High-Flow Rate Stormwater Control Measure Performance Curve Development

Task 4 Technical Memo

Modeling and Performance Curve Development

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1 INTRODUCTION

Nutrient pollution from stormwater is the number one source of water quality impairment in New England and is of particular concern in coastal and urban communities. Reducing nutrient pollution from stormwater sources will require various actions from public and private entities. To date, the Environmental Protection Agency (EPA) Region 1 and the Southeast New England Program (SNEP) "Network" (refer to https://www.epa.gov/snep/southeast-new-england-program-network for more information) have been focused on nutrient removal crediting for green infrastructure practices where performance is based on the storage capacity of the practice. However, many proprietary devices are designed using relatively small filter surface areas with filter media capable of passing relatively high-flow rates for treatment. Such high flow rate (HFR) systems differ from more conventionally designed Stormwater Control Measures (SCMs) which rely on using physical storage capacity for subsequent treatment by filtering stormwater at much lower rates. Because of their smaller footprint, towns and private entities are now considering the use of proprietary and non-proprietary HFR SCMs, especially in circumstances where site constraints prevent the widespread and effective use of more conventionally designed green infrastructure SCMs that have relatively lower flow-rate processing capabilities and larger areal footprints. Many conventional SCMs have existing design storage capacity performance curves which can aid in their design and benefit crediting; however, these performance curves may be inapplicable to high-flow rate filtering devices.

Currently, EPA Region 1 does not provide nutrient reduction credit for HFR SCMs but understands that for certain sites, such devices may represent the most feasible treatment option. Bench-scale laboratory testing for nutrient (or other stormwater pollutant) removal is available for some filter media. Field sampling has also been employed in some cases to verify the results of bench-scale tests. However, little to no long-term continuous modeling has been done to cumulatively assess filter performance over extended periods based on system design (e.g., bypass events; efficiency reduction based on flow rate, etc.). There is a need to better define cumulative performance and crediting of HFR filter systems that accounts for filter bypass events, as well as opportunities to increase HFR filter performance through enhancing HFR designs to include more storage capacity upgradient of the filter.

This technical memorandum (TM) presents an approach for the configuration and calibration of a HFR biofilter system within the EPA Opti-Tool and the development of long-term cumulative performance curves for such a system. The University of New Hampshire Stormwater Center (UNHSC) has been monitoring this HFR biofilter system for a wide range of storm events for Total Phosphorous (TP) and Total Suspended Solids (TSS) reduction. Configuration of the biofiltration system involves fitting the system's physical design specifications within Opti-Tool's configuration constraints and calibrating the model to observed treated flow volume and pollutant load reductions.

After calibration, the long-term performance of the HFR biofiltration system was evaluated using local high-resolution (1min) rainfall data collected over a period of 8 years (2017-2024) by the UNHSC. The Opti-Tool StormWater Management Model (SWMM) model was used to develop flow and pollutant (TP and TSS) loading time series using these climate data. This continuous simulation covers a wide range of storm sizes and antecedent moisture conditions from which the performance curves were generated.

The performance curves were developed for a range of ratios of impervious cover (IC) drainage area to filter bed surface area (SA) and the long-term cumulative percentage load reduction in TP and TSS for an industry-standard vertical design profile of the HFR biofiltration system. These performance curves were developed for a system well-designed to drain the infiltrated volume through the underdrain pipe outlet assuming no infiltration loss to the surrounding or underlying native soils and that these curves reflect the performance of the filter system to remove the pollutants.

Beyond the performance curve developed for the industry-standard HFR biofiltration system, several additional performance curves were developed for two scenarios. The first scenario provides additional storage capacity to the HFR filter system (i.e., capturing 0.1-inch, 0.2-inch, 0.3-inch, 0.4-inch, and 0.5-inch of runoff depth from the impervious drainage areas), which results in substantially increased cumulative performance. A second scenario, using additional underdrain storage of 12 inches below the filter media, was run to develop the performance curve showing the further benefits of providing underdrain storage with the underlying native soil (infiltration rate of 2.41 inches per hour). This was analyzed in conjunction with the additional surface storage of 0.5 inches of runoff depth from the impervious drainage areas.

This TM aims to provide an equitable, consistent crediting approach for high-flowrate stormwater controls through long-term modeling of these systems to create nutrient removal crediting curves based on filter media parameters and flow-rate sizing. These curves can then be used in the SNEP region to give stormwater practitioners another stormwater treatment option that is credited consistently throughout the region.

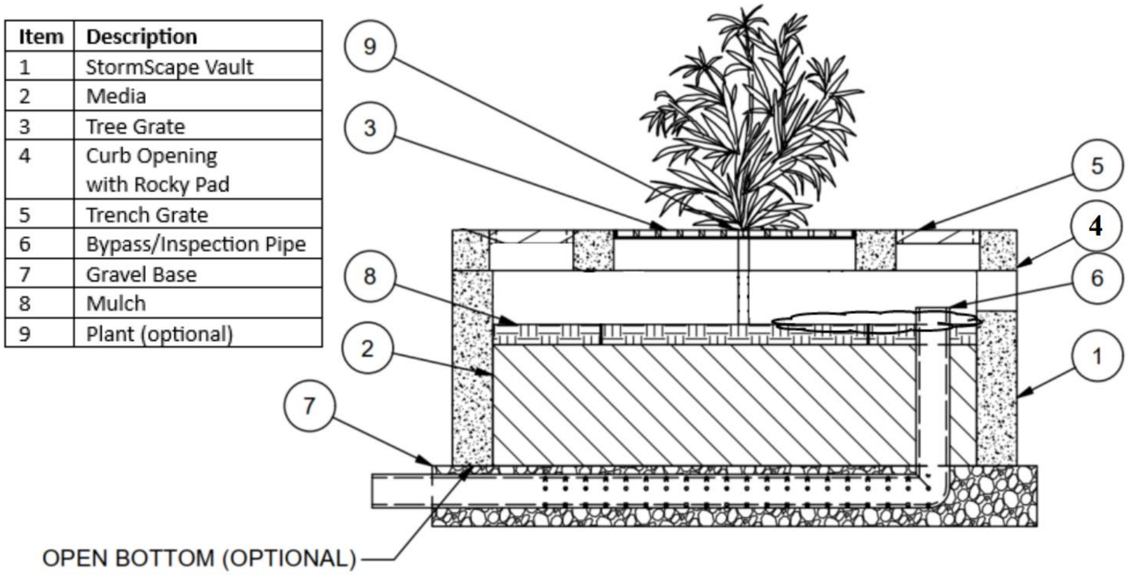
2 HIGH FLOW RATE BIOFILTER PERFORMANCE DATA

The UNHSC, located on the main campus of the University of New Hampshire in Durham, performed field testing of a HFR biofilter system at the site located at the border of the West Edge parking lot on the campus (UNHSC, 2023). The treatment area consists of 9 acres of impermeable pavement. The runoff was collected through a conventional catch basin and branched pipe network, then distributed to the system. The HFR biofilter system was one of three manufactured stormwater systems online during the testing period. The stormwater was sampled at the system influent immediately before treatment occurred and in the outlet pipe immediately after the treatment. The removal rates were calculated from the sampled data as well as an overall evaluation of the HFR biofilter system. A typical HFR biofilter system is shown in Figure 2-1 (Hydro International, 2020).

For the HFR biofilter system, the UNHSC adhered to the 2018 Technology Acceptance Protocol for Washington State Department of Ecology (TAPE) sampling procedures, analytical methods, certified calibration standards, and sample collection at representative locations within the study area. The HFR biofilter system was constrained inside a concrete box with a bottom slab preventing infiltration into native soils that would otherwise introduce losses in water volume and make assessing the performance of the engineered media more difficult. The system includes an underdrain with a pipe diameter of 4 inches. As stormwater enters the inner treatment zone the full surface area of the filtration media is made available for filtration. Most sediment and particulate pollutants are physically captured in the mulch and top layers of the engineered media, while some dissolved pollutants are adsorbed throughout the depth of the media bed. The test system is a confined concrete vault structure with a total media footprint of 6 feet long and 4 feet wide with no additional liners. The HFR system sizing was based on a water quality treatment loading rate of 1.04 gallons per minute per square foot (gpm/sf) (24.96 gpm or 0.056 cubic feet per second) which is equal to a filtration rate of 100 inches per hour. Flows that exceed the water quality loading rate are designed to bypass the system via external bypass structures. The underdrain pipe size was designed with a flow rate that is equal to or exceeds the flow rate of the engineered media.

