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Field Confirmation of Hydraulic Performance of Older Lined Green Street Facilities with the 2008 Stormwater Soil Blend

Infiltration Test Report
May and June, 2017; January 2018

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Date	By	Revision
4/20/18	TJ	Initial draft
5/4/18	TJ	Revision 1

Executive Summary

This report summarizes results from stormwater drawdown tests at eight vegetated stormwater management facilities. Tests consisted of flooding the facilities and recording the rate of ponded depth drawdown. The first series of tests took place between May 25 and June 22, 2017. The second series took place between January 8 and 12, 2018.

Average drawdown rates across individual tests ranged from 10.64 in/hr to 130.59 inches/hour. The average median was 49.88. The first test of each facility had a higher drawdown rate than the last test. In all cases but one, winter drawdown rates were lower than spring drawdown rates.

Figure 1 Infiltration test locations. More than one facility included at some locations.

Background

The SWMM Team initiated an investigation of the performance of older lined green street facilities with multiple goals in mind. 1) determine the “infiltration” performance of the soil based on a 2” per hour assumption that is used in the Stormwater Management Manual (SWMM). 2) Test the water quality of discharge from established facilities. This summary report is part of a larger, multi-year monitoring effort.

Facility Configuration

The facilities chosen were constructed between 2010 and 2014 with 18 inches of 2008 BES Stormwater Facility Blended Soil, a 3” choker coarse of ¼” – ¾”, and ~9” of ¾” – 1½” washed drain rock. An aggregate drain layer extends throughout the footprint of each facility and an HDPE 30mil or 40mil liner is present in every case. The underdrains are 6” or 4” PVC pipe with hand drilled perforations per the BES specification (1/2” holes 5” o.c. with two rows parallel to axis of pipe and 120° apart). The BES Stormwater Facility Blended Soil has a specified fines range between 5% and 15%, with a typical tested value of 5%. This fines content can be achieved without adding any real soil to the blend resulting in a media of sand and compost dominated by sand.

Table 1. Selected characteristics of older lined facilities.

Facility	Build Date	Catchment Area (ft²)	Design Ponding Depth (in)	Purpose of Facility	Nearest HYDRA Gage	Distance to Gage (miles)
5403 109th Ave	12/28/10	10342	6	Water Quality	111	2.64
1318 SE 58th Ave[1]	5/30/14	2954	9	Peak Flow Control[3]	175	0.66
1318 SE 58th Ave[2]	5/30/14	2757	9	Peak Flow Control[3]	175	0.65
2870 SE Grant St	3/11/11	3250	9	Peak Flow Control[3]	171	0.91
2156 SE 28th Pl	3/11/11	4200	9	Peak Flow Control[3]	171	0.91
7930 NE Sandy Blvd	8/7/12	11580	6	Water Quality	213	0.79
8025 NE Sandy Blvd	8/7/12	4800	6	Water Quality	213	0.85
8816 N Edison St	6/27/12	3400	12	Water Quality	160	0.40

1- On Madison. 3- On 58th. 3- Basement sewer backup protection.

Test Objectives

BES performed the tests to provide benchmark data about long term drawdown rates for BES’s standard soil blend for stormwater management facilities. Drawdown rates are influenced by soil blend composition and installation conditions, but also by longer-term factors such as compaction, sediment loads, vegetation establishment, traffic volumes on streets in the catchment, maintenance practices, and surrounding land use. When sizing facilities, BES sets a design infiltration rate of 2 inches/hour for the imported soil blend. The rate accounts for variability including a presumed decline in rates over the years with sedimentation.

This is the first time BES has attempted to conduct representative sampling of drawdown rates in lined facilities which are several years into their functional lives. The facilities were selected because their configurations are representative of BES’s standard configuration for lined green streets facilities (see 2016 SWMM standards). About 10% of BES’ roughly 2000 green streets facilities are fully lined, with the imported layer of blended soil controlling flow attenuation and treatment. It was an important goal to tests results at different times of the year, as seasonal variations are well documented in published studies.

