

# Assessment of Cold Weather Highway Runoff Water Quality and BMP Performance

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## Overview

- Re-assessment of the FHWA National Highway Runoff Database
  - Brief overview of project
  - Cold weather highway runoff water quality
- Assessment of the National BMP Database for Cold Climate and Snowmelt Events
  - Brief overview of National BMP Database
  - Cold Climate BMP Studies and Results



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**POLLUTANT LOADINGS  
AND IMPACTS FROM  
HIGHWAY STORMWATER RUNOFF  
Volume III: Analytical Investigation  
And Research Report**

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Research, Development, and Technology  
Turner-Fairbank Highway Research Center  
6300 Georgetown Pike  
McLean, Virginia 22101-2296

## Research Report

### Purpose of FHWA Study

- To consolidate and analyze highway runoff water quality data collected from sites around the United State.
- Sites were monitored either via FHWA sponsored monitoring or via state transportation agencies

## Steps in the FHWA Project

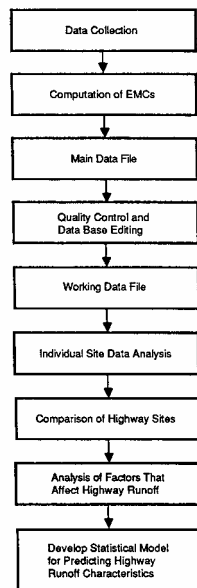


Figure 1. Key steps taken to evaluate highway runoff.

## Location of Highway Runoff Study Sites

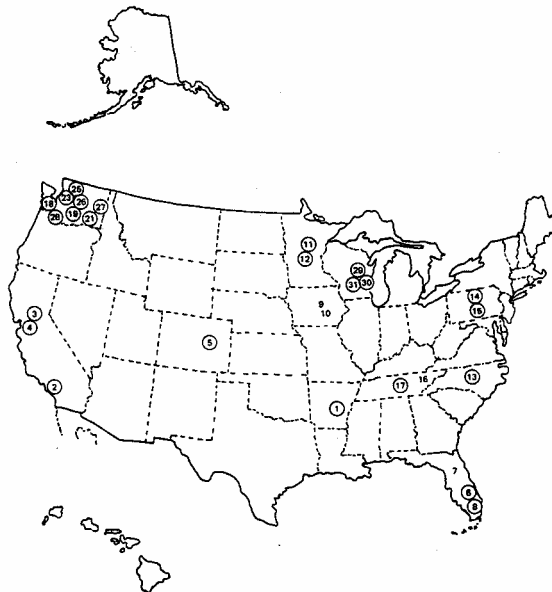


Figure 5. Location of highway runoff study sites.

- Total of 31 Sites in 11 States
- 993 separate storm events monitored
- Studies all completed between 1977 and 1983

# Physical Characteristics of Highway Study Sites

Average Daily Traffic	4 to 200 thousand vehicles per day
Number of Traffic Lanes	1 to 10
Percent Imperviousness	27 to 100
Average Annual Rainfall	7.5 to 97 inches
Section Types	Cut, fill, at grade, and bridges
Road Surface Types	8 site with asphalt, 16 with concrete
Surrounding Land Uses	16 urban-residential, commercial, suburban; 8 non-urban – forest, agriculture, desert, undeveloped

Monitored from 2 to 139 storm events at each site

## Physical characteristics of highway study sites

Table 4. Physical characteristics of highway study sites.

SITE NO.	STATE CODE		AVG DAILY TRAFFIC		NUMBER of TRAFFIC LANES		SECT	SURF	CURB	LAND
			1000 VPD	total	rural	total	monitored	TYPE	TYPE	USE
						(B)	(C)		(A)	
1	AR-1	LITTLE ROCK I-30	42	42	4	4	BF	ASP	NO	U-3
2	CA-1	LOS ANGELES I-405	200	200	8	8	F	CON	YES	U-2
3	CA-2	SACRAMENTO HWY 50	86	43	8	4	G	CON	YES	U-4
4	CA-3	WALNUT CREEK I-680	70	70	6	6	H	CON	YES	U-3
5	CO-1	DENVER I-25	149	149	10	10	G	ASP	YES	U-4
6	FL-1	BROWARD CO HWY 834	20	20	6	6	G	ASP	BOTH	U-2
8	FL-2	MIAMI I-95	140	70	6	3	B	CON	YES	U-1
11	MN-1	MINNEAPOLIS I-94	80	80	10	10	C	CON	YES	U-2
12	MN-2	ST PAUL I-94	65	65	6	6	CF	CON	YES	U-2
13	NC-1	EFLAND I-85	26	26	4	3	G	ASP	NO	N-1
14	PA-1	HARRISBURG I-81 (Ph.1)	24	24	6	6	G	CON	NO	U-4
15	PA-2	HARRISBURG I-81 (Ph.2)	56	28	4	2	G	CON	NO	U-4
17	TN-1	NASHVILLE I-40	88	88	6	6	CG	CON	YES	U-1
18	WA-5	MONTESANO SR-12 (5)	7.3	7.3	2	2	G	ASP	YES	N-4
19	WA-6	PASCO SR-12 (6)	4.0	2.0	4	2	C	CON	YES	N-5
21	WA-9	PULLMAN SR-270E (9)	5.0	2.5	2	1	G	ASP	YES	N-4
23	WA-1	SEATTLE I-5 (1)	106	53	8	4	G	CON	YES	U-3
25	WA-2	SEATTLE SR-520 (2)	84	42	4	2	B	CON	YES	U-1
26	WA-4	SNOQ_PASS I-90 (4)	15	7.7	6	3	G	CON	YES	N-2
27	WA-7	SPOKANE I-90 (7)	35	17	6	3	B	CON	YES	U-1
28	WA-3	VANCOUVER I-205 (3)	17	8.6	6	3	G	CON	YES	U-4
29	WI-1	MILWAUKEE HWY 45	85	85	6	6	CG	CON	YES	U-3
30	WI-2	MILWAUKEE I-794	53	53	8	8	B	CON	YES	U-1
31	WI-3	MILWAUKEE I-94	116	116	8	8	H	ASP	YES	U-3

**NOTES:**

(A) land use surrounding area - U = URBAN 1 = undefined, 2 = commercial/residential, 3 = residential, 4 = NON-URBAN 1 = undefined rural, 2 = forest, 3 = undeveloped, 4 = agricultural,  
 (B) section type - C = cut, F = fill, G = at grade, B = bridge  
 (C) road surface type - CON = concrete, ASP = asphalt

