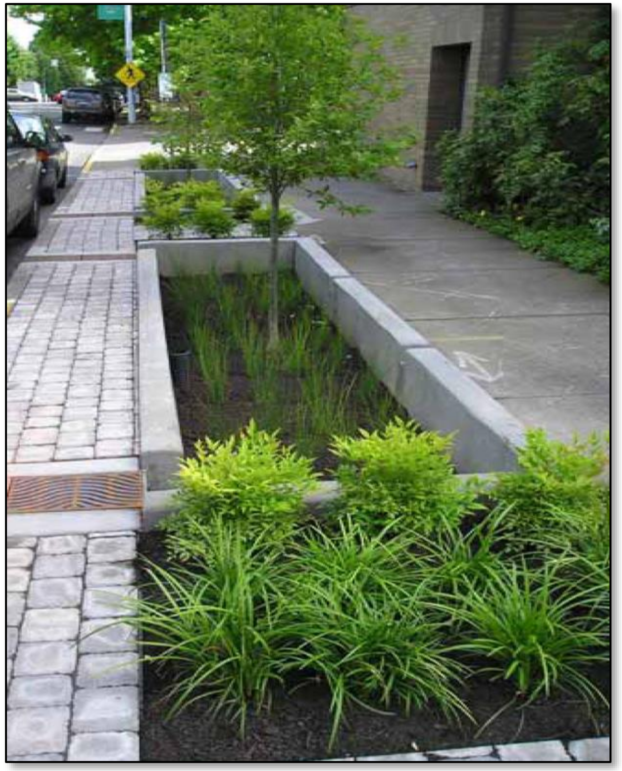
Laboratory Analysis of Stormwater Control Measure Mass Load Capacity and Long-Term Performance

Ocean Protect Webinar- Craig Fairbaugh - 7/28/22



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Background

- Stormwater: only major source of surface water pollution that is increasing in the U.S[1]
- Stormwater Control Measures (SCM)
- Bioretention (BRT)
- High Rate Biofiltration (HRBF)

Midwest bioretention cell[2].

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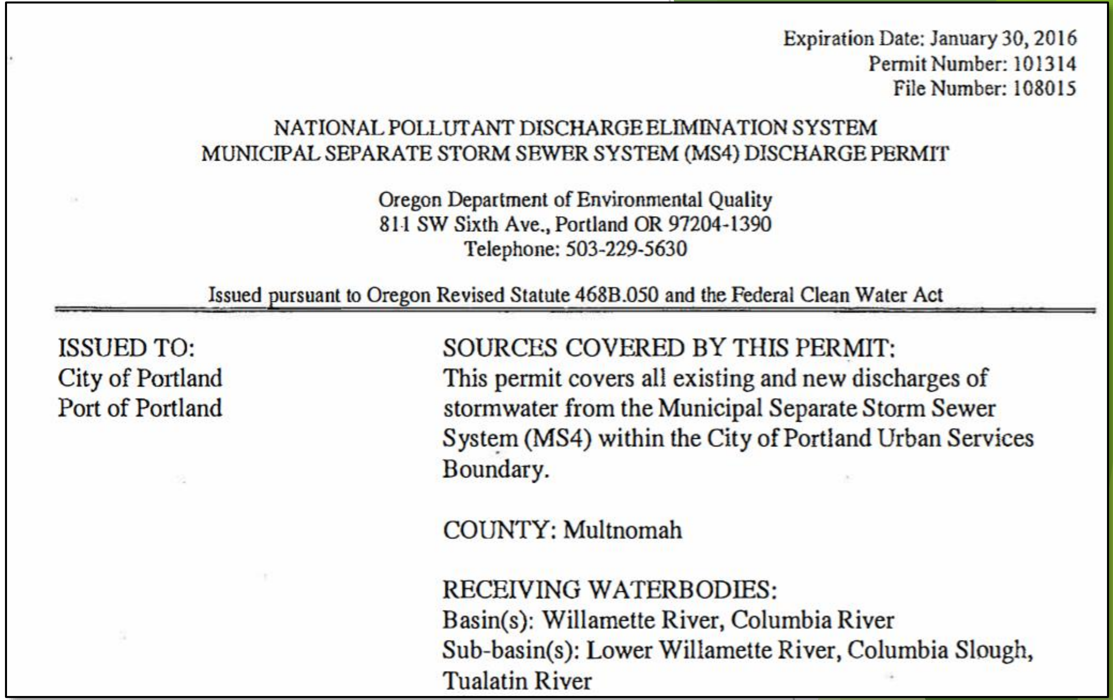
Background

- **Numeric reduction targets**
  - 80% Total Suspended Solids (TSS) removal
- **Performance Verification**
  - Public domain devices – academic research based
  - Manufactured Treatment Devices (MTDs)
    - Testing protocols
    - WA Dept Ecology TAPE[4] - field
    - NJ DEP[5] - lab
- **STEPP[6]**
  - ASTM Committee E64 on Stormwater Control Measures[7]



Expiration Date: January 30, 2016
Permit Number: 101314
File Number: 108015

NATIONAL POLLUTANT DISCHARGE ELIMINATION SYSTEM
MUNICIPAL SEPARATE STORM SEWER SYSTEM (MS4) DISCHARGE PERMIT

Oregon Department of Environmental Quality
811 SW Sixth Ave., Portland OR 97204-1390
Telephone: 503-229-5630

Issued pursuant to Oregon Revised Statute 468B.050 and the Federal Clean Water Act

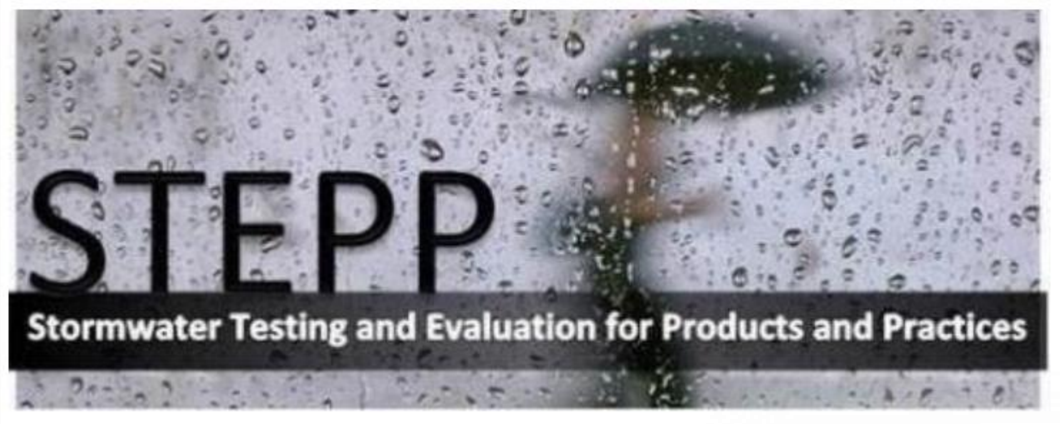
ISSUED TO:
City of Portland
Port of Portland

SOURCES COVERED BY THIS PERMIT:
This permit covers all existing and new discharges of stormwater from the Municipal Separate Storm Sewer System (MS4) within the City of Portland Urban Services Boundary.

COUNTY: Multnomah

RECEIVING WATERBODIES:
Basin(s): Willamette River, Columbia River
Sub-basin(s): Lower Willamette River, Columbia Slough, Tualatin River

City of Portland Municipal Separate Storm Sewer Permit (MS4)[3].



http://nationalstormwateralliance.org/stepp/

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Background

- Q: What about achieving pollutant reduction *over time?*
- A: maintenance

- Q: How do we enforce and test systems for maintenance?

Bioretention system with clogged media and standing water[8].

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Background

- NJDEP sediment loading protocol
  - Allen et al., 2020: TAPE vs NJDEP
- Need additives to better represent constituents in real stormwater?

