OHIO DEPARTMENT OF TRANSPORTATION

Pollutant Removal Effectiveness of Vegetated Biofilters, Exfiltration Trenches and Vegetated Filter Strips for Linear Project Applications

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Vegetated Biofilter Research

Definition of Vegetated Biofilter

- A Vegetated Biofilter (VBF) is a Best Management Practice (BMP) that filters storm water through vegetation. The vegetated biofilter consists of the vegetated portion of the graded shoulder, vegetated slope, and vegetated ditch.
  - ODOT Location and Design Manual Vol. 2 Section 1117.3

Research objectives

- Examine the slope portion of the vegetated biofilter to evaluate capture and treatment of the water quality volume (runoff from first 0.75 in (19 mm) of rain) for highway storm runoff in terms of performance in removing typical roadway runoff contaminants.
  - Impact of slope on performance
  - Accumulation of contaminants in the foreslope soil and vegetation
  - Suitability of foreslope designs to accommodate different concentrations of runoff and/or intensity of storms
  - Potential resuspension of particles
  - Effectiveness under dormant conditions

Brief Summary of Experimental Method

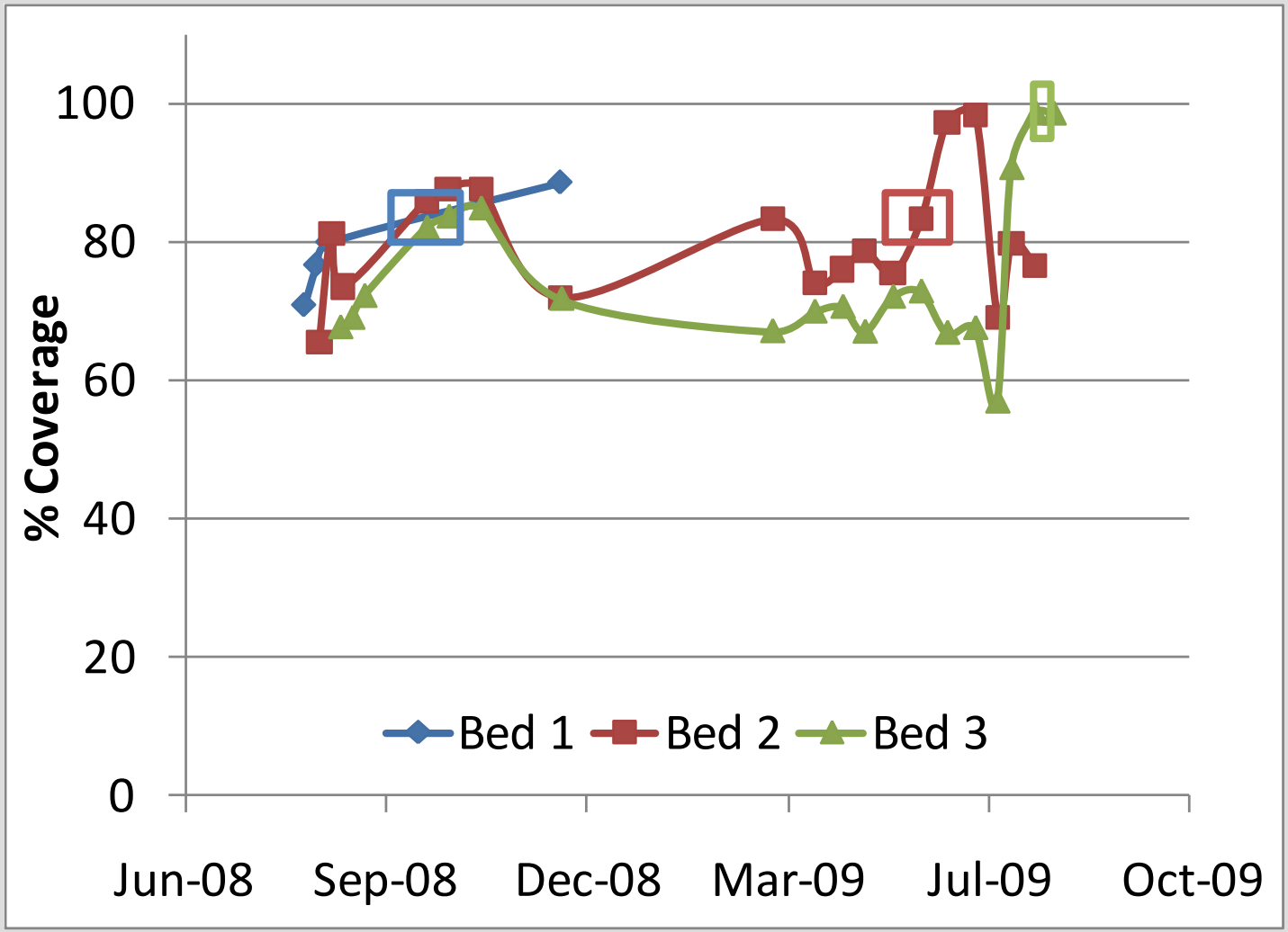
- Construct prototype vegetated biofilters
- Monitor grass coverage
- Formulate artificial runoff
- Apply artificial runoff at varying pollutant concentrations in simulated storm events
- During simulated storm events, collect samples from influent, surface runoff, and underdrain at selected intervals
- Analyze collected samples for concentrations of pollutants
- Collect specimens of grass, roots, and soil from bed and determine amount of pollutants in each

Construction of beds

Construction of beds (ctd)

Grass Coverage – Standard ODOT grass seed mix (ODOT specification 659.09, Slope Mixture 3B)

Seed spread at 4.66 lb/1000ft^2 (22.8g/m^2)



Formulation of artificial runoff and simulated storm events

Artificial Runoff Composition

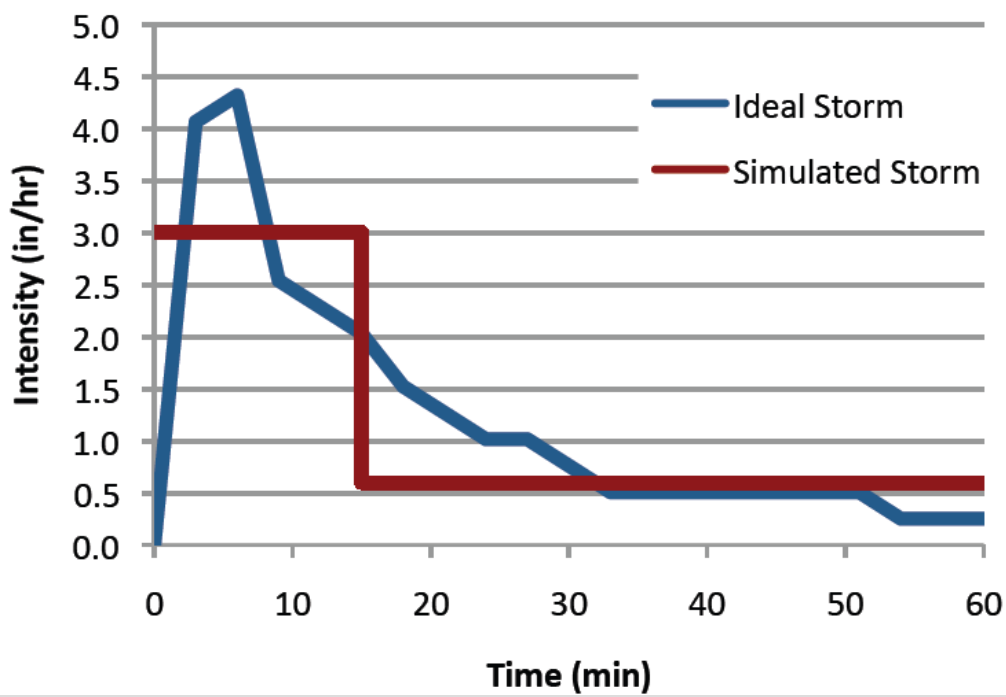
		Total metals								Chlorides	Oil &
	Contaminant	Cd	Cr	Cu	Fe	Ni	Pb	Zn	A-6 TSS	(NaCl)**	Grease
	concentration	(µg/L)	(µg/L)	(µg/L)	(µg/L)	(µg/L)	(µg/L)	(µg/L)	(mg/L)	(mg/L)	(mg/L)
Values from literature (see report for sources)	5th percentile	.05	1	3	249	2	1	7	9		0.4
	Mean	2	6	55	7719	9	271	425	207		5
	95th percentile	6	17	179	16500	30	1133	1660	737		17
Detection Limit		4	5	7	3	19	43	4	-		
Tap Water		<5	<5	<9	84	<18	<43	16	-	50	
Values used for artificial runoff	Low Target	20	25	35	250	95	215	10	9	50	-
	Medium Target	100	125	175	7700	475	1075	425	207	262	5*
	High Target	500	625	875	16500	2375	5375	1700	737		20*

