Setting Realistic Expectations for Stormwater BMP Performance:

New Findings for Nutrients and Bacteria from the International Stormwater BMP Database

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Colorado Watershed Assembly 2012

Overview

- Regulatory Context
- Structural BMP Performance
  - Introduction to the Stormwater BMP Database
  - Performance Findings
- Implications and TMDL Compliance Strategies

The Problem

Top 10 Causes of Impairment in U.S. by # of 303(d) Listings

Cause of Impairment Group Name	Number of Causes of Impairment
Pathogens	10,582
Metals (other than Mercury)	7,436
Nutrients	6,909
Organic Enrichment/Oxygen Depletion	6,412
Sediment	6,139
Polychlorinated Biphenyls (PCBs)	5,578
Mercury	4,716
pH/Acidity/Caustic Conditions	4,131
Cause Unknown - Impaired Biota	3,469
Turbidity	3,118

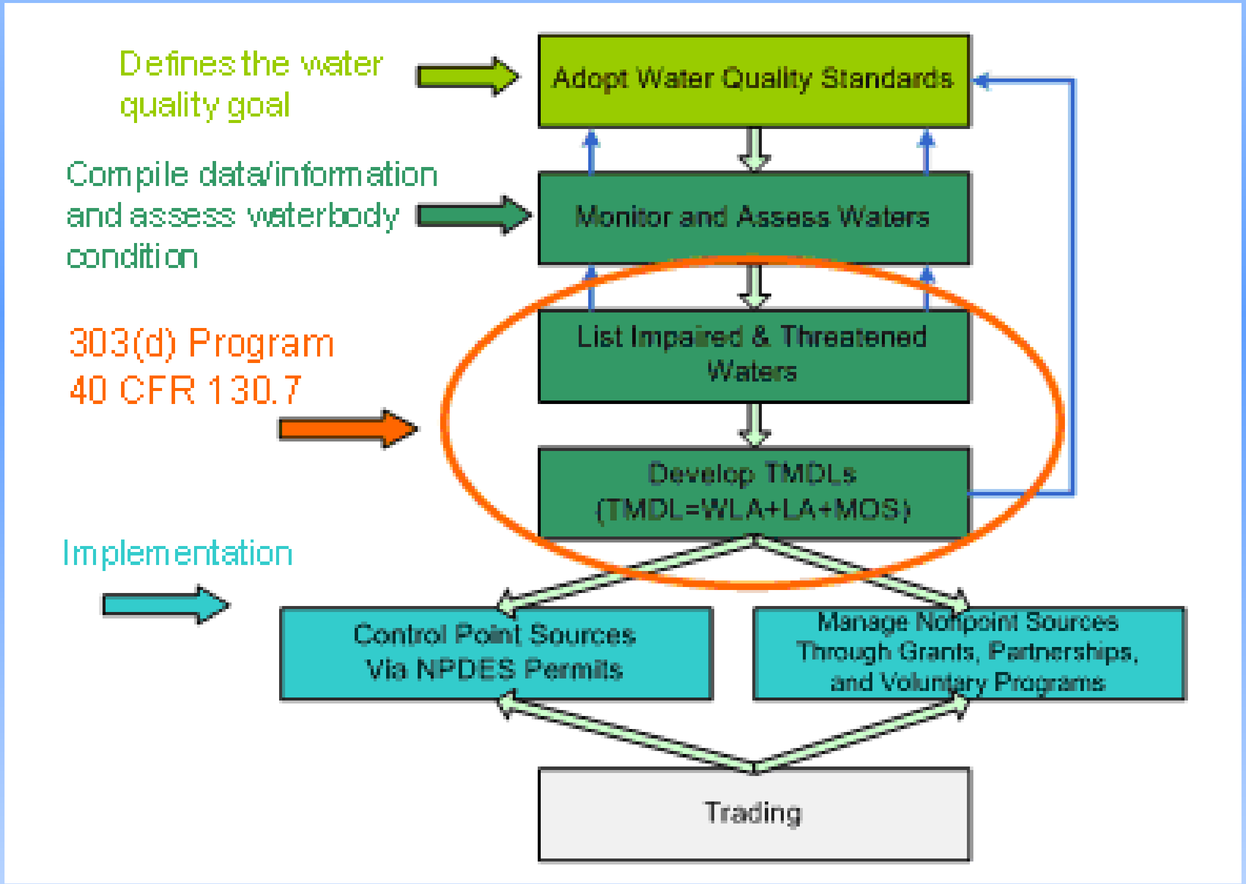
Regulatory Context:

- New nutrient criteria in Colorado (2012, with limited implementation prior to 2022)
- Revised EPA Ambient Rec. Water Quality Criteria (expected Nov. 30, 2012)

Source: EPA http://iaspub.epa.gov/waters10/attains_nation_cy.control?p_report_type=T#tmdl_by_pollutant Accessed May 2012,

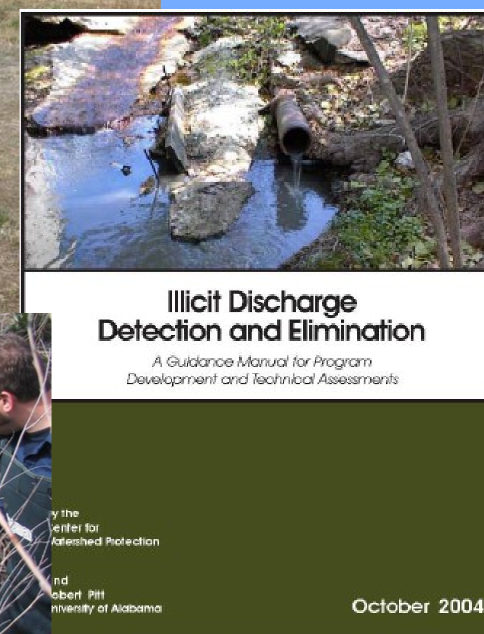
Implications for Watershed & Stormwater Managers/MS4s

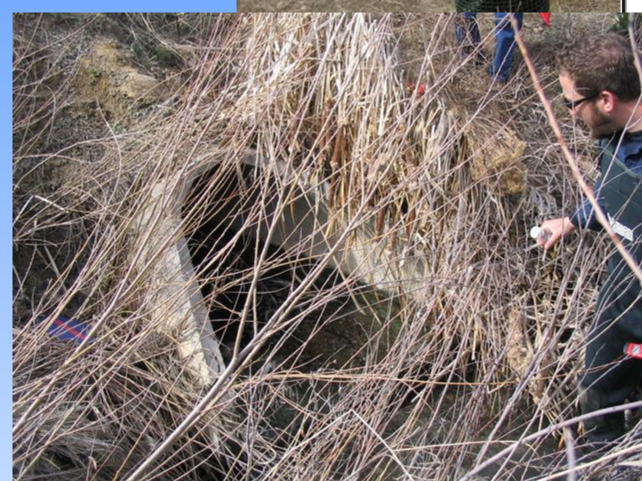
- MS4 permit holders must address issue due to TMDLs
- FIB elevated in urban runoff
- Nutrients are often elevated in urban runoff
- Storm sewer system can be a source during dry weather, too