Eighteen storm events were selected that satisfied the TAPE sampling requirement from 2020 to 2022 field monitoring seasons. Flow data for each storm event was recorded at a 1-minute interval. The water quality samples were taken for TP and TSS from the influent and effluent of the HFR biofilter system. The observed flow volume and the event mean concentration (EMC) for each storm event were multiplied together to estimate the TP and TSS load reductions. The inflow volume, outflow volume, and percent bypass flow for the HFR biofilter system for each storm are shown in Table 2-1.

The total treated flow volume from the storm events was **68%** with **32%** bypassed flow volume (see Table 2-1). The reductions in TP and TSS EMC in the treated flow volume passing through the HFR biofilter system for each event are shown in Table 2-2. The flow-weighted average reductions in TP and TSS concentration from the storm events, excluding the bypass flow volume, were **40%** and **97%** respectively (see Table 2-2). The reductions in TP and TSS load considering both treated flow volume passing through the HFR biofilter system and bypass flow volume for each event are shown in Table 2-3. The total reductions in TP and TSS load from the storm events, after accounting for the bypass flow volume, were **26%** and **37%** respectively (see Table 2-3). There was no observed data for the Total Nitrogen and Total Zinc pollutants from this study.



Item	Description
1	StormScape Vault
2	Media
3	Tree Grate
4	Curb Opening with Rocky Pad
5	Trench Grate
6	Bypass/Inspection Pipe
7	Gravel Base
8	Mulch
9	Plant (optional)

Figure 2-1. A typical High Flow Rate biofilter system (Hydro International, 2020).

Table 2-1. Storm event date, inflow volume, outflow volume, and bypass flow in the HFR biofilter system

Storm Event	Sample Date	Rainfall (in)	Flow		
			Inflow (gal)	Outflow (gal)	Bypass (%)
1	8/29/2020	0.43	14,126	12,807	9%
2	3/26/2021	0.15	1,706	1,766	-3%
3	4/21/2021	0.23	3,729	2,957	21%
4	7/3/2021	1.22	19,916	15,512	22%
5	7/25/2021	0.3	3,509	3,195	9%
6	10/16/2021	0.36	3,926	4,169	-6%
7	3/24/2022	0.87	18,554	10,725	42%
8	4/16/2022	0.41	9,419	7,687	18%
9	4/26/2022	0.34	3,166	2,911	8%
10	5/2/2022	0.32	6,608	5,534	16%
11	5/15/2022	0.42	5,569	3,212	42%
12	5/16/2022	0.23	6,335	3,672	42%

Storm Event	Sample Date	Rainfall (in)	Flow		
			Inflow (gal)	Outflow (gal)	Bypass (%)
13	5/19/2022	0.23	5,118	3,649	29%
14	6/3/2022	0.55	14,700	3,803	74%
15	6/8/2022	0.44	14,191	7,484	47%
16	6/13/2022	0.18	5,180	4,651	10%
17	7/25/2022	0.37	4,474	3,010	33%
18	8/6/2022	0.33	5,780	2,255	61%
Total		7.38	146,006	98,997	**32%**

Table 2-2. Storm event dates and TP and TSS EMC reductions for treated volume in the HFR biofilter system

Storm Event	Date	TP			TSS		
		Inflow (mg/l)	Outflow (mg/l)	Reduction (%)	Inflow (mg/l)	Outflow (mg/l)	Reduction (%)
1	8/29/2020	0.12	0.07	42%	27.00	1.50	94%
2	3/26/2021	0.31	0.13	58%	130.00	44.00	66%
3	4/21/2021	0.08	0.03	63%	31.00	7.00	77%
4	7/3/2021	0.08	0.05	38%	27.00	1.75	94%
5	7/25/2021	0.05	0.04	20%	25.00	4.00	84%
6	10/16/2021	0.1	0.09	10%	24.00	3.50	85%
7	3/24/2022	0.06	0.04	33%	23.00	7.00	70%
8	4/16/2022	0.07	0.04	43%	26.00	7.00	73%
9	4/26/2022	0.09	0.05	44%	30.90	11.90	61%
10	5/2/2022	0.08	0.06	25%	231.00	9.80	96%
11	5/15/2022	0.37	0.19	49%	135.40	27.10	80%
12	5/16/2022	0.16	0.07	56%	106.10	9.90	91%
13	5/19/2022	0.15	0.08	47%	59.70	2.10	96%
14	6/3/2022	0.04	0.04	0%	1,799.60	2.20	100%
15	6/8/2022	0.23	0.13	43%	440.40	34.20	92%
16	6/13/2022	unknown	unknown	unknown	93.22	3.70	96%
17	7/25/2022	0.11	0.11	0%	103.60	10.40	90%
18	8/6/2022	0.15	0.14	7%	1,622.00	5.00	100%
Flow-Weighted Average		0.11	0.07	**40%**	332.12	8.54	**97%**

Table 2-3. Storm event dates and TP and TSS load reductions for total volume in the HFR biofilter system

Storm Event	Date	TP				TSS			
		Inflow (mg)	Outflow (mg)	Untreated (mg)	Reduction (%)	Inflow (mg)	Outflow (mg)	Untreated (mg)	Reduction (%)
1	8/29/2020	6,417	3,394	599	38%	1,443,724	72,721	134,748	86%
2	3/26/2021	2,002	869	0	57%	839,569	294,080	0	65%

Storm Event	Date	TP				TSS			
		Inflow (mg)	Outflow (mg)	Untreated (mg)	Reduction (%)	Inflow (mg)	Outflow (mg)	Untreated (mg)	Reduction (%)
3	4/21/2021	1,129	336	234	50%	437,562	78,358	90,548	61%
4	7/3/2021	6,031	2,936	1,334	29%	2,035,562	102,758	450,159	73%
5	7/25/2021	664	484	60	18%	332,122	48,379	29,756	76%
6	10/16/2021	1,486	1,420	0	4%	356,643	55,232	0	85%
7	3/24/2022	4,214	1,624	1,778	19%	1,615,411	284,190	681,644	40%
8	4/16/2022	2,496	1,164	459	35%	926,976	203,689	170,417	60%
9	4/26/2022	1,079	551	87	41%	370,325	131,149	29,778	57%
10	5/2/2022	2,001	1,257	325	21%	5,777,883	205,279	939,167	80%
11	5/15/2022	7,800	2,310	3,302	28%	2,854,369	329,465	1,208,257	46%
12	5/16/2022	3,837	973	1,613	33%	2,544,483	137,603	1,069,766	53%
13	5/19/2022	2,906	1,105	834	33%	1,156,648	29,003	332,121	69%
14	6/3/2022	2,226	576	1,650	0%	100,139,038	31,670	74,232,844	26%
15	6/8/2022	12,355	3,683	5,840	23%	23,658,010	968,880	11,181,557	49%
16	6/13/2022	unknown	unknown	unknown	unknown	1,827,940	65,138	186,773	86%
17	7/25/2022	1,863	1,253	610	0%	1,754,428	118,486	574,125	61%
18	8/6/2022	3,282	1,195	2,002	3%	35,490,631	42,673	21,647,385	39%
Total		61,788	25,129	20,725	**26%**	183,561,324	3,198,754	112,959,046	**37%**

3 OPTI-TOOL SETUP

The following sections outline the methodology and data input used to develop the Hydrologic Response Unit (HRU) time series, as well as to configure and calibrate the Opti-Tool for the HFR biofilter system.