Test Setup

To avoid confusion, we do not refer to these tests as infiltration tests. While the tests did measure the rate at which water infiltrated into the facilities, no provision was made to achieve a steady state as is typically done in a formal infiltration test. To distinguish these test results from steady state infiltration rates, we refer to them as *drawdown* tests and *drawdown* rates.

The inflow equipment set up for this test was similar to that used in previous tests of green streets and consisted of the following:

- Sensus 1250 Flow Meter
- 100 feet (2 x 50 ft sections) of 2 ½" fire hose
- 6 feet (1 x 6 ft section) of 2 ½" fire hose
- Dechlorinator/Diffuser
- Depth gages (rulers and stakes)

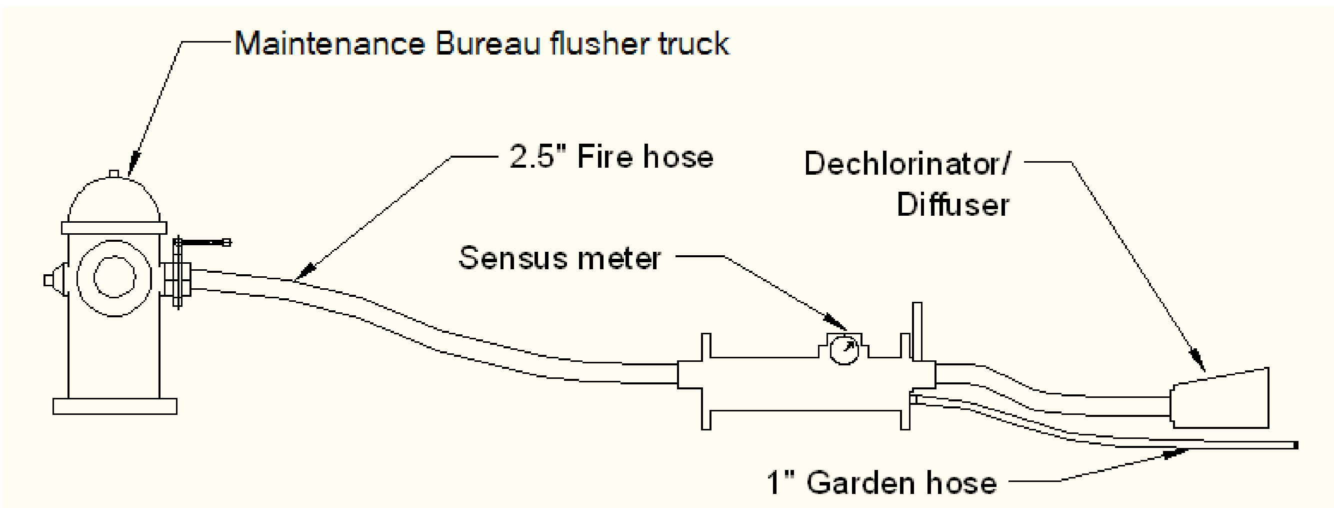

Figure 2 Infiltration test equipment set up (not to scale).

Figure 3 Diffuser in plastic recycling bin

As no fire hydrants are adequately close to the facilities, PBOT Maintenance Operations (PBOTMO) flusher trucks with 4000-gallon tanks were used to supply water for the drawdown tests in May and June. Private flusher trucks were contracted for the January tests.

For each drawdown test, the diffuser was placed inside the facility near the inlet in a plastic recycling bin to reduce scouring and erosion (Figure 3). Except where the available flowrate or volume of water was not adequate, the planter was filled until overflow into the bypass drain commenced. The facility on 109th

Ave did not have a bypass drain, so it was filled until water began flowing out of the inlet.

Depth gages, made of rulers taped to wooden stakes (Figure 4), were temporarily installed in each planter near the bypass drain if there was one, and at the far end of the facility from the inlet if there was not. Once overflow ceased, a stopwatch was started, and elapsed times were recorded at each inch reduction of ponded water.

Figure 4 Depth gage in N Edison green street.

The facility on Madison St. at 1318 SE Madison St. comprised three bays in series. Because the volume of water required to fill up the third bay from the first bay was prohibitively large, the first and third bays were tested independently.

