Expected Performance of Stormwater Controls

Robert Pitt, Ph.D., P.E., BCEE
Emeritus Professor of Urban Water Systems
University of Alabama
Tuscaloosa, Alabama 35487

1

Presentation Topics

- Stormwater control performance as reported by the International BMP Database
- Wet detention pond expected performance
- Monitored biofilter performance to meet strict Numeric Effluent Limits as demonstrated at a large industrial site
- Biofilter underdrain monitoring at Kansas City Green Infrastructure demonstration project to quantify performance by particle size
- Conclusions
- Acknowledgements

2

Stormwater Control Performance as Reported by the International BMP Database

3

International BMP Database Overview

- The International BMP Database includes about 600 stormwater control monitoring studies
- Database and analysis available at www.bmpdatabase.org
- Since 2008, a key focus has been to better integrate green infrastructure through:
  - Monitoring Guidance
  - 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

4

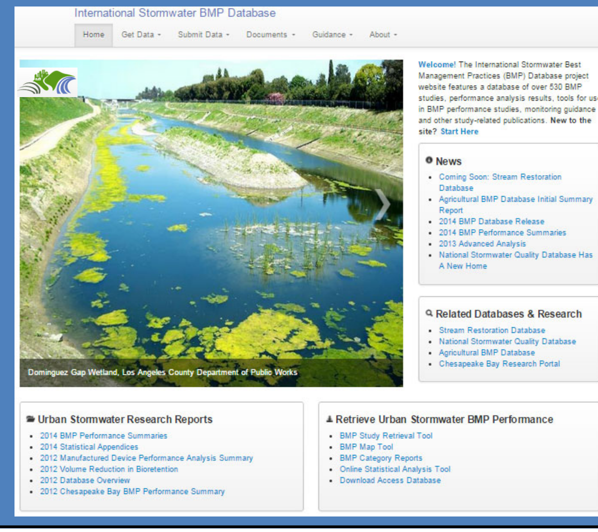
International BMP Database Summary

- 17 general stormwater control categories
- Most recent version posted December 2014
- Most recent categorical analysis July 2012
- 20-30 more study entries entered during 2015-2016
- Over 200 Green Infrastructure stormwater control studies

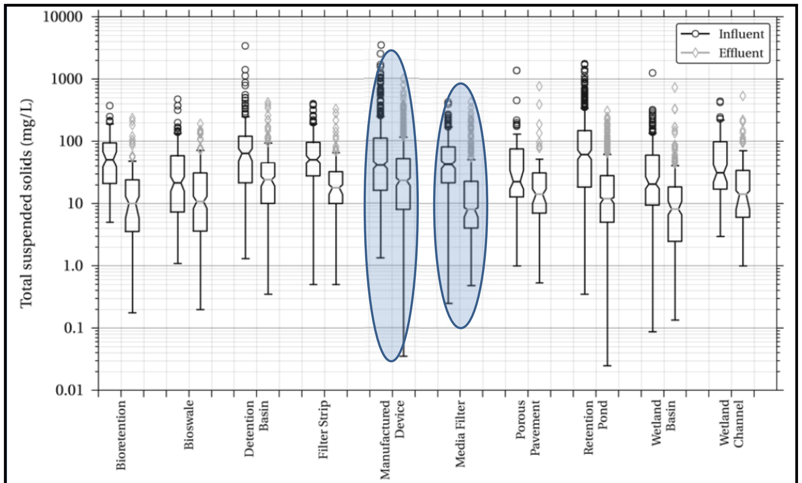
	BMP Category	Count
BR	Bioretention	43
BI	Biofilter - Grass Strip	45
BS	Biofilter-Grass Swale	44
CO	Composite	26
DB	Detention Basin/Vault	43
GR	Green Roof	17
IB	Infiltration Basin	2
LD	LID Site (multiple BMPs)	4
MD	Manufactured Device	104
MF	Media Filter	39
MP	Maintenance Practice	29
OT	Other	6
PP	Porous Pavement/PFC	41
PT	Percolation Trench	13
RP	Retention Pond	77
WB	Wetland Basin	35
WC	Wetland Channel	19
Total BMPs		**587**
CX	Control/Ref. Sites	22

5

Website (www.bmpdatabase.org)

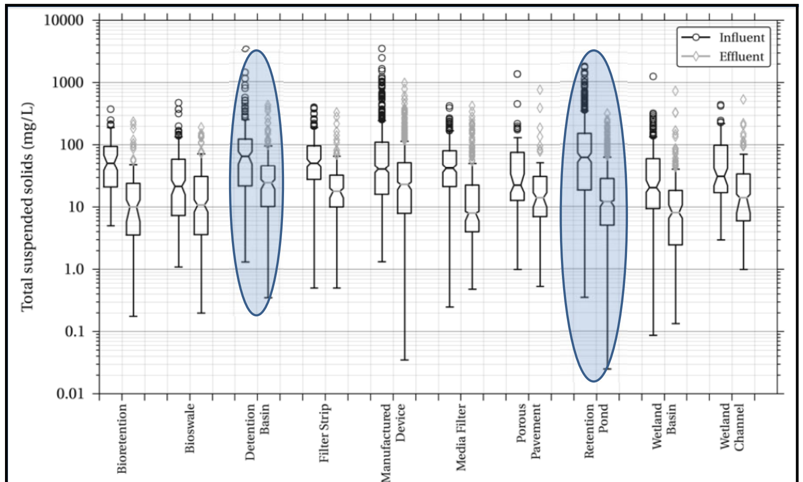


6



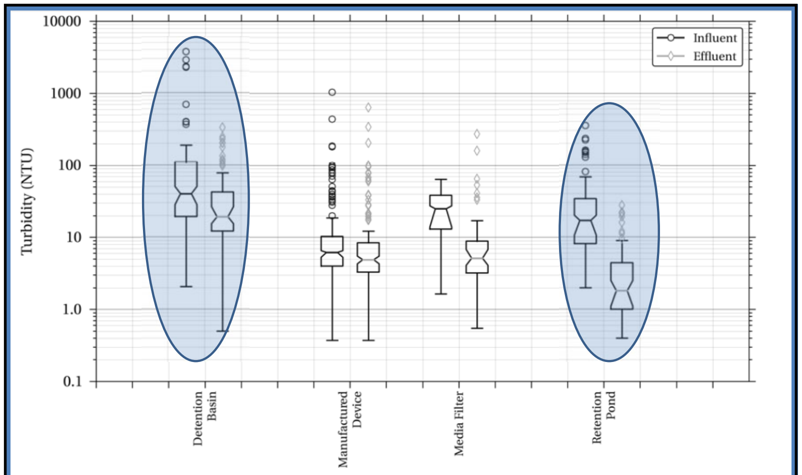
- TSS influent and effluent for different stormwater practices: International Stormwater BMP Database
- Manufactured devices (hydrodynamic devices) and media filters had about the same median influent TSS concentrations, but the media filters had substantially lower effluent TSS concentrations.

7



TSS influent and effluent for different stormwater practices; retention (wet) ponds provided much better effluent quality than detention (dry) ponds, with similar influent quality.

8



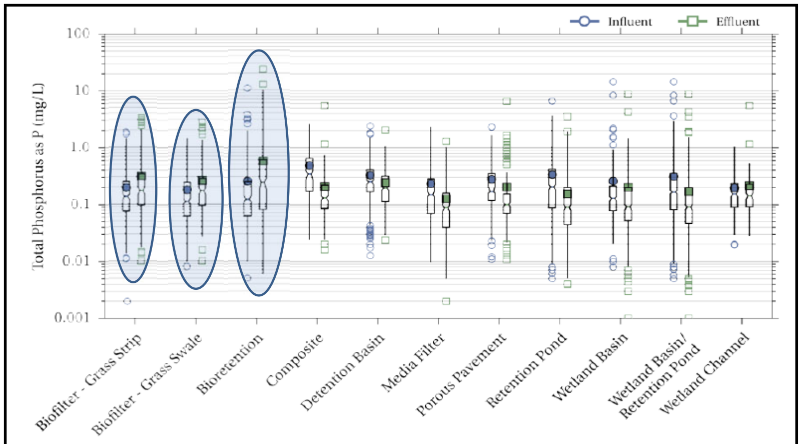
Turbidity influent and effluent for different stormwater practices; again, wet ponds provide much better effluent quality than dry ponds (but also had lower influent turbidity)

9

Why is there such a large difference in performance between a dry and a wet pond?

- Usually due to scour
  - Need at least 3 ft for wet ponds to protect previously captured silt
  - Grass filters may look like dry ponds (and the grass filters can work well, but require lengthy sheetflows with level spreaders, low slopes, good grass stands, no pilot channels, etc.)
  - Terminology issues (in many areas, dry ponds are actually percolation ponds or infiltration ponds with no surface discharges). HIGs

10



Grass filter strips, grass swales, and bioretention total phosphorus effluent concentrations are larger than the influent concentrations due to TP leaching from soils, media, or from fertilizer applications (orthophosphate and dissolved phosphorus show same pattern).

