THE OHIO STATE UNIVERSITY

Monitoring Runoff Particle Size Distribution and Trash in Runoff from Ohio Roads

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Runoff Carries with it Sediment & Trash

- Sediment
  - Typically analyzed as TSS
    - Lump 0.45 µm – 2mm particle sizes
- Trash (Gross Solids)
  - Typically >1/4” (5 mm) diameter
  - TMDLs for trash in CA, MD

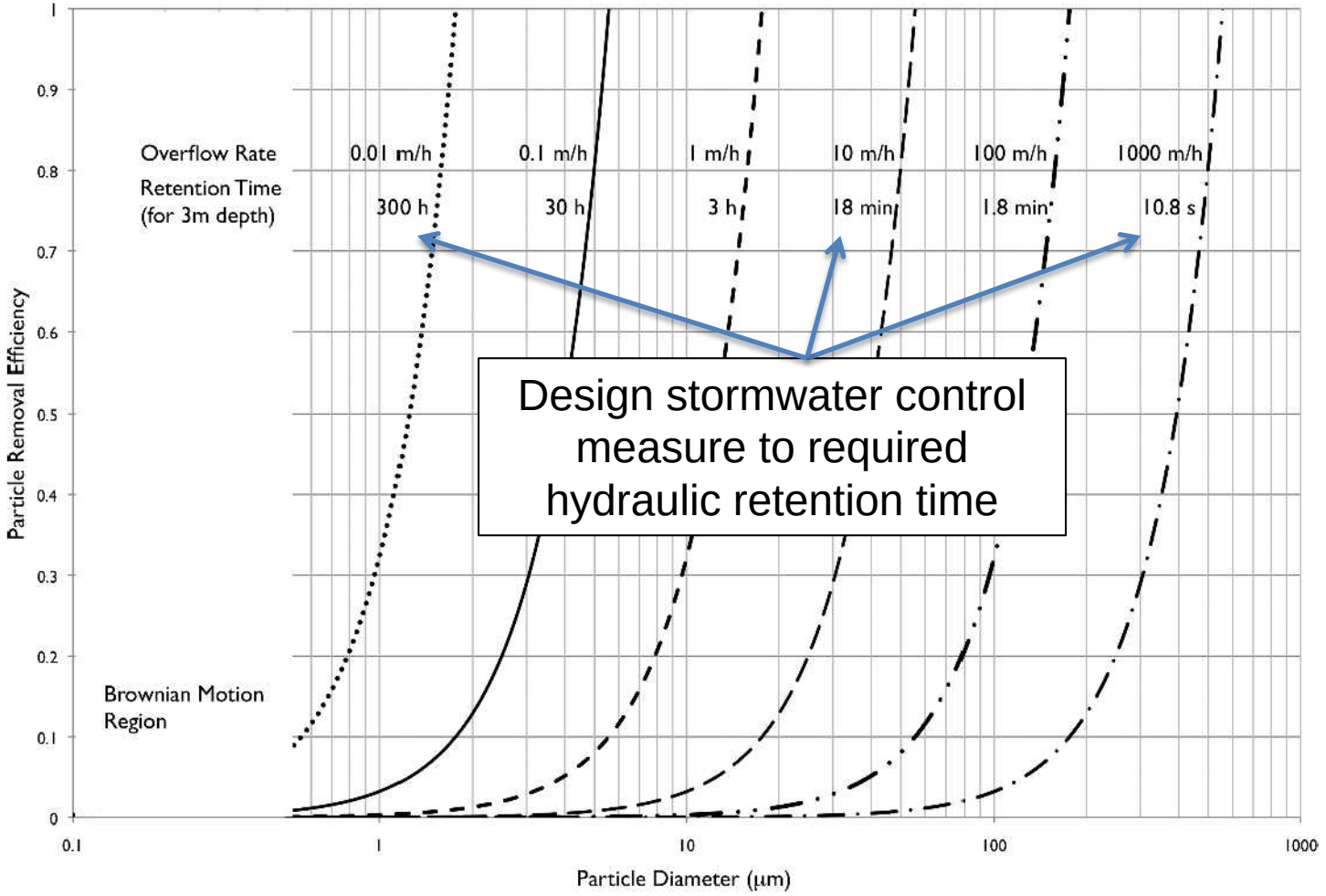
Why Study Particulates?

- For ODOT: permit compliance
- Water quality treatment practices:
  - >80% TSS removal
  - Manufactured treatment systems
    - 21 currently approved
    - All hydrodynamic separators
    - L&D Vol. 2 Section 1117.1
  - Generally, capture particles >75 µm well

Why Does Particle Size Matter?

Ferreira and Stenstrom

2013, Water Env Res

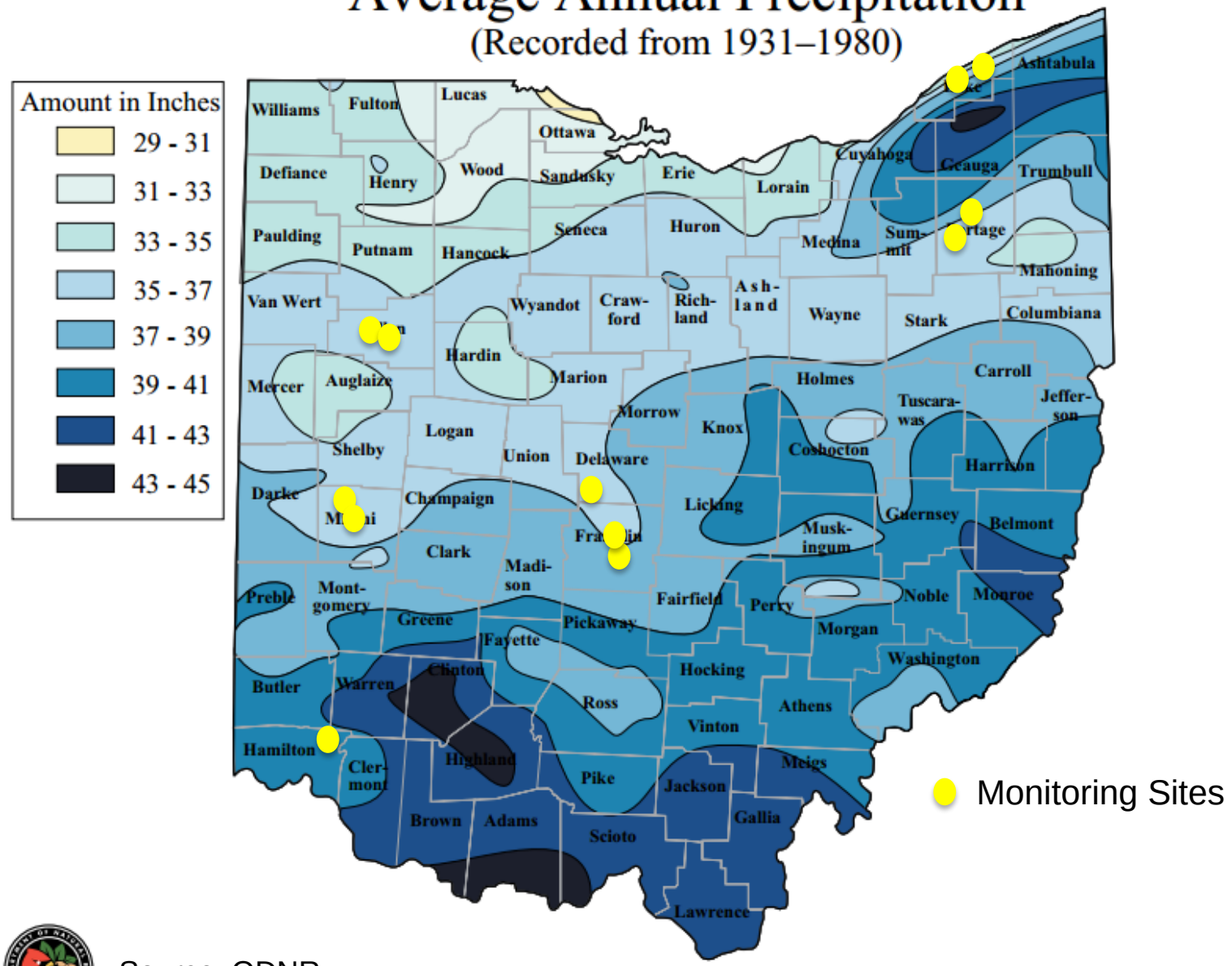


Objectives of Study

- Characterize particle size distributions (PSDs) and TSS in road runoff across Ohio.
- Gross solids collection from road runoff
  - Bulk volume/mass
  - Characterization
- Understand how manufactured treatment devices (MTDs) function under Ohio's conditions