# The World is Lognormal After All

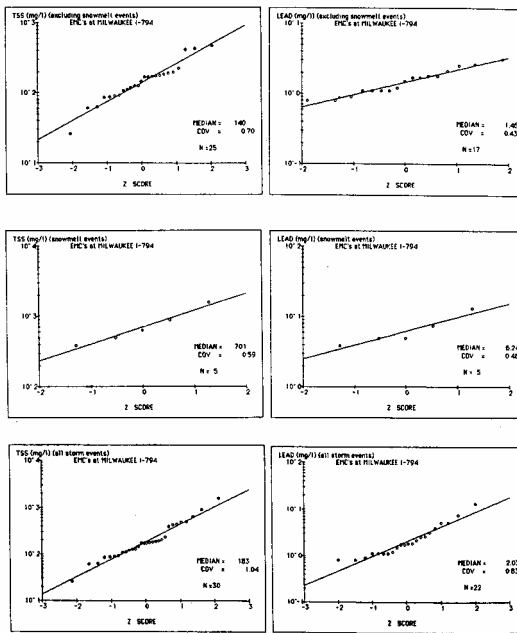
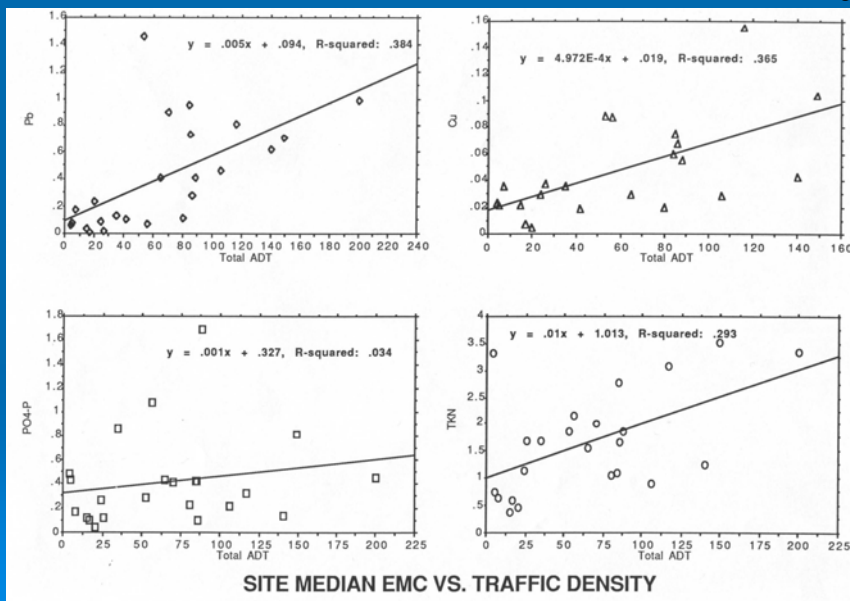


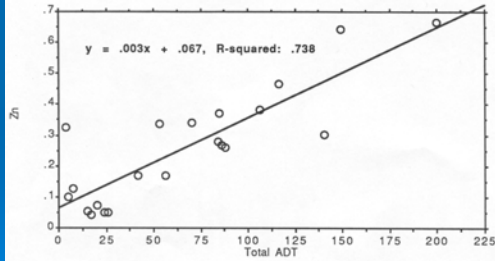
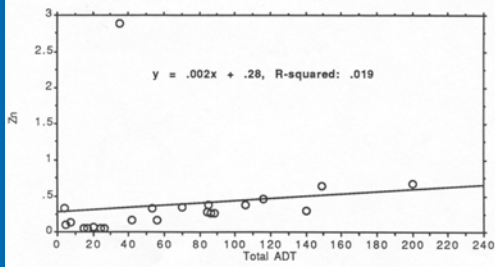
Figure 4. Probability distribution of pollutant EMCs.

## Site Median EMC vs. Traffic Density



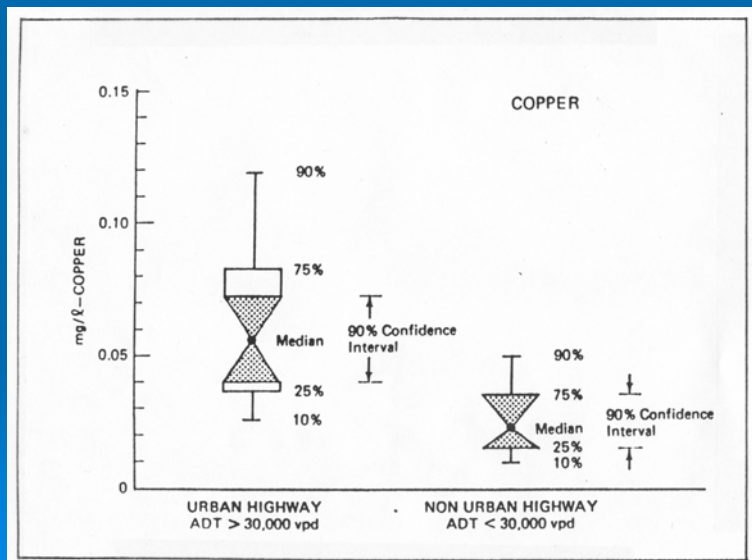
SITE MEDIAN EMC VS. TRAFFIC DENSITY

# Site Median Zinc EMC vs. Traffic Density

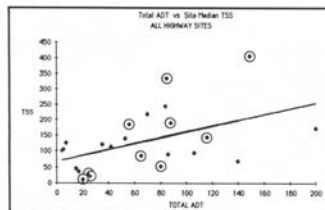
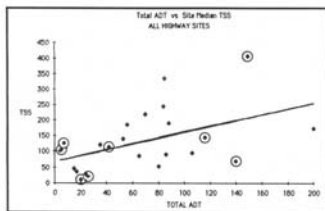
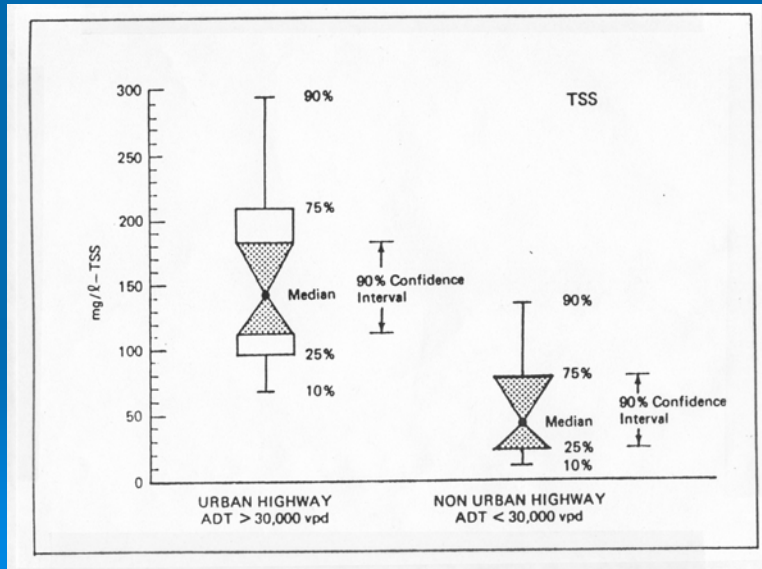


