Evaluation of Hydraulic Control Approaches for Bioretention Systems: Final Findings Presentation

Geosyntec Consultants and Washington State University

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Stormwater Action Monitoring

Research Team

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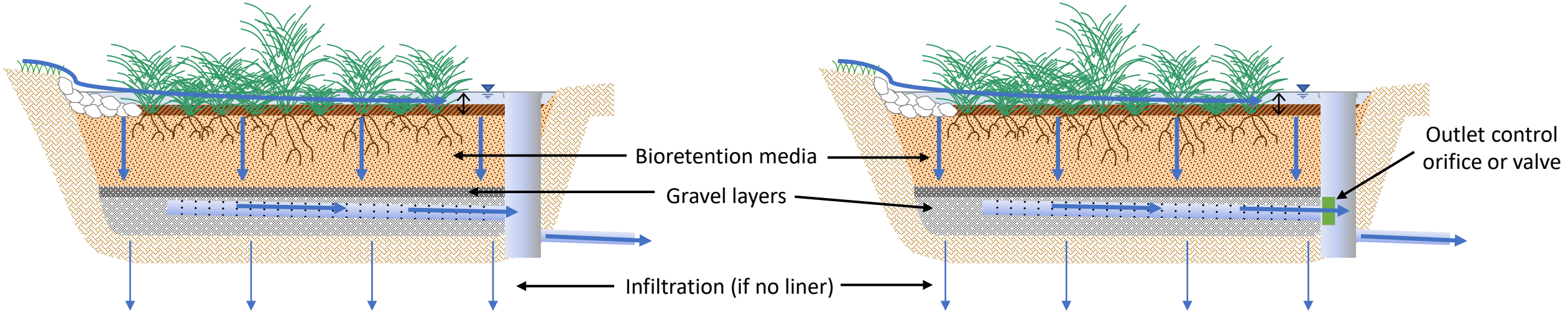
Research Questions

- How does outlet-control vs. media-control affect the **water quality treatment** performance of bioretention?
- How does outlet-control vs. media-control affect the **residence time** of water in bioretention?
- Does outlet-control result in more **consistent hydraulic performance**, initially and over time?
- What is the **stage-storage-discharge relationship** of the mesocosms? Do these match those used in WWHM?
- Are there differences in **plant health and vigor**?
- Does the use of small outlet-control orifices increase the **O&M burden**?

