INTERNATIONAL STORMWATER BMP DATABASE
www.bmpdatabase.org

International Stormwater Best Management Practices (BMP) Database

BMP Performance Data Summary Table

Prepared by

Wright Water Engineers, Inc.
Geosyntec Consultants, Inc.

Under Support From
Water Environment Research Foundation
Federal Highway Administration
Environment and Water Resources Institute of the American Society of Civil Engineers

November 2011

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 (USEPA) (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.

International Stormwater BMP Database Performance Data Summary Table

In 2010, the Water Environment Research Foundation (WERF), Federal Highway Administration (FHWA), and the American Society of Civil Engineers' Environmental and Water Resources Institute (EWRI) co-sponsored a comprehensive stormwater best management practice (BMP) performance analysis technical paper series relying on data contained in the International Stormwater BMP Database (BMP Database).[1] The BMP Database is a publically-available research database that contains results of stormwater BMP studies independently conducted and provided by researchers throughout the U.S. and several other countries. The BMP Database contains performance data for over 450 BMP studies, including over 265,000 water quality records, along with precipitation and flow data. The database is currently limited to post-construction, permanent stormwater BMPs in urban areas. The project is a long-term, multi-faceted effort that includes guidance on BMP monitoring, standardized database reporting information, and recommended performance analysis protocols.

During 2010-2011, a WERF Research Digest and performance analysis technical paper series were completed, providing information on BMP performance for these stormwater parameter categories:

- Nutrients
- Solids
- Metals
- Fecal indicator bacteria
- Runoff volume

This short paper provides a tabular summary of data used in these technical summaries. The WERF Research Digest (available through www.werf.org) or the underlying individual technical summaries should be obtained (www.bmpdatabase.org) for more detailed information.

For each pollutant category analyzed in the technical paper series, a variety of statistics have been completed. For a quick reference, Table 1 provides the median influent and effluent concentrations and associated 95% confidence limits for the median values. Important considerations for use of this table include:

[1] The BMP Database is a long-term project that began in 1994 through the vision of members active in the Urban Water Resources Research Council of ASCE and the leadership of EPA. Funded for many years by EPA, the project is now supported by a coalition of partners including WERF, FHWA, EWRI and the American Public Works Association (APWA).

- The median concentrations in this table are based on a "storm-weighted" approach. There are several viable approaches to evaluating data in the BMP Database, with the two approaches used in previous BMP Database summaries being the "BMP-weighted" and "storm-weighted" approaches. The BMP-weighted approach represents the influent and effluent for each BMP with one value representing the central tendency for each BMP, whereas the storm-weighted approach combines all of the storm events for the BMPs in each category and analyzes the overall storm-based data sets. (Each storm is weighted equally in the storm event based approach.) The storm-weighted approach has been selected for this summary because it provides a much larger number of values for statistical analysis, while retaining the overall variability of storm event concentrations. Some modifications to this approach were used for fecal indicator bacteria, as described in the fecal indicator bacteria technical paper.

- For simplicity, this table does not show number of samples or the number of BMP studies associated with each BMP-constituent concentration; however, this information is provided in the individual technical papers. Some BMP types such as wetland basins and channels, porous pavement and bioretention have much more limited data sets for a number of parameters. Assumptions related to data screening (i.e., excluded studies) are also provided in the individual pollutant summaries.

- Information regarding statistically significant differences between influent and effluent values is provided in the individual technical papers. Comparison of the confidence limits for the medians can provide an approximate measure of significance of differences between the values. Specifically, if the 95% confidence intervals for the inflow and outflow medians do not overlap, the medians are, roughly, significantly different at about a 95% confidence level. More robust hypothesis testing has also been provided in attachments to the solids, nutrients and metals summaries. Specifically, the Mann-Whitney test for independent data sets (unpaired samples) and the Wilcoxon signed rank test (using log-transformed data) for paired inflow-outflow data have been provided.