Technology Name	Approved Hydraulic Loading Rate	
	TAPE Basic Treatment GULD	NJDEP 80 % TSS Removal Certification
BayFilter Enhanced Media Cartridge	0.5	0.5
Kraken Stormwater Filtration System	0.05	0.05
PerkFilter Media Filtration System	1.5	2.54
Up-Flo Filter with 285R Filter Ribbon Media	0.8	1.26
BioPod Biofilter with StormMix Media	1.6	1.8
Filterra Bioretention System	1.82	1.45
Filterra HC	-	3.11

Comparison of certified hydraulic loading rates for filtration manufactured treatment devices[9]

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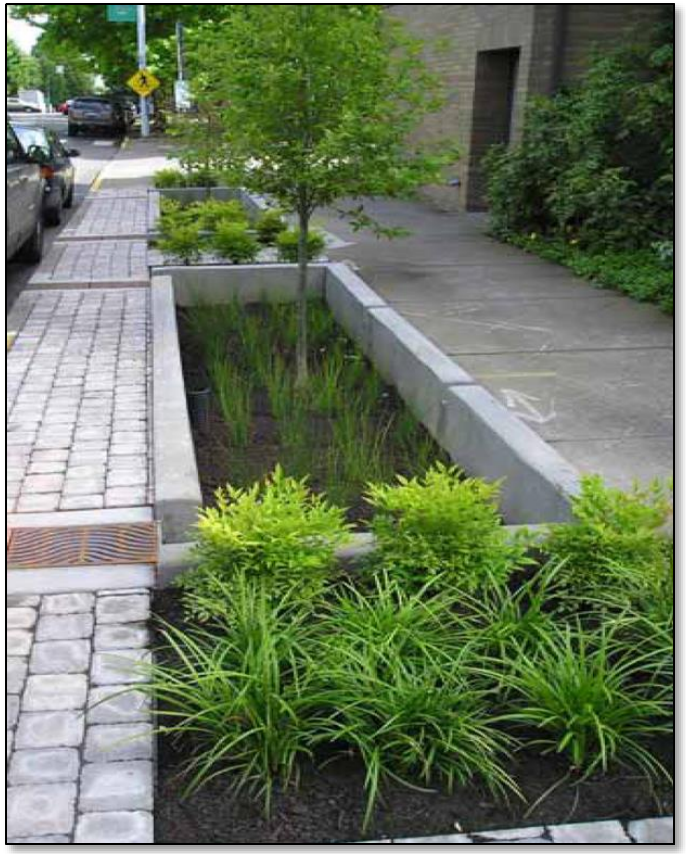
Objective

- Determine the effects that synthetic stormwater made from silica, organics and motor oil have on SCM mass load capacity versus just silica sediment alone.



City of Portland bioretention planter[11].

High rate biofilter, Bellingham, WA[12].

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Methods

HRBF experimental setup

- 2014 Contech Filterra NJDEP report[13] as baseline
- Engineered media from Contech
- 21” engineered media, 4” stone, 3” mulch
- **Hydraulic loading rate = 140”/hr (1.56 gpm/ft^2)**
- 9” design ponding depth above media surface

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Methods

<u>HRBF experimental setup</u>

- Peristaltic pumps
- Slurry tank w/pump (sediment mixing)
  - 2 mixers
  - Recirculation pump
- Source water tank w/pump
- Oil trials = oil pump
- Influent: Seametrics flow meter + data logger
- Effluent: timed bucket

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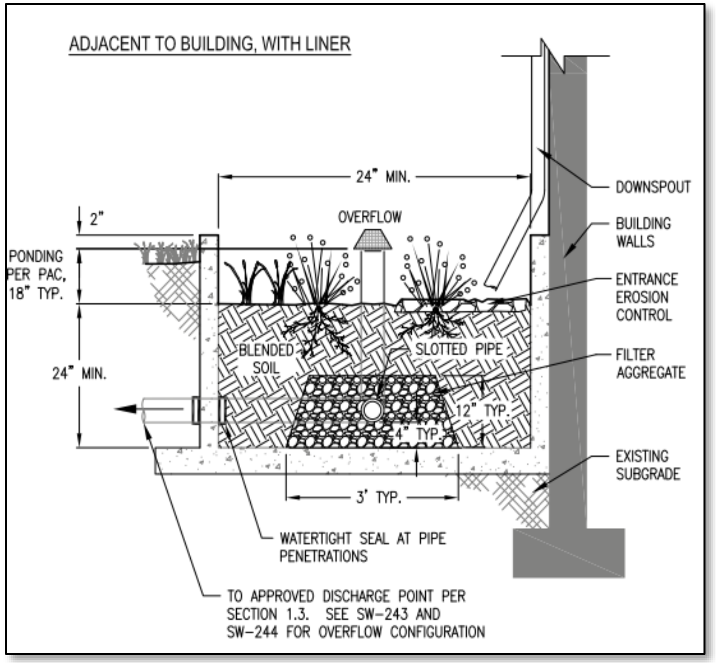
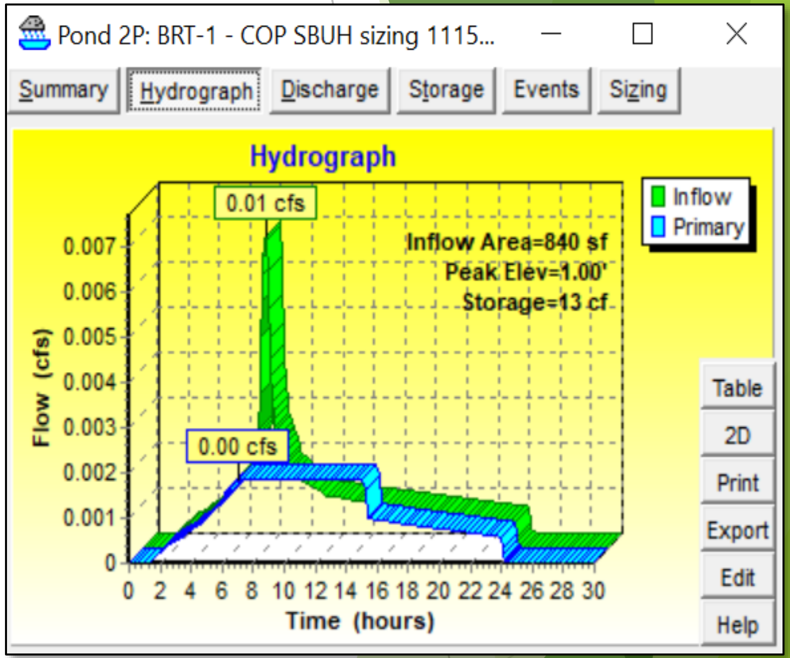
Methods

<u>BRT experimental setup</u>

- COP SW-231 (Presumptive Approach)[14]
- 24" media, 10" stone
  - 60/40 Sand-compost
  - Raised outlet 4" IWS
- 3" mulch (not required by COP)
- 6"/hr media rate (0.06 gpm/sf)
- 12" design ponding depth above media surface
- Santa Barbara Urban Hydrograph (SBUH) runoff method and HydroCAD model
- Drainage area = 840 sf



SW-231 planter design (BES, 2020).



BRT column design hydrograph utilizing media exfiltration rate of 6"/hr (constant velocity).

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Methods

BRT experimental setup

Bioretention stone and 1st lift of media.

Bioretention media and mulch installed.

Bioretention experimental test setup.

