Stormwater Management Manual

Bureau of Environmental Services

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SWMM Monitoring Update, 2022

Background

BES has implemented a monitoring program to support implementation of the Stormwater Management Manual (SWMM) since 2002. The program assesses the performance of public and private facility designs to check facility performance metrics, design assumptions and standards, and alignment with regulatory goals. The program also collects information to improve designs for construction and maintenance ease, and to improve the overall cost effectiveness and efficiency of stormwater management facilities.

The Code, Rules, and Manuals (CRM) team plans and implements the program in partnership with many bureau stakeholders, some of whom lead parts of the program. Primary partners in planning the work include the Monitoring Coordination and Analysis (MCA) team, the Regulatory Strategy and Remediation (RSR) group, and the Green Stormwater Infrastructure O&M team (GSI O&M). Field Operations does most of the technical field work with funding from CRM, and MCA manages most of the resulting data. The Materials Testing Lab (MTL) has been an integral part of many monitoring efforts.

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Green Streets

1. Green Streets - Monitoring Focus Areas

There have been three primary focus areas for green streets monitoring: hydraulic performance, water quality, and pollutant accumulation. In the last couple of years the program has also monitored plant health and soil moisture.

A. Hydraulic Performance

BES monitors the hydraulic performance of green streets to confirm general performance characteristics and facility sizing standards in the SWMM. Parameters include infiltration rates, peak flow attenuation, and volume retention. There have been different phases in BES' hydraulic monitoring program over time. From 2004-2014 the Sustainable Stormwater Division completed an intensive program of field drawdown tests and hydrant flow tests mimicking specific design storms. Tests were completed at more than 40 green streets facilities in different parts of the City. The main goal was to confirm hydraulic performance and facility sizing factors for different design storms and in a range of soil types. Tim Kurtz' 2013 monitoring report summarizes the results. More recently, hydraulic monitoring has focused on confirming infiltration rate design assumptions for imported soil blends.

B. Water Quality and Pollutant Accumulation

BES continues to monitor removal of stormwater pollutants by green street facilities. The focus is on systems with underdrains where the effluent can be sampled. The pollutants typically include total suspended solids (TSS), metals (i.e., copper, lead, zinc) and nutrients (i.e., phosphorus, nitrogen). BES monitors these pollutants due to concerns about potential negative impacts to watershed health and to understand alignment with regulatory objectives. The SWMM is primarily focused on removal of TSS which is the only pollutant reduction standard specified in the manual. In watersheds with a total maximum daily load (TMDL) or on the Oregon Department of Environmental Quality's (DEQ's) 303(d) list of impaired waters, the SWMM also requires reductions in the concentration or level of pollutants of concern. There are no other treatment standards specific to Portland's stormwater management facilities.

Researchers sometimes provide context when presenting water quality results by comparing how discharges from stormwater facilities relate to in-stream standards, thresholds for aquatic or human health impacts, and standards for industrial stormwater discharges (i.e., 1200-Z permitting standards). However, discussions continue about the relevance of those references given the lack of data and understanding about the relationship between discharges from individual stormwater facilities and outfall concentrations or in-stream conditions.

BES began monitoring water quality results for green streets facilities in 2016. The current focus is on results for a group of new facilities, documenting initial results and changes in performance over during the first four years after construction.

Monitoring of sediments in green streets began in 2002. The purpose is to answer questions about potential human health risks due to chemical concentrations, rates of pollutant accumulation, and

pollutant concentrations compared with levels in background samples. BES is currently underway with a ten-year program with an expanded list of sites and pollutants. Examples of pollutants being monitored include metals, PAHs, phthalates, pesticides, and PCBs.

C. Design Impacts on Plant Health and Soil Moisture

For the last couple of years BES has monitored soil moisture and plant health in lined facilities where plant mortality and associated maintenance costs are a concern. The purpose is to identify potential SWMM design changes and retrofit approaches for improving summer conditions for plants.