11

The High P Index Lesson (soil and media having high P leach to underdrain flows); Wisconsin DNR now recommending sand media with no compost or soil additions (maybe peat additions)

Bioretention

Phosphorus as P, Total (mg/L)

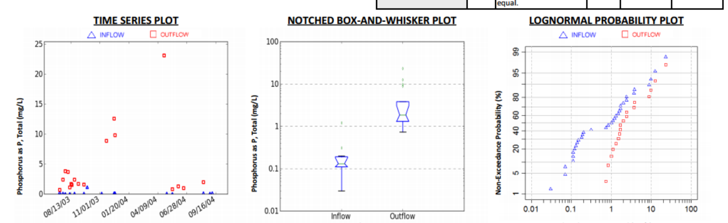
BASIC STATISTICS

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

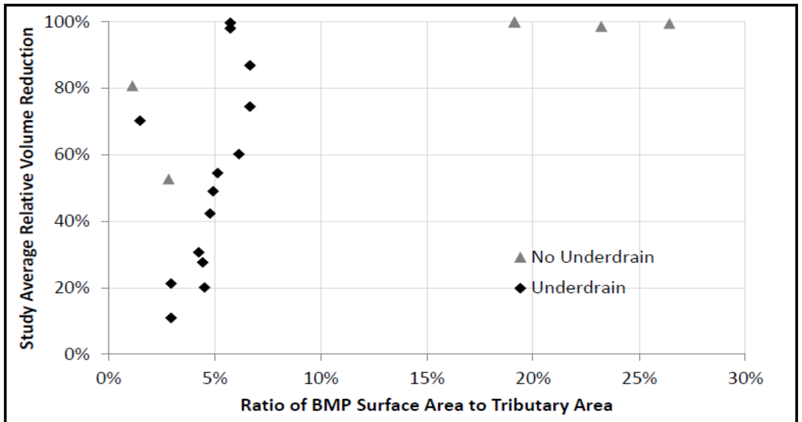
HYPOTHESIS TESTING:

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



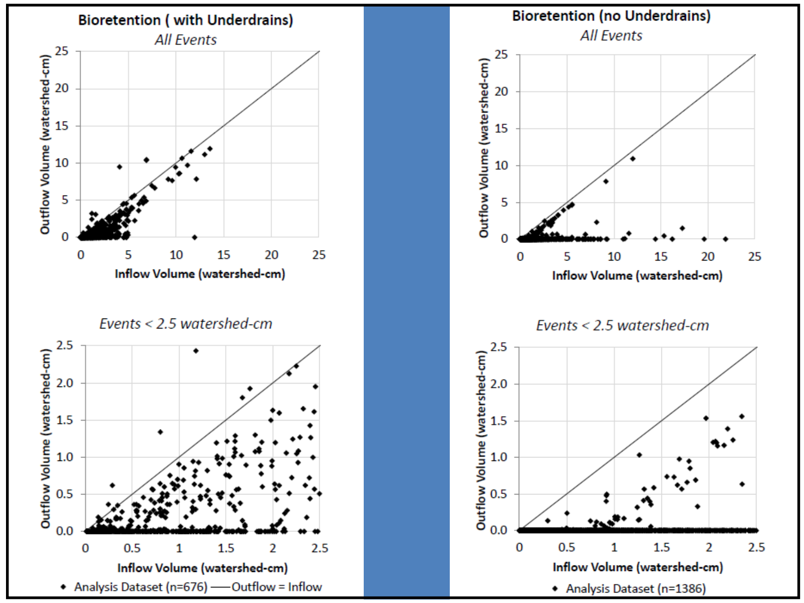
Also see: Hunt et al. (2006): Evaluating Bioretention Hydrology and Nutrient Removal at Three Field Sites in North Carolina
http://psparchives.com/publications/our_work/stormwater/lid/bio_docs/Nutrient%20Removal%20in%20Bioretention-Hunt%20etal%202006.pdf

12



Study average relative percent volume reduction versus the ratio of stormwater control surface area to tributary area (International BMP Database, 2012). "No underdrain" results in larger runoff volume reductions compared to controls with underdrains. "Small" controls provide less runoff volume reductions than relatively larger controls.

13



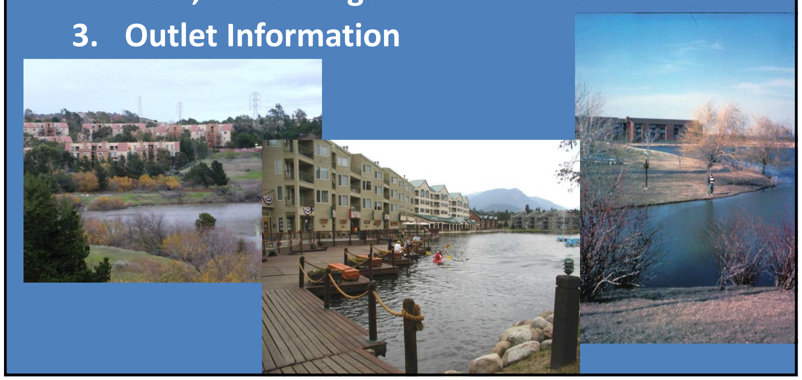
14

Wet Detention Pond Performance

15

Three Categories of Data Needed for Calculating Wet Detention Ponds

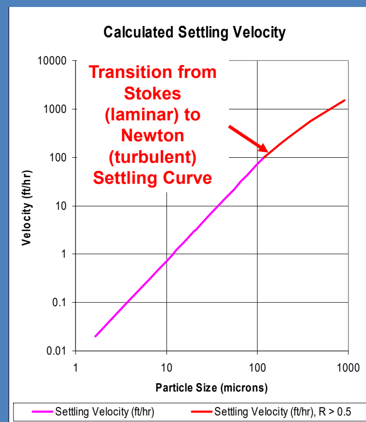
1. **Pond Geometry**
2. **Flow, Initial Stage and Particle Size Data**
3. **Outlet Information**



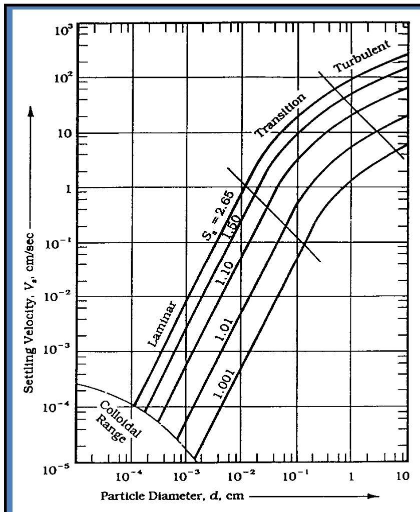
16

Particulate Settling

- Ideal settling can be modeled
  - Using Stokes Law (laminar flow) for smaller particles
  - Settling velocity as a function of Reynolds number and particle size for larger particles under turbulent flow conditions
  - Water temperature and particle density also affect settling rates

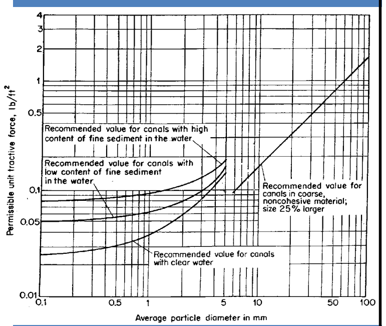


17



Settling velocity of discrete particulates as a function of size and specific gravity (Reynolds and Richards 1996)

Traditional methods can be used to calculate settleability of stormwater particulates and scour of previously settled material.

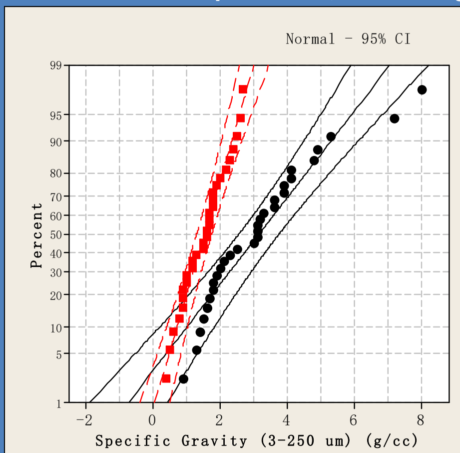


Erodibility of previously settled material based on size and shear stresses (Chow 1959)

18

Changes in Specific Gravity with Sedimentation Treatment at an Industrial Site

Influent: 5th to 95th percentile, 1.3 to 6 g/cc (median: 3.2 g/cc)
Effluent: 5th to 95th percentile, 0.5 to 2.3 g/cc (median: 1.5 g/cc)



Variable
Influent S.G. (3-250 um)
Effluent S.G. (3-250 um)

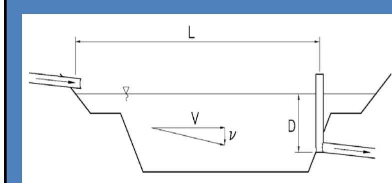
Mean	StDev	N	AD	P
3.167	1.674	30	0.799	0.034
1.533	0.6348	30	0.268	0.661

Preferential removal of higher specific gravity materials results in a shift to lower overall specific gravity of particulates in effluent water (and greater migration distance in receiving water after discharge).