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Methods

<u>BRT media sourcing:</u> COP Stormwater Facility Blended Soil Vendor & Hauler List[15]

August 2021

December 2021

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Methods: NJDEP Filter Protocol[16]

<u>Removal Efficiency trials</u>

- **10 trials at MTFR**
  - "maximum treatment flow rate"
- Influent TSS = 180-220 mg/L
  - COV ≤ 0.10
- Effluent TSS: grab sample
  - Min 5 effluent samples per trial
  - 500 mL minimum
- **80% TSS removal efficiency**
- Known influent volume
- Known influent mass

<u>Sediment Loading trials</u>

- Conduct trials until "failure"
  - **Sediment mass loading vs RE**
  - **Sediment mass loading vs head loss at MTFR**
  - **Sediment mass loading vs effluent flow rate**
- Influent TSS = 360-440 mg/L
  - COV ≤ 0.10
- Effluent TSS: grab sample
  - 3 effluent samples per trial
  - 500 mL minimum
- Known influent volume
- Known influent mass

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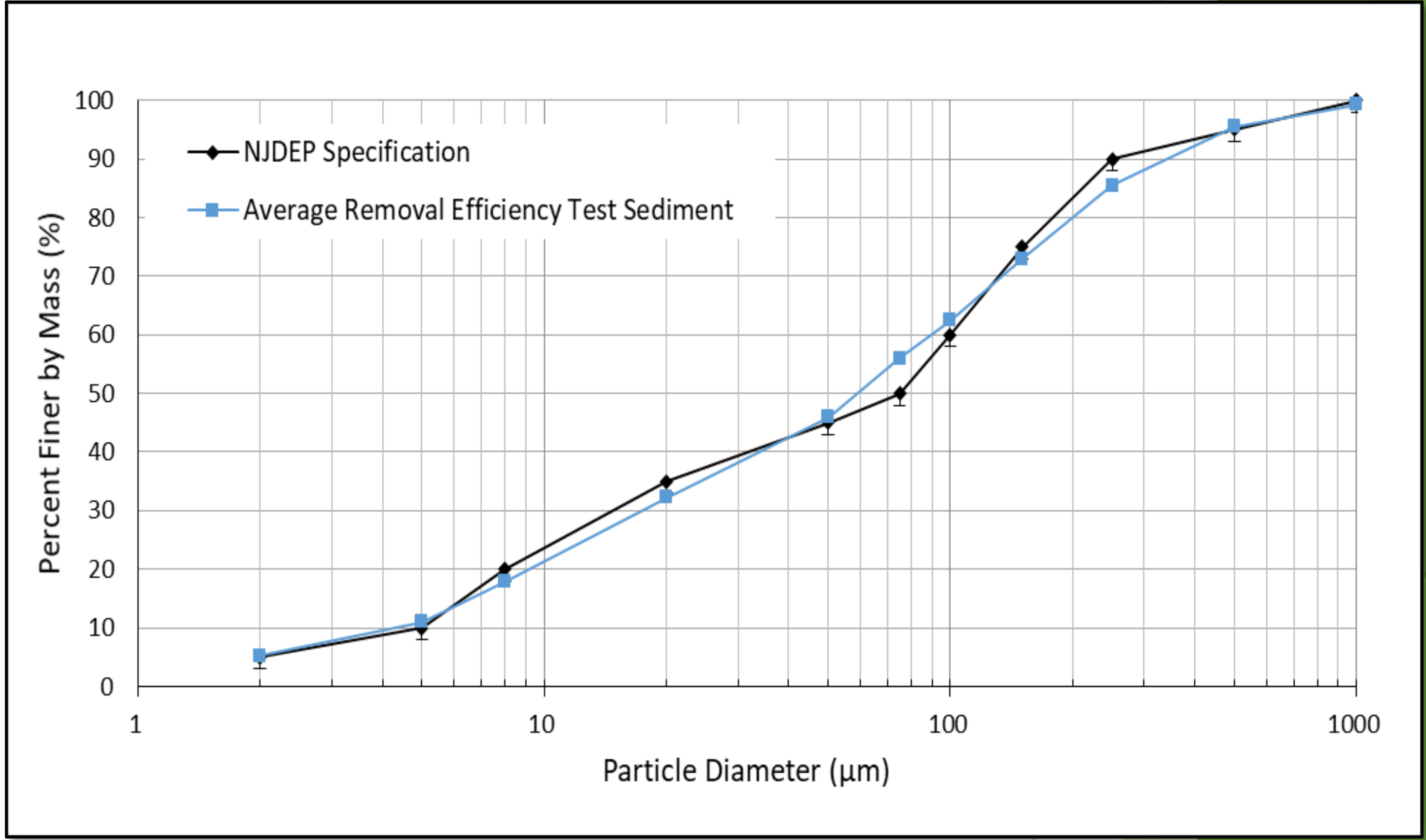
Methods

NJDEP test sediment spec

- "hard, firm, inorganic"
- Specific gravity = 2.65
- Uniformly distributed
- **d50 = 75 µm**
- d20 = 8 µm

AGSCO test sediment

- Inorganic silica
- **d50 = 60 µm**
- d20 = 9 µm



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Methods

<u>Organic test sediment concentration</u>

- Median TVSS:SSC
  - Average = 30.8%
  - SSC more representative of ASTM D3970 (vs TSS)
- **Target = 70% silica:30% compost**

<u>Organic test sediment source:</u>

<u>Cedar Grove compost[18]</u>

- Ecology certified, etc.
- 55.9% organic matter by weight
- **~30% compost -> ~15% organic content**
- Cap compost at 30% to try and retain NJDEP PSD

Cedar Grove compost specification (2018).

Methods

Organic test sediment:
Standard of Practice (SOP)

- Wet sieve < 1000 μm
- 24 hr settling period
- Decant aqueous volume
- Rinse sludge with DI
- Dry for 24-48 hrs @ 100 ˚C
- Weigh sample until Δ mass < 0.1 g

Sieved compost test sediment and rinse water.

Sieved compost solids after decanting rinse water.

Sieved compost test sediment prior to oven drying.

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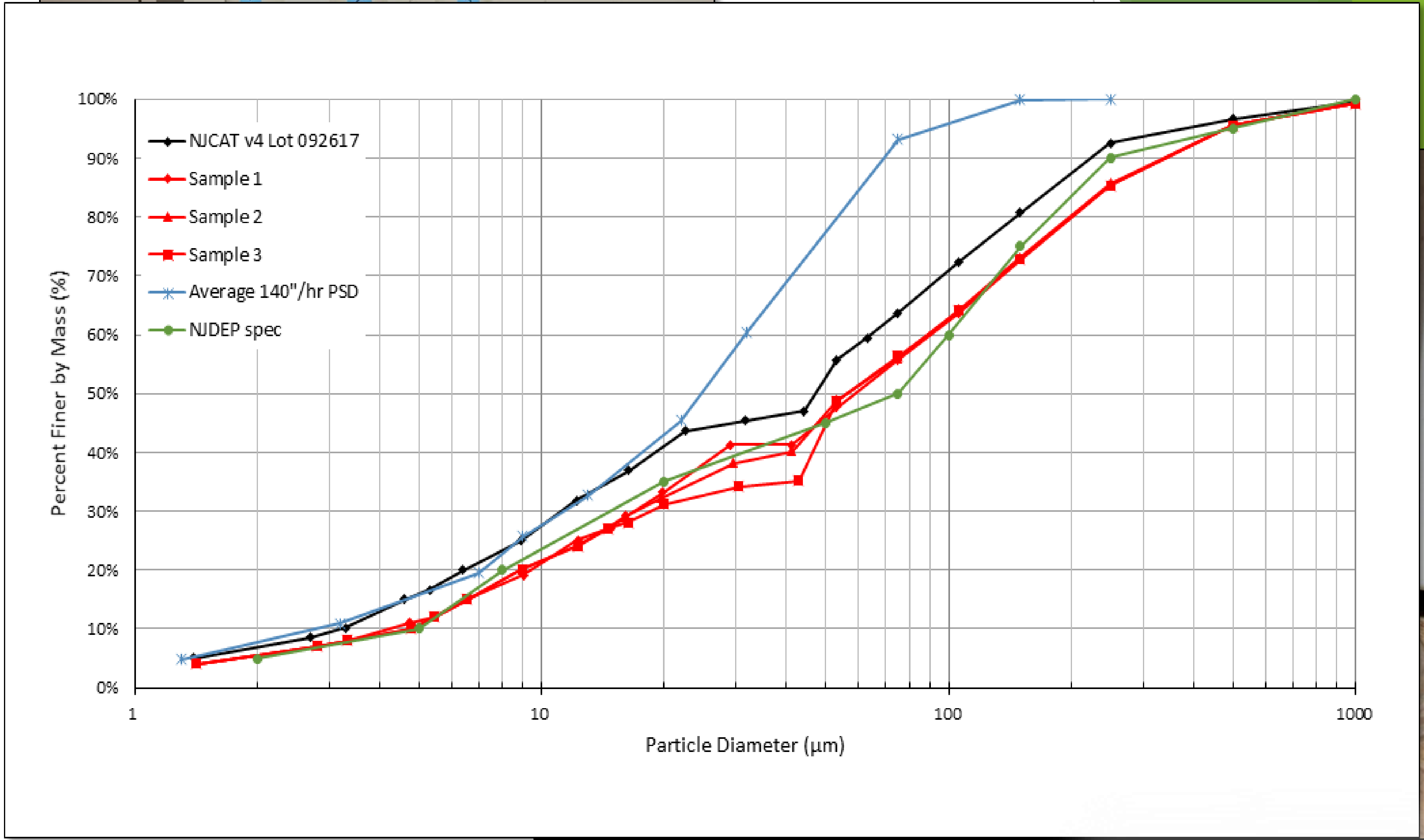
Methods