In all the facilities, the soil was visibly sandy, with the exception of the NE 109th facility, which had a layer of silty sediment on top.

In all facilities, the vegetation cover was overall healthy and lush. There were some weeds and, after field staff pulled those weeds out, some bare patches of soil remained. While the stormwater facilities were designed with 6-12 inches of ponding (see table below), the observed ponding depth varied from 3-10 inches.

Antecedent Conditions

Spring

Conditions immediately prior to each test were dry, with no rain in the five days prior to the test in all cases, but significant rain had fallen within two weeks prior to each test (**Table 2**).

Winter

No rain fell during any of the winter tests, but significant rain had fallen in the two weeks prior to each test (**Table 2**). The last rain prior to each winter test was the previous day: 0.75 inches the day before the January 12, 2018 test, and 0.09 inches before the January 8, 2018 test.

Table 2. Measured rainfall at the HYDRA gauge nearest each facility immediately prior to each test.

Facility	14-Day Rain (in) Spring	14-Day Rain (in) Winter
5403 109th Ave	1.71	2.58
1318 SE 58th Ave[1]	1.78	2.50
1318 SE 58th Ave[2]	1.78	2.50
2870 SE Grant St	1.63	2.41
2156 SE 28th Pl	1.63	2.41
7930 NE Sandy Blvd	1.10	2.44
8025 NE Sandy Blvd	1.10	2.44
8816 N Edison St	1.23	N/A[3]

1- On Madison. 2- On 58th. 3-The facility at 8816 N Edison St was not included in the winter tests because it was modified shortly after the spring tests and no longer satisfied the selection criteria for this investigation.

Drawdown Tests

Except for the two facilities on SE Grant St and the N Edison St facility, six drawdown tests were conducted in each facility—three consecutive tests in late spring and three in midwinter. Due to time constraints, only two tests were conducted in each of the SE Grant St facilities in spring, and the N Edison St facility was not tested in winter (see above). Tests were repeated to determine how drawdown rates varied with soil water content. As no water content measurements were taken, the results were qualitative with regard to soil water.

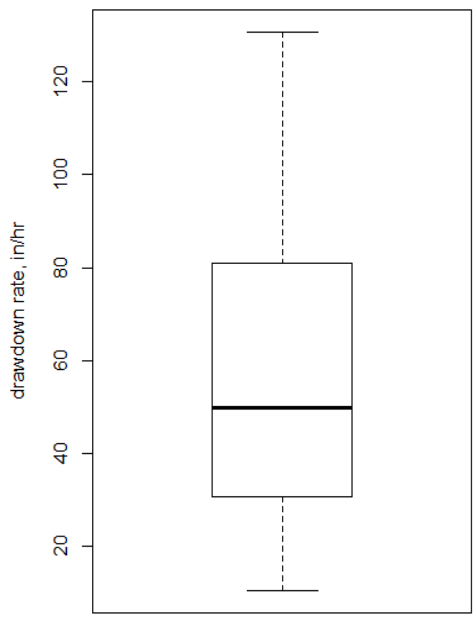

Figure 5 Boxplot of all trial mean drawdown rates. n=46.

Results and Discussion

Incremental drawdown rates spanned a large range (Table 3, Table 4). Averaged over each trial, no drawdown rate approached the SWMM's design rate of 2 in/hr. Mean drawdown rates were an order of magnitude larger than 2 in/hr for all tests, and several spring test mean rates were two orders of magnitude larger (Table 3, Table 4).

Trial mean drawdown rates ranged from a low of 10.64 in/hr to a high of 130.59 in/hr, with a median rate of 49.88 in/hr (Figure 5). The most extreme results were from the 8816 N Edison St facility. Water was pumped into the facility at a rate of approximately 400 gal/min. Given the facility's nominal catchment area of 3400 ft^2, the rainfall intensity required to produce a similar volumetric flow rate is 11.3 in/hr. For reference, the most rainfall ever recorded in one hour is 12 inches on June 22, 1947 in Holt, Missouri. Even with that high flow rate, very little water made it to the third bay of the facility. After 6 minutes, it was clear that there was not enough water in the flusher truck to overflow the facility through the third bay, and water drawdown was instead timed in the first bay. Though less extreme, results were similar at the other test sites, with the exception of the facility on NE 109th Ave.