- Manufactured devices included in the BMP Database incorporate a broad range of unit treatment processes that may result in widely varying performance for individual devices within this broad category. For example, some manufactured devices rely on hydrodynamic gravitational separation only, some provide filtration, others provide peak attenuation, and some provide a treatment train of multiple unit processes. The "manufactured device" category summarized in Table 1 provides only a gross characterization of the range of performance provided by this broad category. More refined analysis based on finer segmentation by unit treatment processes is necessary to draw conclusions for a particular type of device. As a result, the primary use of the data summaries at the broad category level is only for general information related to ranges of effluent concentrations potentially achievable with this general category of BMPs. For example, none of the manufactured devices analyzed for fecal indicator bacteria would be capable of achieving an instream primary contact recreation standard; whereas, some types of manufactured devices can reduce total suspended solids concentrations below 30 mg/L. The on-line BMP Database search tool (www.bmpdatabase.org) could then be

used as a follow-up to refine such broad, general observations and further evaluate how individual manufactured devices performed.

- Rounding in this table may differ slightly from the underlying data summaries.
- Some analyses (e.g., dissolved metals) are affected by large numbers of non-detects, which may not be fully apparent in this condensed summary table, although some flagging has been provided, as described in the table footnotes. Methods used to address non-detects (censored data) are described in each technical memorandum.
- The BMP Database data set is continually growing; therefore, the statistics reported in this table will change as the data set grows. The analysis data set for Table 1 is based on the August 2010 version of the BMP Database for all parameters except metals, which is based on the December 2010 version of the BMP Database.
- A table key defining acronyms and describing how to interpret the reported data is provided following the two-page table.

Users of this storwater quality table should be aware that pollutant load reductions can be achieved by reducing pollutant concentrations, surface runoff volumes, and/or a combination of both. Using bioretention as an example, the existing BMP Database dataset does not show a statistically significant reduction in nitrate concentrations; however, nitrate loads are expected to be reduced at bioretention sites that effectively reduce volumes discharged to surface waters.

Table 1. Summary of Inflow and Outflow Data by BMP Category (Median Values with 95% Confidence Limits for the Median Values)