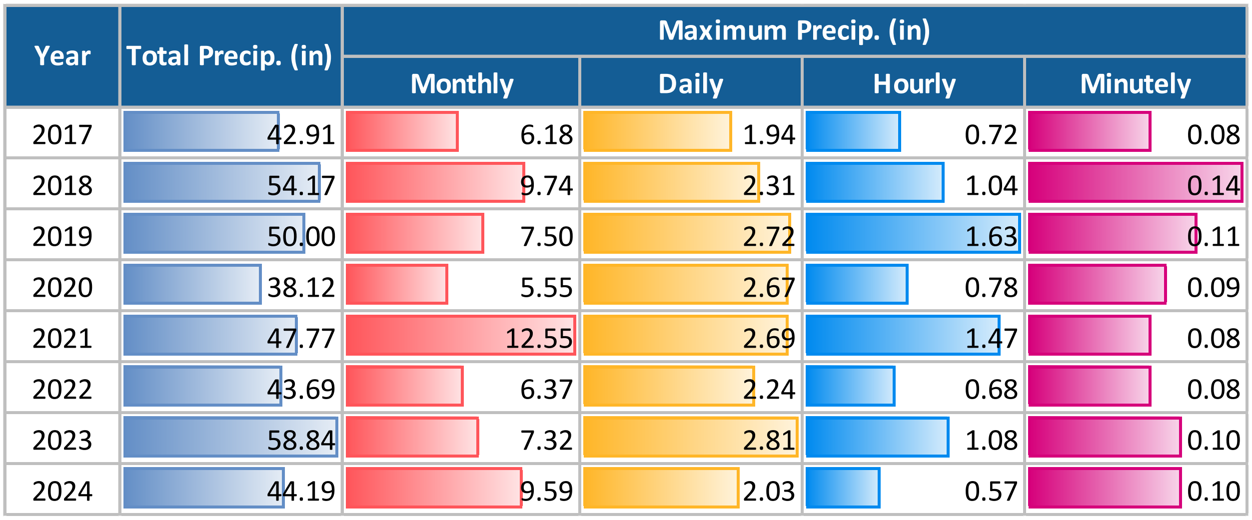
3.1 Commercial HRU Runoff and Pollutant Loading Time Series

The HRU time series of stormwater flow and pollutant loading are the primary inputs to SCMs simulated within the Opti-Tool to develop the long-term cumulative performance curves. The Commercial HRU time series was used to develop performance curves. The HRU time series includes flow and pollutant loading for Total Phosphorus (TP) and Total Suspended Solids (TSS).

The Commercial HRU time series was generated using the regionally calibrated Opti-Tool SWMM model and local meteorological data (i.e., 1-minute precipitation and daily minimum/maximum temperature) collected for a period of 8 years (2017-2024) by the UNHSC. The Opti-Tool software package and details on its development and use are available from the EPA at https://www.epa.gov/tmdl/opti-tool-epa-region-1s-stormwater-management-optimization-tool.

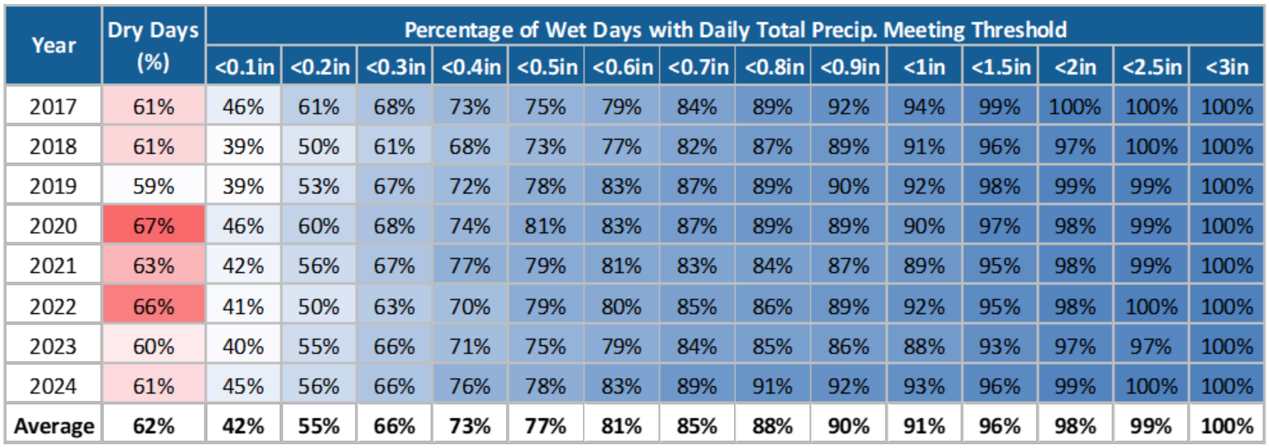
Rainfall was evaluated to identify any data anomalies. Annual total precipitation and the maximum precipitation at monthly, daily, hourly, and minutely intervals were reviewed (Table 3-1). No unusual patterns were detected, and the data appears to be of good quality. The daily frequency of rainfall was analyzed over the observed period and was found to resemble the precipitation patterns in the New England region. At this location, more than 50% of annual precipitation is recorded as less than 0.2 inches (or two-tenths of an inch) per day, as shown in Table 3-2. On average, 62% of the days in a year were dry days. The annual average flow volume and pollutant loading rates from an acre of commercial land use for a period of 8 years (Jan 2017 – Dec 2024) are shown in Table 3-3.

Table 3-1. UNH precipitation data checks for the monitoring period (2017-2024)



Year	Total Precip. (in)	Maximum Precip. (in)			
		Monthly	Daily	Hourly	Minutely
2017	42.91	6.18	1.94	0.72	0.08
2018	54.17	9.74	2.31	1.04	0.14
2019	50.00	7.50	2.72	1.63	0.11
2020	38.12	5.55	2.67	0.78	0.09
2021	47.77	12.55	2.69	1.47	0.08
2022	43.69	6.37	2.24	0.68	0.08
2023	58.84	7.32	2.81	1.08	0.10
2024	44.19	9.59	2.03	0.57	0.10

Table 3-2. The UNH daily rainfall frequency for the monitoring period (2017-2024)



Year	Dry Days (%)	Percentage of Wet Days with Daily Total Precip. Meeting Threshold													
		<0.1in	<0.2in	<0.3in	<0.4in	<0.5in	<0.6in	<0.7in	<0.8in	<0.9in	<1in	<1.5in	<2in	<2.5in	<3in
2017	61%	46%	61%	68%	73%	75%	79%	84%	89%	92%	94%	99%	100%	100%	100%
2018	61%	39%	50%	61%	68%	73%	77%	82%	87%	89%	91%	96%	97%	100%	100%
2019	59%	39%	53%	67%	72%	78%	83%	87%	89%	90%	92%	98%	99%	99%	100%
2020	67%	46%	60%	68%	74%	81%	83%	87%	89%	89%	90%	97%	98%	99%	100%
2021	63%	42%	56%	67%	77%	79%	81%	83%	84%	87%	89%	95%	98%	99%	100%
2022	66%	41%	50%	63%	70%	79%	80%	85%	86%	89%	92%	95%	98%	100%	100%
2023	60%	40%	55%	66%	71%	75%	79%	84%	85%	86%	88%	93%	97%	97%	100%
2024	61%	45%	56%	66%	76%	78%	83%	89%	91%	92%	93%	96%	99%	100%	100%
Average	**62%**	**42%**	**55%**	**66%**	**73%**	**77%**	**81%**	**85%**	**88%**	**90%**	**91%**	**96%**	**98%**	**99%**	**100%**

Table 3-3. Average annual flow and pollutant loading from the commercial HRU (2017-2024)

Commercial HRU				
Imperviousness	**HSG [1]**	**FLOW (in/year)**	**TP (lb/year)**	**TSS (lb/year)**
Pervious	A	0.25	0.01	3.07
Pervious	B	2.27	0.13	33.52
Pervious	C	5.65	0.24	68.70
Pervious	D	10.94	0.42	106.45
Impervious	--	43.47	1.98	606.15

[1]HSG = Hydrologic Soil Group, which represents soil infiltration rates from high (A) to low (D).