*Table 3. **Spring tests.** Summary of **drawdow**n rates by facility.*

Address	Date of test	Incremental rate (in/hr)		Average test drawdown rate (in/hr)		
		Maximum	Minimum	Test 1	Test 2	Test 3
8816 N Edison St.	6/22/17	300.0	69.2	118.68	95.58	90.00
1318 SE 58th Ave. (on Madison, Bay 1)	5/26/17	150.0	33.0	108.00	52.65	44.26
1318 SE 58th Ave. (on Madison, Bay 3)	5/26/17	136.4	34.0	88.24	50.47	49.89
1318 SE 58th Ave. (on 58)	5/26/17	150.0	40.0	102.27	56.56	49.09
2870 SE Grant St.	5/25/17	138.5	37.1	101.22	54.46	N/A
2156 SE 28th Place (on Grant)	5/25/17	163.6	64.3	130.59	78.54	N/A
7930 NE Sandy Blvd	6/21/17	105.9	30.0	75.31	48.13	40.00
8025 NE Sandy Blvd	6/21/17	200.0	47.4	121.62	73.47	57.14
5403 NE 109th Ave.	5/26/17	62.1	9.8	43.58	18.84	15.24

*Table 4. **Winter tests.** Summary of **drawdow**n rate**s** by facility.*

Address	Date of test	Incremental rate (in/hr)		Average test drawdown rate (in/hr)		
		Maximum	Minimum	Test 1	Test 2	Test 3
8816 N Edison St.[1]	N/A	N/A	N/A	N/A	N/A	N/A
1318 SE 58th Ave. (on Madison, Bay 1)[2]	N/A	N/A	N/A	N/A	N/A	N/A
1318 SE 58th Ave. (on Madison, Bay 3)	1/8/18	144.0	13.2	81.03	31.66	23.75
1318 SE 58th Ave. (on 58)	1/8/18	72.0	3.8	32.96	13.64	10.64
2870 SE Grant St.	1/8/18	163.6	30.3	89.63	44.26	35.94
2156 SE 28th Place (on Grant)	1/8/18	116.1	33.6	91.84	49.86	38.71
7930 NE Sandy Blvd	1/12/18	40.5	9.5	21.40	13.05	11.91
8025 NE Sandy Blvd	1/12/18	79.8	14.7	74.73	24.85	19.68
5403 NE 109th Ave.	1/12/18	61.3	17.1	59.25	30.62	25.17

1-The facility at 8816 N Edison St was not included in the winter tests because it was modified shortly after the spring tests and no longer satisfied the selection criteria for this investigation.

2- The 1st Bay on 1318 SE 58th wasn't tested in the winter due to time constraints.

Prior to the spring tests, the NE 109th facility appeared to have received a heavy load of fine sediment due to construction traffic on the adjacent road. The spring drawdown rates here were the lowest of any facility tested, but still well above design rates used in the SWMM. The liner in this facility was also not sealed to the concrete at the top and air was observed bubbling from behind the top of the liner, suggesting that water was leaking between the liner and concrete. By the time of the winter tests, construction at the adjoining lot was completed and the accumulated sediment appeared to have been cleaned out. Winter drawdown rates at NE 109th were higher than spring rates, contrary to the pattern seen in other facilities.

During the first two spring tests, at 2870 SE Grant St and 2156 SE 28th Pl, considerable flow was observed passing through cracks in the concrete rings beneath the beehive outlet drains. Without measuring the rate of flow through these cracks, it is difficult to determine how meaningful the calculated drawdown rates are.

