affect Performance* - Related to the point above about data ranges, there are many factors that affect BMP performance, including:
  - Number of storms sampled
  - Manner in which pollutant removal efficiency is computed
  - Monitoring technique employed
  - Internal geometry and storage volume provided by the practice design
  - Sediment/water column interactions
  - Regional differences in soil type
  - Rainfall, flow rate, and particle sizes of the influent (runoff entering the BMP)
  - Latitude
  - Size and land use of the contributing catchment
- *Incoming Pollutant Concentrations* - In addition, pollutant removal percentages can be strongly influenced by the variability of the pollutant concentrations in incoming stormwater (Schueler, 2000b). If the concentration is near the "irreducible level" (Schueler, 2000a), a low or negative removal percentage can be recorded, even though outflow concentrations discharged from the BMP are relatively low. In other words, if relatively clean water is entering a BMP, then there is limited performance potential that can be achieved by the BMP. BMPs that treat the dirtiest water (runoff with relatively high pollutant concentrations) are likely to achieve higher percent removals.
- *BMP Age* - The data used to determine general removal capabilities are based on "best condition" values. In particular, most of the studies focused on BMPs that were constructed within three years of monitoring (Winer 2000).
- *Volume Reduction* - Several categories of BMPs can be quite effective at reducing the overall volume of runoff. Volume reduction BMPs have a filtering, infiltration, biological uptake, or storage and reuse component that permanently removes some volume of runoff from the outflow. BMPs that reduce volume are also reducing pollutant loads, although a concentration-in vs. concentration-out study would not account for this. For this reason, the removal efficiency of these types of BMPs may be under-reported, especially when a concentration-in versus concentration-out study approach was used.

3.0 Using BMP Data to Improve BMP Design

There has been a strong tendency for stormwater programs to use the median removal efficiencies in determining which BMP to include in stormwater codes and design manuals, and in assigning BMP performance values. Given the data caveats noted above, greater restraint should be applied in using median removal efficiencies.

As discussed above, there are many factors that influence BMP performance. Some of these are related to geography and hydrology, and thus outside of the control of BMP designers. However, some of the variability in the data is explained by design factors. Certain BMP design factors either increase or decrease BMP performance. Use of the median value can lead to design standards that aim towards the middle range of performance, thus mediocre performing BMPs in the ground.

Some of the design factors that influence performance include sizing, contributing drainage area, pretreatment, geometry, use of vegetation, and flow path (e.g., off-line design). BMP design should strive to incorporate as many design factors as possible that enhance performance. If one looks at the BMP plots in Figures 1 – 7, the objective should be to design BMPs that achieve the 75th percentile removal efficiency, rather than the median.

Further work is needed to isolate the design factors that lead to better design and better BMPs. For more discussion on this topic, see *Urban Stormwater Retrofit Practices, Appendix B* (CWP, 2007).

4.0 BMP Removal Efficiency Plots

Figures 1 through 7 are "box and whisker" plots for the various categories of BMPs, as updated in the National Pollutant Removal Performance Database (2006). Tables 1 through 7 show the corresponding tabular data for the plots. The data were grouped into the BMP categories listed in Table 1 below.

Table 1. Number of Studies included in the National Pollutant Removal Performance Database (2006)*

Practice	# of Studies
Dry Ponds	**10**
Quality Control Pond	3
Dry ED Pond	7
Wet Ponds	**46**
Wet ED Pond	15
Multiple Pond System	1
Wet Pond	30
Wetlands	**40**
Shallow Marsh	24
ED Wetland	4
Pond/Wetland System	10
Submerged Gravel Wetland	2
Filtering	**18**
Organic Filter	7
Sand Filter	11
Bioretention	**10**
Infiltration	**12**
Infiltration Trench	3
Porous Pavement	9
Open Channels	**17**
Grass Channel	3
Dry Swale	12

Wet Swale	2

*Proprietary products (e.g., oil-grit separator, stormceptor), ditches (open channel practice), and vertical sand filters (filtering practice) were included as part of the database, but were not analyzed as part of this study.

The plots and tables summarize the following features from the data:

- Median Efficiency = where light grey and dark grey bars meet
- Average Efficiency = small diamond
- 25th Percentile = bottom of light grey bar
- 75th Percentile = top of dark grey bar
- Highest value = top of line
- Lowest value = bottom of line
- Number of studies analyzed for each pollutant = n (located below the pollutant label)

The plots and tables show removal efficiencies for the following pollutants:

- TSS = Total Suspended Solids
- TP = Total Phosphorus
- Sol P = Soluble Phosphorus (ortho-phosphorus and dissolved phosphorus)
- TN = Total Nitrogen
- NOx = Nitrogen as Nitrate (NO_2) & Nitrite (NO_3)
- Cu = Copper
- Zn = Zinc
- Bacteria = Bacteriological indicators (fecal streptococci, enterococci, fecal coliform, *E. coli* and total coliform)

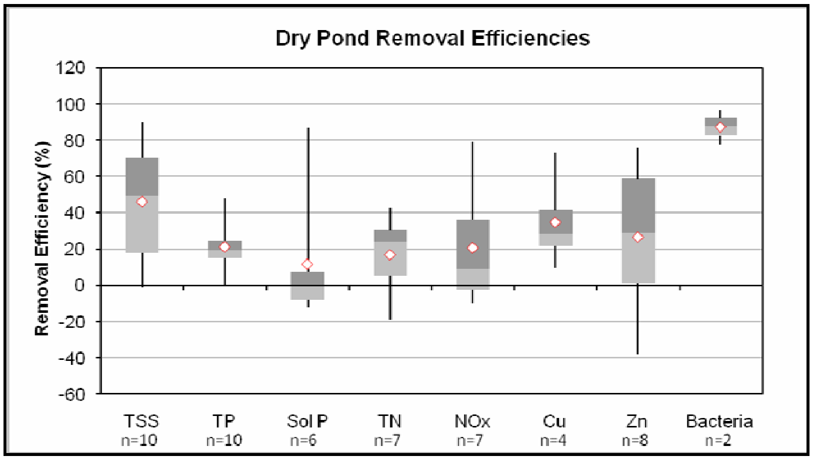

Figure 1. Dry Pond Removal Efficiencies

Table 1. Dry Pond Removal Efficiency Statistics								
	TSS	**TP**	**Sol P**	**TN**	**NO_x**	**Cu**	**Zn**	**Bacteria**
Median	49	20	-3	24	9	29	29	88
Min	-1	0	-12	-19	-10	10	-38	78
Max	90	48	87	43	79	73	76	97
Q1	18	15	-8	5	-2	22	1	83
Q3	71	25	8	31	36	42	59	92
Number	10	10	6	7	7	4	8	2

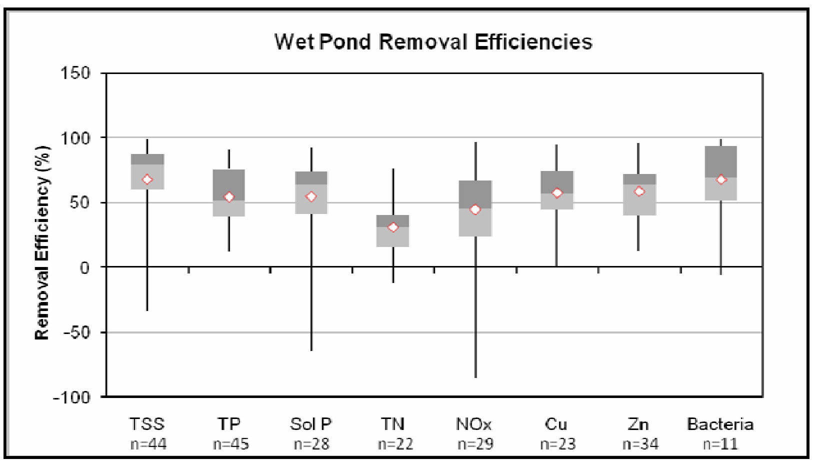

Figure 2. Wet Pond Removal Efficiencies

Table 2. Wet Pond Removal Efficiency Statistics								
	TSS	**TP**	**Sol P**	**TN**	**NO_x**	**Cu**	**Zn**	**Bacteria**
Median	**80**	**52**	**64**	**31**	**45**	**57**	**64**	**70**
Min	**-33**	**12**	**-64**	**-12**	**-85**	**1**	**13**	**-6**
Max	**99**	**91**	**92**	**76**	**97**	**95**	**96**	**99**
Q1	**60**	**39**	**41**	**16**	**24**	**45**	**40**	**52**
Q3	**88**	**76**	**74**	**41**	**67**	**74**	**72**	**94**
Number	**44**	**45**	**28**	**22**	**29**	**23**	**34**	**11**

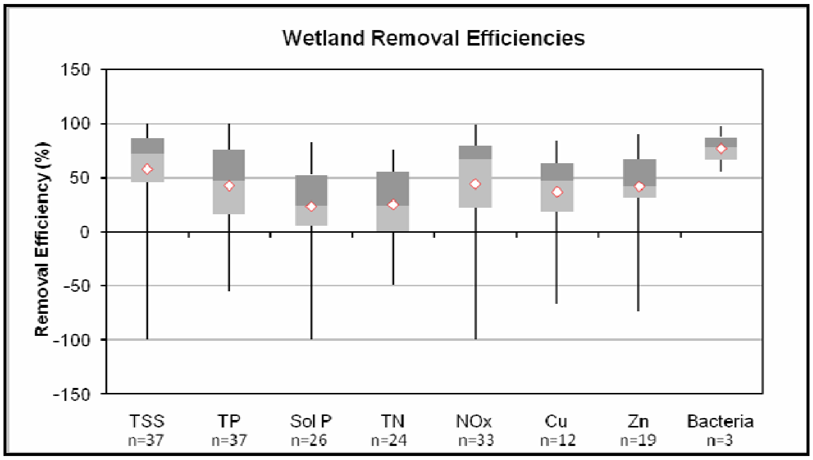

Figure 3. Wetland Removal Efficiencies

Table 3. Wetland Removal Efficiency Statistics								
	TSS	**TP**	**Sol P**	**TN**	**NO_x**	**Cu**	**Zn**	**Bacteria**
Median	72	48	25	24	67	47	42	78
Min	-100	-55	-100	-49	-100	-67	-74	55
Max	100	100	82	76	99	84	90	97
Q1	46	16	6	0	22	18	31	67
Q3	86	76	53	55	80	63	68	88
Number	37	37	26	24	33	12	19	3