3.2 HFR Biofilter Configuration

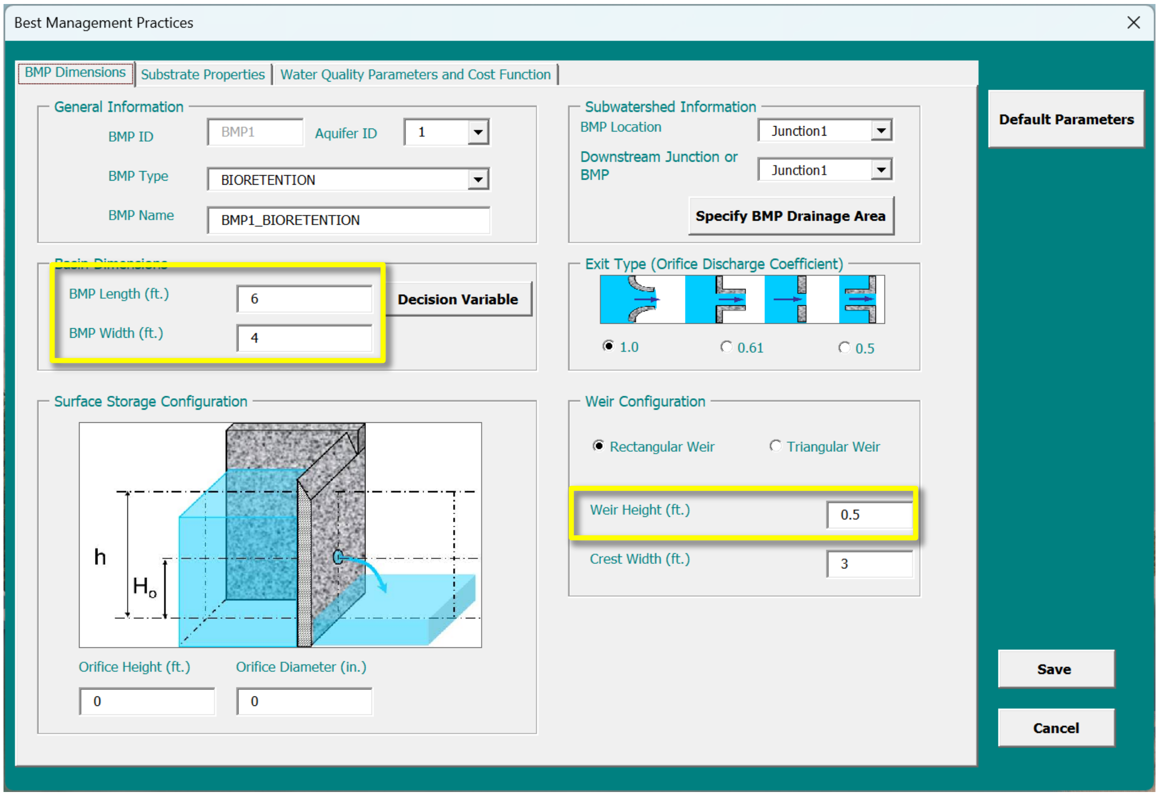
The HFR biofilter system was configured within the Opti-Tool based on the design specifications of the UNH system, for which the inflow and outflow were monitored along with TSS and TP event mean concentrations as described in Section 2. The design specifications of the system are listed in Table 3-4. Figure 3-1 and Figure 3-2 show the Opti-Tool interfaces for entering the HFR biofilter system dimensions and filter media design specification.

Table 3-4. The HFR biofilter system surface storage, soil media, and underdrain specifications in Opti-Tool

Category	Parameter Description	Parameter Value
Surface Storage Configuration	Ponding Depth (ft)	0.5
	Surface Area (ft^2)	24
Soil Media Properties	Depth of Soil Media (ft)	1.5
	Soil Media Porosity (0-1)	0.4
	Infiltration Rate (in/hr)[a]	134
Underdrain Media Properties	Storage Depth (ft)	0.0001
	Media Void Fraction (0-1)	0.4
	Background Infiltration (in/hr)[b]	0

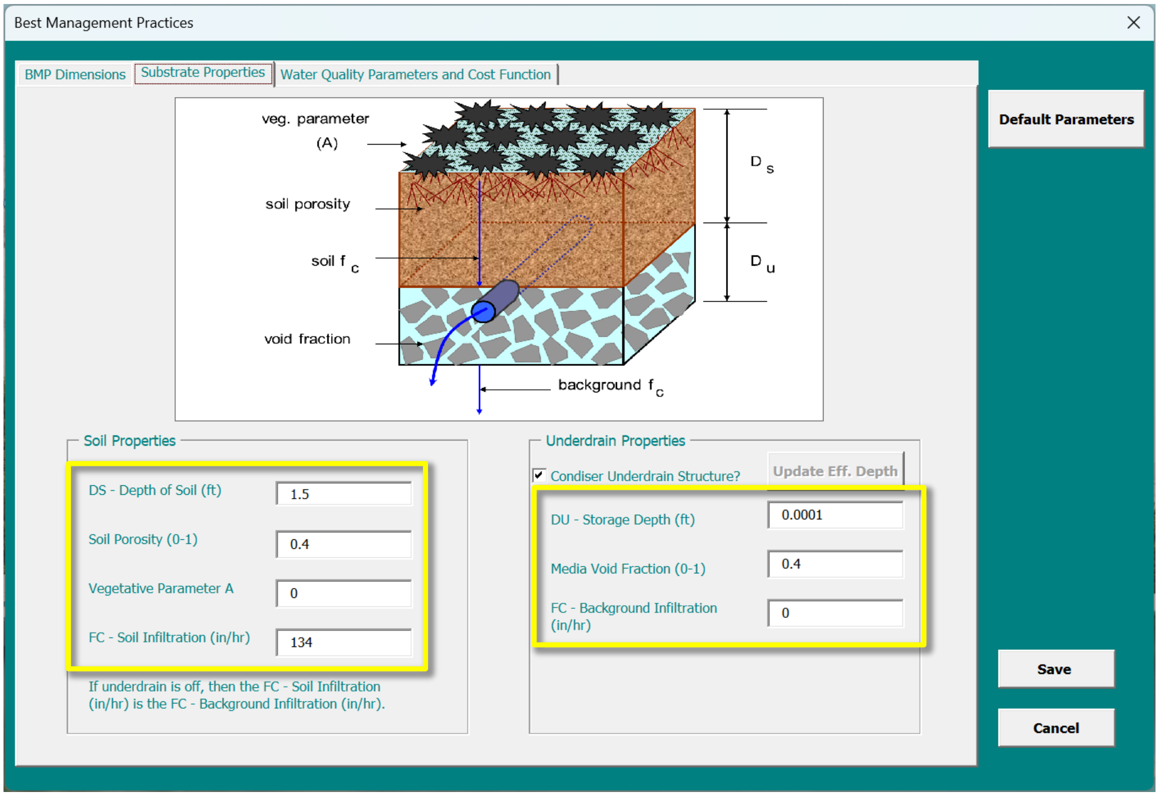
[a] Calibrated high-flow rate media.

[b] Confined concrete vault structure to prevent infiltration into subsoils.



BMP ID: BMP1
Aquifer ID: 1
BMP Type: BIORETENTION
BMP Name: BMP1_BIORETENTION
BMP Location: Junction1
Downstream Junction or BMP: Junction1
BMP Length (ft.): 6
BMP Width (ft.): 4
● 1.0 ○ 0.61 ○ 0.5
● Rectangular Weir ○ Triangular Weir
Weir Height (ft.): 0.5
Crest Width (ft.): 3
Orifice Height (ft.): 0
Orifice Diameter (in.): 0

Figure 3-1. The HFR biofilter system dimensions in Opti-Tool.