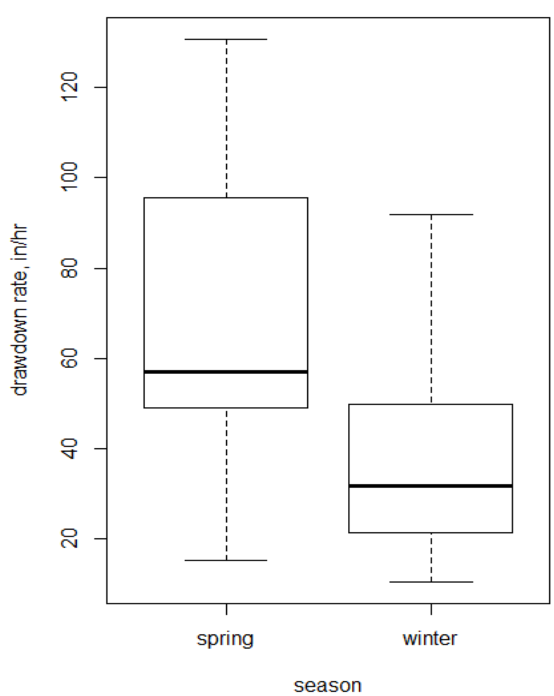

Figure 7 Boxplots of trial mean drawdown rates separated by season; spring(n=25) and winter (n=21).

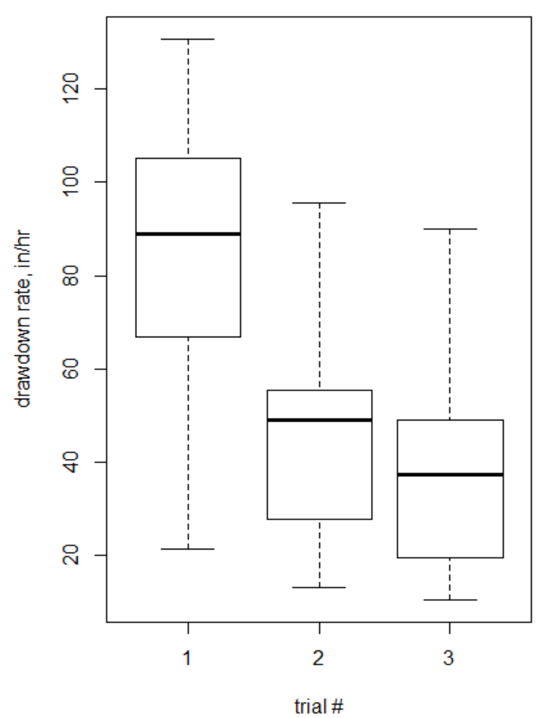

Figure 6 Boxplots of trial mean drawdown rates separated by trial; trial 1 (n=16), trial 2 (n=16), trial 3 (n=14).

Impact of season

Median rates were lower in winter than late spring (Figure 7). Performing a two-tailed t-test with season as the predictor gives a p-value of 6.122 e -4, indicating that season had a statistically significant impact on drawdown rate.

Impact of trial

Median drawdown rate decreased with each trial: rates were highest for the first trial of each facility and lowest for the last (Figure 7). This is consistent with increasing water content decreasing hydraulic conductivity, a well-documented phenomenon. Analysis of variance with trial number as the predictor gives a p-value of 1.97 e -5, indicating that trial number had a significant impact on drawdown rate.

Which trial best represents conservative assumptions is not clear. To obtain a result that is directly comparable to other investigations, studies of infiltration rate or hydraulic conductivity are frequently performed using saturated media. The third trial of each drawdown test would most closely approximate saturated conditions. Given the high drawdown rates observed and large volumes of water required to flood the facilities, however, it is unlikely that any of the facilities regularly receive enough water to increase the water content of their media to levels approaching that present by the third trial, let alone saturated conditions. The third trial at each facility also gave drawdown rates that were still well above design rates. Lined facilities fail to achieve design goals when drawdown rates are sufficiently far from the design rate—either above or below it—and the risk of drawdown rates falling below the design rate seems low. The results of the first trial, then, may be the most conservative, as they may most closely approximate actual field conditions.