Tools to Reduce Bacteria in Runoff & MS4s

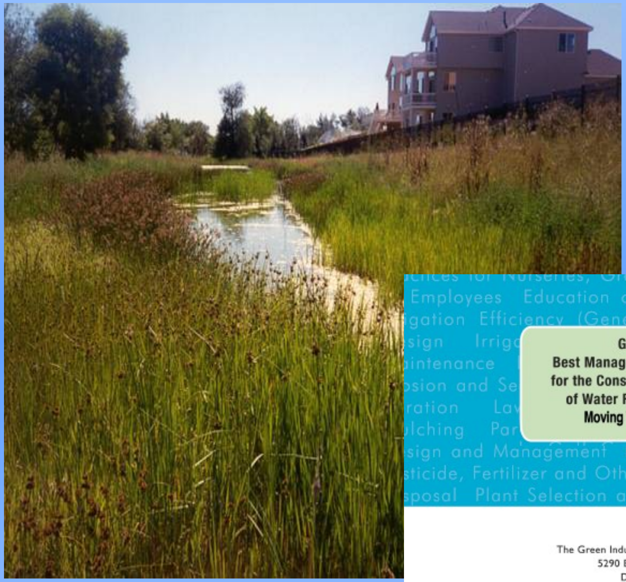
- IDDE (Identify/Remove Illicit Discharges
- Infrastructure Repairs
- Source Controls
- Passive Structural BMPs
- Active Treatment: Disinfection

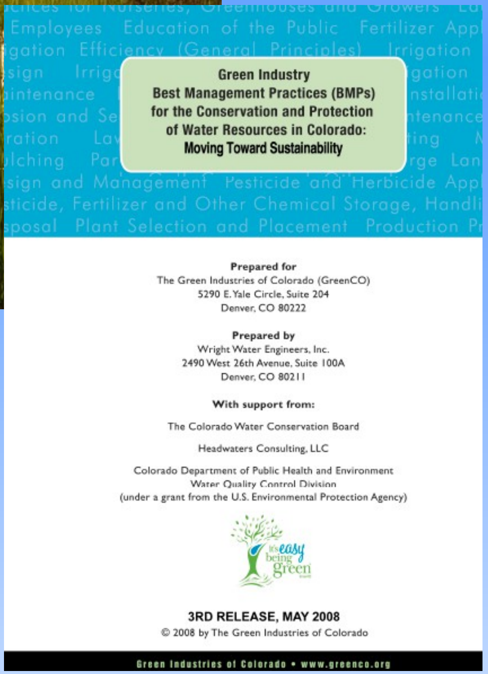




Tools to Reduce Nutrients in Runoff

- IDDE
  (Identify/Remove Illicit Discharges
- Source Controls
  (Landscape BMPs, Washwater Controls)
- Passive Structural BMPs
- Active Treatment: Chemical Addition





Green Industry
Best Management Practices (BMPs)
for the Conservation and Protection
of Water Resources in Colorado:
Moving Toward Sustainability

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it's easy being green

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WERF Water Environment Research Foundation Collaboration. Innovation. Results

ASCE American Society of Civil Engineers

EWRI

EPA

U.S. Department of Transportation
Federal Highway Administration

APWA

Project Team

WWE WRIGHT WATER ENGINEERS, INC.

Geosyntec consultants

Welcome to the International Stormwater Best Management Practices (BMP) Database project website, which features a database of over 500 BMP studies, performance analysis results, tools for use in BMP performance studies, monitoring guidance and other study-related publications. The overall purpose of the project is to provide scientifically sound information to improve the design, selection and performance of BMPs. Continued population of the database and assessment of its data will ultimately lead to a better understanding of factors influencing BMP performance and help to promote improvements in BMP design, selection and implementation.

The project, which began in 1996 under a cooperative agreement between the American Society of Civil Engineers (ASCE) and the U.S. Environmental Protection Agency (USEPA), now has support and funding from a broad coalition of partners including the Water Environment Research Foundation (WERF), ASCE Environmental and Water Resources Institute (EWRI), USEPA, Federal Highway Administration (FHWA) and the American Public Works Association (APWA) (See Project Overview for more information). Wright Water Engineers, Inc. and Geosyntec Consultants are the entities maintaining and operating the database clearinghouse and web page, answering questions, conducting analyses of newly submitted BMP data, conducting updated performance evaluations of the overall data set, disseminating project findings, and expanding the database to include other approaches such as Low Impact Development techniques. The database itself is downloadable to any individual or organization that would like to conduct its own assessments.

What's New

New! 2012 BMP Performance Summaries

New! 2012 BMP Performance Summary for Chesapeake Bay

New! Online Statistical Analysis Tool (Beta Version)

New! Interactive BMP Mapping tool

New! 2012 Database Overview

New! Agricultural BMP Database Kick-off

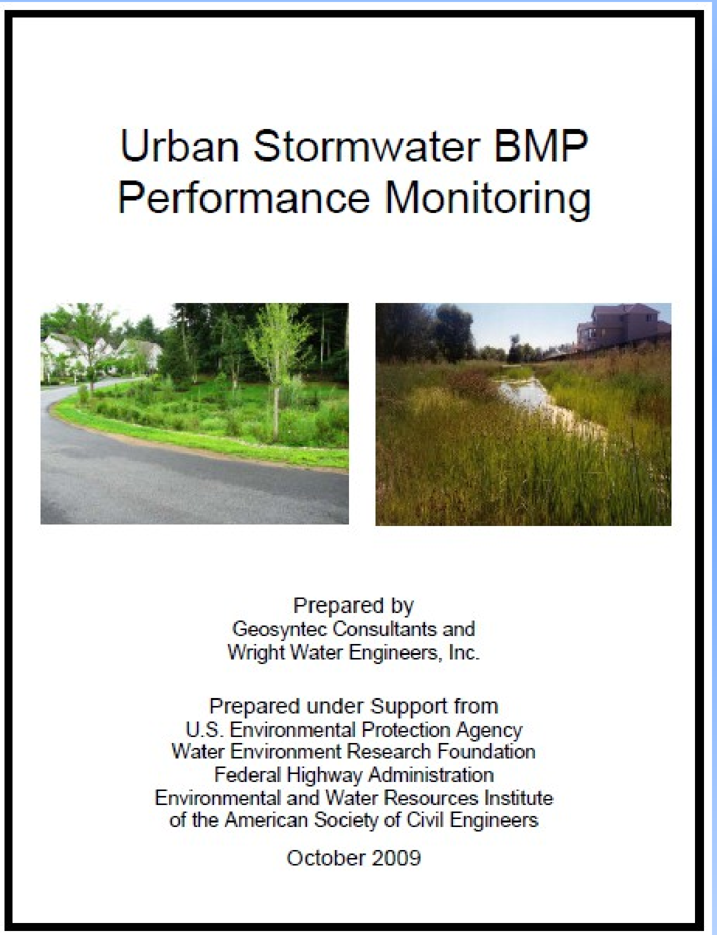
WERF Research Digest

What Type of User Are You? Let us help you enter our website to find the level of detail you need:

Low-Intensity	Mid-Intensity	Researcher	Data Provider	New to BMP Monitoring
Get Basic Performance Summary Information for BMPs Typical Users: Public officials, casual users, those seeking quick/fast answers	Get Detailed Statistical Analysis for Individual BMPs Typical Users: Consultants, Public Works Staff, Designers	Download the Master Database to Conduct Independent Research Typical Users: University Professors	Obtain Data Entry Spreadsheets Typical Users: Public agencies, consulting firms, university researchers	Obtain Monitoring Guidance Typical Users: Public agencies, consulting firms, university researchers, graduate students

BMP Database Overview

- BMP Database includes over 510 BMP monitoring studies, including significant green infrastructure/LID BMPs
- Database & analysis available at www.bmpdatabase.org
- From 2008-2012, a key focus has been to better integrate green infrastructure through:
  - Monitoring Guidance (Updated)
  - New & Updated Reporting Protocols
  - Updated Analysis Protocols



Urban Stormwater BMP
Performance Monitoring

Prepared by
Geosyntec Consultants and
Wright Water Engineers, Inc.