Outlet Control Concept

Typical Bioretention w/ Underdrain
"media-controlled" hydraulics

Outlet-Controlled Bioretention w/ Underdrain
"outlet-controlled" hydraulics

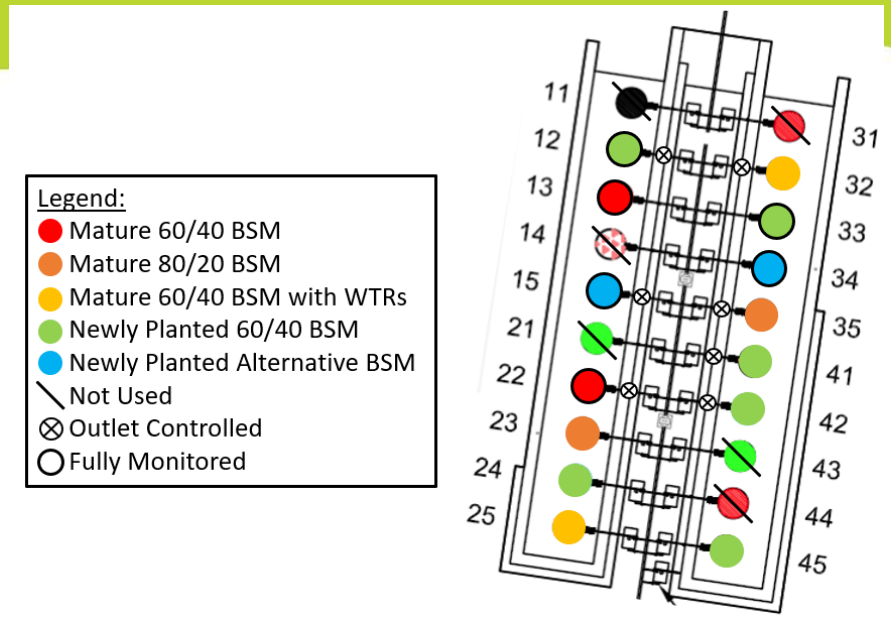


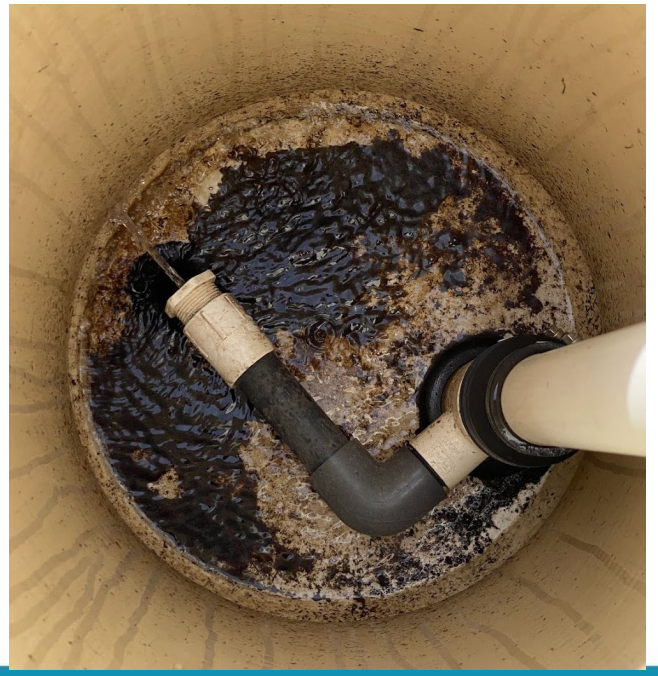
Flow rate controlled by media permeability, typically faster than design rate

Flow rate controlled by outlet orifice or valve set to control to design rate, typically slower than media permeability

Experiment Set-up

- WSU's existing bioretention mesocosm facility at Puyallup
- 14 mesocosms with varying BSM types, ages and hydraulic controls.
- Monitored for 1.5 years, including:
  - Continuous hydraulic monitoring (precipitation/inflow/outflow/ponding/moisture content)
  - 3 special hydraulic tests (drawdown tests, salt-pulse HRT tests)
  - 6 water quality tests (influent/effluent)
  - Periodic plant health and O&M monitoring





Experimental Limitations

- Monitoring performance assessed through 2 winters
  - Some vegetation vigor, WQ performance, and O&M effects may take longer to occur
- Loading rate was relatively low for first 2/3 of monitoring period; tributary area was increased in Feb 2022
  - Predominant flow regime may not have engaged OC very often prior to this adjustment
- Despite strengths of the mesocosm facility, it was not possible to maintain a full water balance accounting of the mesocosm facility
  - Conclusions relied on isolation and interpretation of reliable data

Water Quality Treatment Comparison

- Relatively small difference in WQ treatment performance between media- and outlet-controlled.
- Outlet control slightly improved treatment of TSS, P and NO2-NO3
- Outlet control worsens the export of TKN and Cu
- Zinc removal is effective regardless of outlet hydraulic control

Analyte	Removal Efficiency		
	MC	OC	Difference
Total Suspended Solids	89%	93%	+5%
Total Phosphorus	57%	63%	+6%
Ortho-Phosphorous as P	41%	55%	+14%
Nitrate-Nitrite as N	19%	30%	+11%
Total Zinc	96%	96%	0%
Dissolved Zinc	93%	94%	1%
Total Kjeldahl Nitrogen	-10%	-45%	-34%
Total Copper	78%	72%	-6%
Dissolved Copper	19%	-2%	-21%

Water Quality Treatment Comparison

- Media mix and age have larger influence on treatment
- Alternative BSM shows good to moderate removal for most POCs
- New standard BSM exports dissolved copper and nutrient
- Mature standard BSMs exports dissolved copper and TKN, but most effective for phosphorus

Analyte	Removal Efficiency		
	Alternative BSM	Mature Standard BSM	New Standard BSM
Total Suspended Solids	90%	97%	80%
Total Zinc	96%	97%	94%
Dissolved Zinc	94%	93%	93%
Total Copper	82%	80%	59%
Dissolved Copper	47%	0%	-41%
Total Phosphorus	65%	86%	-32%
Ortho-Phosphorous as P	52%	84%	-78%
Nitrate-Nitrite as N	42%	32%	-7%
Total Kjeldahl Nitrogen	28%	-3%	-171%