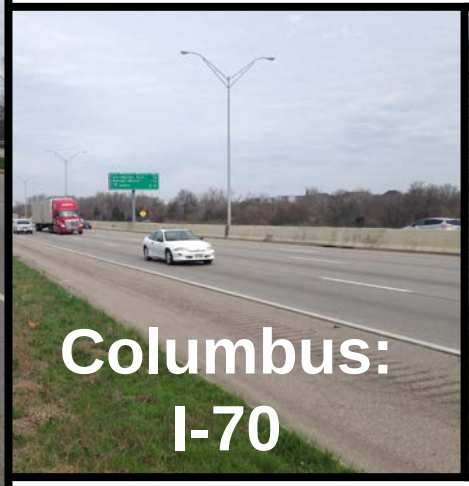
Average Annual Precipitation

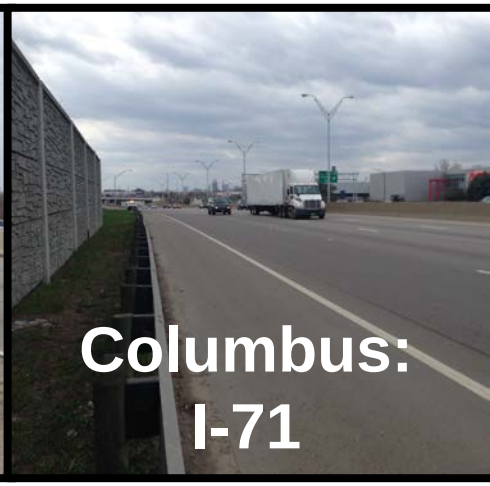
(Recorded from 1931–1980)



Source: ODNR

2016 Monitoring Sites





- Wide range of AADT
- Different functional classes

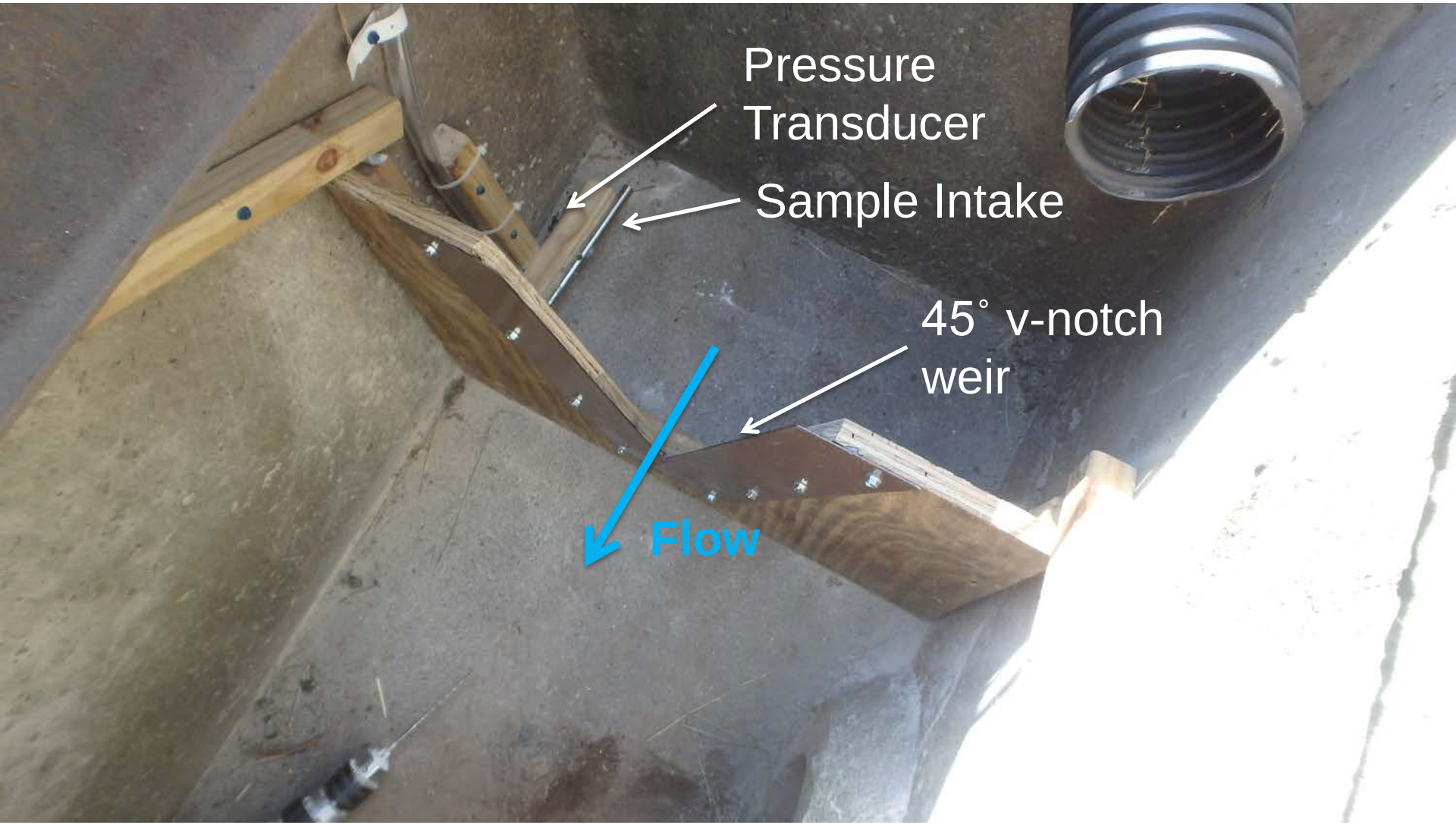
2017 Monitoring Sites

- Variety of surrounding land use, pavement type, & development density

Monitoring Design

- Rainfall measured at each site using a tipping bucket & manual rain gauge
- Monitor concentrated gutter flow in catch basins at 6 sites in 2016 and 6 in 2017
- Runoff volume-proportional samples obtained using ISCO 6712 samplers (EMCs)