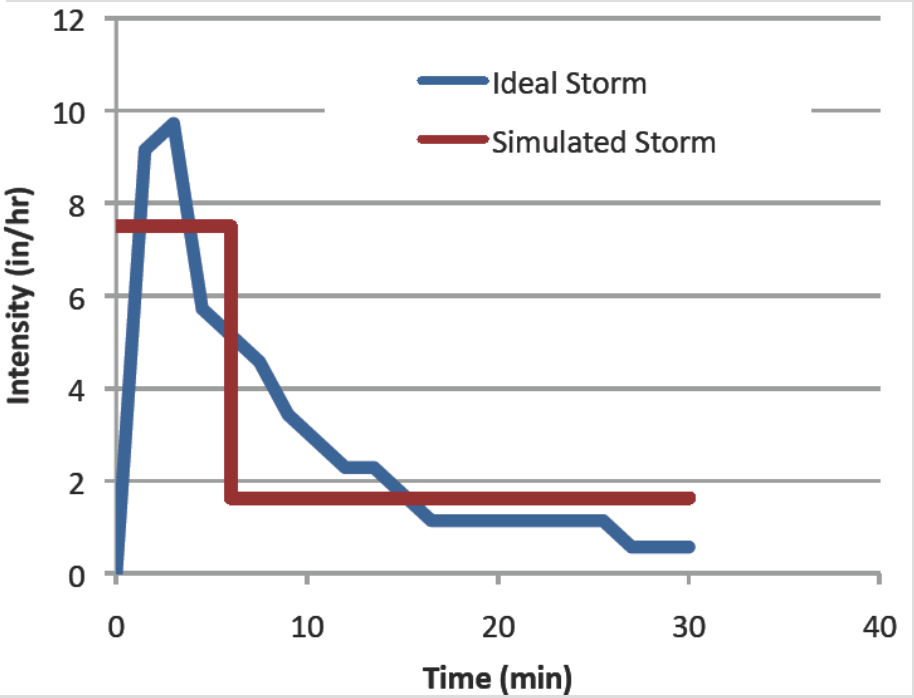
*For Beds 2 & 3 switched to 100 mg/L and 20 mg/L, since levels of 20 mg/L and 5 mg/L did not yield detectable levels of Oil and Grease in effluent samples

**Chlorides applied only during dormant grass experiment

Alkalinity as $CaCO_3$ = 170 mg/L for all levels; pH at 7.0 0.1 for all levels

Simulated Storm Events





Medium Flow Event
2-year Storm

High Flow Event
10-year storm

First portion of storm provides Water Quality Volume = 0.75” (19 mm)

Laboratory Test Matrix

Pollutant concentration	Baseline	8:1	4:1	2:1		Resuspension & Tracer
Slope:						
Flow Rate:		Med	Med	Med	High	
High – Bed 1	9/4/08	9/11/08	9/16/08	9/19-08	9/30/08	10/10-16/08
Med. – Bed 2	5/11/09	5/15/09	5/21/09	5/28/09	6/16/09	6/24-27/09
Low – Bed 3	7/27/09	7/28/09	7/30/09	8/4/09	8/6/09	8/11-13/09
Dormant Medium	3/15/10	3/17/10	3/17/10	3/19/10	-	-