DS - Depth of Soil (ft): 1.5
Soil Porosity (0-1): 0.4
Vegetative Parameter A: 0
FC - Soil Infiltration (in/hr): 134

If underdrain is off, then the FC - Soil Infiltration (in/hr) is the FC - Background Infiltration (in/hr).

☑ Condiser Underdrain Structure?
DU - Storage Depth (ft): 0.0001
Media Void Fraction (0-1): 0.4
FC - Background Infiltration (in/hr): 0

Figure 3-2. The HFR biofilter media and underdrain design specifications in Opti-Tool.

3.3 HFR Biofilter Calibration

The Opti-Tool configuration of the HFR biofilter system was first calibrated for hydrology and then calibrated for pollutant removal. Because the objective of this work is the development of cumulative performance curves based on long-term simulation with a wide range of storm sizes, calibration was performed using the observed influent flow and pollutant load data as a 5-minute time series from the 18 selected observed storm events for input data; calibration was focused on matching the total observed treated flow volume and flow-weighted average pollutant concentration reductions (Table 2-1 and Table 2-2). As opposed to calibrating each storm event individually, this approach eliminates the issue of having multiple parameter values for different storms and lends itself to the long-term simulation needed to develop performance curves. However, comparison plots of observed vs modeled concentration reductions for the 18 storm events were developed to evaluate the storm-by-storm performance of the calibrated model (Figure 3-3 to Figure 3-6). Note that observed influent flow and water quality data for the selected storm events were used as a point source input and no rainfall-runoff response was simulated for the calibration in Opti-Tool.

The observed total treated flow volume percentage across the 18 selected storm events for the HFR biofilter system was 68%. The infiltration rate of the HFR filter media was calibrated to match this value by comparing the bypass volume since it is a closed system (no evapotranspiration and bottom sealed).

Water quality calibration was performed similarly to hydrology. The first-order decay rate for surface storage and underdrain removal rate for each pollutant was adjusted so that the total modeled and observed pollutant load reduction percentages across the 18 selected storm events were similar. The cumulative TP and TSS load reductions in the treated flow volume, excluding the bypass flow, for the HFR biofilter system were 40% and 97%, respectively (see Table 2-2). The total reductions in TP and TSS load from the storm events, after accounting for the bypass flow volume, were 26% and 37%, respectively (see Table 2-3).

Figure 3-3 and Figure 3-4 compare the TP reduction from the selected storm events for the observed and calibrated model. The model was calibrated to achieve an overall reduction of 26% across all storm events, allowing for a consistent set of parameters to estimate the long-term TP reduction of the HFR biofilter system. The storm events were sorted by their total load, revealing that events with higher loads had reductions closer to the average value (Figure 3-3), while high-intensity storms, characterized by high inflow peaks, showed the lowest reductions (Figure 3-4). This tendency indicates that high-peak inflows mostly bypass the biofilter system.

Figure 3-5 and Figure 3-6 compares the TSS reduction from the selected storm events for the observed and calibrated model. The model was specifically calibrated to achieve an overall TSS reduction of 37% across all storm events, using a consistent set of parameters to model the long-term TSS reduction of the HFR biofilter system. The storm events were sorted by their total load, and it was found that events with higher loads showed the lowest reductions in TSS (Figure 3-5), which led to a reduced overall average reduction across all storms. Furthermore, high-intensity storms, characterized by high inflow peaks, also demonstrated the lowest reductions (Figure 3-6). This occurs because the high-peak inflows tend to largely bypass the biofilter system.

This study had no observed data for the Total Nitrogen (TN) and Total Zinc (Zn) pollutants, so no calibration was performed for TN and Zn.

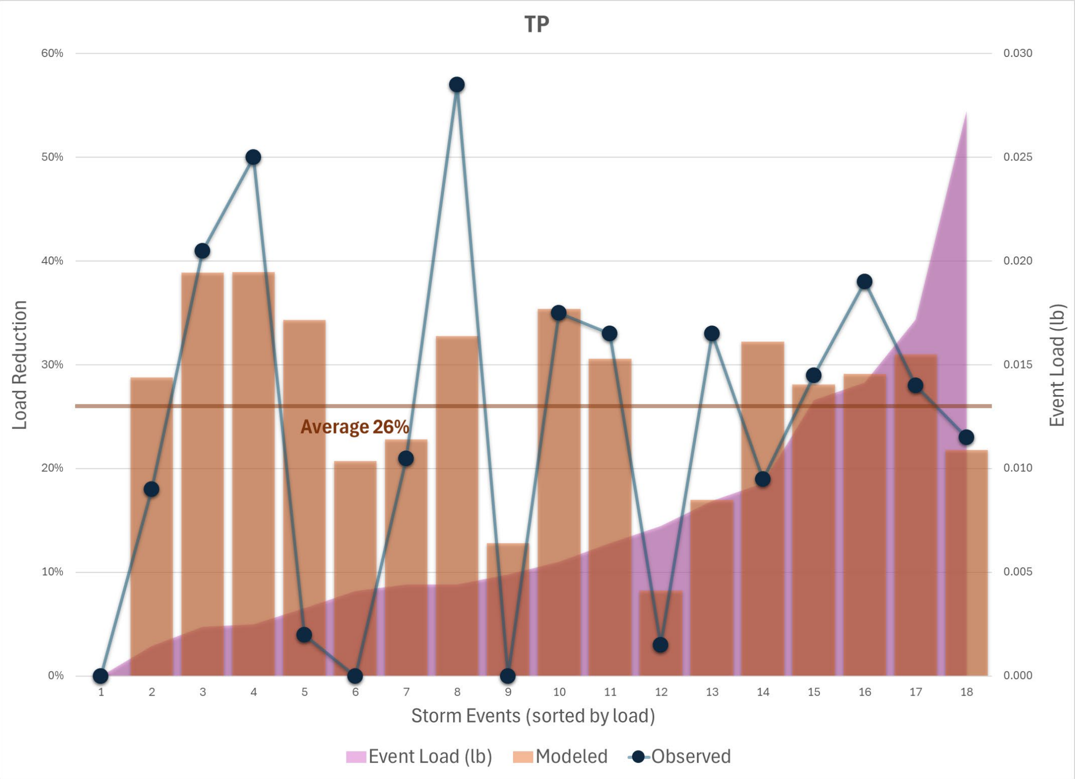


Figure 3-3. TP load reductions and inflow loads for the 18 selected storm events, sorted by event load.