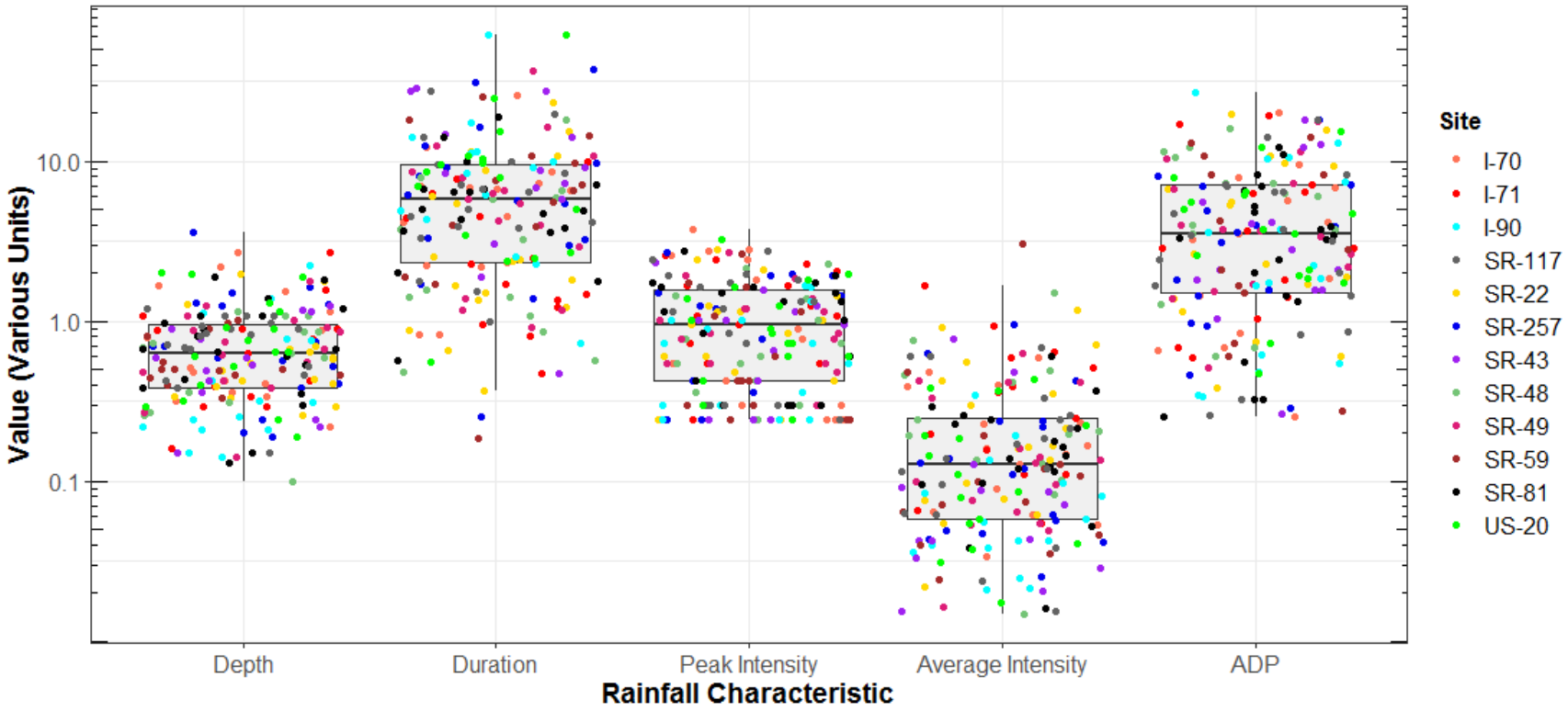
Monitoring Design



Methods for Sample Analysis

- Sampled 176 storms for PSD and TSS across 12 sites during 2016-2017
  - 12-18 storms per monitoring site
- PSD analyzed using Laser Diffraction Particle Counter (Beckman Coulter)
- Reports particle size between 0.04-2000 µm

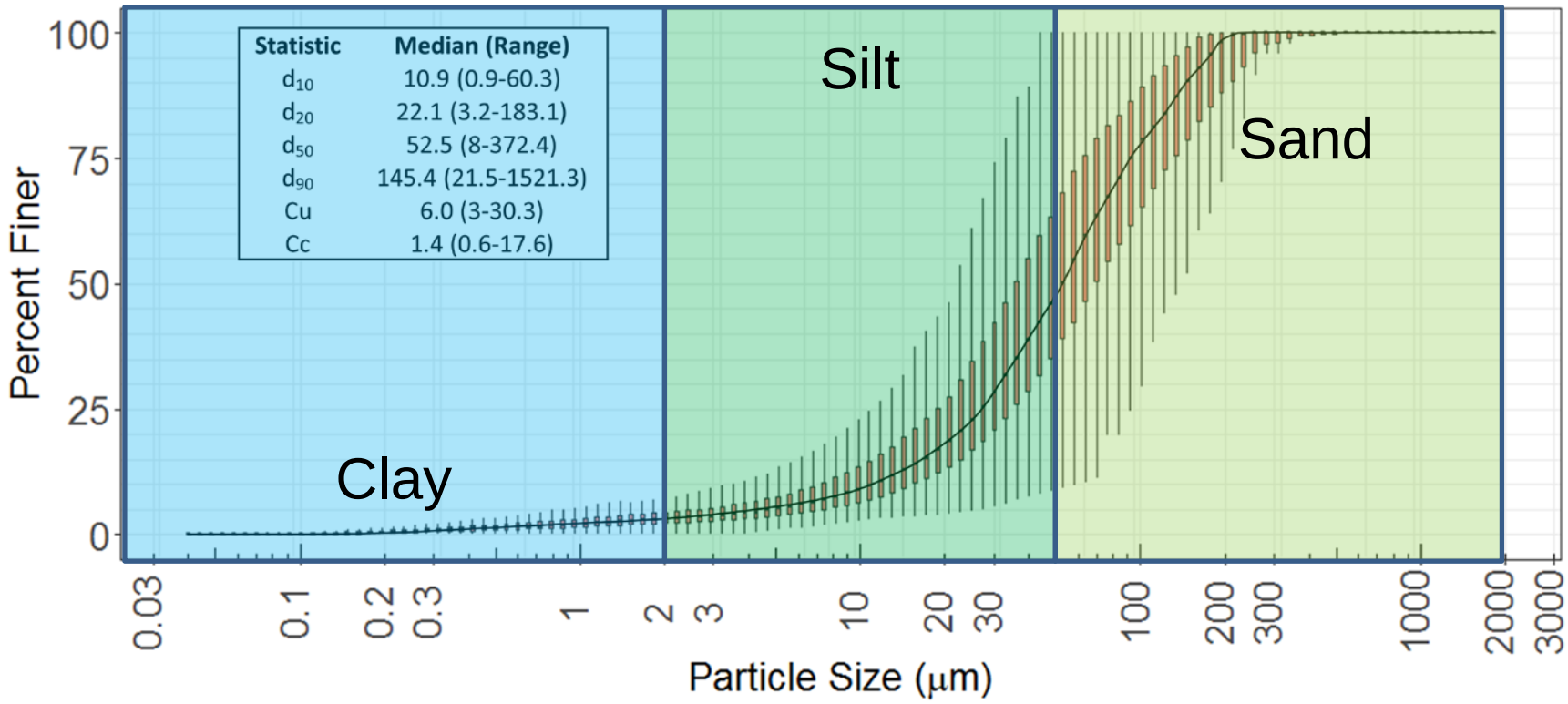
PSD/TSS Sampled Rainfall Events



Depth (in), duration (hrs), antecedent dry period (ADP, days), peak intensity (in/hr), and average intensity (in/hr)

Variability in PSDs

All 176 measured PSDs in one figure



Median d_{50} = 52.5 µm,
which is a very fine sand

Particle Size for Road Particulates

For the average sample at a site

Statistic	I-70	I-71	SR-257	SR-22	SR-48	SR-49	I-90	SR-43	SR-59	SR-81	SR-117	US-20
% Sand	39.6	37.1	45.4	54.2	66.3	62.9	56.7	49.2	48.0	27.1	50.5	46.9
% Silt	55.2	58.6	50.5	42.0	31.5	34.7	40.8	47.1	48.8	64.5	45.9	49.2
% Clay	5.2	4.3	4.1	3.9	2.2	2.3	2.5	3.7	3.1	8.4	3.5	3.9