		BR	BS	DB	BI	MD	MF	PP	RP	WB	WC
TSS (mg/L)	In	50 (39-68)	21 (15-26)	64 (47-76)	51 (45-59)	41 (36-46)	42 (36-48)	22 (16-28)	60 (49-70)	20 (16-26)	31 (22-42)
	Ef	10 (6-13)	10 (7-11)	24 (19-27)	18 (14-20)	23 (19-25)	8 (6-8)	14 (10-17)	12 (10-12)	8 (6-9)	14 (8-16)
TDS (mg/L)	In	NA	77 (66-79)	100 (83-129)	46 (34-52)	126 (96-165)	38 (27-40)	NA	104 (79-124)	NA	NA
	Ef	NA	70 (56-79)	110 (79-121)	90 (76-98)	87 (72-122)	54 (46-58)	NA	167 (130-181)	NA	NA
Tur-bidity (NTU)	In	NA	NA	39 (27-50)	NA	6 (5-7)	25 (14-27)	NA	17 (10-20)	NA	NA
	Ef	NA	NA	19 (15-26)	NA	4 (4-5)	5 (4-6)	NA	1 (1-1)	NA	NA
Phos-phorus (Total) (mg/L)	In	0.14 (0.12-0.15)	0.26 (0.21-0.26)	0.16 (0.14-0.19)	0.12 (0.09-0.16)	0.22 (0.16-0.22)	0.19 (0.16-0.20)	0.12 (0.09-0.13)	0.27 (0.23-0.29)	0.12 (0.10-0.12)	0.18 (0.15-0.22)
	Ef	0.13 (0.10-0.16)	0.21 (0.18-0.23)	0.21 (0.16-0.23)	0.20 (0.17-0.20)	0.14 (0.11-0.14)	0.10 (0.08-0.11)	0.10 (0.07-0.11)	0.11 (0.08-0.11)	0.08 (0.06-0.08)	0.14 (0.11-0.15)
Ortho-P (mg/L)	In	0.04 (0.01-0.04)	NA	0.04 (0.03-0.04)	0.03 (0.03-0.03)	0.21 (0.13-0.25)	0.04 (0.03-0.05)	NA	0.11 (0.09-0.13)	0.05 (0.04-0.06)	0.05 (0.02-0.05)
	Ef	0.16 (0.07-0.45)	NA	0.08 (0.05-0.10)	0.12 (0.11-0.13)	0.12 (0.07-0.13)	0.02 (0.02-0.03)	NA	0.04 (0.04-0.05)	0.02 (0.02-0.03)	0.06 (0.03-0.07)
Phos-phorus (D) (mg/L)	In	NA	0.09 (0.07-0.10)	0.08 (0.06-0.08)	0.09 (0.06-0.11)	0.08 (0.05-0.11)	0.10 (0.07-0.11)	NA	0.11 (0.08-0.11)	0.08 (0.05-0.09)	0.08 (0.07-0.10)
	Ef	NA	0.09 (0.06-0.11)	0.23 (0.16-0.26)	0.30 (0.21-0.35)	0.07 (0.05-0.08)	0.09 (0.08-0.11)	NA	0.06 (0.04-0.06)	0.04 (0.03-0.04)	0.09 (0.07-0.10)
Nitrogen (Total) (mg/L)	In	1.38 (1.25-1.59)	1.40 (1.13-1.62)	NA	0.59 (0.50-0.63)	2.25 (1.98-2.65)	1.02 (0.85-1.39)	NA	1.75 (1.50-1.90)	1.14 (1.05-1.28)	1.62 (1.38-1.89)
	Ef	1.09 (0.98-1.24)	2.45 (1.77-2.75)	NA	0.62 (0.54-0.66)	2.21 (1.85-2.34)	0.77 (0.67-0.91)	NA	1.27 (1.16-1.35)	1.21 (1.06-1.21)	1.78 (1.40-2.00)
TKN (mg/L)	In	1.10 (0.92-1.20)	1.40 (1.11-1.42)	1.50 (1.40-1.60)	0.70 (0.46-0.86)	1.60 (1.43-1.75)	1.20 (0.92-1.25)	1.50 (1.10-2.20)	1.30 (1.15-1.36)	0.99 (0.62-1.05)	1.60 (1.20-1.70)
	Ef	1.01 (0.84-1.30)	1.60 (1.20-1.80)	1.30 (1.10-1.40)	0.50 (0.43-0.62)	1.51 (1.40-1.60)	0.71 (0.61-0.80)	1.15 (0.91-1.35)	1.10 (1.00-1.15)	1.06 (0.95-1.13)	1.20 (0.90-1.30)
Nitrate (NO_x) (mg/L)	In	0.30 (0.26-0.35)	0.50 (0.36-0.53)	0.63 (0.48-0.68)	0.30 (0.25-0.35)	0.38 (0.33-0.40)	0.34 (0.29-0.38)	0.66 (0.49-0.77)	0.40 (0.32-0.42)	0.21 (0.15-0.23)	0.55 (0.39-1.15)
	Ef	0.23 (0.17-0.27)	0.38 (0.22-0.47)	0.42 (0.33-0.51)	0.28 (0.23-0.30)	0.43 (0.38-0.45)	0.53 (0.45-0.63)	1.00 (0.83-1.23)	0.15 (0.11-0.16)	0.08 (0.05-0.10)	0.62 (0.33-0.96)
TOC (mg/L)	In	NA	13 (11-17)	9 (8-10)	13 (11-20)	27 (23-28)	12 (8-14)	NA	14 (13-15)	NA	NA
	Ef	NA	13 (11-16)	13 (11-13)	13 (11-14)	23 (19-26)	11 (8-12)	NA	11 (10-11)	NA	NA
Fecal Coliform (#/100 mL)	In	NA	NA	749 (303-7563)	2628 (1116-18620)	993 (499-2187)	605 (179-1112)	NA	1971 (521-2673)	NA	NA
	Ef	NA	NA	813 (196-3647)	4724 (2852-18572)	2462 (1438-3431)	216 (101-464)	NA	133 (35-411)	NA	NA