SITE MEDIAN ZINC EMC VS. TRAFFIC DENSITY

# Copper Concentrations vs. ADT



# TSS EMC's Vs. ADT



INFLUENCE OF OTHER SITE FACTORS

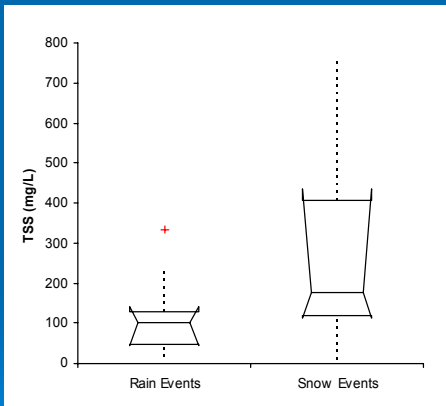
## Effects of Other Factors



# Ratio of Snowmelt to Rain Events – Non-Urban Sites

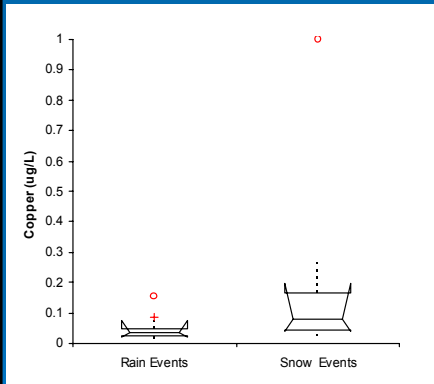
NONURBAN SITES															
SITE	CODE	RAIN	DUR.	RUNOFF	Rv	SS	VSS	TOC	COD	NO2+3	TKN	PO4-P	Cu	Pb	Zn
13	NC-1	0.59		0.61	1.63	0.70	0.83	0.67	0.39	1.26	4.76	1.13	0.61	1.82	2.54
14	PA-1	0.87	0.45	0.45	1.20	4.08	2.50	2.00	1.35	1.79	1.16	1.71	2.14	1.81	3.23
19	WA-6	1.00	0.49	0.84	0.90	1.53	1.92	2.60	1.52	1.04	0.42	1.40		2.97	0.80
21	WA-9	0.56	1.47	0.43	1.41	4.47	2.19		2.85			3.37	1.54	2.91	3.13
26	WA-4	1.61	0.77	1.91	1.18	2.88	2.56	4.00	1.37	0.70	1.11	2.16	0.92	2.58	1.59
28	WA-3	0.81	0.60	0.83	1.05	3.35	2.78		1.41	0.80	0.47	2.65	2.94		2.15
	Mean	0.91	0.77	0.85	1.23	3.08	2.20	2.58	1.58	1.13	1.67	2.10	1.72	2.43	2.33
	Median	0.85	0.68	0.73	1.21	2.39	1.99	1.93	1.28	1.06	1.04	1.93	1.40	2.36	2.03
	COV	0.40	0.50	0.59	0.21	0.81	0.47	0.89	0.72	0.39	1.25	0.42	0.70	0.25	0.56

# TSS Box Plots of Rain and Snow Events



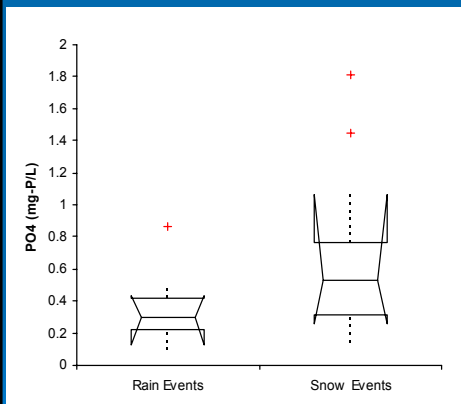
Rank-Sum Test - A non-parametric hypothesis test on the difference between the medians of two independent groups (if $p > 0.05$ , medians are not statistically different) - analyzed with: Analyse-It, General 1.68				
Test	<b>Mann-Whitney test</b>			
Alternative hypothesis	SS: Rain Events $\neq$ Snow Events			
n	30			
SS	n	Rank sum	Mean rank	U
Rain Events	15	171.0	11.40	174.0
Snow Events	15	294.0	19.60	51.0
Difference between medians	-96.287			
95.5% CI	-270.973 to -17.944 (exact)			
Mann-Whitney U statistic	174			
2-tailed p	0.0099 (exact)			

# Copper Box Plots of Rain and Snow Events



Test	Mann-Whitney test			
Alternative hypothesis	Cu: Rain Events $\neq$ Snow Events			
n	29	(cases excluded: 1 due to missing values)		
	Cu	n	Rank sum	Mean rank
	Rain Events	14	156.0	11.14
	Snow Events	15	279.0	18.60
				U
				159.0
				51.0
Difference between medians	-0.040			
95.4% CI	-0.107 to -0.006 (exact)			
Mann-Whitney U statistic	159			
2-tailed p	0.0178 (exact tables used, 7% ties)			

# Total Phosphorus – Rain events and snow events



Test	Mann-Whitney test			
Alternative hypothesis	PO4-P: Rain Events $\neq$ Snow Events			
Performed by	Marc Leisenring			
n	28			
	PO4-P	n	Rank sum	Mean rank
	Rain Events	14	152.0	10.86
	Snow Events	14	254.0	18.14
				U
				149.0
				47.0
Difference between medians	-0.236			
95.0% CI	-0.514 to -0.030 (exact)			
Mann-Whitney U statistic	149			
2-tailed p	0.0186 (exact)			

# Summary

- FHWA National Highway Runoff Database is a source of Snow wash-off data
- Snow wash-off data shows that these events are statistically different than rain events in water quality for most constituents
- Although data is old, it may still be very useful for planning and assessments
  - Most pollutants likely have not changed much
  - Recommend that lead is not accurate any more (elimination of leaded fuels)