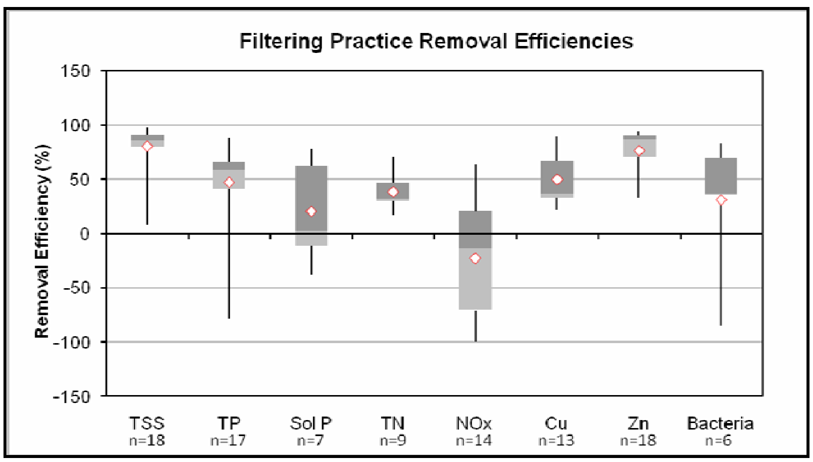

Figure 4. Filtering Practice Removal Efficiencies

Table 4. Filtering Practice Removal Efficiency Statistics								
	TSS	**TP**	**Sol P**	**TN**	**NO_x**	**Cu**	**Zn**	**Bacteria**
Median	86	59	3	32	-14	37	87	37
Min	8	-79	-37	17	-100	22	33	-85
Max	98	88	78	71	64	90	94	83
Q1	80	41	-11	30	-70	33	71	36
Q3	92	66	63	47	21	67	91	70
Number	18	17	7	9	14	13	18	6

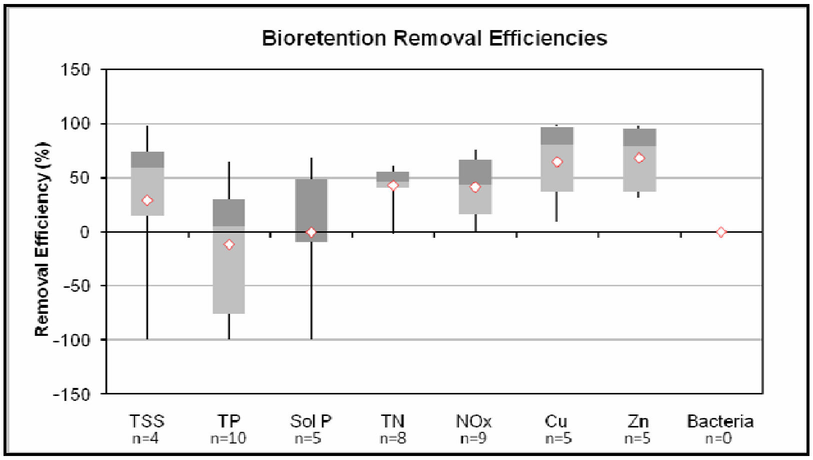

Figure 5. Bioretention Removal Efficiencies

Table 5. Bioretention Removal Efficiency Statistics								
	TSS	**TP**	**Sol P**	**TN**	**NO_x**	**Cu**	**Zn**	**Bacteria**
Median	**59**	**5**	**-9**	**46**	**43**	**81**	**79**	**N/A**
Min	**-100**	**-100**	**-100**	**-2**	**0**	**9**	**31**	**N/A**
Max	**98**	**65**	**69**	**61**	**76**	**99**	**98**	**N/A**
Q1	**15**	**-76**	**-9**	**40**	**16**	**37**	**37**	**N/A**
Q3	**74**	**30**	**49**	**55**	**67**	**97**	**95**	**N/A**
Number	**4**	**10**	**5**	**8**	**9**	**5**	**5**	**0**

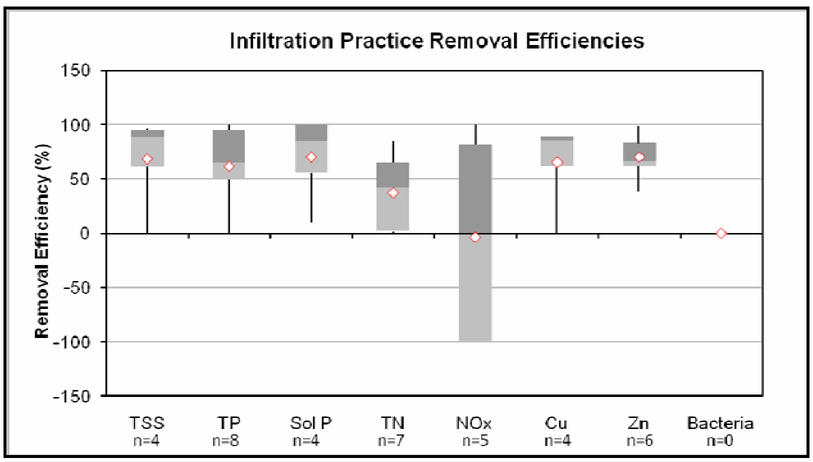

Figure 6. Infiltration Practice Removal Efficiencies

Table 6. Infiltration Practice Removal Efficiency Statistics								
	TSS	**TP**	**Sol P**	**TN**	**NO_x**	**Cu**	**Zn**	**Bacteria**
Median	**89**	**65**	**85**	**42**	**0**	**86**	**66**	**N/A**
Min	**0**	**0**	**10**	**0**	**-100**	**0**	**39**	**N/A**
Max	**97**	**100**	**100**	**85**	**100**	**89**	**99**	**N/A**
Q1	**62**	**50**	**55**	**2**	**-100**	**62**	**63**	**N/A**
Q3	**96**	**96**	**100**	**65**	**82**	**89**	**83**	**N/A**
Number	**4**	**8**	**4**	**7**	**5**	**4**	**6**	**0**

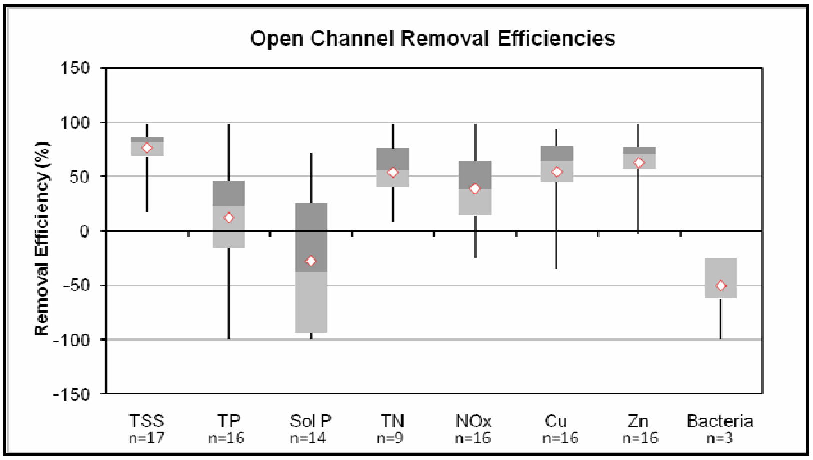

Figure 7. Open Channel Removal Efficiencies

Table 7. Open Channel Removal Efficiency Statistics								
	TSS	TP	Sol P	TN	NO_x	Cu	Zn	Bacteria
Median	81	24	-38	56	39	65	71	-25
Min	18	-100	-100	8	-25	-35	-3	-100
Max	99	99	72	99	99	94	99	-25
Q1	69	-15	-94	40	14	45	58	-63
Q3	87	46	26	76	65	79	77	-25
Number	17	16	14	9	16	16	16	3

4.0 References

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Analysis of Treatment System Performance

International Stormwater Best Management Practices (BMP) Database [1999-2008]

Prepared by:

Geosyntec Consultants
Wright Water Engineers, Inc.

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

June 2008

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Analysis of Treatment System Performance
Disclaimer

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.

Analysis of Treatment System Performance
Introduction

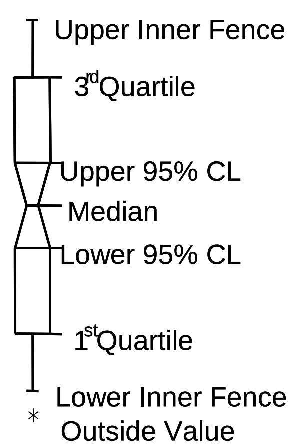
The following summaries analyze available monitoring data drawn from the International Stormwater Best Management Practices (BMP) Database to determine whether any differences in treatment performance may be determined based on BMP category (e.g. detention basin, media filter, wetland basin, etc). These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

Note on Hydrodynamic Devices:

For this overview-level analysis, BMPs have been grouped into broad categories. These categories may mask distinctive differences in design and performance in subcategories for multiple BMP types. This is particularly true for the Hydrodynamic Device (HD) category, which represents a wide range of various proprietary and non-proprietary device types. Each of the BMPs categorized as HD device types incorporates or emphasizes a number of different unit processes and design elements (e.g., storage versus flow-through designs, inclusion of media filtration, etc.) that vary significantly throughout the category. These design features likely have significant effects on BMP performance and the underlying detailed data analysis for each HD device (available from www.bmpdatabase.org) should be referenced before drawing conclusions on the *performance of Hydrodynamic Devices (and to some extent other BMP types.) At this time it is not possible to identify which unit processes or design elements represent key differentiators in performance, nor to further subdivide this category. Any interpretation or use of the results presented herein should fully acknowledge the widely varied nature of Hydrodynamic Devices, as well as other BMP categories. We recommend that for HD devices in particular that more attention be paid to the observed ranges in performance than median or mean effluent values. The Project Team's future plans include developing additional BMP categories (and subcategories) as more studies become available.*

References

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Analysis of Treatment System Performance - Solids

SEE INTRODUCTION FOR INTERPRETATION OF THESE FIGURES

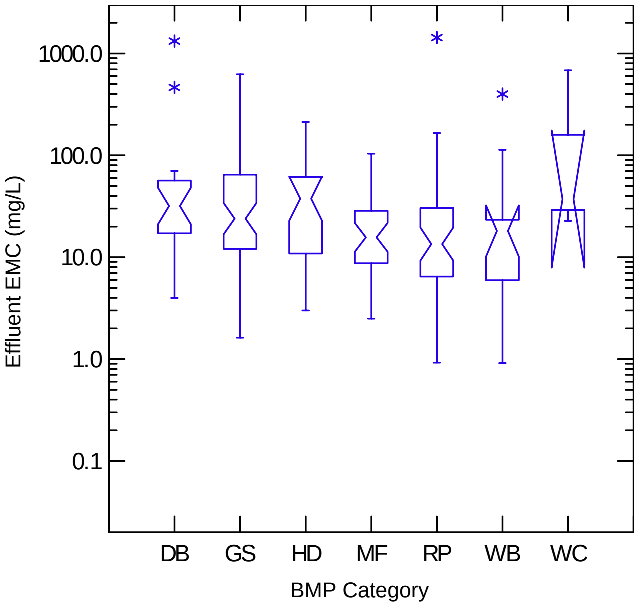

Figure 1. Mean effluent TSS concentration by BMP category

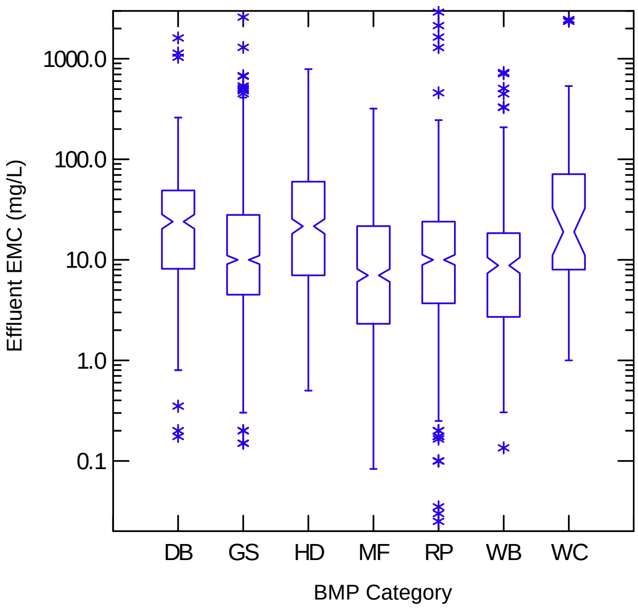

Figure 2. Individual effluent TSS EMCs by BMP category

Total Suspended Solids (mg/L)

Total suspended solids (TSS) represent 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. Particle size distribution may play a significant role in BMP performance. For example, coarse sand settles more rapidly than finer particles associated with clayey or silty soils.