Metals (µg/L)		BR	BS	DB	BI	MD	MF	PP	RP	WB	WC
As D	In	NA	0.5* (0.5-0.6)	1.1 (0.8-1.2)	0.6* (0.5-0.7)	NA	0.5 (0.5-0.6)	NA	NA	NA	NA
	Ef	NA	0.6* (0.5-0.7)	1.1 (0.8-1.2)	0.8* (0.5-1.0)	1.0 (1.0-1.2)	0.6 (0.5-0.6)	NA	NA	NA	NA
As T	In	NA	1.7 (1.2-1.9)	2.5 (1.9-2.6)	0.9 (0.6-1.0)	1.3 (1.0-1.6)	1.0 (0.8-1.2)	DL	1.3 (1.0-1.8)	NA	NA
	Ef	NA	1.2 (1.0-1.3)	1.8 (1.2-1.8)	1.0 (0.5-1.0)	1.9 (1.3-2.4)	0.9 (0.7-1.0)	DL	1.0 (0.5-1.0)	NA	NA
Cd D	In	NA	0.2 (0.2-0.3)	0.5* (0.5-0.5)	0.2 (0.2-0.2)	1.0* (1.0-1.0)	0.2 (0.2-0.2)	0.1* (0.1-0.1)	0.3* (0.3-0.3)	0.4* (0.1-0.5)	NA
	Ef	NA	0.2 (0.1-0.2)	0.5* (0.5-0.5)	0.2 (0.1-0.2)	1.0* (0.5-1.0)	0.2 (0.1-0.2)	0.1* (0.1-0.1)	0.1* (0.1-0.1)	0.5* (0.1-0.5)	NA
Cd T	In	NA	0.5 (0.4-0.5)	0.5* (0.5-0.5)	0.5 (0.4-0.6)	1.0* (1.0-1.0)	0.4 (0.3-0.4)	DL	0.6 (0.5-0.8)	0.3 (0.2-0.3)	2.4* (0.5-2.5)
	Ef	NA	0.3 (0.3-0.3)	0.5* (0.5-0.5)	0.2 (0.2-0.2)	1.0* (0.6-1.0)	0.2 (0.1-0.2)	DL	0.4 (0.3-0.5)	0.5 (0.1-0.5)	0.5* (0.5-0.5)
Cr D	In	NA	1.3 (1.0-1.4)	2.6 (1.4-3.1)	1.9 (1.4-2.1)	2.5 (2.5-2.5)	1.0 (1.0-1.0)	DL	2.0 (1.0-2.0)	NA	NA
	Ef	NA	1.2 (1.0-2.7)	1.9 (1.2-2.0)	1.6 (1.2-1.7)	2.5 (2.5-2.5)	1.0 (1.0-1.0)	DL	1.0 (1.0-1.0)	NA	NA
Cr T	In	NA	2.9 (1.8-5.8)	6.7 (4.9-7.5)	4.9 (3.8-5.6)	3.6 (2.5-4.0)	2.3 (1.6-2.5)	DL	5.0 (4.0-5.0)	NA	4.5 (2.7-5.0)
	Ef	NA	2.2 (1.5-3.3)	3.2 (2.2-3.5)	2.7 (2.3-3.3)	2.6 (2.5-3.5)	1.0 (1.0-1.0)	DL	2.0 (1.0-2.0)	NA	4.0 (1.0-4.0)
Cu D	In	NA	8.9 (7.9-11.0)	5.3 (3.7-6.9)	11.1 (8.7-13.0)	7.0 (6.0-8.0)	5.4 (4.5-6.5)	5.5 (3.8-5.6)	7.5 (7.0-8.2)	5.9 (4.8-8.0)	NA
	Ef	NA	7.9 (6.7-9.2)	4.8 (3.0-5.3)	5.3 (4.6-5.9)	6.0 (5.0-7.0)	4.2 (3.6-5.3)	6.0 (5.6-7.0)	5.0 (4.0-5.0)	5.0 (5.0-5.5)	NA
Cu T	In	18 (12-23)	12 (10-15)	10 (6-10)	24 (20-27)	14 (12-15)	15 (13-15)	13 (11-19)	10 (10-10)	6 (5-7)	10 (6-10)
	Ef	9 (6-11)	8 (7-9)	7 (5-9)	7 (6-8)	11 (9-12)	7 (5-8)	10 (9-11)	6 (5-6)	4 (3-4)	8 (5-10)
Pb D	In	NA	1.2 (1.0-1.4)	1.9* (1.0-2.5)	1.0 (1.0-1.0)	5.0* (3.4-5.0)	1.0 (1.0-1.0)	DL	1.8* (1.5-2.7)	1.0 (0.5-1.0)	9.0 (0.5-12)
	Ef	NA	1.1 (1.0-2.1)	2.0* (1.0-2.5)	0.5 (0.5-0.5)	2.6* (1.5-3.4)	1.0 (1.0-1.0)	DL	1.5* (1.0-1.5)	1.0 (1.0-2.0)	6.4 (0.5-25)
Pb T	In	NA	4.3 (3.4-6.4)	10.0 (5.0-10.0)	8.6 (6.3-11.0)	7.9 (5.9-12.0)	10.0 (6.9-10.0)	5.9 (5.0-7.6)	10.0 (8.0-10.0)	2.0 (1.6-2.3)	10.0 (10.0-10.0)
	Ef	NA	2.0 (2.0-2.0)	5.0 (2.5-7.9)	2.0 (1.3-2.2)	5.0 (5.0-5.0)	1.5 (1.1-1.5)	2.5 (2.5-2.5)	3.0 (2.0-3.0)	1.0 (1.0-1.0)	6.4 (3.6-10.0)
Ni D	In	NA	4.3 (2.0-4.5)	2.6 (2.0-3.7)	2.7 (2.1-2.9)	2.0* (1.0-2.0)	2.0 (2.0-2.0)	1.0* (1.0-1.0)	10.0* (1.6-10.0)	NA	NA
	Ef	NA	2.0 (2.0-2.0)	2.6 (2.0-3.2)	2.1 (2.0-2.2)	2.4* (2.0-2.8)	2.0 (2.0-2.0)	0.5* (0.5-0.5)	10.0* (2.3-10.0)	NA	NA
Ni T	In	NA	6.9 (4.8-9.6)	6.5 (5.0-10.0)	4.9 (4.3-5.3)	5.0 (3.0-5.5)	3.6 (3.2-4.2)	2.8 (2.5-3.3)	6.0 (4.0-7.7)	NA	4.5 (3.0-10.0)
	Ef	NA	3.0 (2.4-4.3)	3.7 (2.4-4.5)	2.9 (2.4-3.2)	5.0 (4.0-5.0)	2.3 (2.0-2.8)	1.8 (1.6-2.1)	2. 8 (2.1-5.0)	NA	3.0 (2.0-3.0)
Zn D	In	NA	45 (35-56)	15 (9-17)	39 (33-47)	47 (37-58)	52 (37-60)	12 (9-13)	23 (20-28)	45 (35-66)	10* (10-10)
	Ef	NA	25 (22-29)	13 (8-17)	14 (11-18)	54 (45-64)	12 (9-17)	7 (6-9)	10 (10-10)	19 (10-23)	10* (10-10)
Zn T	In	74 (66-94)	40 (30-40)	66 (40-107)	99 (80-110)	90 (79-97)	90 (80-101)	62 (49-81)	53 (49-60)	52 (45-60)	30 (20-30)
	Ef	20 (10-26)	30 (30-30)	24 (15-35)	24 (17-27)	60 (53-65)	15 (15-20)	18 (15-20)	20 (17-20)	20 (16-24)	15 (11-20)