**WWE**

 **GEOSYNTEC CONSULTANTS**

**ASCE**

American Society of Civil Engineers  
Urban Water Resources Research Council

 **EPA**  
United States  
Environmental Protection  
Agency

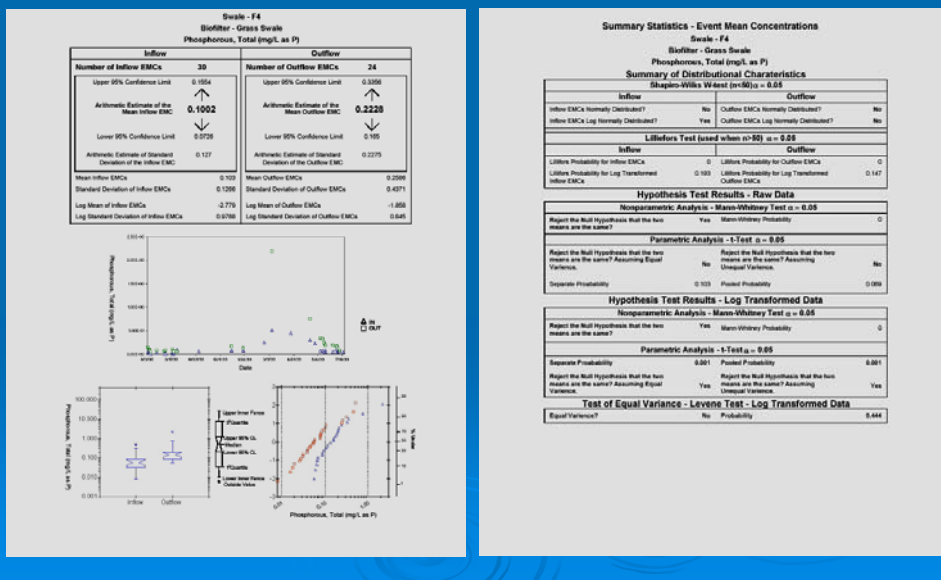
**Results of Analyses of  
the Expanded EPA/ASCE  
National Stormwater  
Best Management  
Practices Database –  
Cold Weather Events**

# The Problem

- Widespread use of BMPs without sufficient understanding of performance and factors leading to performance
- Inconsistent data reporting methods limit scientific comparison/evaluation of studies
- Differences in monitoring strategies and data evaluation methods result in wide range of reported “effectiveness” (e.g. – to + percent removals)



## Updated Statistical Analysis – PDF Documents Water Quality Analysis



# Updated Statistical Analysis – PDF Documents

## Flow and Precipitation

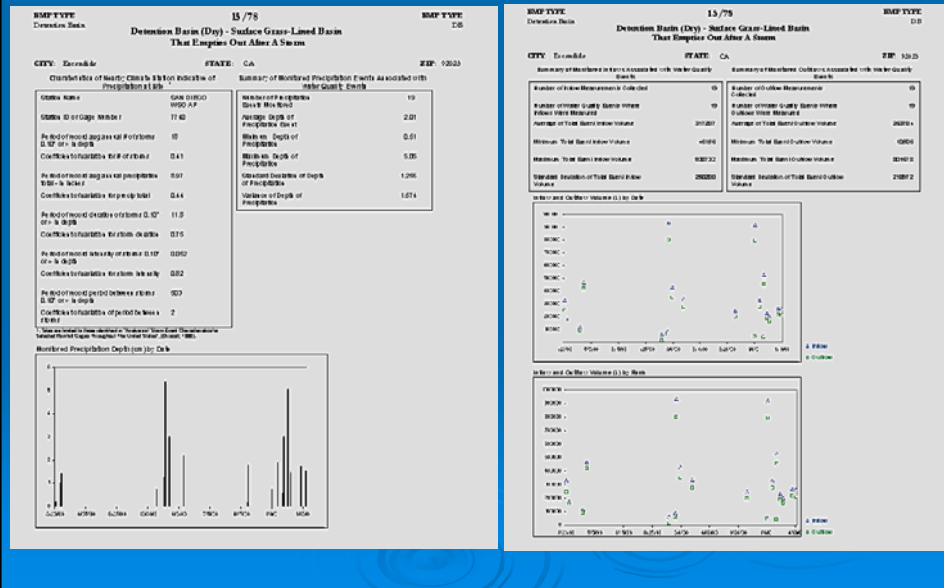


Table 1: Number of Statistical Summaries that are Available from the ASCE/EPA Database Analysis by BMP Type and Parameter

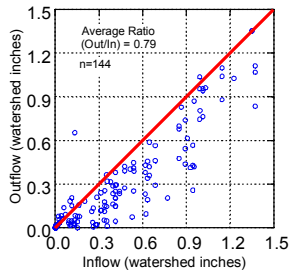
Parameter	Biofilter Grass Strip	Biofilter Grass Swale	Detention Undergrnd Vault, Tank or Pipe(s)	Detention Basin (Dry) Concrete or Lined Tank/Basin With Open Surface	Detention Basin (Dry) Surface Grass-Lined Basin That Empties Out After A Storm	Filter Geotextile Fabric Membrane (Vertical)	Filter Other Media	Filter Peat Mixed With Sand	Filter Sand
Cadmium, Dissolved	1	6	1		3		3	4	
Cadmium, Total	1	7	1	1	5		2	4	
Copper, Dissolved	3	8	1	1	4	6	1	6	
Copper, Total	3	11	1	2	9	6	3	6	
Lead, Dissolved	3	8	1	1	4	6	1	6	
Lead, Total	5	12	1	2	9	6	3	6	
Nitrate + Nitrite, Dissolved					1				
Nitrate + Nitrite, Total		2	1		1		1		
Nitrate Nitrogen, Dissolved			1		1		1		
Nitrate Nitrogen, Total	5	10		2	5	6	2	6	
Nitrogen, Kjeldahl, Total	5	7		1	6	6	1	6	
Nitrogen, Total		4			4				
Nitrogen, Total Organic					1				
Oil and Grease		2			4		2	1	
Phosphate, Ortho	2	8	1		9	1	1	5	
Phosphorous, Dissolved					1				
Phosphorous, Suspended					1				
Phosphorous, Total	5	13		2	8	6	3	6	
Phosphorous, Total					3				
Residue, Total			1					1	
Solids, Total		2							

Table 1 cont: Number of Statistical Summaries that are Available from the ASCE/EPA Database Analysis by BMP Type and Parameter