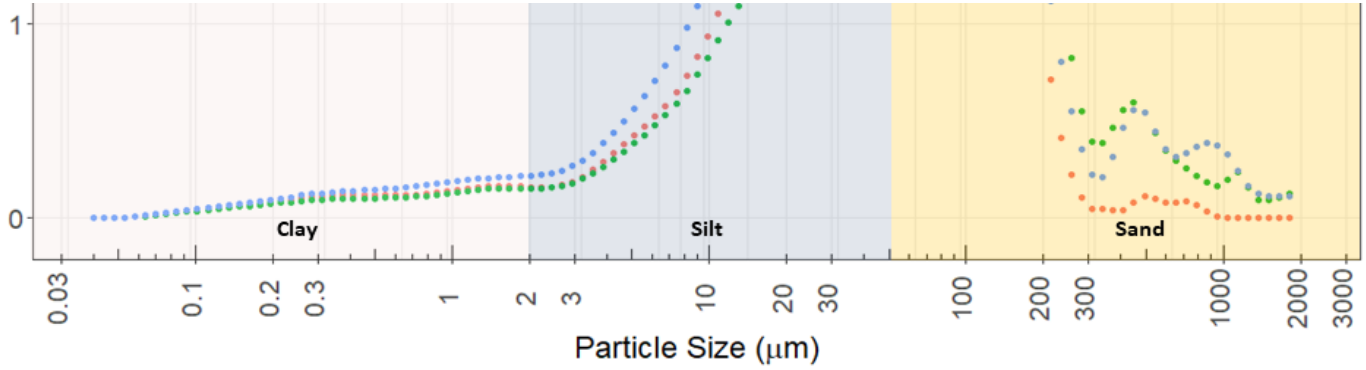
*Using USDA soil classification system

1. Settling mechanisms – short HRT (seconds to minutes)
2. Settling or filtration mechanisms – moderate HRT (30 mins to many hours)
3. Filtration mechanisms

PSD by Season

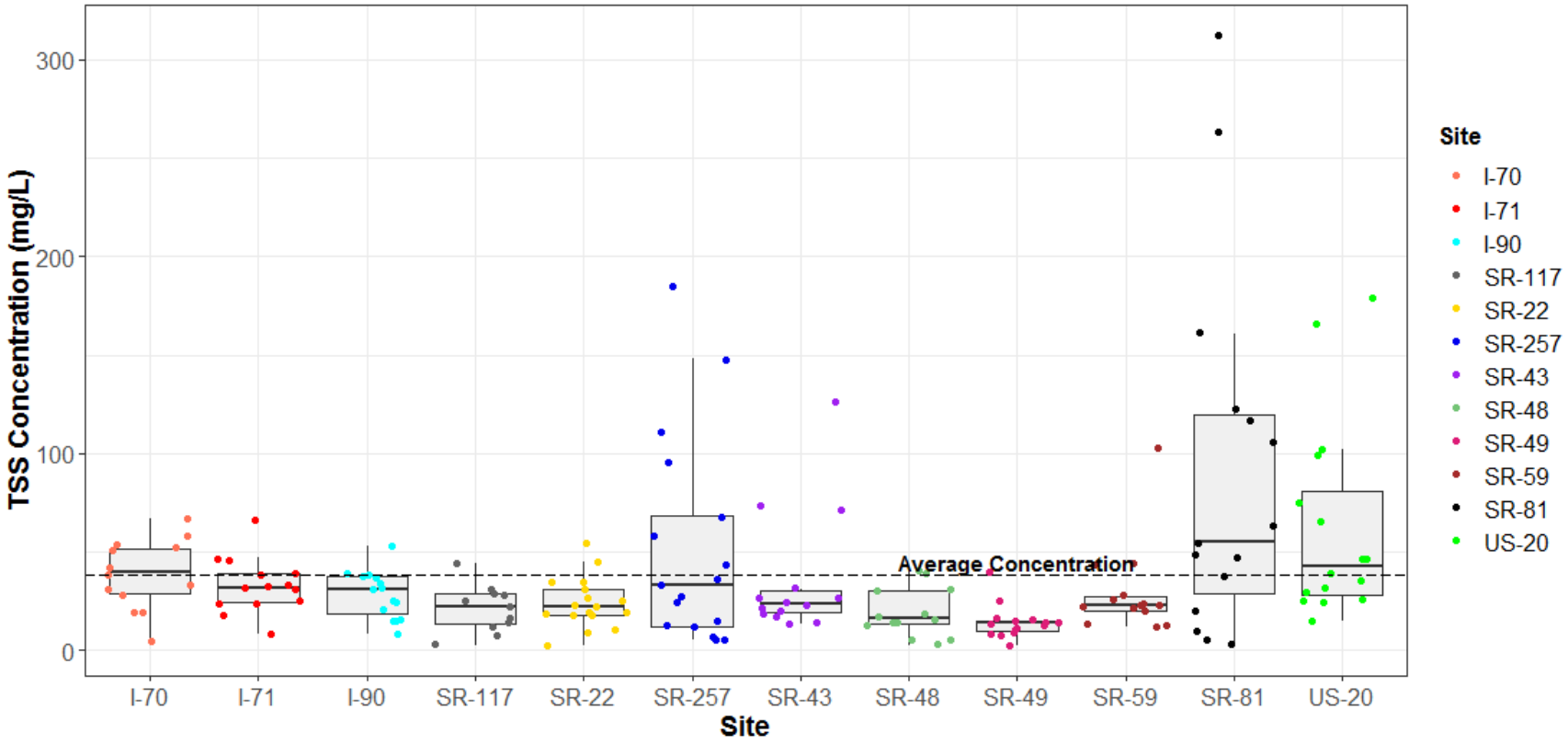
Particle sizes generally largest in the summer (higher intensity rainfall)

- Significantly larger particles in low density residential areas & principal arterial roads
- No difference in PSD across urban, suburban, rural or concrete and asphalt wearing courses
- Where differences in PSD occurred, they were small and therefore we do not recommend different BMP/SCM designs



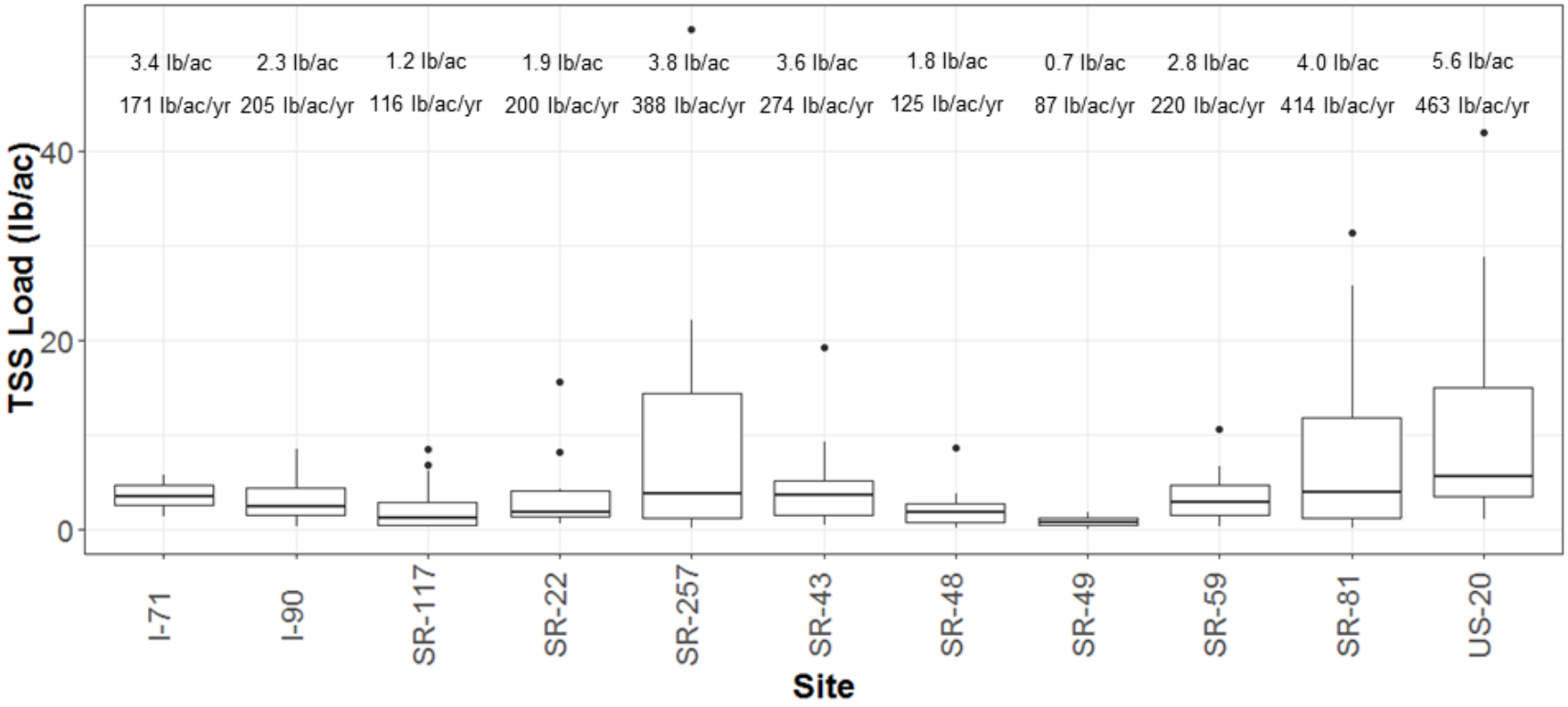
TSS Concentrations by Site

Mean TSS concentration = 35 mg/L



TSS Load by Site

Average TSS load 242 lb/ac/yr



- Hydrologic response similar across sites
- Higher TSS concentration = higher TSS loads