2. Green Streets Design Variables - Slough 104B Project

CRM continues to monitor the 53 green streets facilities BES constructed in 2018 as part of the Slough 104B project. BES built the facilities to filter and treat runoff draining to the Columbia Slough; all of them have underdrains. The facilities along higher-traffic streets also have full liners to protect groundwater from contamination in the event of a spill to comply with requirements of the Columbia Slough wellhead protection area, where the project is located. Performance monitoring has focused on water quality, plant health and soil moisture, and drawdown rates.

Engineering Services worked with CRM during the design phase to incorporate an eight-block experimental design allowing comparison of performance results for different treatments. The design variables in the different treatments include whether or not the facility is fully lined, the underdrain configuration, and the composition of the soil blend. The variables are summarized in Table 1. There are five to seven facilities in each experimental block.

Table 1. Slough 104B Project Design Variables

Variable	Value 1	Value 2
1. Liner	Fully lined	No liner
2. Soil type	BES standard blend (2008 specification)	High-fines trial blend Proposed special spec.
3. Underdrain type	Old standard underdrain (2016 specification)	New standard underdrain (2020 specification)

A. Slough 104B Project – Water Quality

Field Operations is beginning the final year of a four-year program taking paired inflow and outflow grab samples at 12 of the Slough 104B green streets facilities. Data will be collected for a total of eight storms, sampling two rain events per wet season. The purpose is to compare water quality performance by soil type in lined facilities during the first four years after construction. There are two hypothesis: the first is that there will be an initial flush of pollutants and subsequent tapering of discharge levels; the second is that the high-fines blend will export less phosphorus and nitrogen than the standard blend due to the smaller percentage of compost in the high-fines blend.

Key Conclusions and Findings
A 2019 study of water quality results for a group of established facilities indicated good results for TSS and some other pollutants, but increased levels of effluent orthophosphate and nitrate.

Water quality testing at the Slough 104B project will expand BES' set of water quality data for green streets facilities with underdrains, adding to the data set analyzed by Emma Kohlsmith in her 2019 thesis at Portland State University (PSU) and resulting ASCE publication. Kohlsmith analyzed data from seven lined green streets facilities that were four to eight years old (a group of "older lined facilities"), using data collected by Field Operations supplemented by her own sampling. BES, PSU, and the University of Portland (UP) collaborated in the effort.

Kohlsmith found TSS reductions met BES' standard for treatment and documented reductions in ammonia, total copper, total zinc, and dissolved zinc. However, there were increased levels of orthophosphate and nitrate in the outflow.

Key Conclusions and Findings
In 2021 WA DOE confirmed it will continue to credit stormwater soil blends containing compost for copper removal. Recent research by WSU shows dissolved carbon in effluent effectively binds metals and makes them unavailable to biota.

Results to date for the Slough 104B project are consistent with findings from larger-scale field testing funded by the State of Washington for bioretention soil blends containing compost. As reported by the Washington Department of Ecology (DOE) in 2021, bioretention soil blends containing sand and compost (like BES' standard soil blend) provide substantial reductions in TSS, total lead, total zinc, fecal coliform, E. coli, oil and grease, and other organic compounds. The WA DOE research also shows exports of phosphorus, nitrogen, and copper can sometimes occur at levels of concern, particularly initially, with somewhat reduced nutrient exports over time. CRM staff, in coordination with the Regulatory Strategy and Remediation team, continue to track outside research concerning bioretention water quality performance and potential methods for improving results. An example is research by UP documenting the benefit of adding locally-sourced water treatment residuals to the imported soil blend to reduce the export of phosphorus. It's important to note there are no TMDLs or 303(d) listings for nitrogen for Portland's waterbodies.

B. Slough 104B Project – Plant Health

The hypothesis for the Slough 104B project study is that plant health will be better in unlined systems since plant roots can access the native soil, in contrast to conditions in fully-lined systems. For the two soil blends, the hypothesis is that the blend containing more loam will improve conditions for plants because it has better water holding characteristics. For the two underdrain systems, the hypothesis is that the shortened underdrain will increase moisture available to plants by increasing the volume of the imported blended soil, increasing the residence time of the runoff as it passes through the facility, and providing a small reserve of water below the underdrain. The bottom of the underdrain is four inches above the liner.