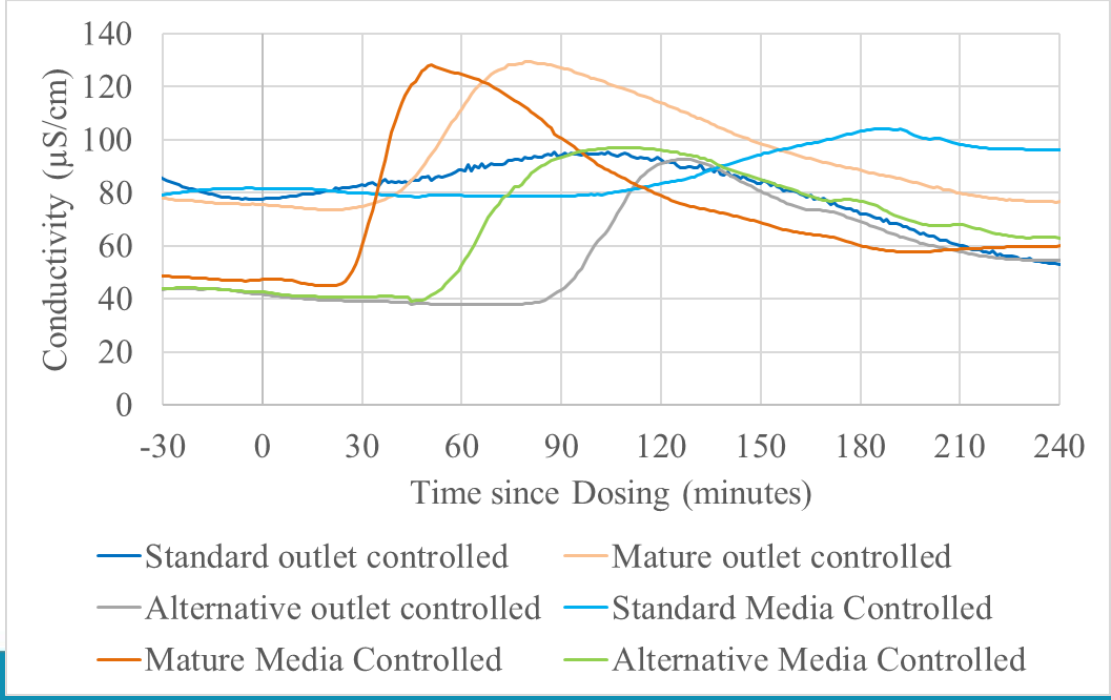
Residence Time Comparison

- The MRT for outlet-controlled mesocosms is **longer** compared to media-controlled mesocosms due to the flow restriction effect of the orifices.
- The MRT for outlet-controlled mesocosms are much more **consistent** compared to media-controlled mesocosms