Gross Solids Sampling

- Purpose built metal mesh netting
  - Nominal opening 0.25 inches
  - Drop into catch basin to capture gross solids

Gross Solids Sampling

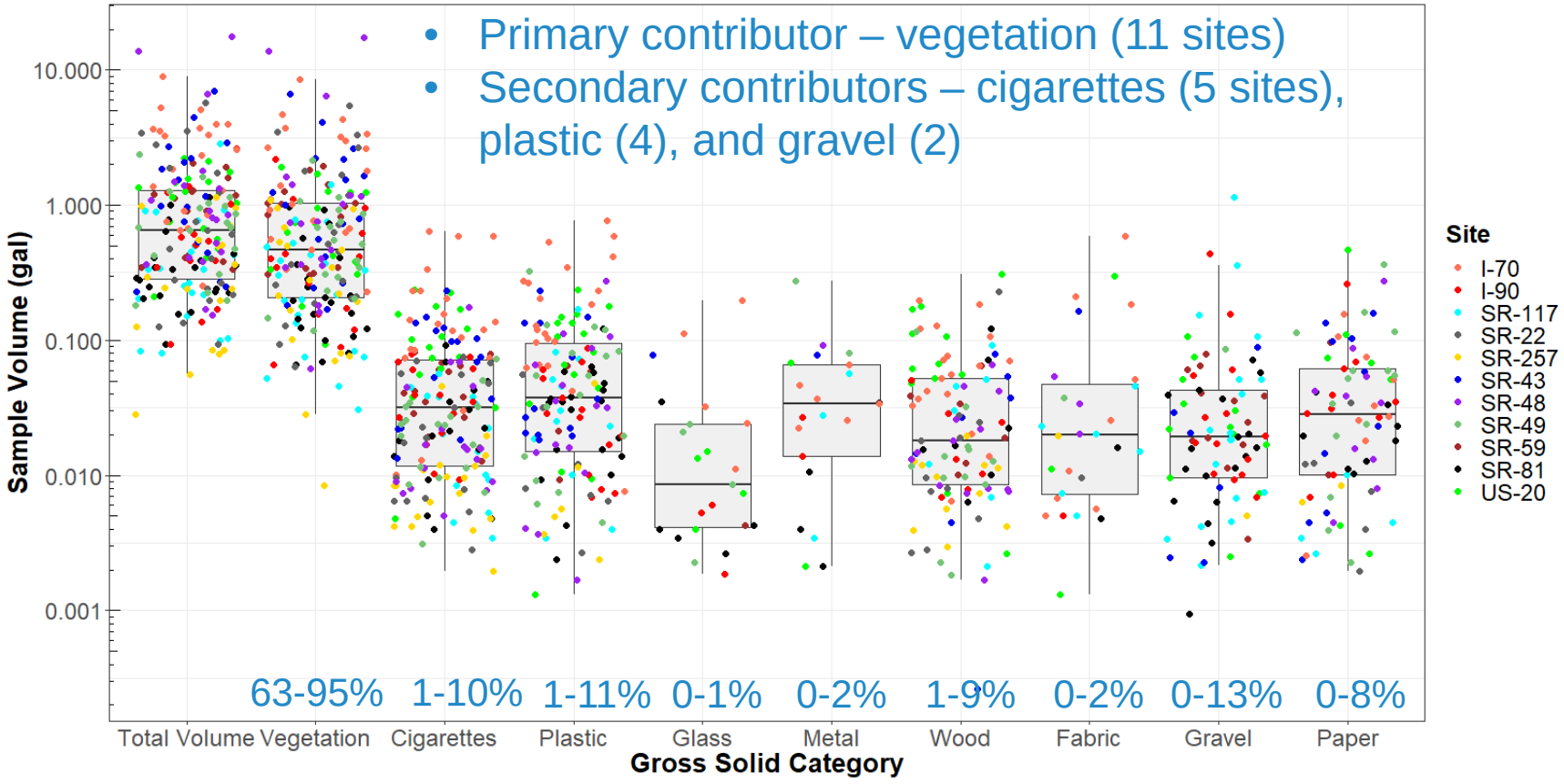
- Sites visited every 11.6 ± 7.3 days
  - All accumulated debris and trash removed and taken to lab for analysis

- 202 total samples collected at 11 sites
- 14-22 samples per site
- 39 spring, 103 summer, & 60 fall samples collected

Gross Solids Laboratory Methods

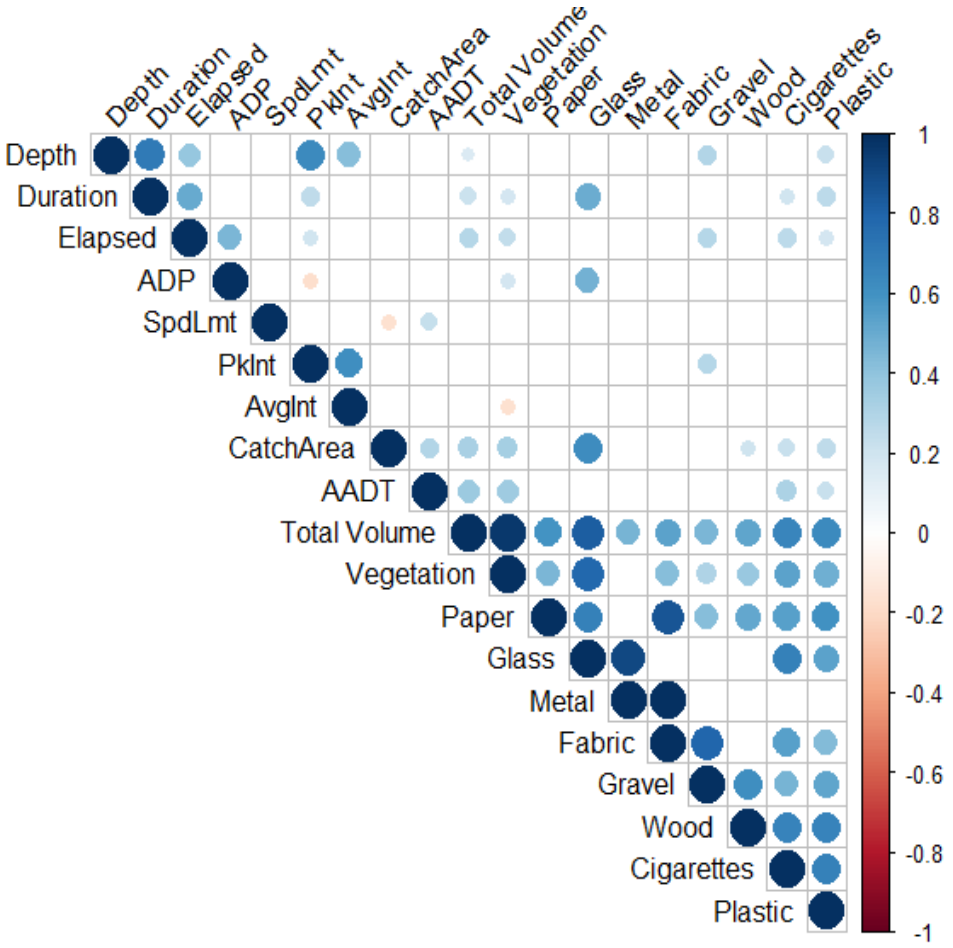
- Characterized wet weight and volume for each sample & nine categories
  - Vegetation
  - Cigarettes
  - Plastic
  - Wood
  - Glass
  - Metal
  - Fabric
  - Paper
  - Gravel