The GSI O&M and CRM teams continue to collaborate in periodic visual assessments of plant coverage and health. The assessments conform with GSI O&M's standard protocols for plant health assessments. Field visits began in early 2019, immediately after construction was completed. With few exceptions, the facility scores for vegetation health and coverage were excellent or good throughout the two-year startup period. Consistent with BES practice, the systems received summer irrigation during the startup period. The June 2021 assessment, at the beginning of the first summer without irrigation, indicated the plants had continued to establish well.

2021 Decline in Plant Coverage and Health – 104B Project

Key Conclusions and Findings
The Slough 104B results confirm long-time reports from the GSI O&M team that plants in lined facilities have much lower average vigor and higher mortality rates compared with plants in infiltration facilities where roots have access to native soil. Lined facilities with shade fared slightly better.

For lined facilities there was a significant downturn in the standard GSI O&M ratings for plant cover and plant health between assessments completed in June 2021 and in April 2022. In April 2022, staff were able to confirm plant mortality from summer 2021 based on new plant growth. The average score for plant cover in lined facilities fell from 1.4 to 3.8 during the interval and the average score for plant health declined from 2.0 to 3.6[1]. In contrast, the average scores for unlined facilities were stable during the period. See Figure 1 and Figure 2 for a comparison of changes in the averages for plant cover and plant health (vigor) on the two dates.

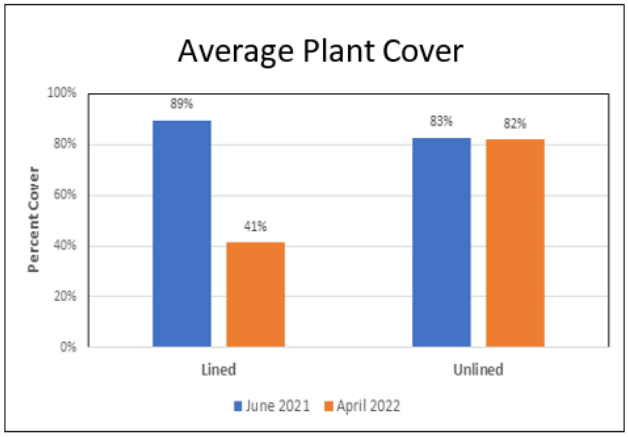

Figure 1. Slough 104B – Plant Cover

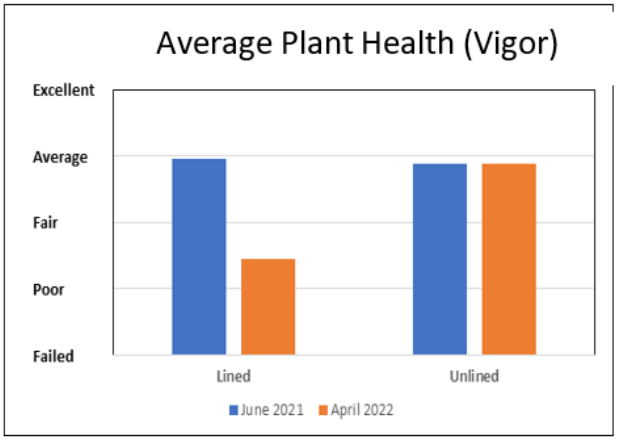

Figure 2. Slough 104B - Plant Health (Vigor)

Among lined facilities, the influences of underdrain type and soil type on the results for plant coverage and health were not statistically significant. The high variability of the data contributed to that outcome. However, there were some general trends in the data for lined facilities based on a visual inspection of the distribution of results by soil type and underdrain type.

- The systems combining the old standard underdrain and the standard soil blend produced the worst distribution of results by far for plant coverage and health.
- The benefit of the high-fines soil blend for plant coverage and health was more apparent in the distribution of outcomes than the effect of the short underdrain.
- The facilities with the high-fines soil blends produced the best distribution of outcomes for both underdrain types.

CRM will release a separate report providing a more detailed analysis of the results.

[1] GSI O&M uses a five-category scale for rating plant coverage and plant health, with a 1 indicating excellent conditions and a 5 indicating the poorest conditions. A rating of 5 for plant cover means desirable plants cover less than one quarter of the planted facility area; a rating of 5 for plant health is described as failure (plants are dead or nearly dead).