Prepared under Support from
U.S. Environmental Protection Agency
Water Environment Research Foundation
Federal Highway Administration
Environmental and Water Resources Institute
of the American Society of Civil Engineers

October 2009

BMP Summary

- New Green Infrastructure BMP Categories:
  - Bioretention
  - Green Roofs
  - Rainwater Harvesting
  - Site-scale LID
- Adding more studies is an ongoing objective
- Most recent version posted in January 2012
- Most recent analysis July 2012

BMP Category	#
Bioretention	30
Detention Basin	39
Green Roof	13
Biofilter - Grass Strip	45
Biofilter - Grass Swale	41
Infiltration Basin	2
LID (Site Scale)	2
Manufactured Device	79
Media Filter	37
Percolation Trench/Well	12
Porous Pavement	35
Retention Pond	68
Wetland Basin	31
Wetland Channel	19
Composite	25
Maintenance Practice	28
Other	6
Total	**512**
Control Sites	19

Examples of BMPs

Grass Buffer

Grass Swale

Rain Garden (Bioretention)

Green Roof

Extended Detention Basin

Permeable Pavement

Retention Pond

Wetland Basin

Three Ways to Access BMP Database Information

1. On-line Search Engine
2. Overall Performance Summary Technical Papers
3. Download Access Database

INTERNATIONAL STORMWATER BMP DATABASE
www.bmpdatabase.org

International Stormwater Best Management Practices (BMP) Database Pollutant Category Summary Statistical Addendum:

TSS, Bacteria, Nutrients, and Metals

Prepared by
Geosyntec Consultants, Inc.
Wright Water Engineers, Inc.

Under Support From
Water Environment Research Foundation
Federal Highway Administration
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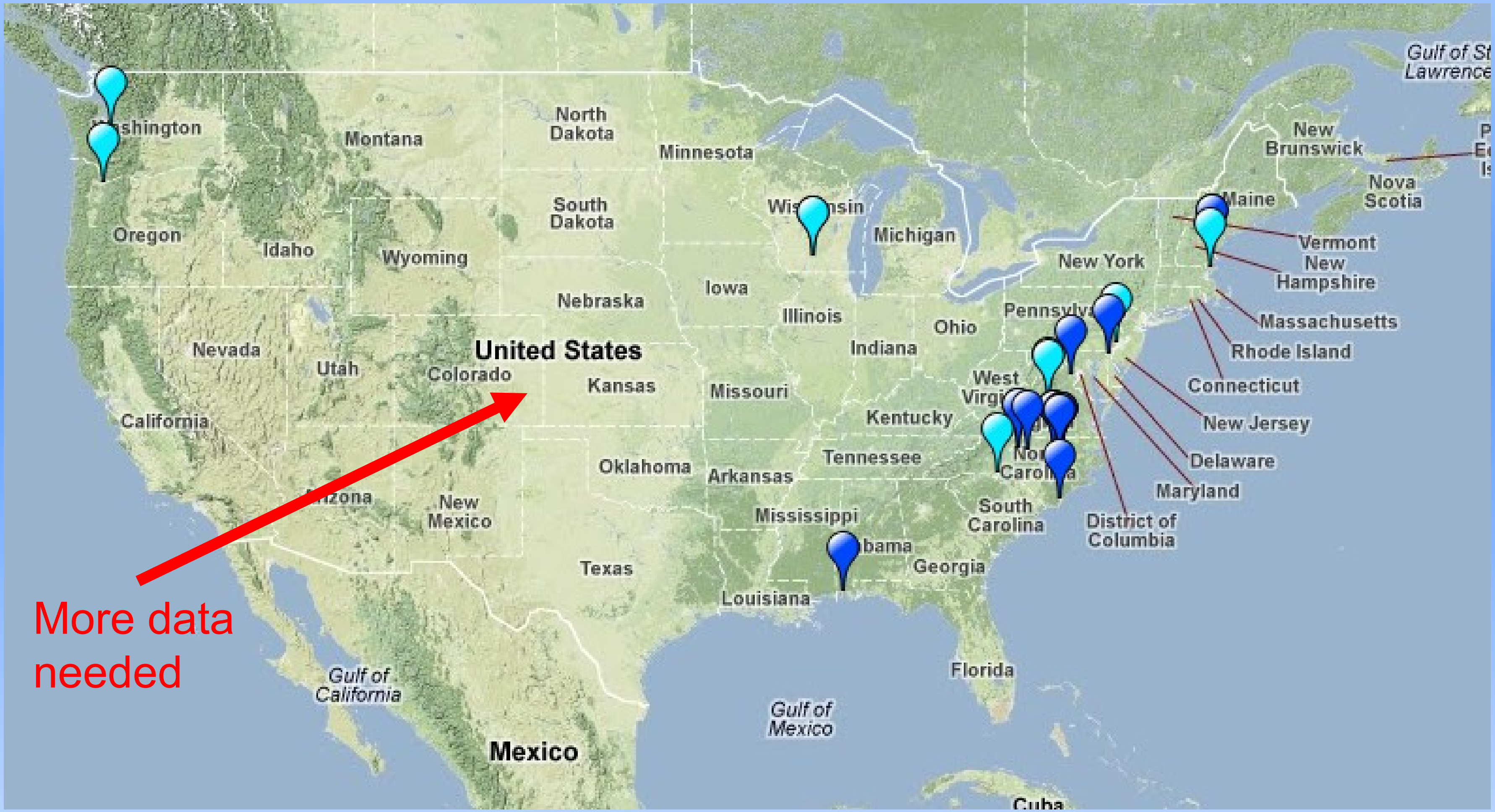
April 2012

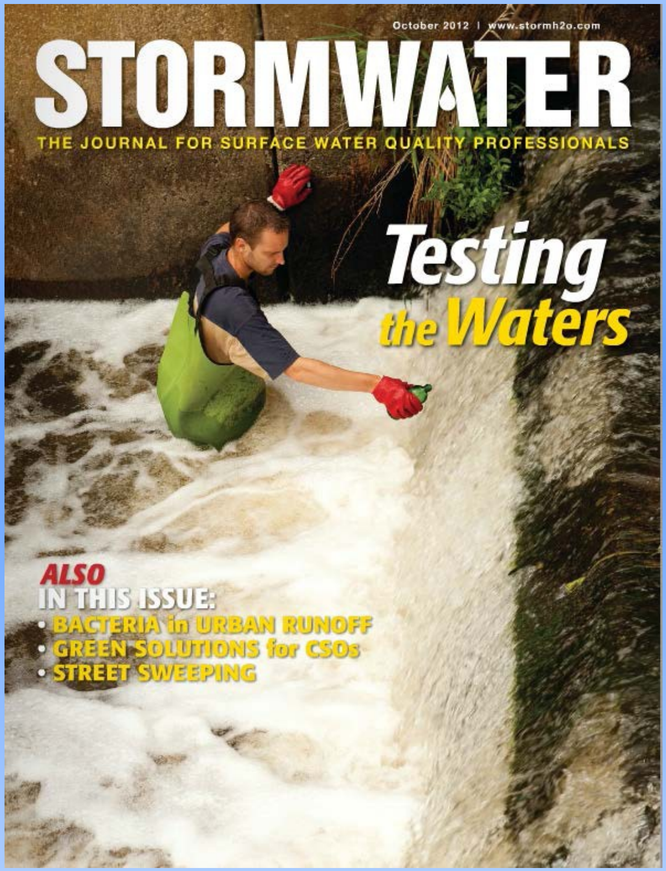
Geographic Distribution of Data (U.S. portion)