19

Particulate Settling

- **Ideal Settling: Particle path is vector sum of particle velocity through pond and settling (upflow) velocity**



$$\frac{V}{v} = \frac{L}{D} \rightarrow v = \frac{Q_{out}}{A}$$

- L = Pond Length
- D = Outlet Depth
- V = Water Velocity through Pond
- v = Settling Velocity
- Q_{out} = Outflow from Pond
- A = Pond Surface Area

20

Particle Settling Derivation

$$\frac{V}{v} = \frac{L}{D}$$

$$V = \frac{Q}{a}$$

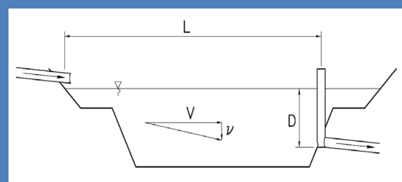
$$V = \frac{Q_{out}}{DW}$$

- L = Pond length
- D = Outlet depth
- V = Water velocity through pond
- v = Settling velocity
- Q_{out} = Outflow from pond
- *a* = Pond cross sectional area
- W = pond width

Substituting this relationship of V into the first equation:

$$\frac{Q_{out}}{DWv} = \frac{L}{D}$$

$$\frac{Q_{out}}{Wv} = L$$



21

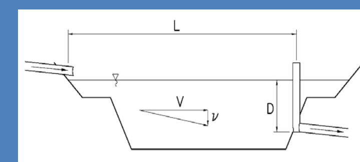
Particle Settling Derivation (cont.)

$$\frac{Q_{out}}{v} = LW$$

$$\frac{Q_{out}}{v} = A$$ where A = Pond Surface Area, LW

$$v = \frac{Q_{out}}{A}$$ where Q_{out} = Pond Outflow Rate (ft^3/s), v = Particle Settling Velocity (ft/s)

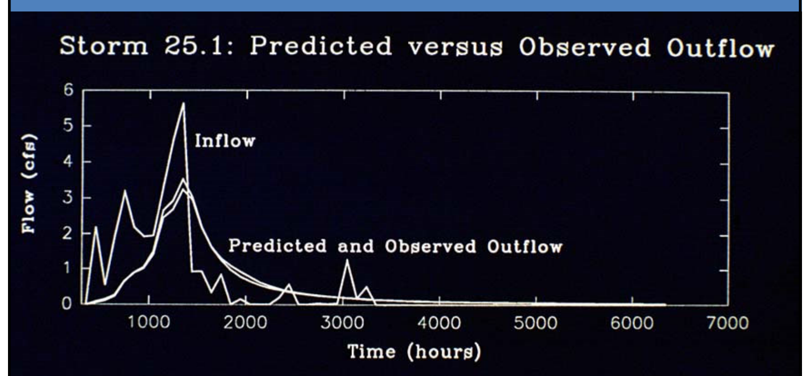
Therefore, particle settling is a function of the pond outflow rate and the pond surface area only. Applied to each flow entering the pond during continuous modeling.



22

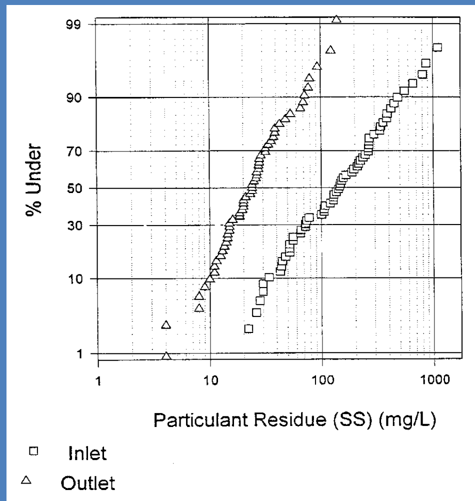
The Monroe St. detention pond in Madison has been monitored by the WI DNR and USGS for many years. The data have been used to verify the wet detention pond routines in WinSLAMM and Detpond (amongst other ponds). Retrofitted to result in 90% SS control, the long-term monitored results were 87%.

23



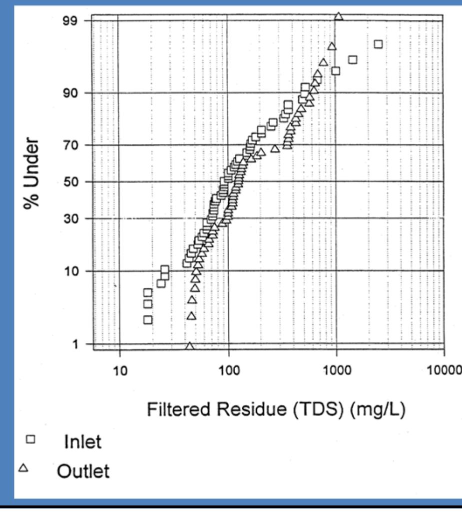
24

Suspended Solids Control at Monroe St. Detention Pond, Madison, WI (USGS and WI DNR data)



25

Total Dissolved Solids Control at Monroe St. Detention Pond, Madison, WI (USGS and WI DNR data)



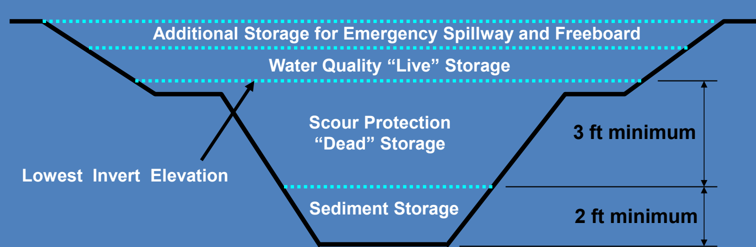
26

Wet Detention Pond Performance Calculation Data Requirements

- Surface area of pond
- Water quality volume (live storage above lowest pond water surface elevation, usually the pond volume between the water quality outlet and the emergency spillway)
- Depth of water over the sediment to prevent scour
- Stage-discharge relationship for all outlets
- Particle size distribution of inflowing particulates
- Hydrograph of influent flows

27

Conceptual Issues – Pond Geometry and Scour



The "dead" storage is needed to prevent scour of previously deposited material and should be at least 3 ft. deep over the sediment. Sediment storage volume is also needed and can be estimated using the program, or should be at least 2 ft. deep.

28

Monitored Biofilter Performance to Meet Strict Numeric Effluent Limits

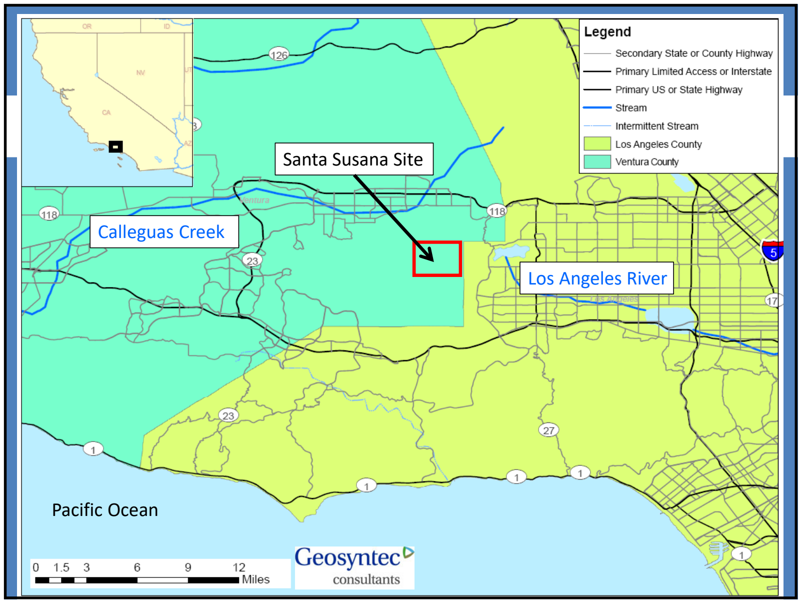
29

Santa Susana Field Laboratory Site Introduction

- 2800-acre former federal government rocket engine testing and energy research facility (1950-1988)
- Owned by the Boeing Company (post-1966) and the U.S. Government
- Activities currently limited to demolition, remediation, and restoration
- Future parkland and open space

Astronaut Buzz Aldrin at SSFL
(Ref: Rocketdyne Archives)

30



31

SSFL Surface Water Expert Panel work products can be found at:
http://www.boeing.com/aboutus/environment/santa_susana/water_quality.html

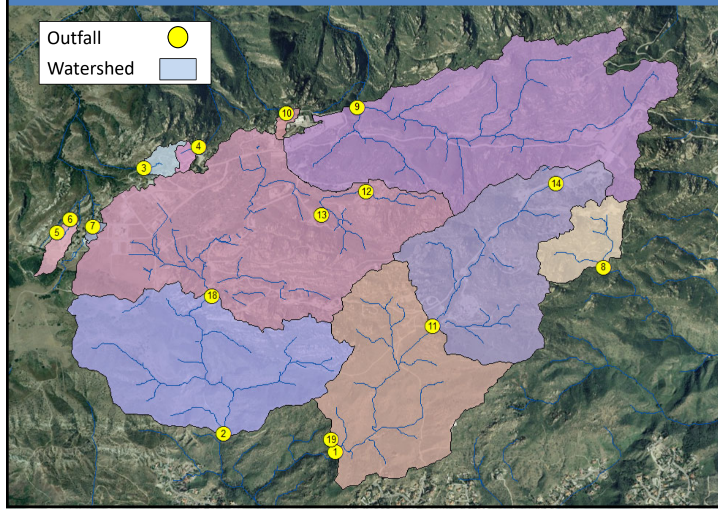
32

Regulation of SSFL Stormwater

- Stormwater discharges are regulated by the Los Angeles Regional Water Quality Control Board (LARWQCB) through an individual NPDES permit, which requires:
  - Composite discharge sampling during storms, and
  - Compliance with very protective Numeric Effluent Limits (NELs)
- NELs for a wide range of constituents, including:
  - Dioxins (TCDD TEQ): 2.8×10^{-8} μg/L
  - Total Lead: 5.2 μg/L
  - Total Copper: 14 μg/L