Average Residence Time Results

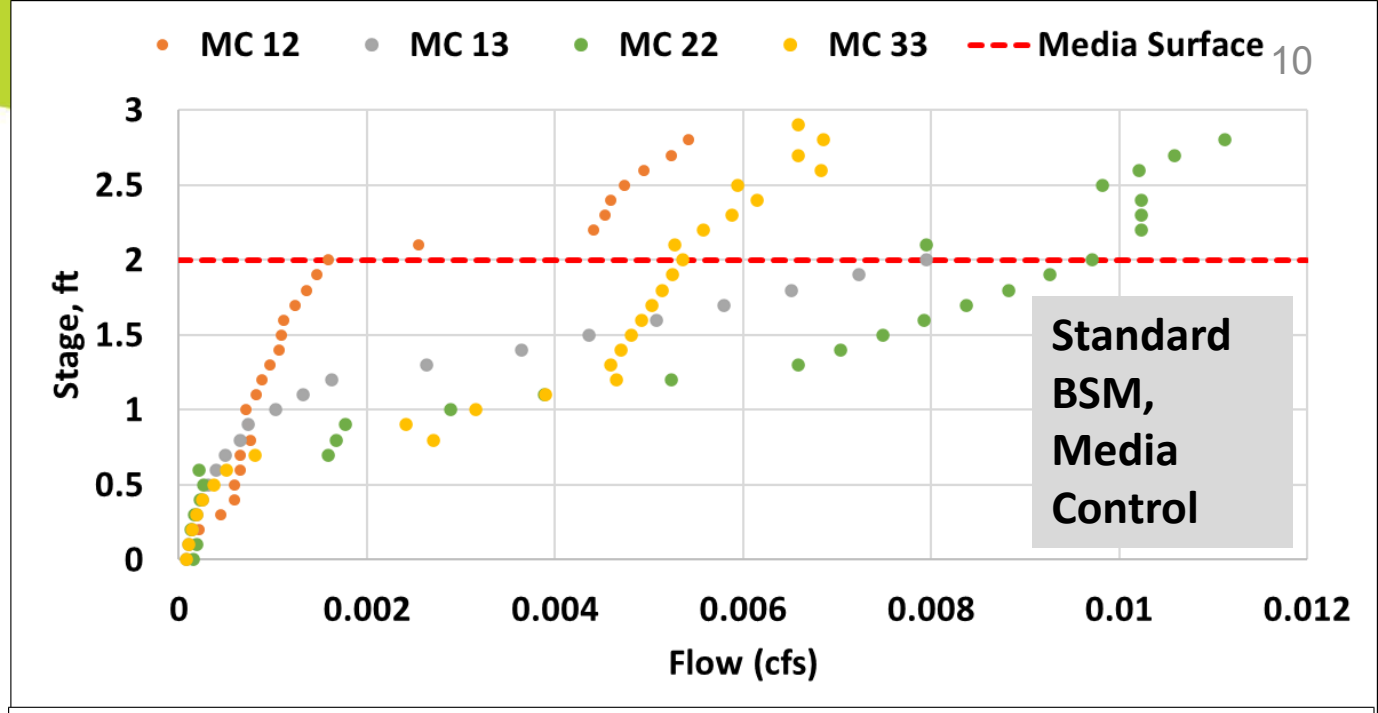
BSM Type	Mean Residence Time (min)	
	MC	OC
New Standard	85	101
Mature Standard	31	104
Alternative	67	101