Geographic Distribution of Bioretention Studies as of July 2012

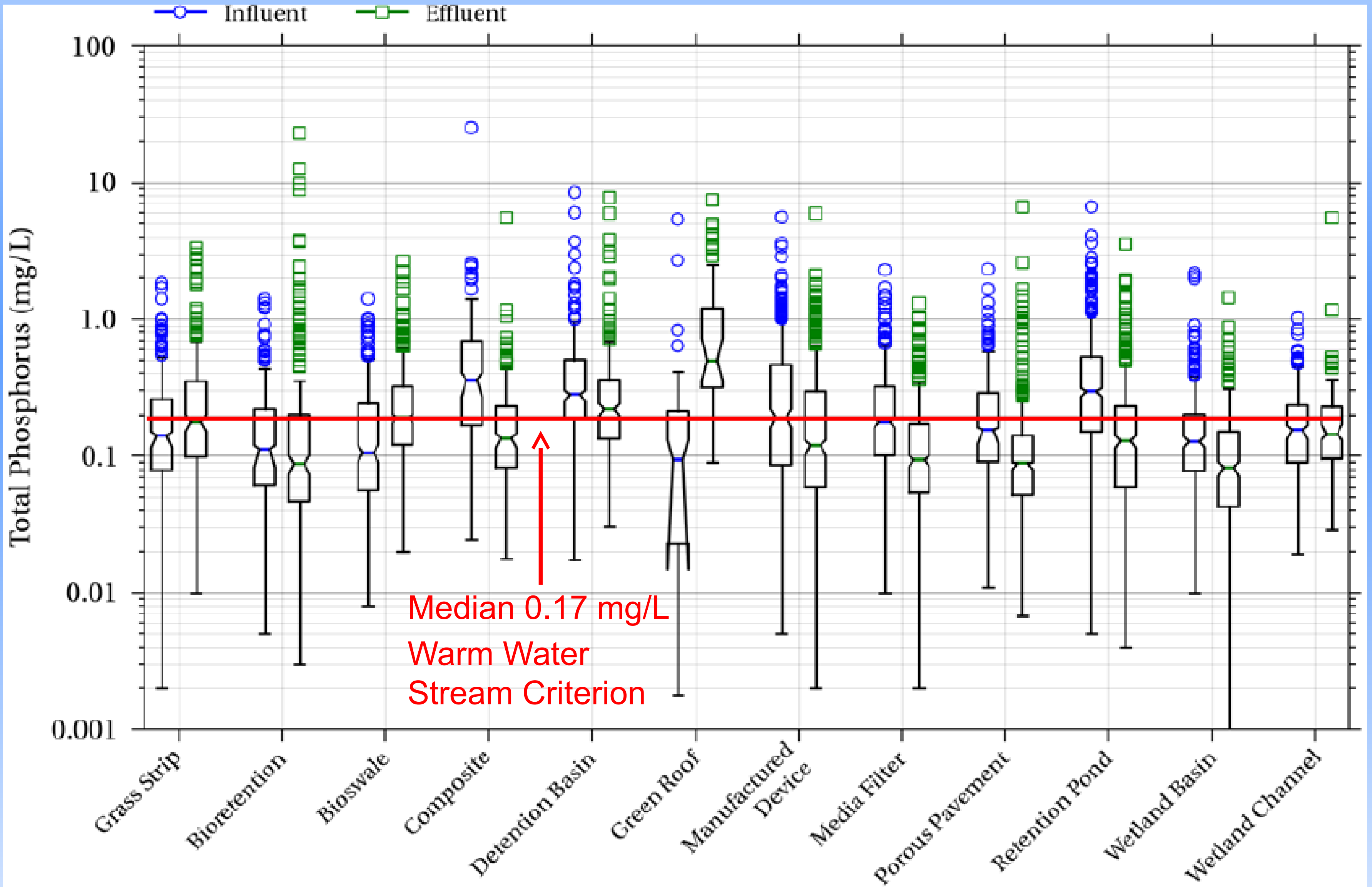


New BMP Database Reports (July 2012)
(all available at www.bmpdatabase.org)

- New Water Quality Summaries: Nutrients, TSS, Metals, Bacteria
- Narrative Overview-- "Plain English" on What's in the Database
- Manufactured Devices by Unit Treatment Process
- Expanded Volume Reduction Analysis Focused on Bioretention
- Chesapeake Bay Tech Memo
- Agricultural BMP Database
- New Stormwater Magazine Article on Fecal Indicator Bacteria



BMP Database Influent-Effluent Total Phosphorus (mg/L)



BMP Database Influent-Effluent Total Phosphorus (mg/L)

BMP Type	Count of Studies and EMCs		25th Percentile		Median (95% Conf. Interval*)		75th Percentile	
	In	Out	In	Out	In	Out	In	Out
Grass Strip	20, 358	20, 280	0.08	0.10	0.14 (0.11, 0.15)	*0.18 (0.15, 0.20)****	0.26	0.35
Bioretention	18, 271	18, 249	0.06	0.05	0.11 (0.08, 0.12)	0.09 (0.07, 0.10)	0.22	0.20
Bioswale	20, 331	22, 364	0.06	0.12	0.11 (0.09, 0.12)	*0.19 (0.17, 0.20)****	0.24	0.32
Composite	9, 176	10, 153	0.17	0.08	0.36 (0.27, 0.40)	0.13 (0.11, 0.15)**	0.69	0.23
Detention Basin	18, 250	19, 275	0.19	0.13	0.28 (0.25, 0.30)	0.22 (0.19, 0.24)**	0.51	0.36
Green Roof	2, 22	5, 60	0.02	0.31	0.09 (0.02, 0.13)	0.50 (0.36, 0.72)***	0.21	1.20
Manufactured Device	45, 602	52, 641	0.09	0.06	0.19 (0.16, 0.22)	0.12 (0.10, 0.13)**	0.46	0.30
Media Filter	28, 433	28, 403	0.10	0.05	0.18 (0.16, 0.19)	0.09 (0.08, 0.10)**	0.32	0.17
Porous Pavement	13, 231	22, 389	0.09	0.05	0.15 (0.12, 0.16)	0.09 (0.08, 0.09)**	0.29	0.14
Retention Pond	46, 657	48, 654	0.15	0.06	0.30 (0.27, 0.31)	0.13 (0.12, 0.14)**	0.53	0.23
Wetland Basin	13, 282	13, 278	0.08	0.04	0.13 (0.11, 0.14)	0.08 (0.07, 0.09)**	0.20	0.15
Wetland Channel	8, 167	8, 147	0.09	0.10	0.15 (0.13, 0.17)	0.14 (0.13, 0.17)	0.23	0.23

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

**Hypothesis testing in Attachment 4 shows statistically significant decreases for this BMP category.

***Hypothesis testing in Attachment 4 shows statistically significant *increases* for this BMP category.

Shop Creek Wetland-Pond System (95-97)

Composite—Overall Site BMP

Phosphorus as P, Total (mg/L)