Photographs of experiments

Photographs of experiments

Influent tanks

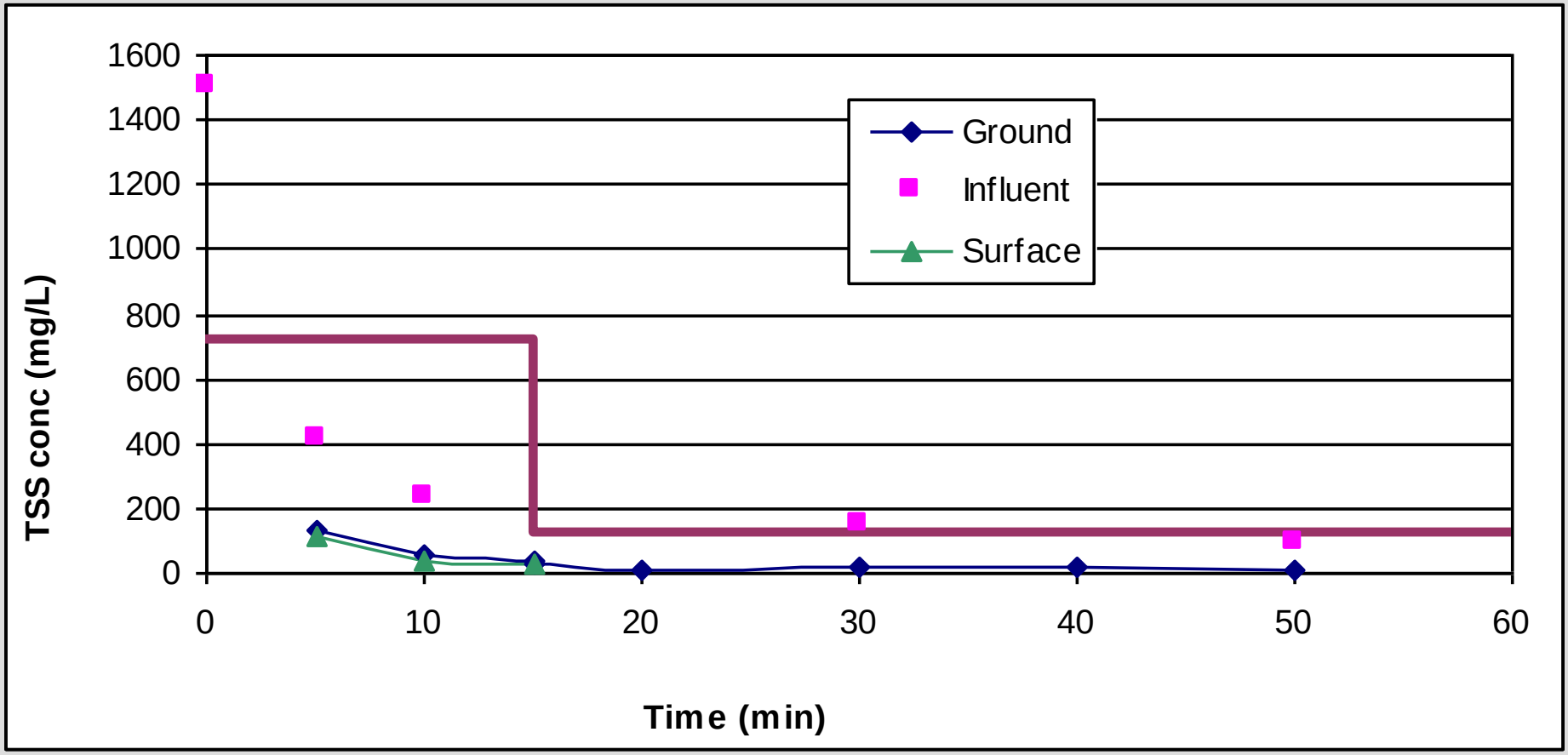
Photographs of experiments

Collecting influent samples

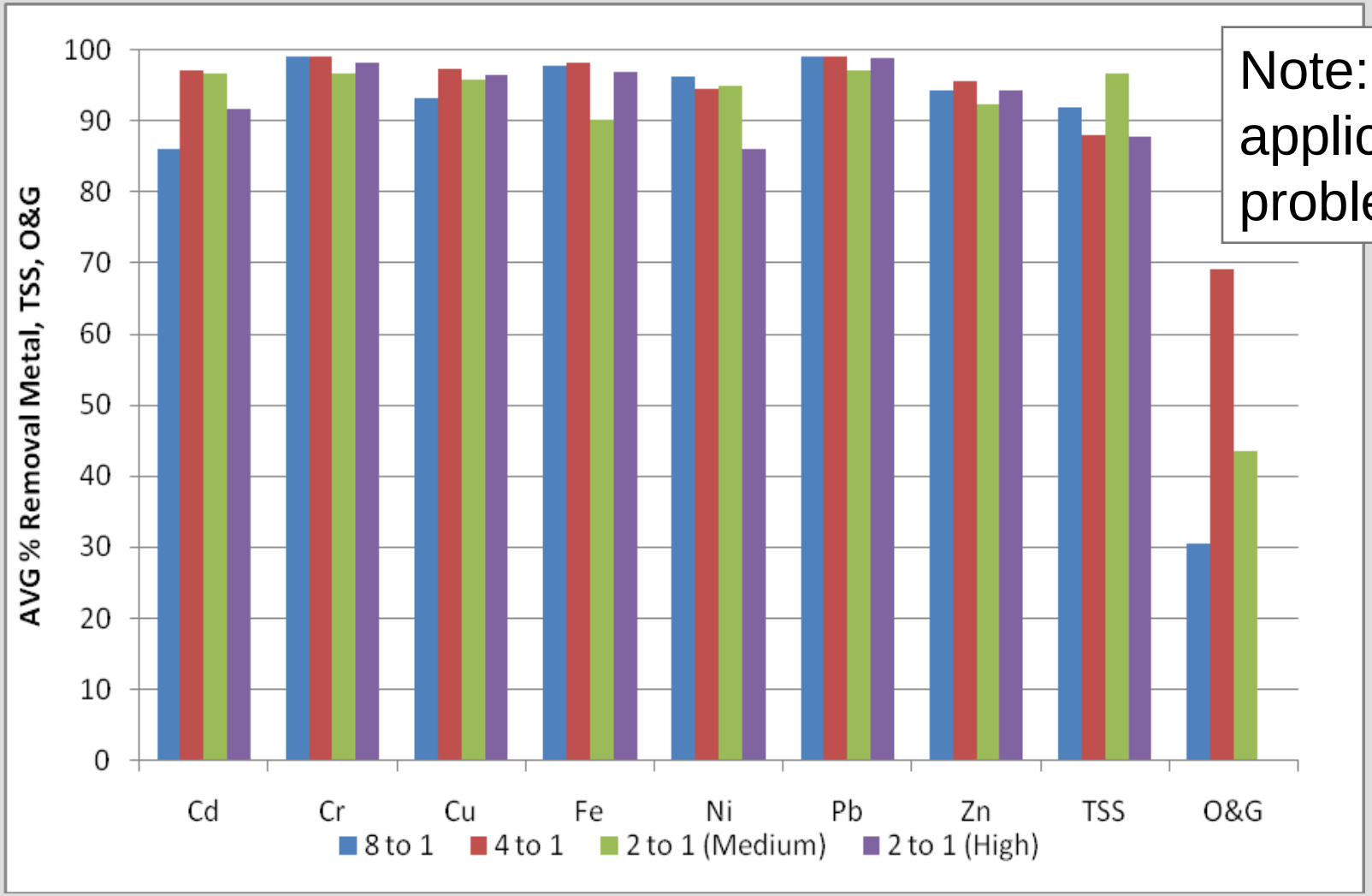
Photographs of experiments

Collecting effluent samples

TSS Concentration
4:1 slope, medium flow, high concentration

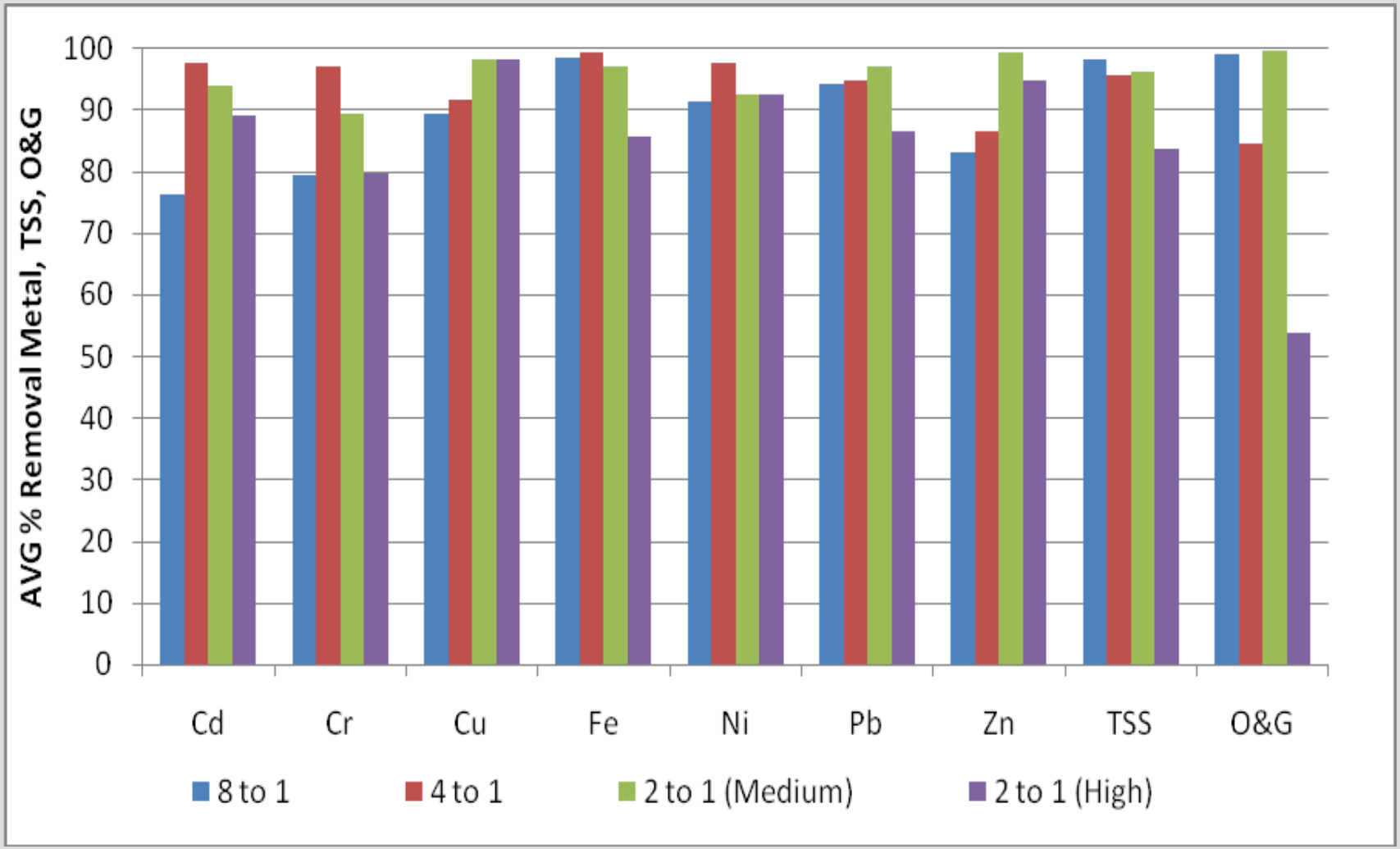


EMC-based removal of constituents
High concentration

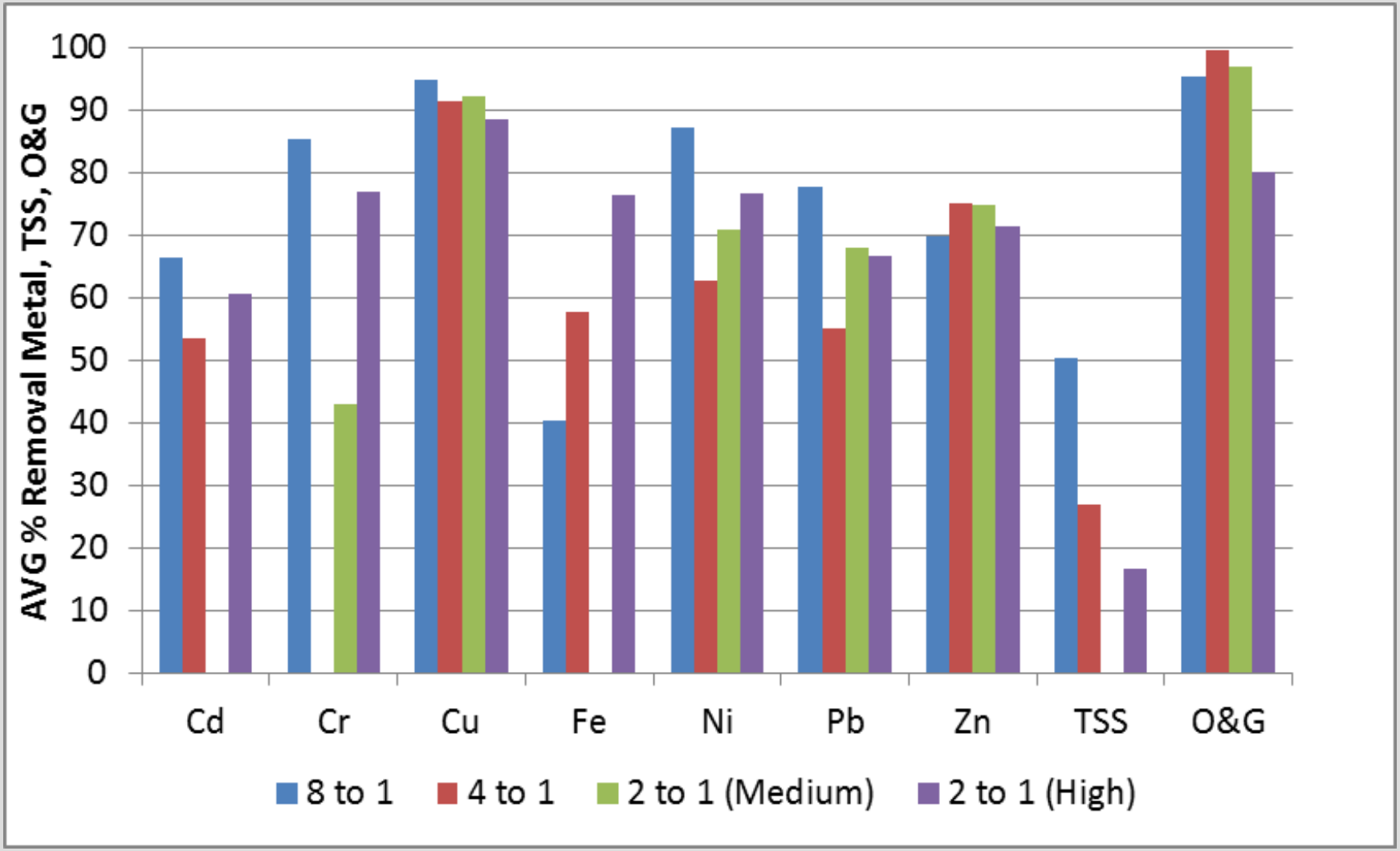


Note: O&G application problematic

EMC-based removal of constituents
Medium concentration



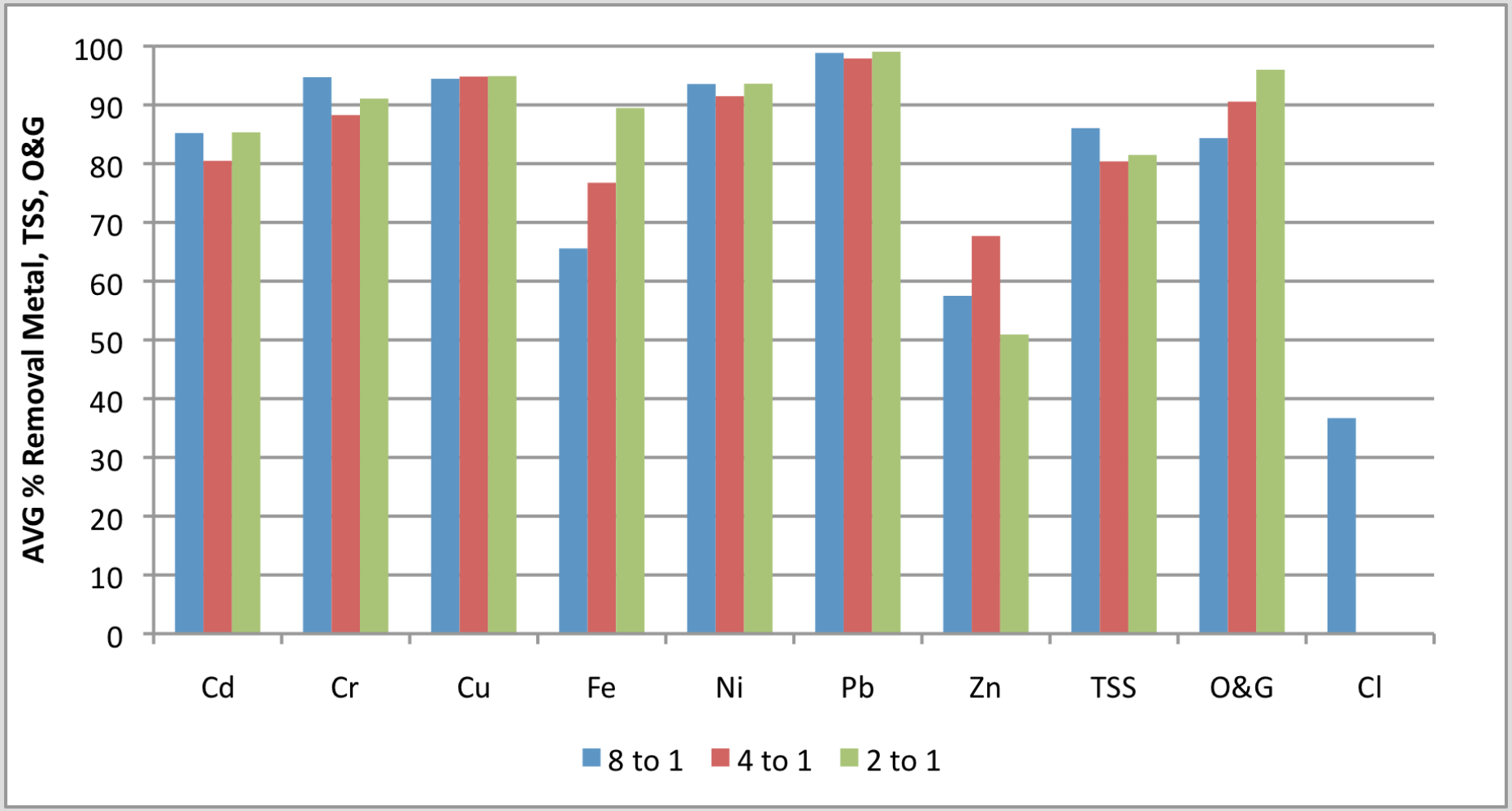
EMC-based removal of constituents Low Concentration



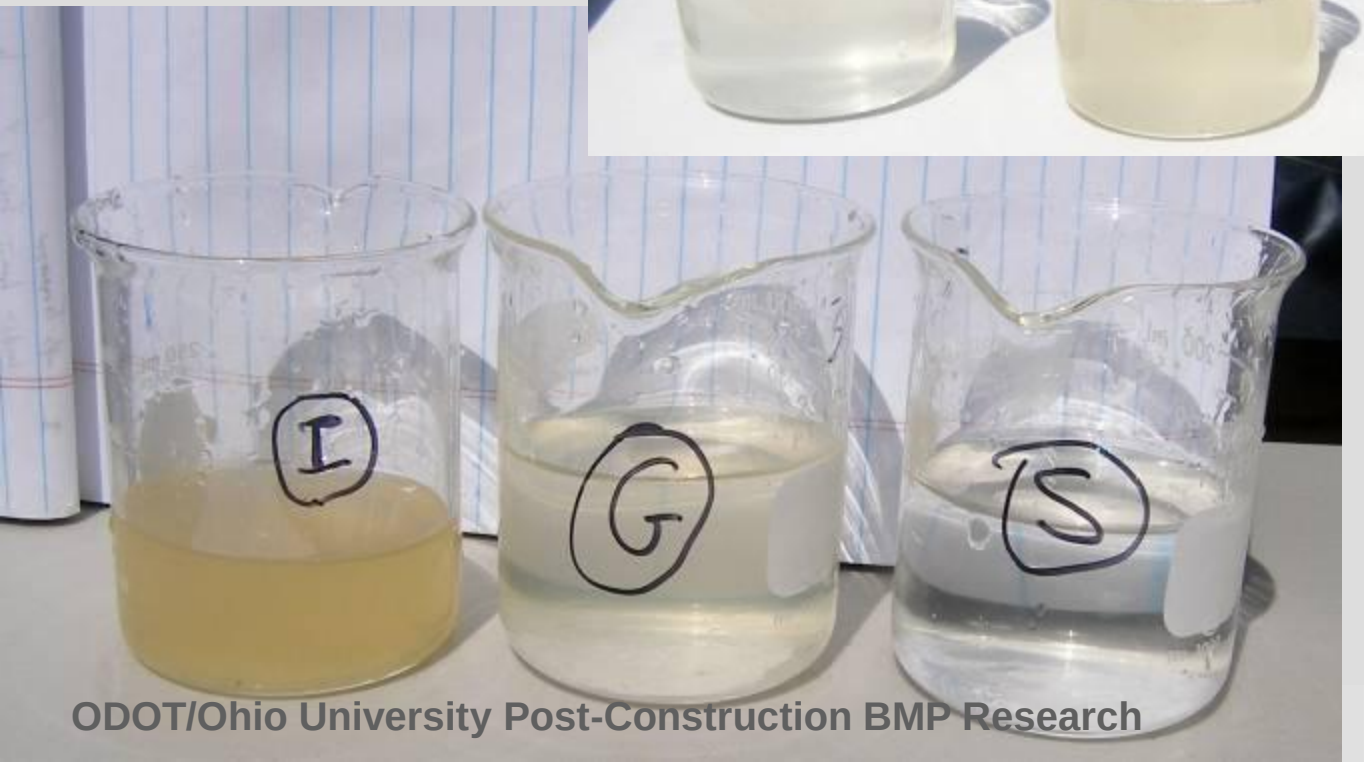
Views of dormant grass in Bed 2

Dormant - EMC-based removal of constituents Medium Concentration

Dormant grass



Photographs of experiments



Influent, Ground (Underdrain), and Surface samples – high concentration

Active Growth Conclusions

- The vegetated biofilter performed well at all slopes (8:1, 4:1, 2:1) and flows (medium and high storm events) at medium and high pollutant (TSS, Cd, Cr, Cu, Fe, Ni, Pb, and Zn) concentrations.
  - High concentration TSS removals were also always above 85%
  - Medium concentration TSS removals were above 95%, except 83% for 2:1 high flow
  - High concentration EMC removals were above 90% for all metals, except Cd at 8:1, Ni at 2:1 high flow, which were above 85%
  - Medium concentration EMC removals were above 80%, except Cd and Cr at 8:1, which were above 75%
- Removals were mixed at low concentrations, which was expected since all treatment processes will have a performance threshold and minimal or no treatment may be provided for a relatively “clean” influent.

Dormant State Conclusions

- Medium concentration simulated stormwater runoff was applied at all three slopes (8:1, 4:1, 2:1)
- Vegetation coverage was 60% (vs. 83% in summer)
- Over 80% removal for most total metals (Cd, Cr, Cu, Ni, Pb)
  - Total Fe about 75% removed
  - Total Zn about 58% removed
- Chlorides only slightly removed at 8:1 slope
- TSS removal about 80% or above
  - Contrasted to about 95% in summer for medium flow events

General Conclusions

- For high concentrations of oil, successful removal was achieved.
- Resuspension tests at the slopes and flow rates studied indicated that resuspension was not an issue.
- The majority of uptake of metals occurred in the vegetated root structure and within the first yard or meter from the inlet.
- Within the parameters of this study, findings indicate that a high coverage foreslope of a vegetated biofilter significantly reduces pollutants.