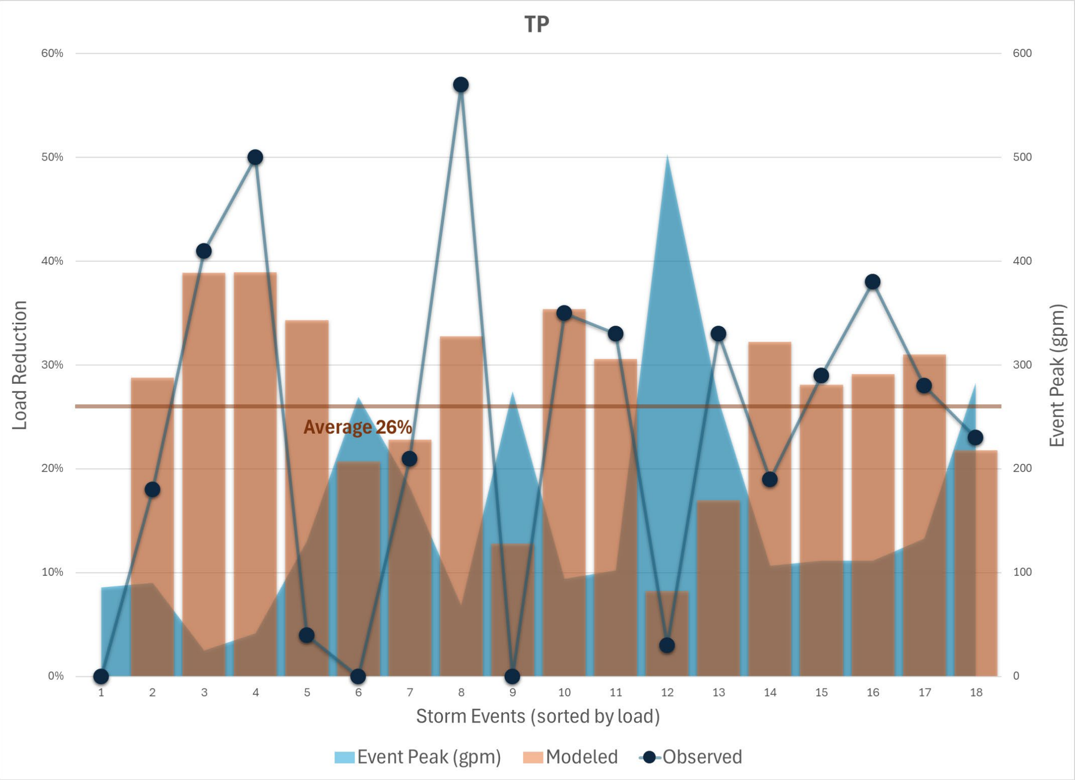


Figure 3-4. TP load reductions and inflow peak for the 18 selected storm events, sorted by event load.

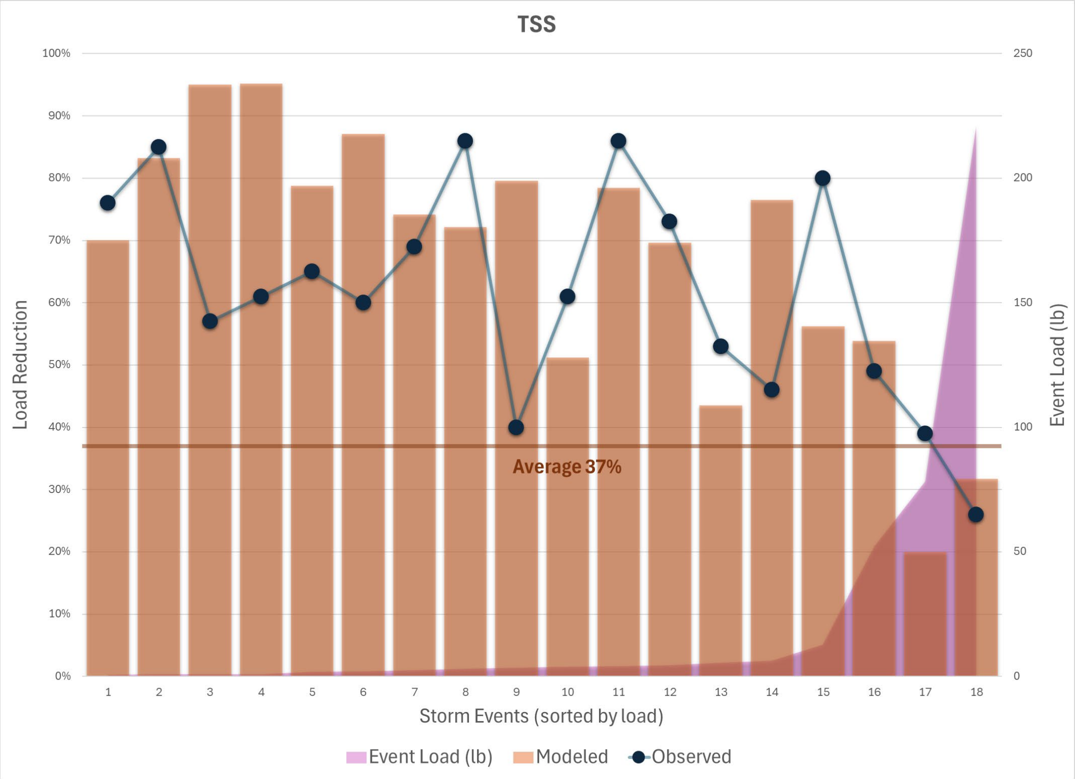


Figure 3-5. TSS load reductions and inflow loads for the 18 selected storm events, sorted by event load.

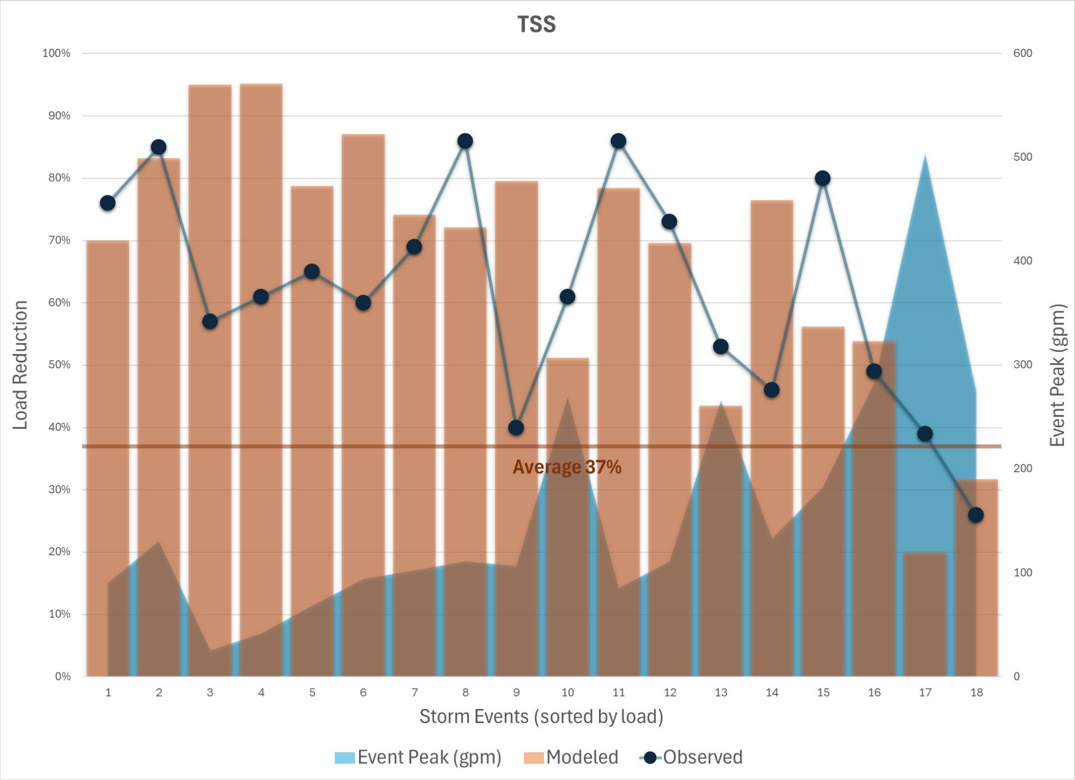


Figure 3-6. TSS load reductions and inflow peak for the 18 selected storm events, sorted by event load.

4 CUMULATIVE PERFORMANCE CURVES

After configuration and calibration of the HFR biofilter system using the 18 selected storm events with observed performance data, the long-term performance was evaluated using UNH rainfall data collected at 1-minute high-resolution for a period of 8 years (2017-2024). The regionally calibrated Opti-SWMM model (U.S. EPA., 2016) was used to develop flow and pollutant (TP and TSS) loading time series as discussed in Section 3.1. The results of this long-term simulation cover a wide range of climate conditions and allow for the creation of performance curves for the HFR biofilter system.

The performance curves developed using the Opti-Tool show the relationship between the HFR biofilter system's annual average treatment efficiency for a given pollutant over a range of ratios of the impervious cover drainage area to the biofilter bed surface area (IC/SA). Additional performance curves were developed to represent cumulative performance associated with providing additional storage capacity (i.e., capturing 0.1-inch, 0.2-inch, 0.3-inch, 0.4-inch, and 0.5-inch of runoff depth from the impervious drainage areas) upstream of the HRF biofilter system which results in substantially increased cumulative performance.