BASIC STATISTICS

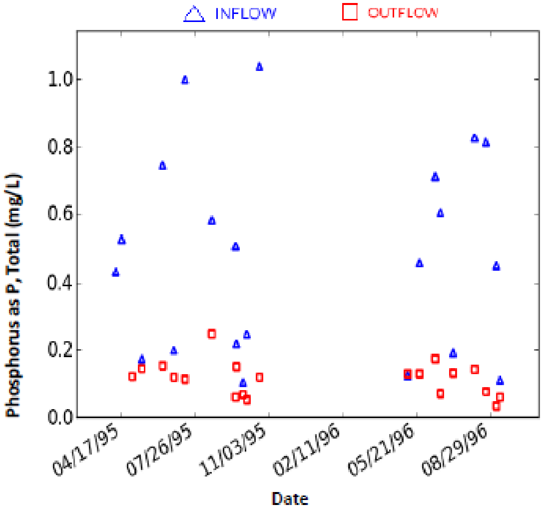
PERFORMANCE METRIC	INFLOW	OUTFLOW	COMPARISON
Number of EMCs:	21	20	--
Percent Non-Detects:	0%	0%	--
Median:	0.46	0.12	Decreased*
Mean:	0.48	0.12	Decreased
Standard Deviation:	0.29	0.05	--
25th Percentile:	0.2	0.07	Decreased
75th Percentile:	0.71	0.14	Decreased
Well-fit to normal distribution?	Yes	Yes	--
Well-fit to lognormal distribution?	Yes	Yes	--

*Statistically Significant Difference in Median?	YES

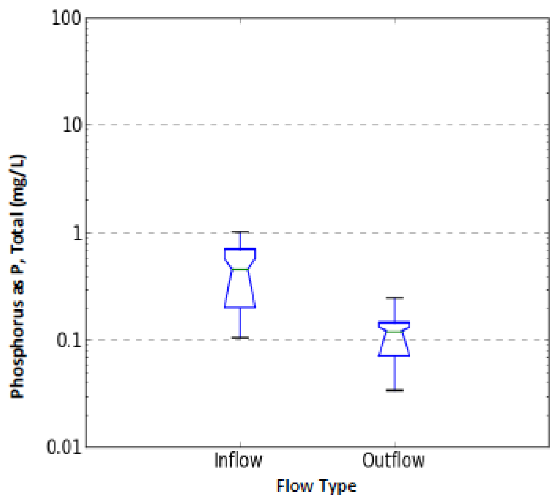
HYPOTHESIS TESTING:

STATISTICAL TEST	DATA	NULL HYPOTHESIS	p-value	Reject Null Hypothesis?	
				α=0.05	α=0.10
Mann-Whitney:	Raw	The inflow and outflow median EMCs are equal.	0	YES	YES
t-Test: (Assume Equal Variance)	Raw	The inflow and outflow mean EMCs are equal.	0	YES	YES
	Log	The inflow and outflow mean EMCs are equal.	0	YES	YES
t-Test: (Assume Unequal Variance)	Raw	The inflow and outflow mean EMCs are equal.	0	YES	YES
	Log	The inflow and outflow mean EMCs are equal.	0	YES	YES
Levene (Raw Data):	Raw	The two variances are equal.	0	YES	YES
	Log	The two variances are equal.	0.059	NO	YES

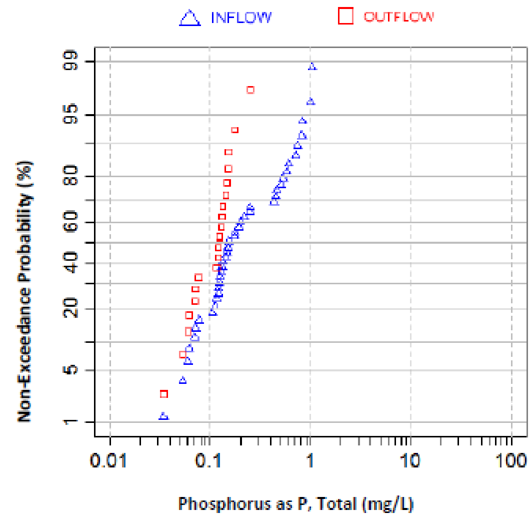
TIME SERIES PLOT



NOTCHED BOX-AND-WHISKER PLOT



LOGNORMAL PROBABILITY PLOT



Shop Creek Wetland-Pond System (95-97)

Composite—Overall Site BMP

Kjeldahl nitrogen (TKN) (mg/L)

BASIC STATISTICS

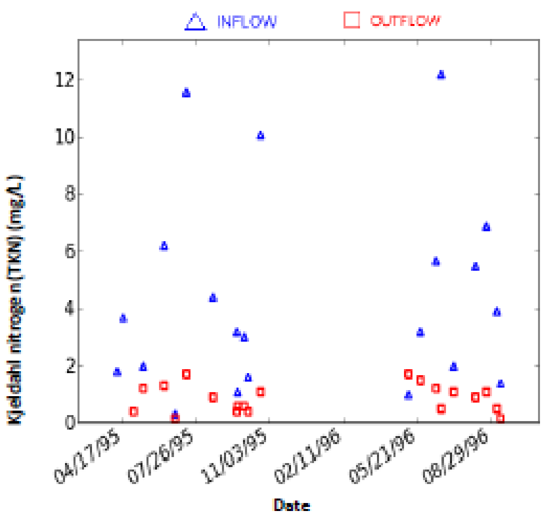
PERFORMANCE METRIC	INFLOW	OUTFLOW	COMPARISON
Number of EMCs:	21	20	--
Percent Non-Detects:	0%	10%	--
Median:	3.2	0.9	Decreased*
Mean:	4.32	0.87	Decreased
Standard Deviation:	3.36	0.47	--
25th Percentile:	1.8	0.48	Decreased
75th Percentile:	5.7	1.2	Decreased
Well-fit to normal distribution?	No	Yes	--
Well-fit to lognormal distribution?	Yes	No	--

*Statistically Significant Difference in Median?	YES

HYPOTHESIS TESTING:

STATISTICAL TEST	DATA	NULL HYPOTHESIS	p-value	Reject Null Hypothesis? α=0.05	Reject Null Hypothesis? α=0.10
Mann-Whitney:	Raw	The inflow and outflow median EMCs are equal.	0	YES	YES
t-Test: (Assume Equal Variance)	Raw	The inflow and outflow mean EMCs are equal.	0	YES	YES
	Log	The inflow and outflow mean EMCs are equal.	0	YES	YES
t-Test: (Assume Unequal Variance)	Raw	The inflow and outflow mean EMCs are equal.	0	YES	YES
	Log	The inflow and outflow mean EMCs are equal.	0	YES	YES
Levene (Raw Data):	Raw	The two variances are equal.	0.001	YES	YES
	Log	The two variances are equal.	0.425	NO	NO

TIME SERIES PLOT



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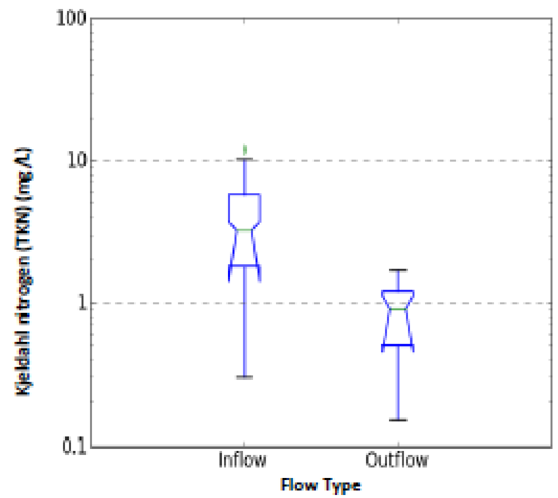