- How does organic matter affect PSD?
- Hydrometer sieve method



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Methods

Hydrocarbon concentration

- National Stormwater Quality Database[18]: Sites <20 acres
- Total petroleum hydrocarbons (TPH)
  - Mean = 5.6 mg/L; Median = 5.7 mg/L
- Oil & Grease
  - Mean = 7.1 mg/L; Median = 5.3 mg/L
- **Target concentration = 7 mg/L**

Hydrocarbon source

- Shell 5W-30 motor oil
  - SG = 0.88 (60°F)

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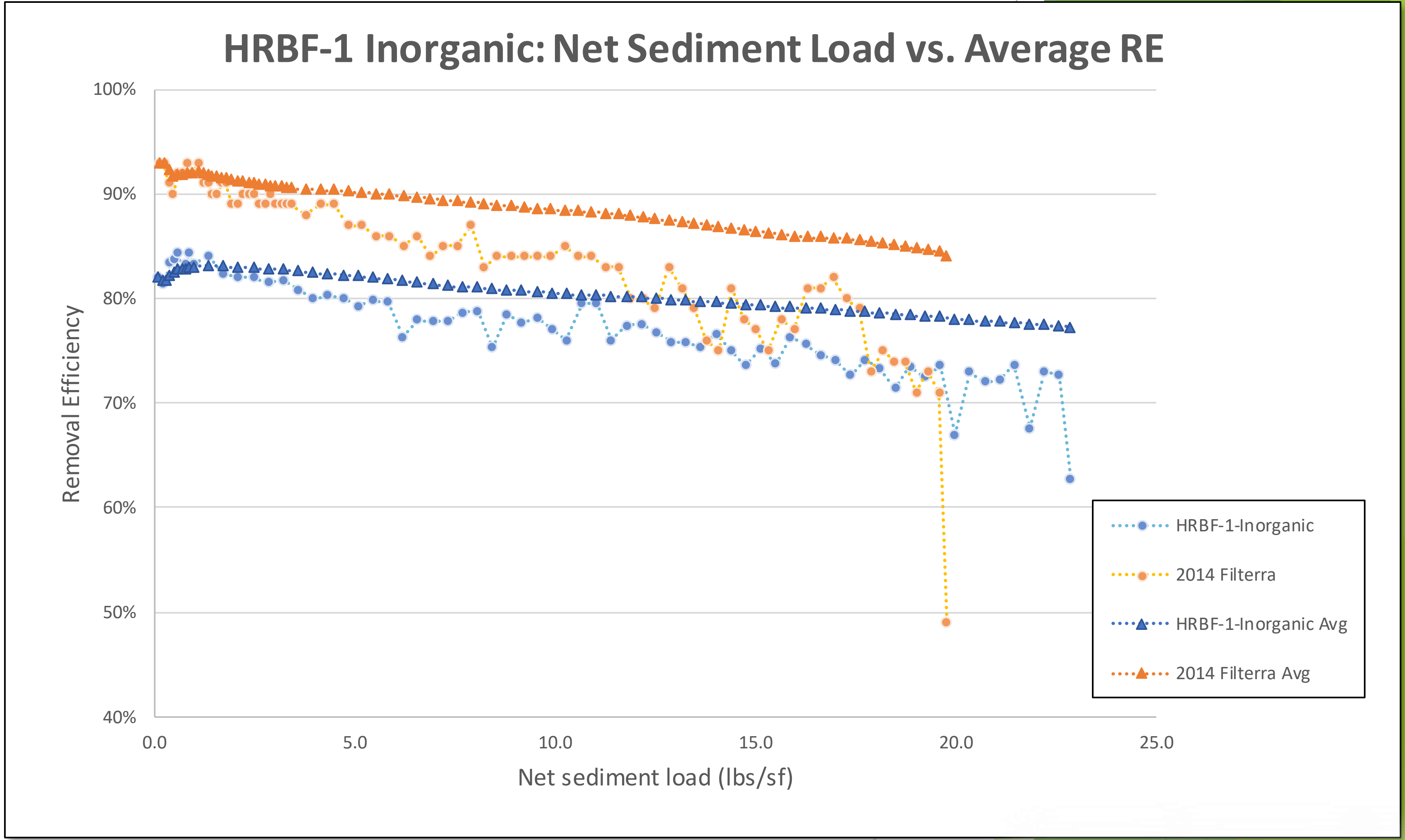
Results: Objective 1

HRBF-1: Inorganic

- **69 trials**
- **9” ponding @ trial 69**
- 16,650 gal treated
- **63.1 lbs treated**
  - 22.9 lbs/ft^2
- Avg Inf TSS = 478.8 mg/L
- Avg TSS RE = 77.2%
- Differences vs 2014 Filterra?
  - Higher influent TSS
  - Auger vs slurry tank