Gross Solids Volume by Category



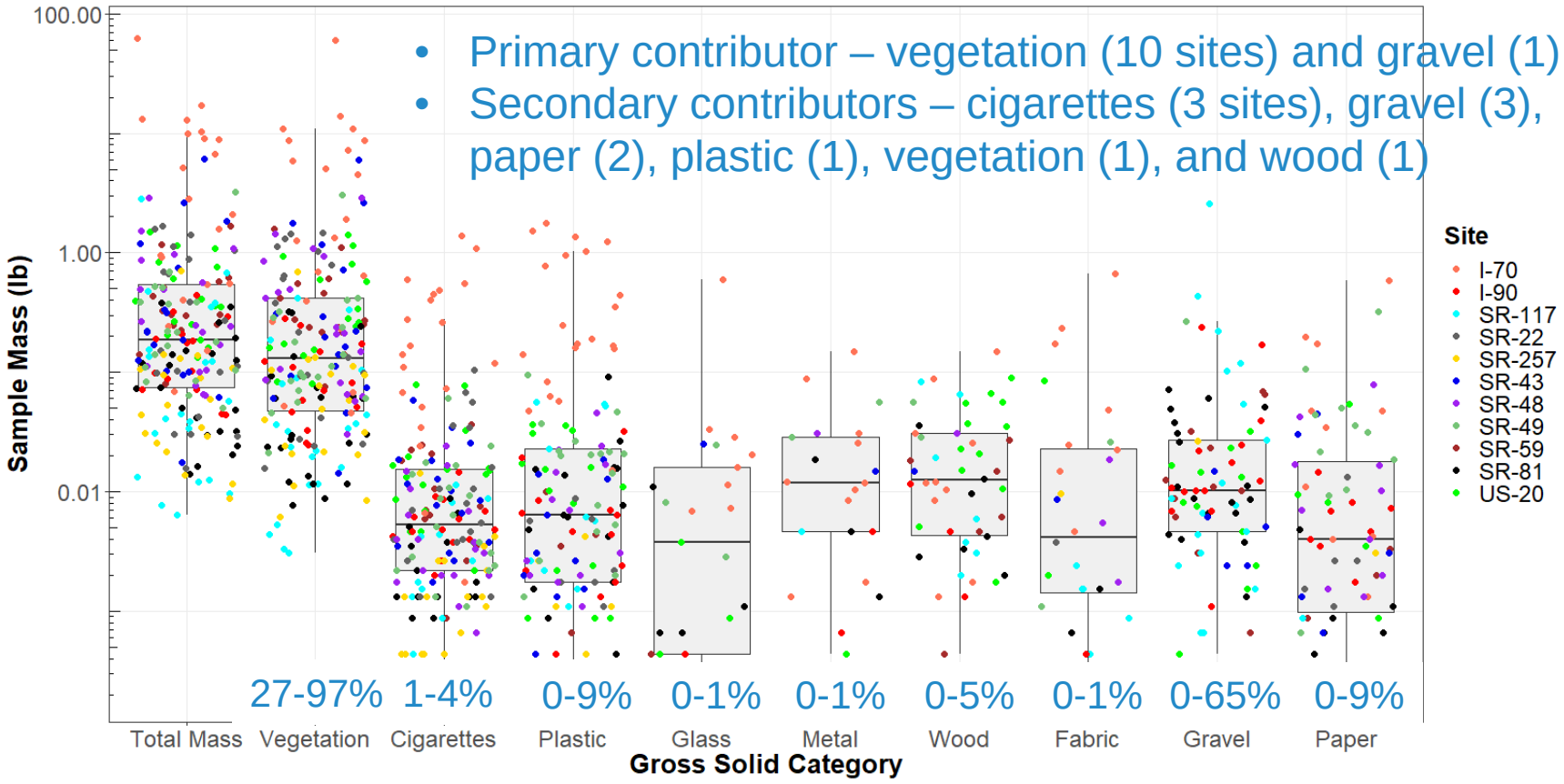
Predictors of Gross Solids Volume

Explored using Spearman's Rank Correlation Coefficients



- AADT correlated to total volume, vegetation, plastic, and cigarettes
- Rainfall depth and duration correlated to total volume, plastic
- Elapsed time since previous sample event correlated to vegetation, plastic, cigarettes, total volume

Gross Solids Mass by Category



Seasonality of Gross Solids Mass

- Total mass and vegetation
  - Fall > Summer
- Plastic
  - Spring > Summer
- Gravel
  - Spring > Fall
  - Summer > Fall
  - Related to plowing and freeze/thaw?

Autumn Season

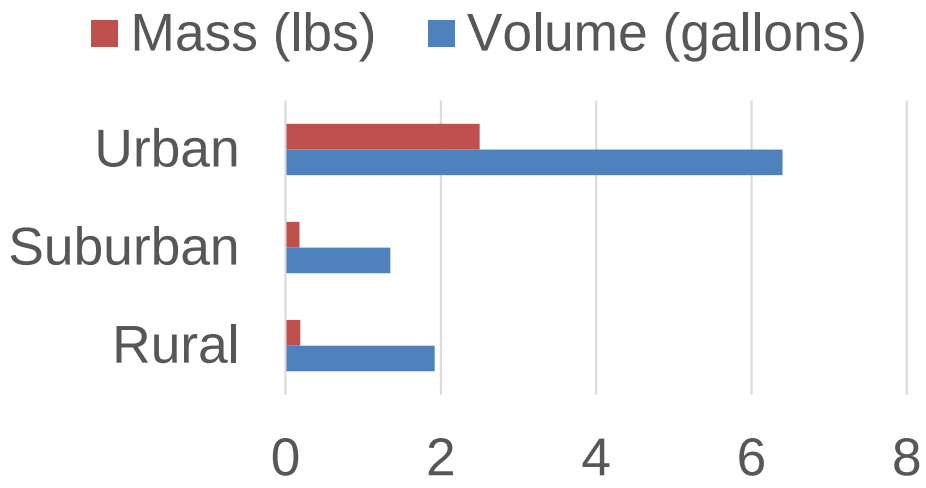
Particularly high maintenance load for
catch basin inserts or manufactured treatment devices

Oct 24, 2016

Nov 8, 2016

Urban vs. Suburban vs. Rural

- Multiple linear regression:
  - On average, 12 times higher gross solids mass and 4 times higher volume from urban than suburban or rural sites
  - Similar trends for vegetation, plastic and cigarettes



Maintenance Needs after Mowing

- Plan for street sweeping after mowing?