Vegetated Biofilter Final Report at ODOT website

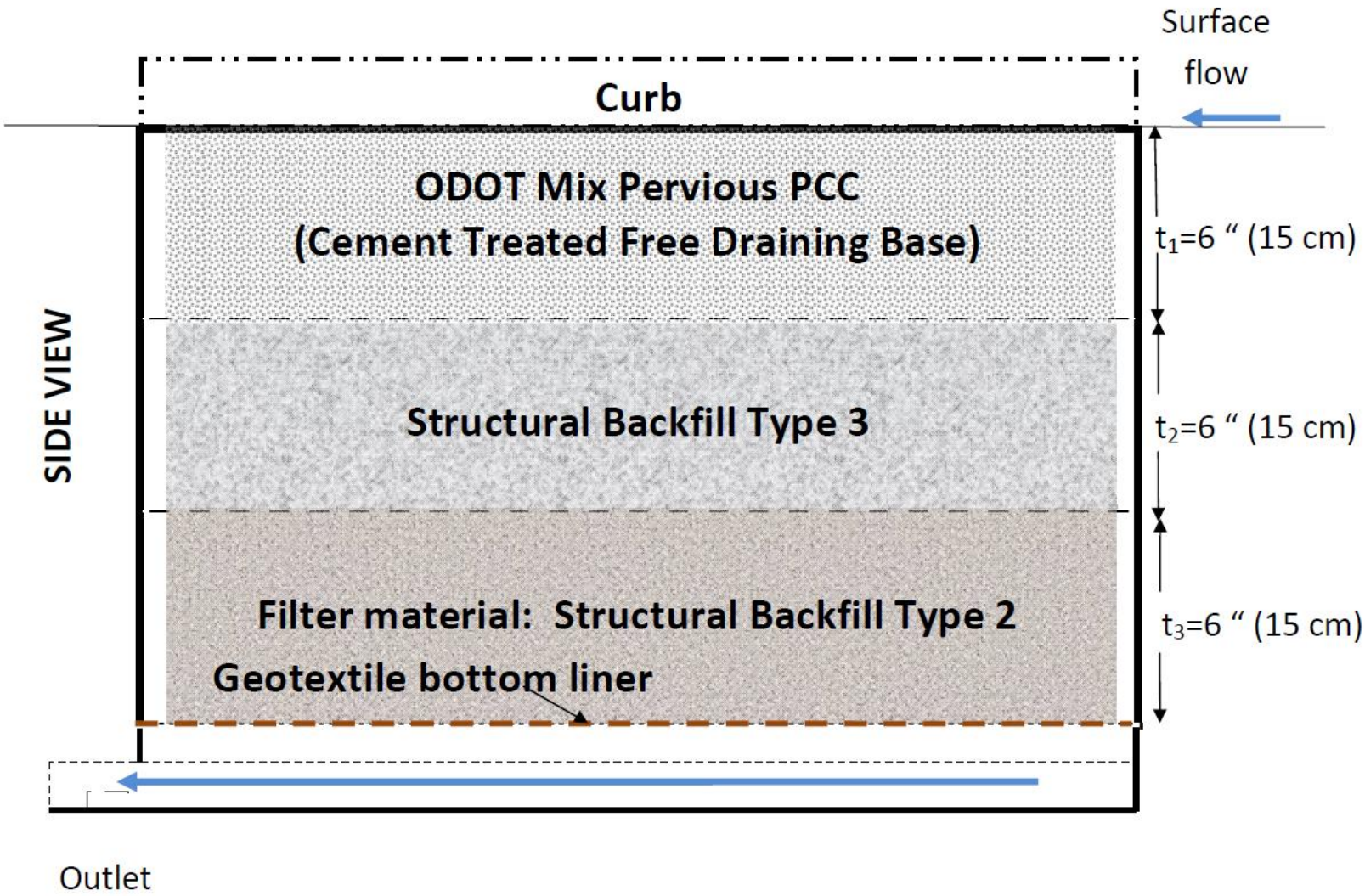
- http://www.dot.state.oh.us/Divisions/TransSysDev/Research/reportsandplans/Pages/HydraulicReportsDetail.aspx#134349
- Under “Hydraulics” at ODOT report web site.

Exfiltration Trench Research

ODOT Definition of Exfiltration Trench

- ODOT Location and Design Manual Volume 2 Section 1117.1: "An exfiltration trench (ExT) captures roadway drainage at the outside edge of shoulder through the use of a permeable concrete surface. Storm water is filtered through the ExT until it reaches a 4-inch perforated conduit connected to a 4-inch nonperforated outlet conduit. The 4-inch outlet conduit may discharge into a drainage structure or onto the slope using a reinforced concrete outlet."

Sketch of Exfiltration Trench



Research Objectives

- Validate the performance of the exfiltration trench porous pavement and filter media in the laboratory
  - Determine performance efficiency as percentage change between effluent and influent concentration
  - Document primary pollutants captured
  - Determine applicable maintenance methods and results
  - Examine durability of porous pavement
- Evaluate performance of exfiltration trenches in the field

Previous Concrete - Test plan (10 specimens)

1. Determine the initial porosity of each specimen using the procedure adapted from Montes, Valavala, and Haselbach [2005].
2. Determine permeability of specimen using clean tap water.
3. Introduce sand-contaminated influent (tap water and sand) to induce clogging; measure permeability
4. Perform mass balance on suspended material
5. Repeat Steps 3-4 until the permeability declines to an asymptotic value.
6. Conduct a “maintenance procedure”: sweeping, vacuuming, or jet washing.
7. Measure the permeability using clean water of the cleaned specimen. In normal field conditions, the permeability of the exfiltration trench top layer would vary between this recoverable permeability value and the steady-state limit permeability.
8. Repeat Steps 1-7 using soil-contaminated influent (tap water and A-6 soil). Use specimens 4-6.
9. Repeat Steps 1-7 using the high, medium, and low concentration artificial storm water. Measure permeability, TSS concentrations, and concentrations of total and dissolved metals. Use specimens 7-9.
10. Repeat Steps 1-9 with ORMCA Mix after finishing ODOT Mix.

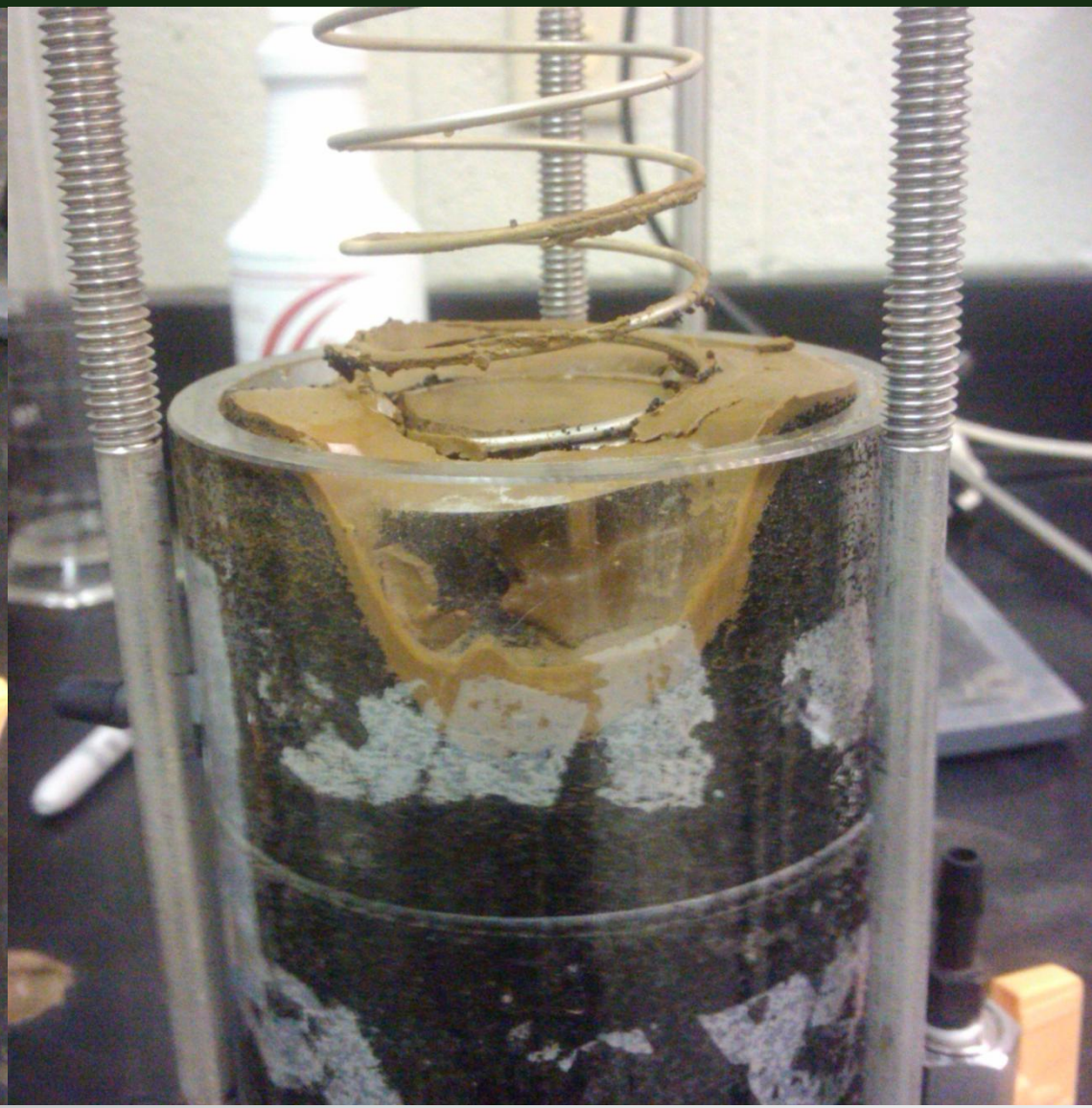
Filter Media

- Media selected for testing
  - ODOT specified sand (Type 2 backfill)
  - Manganese greensand
- Filter Media – Test Procedure
  - Use a constant head permeameter
  - Prepare appropriately sized specimens, based on standard test requirements (2.5 in (6.4 cm) diameter) in test molds; determine volume and density
  - Conduct constant head tests to determine clean water permeability
  - Conduct clogging tests using two different influents (A-6 soil mixed in tap water and artificial runoff)
    - Periodically monitor permeability until it declines to an asymptotic value
    - Determine mass balances