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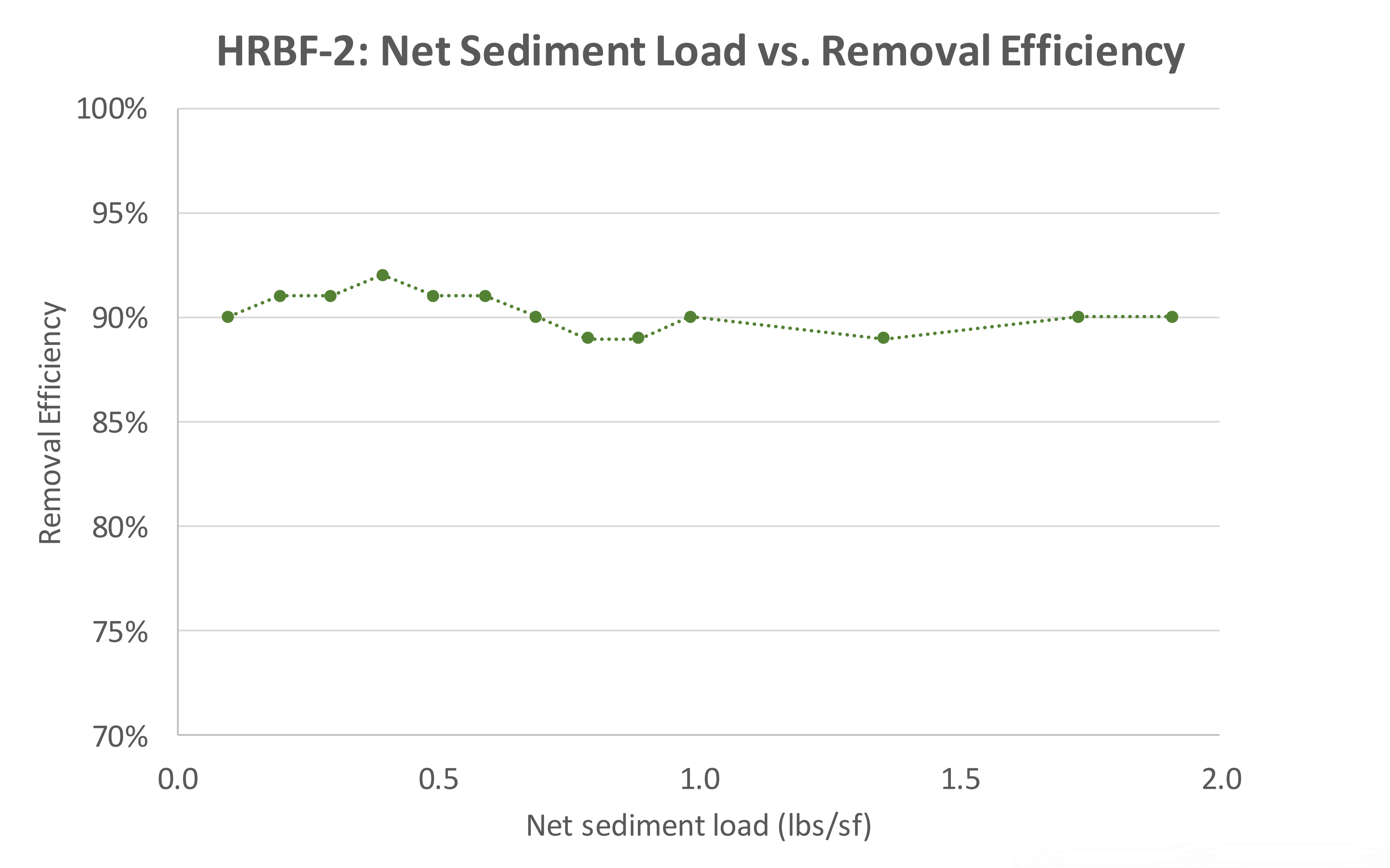
Results: Objective 1

<u>HRBF-2: Inorganic/Organic/Oil</u>

- **13 trials**
- **9" ponding @ trial 13**
- 2,202 gal treated
- **5.3 lbs treated**
  - 1.9 lbs/ft^2
- Avg Inf TSS = 426.3 mg/L
  - 23% compost
  - 3rd party lab: 17% TVSS:TSS
- Avg TSS RE = 90.3%
- **Oil loading = 22.9 g/ft^2**



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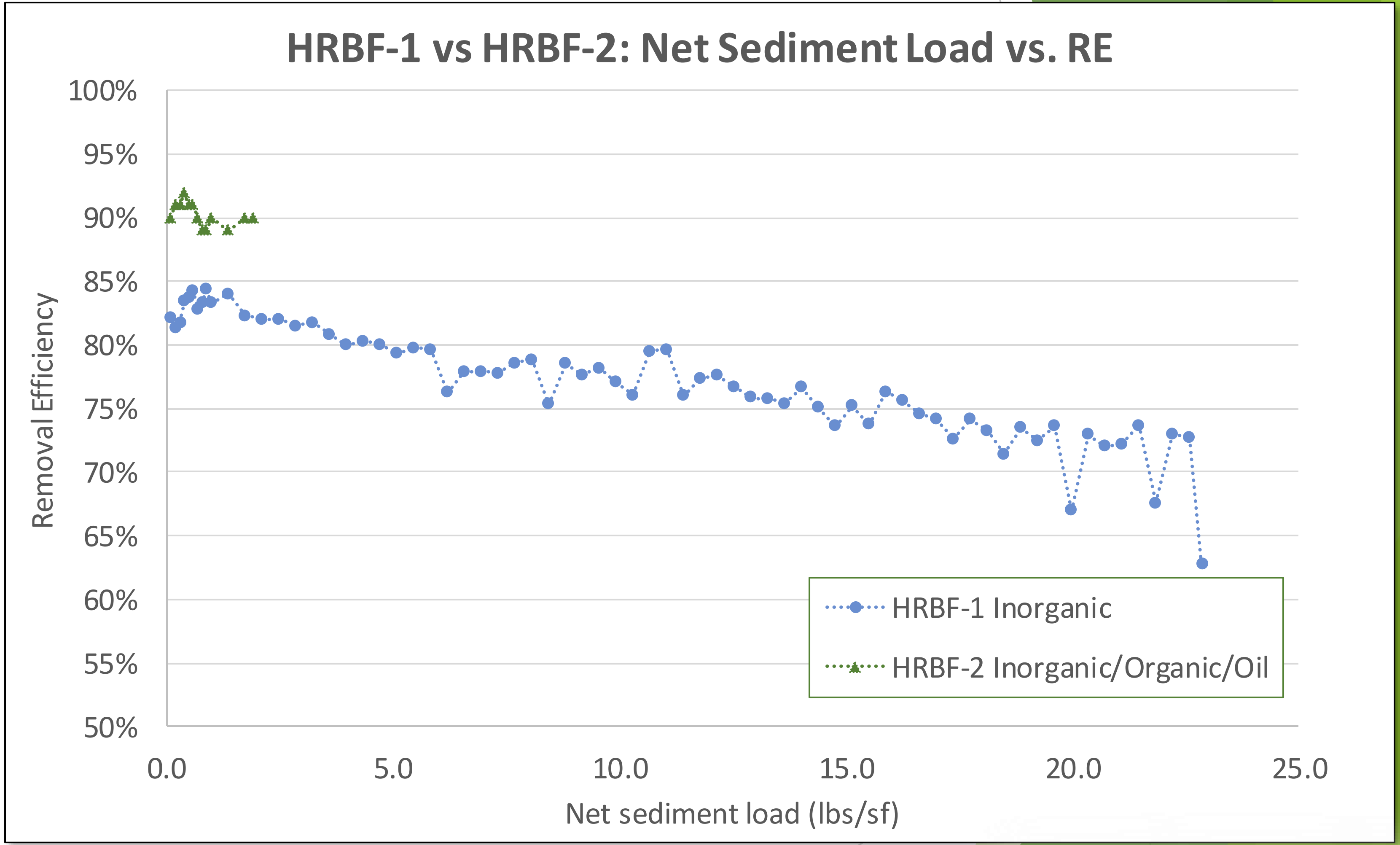
Results: Objective 1

HRBF-1 Inorganic vs HRBF-2 Inorganic/Organic/Oil

- Both trials concluded @ 9" bypass
- 22.9 lbs/ft^2 vs 1.9 lbs/ft^2
- **Adding oil and organics decreased mass capacity**