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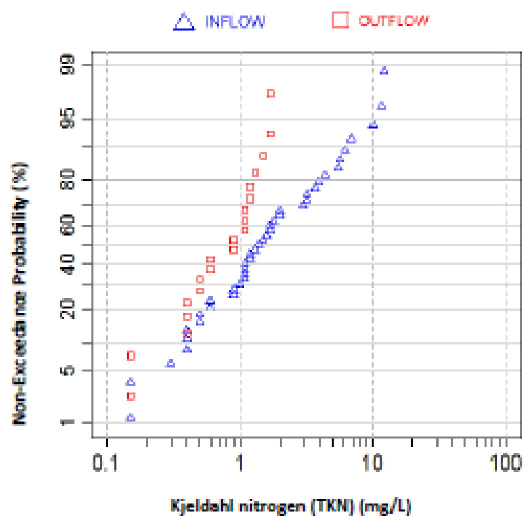


Learning from What Went Wrong: The High P Index Lesson

Bioretention

Phosphorus as P, Total (mg/L)

BASIC STATISTICS

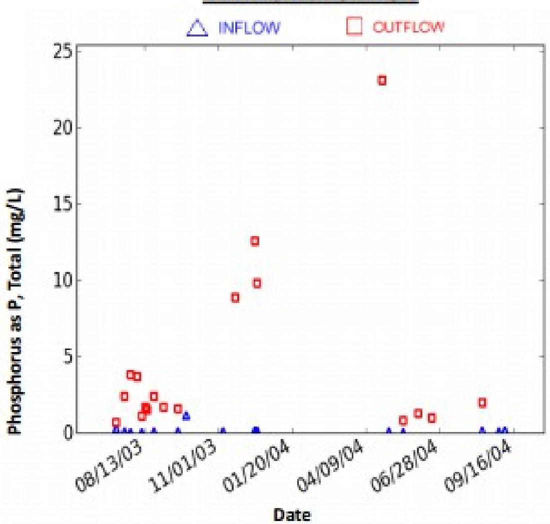
PERFORMANCE METRIC	INFLOW	OUTFLOW	COMPARISON
Number of EMCs:	15	18	--
Percent Non-Detects:	0%	0%	--
Median:	0.13	1.85	Increased*
Mean:	0.21	4.45	Increased
Standard Deviation:	0.27	5.63	--
25th Percentile:	0.11	1.35	Increased
75th Percentile:	0.19	3.77	Increased
Well-fit to normal distribution?	No	No	--
Well-fit to lognormal distribution?	Yes	Yes	--

*Statistically Significant Difference in Median?	YES

HYPOTHESIS TESTING:

STATISTICAL TEST	DATA	NULL HYPOTHESIS	p-value	Reject Null Hypothesis?	
				α=0.05	α=0.10
Mann-Whitney:	Raw	The inflow and outflow median EMCs are equal.	0	YES	YES
t-Test: (Assume Equal Variance)	Raw	The inflow and outflow mean EMCs are equal.	0.008	YES	YES
	Log	The inflow and outflow mean EMCs are equal.	0	YES	YES
t-Test: (Assume Unequal Variance)	Raw	The inflow and outflow mean EMCs are equal.	0.006	YES	YES
	Log	The inflow and outflow mean EMCs are equal.	0	YES	YES
Levene (Raw Data):	Raw	The two variances are equal.	0.039	YES	YES
	Log	The two variances are equal.	0.333	NO	NO

TIME SERIES PLOT



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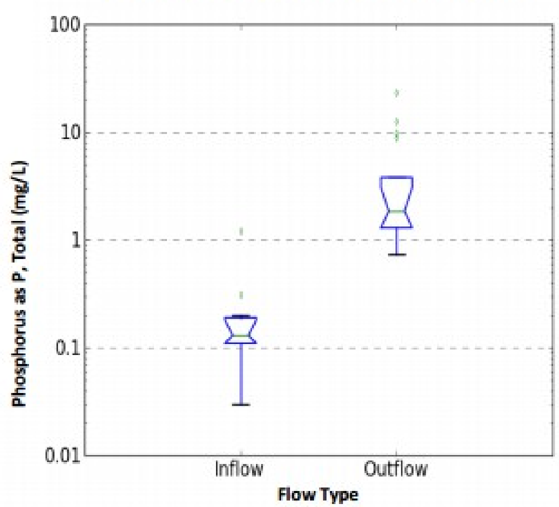