Applying Ohio Road Stormwater Data to MTDs

Goals:

- Determine which MTDs meet 80% TSS removal
- What are costs to purchase, install, and maintain these MTDs?
- What TSS removal can we expect under PSDs and TSS concentrations measured during this project?
- Cost-benefit analysis for MTDs

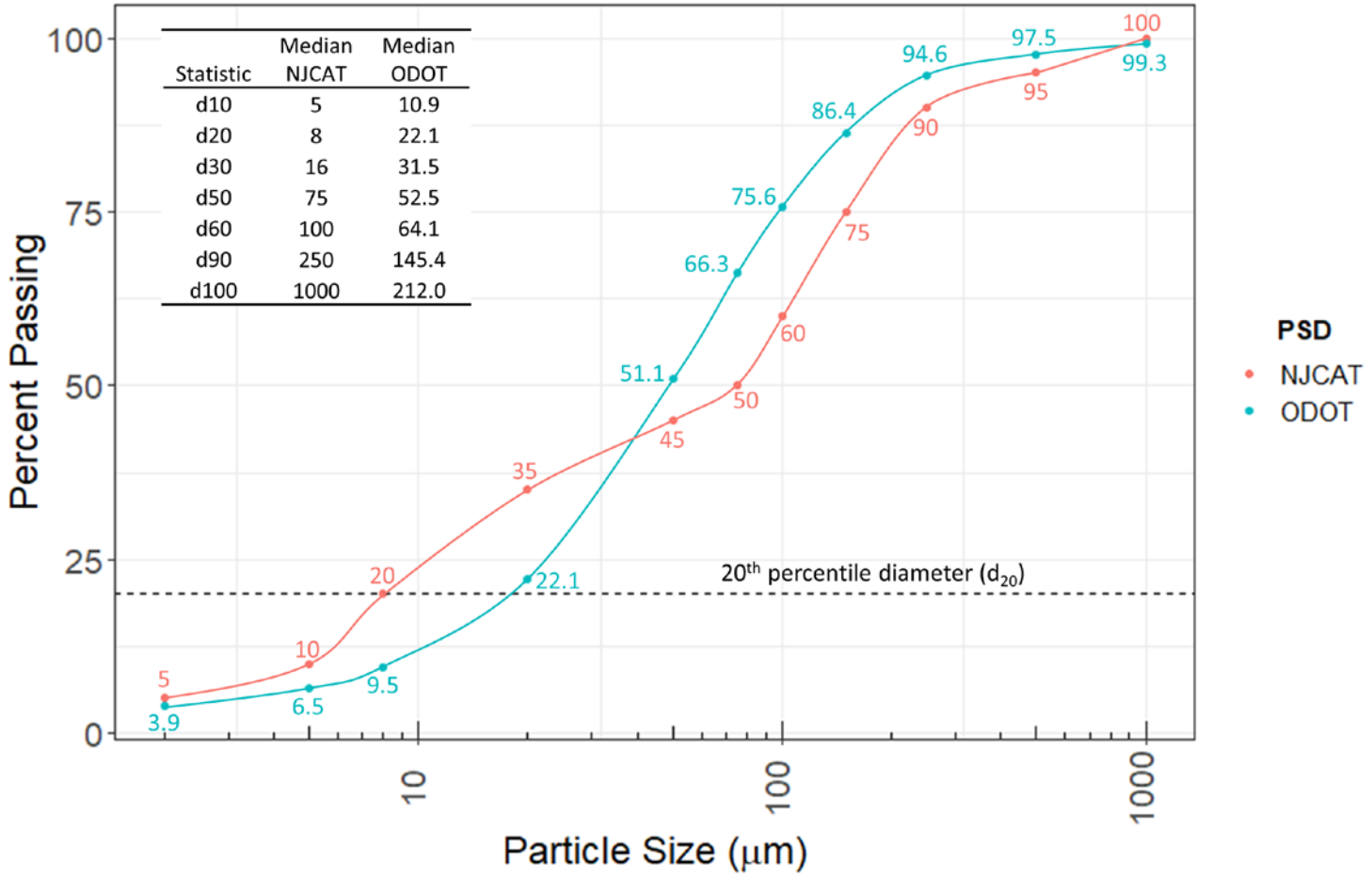
Most MTD Testing Completed in Laboratory Setting

- Constant flow rates
- Constant, high TSS concentration (200 mg/L) with similar PSD to this study
- New Jersey DEP sets standards
  - https://www.nj.gov/dep/stormwater/mtd_guidance.htm

New Jersey Department of Environmental Protection
Laboratory Protocol to Assess Total Suspended Solids Removal by a Hydrodynamic Sedimentation Manufactured Treatment Device

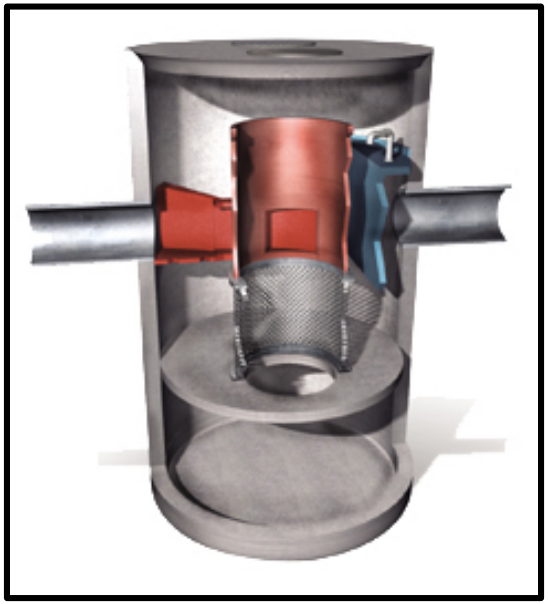
January 25, 2013

Test Sediment vs. Ohio Sediment



NJCAT Approved MTDs

50% TSS Removal	BMP Type	80% TSS Removal	BMP Type
Aqua-Swirl	Hydrodyamic Separator	Aqua-Filter	Filtration Vault
BaySaver	Hydrodyamic Separator		Filtration
Barracuda	Hydrodyamic Separator	BayFilter	Vault
CDS	Hydrodyamic Separator	Biopod	High-Flow Filtration
Downstream Defender	Hydrodyamic Separator	Filterra	High-Flow Filtration
DVS	Hydrodyamic Separator	Kraken	Filtration Vault
First Defense HC	Hydrodyamic Separator	PerkFilter	Filtration Vault
HydroStorm	Hydrodyamic Separator	StormKleener	Filtration Vault
Nutrient Separating Baffle Box	Baffles, Screens, & Skimmer Vault	StormFilter	Filtration Vault
SciClone	Hydrodyamic Separator	Up-Flo Filter	Filtration Vault
SiteSaver	Hydrodyamic Separator		
StormPro	Hydrodyamic Separator		
Terre Kleen	Hydrodyamic Separator		



What are the Costs?

- Contacted 6 manufacturers for purchase, installation, and maintenance costs of various models of MTDs
  - Hydrodynamic separators
  - Underground filter vaults
  - High-flow media filters
- Determined approximate drainage area for each device using rational method
  - C = 0.9, i = 1.85 in/hr, Q = certified flow rate

Example Data: Hydrodynamic Separators

Model	Approximate Drainage Area (ac)	NJDEP-certified Flows (cfs)	Estimated Cost to Purchase	Estimated Installation Cost	Annualized Maintenance Cost	30-Year Cost per Acre	30-Year Cost
CDS (Contech)							
CDS-3	0.31	0.52	$7,250	$3,000	$540	$84,691	$26,450
CDS-4	0.56	0.93	$10,000	$4,000	$800	$68,032	$38,000
CDS-5	0.90	1.50	$12,000	$5,000	$800	$45,510	$41,000
CDS-6	1.26	2.10	$18,000	$6,000	$800	$38,057	$48,000
CDS-7	1.68	2.80	$22,000	$7,000	$1,000	$35,084	$59,000
CDS-8	2.22	3.70	$30,000	$8,000	$1,000	$30,600	$68,000
CDS-10	3.48	5.80	$50,000	$9,000	$1,200	$27,272	$95,000
DVS (Oldcastle)							
DVS-36	0.36	0.6	$8,000	$3,000	$1,500	$155,400	$56,000
DVS-144	5.41	9	$71,500	$12,000	$2,500	$29,323	$158,500

Return on Investment

- Utilized 0.5, 2, and 10 acre drainage areas for case studies
- Utilized NJCAT-certified TSS removal rates
- Used measured TSS load from this study
- Chose solution that was lowest 30-year cost
  - May result in multiple BMPs
- Compared using annual cost per lb of TSS removed

Return on Investment

2 acre drainage area

MTD	% TSS Removal	TSS Load (lb/ac/yr)	Manufacturer	Chosen Solution	30-Year Cost	Sediment Removed (lbs/ac/yr)	Annual Cost per Pound of Sediment Removed
Hydrodynamic Separator	50	242	Contech	1 CDS-8	$68,000	121	$9.37
			Oldcastle	1 DVS-144	$158,500	121	$21.83
Filtration Vault	80		Contech	2 27-cartridge	$465,800	193.6	$40.10
			Oldcastle	3 8 by 18 ft	$472,800	193.6	$40.70
			Bioclean	1 KF-10-16, 1 KF-4-6	$377,920	193.6	$32.53
High-Flow Filter	80		Contech	12 7x13	$744,000	193.6	$64.05
			Oldcastle	7 8x16	$542,500	193.6	$46.70