Although EPA does not provide a national recommended numeric water quality criterion for TSS, many NPDES construction dewatering and wastewater permits identify 30 mg/L as the average permissible TSS concentration. Median concentrations for all of the BMP categories are below 30 mg/L.

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 biofilters, media filters and retention ponds. Median averaged effluent concentrations for detention basins, biofilters, wetland channels and hydrodynamic devices are above 15 mg/L, while those for media filters, retention ponds and wetland basins range between approximately 10 to 14 mg/L.

Media filters, biofilters and hydrodynamic devices are all primarily flow-through systems (i.e. no significant detention of flows). Of the storage-type categories, those which include some kind of permanent pool (i.e., retention ponds and wetland basins) exhibit significantly lower effluent levels. Hydrodynamic devices that include storage components were not analyzed separately in this summary report.

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

Median effluent TSS EMCs for all BMP categories exhibited statistical significance between influent and effluent EMCs. Effluent concentrations appear to be greater than influent concentrations for wetland channels.

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	22	31.04	16.07	46.01	NO	25.00	21.26	29.04	YES
GS	Biofilter	56	23.92	15.07	32.78	YES	10.00	9.08	11.02	YES
HD	Hydrodynamic Device	30	37.67	21.28	54.02	NO	21.90	18.49	25.93	YES
MF	Media Filter	33	15.86	9.74	21.98	YES	7.60	6.56	8.81	YES
RP	Retention Pond	43	13.37	7.29	19.45	YES	10.00	8.93	11.20	YES
WB	Wetland Basin	14	17.77	9.26	26.29	NO	9.40	7.85	11.25	YES
WC	Wetland Channel	3	37.25	8.02	187.13	NO	19.00	10.93	33.03	YES[3]

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

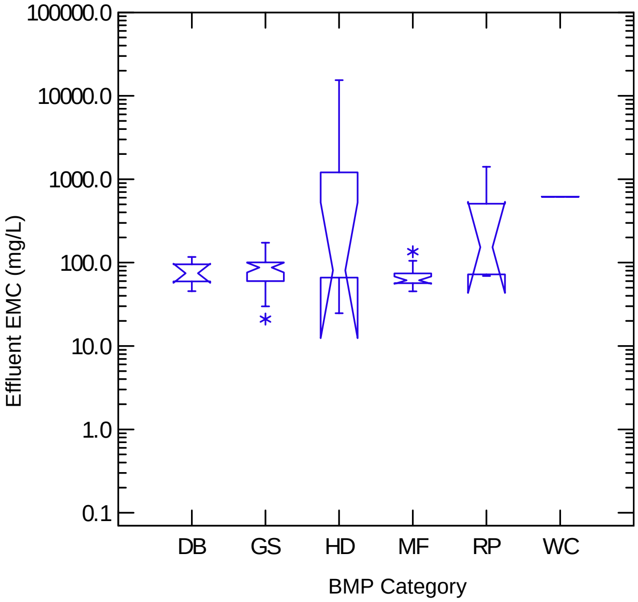

Figure 1. Mean effluent TDS concentration by BMP category

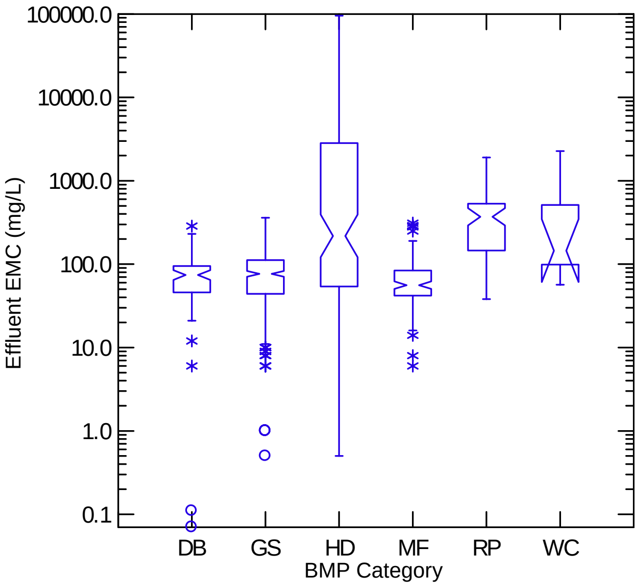

Figure 2. Individual effluent TDS EMCs by BMP category

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)

A statistically significant difference is not exhibited between average influent and effluent TDS concentrations for any BMP category.

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

A statistically significant difference between influent and effluent TDS EMCs is exhibited for biofilters and retention ponds. Effluent concentrations appear to be greater than influent concentrations for 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	65.90	40.71	91.06	NO	74.00	64.42	85.01	NO
GS	Biofilter	37	85.29	75.17	95.41	NO	77.00	71.15	83.33	YES[3]
HD	Hydrodynamic Device	6	63.73	15.25	501.30	NO	228.00	125.96	412.71	NO
MF	Media Filter	17	61.80	54.83	68.17	NO	56.00	50.69	61.87	NO
RP	Retention Pond	6	152.80	43.68	549.61	NO	380.00	297.39	485.55	YES
WC	Wetland Channel	1	Insufficient sample size for analysis.				215.77	51.21	909.08	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

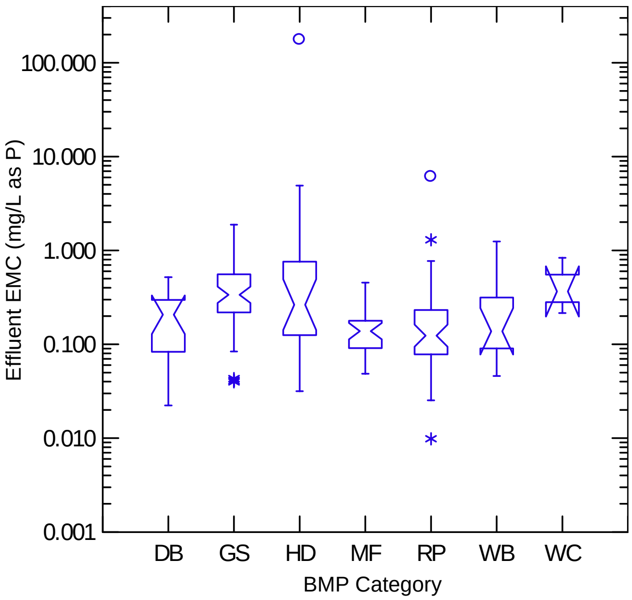

Figure 1. Mean effluent TP concentrations by BMP category

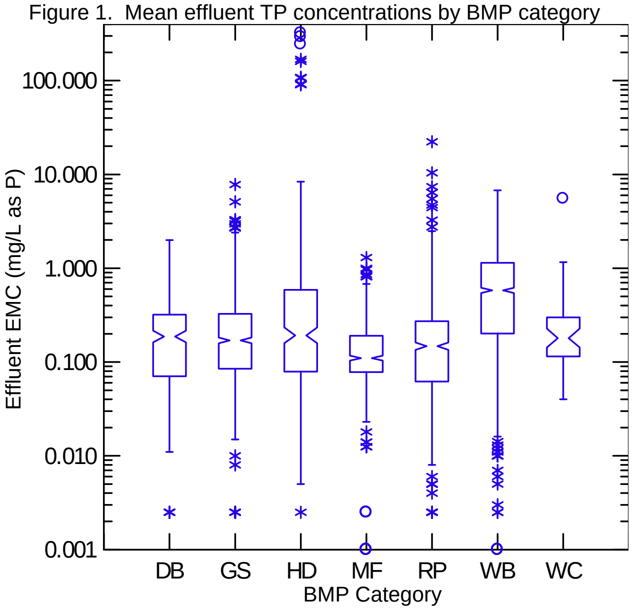

Figure 2. Individual effluent TP EMCs by BMP category

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)

A statistically significant difference between median influent and effluent values is exhibited in biofilters, hydrodynamic devices, media filters and retention ponds. Effluent concentrations for biofilters tend to be greater than influent concentrations.

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

A statistically significant difference between median influent and effluent values is exhibited in media filters and retention ponds. Effluent concentrations appear to be greater than influent concentrations for wetland channels; however, only three studies were provided for wetland channels. Median effluent Total Phosphorus EMCs are lowest for media filters and retention ponds. Wetland Channels also exhibit a significant difference between influent and effluent Total 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	19	0.19	0.12	0.32	NO	0.19	0.16	0.22	NO
GS	Biofilter	55	0.34	0.26	0.41	YES[3]	0.17	0.16	0.18	NO
HD	Hydrodynamic Device	21	0.26	0.12	0.48	YES	0.20	0.16	0.24	NO
MF	Media Filter	28	0.14	0.11	0.16	YES	0.11	0.10	0.12	YES
RP	Retention Pond	40	0.12	0.09	0.16	YES	0.15	0.13	0.16	YES
WB	Wetland Basin	12	0.14	0.04	0.24	NO	0.58	0.54	0.62	NO
WC	Wetland Channel	3	0.37	0.16	0.65	NO	0.20	0.16	0.25	YES[3]