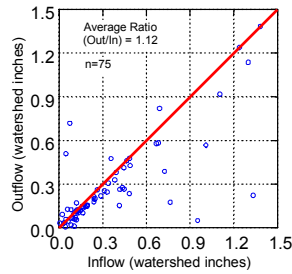
Parameter	Hydrodynamic Devices	Infiltration (Percolation) Trench	Oil & Water Separator	Porous Pavement Asphalt	Porous Pavement Poured Concrete	Retention Pond (Wet) Surface Pond With a Permanent Pool	Wetland Basin With Open Water Surfaces	Wetland Basin Without Open Water (Wetland Meadow Type)	Wetland Channel With Wetland Bottom
Cadmium, Dissolved	4					1	1		
Cadmium, Total	5			1	1	10	2		
Copper, Dissolved	7					4	1		
Copper, Total	9			1	1	13	2		
Lead, Dissolved	7					5	1		2
Lead, Total	8	1		1	1	16	3		3
Nitrate + Nitrite, Dissolved									
Nitrate + Nitrite, Total	4					10	3		
Nitrate Nitrogen, Dissolved	1								
Nitrate Nitrogen, Total	2	1		1		4	3		3
Nitrogen, Kjeldahl, Total	4	1		1	1	13	4		2
Nitrogen, Organic Dissolved						2			
Nitrogen, Organic Kjeldahl, Total									
Nitrogen, Total	1	1		1		6	6		4
Nitrogen, Total Organic						6	3		1
Oil and Grease	3			1	1	2	2		1
Phosphate, Ortho	3					4	2	2	

# Runoff Volume Control

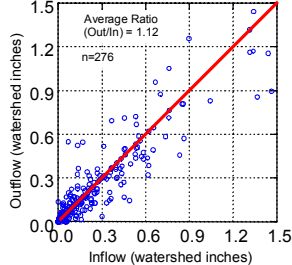
Biofilters (N=16)  
(Swale and Filter Strips)



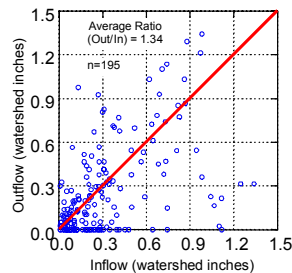
Detention Basins (N=11)  
(Dry Ponds)



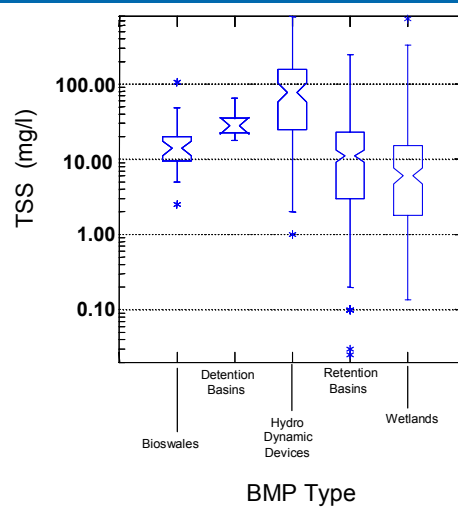
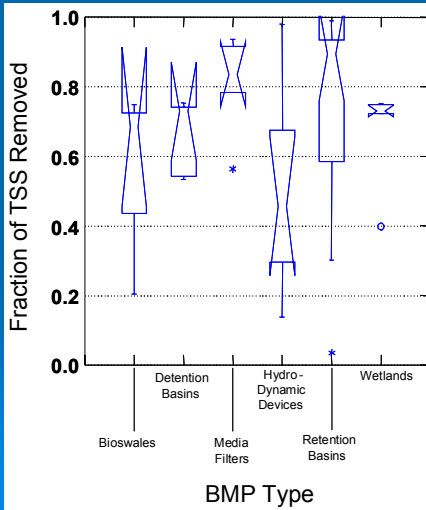
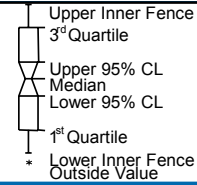
Retention Ponds (N=20)  
(Wet Ponds)



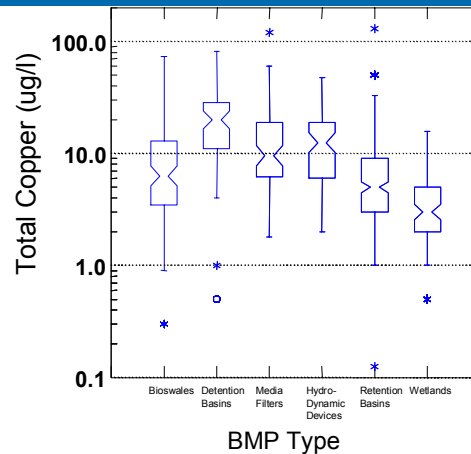
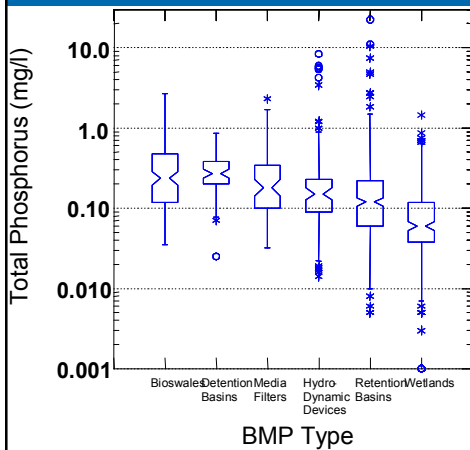
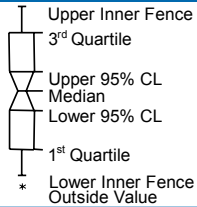
Wetland Basins (N=10)