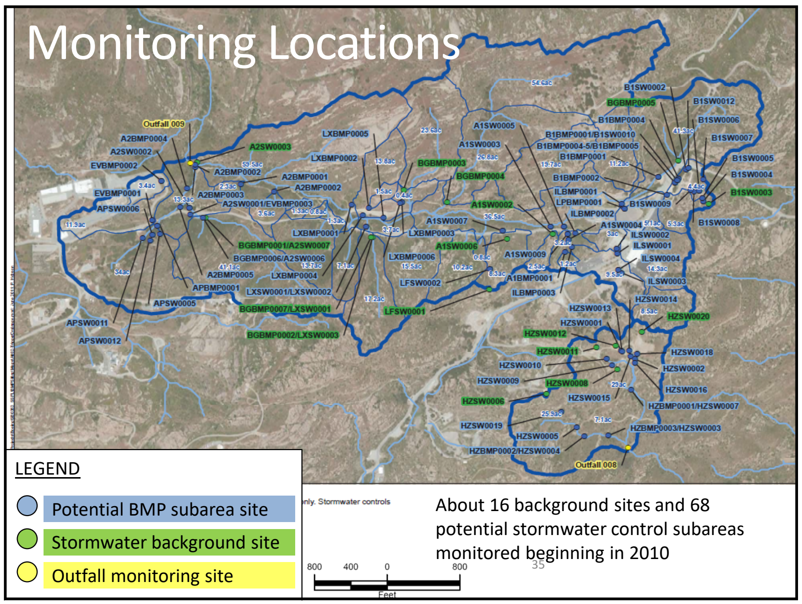
33

Outfalls 008/009



34

Monitoring Locations



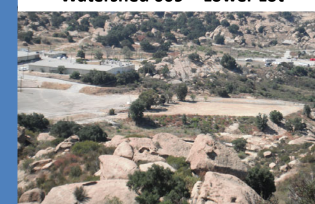
About 16 background sites and 68 potential stormwater control subareas monitored beginning in 2010

35

Outfalls 008/009

Watershed 009 - Northern Drainage

Watershed 009 – Lower Lot



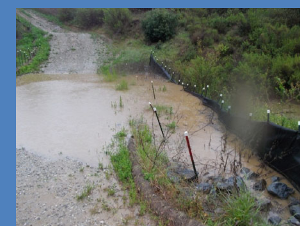
36

Source Controls

- NPDES pollutant sources include impacted surface soils, impervious areas, and natural background soils.
- ISRA, pavement/building removal, and erosion controls address all three sources.

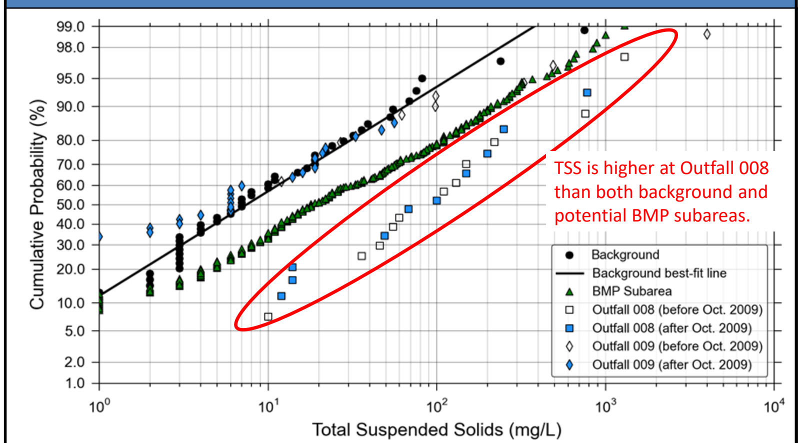
37

Erosion Controls



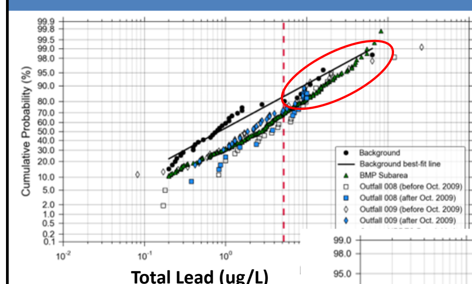
38

Total Suspended Solids

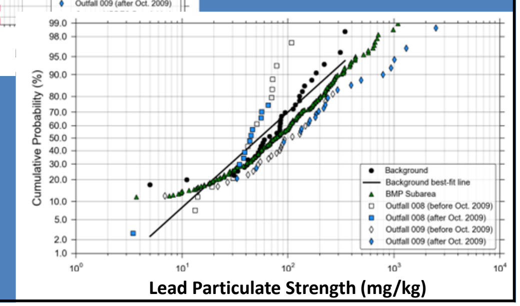


39

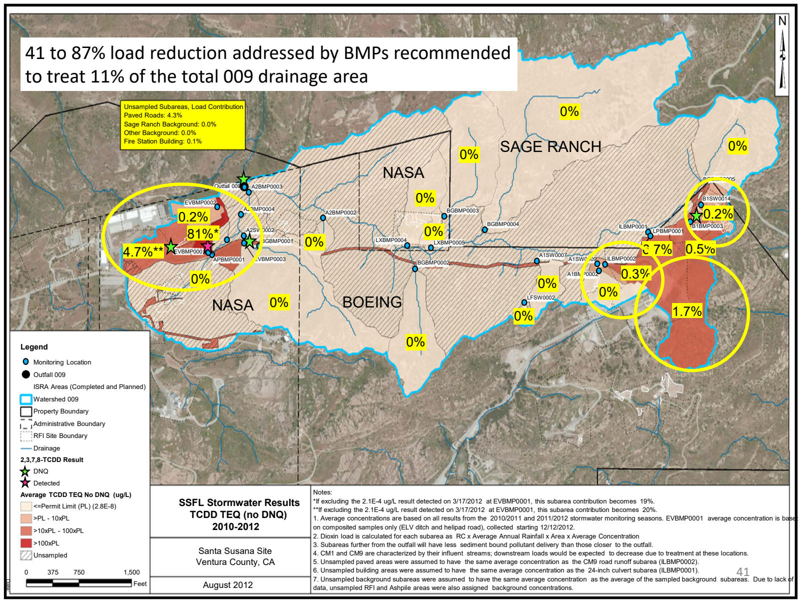
Lead



- Background subareas exceed NPDES Permit Limit
- Outfall results near background



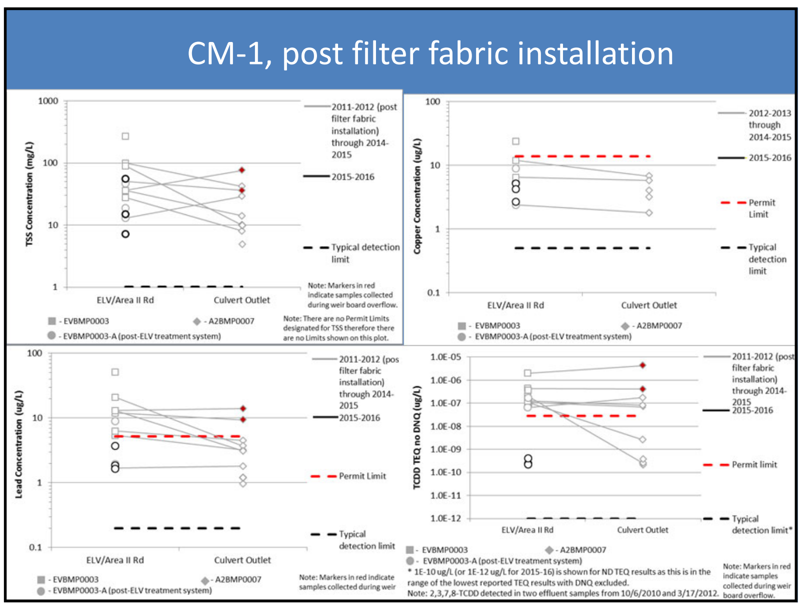
40


41 to 87% load reduction addressed by BMPs recommended to treat 11% of the total 009 drainage area
SAGE RANCH
NASA
BOEING
SSFL Stormwater Results TCDD TEQ (no DNQ) 2010-2012
Santa Susana Site Ventura County, CA
August 2012