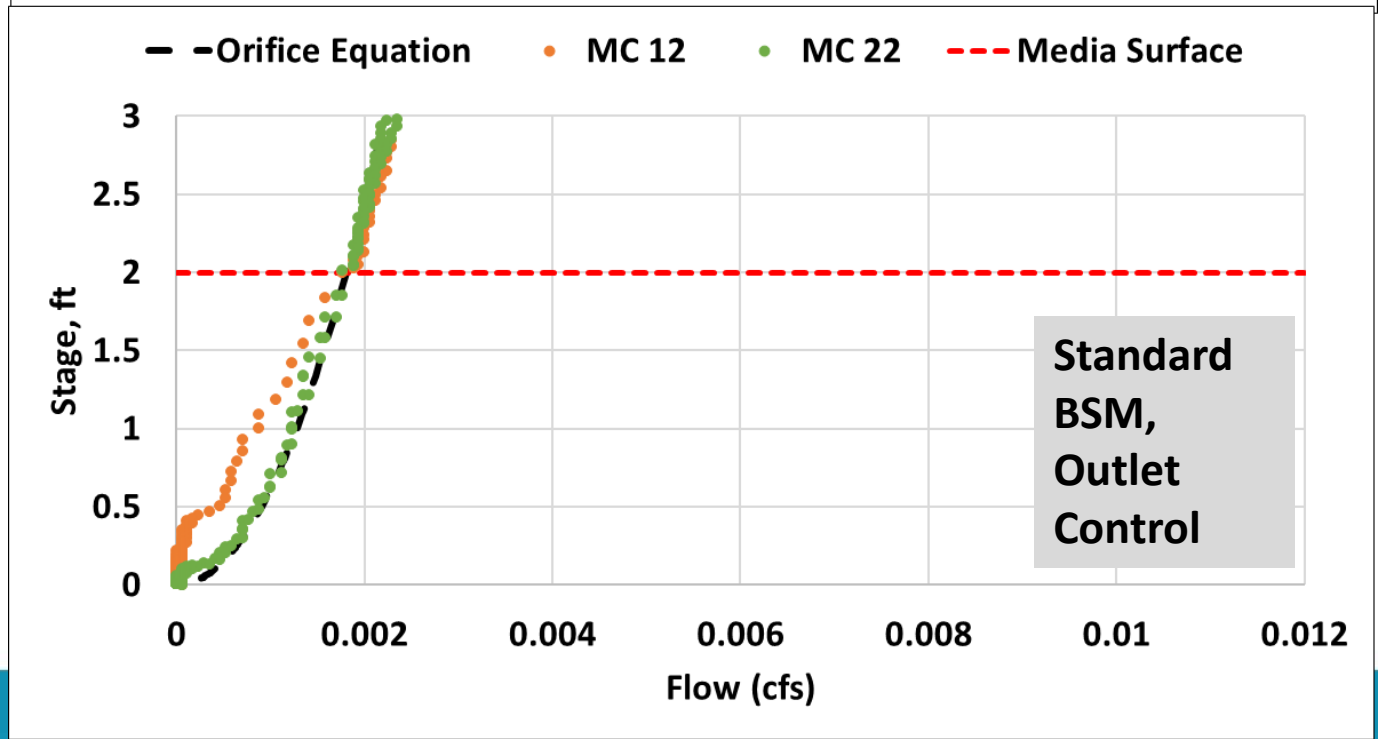
Example Conductivity Chart



Stage-Discharge Comparison

- The discharge rate with outlet control is **lower**, more **consistent** and **predictable** using orifice equation.