## Box plots of the fractions of Total Suspended Solids (TSS) removed and of effluent quality of selected BMP types



## Box plots of effluent quality of selected BMP types for Total Phosphorus and Total Copper



## Major Analysis Findings

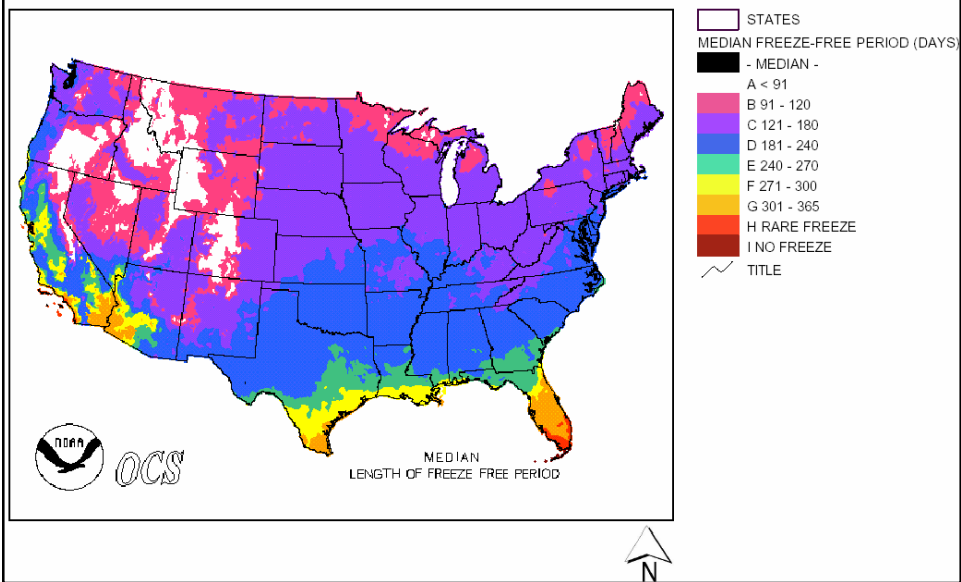
- Results of the analyses of the now expanded database have reinforced the initial finding that BMPs are best described by:
  1. how much they reduce runoff volumes,
  2. how much of the runoff that occurs is treated (and not) by the BMP (e.g., bypass or overflow),
  3. and of the runoff treated what effluent quality (concentrations and potential toxicity) is achieved?
  
- Percent removal is an erroneous measure of performance

## Analysis Findings Cont.

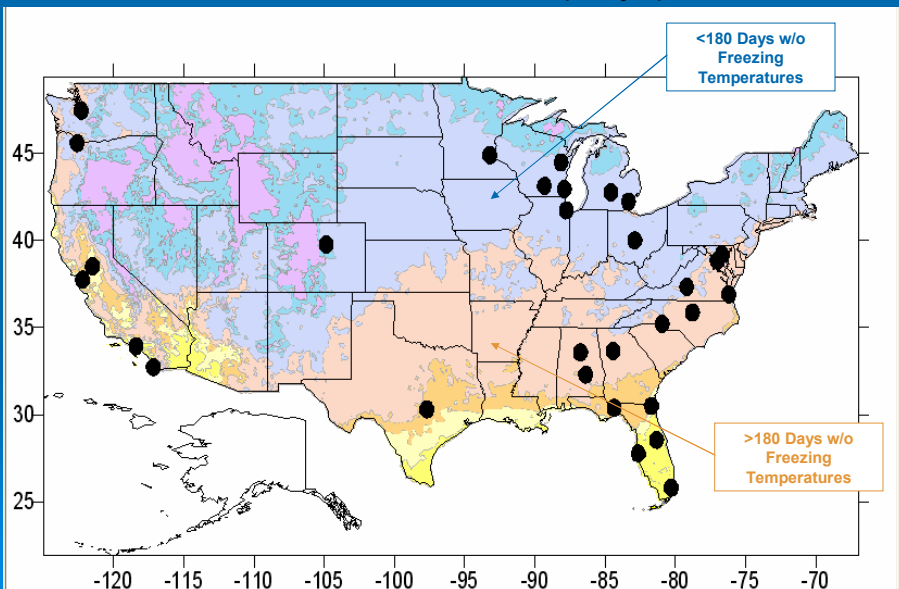
These Basic BMP performance descriptions can be utilized to:

- assess the concentrations that BMPs are able to achieve (concentration TMDLs),
- assess effects on total loadings (TMDLs),
- frequency of potential exceedances of water quality criteria or other targets, and
- other desired water quality performance measures.

# Median Freeze-free Period (Days)



# NSW Database Sites Analyzed Relative to Median Freeze-free Period (Days)



# BMP Studies – Cold Regions

- Number of BMPs located in cold regions
  - 144 BMPs in “Warm” Climates
  - 24 in “Cold” Climates
- Number of BMPs with apparent cold season/weather data (by BMP Type)

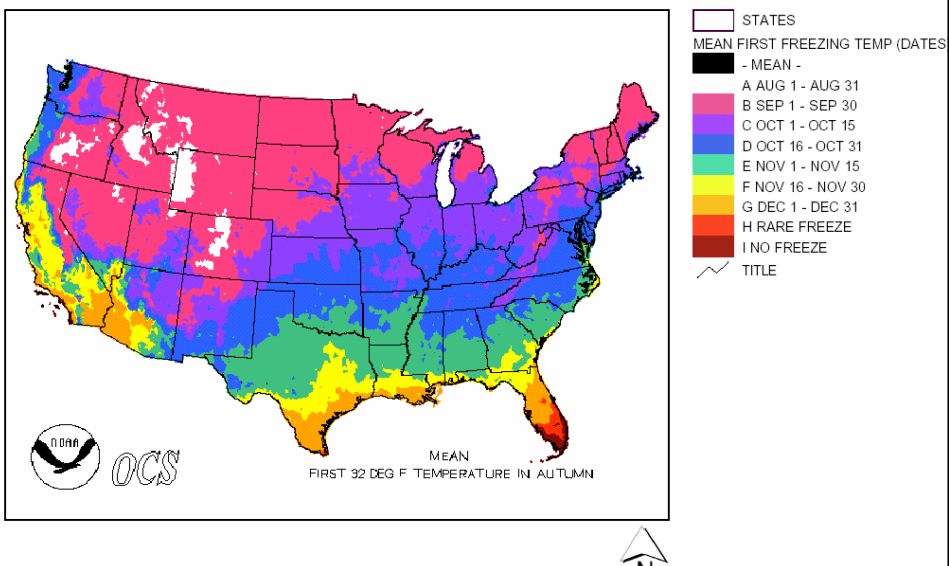
“WARM CLIMATE”

BMP Category	Number of BMPs
Detention Basin	22
Biofilter	32
Hydrodynamic Device	15
Media Filter	27
Porous Pavement	4
Percolation Trench/Well	1
Retention Pond	21
Wetland Basin	13
Wetland Channel	9