Summer 2021 Vegetation Browning Results – 104B Project

The summer of 2021 was extreme, with temperatures reaching 116°F during a heat dome at the end of June and virtually no rain between mid-June and mid-September. Staff documented significant browning of the vegetation in a subset of lined facilities during a site visit at the end of July. Site visits were also made at the end of August and the end of September to document browning levels in all 53 facilities. CRM will provide detailed results in a separate report. The following bullets provide a general summary.

Unlined facilities – Summer 2021 Browning Results:

- Unlined facilities exhibited relatively little browning - average browning at the end of the summer for the 24 unlined facilities was 15%.
- There weren't discernable differences in results by underdrain type and soil blend.
- (Many facilities are unshaded but some have partial shade.)

Lined facilities – Summer 2021 Browning Results:

- Lined facilities exhibited strong browning - average browning at the end of the summer for the 29 lined facilities was 80-100%, with just two exceptions.
- Browning rates were 0-50% in late July in a subset of facilities with the high-fines soil blend; rates were 80-90% on the same date for a paired group of facilities with the standard soil blend.
- The underdrain type did not have a discernable effect on browning rates in the lined facilities.
- (More facilities are unshaded in comparison with conditions for the group of unlined facilities.)

Figure 3. Facility 52 at the end of July 2021. Browning rate of 10%.

Figure 4. Facility 52 at the end of September 2021. Browning rate of 90%.

Summer 2021 Browning in Lined Facilities in Other Parts of Portland

BES staff visited an additional 53 fully-lined green streets facilities in other parts of Portland in September 2021 to compare browning at those facilities with the browning results for lined facilities at the Slough 104B project. The additional facilities were not randomly selected but included clusters of facilities in at least five distinct locations and settings in SW, NW, and SE Portland. Although some of the facilities exhibited significant browning, the results for the additional 53 facilities were much more mixed compared with results from the Slough 104B project. The presence of shade, including partial shade, appeared to be an important factor. That was particularly apparent in southwest Portland where more than half of the additional facilities are located.

C. Slough 104B Project – Soil Moisture

In June 2020 BES installed in-situ moisture monitoring systems in six Slough 104B facilities. There are three sensors in each facility providing continuous soil moisture data. The goal is to better understand the impact of design changes on soil moisture, with particular attention to plant-related factors such as the initial water holding capacity after draining by gravity (field capacity), the drying rate after rain or irrigation, and the time interval before the onset of wilting point conditions in the summer.

From June 2020 through December 2021 (Phase I), the experimental design compared moisture differences in lined facilities by underdrain configuration. All of the facilities were fully lined and had the high-fines soil blend; three facilities were built with the old standard underdrain (long) and three facilities with the new (short) underdrain. Each of the sensors was installed at a depth of 8 inches below grade, collecting data from the root zone.

In November 2021, after gathering more than a year of data, the MCA team completed an analysis and internal memorandum for the Phase I soil moisture data. Fitting a Generalized Additive Model (GAM) to the drying-period data, MCA concluded the estimated field capacity in systems with the short underdrain was slightly higher than in the systems fitted with the long underdrain, while the estimated drying rates for the two underdrain types were similar. The net effect based on the modeling is that during an extended dry period it takes a couple of days longer for the systems with the short underdrain to reach a specific moisture content (e.g., wilting point conditions).

Key Conclusions and Findings
Summer 2021 was the first summer without irrigation for the Slough 104B facilities. In the second half of the summer the plants in the six facilities with moisture sensors were subject to severe stress (<15% moisture content) for about 8 weeks.

BES does not have plant- and soil-specific reference values for the soil moisture content at the onset of wilting point conditions as the soil dries. However, published research suggests many plants are stressed at a sustained moisture content of less than 15%. The average soil moisture in all six of the facilities was below 15% by the last week in July in 2021; in the second half of the summer plants were subject to severe moisture stress for approximately 8 weeks. The average moisture content was slightly under 10% in the group of six in mid-September, just before the first rainfall.