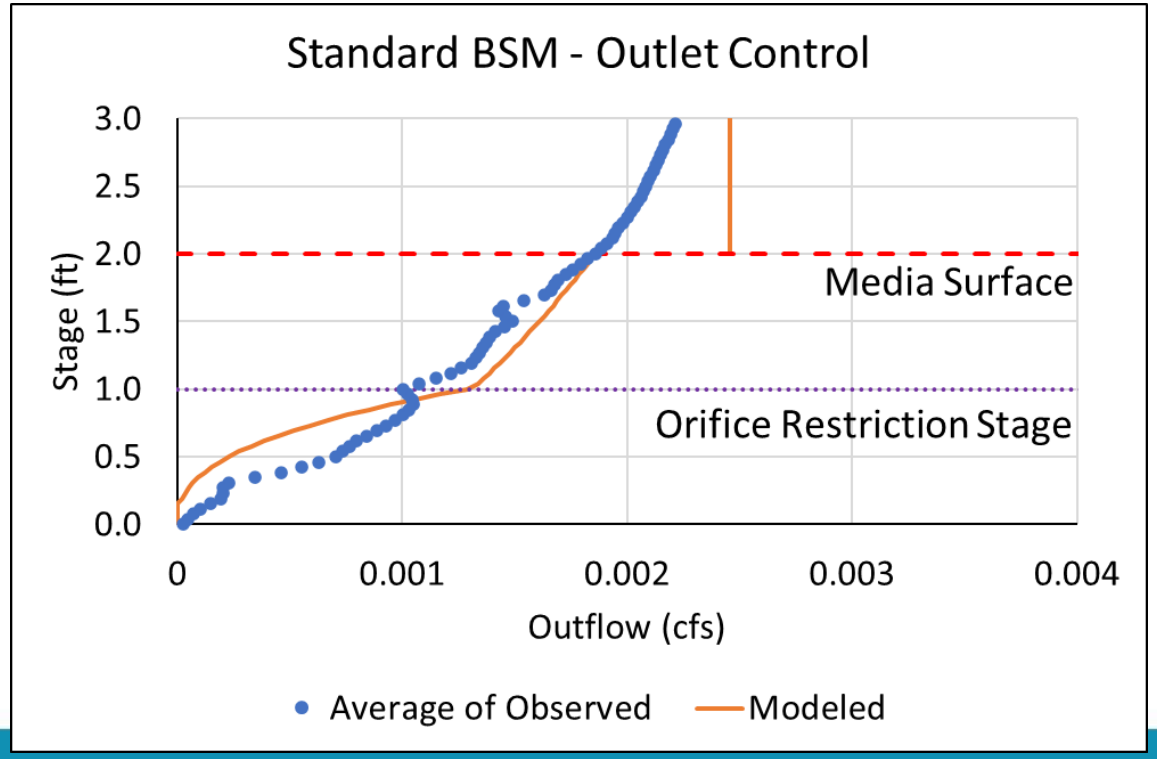




WWHM Modeling

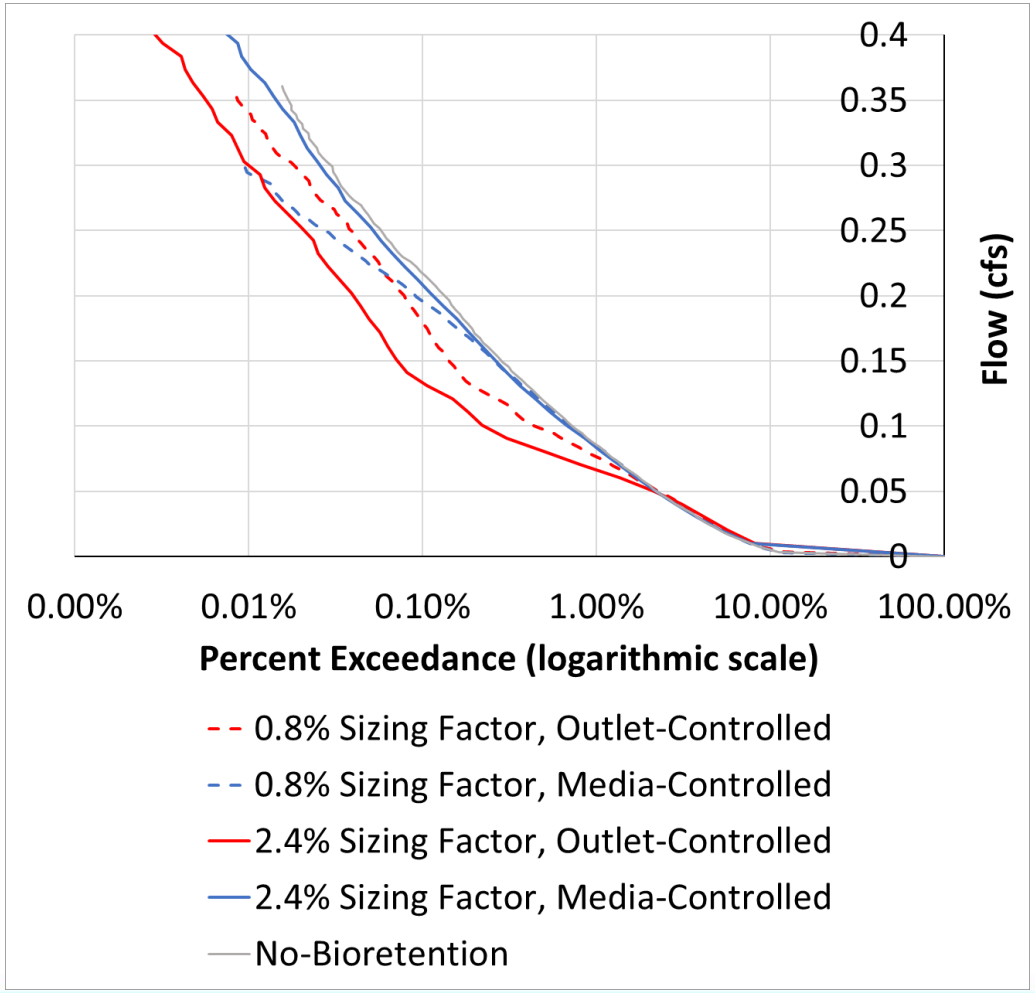
- To model **media control** bioretention elements in WWHM: higher permeability and lower effective porosity were observed compared to the default bioretention media SMMWW.
- To model **outlet control** bioretention elements in WWHM: WWHM produces discharge rate independent of stage within the ponding stage, which has some impact on reliability of simulation results.

Soil Media Parameters	Default: SMMWW	Adjustment based on findings from this study
K_{sat} (in/hr)	6	10 - 16
Porosity	47%	15% - 18%