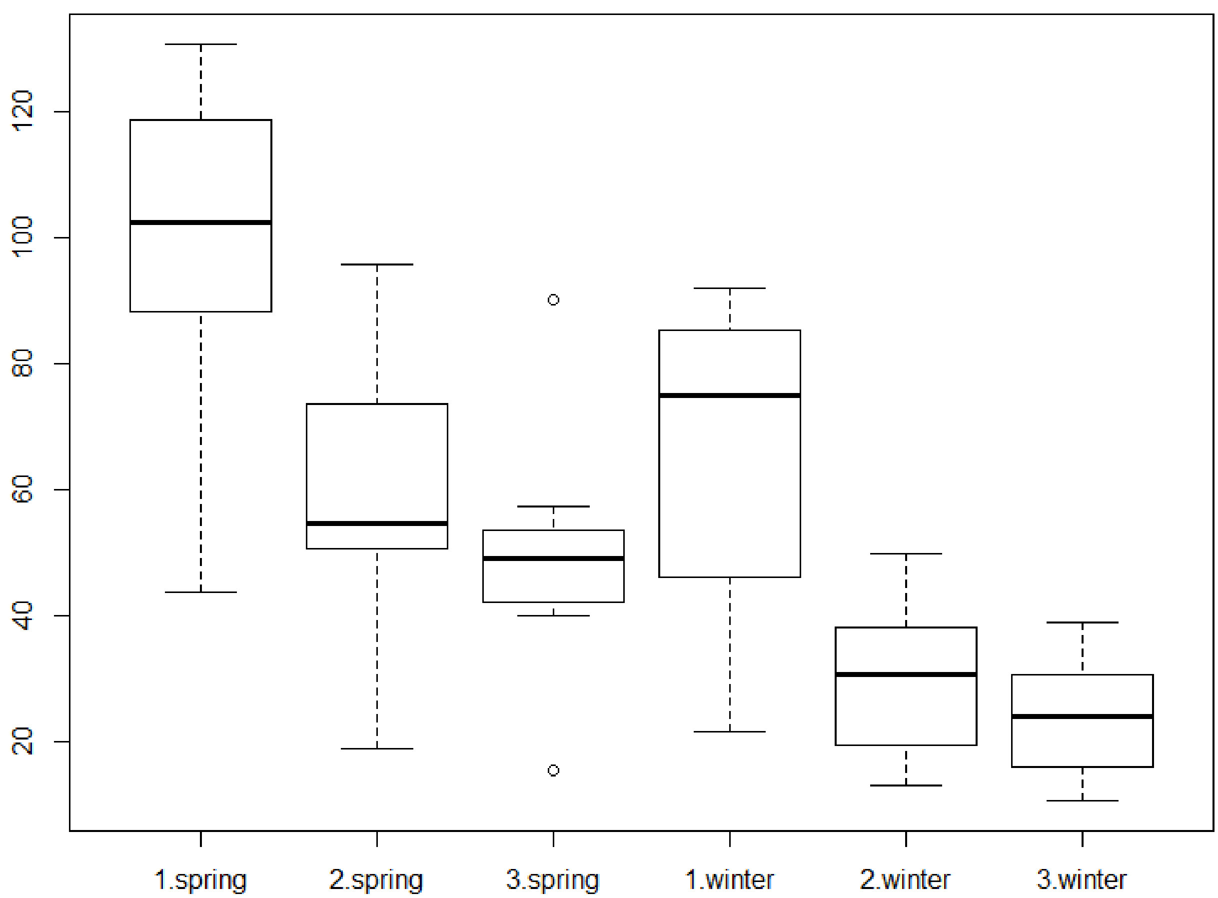

Figure 8 Test data separated by both trial and season; 1.spring (n=9), 2.spring (n=9), 3.spring (n=7), 1.winter (n=7), 2.winter (n=7), 3.winter (n=7).

Figure 6 and Figure 8 show that rates for the first trial in each facility were larger than rates for the second and third trials.

Conclusions

The drawdown rates observed in these tests far exceed those specified in the SWMM for facility design. This likely impairs these facilities' ability to achieve the flow control performance for which they were constructed.

It is unclear how this impacts water quality performance. Facilities with higher infiltration rates filter more water than they were designed to, but facilities with infiltration rates that are too fast may not provide adequate treatment.