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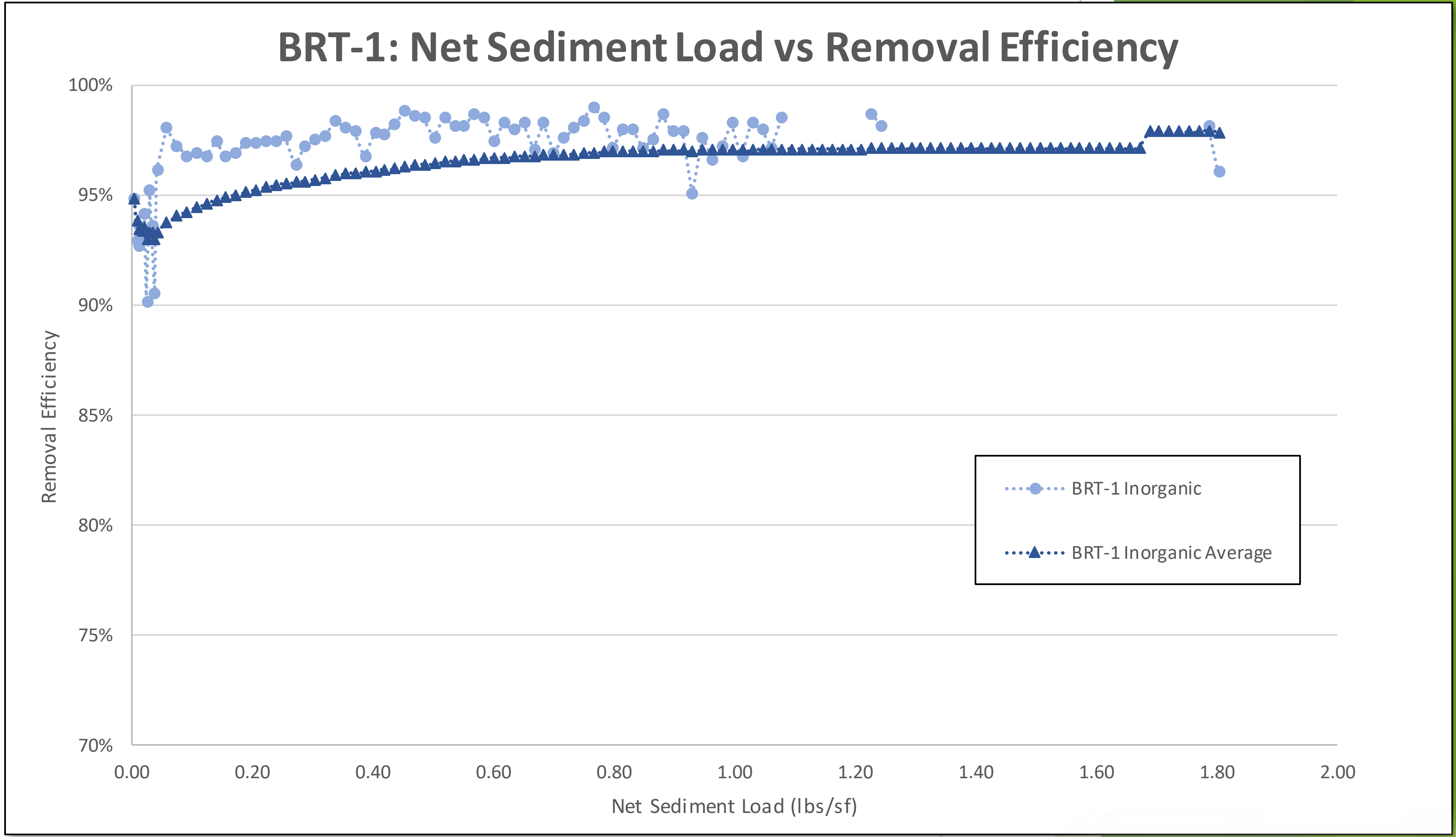
Results: Objective 1

BRT-1 Inorganic

- **117 trials**
- **No failure**
  - Approx 30% PDX annual rainfall
  - Max ponding = 3”
- 6,479 gal treated
- **24.0 lbs treated**
  - 1.8 lbs/ft^2
- Avg Inf TSS = 427.8 mg/L
- Avg TSS RE = 97.9%



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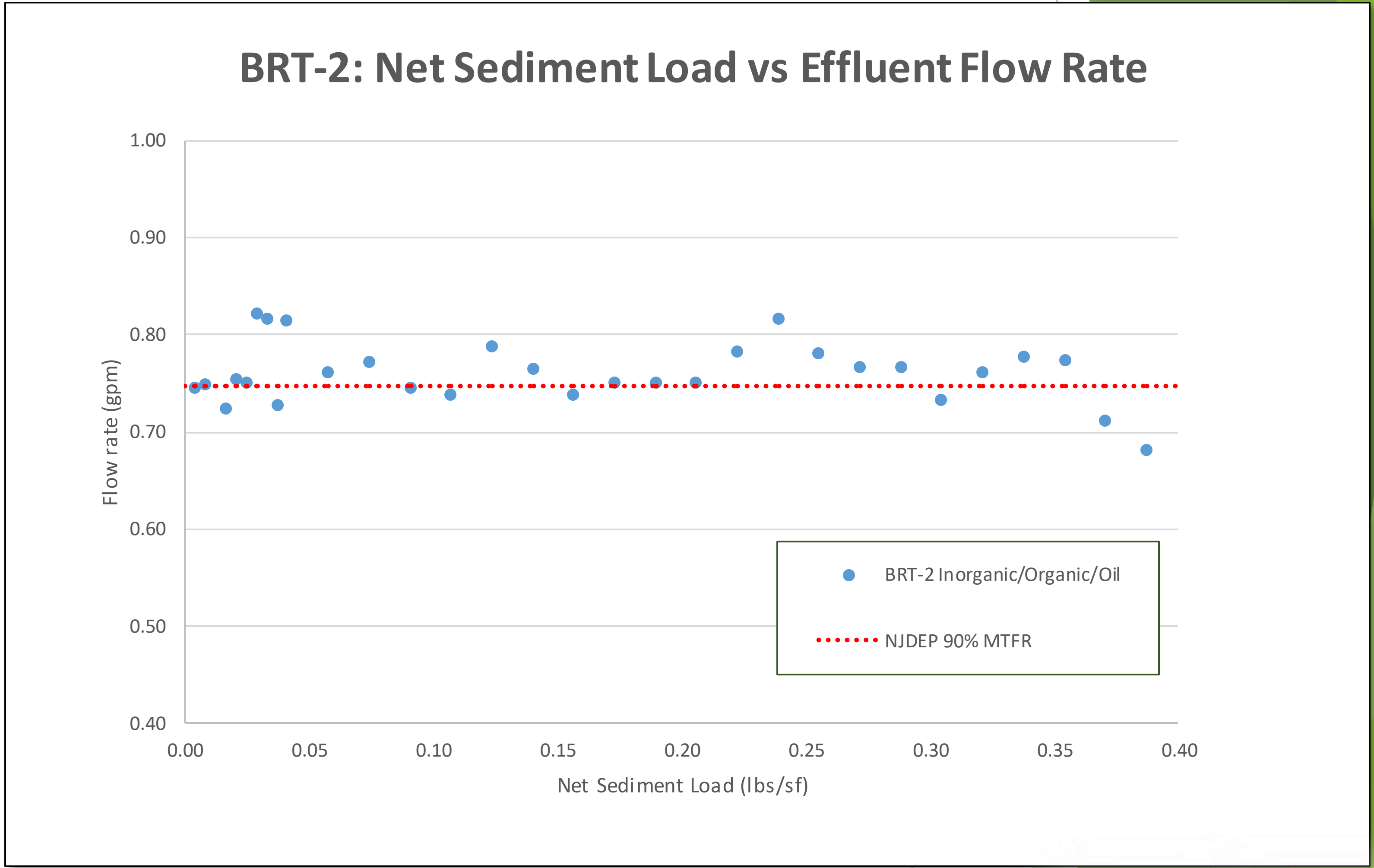
Results: Objective 1

BRT-2 Inorganic/Organic/oil

- **31 trials**
- **<90% Effluent MTFR**
- <80% TSS Removal
  - Compost flushing
- 1,508 gal treated
- 5.2 lbs treated
  - 0.39 lbs/ft^2
- Avg Inf TSS = 453 mg/L
- Avg TSS RE = 80.6%
- **Oil loading = 2.99 g/ft^2**