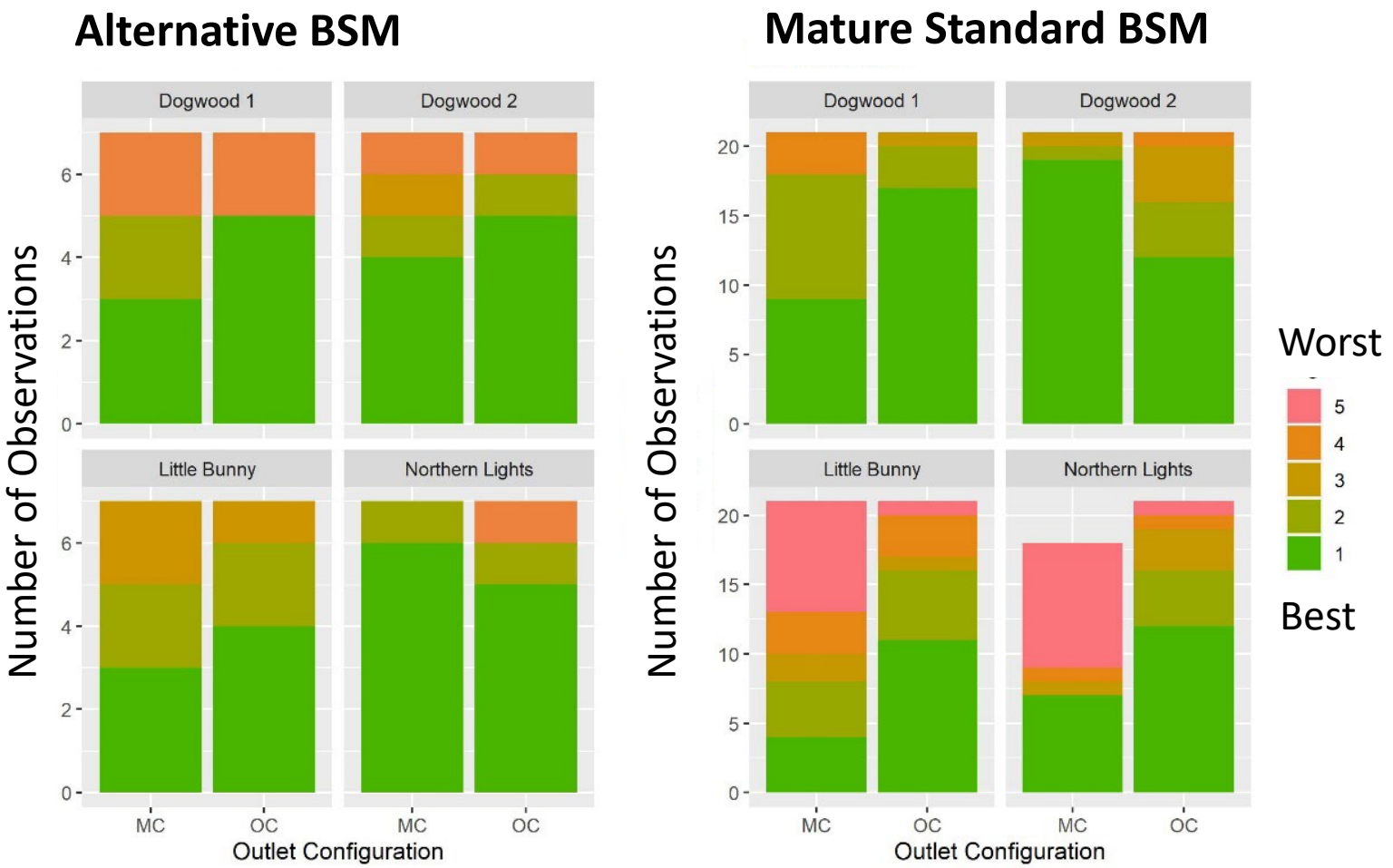
Impact of Differences in SSD on Flow Control

- Limited effect at lower range of bioretention sizing
- Diverging effect at higher range of sizing factors
  - MC – performance reduces with increased size, approaches no control
  - OC – performance improves with increased size



Plant Health and Vigor Comparison

- Outlet control slightly improved the plant vigor for alternative and mature standard BSMs
- For new standard BSMs, plants are vigorous regardless of outlet control



Plant Health and Vigor Comparison

	Alternative	Mature Standard
Media Control		
Outlet Control		

O&M Comparison

- O&M activities were recorded throughout the study period.
- Some biofouling were observed at two mesocosms with new standard BSM soon after the installation. This issue impacted both the media-controlled and the outlet-controlled mesocosms.
- No difference was found in O&M between media and outlet controlled mesocosms.

Primary Findings

- Little difference in WQ, plant vigor, and O&M within study duration
- Some apparent differences in WQ performance (+ and -), but performance much more influenced by BSM type and age than hydraulic control approach
- OC produced more predictable and stable residence time and hydraulic performance
  - At smallest sizing factors, hydraulic control approach had little effect
  - As sizing factors increase, OC produced meaningful flow control, while MC flow control reduced
- WWHM is generally able to assess the benefits of OC
  - Some notable differences between WWHM results and mesocosm monitoring that may warrant investigation