Media specifications

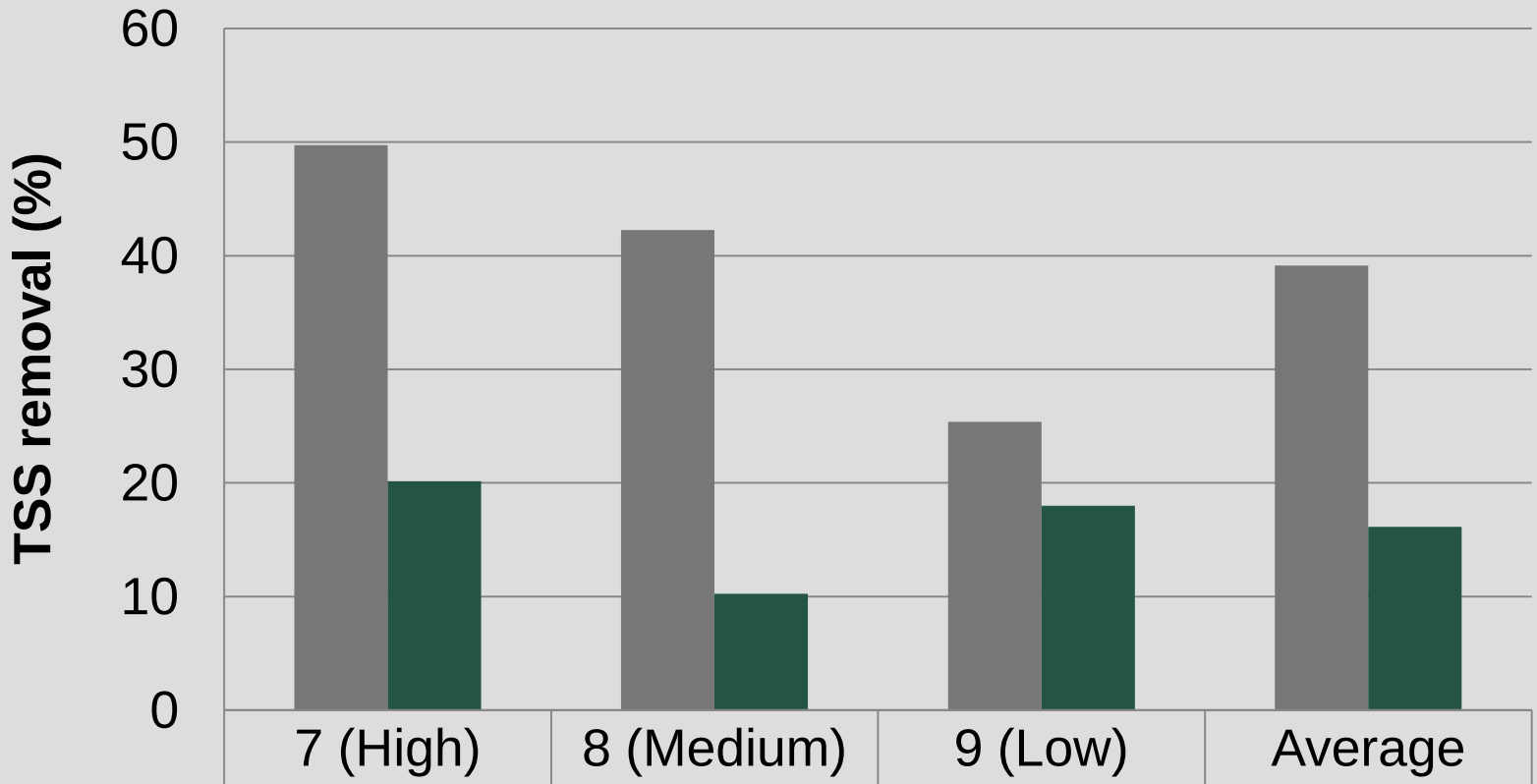
- Sand grain size
  - Effective size: 0.24-0.69 mm
  - Uniformity coefficient 1.7 - 2.7.
  - Initial permeability 0.061±0.002 cm/s
- Greensand grain size
  - Effective size: 0.3 – 0.35 mm
  - Uniformity coefficient is smaller than 1.6.
  - Initial permeability 0.121±0.015 cm/s

Testing with artificial runoff



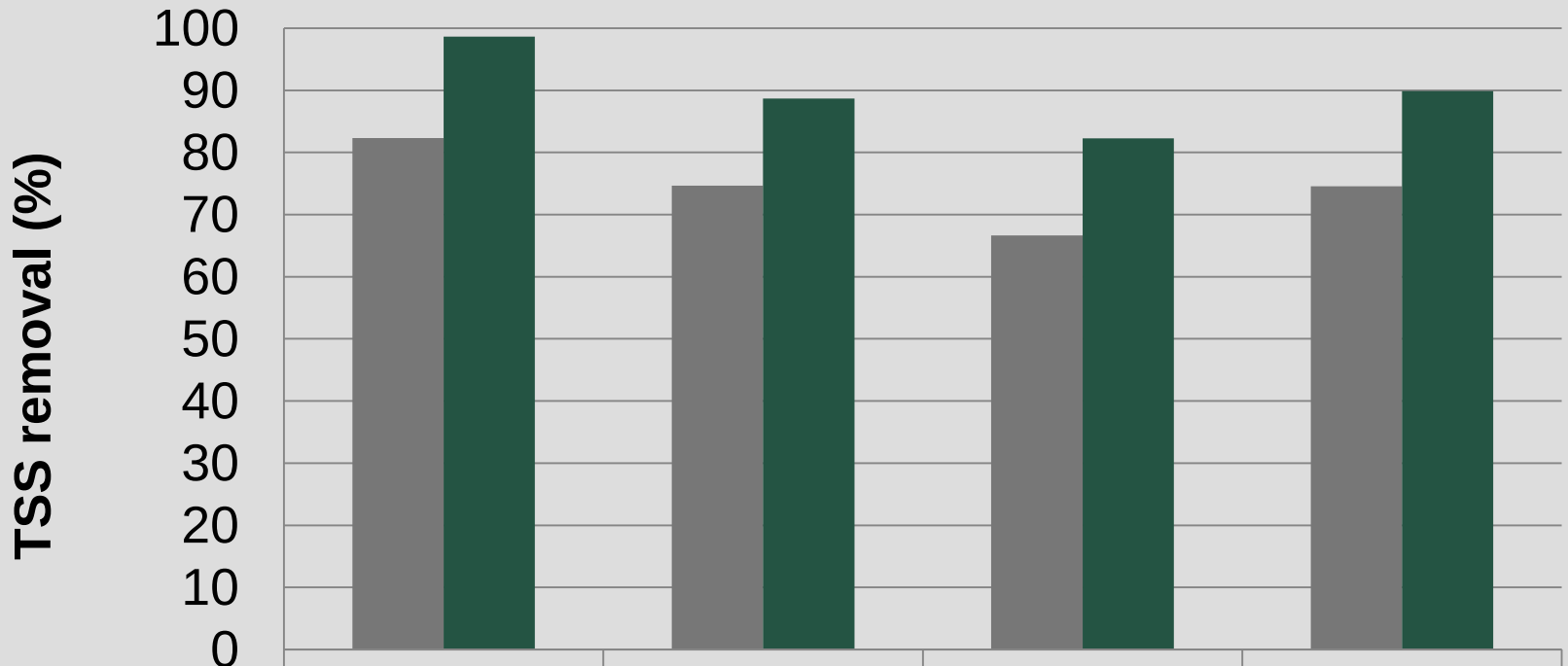
Removals

Removals of TSS from artificial runoff by pervious concrete



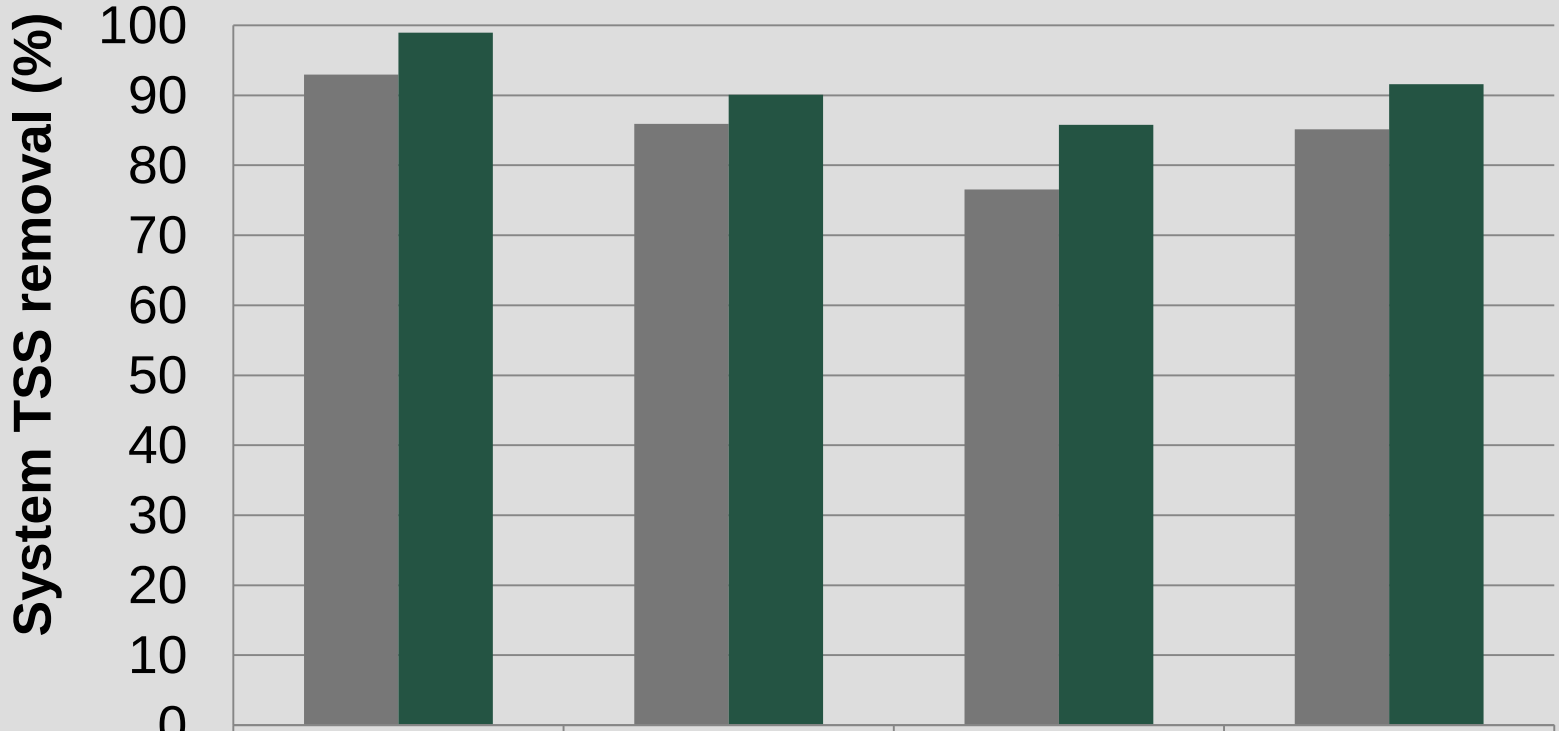
	7 (High)	8 (Medium)	9 (Low)	Average
ODOT	49.74	42.26	25.38	39.13
ORMCA	20.15	10.23	17.98	16.12