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

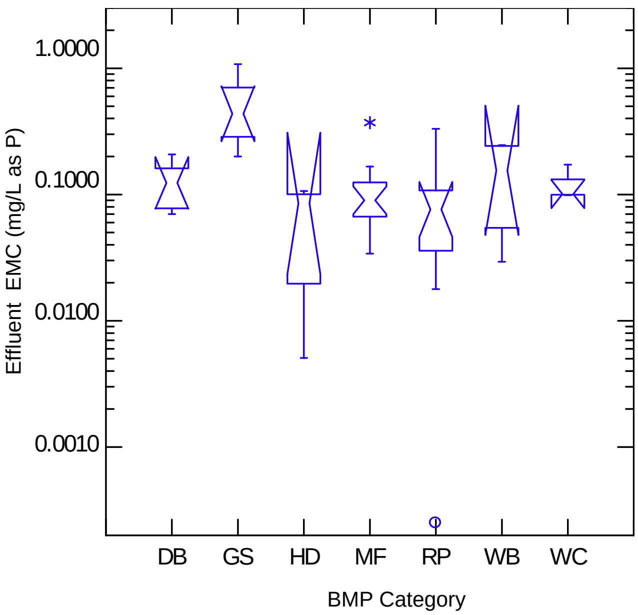

Figure 3. Mean effluent Dissolved Phosphorus concentrations by BMP category

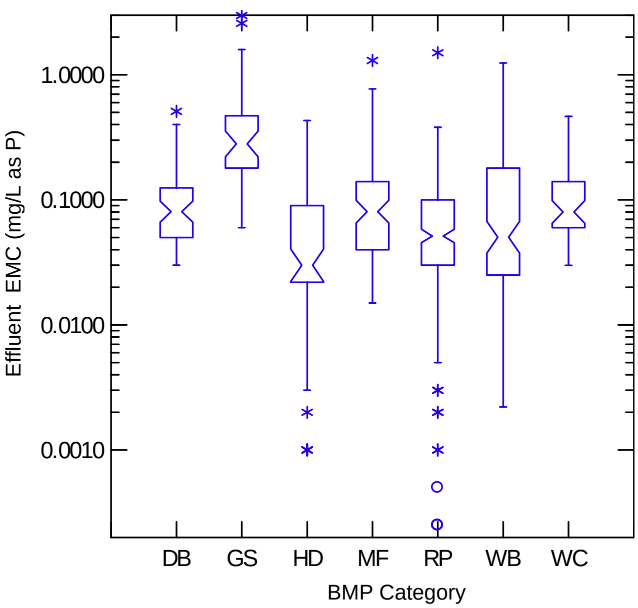

Figure 4. Individual effluent Dissolved Phosphorus EMCs by BMP category

Dissolved Phosphorus (mg/L as P)

Dissolved Phosphorus (DP) is reported much less frequently in the International Stormwater Best Management (BMP) Database than Total Phosphorus.

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

Results for hydrodynamic devices, wetland basins and wetland channels do not yield a significant difference in mean influent and effluent dissolved phosphorus EMCs, while the remaining categories exhibit a significant difference. Biofilters exhibit the highest mean effluent Dissolved Phosphorus, due to effluent concentrations being greater than influent concentrations.

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

Biofilters, retention ponds, wetland basins and wetland channels exhibit a statistically significant difference between effluent EMCs and influent EMCs; however, fewer than five studies each are available for the wetland BMP categories. Effluent concentrations appear to be greater than influent concentrations for biofilters.

Although median effluent Dissolved Phosphorus EMCs appear to be significantly lower for hydrodynamic devices relative to the other BMP categories, there is no significant difference between influent and effluent EMCs for this BMP 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	6	0.12	0.07	0.18	YES	0.09	0.07	0.11	NO
GS	Biofilter	8	0.44	0.21	0.67	YES[3]	0.29	0.23	0.37	YES[3]
HD	Hydrodynamic Device	4	0.09	0.04	0.13	NO	0.03	0.03	0.04	NO
MF	Media Filter	15	0.09	0.07	0.11	YES	0.08	0.07	0.10	NO
RP	Retention Pond	12	0.08	0.04	0.11	YES	0.05	0.05	0.06	YES
WB	Wetland Basin	4	0.17	0.03	0.31	NO	0.05	0.04	0.07	YES
WC	Wetland Channel	3	0.10	0.07	0.13	NO	0.08	0.06	0.10	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
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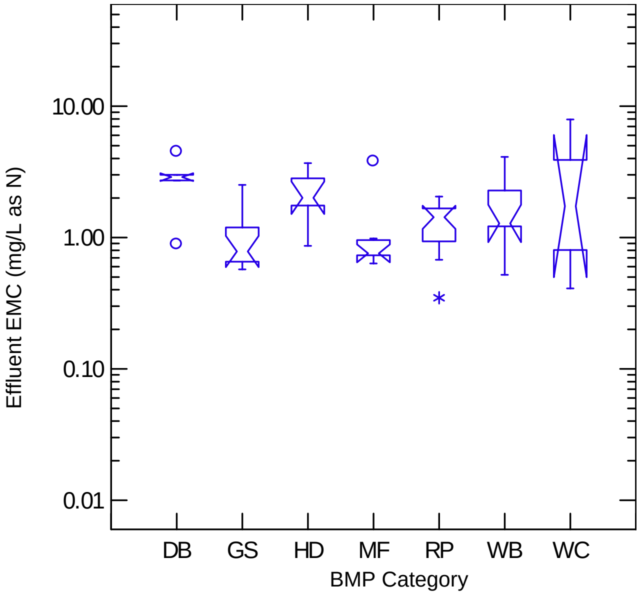

Figure 1. Mean effluent TN concentrations by BMP category

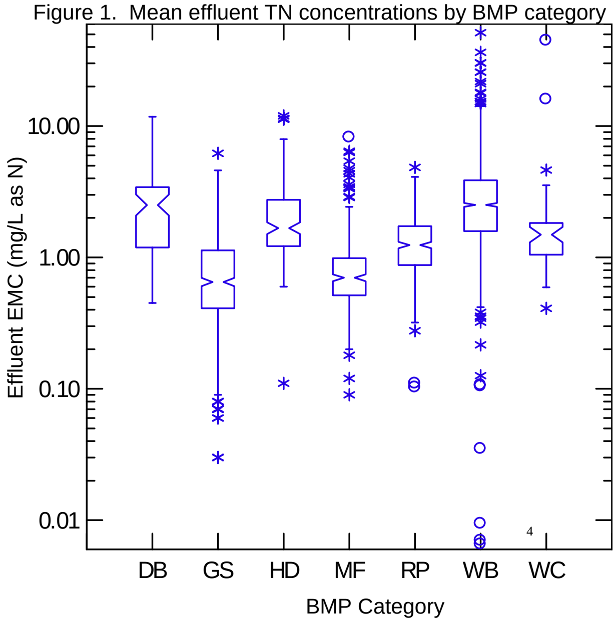

Figure 2. Individual effluent TN EMCs by BMP category

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, only two categories (biofilters and retention ponds) included more than ten studies reporting Total Nitrogen, which limits comparisons of relative performance across BMP categories.

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

All BMP categories except detention basins, wetland basins and wetland channels exhibit a significant difference between the median of average influent and effluent concentrations. Detention basins and wetland channels only had three studies each reporting total nitrogen. Effluent concentrations for hydrodynamic devices tend to be greater than influent concentrations.

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

All BMP categories except wetland basins and wetland channels exhibit a significant difference between the median influent and effluent concentrations. Effluent EMCs for wetland channels only include three BMPs in this dataset. Effluent concentrations for detention basins, hydrodynamic devices and media filters appear to be greater than influent concentrations.

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	3	2.72	1.81	3.63	NO	2.52	2.10	3.04	YES[3]
GS	Biofilter	12	0.78	0.53	1.03	YES	0.65	0.60	0.70	YES
HD	Hydrodynamic Device	7	2.01	1.37	2.65	YES[3]	1.67	1.51	1.85	YES[3]
MF	Media Filter	7	0.76	0.62	0.89	YES	0.70	0.66	0.74	YES[3]
RP	Retention Pond	20	1.43	1.17	1.68	YES	1.25	1.18	1.32	YES
WB	Wetland Basin[4]	7	1.15	0.82	1.62	NO	1.21	1.14	1.28	NO
WC	Wetland Channel	3	1.91	0.69	4.81	NO	1.52	1.30	1.78	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.
4. Two studies were excluded due to apparent influent data quality issues.

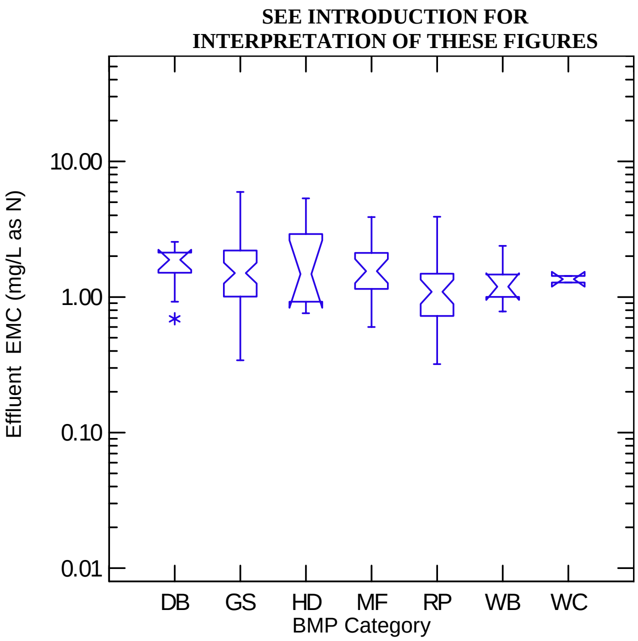

Figure 3. Mean effluent TKN concentrations by BMP category

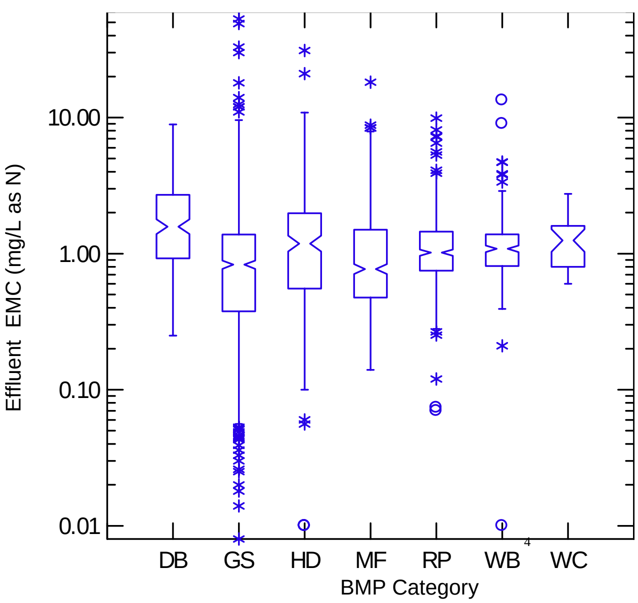

Figure 4. Individual effluent TKN EMCs by BMP category

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 variability (Cv < 1).

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

A significant difference between average influent and effluent TKN is exhibited in all BMPs except for hydrodynamic devices, wetland basins and wetland channels (which had only two BMPs). 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. Effluent concentrations for detention basins tend to be greater than influent concentrations.

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

The difference between influent and effluent EMCs for all BMP categories is significantly significant, except for detention basins and wetland channels. However, the sample size is small for wetland channels, with only two BMPs. Effluent concentrations appear to be greater than influent concentrations for wetland basins and hydrodynamic devices.

	BMP Category	Number of BMPs	Median of Avg. Effluent (95% Confidence Interval)[1] Median	LCL	UCL	Significant Difference Between Average Influent and Effluent[2]	Median of Effluent EMCs (95% Confidence Interval)[1] Median	LCL	UCL	Significant Difference Between Influent and Effluent EMCs[2]
DB	Detention Basin	10	1.89	1.58	2.19	YES[3]	1.60	1.41	1.81	NO
GS	Biofilter	48	1.51	1.24	1.78	YES	0.83	0.77	0.89	YES
HD	Hydrodynamic Device	10	1.48	0.87	2.47	NO	1.19	1.04	1.35	YES[3]
MF	Media Filter	22	1.55	1.22	1.83	YES	0.77	0.71	0.84	YES
RP	Retention Pond	30	1.09	0.87	1.31	YES	1.03	0.97	1.08	YES
WB	Wetland Basin[4]	7	1.05	0.82	1.34	NO	1.09	1.03	1.15	YES[3]
WC	Wetland Channel	2	1.35	1.18	1.52	NO	1.40	1.20	1.64	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.
4. Two studies were excluded due to apparent influent data quality issues.

