National Pollutant Removal Performance Database

Version 3

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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)

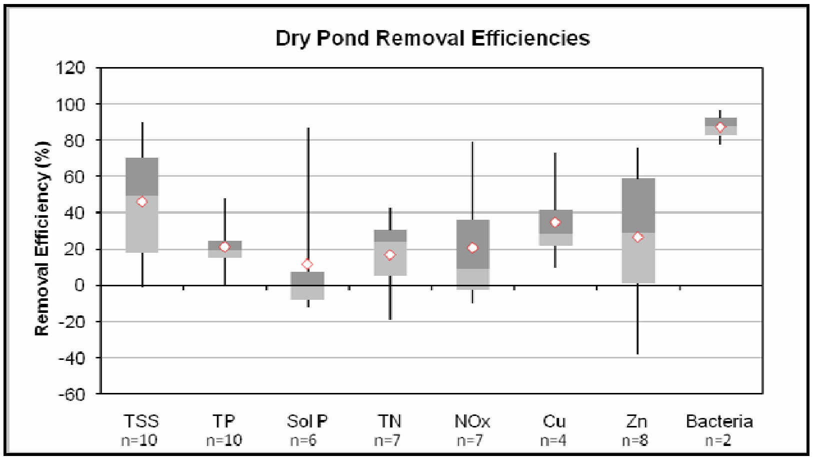

Figure 1. Dry Pond Removal Efficiencies

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

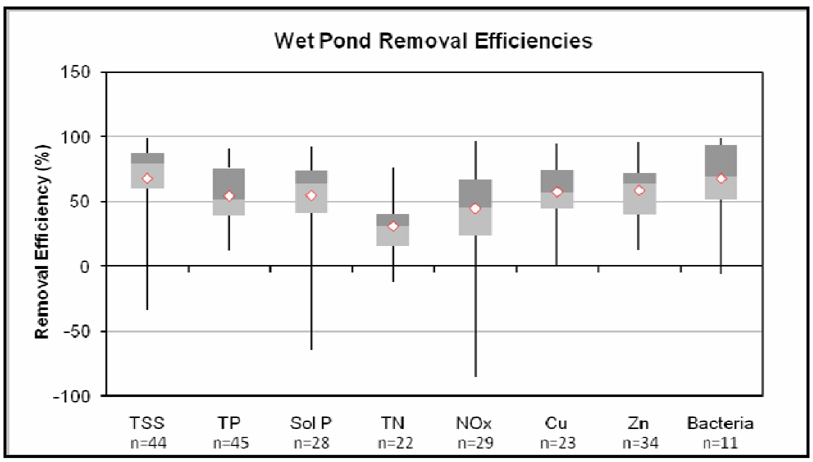

Figure 2. Wet Pond Removal Efficiencies

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**

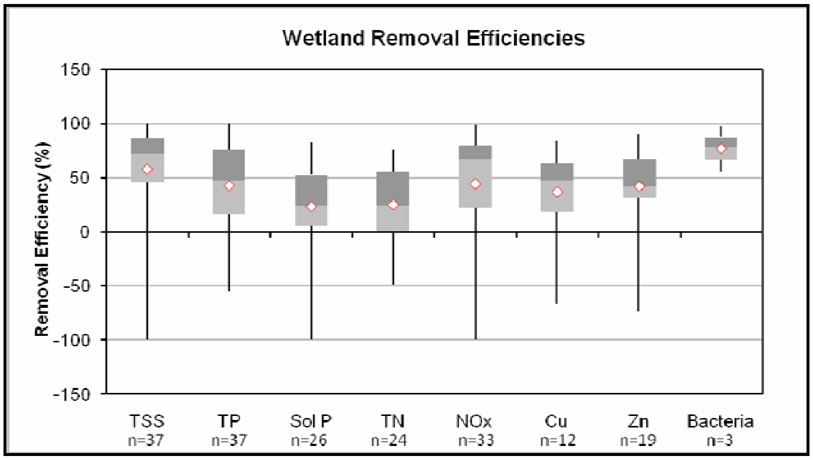

Figure 3. Wetland Removal Efficiencies

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

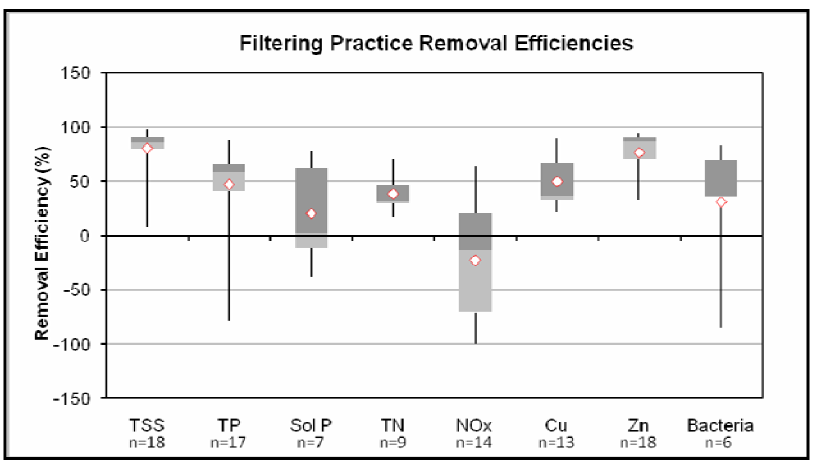