The data from these tests indicate there is wide variability in drawdown rates for Portland's standard soil blend for stormwater facilities. The results show strong variability by season, by moisture content (as observed over the course of three successive fillings during the tests), and by facility. Nonetheless, all of the observed rates substantially exceed BES' design assumption of 2 in/hr.

For reference, in 2014 Seattle Public Utilities (SPU) documented infiltration rates in a group of bioretention facilities for the same purpose. A comparison of Portland and Seattle results should be generally valid: Portland's standard soil blend is almost equivalent to Washington's standard soil blend, and facility configurations are similar. Seattle contracted with Herrera to assemble existing infiltration data from field installations; Herrera's summary, contained in a memorandum to SPU, reported data for 11 bioretention installations with underdrains in northwest Washington (Herrera 2014). Herrera reported: "Mean infiltration rates across the individual tests ranged from 11.8 to 45.1 in/hr with an overall mean of 26.9 in/hr." Portland mean infiltration rates ranged from 11.91 to 130.59 in/hr with an overall median of 49.88.

References

Hererra. 2014, Long Term City of Seattle Bioretention Soil Mix Design Infiltration Rate Assumption for Modeling. Memorandum, prepared for the City of Seattle by Herrera Environmental Consultants, Inc, Seattle.

Appendix

Table 5. Summary statistics for all tests and trials.

Min.	10.64
1st Qu.	30.88
Med.	49.88
Mean	56.27
3rd Qu.	80.41
Max.	130.60
Std. Dev.	32.86
CoV	58.39%

Table 6. Summary statistics for all tests separated by season.

Season	Spring	Winter
Min.	15.24	10.64
1st Qu.	49.09	21.40
Med.	57.14	31.66
Mean	70.55	39.27
3rd Qu.	95.58	49.86
Max.	130.60	91.84
Std. Dev.	31.70	25.77
CoV	44.94%	65.64%

Table 7. Summary statistics of all tests separated by trial.

Trial	1	2	3
Min.	21.40	13.05	10.64
1st Qu.	70.86	29.18	20.70
Med.	88.94	49.00	37.33
Mean	83.77	46.04	36.53
3rd Qu.	103.70	54.98	47.88
Max.	130.60	95.58	90.00
Std. Dev.	31.67	23.53	21.49
CoV	37.81%	51.10%	58.82%

Table 8. Summary statistics of all tests separated by season and trial.

Season	Spring			Winter		
Trial	1	2	3	1	2	3
Min.	43.58	18.84	15.24	21.40	13.05	10.64
1st Qu.	88.24	50.47	42.13	46.10	19.24	15.80
Med.	102.30	54.46	49.09	74.73	30.62	23.75
Mean	98.83	58.74	49.37	64.41	29.71	23.69
3rd Qu.	118.70	73.47	53.52	85.33	37.96	30.56
Max.	130.60	95.58	90.00	91.84	49.86	38.71
Std. Dev.	26.79	21.79	22.32	27.80	14.03	10.82
CoV	27.11%	37.10%	45.21%	43.16%	47.24%	45.70%

Table 9. Summary statistics excluding trial 1 and separated by season.

Season	Spring	Winter
Min.	13.05	10.64
1st Qu.	22.73	15.15
Med.	33.80	25.01
Mean	36.40	26.70
3rd Qu.	49.29	34.87
Max.	78.54	49.86
Std. Dev.	21.81	12.44
CoV	39.91%	46.60%

Comparison with HOBO data

In December 2016, BES installed HOBO pressure transducers in each of the tested facilities to monitor ponded depth, with sampling occurring continuously at 4-minute intervals. Continuous sampling provides many more data points over a wider range of conditions than manual flood tests can, which in turn allows a more robust statistical analysis of facility performance. Additionally, flood test data can be used to validate contemporaneous HOBO data.