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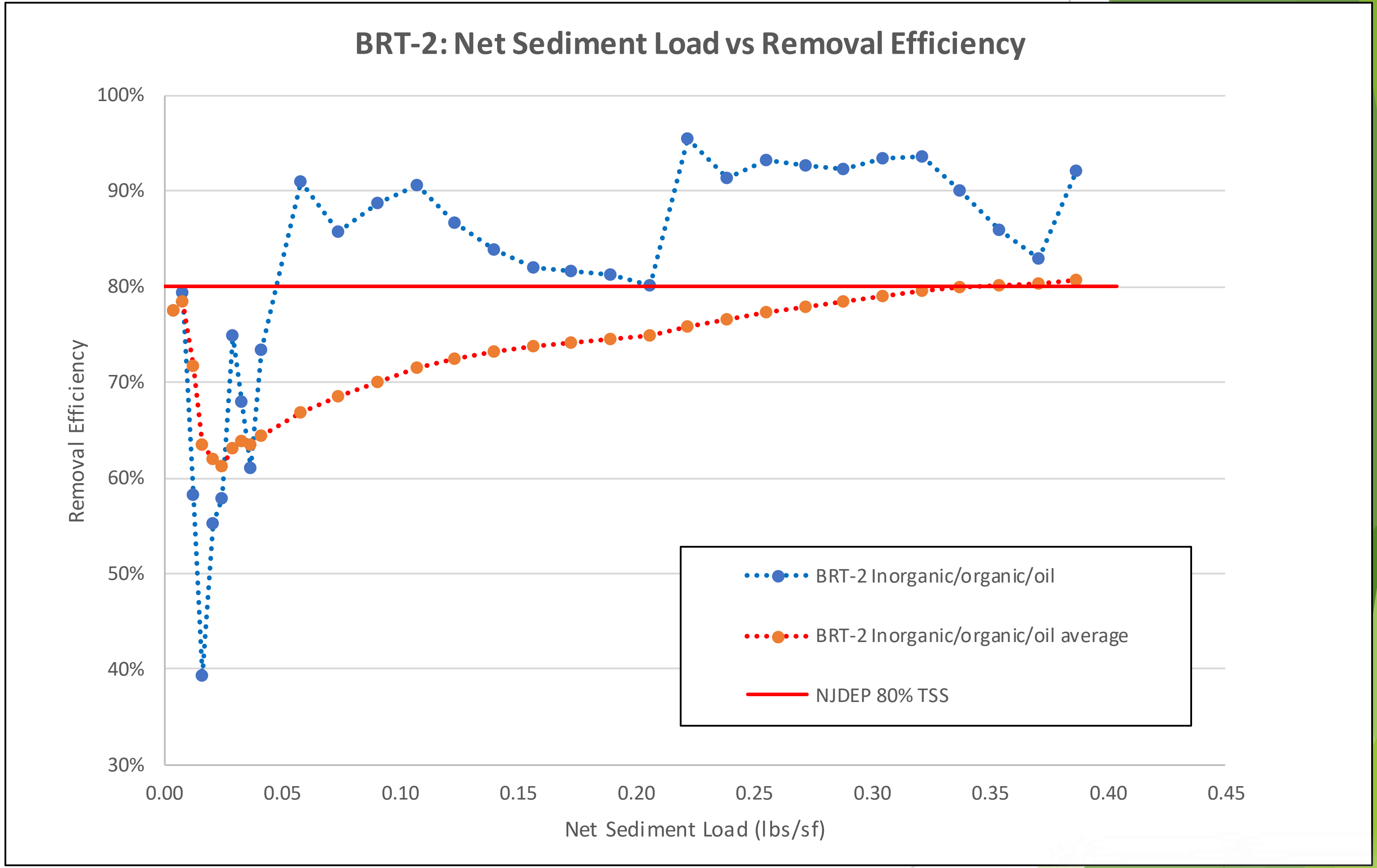
Results: Objective 1

BRT-2 Inorganic/Organic/Oil

- 31 trials
- <90% Effluent flow rate failure
- <80% TSS Removal
  - Compost flushing
- 1,508 gal treated
- 5.2 lbs treated
  - 0.39 lbs/ft^2
- Avg Inf TSS = 449 mg/L
- TSS RE = 80.6%
- Oil loading = 2.99 g/ft^2



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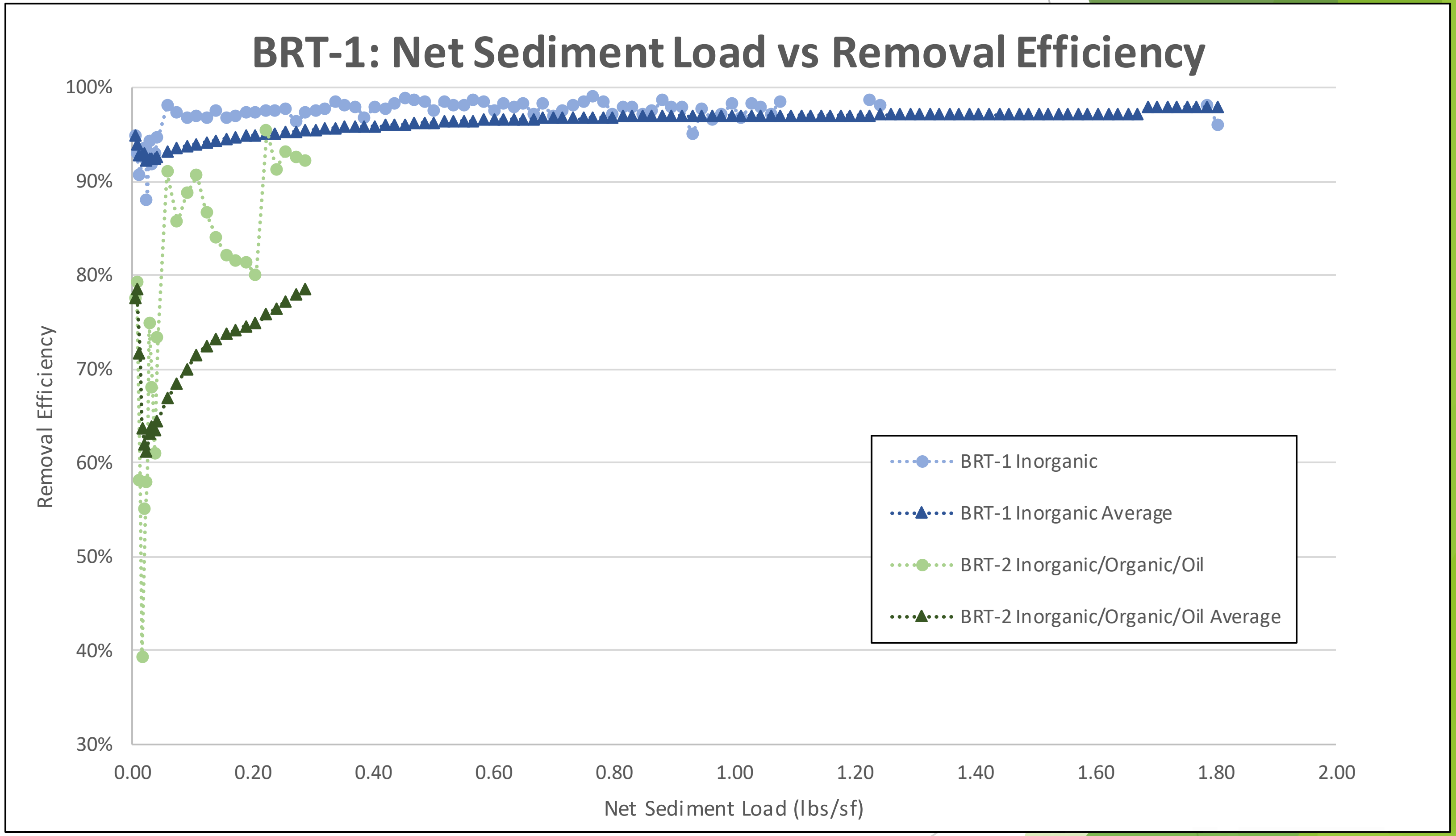
Results: Objective 1