- Hydrodynamic separators cheaper as watershed area increases
- Costs to move to filtration are 2 to 4 times higher per lb of sediment removed (*assuming 50% TSS removal for HDS)

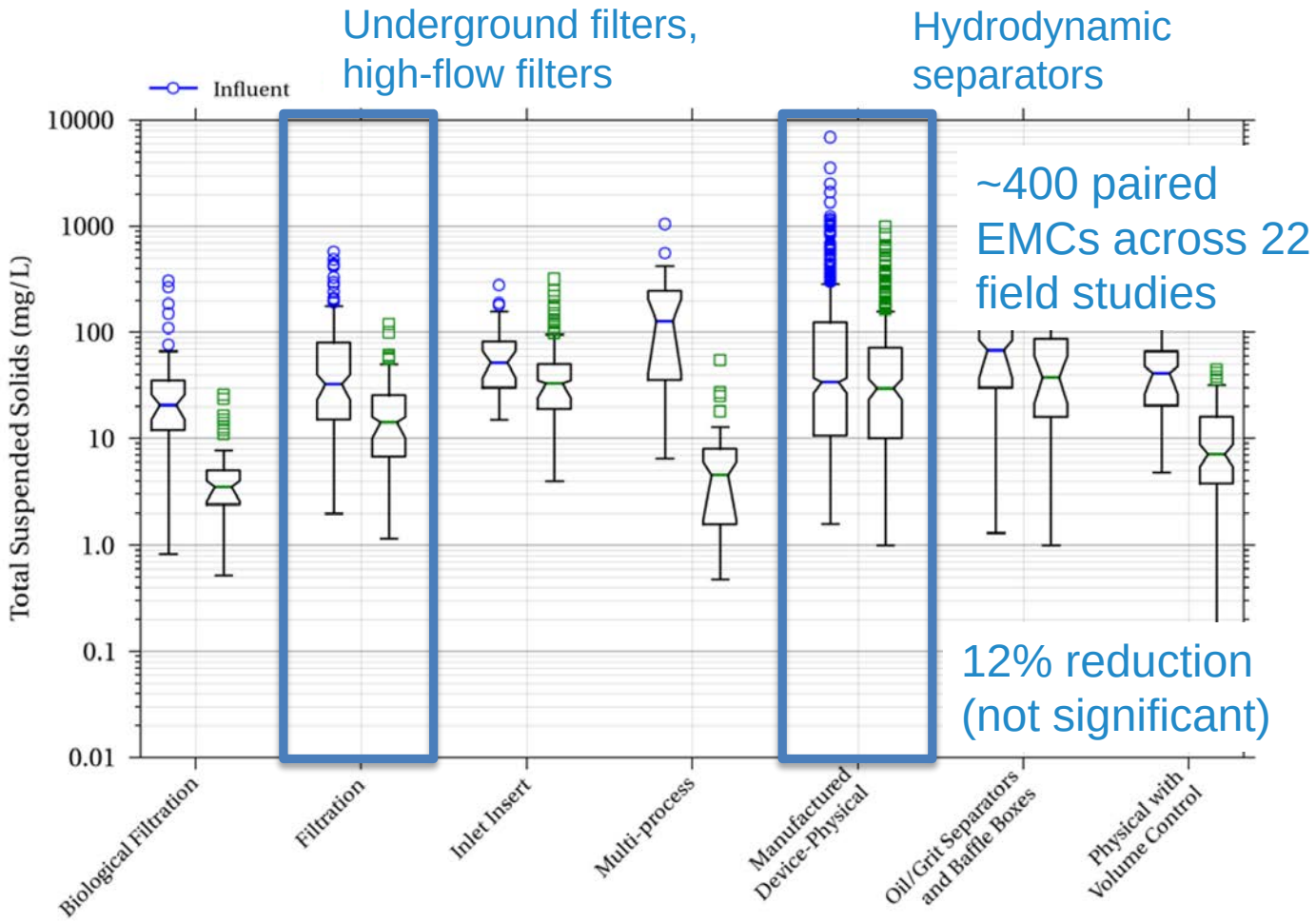
How do MTDs Perform under Field-Measured TSS and PSDs?

- Table 4 practices approved for 80% TSS removal
  - If <100 mg/L influent TSS, effluent must be 20 mg/L or lower
  - 35 mg/L mean TSS from roads in this study
- Question: Do the NJCAT lab testing results translate to the field?

International Stormwater BMP Database

- Database of field monitoring studies of stormwater BMPs from across the USA
- Over 700 BMP studies performed by researchers and municipalities
  - Report every 3-5 years with performance summaries
  - Manufactured treatment device report (2012)
  - http://www.bmpdatabase.org/

MTD TSS Performance



Source: International Stormwater BMP Database MTD Report (2012)

MTD TSS Performance

BMP Type	Median (95% Conf. Interval)*	
	In	Out
Biological Filtration	20.5 (15.5, 25.9)	**3.5 (2.5, 4.0)****
Filtration	32.3 (23.0, 40.0)	**14.2 (10.0, 15.0)****
Inlet Insert	51.7 (37.0, 67.0)	**32.9 (24.0, 35.0)****
Multi-process	127.4 (41.0, 206.0)	**4.5 (1.7, 6.0)****
Manufactured Device-Physical	33.6 (26.8, 37.0)	29.7 (23.4, 36.0)
Oil/Grit Separators and Baffle Boxes	67.6 (35.2, 84.0)	37.3 (21.2, 59.8)**
Physical with Volume Control	41.2 (26.8, 47.6)	**7.1 (5.4, 8.8)****

Very similar influent concentrations to mean 35 mg/L observed in this study

BMPs & TSS Treatment Efficiency

Charters et al. (2015)

Treatment system	Reference	Particle size range (μm)	Percentage removal (%) [min. – max.; mean]	
Median d_{50} = 70 μm from roads in New Zealand				
Hydrodynamic separator (experi performance)	Using measured PSDs in this study, percent TSS removal would be:	<70	0%	
		70–150	19–21%	
		150–250	41–69%	
		250–425	58–87%	
		>425	95–100%	
		Total TSS Removal (%)		**12-15%**
Dry detention basin		<8	57–75%	
		8–20	84–91%	
		20–100	84–95%	
		>100	100%[a]	
		Total TSS Removal (%)		**87-95%**
Pond and wetland		<2	84%	
		2–63	96%	
		63–2000	100%	
		>2000	100%	
		Total TSS Removal (%)		**97%**

Hydrodynamic Separator	13
Dry Detention	89.5
Wet Pond/Wetland	97.1

Region Conservation Authority (2002)

For HDS units, 10-15% TSS removal would not reduce TSS concentrations from 35 mg/L to 20 mg/L.

Closing Thoughts

- For 176 storm events samples:
  - Mean TSS concentrations from Ohio's roads were 35 mg/L
  - Particle size distribution was similar to NJCAT distribution
    - d_{50} = 52.5 µm
    - d_{20} = 22.1 µm
  - NJCAT testing does not seem representative of field conditions
  - Should always test devices under field conditions

Closing Thoughts

- Gross solids volume: ¼ gallon to 20 gallons every 11.6 days
  - 63-95% by volume is vegetation
  - Gravel/aggregate, cigarettes, plastic next most common (all <15% by volume)
- Gross solids mass: 0.1 lbs to 62 lbs every 11.6 days
  - Presence of large amounts of vegetation related to mowing of right-of-way and leaf-drop in the autumn (targeted maintenance?)

Closing Thoughts

- Average TSS loading rate 242 lb/ac/yr
- Average gross solids loading rate 150 lb/ac/yr
  - Thus, TSS represents 62% and gross solids 38% of the total measured solids

Questions?

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