The Phase II moisture monitoring program began in March 2022 and will continue into fall 2022. The experimental design will compare differences by soil type in lined facilities, with the same monitoring structure as in Phase I. There are three facilities in each treatment and three sensors in each facility. All of the facilities have the short underdrain.

D. Slough 104B Project – Hydraulic Performance of the High-fines Soil Blend

In February 2022 the CRM team and Field Operations completed drawdown tests at seven lined facilities containing the high-fines soil blend. Concerns about the potential for unacceptably low infiltration rates has slowed BES' adoption of a specification with more loam. The drawdown tests were therefore an important milestone for the Slough 104B monitoring program and the development of a BES special soil specification based on the high-fines blend. The facilities were a little over three years old at the time of the tests and therefore the results reflect conditions after plant establishment - root systems are thought to significantly influence the permeability of soil blends in bioretention facilities, helping maintain porosity and infiltration rates. Staff selected February for the tests given evidence in Portland and elsewhere of slower infiltration rates in the winter due to increased water viscosity with colder temperatures.

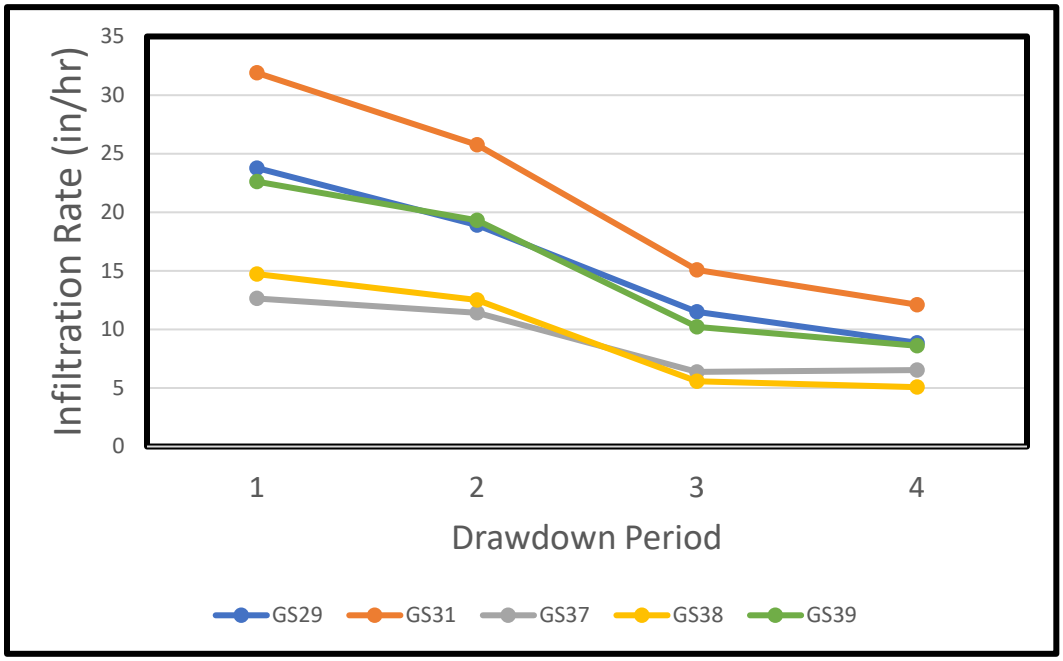

Figure 5. Winter infiltration test results, high-fines soil blend in mature facilities

Staff filled each of the facilities four times in succession over the course of six hours. The drawdown rates after the fourth filling, taken as the final result, ranged from 5 to 12 in/hr (see Figure 5). That range is lower than the range observed in January 2018 during similar testing of a group of lined facilities containing the standard soil blend. (Those rates ranged from 11 to 39 in/hr.) However, the average for facilities with the high-fines

Key Conclusions and Findings
Winter tests confirmed the adequacy of drawdown rates in a group of Slough 104B facilities containing a soil blend with 1/3rd loam. The results support moving forward with a specification for a "high-fines" soil blend that provides conditions for better plant health.

blend is adequate as a basis for proceeding with a special soil specification similar in composition to the Slough 104B high-fines blend. The design assumption in the 2020 SWMM for infiltration for the imported soil blend is 6 in/hr (2020 SWMM).