BRT-1 Inorganic vs

BRT-2 Inorganic/Organic/Oil

- No bypass
- BRT-1 headloss
  - 3” ponding @ 1.8 lbs/ft^2
- BRT-2 headloss
  - 3” ponding @ 0.37 lbs/ft^2
- BRT-2 max ponding > BRT-1 max ponding
- **Adding oil and organics decreased mass capacity**



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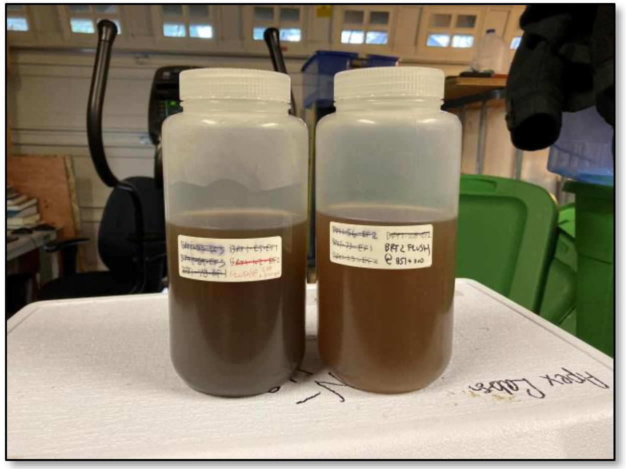
Results: Flushing

- BRT-1 lowest V
- HRBF-2 & BRT-1
  - ≥90% TSS RE
- HRBF low turbidity
- BRT-2 QA/QC
  - **7 lbs TSS leached?**

System	Flushing volume (gal)	Turbidity (NTU)	Media Volume (cf)	Flushing Volume per Media Volume (gal/cf)
HRBF-1	249.82	13.5	4.83	51.7
HRBF-2	220.43	9.92	4.83	45.6
BRT-1	999.57	17.8	22.93	43.6
BRT-2	**2000**	**254**	**22.93**	**87.2**

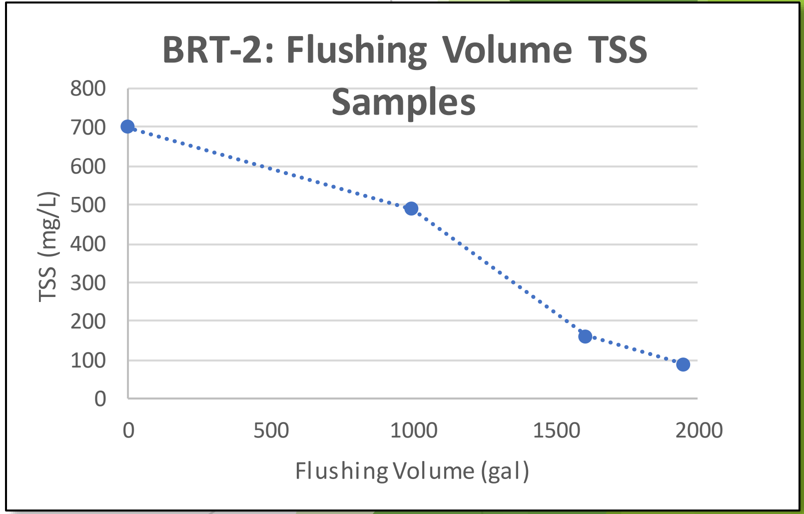
BRT and HRBF flushing volume and turbidity results.



BRT-2 flushing samples 3 and 4.

BRT-2 Flushing Sample	Flushing Volume (gal)	TSS (mg/L)	Estimated Cumulative Flushing Load (lbs)
1	0	702	-
2	1000	490	4.97
3	1608	161	1.65
4	1951	89	0.36

BRT-2 flushing volume TSS results.



BRT-2 TSS vs flushing volume.

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Results: Additional discussion

- BRT-1 & BRT-2 discolored effluent
- Bioretention phosphorus leaching
  - Ecology 2013[19]
  - Ecology 2021[20]
  - BMP database[21,22]
- **Effluent total P**
  - **Min = 0.892 mg/L**
  - **Max = 3.80 mg/L**
  - **Mean DP:TP = 84%**
- TAPE TP influent = 0.1-0.5 mg/L
  - 50% total P removal
  - TP effluent = 0.05-0.25 mg/L
- **BRT column P leaching: orders of magnitude higher than TAPE effluent values**

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Healthy Plants = Water Quality?

Engineered media = Water Quality

EWRI Stormwater Media Filtration Committee

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Conclusions

- **Mass load capacity is *lower* when adding organics and oil to silica test sediment**
  - NJDEP filter protocol laboratory results likely overestimate mass capacity
- Annual mass retained and typical maintenance intervals need more data
- **BRT media stability is variable and demonstrated significant leaching of solids and nutrients**
  - **Better media QAQC likely to improve removal efficiency and loading results**
- Alternative media specifications with less compost can reduce nutrient export

Next Steps?

- **Standard methods needed for including organic test sediment and hydrocarbons to laboratory test sediment**
  - **ASTM E64 committee**
- How do varying concentrations of organics and oil affect mass load capacity?
- Does accelerated lab testing of non-vegetated systems represent RE and mass load capacity of in-situ vegetated systems?
- BRT mass load capacity without mulch?
- Does typical maintenance restore system performance?

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References

1. https://nationalstormwateralliance.org/
2. https://bluegrasslawn.com/msd-bio-retention
3. https://www.portlandoregon.gov/bes/37485
4. https://ecology.wa.gov/Regulations-Permits/Guidance-technical-assistance/Stormwater-permittee-guidance-resources/Emerging-stormwater-treatment-technologies
5. https://www.nj.gov/dep/stormwater/treatment.html#:~:text=Stormwater%20Manufactured%20Treatment%20Devices,the%20requirements%20for%20major%20development.
6. http://nationalstormwateralliance.org/stepp/
7. https://www.astm.org/get-involved/technical-committees/committee-e64/subcommittee-e64
8. https://stormwater.pca.state.mn.us/index.php?title=File:Failing_BMP_1.jpg
9. Allen, V.; Berg, D.; Fairbaugh, C.; 2020. “Improving post-construction stormwater management program results through incorporation of performance verification standards for stormwater control measures.” WEFTEC 2020 Conference proceedings.
10. https://www.neponset.org/wp-content/uploads/2011/12/oil-runoff-into-storm-drain-e1440173641920.jpg2020
11. https://www.urbangardensweb.com/2009/11/01/growing-green-streets-to-go-with-the-flow/portland-green-streets-5/
12. http://www.njcat.org/uploads/newDocs/FilterraVerificationReportFinal.pdf
13. http://www.njcat.org/uploads/newDocs/FilterraVerificationReportFinal.pdf
14. https://www.portland.gov/bes/stormwater/swmm
15. https://www.portlandoregon.gov/bes/article/582089
16. https://www.nj.gov/dep/stormwater/pdf/Filter_Protocol_Final_2022_01_14.pdf
17. https://cedar-grove.com/docs/Organic_compost_quarterly_10-15-2018_QA.pdf
18. https://bmpdatabase.org/national-stormwater-quality-database
19. https://apps.ecology.wa.gov/publications/SummaryPages/1310017.html
20. https://apps.ecology.wa.gov/publications/documents/2110023.pdf
21. https://static1.squarespace.com/static/5f8dbde10268ab224c895ad7/t/5fbd3c237ad3fe66120f69ea/1606237239545/2016_BMPDBSummaryStatistics_03-SW-1COh.pdf
22. https://www.waterrf.org/resource/international-stormwater-bmp-database-2020-summary-statistics

Thank you!

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https://pdxscholar.library.pdx.edu/open_access_etds/5926/

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