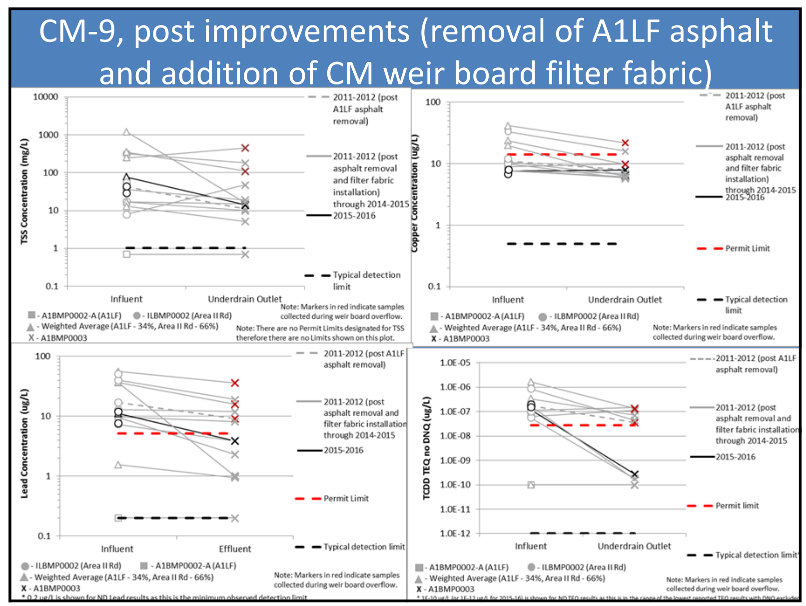
41


Treatment Controls
13 culvert modifications

42

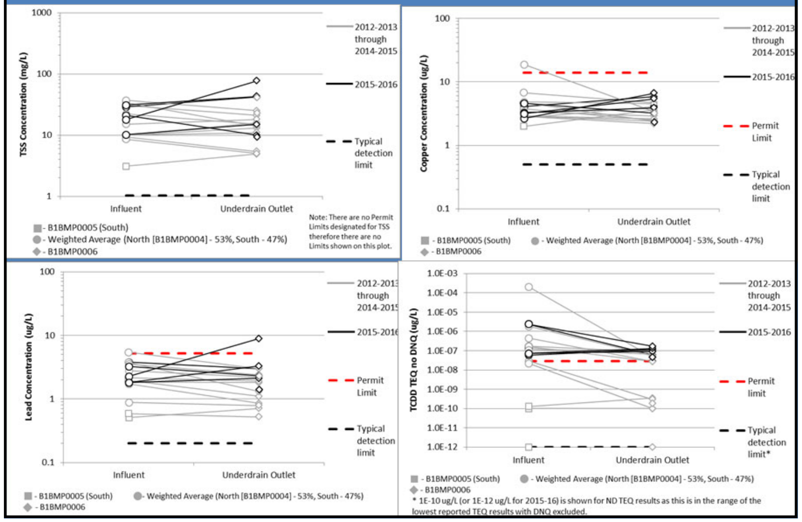

CM-1, post filter fabric installation

43


CM-9, post improvements (removal of A1LF asphalt and addition of CM weir board filter fabric)

44

B-1 Media Filter (CM), post curb cuts



45

Basic Culvert Modifications (typically under-sized biofilters): CM-1, CM-9, and B-1 Statistical Analysis

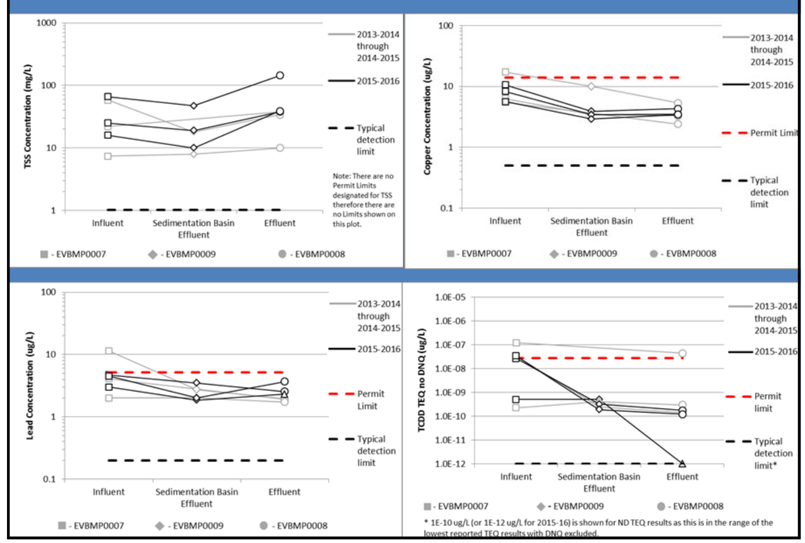
	TSS (mg/L)		Dioxin (µg/L)		Lead (µg/L)	
	Influent	Effluent	Influent	Effluent	Influent	Effluent
Average	82	37	5.2E-06	2.7E-07	7.5	4.4
Total pairs of observations	52		45		52	
Number of influent samples having larger concentrations than effluent samples	31		30		37	
p-value by paired nonparametric sign test	0.059		0.0011		<0.001	
Average percent change	55%		95%		42%	

46

ELV Treatment Train having Sedimentation and Media Filtration (all pumped control)

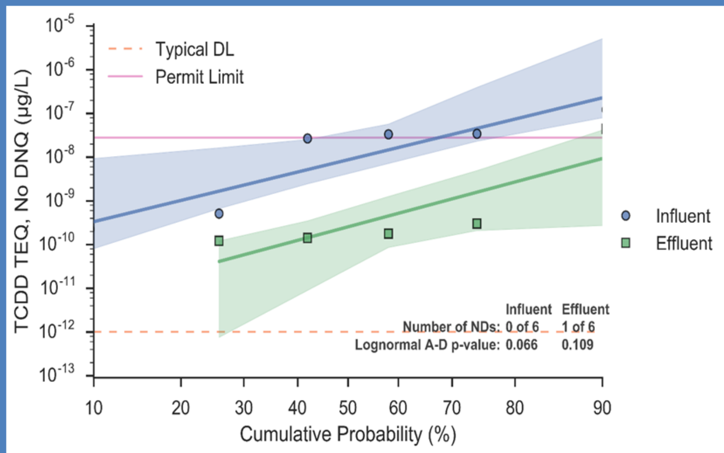
47

ELV Treatment Train



48

Log-normal Probability Plot of Influent and Effluent Dioxins at ELV Stormwater Treatment Train



49

ELV Treatment Train Performance Data – Influent to Final Media Tank Effluent

	TSS (mg/L)		Dioxin (µg/L)		Lead (µg/L)	
	Influent	Effluent	Influent	Effluent	Influent	Effluent
Average	32	51	3.6E-08	7.5E-09	5.0	2.4
Total pairs of observations	6		6		6	
Number of influent samples having larger concentrations than effluent samples	1		5		6	
p-value by paired nonparametric sign test	0.11		0.11		0.016	
Average percent change (minus sign indicating higher effluent results)	-56% (washout of media during initial events)		79%		53%	

P values relatively high due to few data collected so far at this location (new control)