Removals of TSS from artificial runoff by filter media



	7 (High)	8 (Medium)	9 (Low)	Average
Sand	82.33	74.66	66.67	74.55
Greensand	98.63	88.71	82.28	89.87

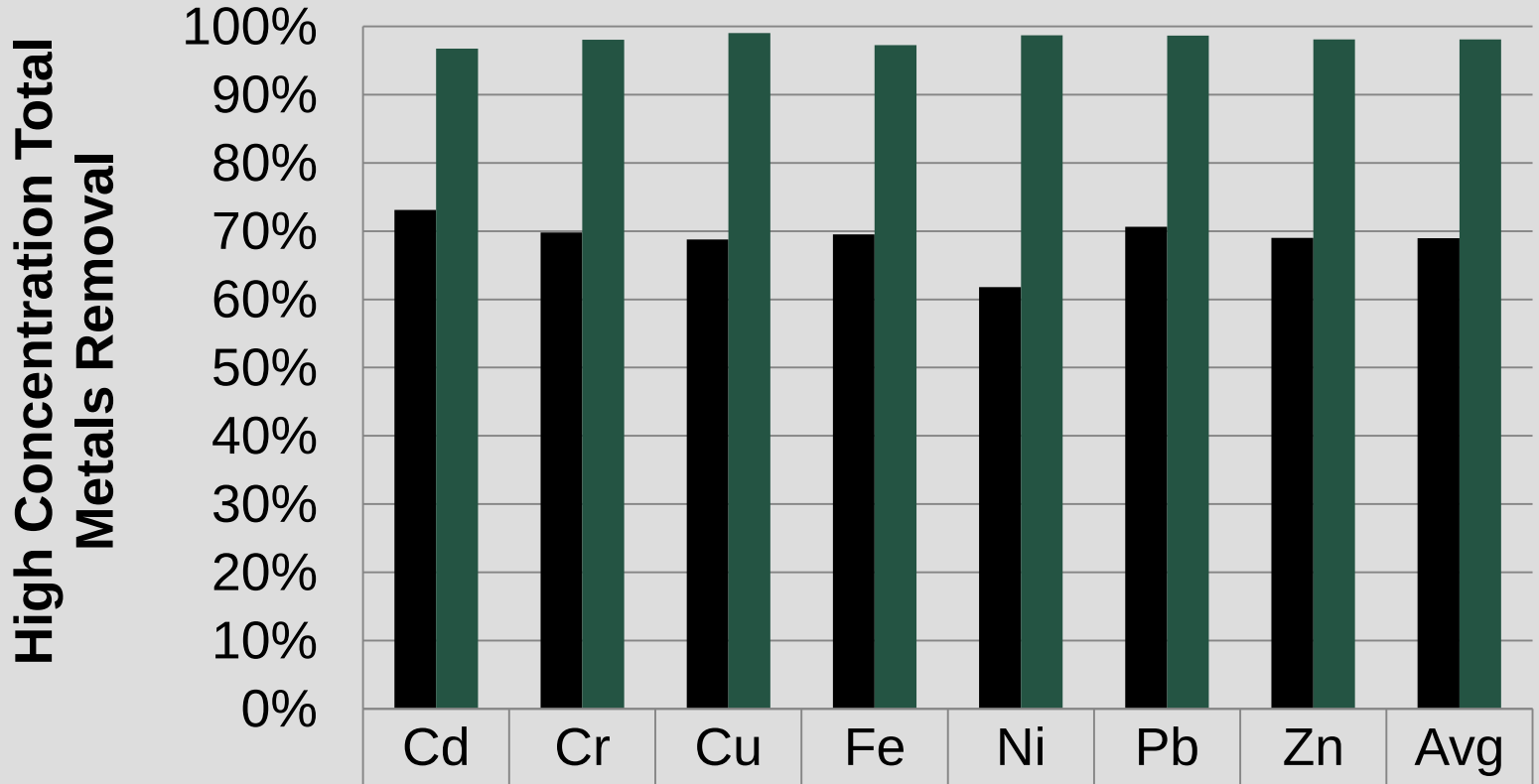
Removals of TSS from artificial runoff by composite system



	7 (High)	8 (Medium)	9 (Low)	Average
ODOT/Sand	92.95	85.93	76.53	85.14
ORMCA/Greensand	98.93	90.08	85.77	91.59