Figure 4. Filtering Practice Removal Efficiencies

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

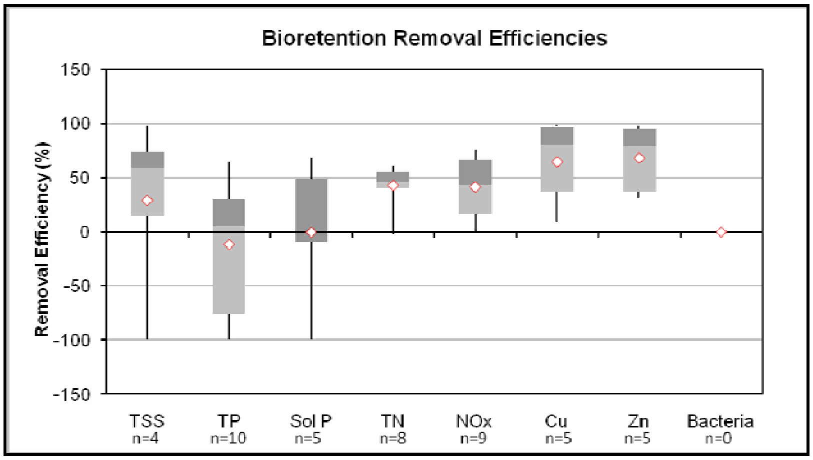

Figure 5. Bioretention Removal Efficiencies

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**

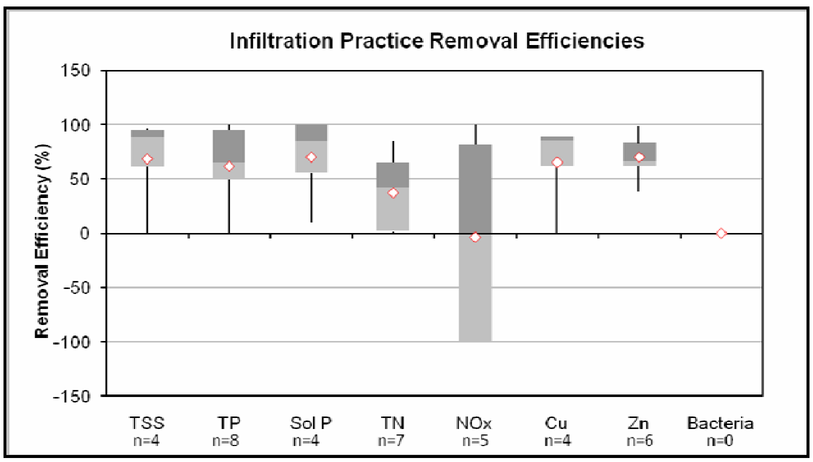

Figure 6. Infiltration Practice Removal Efficiencies

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**

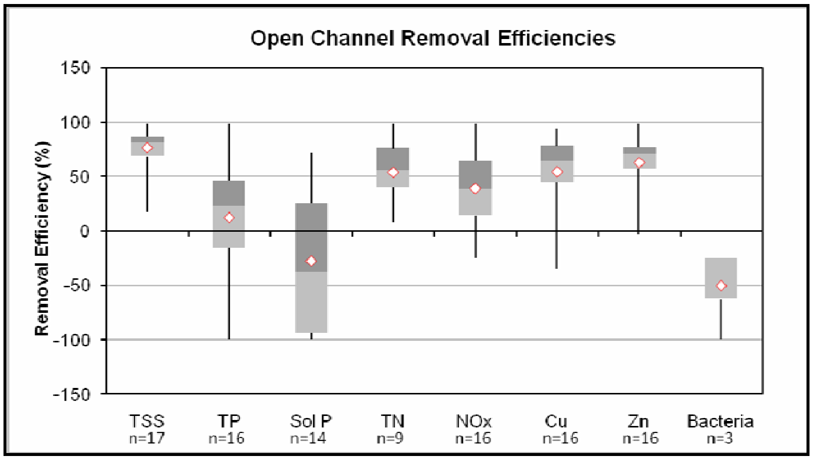

Figure 7. Open Channel Removal Efficiencies

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

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