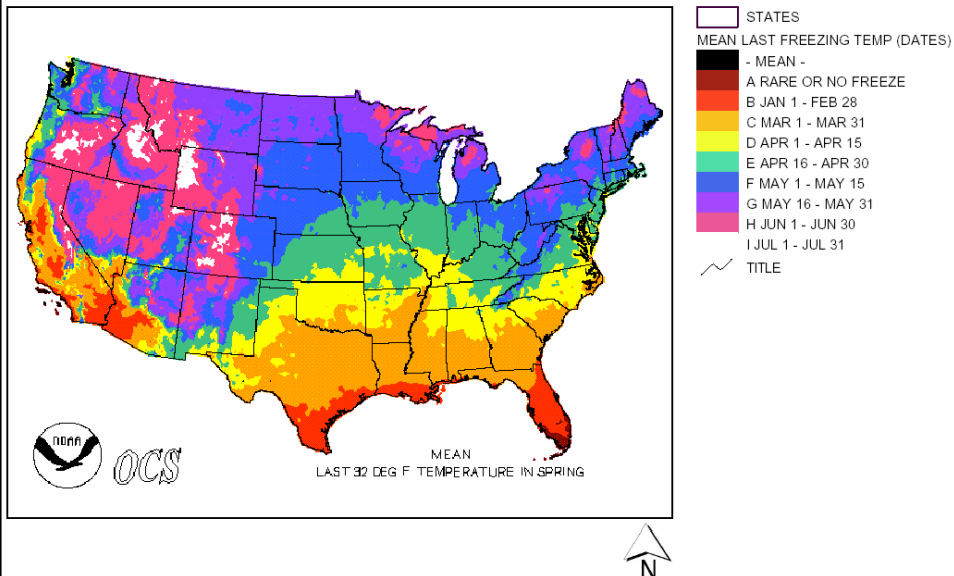
“COLD CLIMATE”

BMP Category	Number of BMPs
Detention Basin	2
Hydrodynamic Device	3
Porous Pavement	1
Retention Pond	12
Wetland Basin	2
Wetland Channel	4

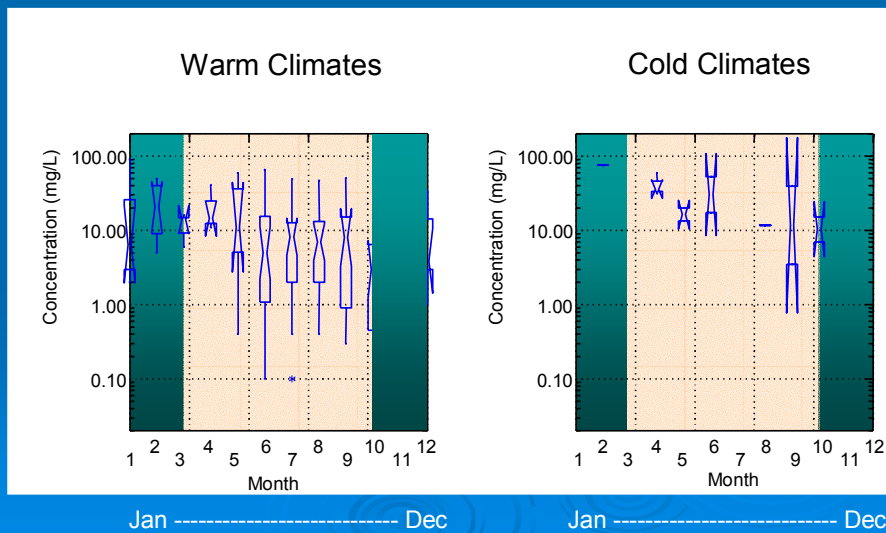
# Mean First Freezing Temp



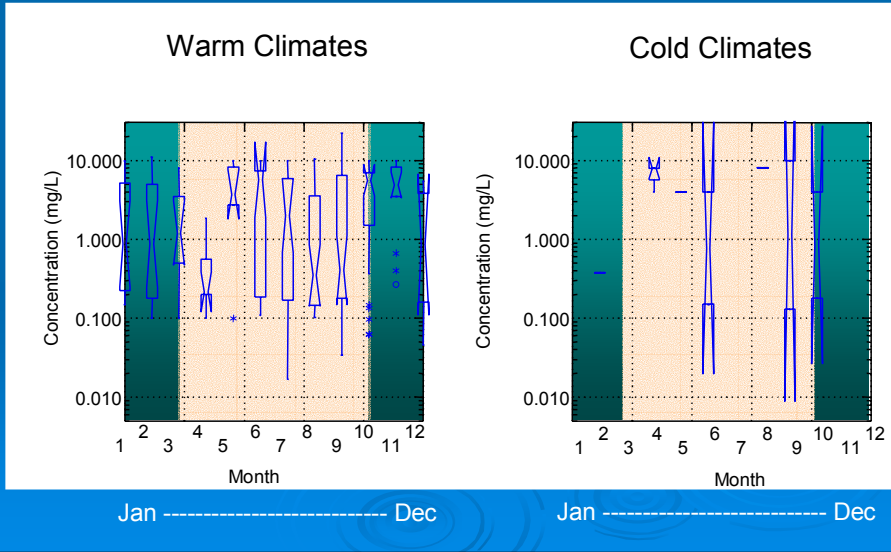
# Mean Last Freezing Temp



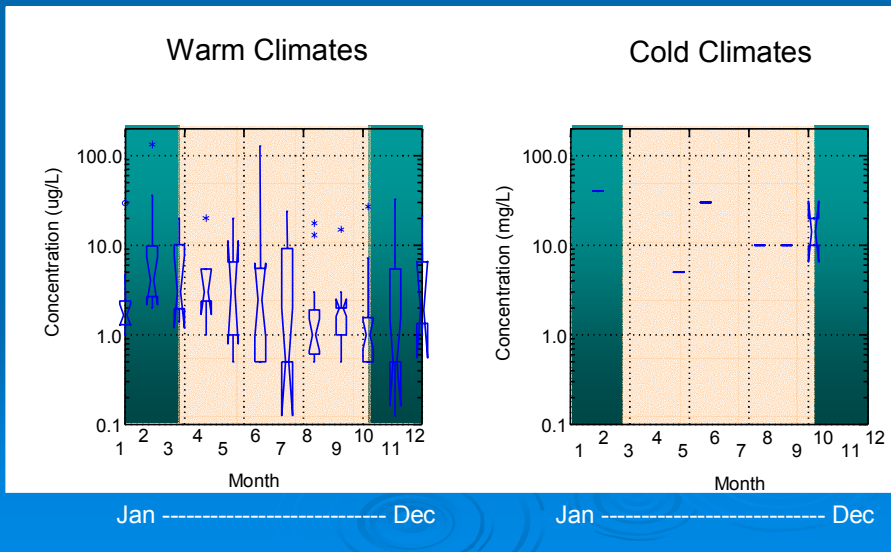
# Wet Pond – Cold Weather TSS Effluent Concentration