CRM staff are developing a report summarizing results for the February 2022 tests. There is an existing CRM memorandum summarizing results for the 2017 tests.

3. Green Streets Soil Retrofits – Soil Moisture Study

The GSI O&M team is monitoring soil moisture at two retrofit trial projects using a portable moisture meter. The projects are being implemented to test different approaches for retrofitting facilities which haven't successfully sustained plants over time. CRM is working with GSI O&M to confirm the extent to which the approaches increase plant-available soil moisture during dry periods, delaying the onset of wilting point conditions. Visual assessments of plant coverage and plant health are also part of the studies.

Figure 6. SW Multnomah soil retrofit

GSI O&M replanted six lined green streets facilities at NE 97th/Glisan in 2019. There are three trial treatments: in two facilities staff mixed a specified quantity of biochar into each planting hole, in two facilities biochar was evenly incorporated into surface mulch that was added after replanting, and the two control facilities were replanted without modifications. GSI O&M replanted nine lined facilities on SW Multnomah in 2019. There are three treatments: in three facilities staff amended the existing soil blend with loam and compost, in three facilities the shallow (9-inch) soil profile was completely replaced with a loam/compost mix, and three control facilities were replanted without other changes.

The portable monitoring unit employs time domain reflectometry (TDR) technology. The unit averages soil moisture over the upper 8 inches of the soil profile. The standard practice is to document the initial moisture content at field capacity (one to two days after the end of a rain or irrigation event) and to sample again at least three times over the following two weeks to develop a drying curve. The systems are hand watered approximately every two weeks. Data from the controls allow comparison of the incremental benefit of the different treatments.

The initial data for NE 97th/Glisan indicates the biochar treatment with mulch maintains soil moisture at a slightly higher level over the course of drying periods compared with the other biochar treatment and the control. The initial data for SW Multnomah indicates both the amendment and replacement approaches maintains soil moisture at a substantially higher level through drying periods compared with the control.

4. Green Streets Pollutant Accumulation Study

The MCA team is in year three of a ten-year study of pollutant accumulation in green streets sediment. Building on previous sediment sampling in green streets facilities, the current plan calls for sampling a total of 93 facilities over ten years for analytes including metals, PAHs, and phthalates. Peter Bryant gave a Breaktime presentation about the monitoring study in 2020 and in 2017 MCA produced an

internal report about results from a previous BES study. The initial analysis concluded that no pollutants were accumulating at a rate that would be concerning for human health exposure.

5. Green Streets Pilot of an In-line Orifice Configuration

CRM is working with Stormwater Maintenance Engineering to pilot an in-line orifice configuration for green streets with underdrains where the design doesn't include a domed-grate ("beehive") overflow unit. A flow-control orifice is now required by the SWMM for certain green streets facilities with underdrains. The 2020 SWMM includes a standard orifice configuration for systems with a domed-grate, but for systems without overflow units there is a need for a simple in-line configuration allowing easy access to the orifice from the surface. In spring 2022, staff retrofitted two existing facilities adjacent to Parkrose Middle School with devices. Monitoring in fall 2022 will include visual observations to confirm basic functions and staff will install water level sensors in one of the facilities to record how the internal water level in the facility responds to the presence of the orifice.

Ecoroofs

1. Ecoroofs - Monitoring Focus Areas

There have been two primary focus areas in Portland's monitoring of ecoroofs: hydraulic performance and water quality performance.

A. Hydraulic Performance

Figure 7. Walmart ecoroof

BES monitors hydraulic variables including peak flow attenuation and volume retention to confirm performance in different design storms and to check the adequacy of standard sizing factors and design assumptions. Many factors influence ecoroof performance, including storm length and intensity, the length of the antecedent dry period, seasonal temperatures, solar aspect, and the composition and depth of the growing media. It is therefore important to obtain location-specific performance data and results for multiple installations. Long-term performance data is needed to confirm results, and the most valuable experimental designs typically include side-by-side comparisons of data from ecoroofs and conventional roof areas.