50

Lower Lot Biofilter

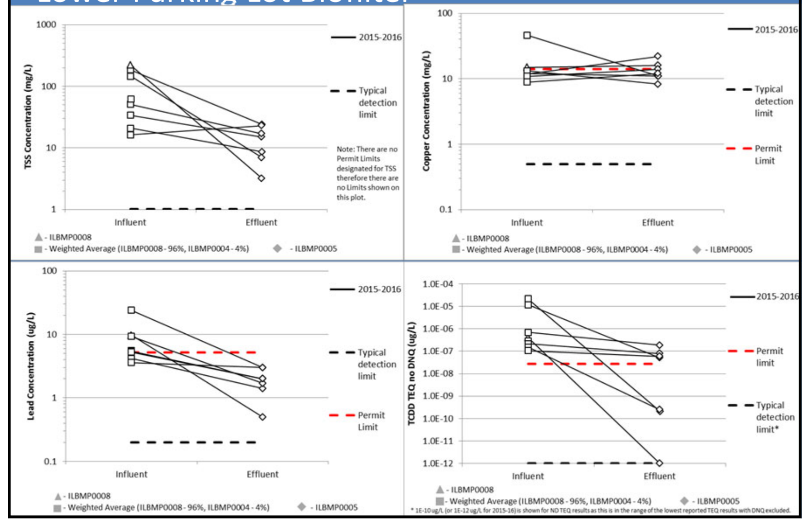
51

52

Detention Bioswale under Construction and after Planting

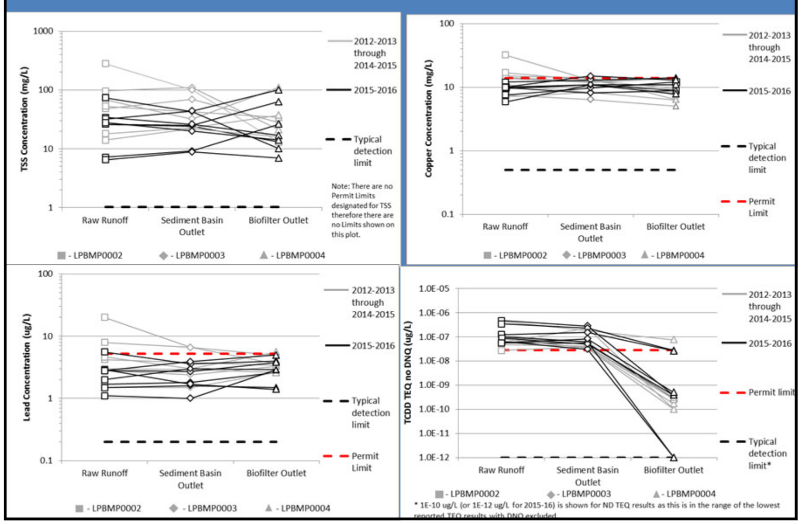
53

Southern Detention Bioswale Pre-Treatment for Lower Parking Lot Biofilter



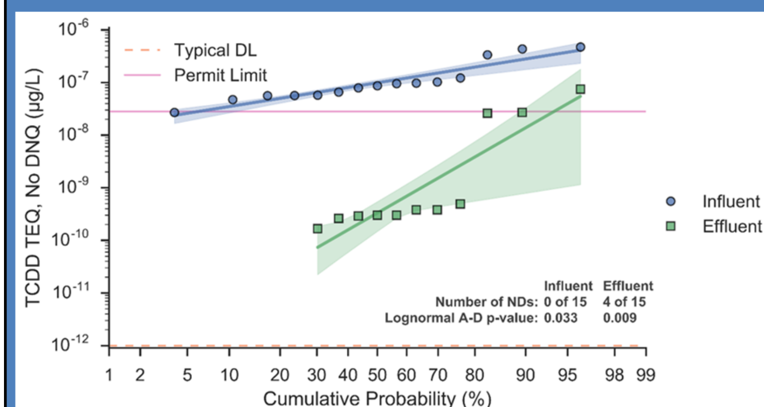
54

Lower Lot Biofilter



55

Log-normal Probability Plot of Dioxins at Lower Lot Biofilter



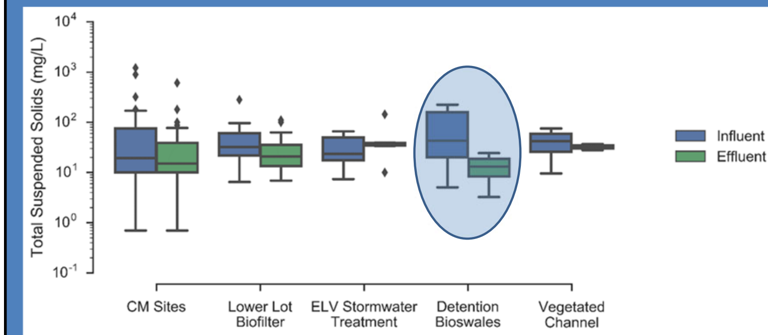
56

Lower Lot Biofilter Performance Data – Influent Runoff to Biofilter Outlet

	TSS (mg/L)		Dioxin (µg/L)		Lead (µg/L)	
	Influent	Effluent	Influent	Effluent	Influent	Effluent
Average	54	34	1.4E-07	8.7E-09	4.3	3.3
Total pairs of observations	15		15		15	
Number of influent samples having larger concentrations than effluent samples	8		15		6	
p-value by paired nonparametric sign test	0.50		<0.001		0.40	
Average percent change	37%		94%		22%	

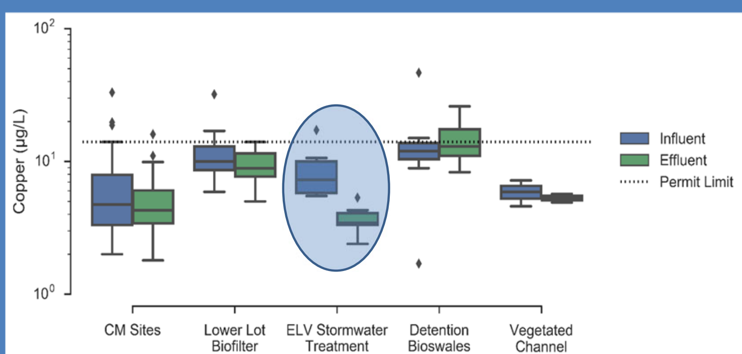
57

SSFL Stormwater Controls Multiple Box Plot for TSS



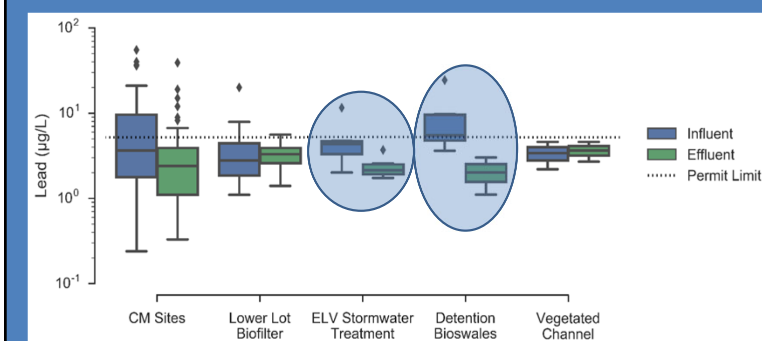
58

SSFL Stormwater Controls Multiple Box Plot for Copper



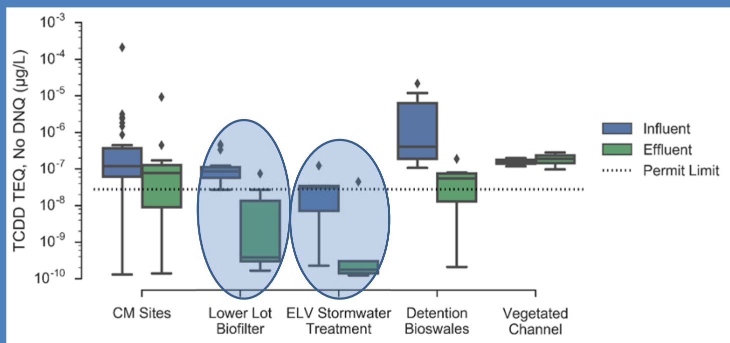
59

SSFL Stormwater Controls Multiple Box Plot for Lead



60

SSFL Stormwater Controls Multiple Box Plot for Dioxins



61

Influent and Effluent Summary as compared to the Outfall 009 Permit Limits (B-1, CM-9, and CM-1), 2009-2016

Parameter	% of Samples Greater than Permit Limits		Average Exceedance Ratio (Result: Permit Limit)	
	Influent	Effluent	Influent	Effluent
Lead	38%	21%	3.2	2.6
TCDD TEQ no DNQ	78%	57%	230	17

62

Influent and Effluent Summary as compared to the Outfall 009 Permit Limits (Lower Lot Biofilter), 2012-2016

Parameter	% of Samples Greater than Permit Limits		Average Exceedance Ratio (Result: Permit Limit)	
	Influent	Effluent	Influent	Effluent
Lead	20%	6.7%	2.1	1.1
TCDD TEQ no DNQ	93%	6.7%	5.4	2.7

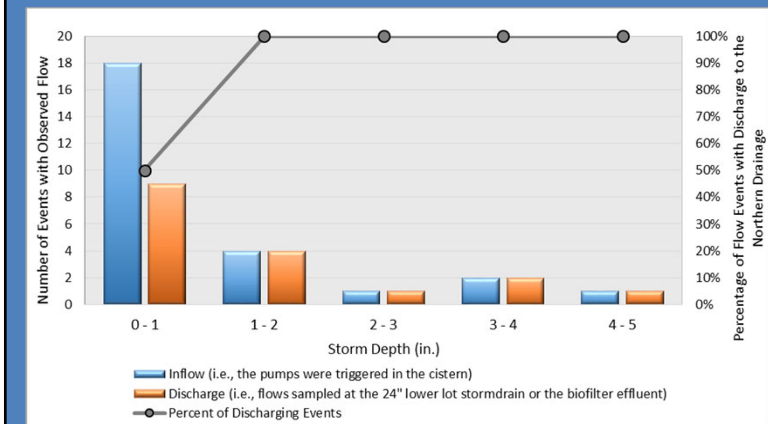
63

Influent and Effluent Summary as compared to the Outfall 009 Permit Limits (ELV Stormwater Treatment Train), 2013-2016

Parameter	% of Samples Greater than Permit Limits		Average Exceedance Ratio (Result: Permit Limit)	
	Influent	Effluent	Influent	Effluent
Lead	17%	0%	2.2	N/A
TCDD TEQ no DNQ	50%	17%	2.3	1.6