# Wet Pond – Cold Weather TP Effluent Concentration



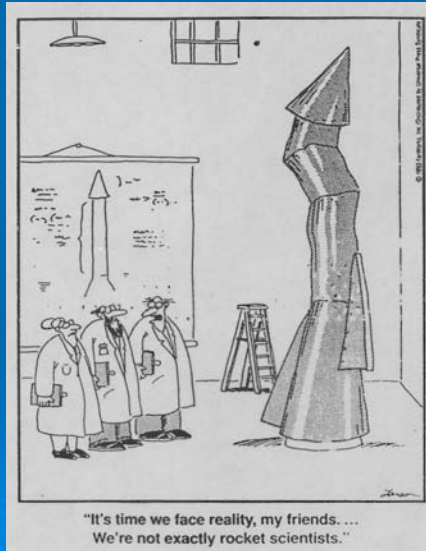
# Wet Pond – Cold Weather TPb Effluent Concentration



# Summary

- National BMP Database has good data on rain event BMP performance
  - Effluent data on numerous BMPs for rain events and established differences in effluent quality for BMP types
  - Better overall description of performance has been developed
  - Hydrology source control of some BMPs found
- People don't like to sample during snow melt events
- Real need to sponsor BMP performance studies that include snow melt runoff and treatment

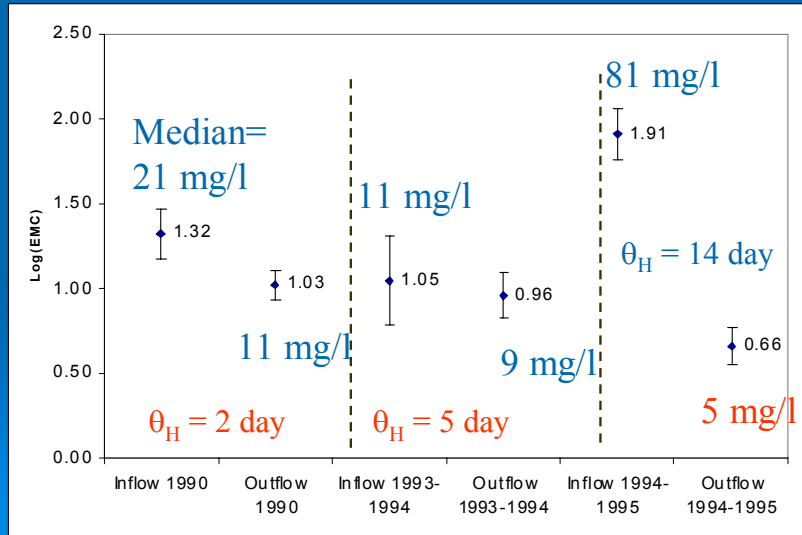
[www.bmpdatabase.org](http://www.bmpdatabase.org)



## Example Study -SWFWMD Pond

- Drainage area, 6.5 acres
- Land use (commercial, office)
  - 30% roof tops and parking lots, 6% crushed stone, 64 % grassed
  - Drained by swales to pond
- Five year study with two design modifications
  - 1990 (shallow and vegetated,  $\theta_H = 2$  day)
  - 1993 (volume increased, 35% veg,  $\theta_H = 5$  day)
  - 1994 (area enlarged, replant littoral zone,  $\theta_H = 14$  day)

Inflow and Outflow Log Mean TSS Concentrations (mg/l) and 95 Percent Confidence Limits for 3 Different Designs of a Wet Pond Located at SWFWMD Service Office in Tampa, Florida.



## Measures of Performance (Repeated)

- How much stormwater runoff is prevented? (“hydrological source control”)
- How much of the runoff that occurs is treated by the BMP or not (“hydraulic performance”)?
- Of the runoff treated, what is the effluent quality? (“concentration characteristics achieved”)

## Performance Criteria for Commercial BMPs is Needed, but Problematic

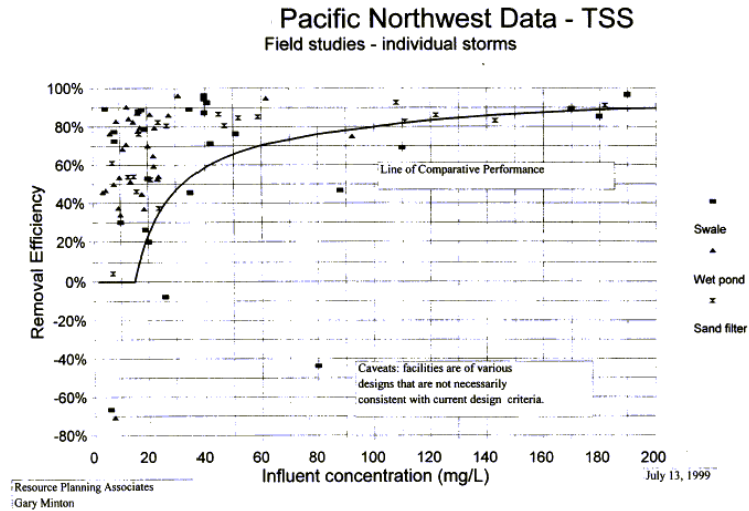
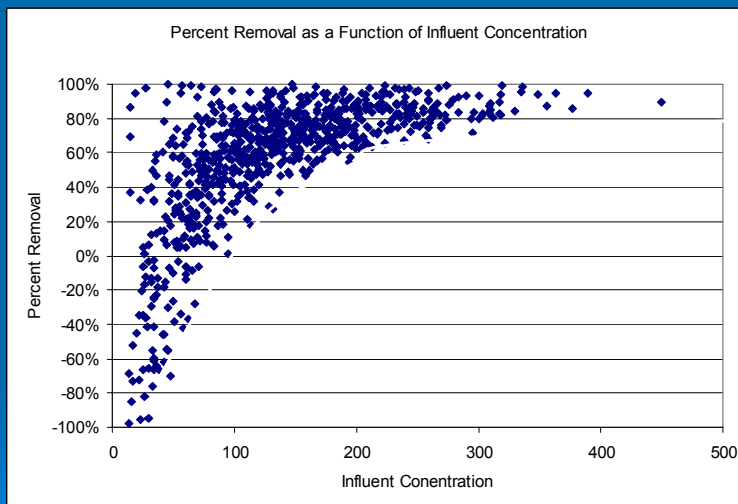


Figure 2 : Removal Efficiency (ER Method) of TSS as a Function of Influent Concentration (Minton, 1999)

## Spurious Correlation (Type VII; Benson, 1965)



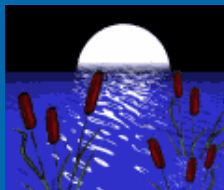
Ratio vs. it's denominator always shows a relationship – It does not indicate anything!

## Percent Removal as a BMP Performance Description is Not Valid

Unless, it is accompanied by treatability data  
(settling velocity distribution by mass)

Percent Removal requirements can  
discourage good source controls

## Questions



[www.bmpdatabase.org](http://www.bmpdatabase.org)