The performance curves are intended to be used to estimate long-term cumulative pollutant removal efficiencies for the HFR biofiltration system that are based on similar design standards (filter media parameters and filtration rate) and sized to the design IC/SA ratio. Two sets of performance curves for the HFR Biofilter system were developed: TP and TSS for a typical design (minimal storage) and enhanced designs providing increased surface storage.

Another scenario with additional underdrain storage of 12 inches below the biofilter media was also run to develop the performance curve showing the added benefits of providing underdrain storage with the underlying native soil of an infiltration rate of 2.41 inches per hour. This was analyzed in conjunction with the additional surface storage of 0.5 inches of runoff depth from the impervious drainage areas.

4.1 TSS Performance Curves

The design of a HFR biofilter system depends on the hydraulic loading ratio, a ratio of the impervious cover drainage area to the filter media surface area (IC/SA), due to their high flow rate media. Consequently, the x-axis of the performance curve is expressed as an IC/SA ratio, rather than the physical storage volume of the system. Six performance curves were developed covering a range of IC/SA, both with and without additional surface storage (see Table 4-1 and Figure 4-1 through Figure 4-6). This surface storage temporarily holds the runoff from the impervious drainage area, allowing it to flow through the media.

An IC/SA ratio of 100 results in a sediment load reduction of 95% and effectively captures nearly all surface runoff from the impervious drainage area. In contrast, a ratio of 5,000 reduces the sediment load by only 35%, as approximately 70% of the surface runoff bypasses the system untreated. However, if temporary storage is designed upstream of the system to capture 0.5 inches of runoff depth from the impervious drainage area, the larger ratio of 5,000 can achieve a sediment load reduction of 93%.

The performance curves indicate that the reduction in TSS decreases as the IC/SA ratio increases, primarily due to a rise in the untreated bypass flow. Additionally, these curves suggest that TSS reduction can be enhanced by increasing surface storage, which helps to lower the amount of untreated bypass flow.

Table 4-1. Performance curves for the long-term (8 years) cumulative load reduction of TSS in the HFR biofilter system with and without extra storage

IC/SA Ratio	TSS Reduction (%)	Additional storage upstream of the device				
		0.1 inch	0.2 inch	0.3 inch	0.4 inch	0.5 inch
100	94.6%	95.3%	95.5%	95.6%	95.6%	95.7%
500	84.5%	89.6%	91.9%	93.3%	94.1%	94.5%
1,000	74.6%	84.7%	89.1%	91.6%	93.2%	94.2%
1,500	66.2%	80.7%	86.9%	90.4%	92.6%	94.0%
2,000	59.0%	77.6%	85.2%	89.5%	92.1%	93.8%
2,500	52.9%	75.0%	83.8%	88.7%	91.7%	93.7%
3,000	48.0%	73.0%	82.7%	88.0%	91.4%	93.6%
3,500	43.9%	71.3%	81.7%	87.5%	91.2%	93.5%
4,000	40.4%	69.8%	80.9%	87.1%	90.9%	93.4%
4,500	37.4%	68.6%	80.2%	86.7%	90.7%	93.3%
5,000	34.8%	67.5%	79.7%	86.4%	90.5%	93.2%

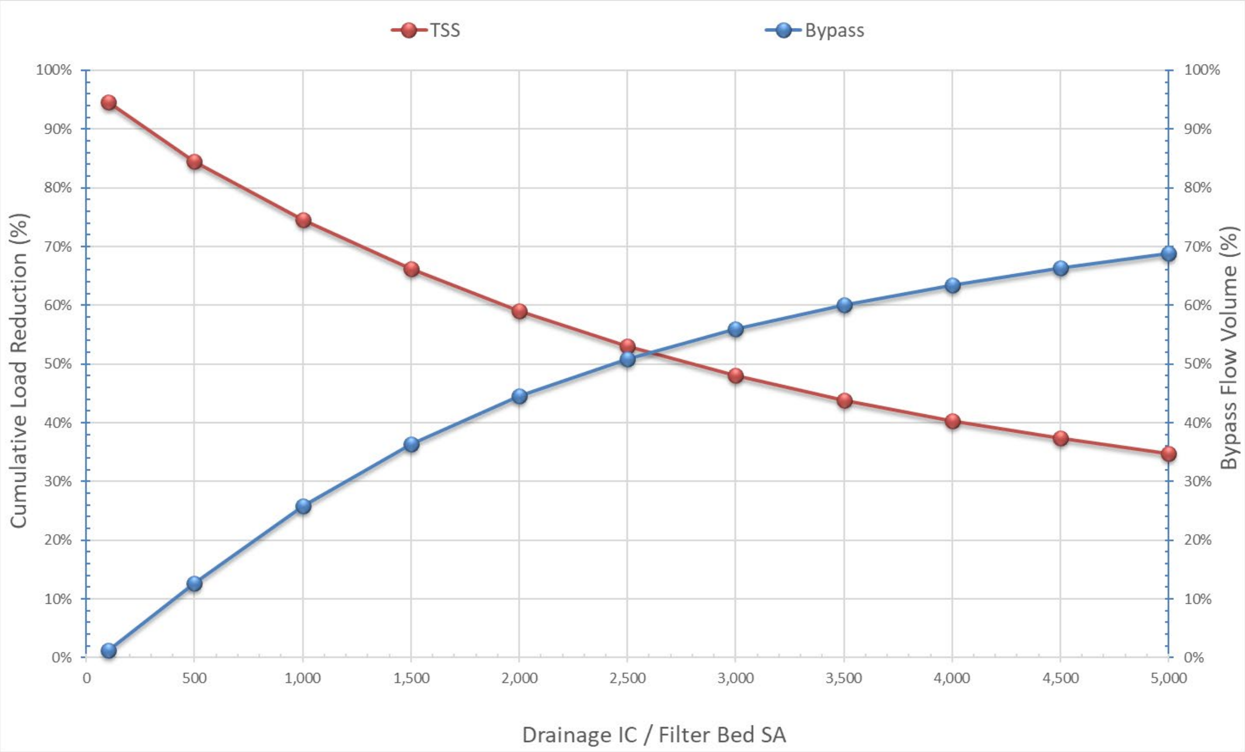


Figure 4-1. The HFR biofilter's cumulative TSS load reduction curve without extra storage.