64

Binned Presence/Absence of Discharge at the SSFL Biofilter



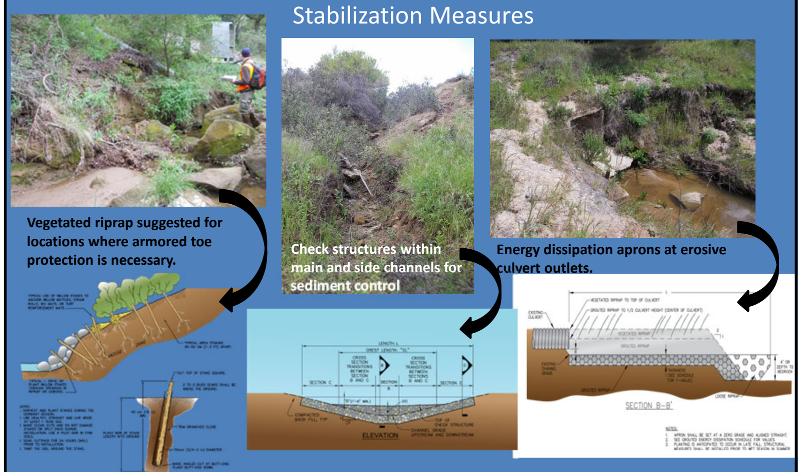
65

Percent of Cumulative Sediment Loading until Clogging

BMP	Cumul-ative TSS load (kg)	Cumul-ative TSS load per media area (kg/m²)	% of "sediment load to the media until initial maintenance is needed"	TSS load per media area in average rainfall year (kg/m²)	Number of average years until media replacement is expected
ELV Treatment Train	44.7	2.2	4.5%	2.7	17
Lower Lot Biofilter	674	3.1	6.2%	2.0	23
B-1	219	12	24%	4.8	7.8
CM-1	387	65	132%	9.3	N/A
CM-9	215	36	74%	8.7	1.5

66

Other Site Controls Included Stream Stabilization: Northern Drainage Restoration, Mitigation and Monitoring Plan: Channel Stabilization Measures



67

Subarea Ranking Methodology to Select Locations for Additional Subarea Stormwater Controls

- Innovative, statistically rigorous approach
- Rank potential subarea monitoring sites based on comparisons of:
  - Stormwater subarea concentrations with NPDES permit limits
  - Stormwater subarea particulate strengths with stormwater background particulate strengths
- Monitoring locations were scored based on number and percent of samples above NPDES permit limits and/or background
- Locations then ranked based on scores, and top locations identified
- Process to be repeated annually

68

Example:

Site A: n = 10, m = 7 → $Weight_A$ = 0.83

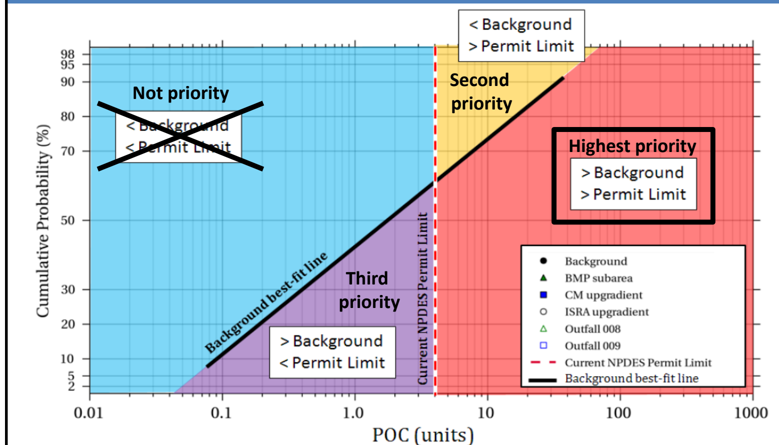
Site B: n = 14, m = 2 → $Weight_B$ = 0.01

Based on weight alone, Site A would be prioritized over Site B.

Total Number of Observations (n)	Total Number of Critical Values in Data Set (m)													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	50													
2	50	[illegible]												
3	50	[illegible]	87											
4	31	[illegible]	69	94										
5	19	[illegible]	50	81	97									
6	11	[illegible]	50	66	89	98								
7	6	[illegible]	50	50	77	94	[illegible]							
8	4	[illegible]	36	50	64	86	[illegible]	99						
9	2	[illegible]	25	50	50	75	[illegible]	98	99					
10	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	83	95	99	99				
11	1	[illegible]	11	27	50	50	73	89	97	99	99			
12	0	[illegible]	7	19	39	50	63	81	93	98	99	99		
13	0	[illegible]	5	13	29	50	50	71	87	95	99	99	99	
14	[illegible]	1	3	9	21	40	50	61	79	91	97	99	99	99
15	0	0	2	6	15	30	50	50	70	85	94	98	99	99

69

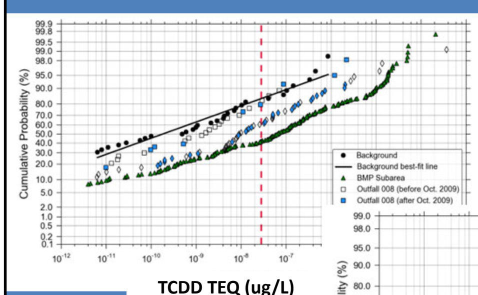
Basic Approach (example)

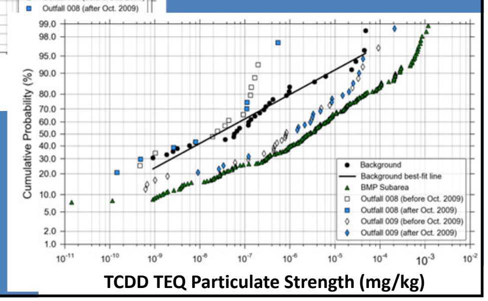


70

Dioxin (TCDD TEQ)

- Background subareas exceed NPDES Permit Limit
- Subareas greater than Outfalls
- TSS/erosion is not always the issue





71

Example Ranking Results

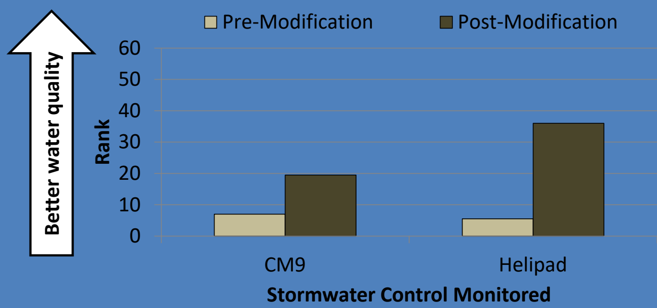
Rank from Average Weights	Potential BMP Subarea (Co-location(s))	Watershed	Description	Approx. Upstream DA (ac)	Events Sampled	Multi-constituent Score	Rank from Max Metal Weight	Rank from Max Dioxin Weight	Rank from TSS Weight
1	**EVBMP0003 (A2SW0001)[ab]**	Outfall 009	ELV road runoff/CM-1 upstream west	11.8	14	0.94	1	1	32
2	**B1BMP0004 (B1SW0015)[a]**	Outfall 009	B-1 media filter inlet north	3.7	2	0.72	9	5	74
3	**ILBMP0001[b]**	Outfall 009	Lower parking lot 24" stormdrain	23	10	0.68	14	4	39.5
4	**EVBMP0001-A[b]**	Outfall 009	ELV culvert inlet (helipad road and ELV ditch, composite)	2.5	5	0.67	16.5	3	15
5.5	**EVBMP0002[b]**	Outfall 009	Helipad (pre-sandbag berms)	4.1	6	0.66	15	6	31
5.5	**ILBMP0002[a]**	Outfall 009	Road runoff to CM-9	2.5	7	0.66	3	12	15
7	**A1SW0009-A**	Outfall 009	CM-9 downstream-underdrain outlet (post-building 1324 parking lot asphalt removal, pre-filter fabric over weir boards)	16.4	1	0.63	2	19.5	74
8	**APBMP0001**	Outfall 009	Ashpile culvert inlet / road runoff	34	2	0.60	4	19.5	74
9	**LPBMP0001-A[b]**	Outfall 009	Lower Parking Lot sheetflow (post-gravel bag berms)	5.1	6	0.52	30	2	27
12.5	LPBMP0001[b]	Outfall 009	Lower Parking Lot sheetflow (pre-gravel bag berms)	5.1	2	0.50	9	19.5	15
15.5	**A2SW0002-A**	Outfall 009	CM1 effluent (post-filter fabric over weir boards)	52.8	4	0.43	18.5	19.5	28.5
15.5	A1SW0009-B	Outfall 009	CM-9 downstream-underdrain outlet (post-filter fabric over weir boards, post-building 1324 parking lot asphalt removal)	16.4	4	0.43	18.5	19.5	15
17	**B1BMP0003 (B1BMP0002)**	Outfall 009	B-1 parking lot / road runoff to culvert inlet	5.2	12	0.43	38	7	33
27	B1SW0014-B	Outfall 009	B-1 media filter effluent (post-media filter reconstruction)	4.7	4	0.27	32.5	19.5	74
28	LXBMP0004[b]	Outfall 009	LOX southwest downstream of sandbag berm	10.6	5	0.26	9	40.5	1
34	EVBMP0001[b]	Outfall 009	ELV culvert inlet (helipad road gutter)	1.8	3	0.11	25	31.5	15
36	EVBMP0002-A[ab]	Outfall 009	Helipad (post-sandbag berms)	4.1	5	0.09	40	29.5	74

Notes
1) Potential BMP subareas sorted by multi-constituent score, computed as described in Section 5.
2) ([a]) These potential BMP subarea monitoring subareas are upstream of existing stormwater quality treatment controls.
3) ([b])These potential BMP subarea monitoring subareas have new planned (i.e., designed and ready for construction) stormwater quality treatment controls.
4) (**) NPDES outfalls are included for comparison and method testing purposes only, stormwater controls are not being contemplated at these locations.
5) The rounding of weights may account for similar weights being ranked differently
6) Approximate drainage areas based on the cumulative drainage area of the SWMM catchment in which the monitoring location is located (Geosyntec, 2011). At locations where the monitoring point is upstream of the catchment outfall a "<" sign is used.
7) Bolded locations indicate that both the NPDES permit limit and 95th percentile background particulate strength threshold were exceeded for any one COC

72

Water Quality Improvements

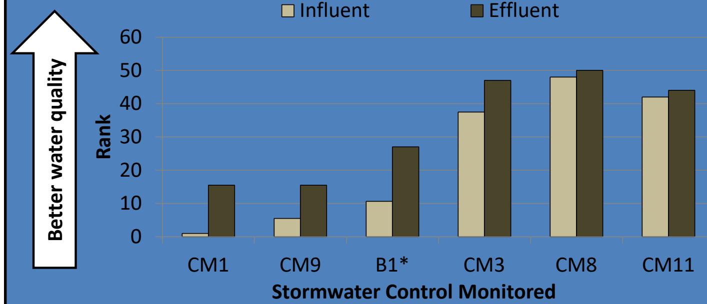
- Demonstrated by ranks, pre- and post-BMP modification (filter fabric added to CM weir boards; helipad sand bag berm constructed)
- Limited to sites with at least 2 samples



73

Water Quality Improvements

- Demonstrated by ranks, comparing influent and effluent.
- Limited to sites with at least 2 samples.