BES has monitored the performance of four ecoroofs to date, beginning with the Hamilton Building ecoroof in 2002. The results indicate ecoroofs generally provide good to excellent flow control and retention, with the best results during spring, summer, and fall, and for smaller storms. CRM continues monitoring to refine design requirements, assess SWMM crediting of ecoroofs for stormwater management in different service areas (e.g., CSO vs. MS4), and to track the influence of

industry design changes such as changes in the composition of the growing media. Tim Kurtz' 2013 report summarizes data for the Hamilton, Multnomah County, and Portland buildings.

B. Water Quality Performance

BES monitors ecoroof effluent for TSS, metals (e.g., copper, lead, zinc) and nutrients (e.g., phosphorus, nitrogen) because of concerns about potential negative impacts to watershed health and to understand alignment with regulatory objectives. Although some of the concerns about water quality performance are specific to ecoroofs (e.g., related to ecoroof growing media and roofing materials), concerns about nutrients and metals are similar to the concerns for other vegetated systems such as lined planters. Vegetated systems can export levels of nutrients and metals which might be a concern depending on where the runoff is discharged.

Tim Kurtz' 2013 report summarizes water quality data for the Hamilton, Multnomah County, and Portland buildings. Pranoti Deshmuk's 2019 thesis summarizes water quality data for nutrients and metals from ecoroofs at six locations in Portland, and Alex Bans' 2020 thesis reports on seasonal water quality results and drivers at the Walmart ecoroof.

2. Ecoroofs - Monitoring at the Walmart Building

Key Conclusions and Findings
PSU researchers analyzed three years of data from the Walmart ecoroof and reported the lowest winter retention rate (median value) was ~50%, with no significant difference between retention for the 3-inch roof and the 5-inch roof.

The Walmart Supercenter on Hayden Island has been the main focus of BES' ecoroof monitoring effort since the building was constructed in 2013. BES partnered with Walmart to install monitoring equipment including in-ground flumes for measuring outflow rates and other dedicated equipment. The setup provides comparative data for roof areas with three inches of growing media, five inches of growing media, and a control (conventional roof). PSU analyzed three years of the hydrologic data (Chang et al.,2021), and found retention was similar for the two media depths, with retention more strongly influenced by storm intensity and the length of the antecedent dry weather period than the media depth. The MCA and CRM teams are currently analyzing eight years of data. The influence of different media depths is a primary focus: if monitoring confirms that shallower, lighter systems provide hydraulic benefits similar to deeper roofs, BES will have a basis for crediting roofs with shallower media layers for stormwater management.

Manufactured Stormwater Treatment Technologies (MSTTs)

Maintenance Intervals

Figure 8. Flow test of catch basin MSTTs

In 2019 and 2020 the CRM team led testing of a group of catch basin MSTTs BES constructed along the Beaverton-Hillsdale Highway at SW Shattuck Road. BES installed the units to treat runoff draining to Fanno Creek. The small devices were the first of their kind in Portland along a busy arterial. The monitoring goal was to document whether the devices could continue to function for at least a year before needing maintenance; the plan called for hydraulically testing the four devices on a quarterly basis to confirm how long they continued to filter the design flow rate. Staff completed three quarterly tests, but the fourth and final test was not completed due to logistical constraints created by the pandemic. The results were therefore inconclusive. It's important to note the data for two of the four devices in the study were brought into question due to problems with the performance of the street inlets - during site visits in late fall of 2021 staff documented repeated clogging of the curb inlets serving the two installations. PBOT has confirmed the B-H Highway is swept on a regular basis in the fall and that the inlet design is vulnerable to clogging by street sweepers.

In 2022, the CRM team will begin a year-long program to document sediment accumulation rates and maintenance requirements for a group of catch basin MSTTs PBOT installed along SW Naito Parkway in 2021 to treat runoff draining to the Willamette River. The units are the first of their type in Portland, manufactured by a different vendor than those along the Beaverton-Hillsdale Highway. There is concern small catch basin units may require more frequent maintenance visits in locations with relatively heavy traffic (e.g., along SW Naito Parkway). SW Naito Parkway is part of PBOTs street sweeping program and the monitoring program will include inspection of the inlets on a regular basis to document any clogging that could affect maintenance intervals. The results will help inform BES' selection criteria for MSTTs.