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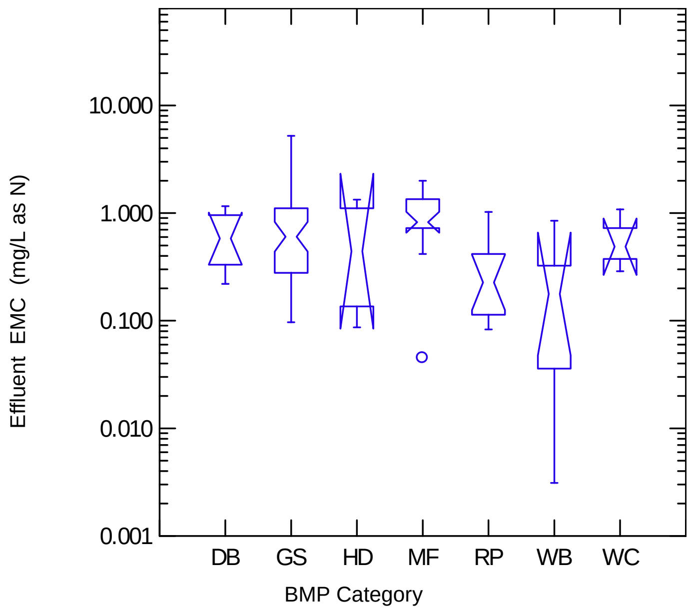

Figure 5. Mean effluent Nitrate Nitrogen concentrations by BMP category

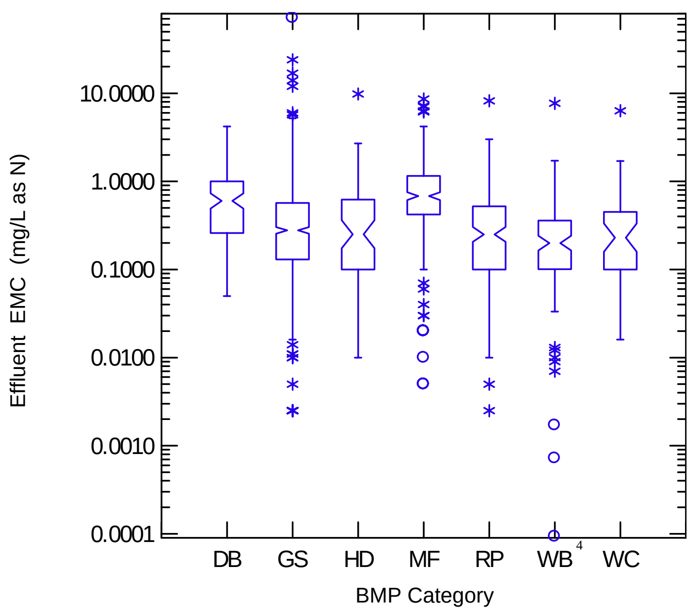

Figure 6. Individual effluent Nitrate Nitrogen EMCs by BMP category

Total Nitrate Nitrogen (mg/L as N)

Nitrogen 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, including either grass strips or grass swales.

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

A significant difference between averaged influent and effluent EMCs is identified for all BMP categories except hydrodynamic devices and wetland basins (which only have four studies and three studies, respectively). Effluent concentrations for media filters tend to be greater than influent concentrations. 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)

A significant difference between influent and effluent EMCs is exhibited in biofilters, media filters, retention ponds, wetland basins and wetland channels. Effluent concentrations appear to be greater than influent concentrations for media filters and wetland channels. Detention basins and hydrodynamic devices do not show significantly different effluent concentrations; however, both BMP categories have less than 10 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	9	0.58	0.25	0.91	YES	0.61	0.50	0.74	NO
GS	Biofilter	47	0.60	0.41	0.79	YES	0.28	0.26	0.30	YES
HD	Hydrodynamic Device	4	0.51	0.08	1.34	NO	0.30	0.20	0.44	NO
MF	Media Filter	19	0.82	0.60	1.05	YES[3]	0.68	0.62	0.76	YES[3]
RP	Retention Pond	12	0.23	0.13	0.37	YES	0.25	0.20	0.31	YES
WB	Wetland Basin[4]	5	0.13	0.07	0.26	NO	0.20	0.17	0.24	YES
WC	Wetland Channel	3	0.49	0.13	0.85	YES	0.25	0.18	0.35	YES[3]

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.
4. Two studies were excluded due to apparent influent data quality issues.

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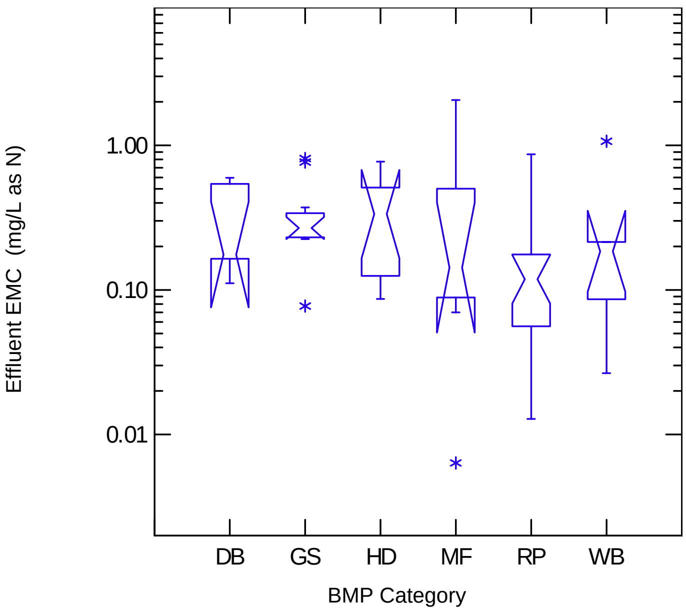

Figure 7. Mean effluent Nitrate+Nitrite N concentrations by BMP category

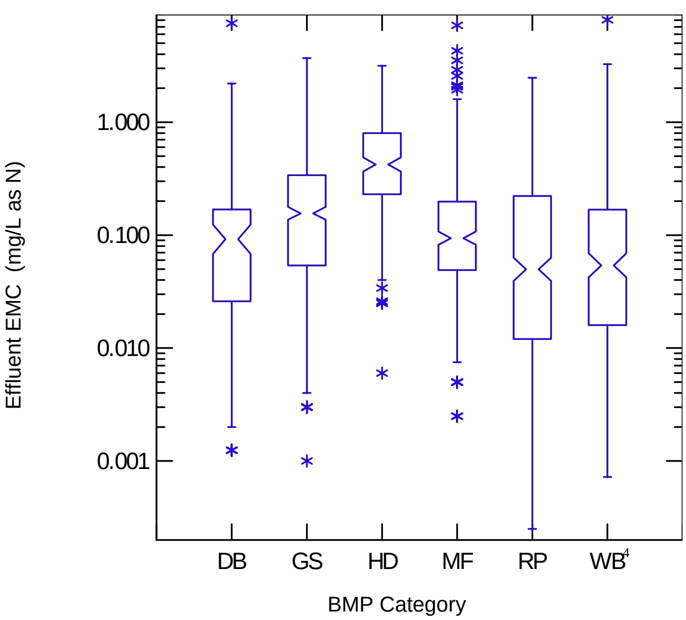

Figure 8. Individual effluent Nitrate+Nitrite Nitrogen EMCs by BMP category

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)

A significant difference between the medians of averaged influent and effluent concentrations is exhibited for detention basins, hydrodynamic devices and retention ponds. Retention ponds also have significantly lower effluent EMCs than the hydrodynamic devices.

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

A significant different between median effluent EMCs and median influent EMCs is exhibited in all BMPs except for hydrodynamic devices. Effluent concentrations appear to be greater than influent concentrations for biofilters. Retention ponds and wetland basins show significantly lower effluent EMCs relative to the 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	5	0.16	0.06	0.30	YES	0.09	0.07	0.13	YES
GS	Biofilter	12	0.27	0.22	0.32	NO	0.16	0.14	0.18	YES[3]
HD	Hydrodynamic Device	9	0.34	0.20	0.47	YES	0.43	0.37	0.50	NO
MF	Media Filter	7	0.14	0.05	0.30	NO	0.09	0.08	0.11	YES
RP	Retention Pond	22	0.12	0.08	0.16	YES	0.05	0.04	0.06	YES
WB	Wetland Basin[4]	5	0.13	0.04	0.36	NO	0.06	0.04	0.07	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.
4. Two studies were excluded due to apparent influent data quality issues.

Analysis of Treatment System Performance - Lead

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INTERPRETATION OF THESE FIGURES

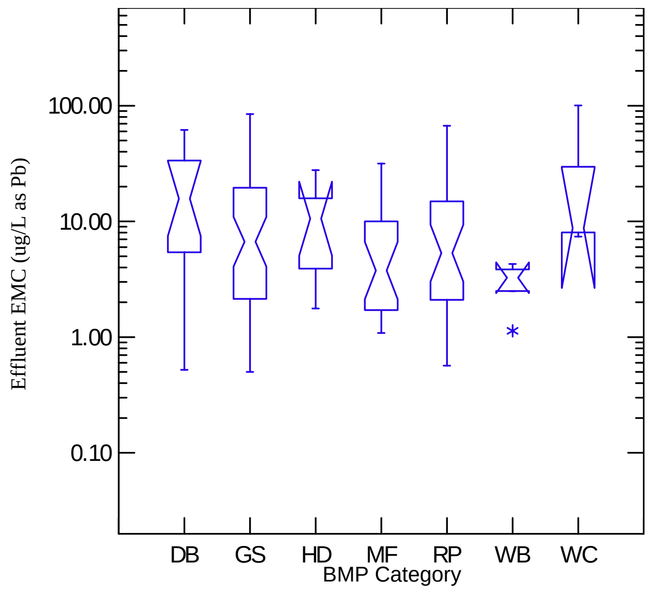

Figure 1. Mean effluent Total Lead concentrations by BMP category

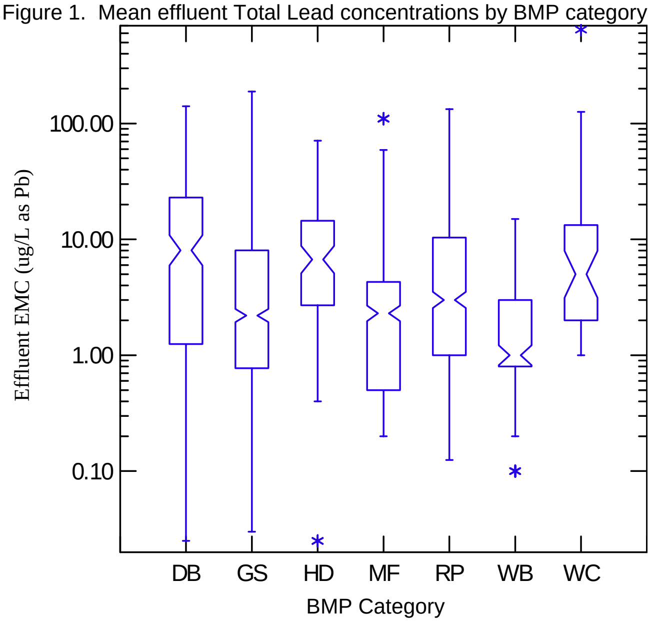

Figure 2. Individual effluent Total Lead EMCs by BMP category

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 by media filters and retention ponds. Of the BMP 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, except for detention basins. Distribution of effluent EMCs are the lowest for media filters, biofilters and wetland basins, all of which employ 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 limit.