Table Notes

Explanation of Data Provided:

Table Entry			Explanation
Zn T	In	74	Median influent total zinc value
		(66-94)	95% confidence interval for median influent zinc value
	Ef	20	Median effluent total zinc value
		(10-26)	95% confidence interval for median effluent zinc value

* = Greater than 50% non-detects in the influent
NA = Not available for analysis
DL = Data set has greater than 80% non-detects; summary statistics have been excluded from this table

BMP Type:
BR = Bioretention (with underdrains)
BS = Biofilter - grass swale
DB = Detention basin (dry, grass-lined)
BI = Biofilter - grass strip
MD = Manufactured device (all categories)
MF = Media filter (all categories)
PP = Permeable pavement (all categories)
RP = Retention pond (wet pond)
WB = Wetland basin
WC = Wetland channel

Parameter-related Acronyms:
TSS = Total suspended solids
TDS = Total dissolved solids
Ortho-P = Phosphorus, Orthophosphate as Phosphorus
TKN = Total Kjeldahl nitrogen
TOC = Total organic carbon
As = Arsenic
Cd = Cadmium
Cr = Chromium
Cu = Copper
Pb = Lead
Ni = Nickel
Zn = Zinc

Sample Type:
In = influent
Ef = effluent

Units:
mg/L = milligrams per liter
µg/L = micrograms per liter (for metals)
NTU = nephelometric turbidity units (for turbidity)
#/100 mL = colonies per 100 milliliters (for bacteria)

Sample Fraction:

D = Dissolved
T = Total