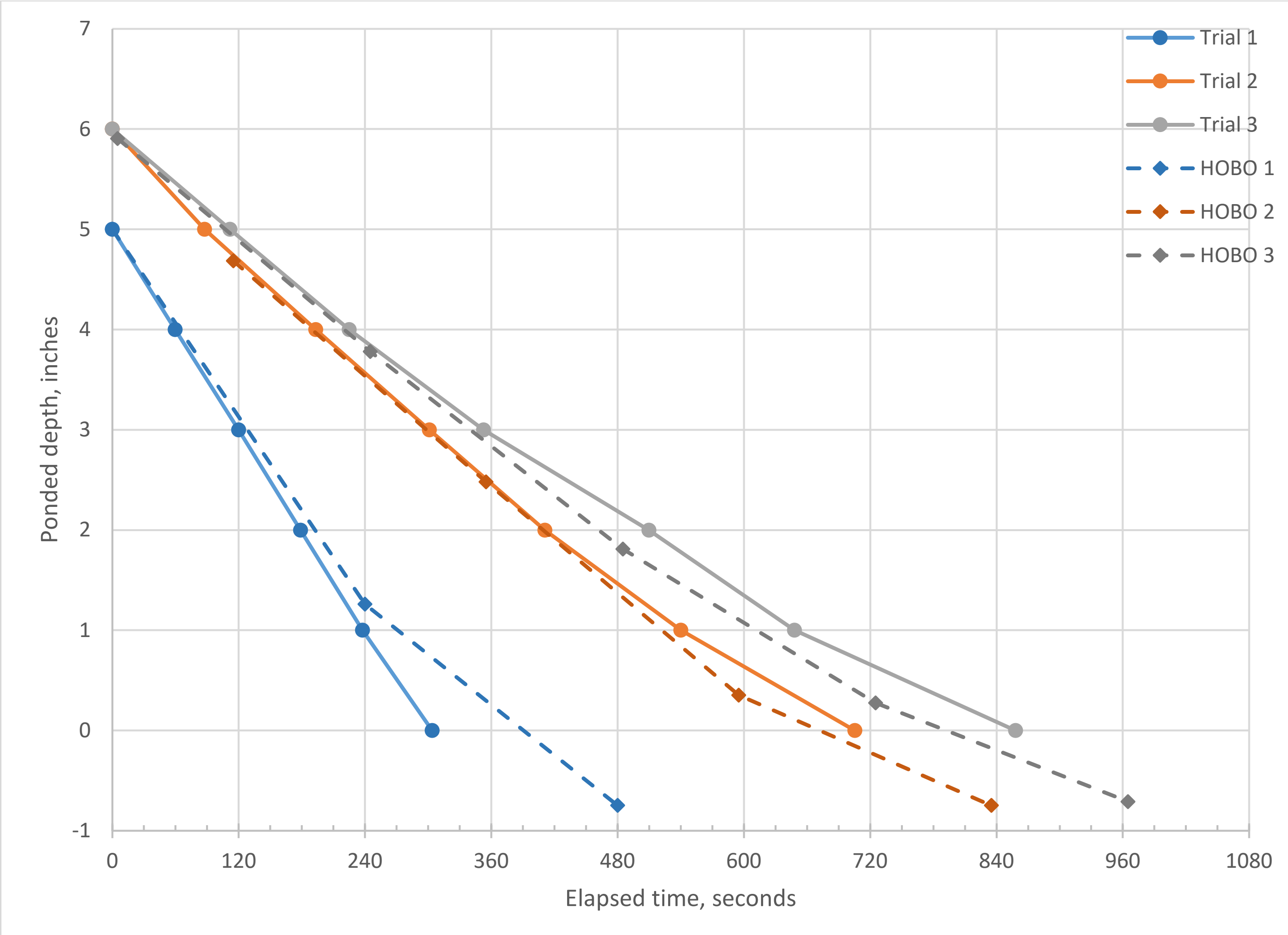

Figure 9. Results of simulated infiltration tests and HOBO data. 5403 NE 109th. 1-12-2018

HOBO and flood test data match well (Figure 9), providing evidence that HOBO data are reliable. Due to the infrequency of ponding in the monitored facilities, however, the HOBO record to date has added few meaningful measurements to the analysis. A forthcoming report will more thoroughly address the use of HOBO gages in monitoring of green stormwater infrastructure.