	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	15	15.77	4.67	26.87	NO	8.10	6.00	10.94	NO
GS	Biofilter	50	6.70	2.81	10.59	NO	2.20	1.93	2.50	YES
HD	Hydrodynamic Device	9	10.56	4.27	16.85	NO	6.80	5.20	8.89	YES
MF	Media Filter	24	3.76	1.08	6.44	YES	2.34	2.00	2.73	YES
RP	Retention Pond	30	5.32	1.63	9.01	YES	3.00	2.55	3.53	YES
WB	Wetland Basin	5	3.26	2.31	4.22	NO	1.20	0.98	1.46	YES
WC	Wetland Channel	3	8.75	2.82	29.49	NO	5.00	2.99	8.35	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.

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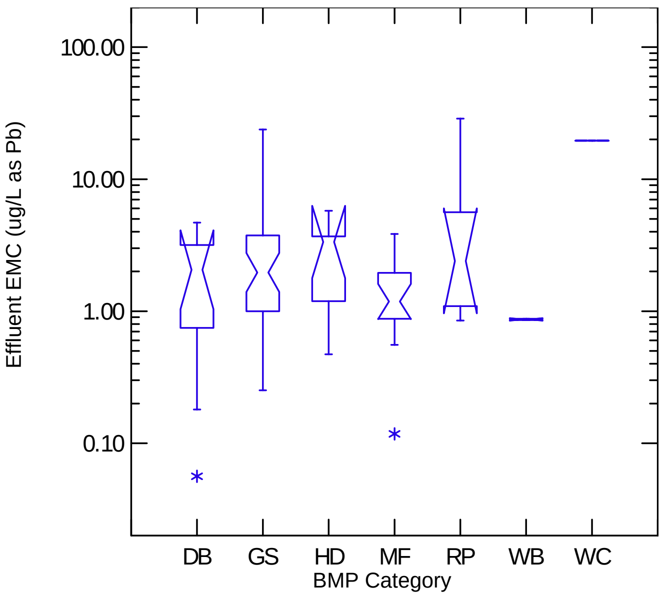

Figure 3. Mean effluent Dissolved Lead concentrations by BMP category

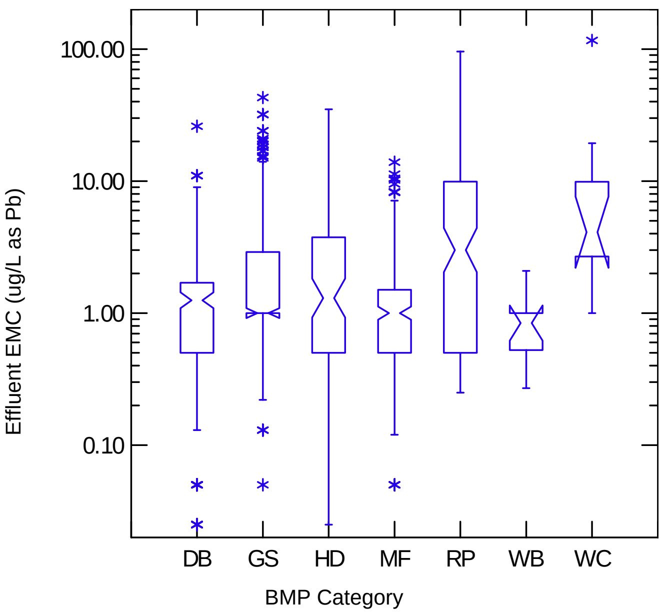

Figure 4. Individual effluent Dissolved Lead EMCs by BMP category

Dissolved Lead (µg/L as Pb)

USEPA recommended freshwater criteria for Dissolved Lead are 65 µg/L (acute) and 2.5 (chronic)*. With the exception of a single EMC reported for a retention pond, effluent concentrations in this dataset were well below the freshwater acute criterion, and most median effluent concentrations were also below the chronic criterion. Exceptions included wetland channels, which had a limited number of samples, and retention ponds, which were influenced by the previously mentioned single high sample.

Analysis of Mean Effluent Dissolved 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 exhibited by biofilters, media filters and retention ponds.

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

Only media filters exhibited significantly lower median effluent EMCs than influent EMCs. Effluent EMCs for wetland basins appear to be greater than influent EMCs; however, only two studies were available for this BMP. Distribution of effluent EMCs was comparable for and the lowest for biofilters, media filters and wetland basins, all of which employ filtration as a primary unit process.

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 2006 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	11	2.06	0.93	3.19	NO	1.25	1.08	1.44	NO
GS	Biofilter	38	1.96	1.26	2.67	YES	1.00	0.91	1.09	NO
HD	Hydrodynamic Device	8	3.34	2.22	4.47	NO	1.35	0.95	1.91	NO
MF	Media Filter	17	1.18	0.77	1.60	YES	1.00	0.89	1.12	YES
RP	Retention Pond	8	2.48	0.98	5.36	YES	3.00	2.04	4.42	NO
WB	Wetland Basin	2	0.87	0.85	0.89	NO	1.00	0.72	1.39	YES[3]
WC	Wetland Channel	1	Insufficient sample size for analysis.				6.00	2.80	12.88	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 - Zinc

SEE INTRODUCTION FOR
INTERPRETATION OF THESE FIGURES

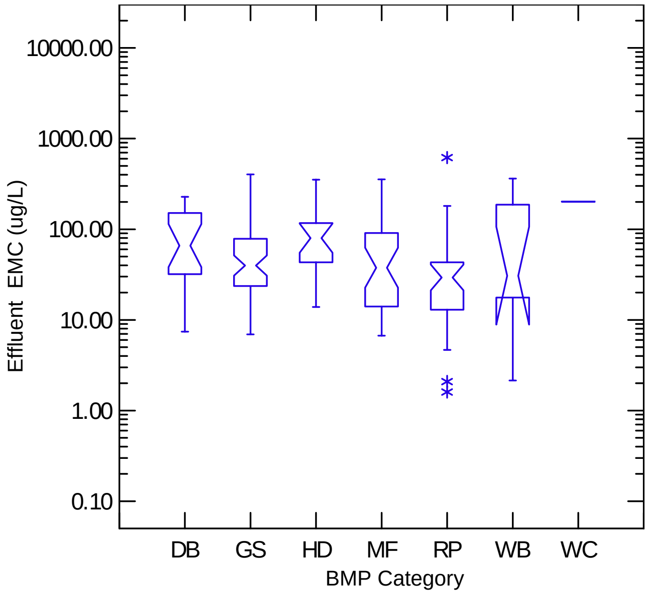

Figure 1. Mean effluent Total Zinc concentration by BMP category

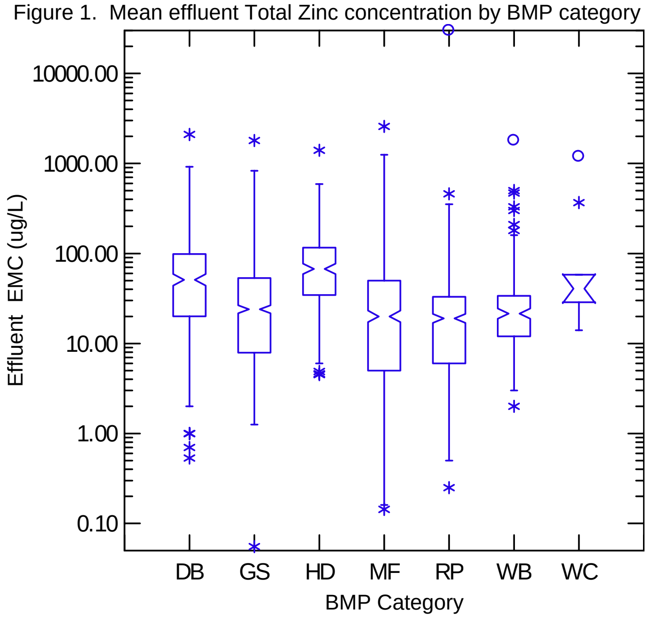

Figure 2. Individual effluent Total Zinc EMCs by BMP category

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)

All BMP categories exhibit a significant difference between the medians of average influent and average effluent. Overall, retention ponds report the lowest distribution of average effluent Total Zinc levels. Hydrodynamic devices and detention ponds had the highest total zinc median effluent EMCs.

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

All BMP categories report significantly higher median influent EMCs than median effluent EMCs for Total Zinc (note that the wetland channel dataset is limited to only one BMP). Detention basins and hydrodynamic devices represent the highest effluent values. Biofilters, media filters, retention ponds and wetland basins had comparable effluent concentrations.

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	21	60.20	20.70	99.70	YES	51.00	44.15	58.92	YES
GS	Biofilter	54	39.83	28.01	51.65	YES	24.00	21.65	26.61	YES
HD	Hydrodynamic Device	18	80.17	52.72	107.61	YES	67.41	58.92	77.12	YES
MF	Media Filter	34	37.63	16.80	58.46	YES	20.00	17.27	23.17	YES
RP	Retention Pond	34	29.35	21.13	37.56	YES	19.00	16.95	21.29	YES
WB	Wetland Basin	9	30.71	12.80	66.69	YES	22.00	19.31	25.06	YES
WC	Wetland Channel	1	Insufficient sample size for analysis.				50.80	15.68	164.60	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