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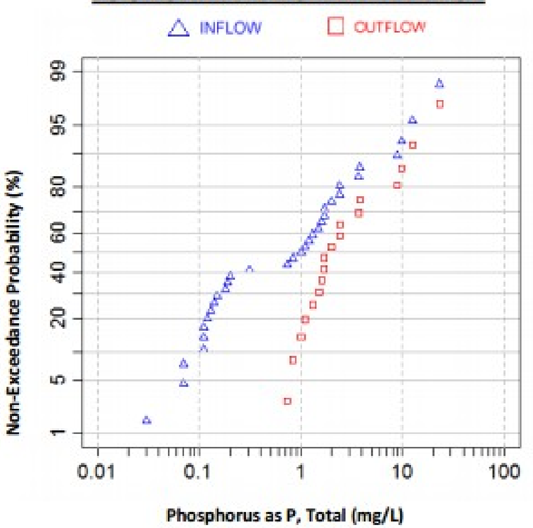
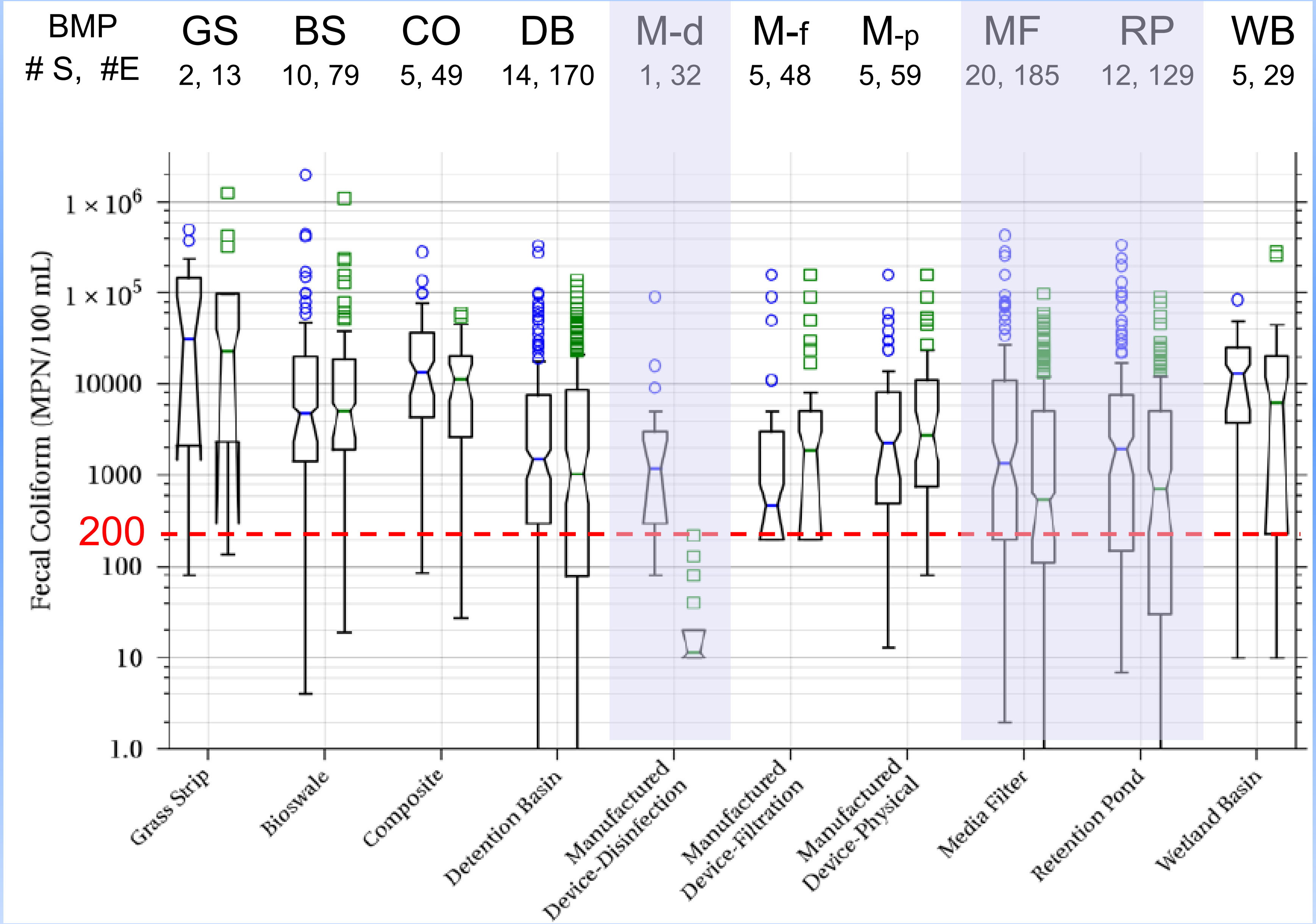
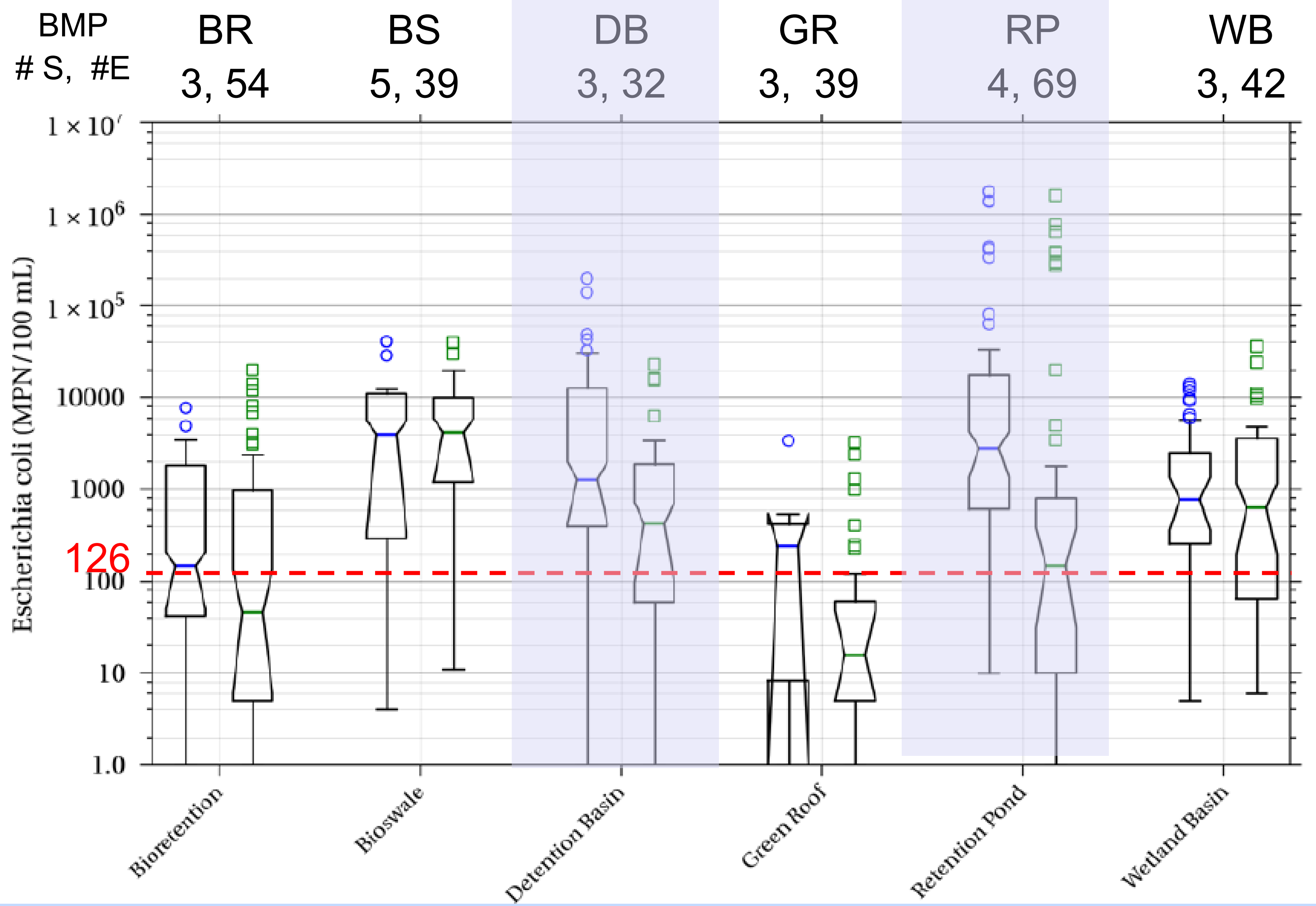


Fecal Coliform Inflow-Outflow Boxplots



E. Coli Inflow-Outflow Boxplots



Volume Reduction

- Volume x Concentration = Load; therefore reducing volume of runoff can be a key strategy for reducing pollutant loads.
- Increasing emphasized by EPA and others, may be a component of future stormwater regulations.
- BMP Database recommends use of multiple metrics to evaluate volume reduction.