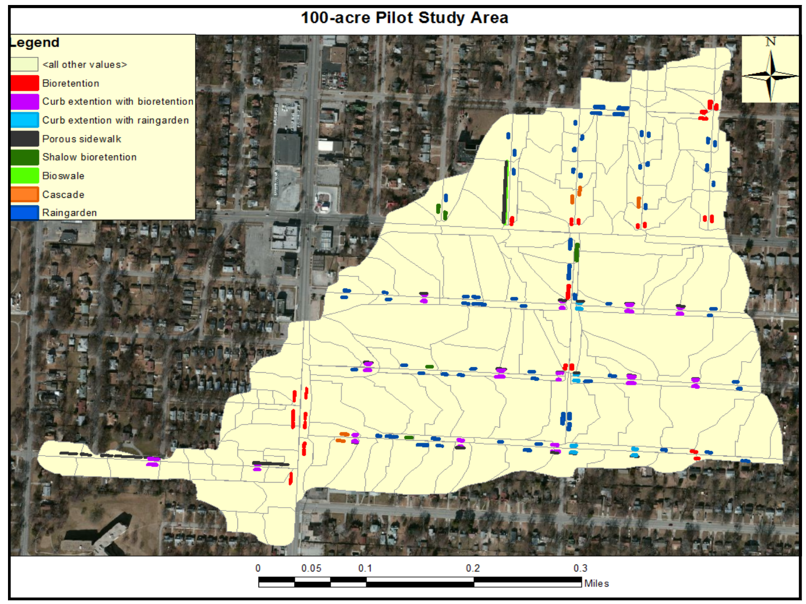


*Average of impacted B1 influent streams

74

Biofilter Underdrain Monitoring at Kansas City Green Infrastructure Demonstration Project to Quantify Performance by Particle Size

75

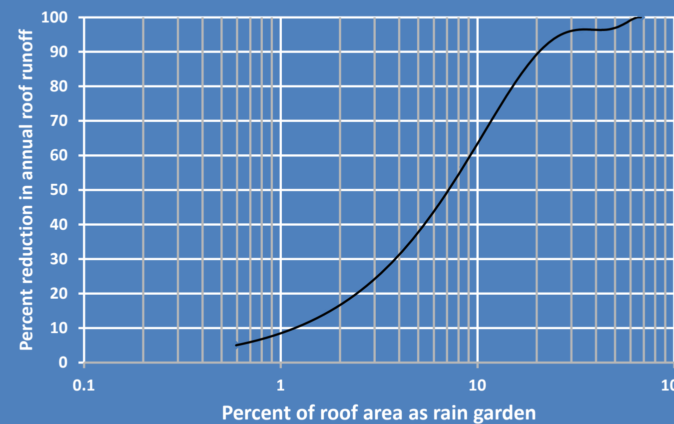


76

1324 76th St. monitoring location, biofilter and adjacent porous concrete sidewalk

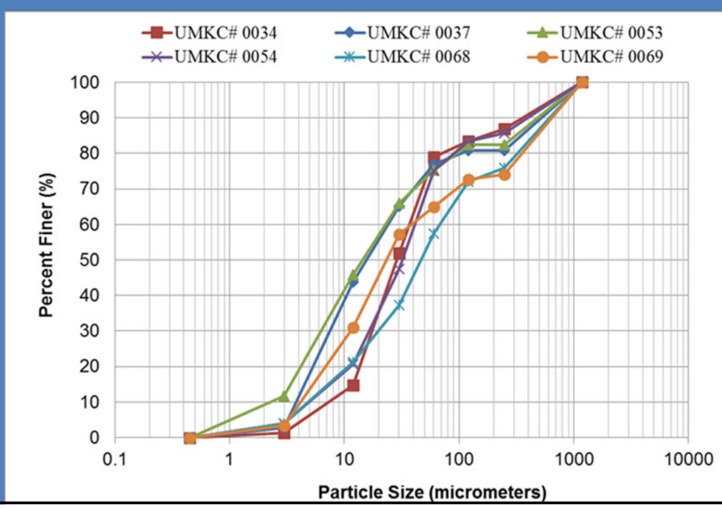
77

Percentage Reductions of Annual Runoff Flows with Rain Gardens

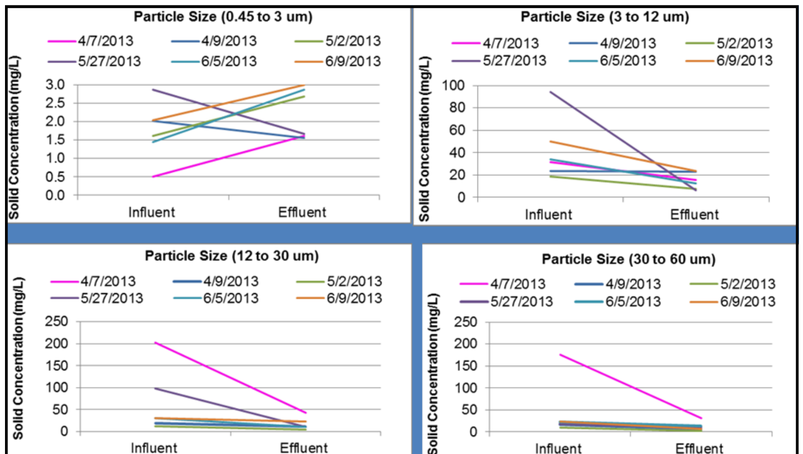


78

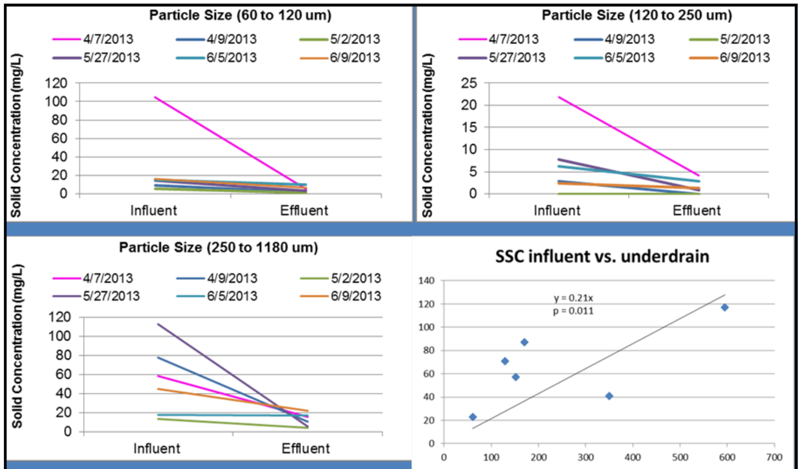
Influent Particle Size Distribution (PSD) for Six Events (out of 79) that had Underdrain Flows (median size ranged from 13 to about 50 µm)



79



80



81

Conclusions

- The International BMP Database contains an excellent summary of monitored performance of many categories of stormwater controls.
- Robust statistical stormwater control ranking methodology applicable to other sites!
- NEL compliance is a significant challenge with complications
  - Ubiquitous background sources (atmospheric inventory and soils)
  - Multiple landowners (NASA and Boeing)
  - Multiple jurisdictions and agency involvement (often hinders progress)
  - Unknown/variable performance of passive treatment systems
  - Implementability at point of compliance

82

- Bioretention with underdrains hinders infiltration potential, but may be necessary to prevent extensive ponding of water in areas having health risks associated with mosquitoes.
- Sedimentation is a robust stormwater control.
- Complementary controls and treatment trains provide the best overall performance at complex sites having numerous and challenging numeric discharge limits.
- Performance of stormwater controls is dependent on treatment flow rate, influent concentrations, and particle size distributions.

83

Acknowledgements

- This presentation is a summary of several stormwater research and implementation projects. Primary sponsors included The Boeing Co. and the US EPA.
- Many colleagues assisted in these projects, especially Geosyntec Consultants, Inc., Wright Water Engineers, and the SSFL surface water expert panel.

84