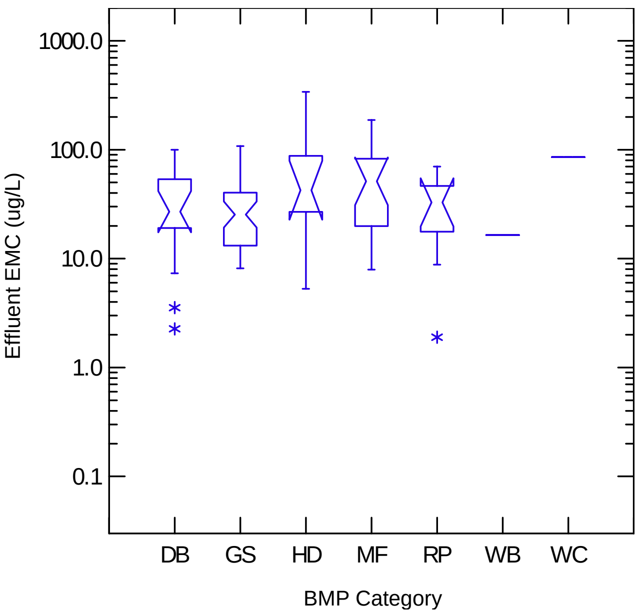

Figure 3. Mean effluent Dissolved Zinc concentration by BMP category

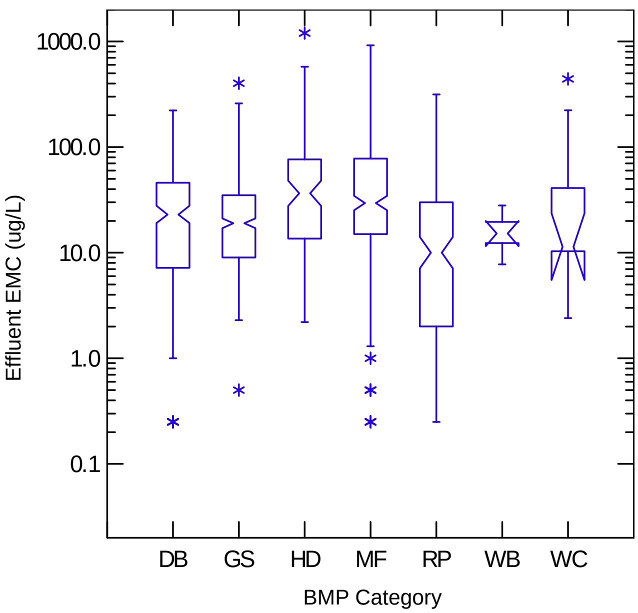

Figure 4. Individual effluent Dissolved Zinc EMCs by BMP category

Dissolved Zinc (µg/L)

Dissolved Zinc is reported most frequently in the International Stormwater BMP Database for biofilters and media filters. Wetland BMP categories only contain one study each, limiting conclusions that can be drawn regarding these BMP categories.

USEPA recommended freshwater chronic and acute criteria for Dissolved Zinc are both 120 µg/L. Median effluent concentrations for all BMP categories were well below this value.

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

A significant difference between averaged influent and effluent concentrations is exhibited for all BMP categories evaluated except for retention ponds. Significant differences in performance among BMP categories were not apparent.

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

All categories 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); however, the result using this analysis approach is strongly influenced by a large number of very low effluent values reported for a single retention pond. Effluent concentrations appear to be greater than influent concentrations for detention basins, hydrodynamic devices and wetland basins.

* Based on USEPA 2006 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	15	25.84	10.75	40.93	YES	24.00	19.95	28.87	YES[3]
GS	Biofilter	41	25.40	18.71	32.09	YES	19.20	17.23	21.39	YES
HD	Hydrodynamic Device	9	42.46	10.38	74.55	YES	37.64	28.56	49.52	YES[3]
MF	Media Filter	20	51.25	29.04	73.46	YES	30.00	25.60	35.15	YES
RP	Retention Pond	9	32.86	17.70	48.01	NO	10.00	7.48	13.37	YES
WB	Wetland Basin	1	Insufficient sample size for analysis.				17.90	1.46	23.81	YES[3]
WC	Wetland Channel	1	Insufficient sample size for analysis.				17.90	3.69	86.88	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

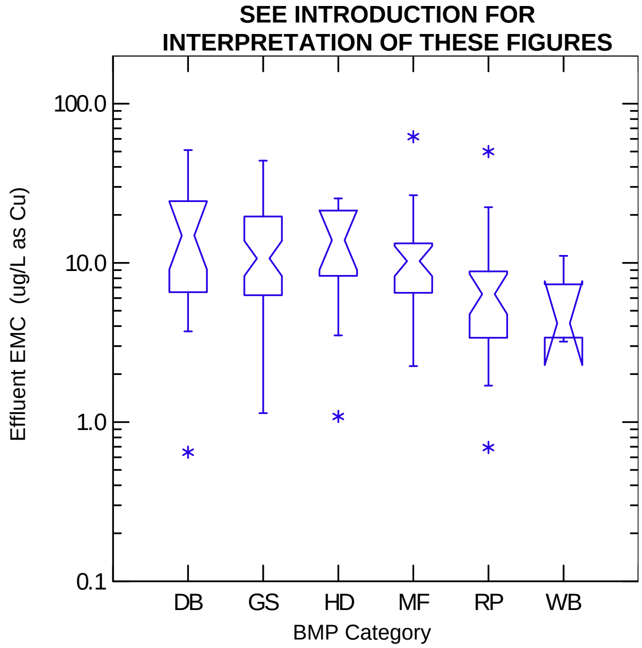

Figure 1. Mean effluent Total Copper concentration by BMP category

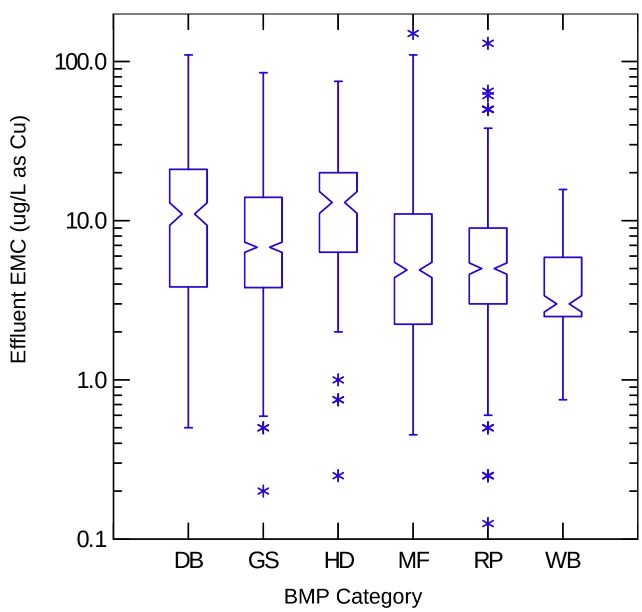

Figure 2. Individual effluent Total Copper EMCs by BMP

Total Copper (µg/L as Cu)

Total Copper is well-reported in the International Stormwater Best Management Practices (BMP) Database.

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, media filters, retention ponds and wetland basins. Detention basins and hydrodynamic devices did not show significant differences between median influent and effluent concentrations. Conclusions drawn regarding the wetland basin dataset are limited 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 analyzed, hydrodynamic devices and detention basins fail to exhibit a significant difference in median influent and effluent EMCs. Additionally, the median effluent concentrations for biofilters, media filters, retention ponds and wetland basins are significantly lower than those for hydrodynamic devices and detention 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	19	12.10	5.41	18.80	NO	11.00	9.36	12.93	NO
GS	Biofilter	50	10.66	7.68	13.68	YES	6.80	6.32	7.32	YES
HD	Hydrodynamic Device	12	14.17	8.33	20.01	NO	13.60	11.66	15.86	NO
MF	Media Filter	27	10.25	8.21	12.29	YES	5.00	4.48	5.58	YES
RP	Retention Pond	27	6.36	4.70	8.01	YES	5.00	4.61	5.42	YES
WB	Wetland Basin	4	4.23	0.62	7.83	YES	3.00	2.66	3.39	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

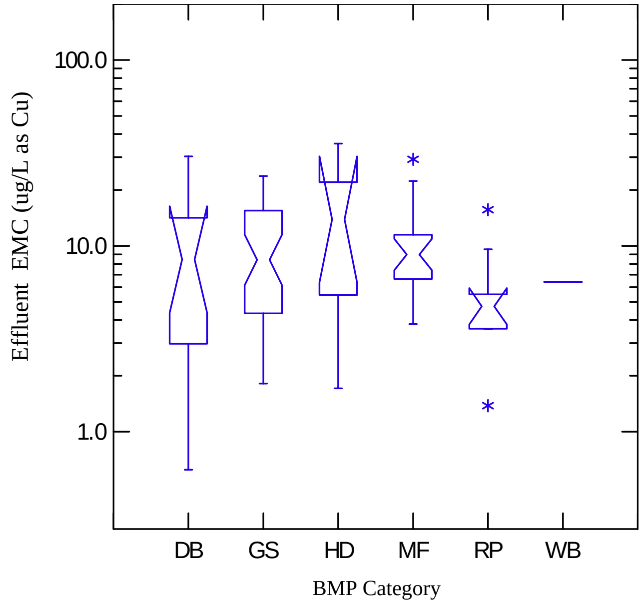

Figure 3. Mean effluent Dissolved Copper concentration by BMP category

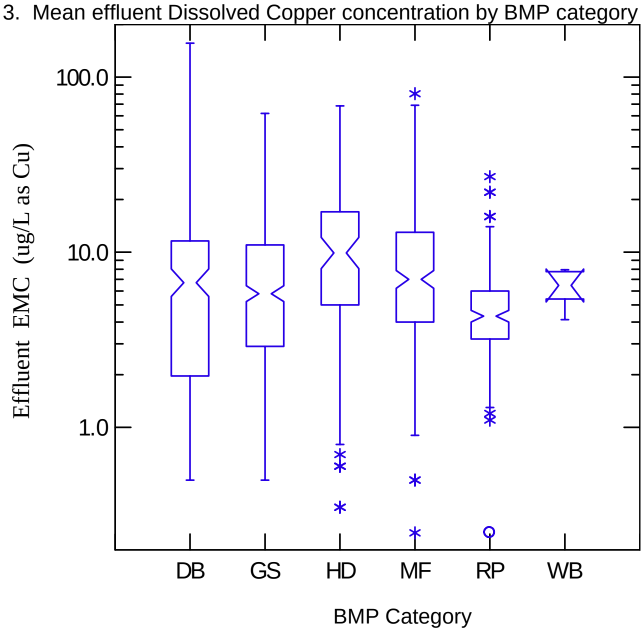

Figure 4. Individual Effluent Dissolved Copper EMC by BMP category

Dissolved Copper (µg/L as Cu)

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

USEPA freshwater criteria for Dissolved Copper are 9 ug/L (chronic) and 13 ug/L (acute).* With the exception of hydrodynamic devices, the median effluent concentrations for all of the BMP categories are below both chronic and acute criteria.

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

All BMP categories showed a significant difference between median influent and effluent averaged EMCs. Detention basins appear to have effluent concentrations that are significantly great than influent concentrations.

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

Biofilters, retention ponds and wetland basins exhibit a significant difference in median influent and effluent EMCs. Wetland basin effluent concentrations appear to be greater than influent concentations; however, this conclusion is limited by the small sample size (n=1). The distribution of effluent EMCs for retention ponds is also significantly lower than for other BMP categories.

* Based on USEPA 2006 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	15	7.37	3.28	11.45	YES[3]	6.70	5.58	8.05	NO
GS	Biofilter	41	8.40	5.65	11.15	YES	5.90	5.31	6.55	YES
HD	Hydrodynamic Device	8	13.92	4.40	23.44	YES	10.90	8.88	13.38	NO
MF	Media Filter	20	9.00	7.28	10.72	YES	7.00	6.25	7.84	NO
RP	Retention Pond	9	4.73	3.73	5.73	YES	4.37	4.05	4.71	YES
WB	Wetland Basin	1	Insufficient sample size for analysis.				7.36	6.44	9.04	YES[3]

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.