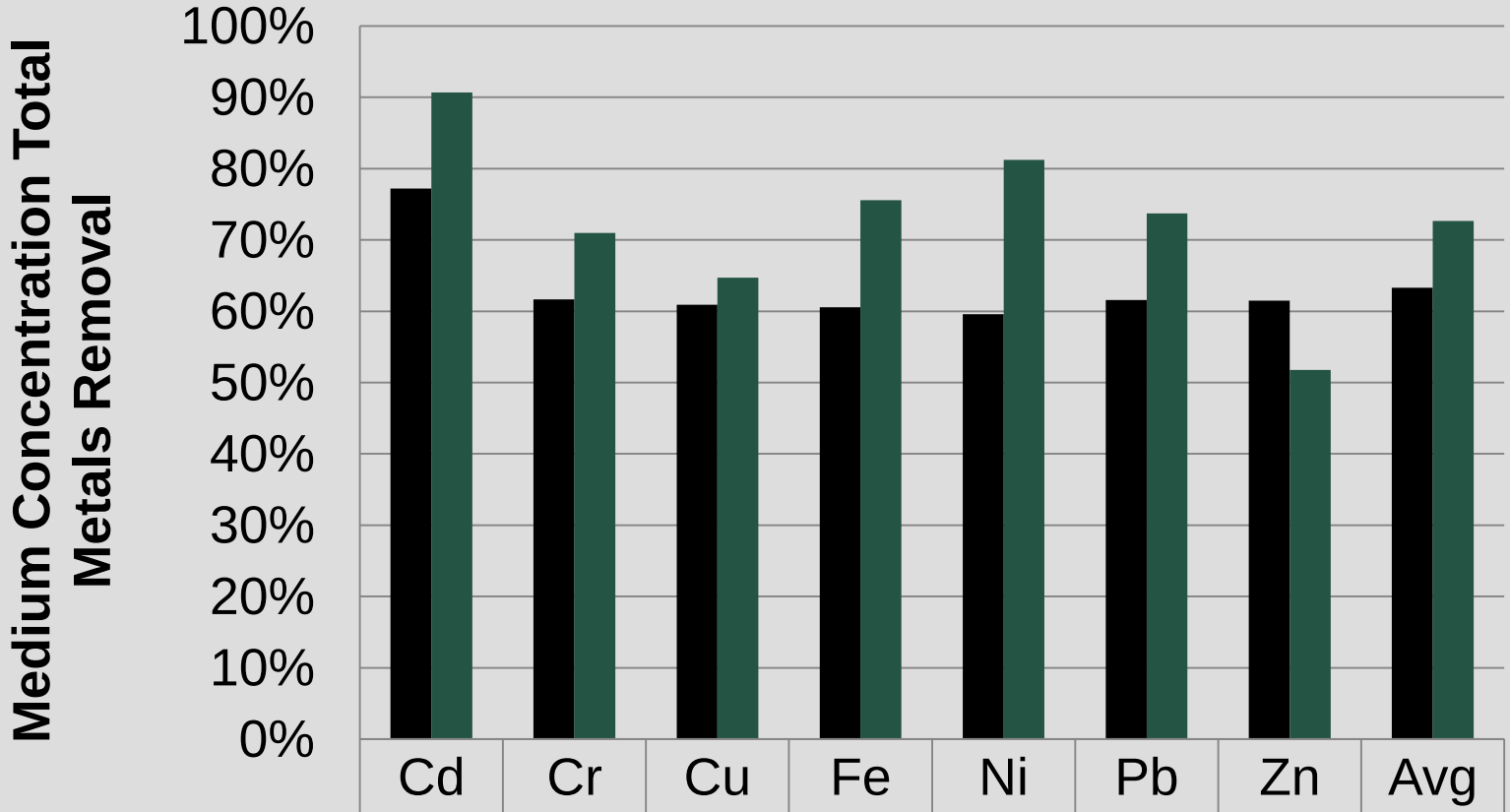
Medium Concentration test results

High concentration total metals removals Complete system



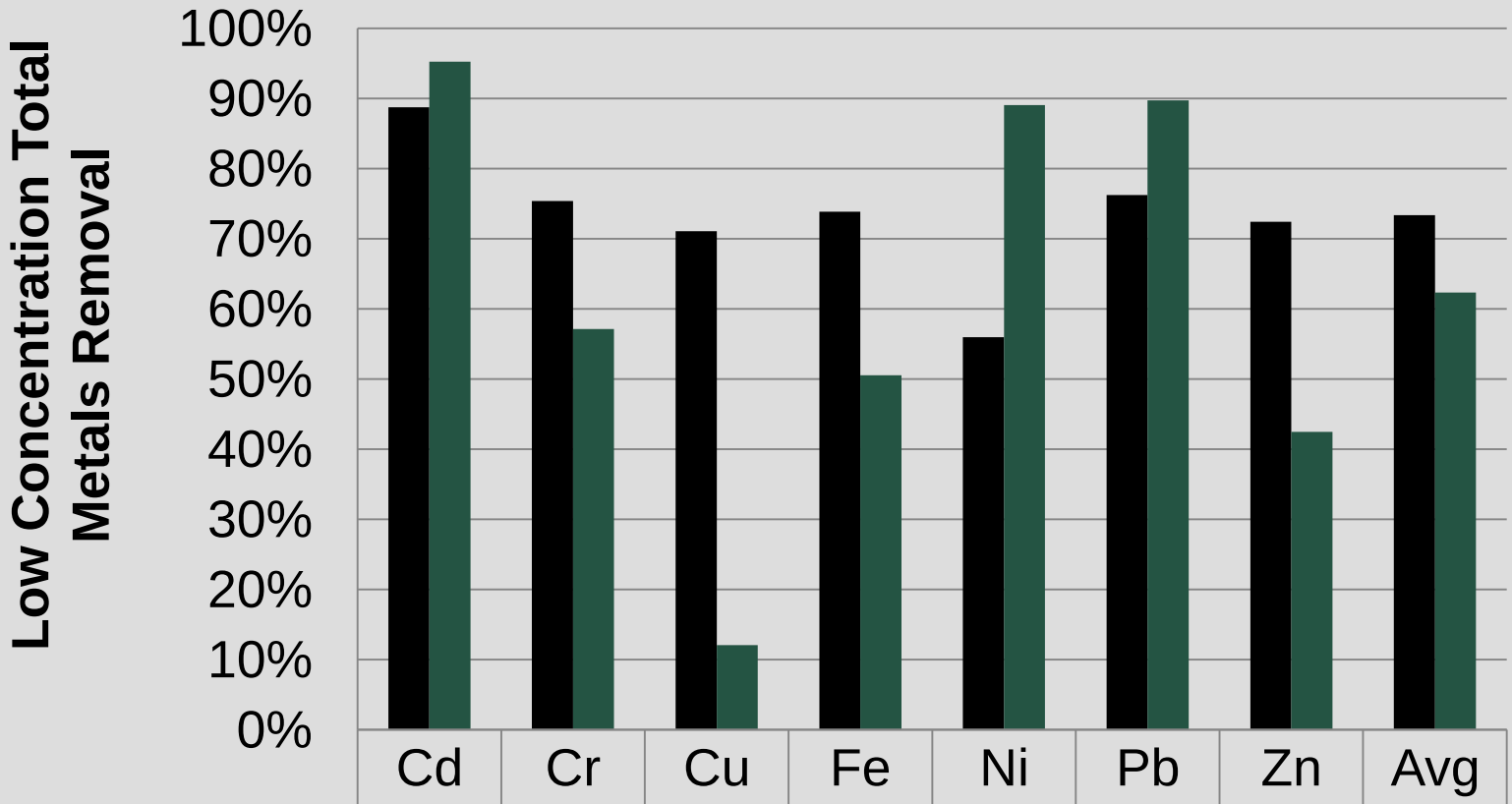
	Cd	Cr	Cu	Fe	Ni	Pb	Zn	Avg
ODOT/Sand	73.10	69.82	68.79	69.53	61.81	70.64	69.00	68.95
ORMCA/Greensand	96.75	98.02	99.05	97.26	98.68	98.67	98.11	98.08

Medium concentration total metals removals Complete system



	Cd	Cr	Cu	Fe	Ni	Pb	Zn	Avg
ODOT/Sand	77.23	61.66	60.90	60.57	59.57	61.59	61.46	63.28
ORMCA/Greensand	90.67	70.97	64.71	75.56	81.24	73.70	51.75	72.66

Low concentration total metals removals Complete system



	Cd	Cr	Cu	Fe	Ni	Pb	Zn	Avg
■ ODOT/Sand	88.72	75.37	71.10	73.84	55.98	76.22	72.44	73.38
■ ORMCA/Greensand	95.23	57.13	12.05	50.53	89.07	89.75	42.45	62.32

Summary and Conclusions for Laboratory Study

- ODOT pervious concrete mix performed better than the ORMCA mix in removing particulate matter in the form of sand (61% compared to 39%) as well as particulates from an artificial runoff (25-50% compared to 10-20%)
- Composite system TSS removals from artificial runoff were about 85% for the ODOT Mix + sand system and 92% for ORMCA Mix + greensand

Summary and Conclusions for Laboratory Study

- Composite system metals removals from artificial runoff depended on the metal and concentration level. For total metals (Cd,Cr,Cu,Fe,Ni,Pb,Zn) removals through the ODOT pervious concrete-sand composite system typically averaged 66-73%
- Maintenance (sweeping, vacuuming and power washing) recovered
  - About 20% permeability from sand-clogged pervious concrete
  - About 80% to original permeability from pervious concrete receiving A-6 soil

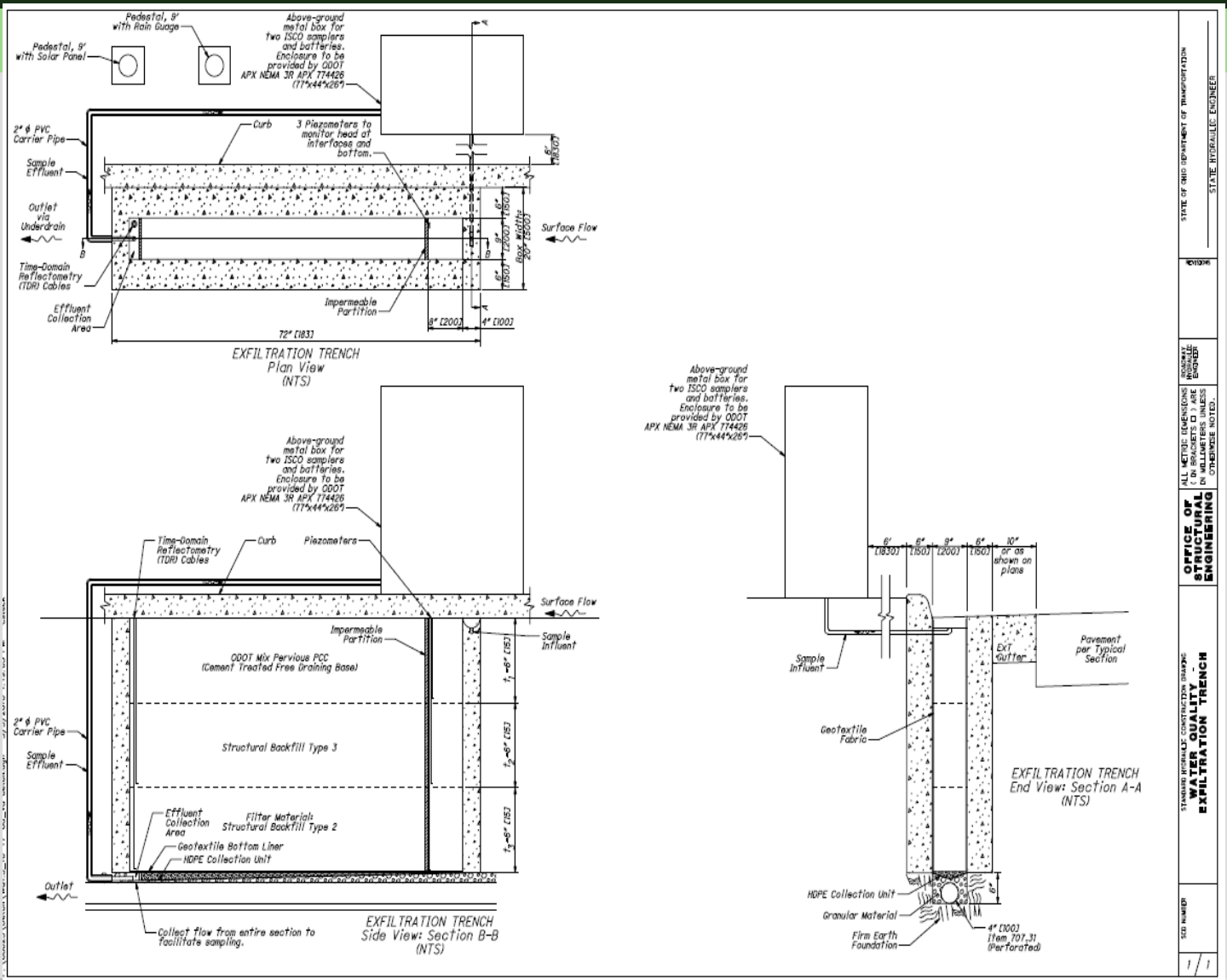
Recommendations from Laboratory Study

- If the pervious concrete layer can be cleaned or rinsed prior to installation, this should be done to improve longevity and postpone potential clogging in the filter
- In order for the system to perform well in its initial operation, the Type 3 aggregate and Type 2 filter sand should be washed prior to placement

Field Research Plan

- Study two sites for one full year
  - First site SR7 Reno OH, started August 6, 2010
    - Standard ODOT design with instrumentation
    - Asphalt pavement with concrete curb.
  - Second site US Route 50A Interchange at Columbus Road, Athens OH
    - Modified design based on laboratory research results
    - Estimated to start late summer/early fall 2011

Instrumentation and design for first installation



Unveiling the empty exfiltration trench hole

The Contractor had already filled hole with sand and aggregate layers, which were removed to install the exfiltration trench for this study.

Dimensions: 9.75 in wide, 18 in deep, 16 ft long

Installing Type 2 filter layer

5 10:

5 10:34AM

Pervious concrete layer

The finished Exfiltration Trench

Instrumentation cabinets and rain gauge

Pro-Pak sample collection bags in sampler
Rain gauge

Questions