Exhibit 2. Simple Metrics for Interpreting Single-Event Volumetric Data

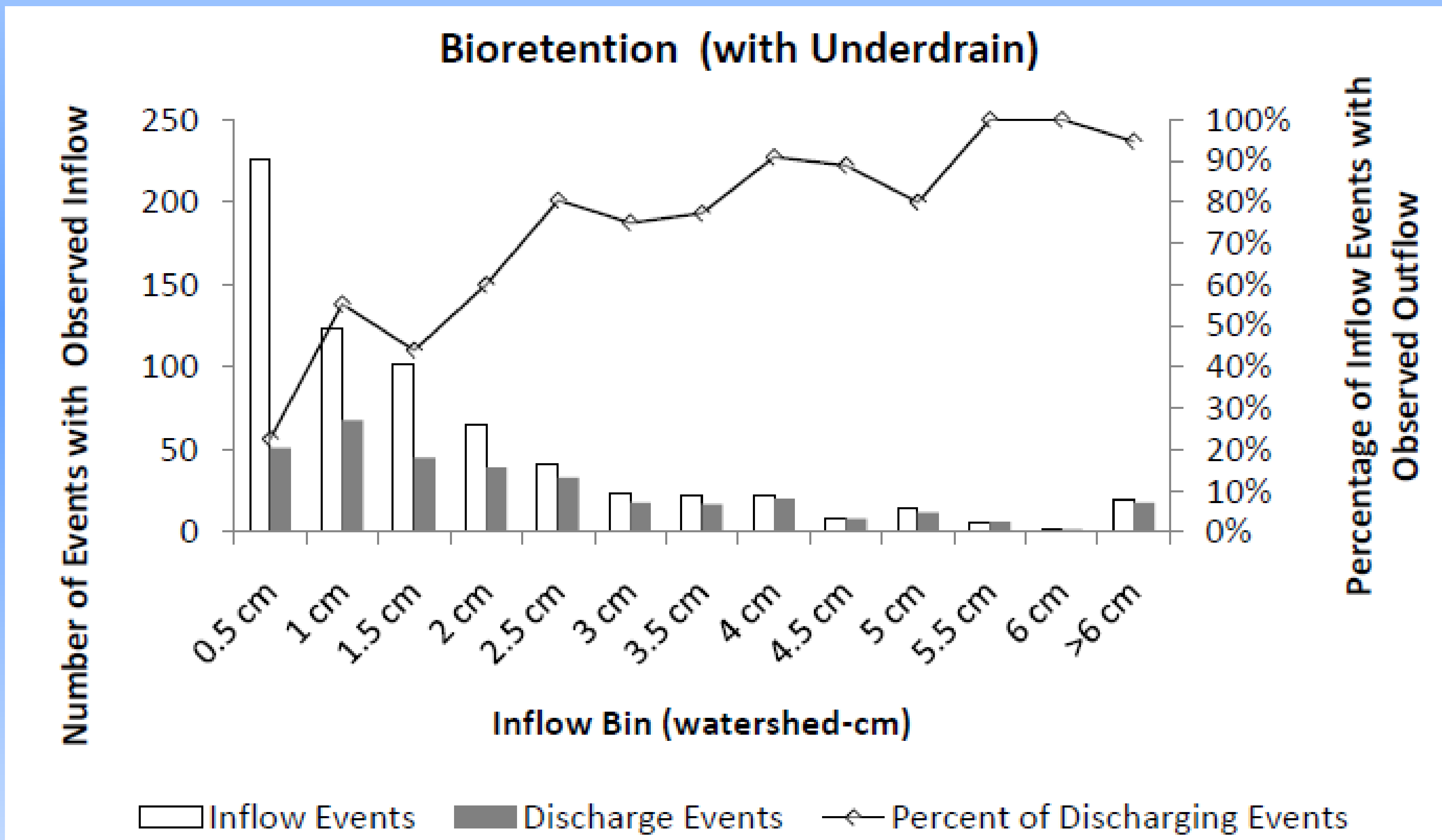
Metric	Application
Presence/Absence of Discharge	Practice level and site level
Absolute Volume Reduction (Out – In)	Practice level only
Relative Volume Reduction (Out – In)/In	Practice level only
Discharge Volume per Area	Practice level and site level
Discharge Volume per Impervious Area	Practice level and site level

Volume Reduction Analysis

BMP Category	# of Studies	25th Percentile	Median	75th Percentile	Average
Biofilter – Grass Strips	16	18%	34%	54%	**38%**
Biofilter – Grass Swales	13	35%	42%	65%	**48%**
Bioretention (with underdrains)	14	33%	52%	73%	**56%**
Bioretention (without underdrains)	6	85%	99%	100%	**89%**
Detention Basins – Surface, Grass Lined	11	26%	33%	43%	**33%**

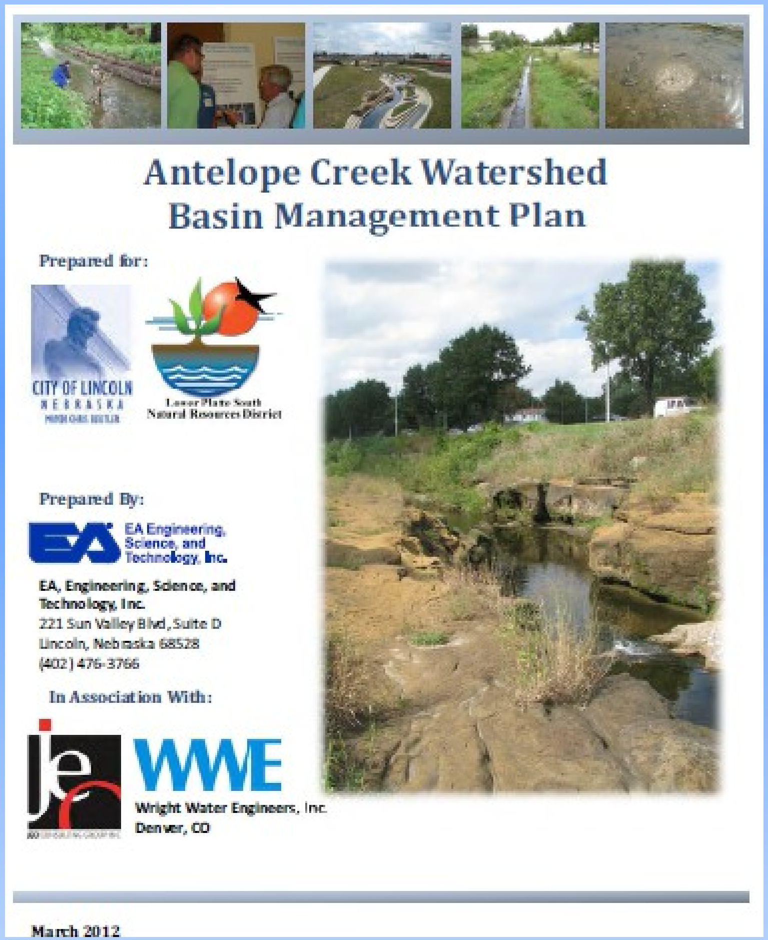
NOTES: 1) Relative percent volume reduction for each study = 100 x [(Study Total Inflow Volume - Study Total Outflow Volume)/ (Study Total Inflow Volume)]; 2) Summary does not reflect performance categorized according to storm size (bin). This is an important limitation of this summary, since large storms that may result in bypass or overflow conditions may not be represented in the limited period of record typically associated with BMP monitoring.

Role of Volume Reduction in Reducing Frequency of Discharges



Nebraska Case Study: Cost Estimates for E. coli TMDL

- 7.7 sq. mi. Antelope Creek Watershed, Lincoln
- Source load estimates by land use & BMP evaluation using WinSLAMM
- Curb-cut bioretention retrofits identified as a key BMP
- Est. Cost: $57 million over 40-year plan
- City will start w/ source controls and pilot projects using 5-year plans



General Conclusions Related to BMP Performance: Bacteria

- Data set remains limited for most BMP category-FIB combinations.
- Results to date do not support attainment of numeric effluent limits for FIB in stormwater.
- Retention (wet) ponds appear to provide best performance on a density/concentration basis.
- Bioretention and other infiltration-oriented practices can reduce bacteria loads by reducing frequency and volume of runoff.
- Disinfection works at point of outfall, but not realistic in many contexts.
- Some BMP types appear to export bacteria.

General Conclusions Related to BMP Performance: Phosphorus

- Multiple BMP types demonstrate the ability to reduce total phosphorus concentrations. BMPs with permanent pools performed particularly well.
- Generally, BMPs with unit treatment process for removing particulates (e.g., filtration and sedimentation) are expected to provide good removal for total phosphorus.
- Some BMP types such as grass swales and buffer strips may export phosphorus.
- At the category level, bioretention did not demonstrate statistically significant concentration reductions, but is expected to reduce loads through volume reduction.

Conclusions Related to LID

- The BMP Database is a steadily growing source of information related to LID practices.
- More LID practice data are needed in Colorado and other semi-arid and mid-western states.
- LID practices can often reduce pollutant concentrations; however, the major benefits are often driven by volume reduction. [*This is a key limitation of numeric effluent limits for stormwater*.]
- While LID practices have many benefits, stormwater managers should have realistic expectations that watershed-scale implementation, particularly in retrofit conditions, is still costly.

Questions?

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