Overview of Performance by BMP Category and Common Pollutant Type

International Stormwater Best Management Practices (BMP) Database [1999-2008]

Prepared by:

Geosyntec Consultants
Wright Water Engineers, Inc.

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

June 2008

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.

UNDER NO CIRCUMSTANCES, INCLUDING CLAIMS OF NEGLIGENCE, SHALL THE SPONSORS OR THE PROJECT TEAM MEMBERS BE LIABLE FOR ANY DIRECT, INDIRECT, INCIDENTAL, SPECIAL, OR CONSEQUENTIAL DAMAGES INCLUDING LOST REVENUE, PROFIT OR DATA, WHETHER IN AN ACTION IN CONTRACT OR TORT ARISING OUT OF OR RELATING TO THE USE OF OR INABILITY TO USE THE DATABASE, EVEN IF THE SPONSORS OR THE PROJECT TEAM HAVE BEEN ADVISED OF THE POSSIBILITY OF SUCH DAMAGES.

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.

Analysis of Treatment System Performance
Overview of Performance by BMP
Category and Common Pollutant Type

The following one-page tabular summary provides analysis results from available monitoring data drawn from the International Stormwater Best Management Practices (BMP) Database as of October 2007 to determine whether any differences in treatment performance may be determined based on BMP category (e.g. detention basin, media filter, wetland basin, etc). Summary statistics are provided for the median and upper and lower 95th percentile confidence limits for the median for each BMP study's average influent and effluent event mean concentrations (EMCs) over the entire respective monitoring period, grouped by BMP category. For each water quality constituent examined, only those BMP studies reporting at least three influent and effluent EMCs were included in the analysis data set. Additionally, the Database may contain additional studies not included in these analysis results due to unique site features or monitoring designs that may also be useful in assessing BMP performance.

Note on Hydrodynamic Devices:

For this overview-level analysis, BMPs have been grouped into broad categories. These categories may mask distinctive differences in design and performance in subcategories for multiple BMP types. This is particularly true for the Hydrodynamic Device (HD) category, which represents a wide range of various proprietary and non-proprietary device types. Each of the BMPs categorized as HD device types incorporates or emphasizes a number of different unit processes and design elements (e.g., storage versus flow-through designs, inclusion of media filtration, etc.) that vary significantly throughout the category. These design features likely have significant effects on BMP performance and the underlying detailed data analysis for each HD device (available from www.bmpdatabase.org) should be referenced before drawing conclusions on the performance of Hydrodynamic Devices (and to some extent other BMP types.) At this time it is not possible to identify which unit processes or design elements represent key differentiators in performance, nor to further subdivide this category. Any interpretation or use of the results presented herein should fully acknowledge the widely varied nature of Hydrodynamic Devices, as well as other BMP categories. We recommend that for HD devices in particular that more attention be paid to the observed ranges in performance than median or mean effluent values. The Project Team's future plans include developing additional BMP categories (and subcategories) as more studies become available.

Median of Average Influent and Effluent Concentrations of Best Management Practices

Constituents	Sample Location	Detention Pond (n=25)[1]	Wet Pond (n=46)[1]	Wetland Basin (n=19)[1]	Biofilter (n=57)[1]	Media Filter (n=38)[1]	Hydrodynamic Devices (n=32)[1]	Porous Pavement (n=6)[1]
Suspended Solids (mg/L)	Influent	72.65 (41.70-103.59)	34.13 (19.16-49.10)	37.76 (18.10-53.39)	52.15 (41.41-62.88)	43.27 (27.25-59.58)	39.61 (21.95-76.27)	xx
	Effluent	31.04 (16.07-46.01)	13.37 (7.29-19.45)	17.77 (9.26-26.29)	23.92 (15.07-32.78)	15.86 (9.74-21.98)	37.67 (21.28-54.02)	16.96 (5.90-48.72)
Total Cadmium (µg/L)	Influent	0.71 (0.45-1.28)	0.49 (0.20-0.79)	0.36 (0.11-0.60)	0.54 (0.40-0.67)	0.25 (0.12-0.49)	0.74 (0.37-1.11)	xx
	Effluent	0.47 (0.25-0.87)	0.27 (0.12-0.61)	0.24 (0.11-0.55)	0.30 (0.26-0.35)	0.19 (0.1-0.37)	0.57 (0.25-1.33)	xx
Dissolved Cadmium (µg/L)	Influent	0.24 (0.15-0.33)	0.19 (0.10-0.28)	xx	0.25 (0.21-0.28)	0.16 (0.11-0.21)	0.33 (0.11-0.55)	xx
	Effluent	0.25 (0.17-0.36)	0.11 (0.08-0.15)	xx	0.21 (0.19-0.23)	0.13 (0.10-0.18)	0.31 (0.13-0.71)	xx
Total Copper (µg/L)	Influent	20.14 (8.41-31.79)	8.91 (5.29-12.52)	5.65 (2.67-38.61)	31.93 (25.25-38.61)	14.57 (10.87-18.27)	15.42 (9.20-21.63)	xx
	Effluent	12.10 (5.41-18.80)	6.36 (4.70-8.01)	4.23 (0.62-7.83)	10.66 (7.68-13.68)	10.25 (8.21-12.29)	14.17 (8.33-20.01)	2.78 (0.88-8.78)
Dissolved Copper (µg/L)	Influent	6.66 (0.73-12.59)	7.33 (5.40-9.26)	xx	14.15 (10.14-18.16)	7.75 (4.55-10.96)	13.59 (9.82-17.36)	xx
	Effluent	7.37 (3.28-11.45)	4.37 (3.73-5.73)	xx	8.40 (5.65-11.45)	9.00 (7.28-10.72)	13.92 (4.40-23.44)	xx
Total Chromium (µg/L)	Influent	7.36 (5.49-9.88)	6.00 (3.58-10.08)	xx	5.63 (4.49-7.05)	2.18 (1.66-2.86)	4.07 (2.39-6.91)	xx
	Effluent	3.18 (2.10-4.84)	1.44 (0.79-2.66)	xx	4.64 (3.08-6.98)	1.48 (0.82-2.70)	3.52 (2.14-5.80)	xx
Total Lead (µg/L)	Influent	25.01 (12.06-37.95)	14.36 (8.32-20.40)	4.62 (1.43-11.89)	19.53 (10.11-28.95)	11.32 (6.09-16.55)	18.12 (5.70-30.53)	xx
	Effluent	15.77 (4.67-26.87)	5.32 (1.63-9.01)	3.26 (2.31-4.22)	6.70 (2.81-10.59)	3.76 (1.08-6.44)	10.56 (4.27-16.85)	7.88 (1.64-37.96)
Dissolved Lead (µg/L)	Influent	1.25 (0.33-2.17)	3.40 (1.12-5.68)	0.50 (0.33-0.67)	2.25 (0.77-3.74)	1.44 (1.05-1.82)	1.89 (0.83-2.95)	xx
	Effluent	2.06 (0.93-3.19)	2.48 (0.98-5.36)	0.87 (0.85-0.89)	1.96 (1.26-2.67)	1.18 (0.77-1.60)	3.34 (2.22-4.47)	xx
Total Zinc (µg/L)	Influent	111.56 (51.50-171.63)	60.75 (45.23-76.27)	47.07 (24.47-90.51)	176.71 (128.28-225.15)	92.34 (52.29-132.40)	119.08 (73.50-164.67)	xx
	Effluent	60.20 (20.70-99.70)	29.35 (21.13-37.56)	30.71 (12.80-66.69)	39.83 (28.01-51.56)	37.63 (16.80-58.46)	80.17 (52.72-107.61)	16.60 (5.91-46.64)
Dissolved Zinc (µg/L)	Influent	26.11 (5.20-75.10)	47.46 (37.65-57.27)	xx	58.31 (32.46-79.16)	69.27 (37.97-100.58)	35.93 (4.96-66.90)	xx
	Effluent	25.84 (10.75-40.93)	32.86 (17.70-48.01)	xx	25.40 (18.71-32.09)	51.25 (29.04-73.46)	42.46 (10.38-74.55)	xx
Total Phosphorus (mg/L)	Influent	0.19 (0.17-0.22)	0.21 (0.13-0.29)	0.27 (0.11-0.43)	0.25 (0.22-0.28)	0.20 (0.15-0.26)	0.24 (0.01-0.46)	xx
	Effluent	0.19 (0.12-0.27)	0.12 (0.09-0.16)	0.14 (0.04-0.24)	0.34 (0.26-0.41)	0.14 (0.11-0.16)	0.26 (0.12-0.48)	0.09 (0.05-0.15)
Dissolved Phosphorus (mg/L)	Influent	0.09 (0.06-0.13)	0.09 (0.06-0.13)	0.10 (0.04-0.22)	0.09 (0.07-0.11)	0.09 (0.03-0.14)	0.06 (0.01-0.11)	xx
	Effluent	0.12 (0.07-0.18)	0.08 (0.04-0.11)	0.17 (0.03-0.31)	0.44 (0.21-0.67)	0.09 (0.07-0.11)	0.09 (0.04-0.13)	xx
Total Nitrogen (mg/L)	Influent	1.25 (0.83-1.66)	1.64 (1.39-1.94)	2.12 (1.58-2.66)	0.94 (0.94-1.69)	1.31 (1.19-1.42)	1.25 (0.33-2.16)	xx
	Effluent	2.72 (1.81-3.63)	1.43 (1.17-1.68)	1.15 (0.82-1.62)	0.78 (0.53-1.03)	0.76 (0.62-0.89)	2.01 (1.37-2.65)	xx
Nitrate-Nitrogen (mg/L)	Influent	0.70 (0.35-1.05)	0.36 (0.21-0.51)	0.22 (0.01-0.47)	0.59 (0.44-0.73)	0.41 (0.30-0.51)	0.40 (0.06-0.73)	xx
	Effluent	0.58 (0.25-0.91)	0.23 (0.13-0.37)	0.13 (0.07-0.26)	0.60 (0.41-0.79)	0.82 (0.60-1.05)	0.51 (0.08-1.34)	xx
TKN (mg/L)	Influent	1.45 (0.97-1.94)	1.26 (1.03-1.49)	1.15 (0.81-1.48)	1.80 (1.62-1.99)	1.52 (1.07-1.96)	1.09 (0.52-1.67)	xx
	Effluent	1.89 (1.58-2.19)	1.09 (0.87-1.31)	1.05 (0.82-1.34)	1.51 (1.24-1.78)	1.55 (1.22-1.83)	1.48 (0.87-2.47)	1.23 (0.44-3.44)

[1] Actual number of BMPs reporting a particular constituent may be greater or less than the number reported in this table, which was based on number of studies reported in database based on BMP category.

Notes: xx- Lack of sufficient data to report median and confidence interval. Values in parenthesis are the 95% confidence intervals about the median. Differences in median influent and effluent concentrations does not necessarily indicate that there was a statistically significant difference between influent and effluent. See "Analysis of Treatment System Performance, International Stormwater BMP Database (1997-2007) (Geosyntec and WWE 2007) for more detailed information. Source: International Stormwater BMP Database June 2008 (www.bmpdatabase.org)