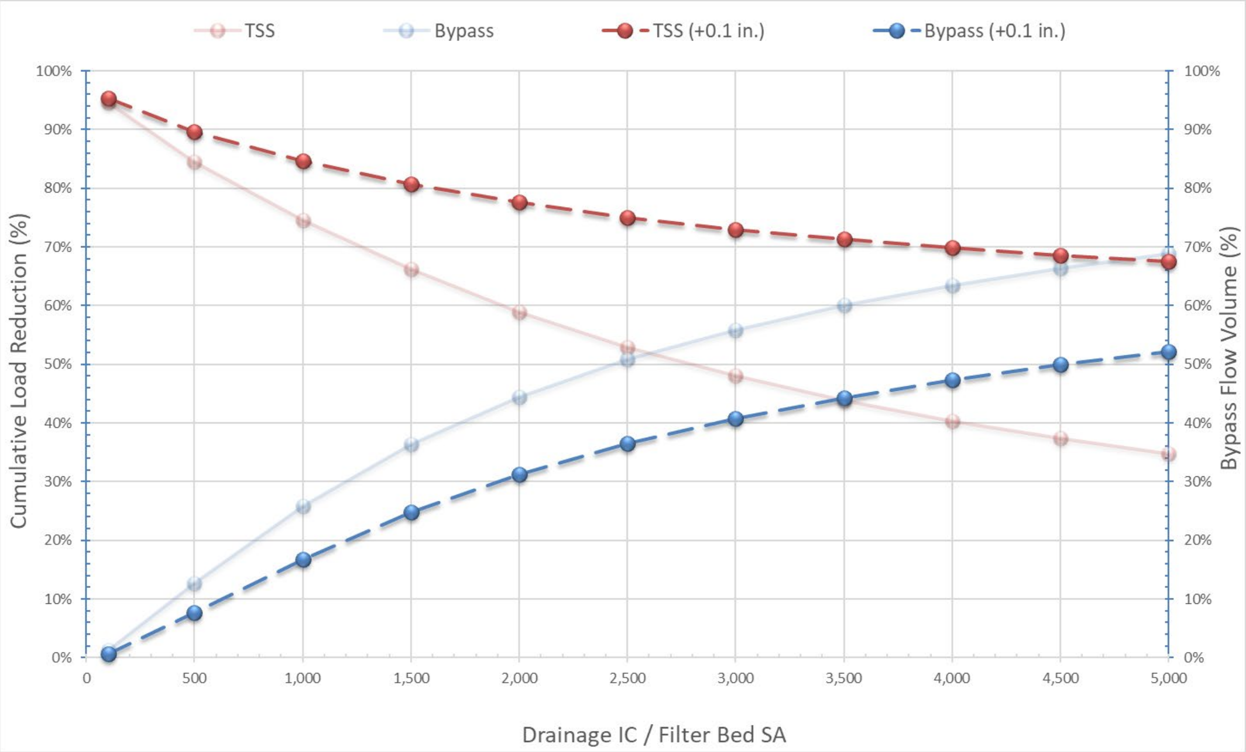


Figure 4-2. The HFR biofilter's cumulative TSS load reduction curve with an extra 0.1 inches of runoff storage from the impervious area.

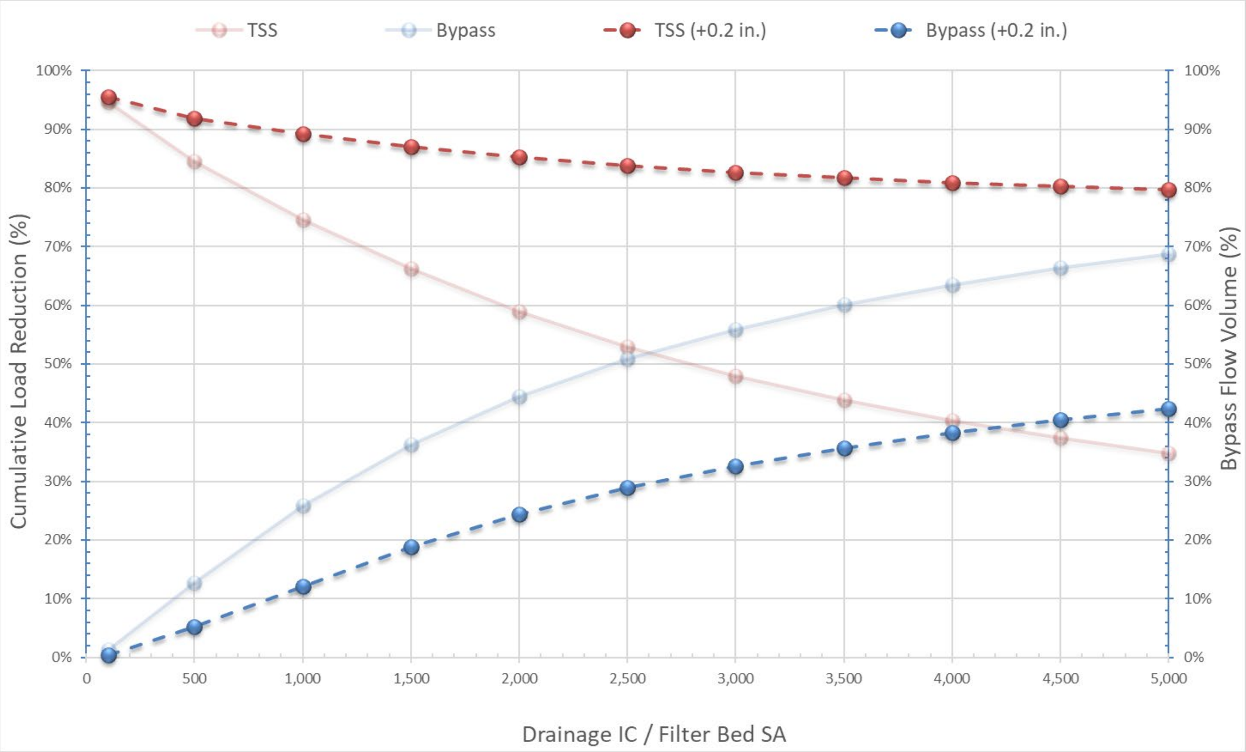


Figure 4-3. The HFR biofilter's cumulative TSS load reduction curve with an extra 0.2 inches of runoff storage from the impervious area.

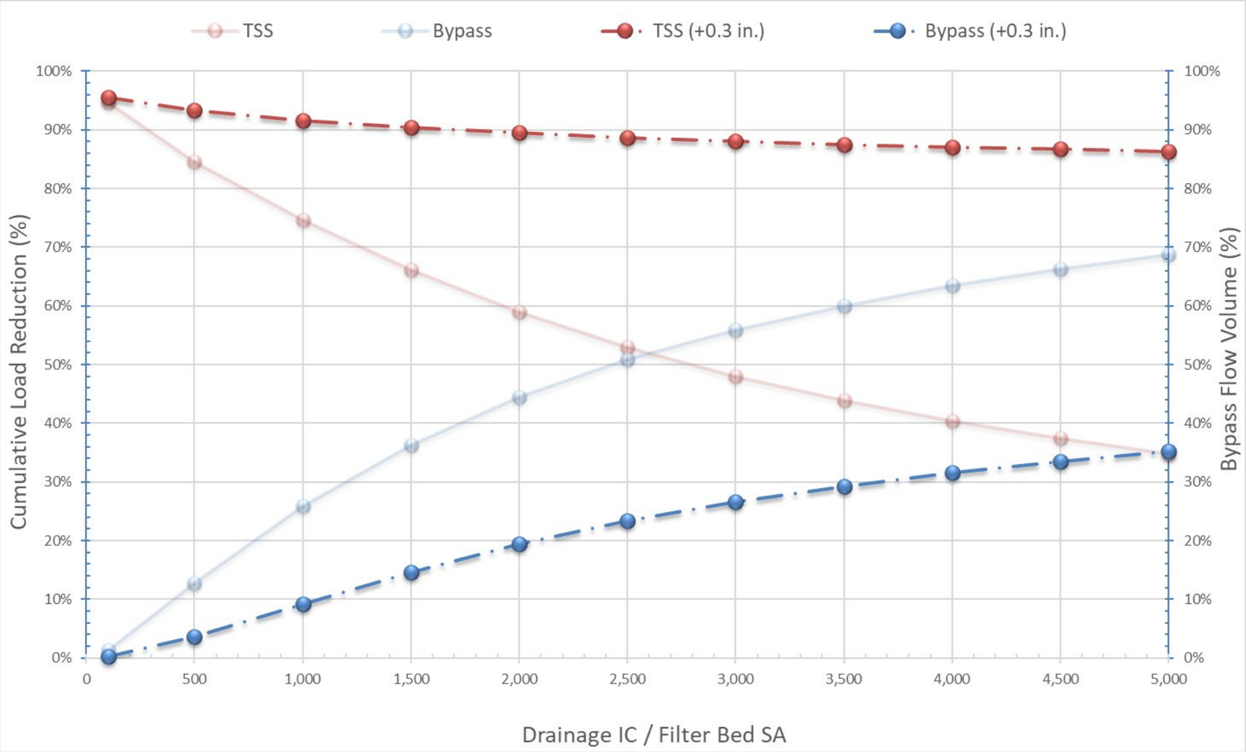


Figure 4-4. The HFR biofilter's cumulative TSS load reduction curve with an extra 0.3 inches of runoff storage from the impervious area.

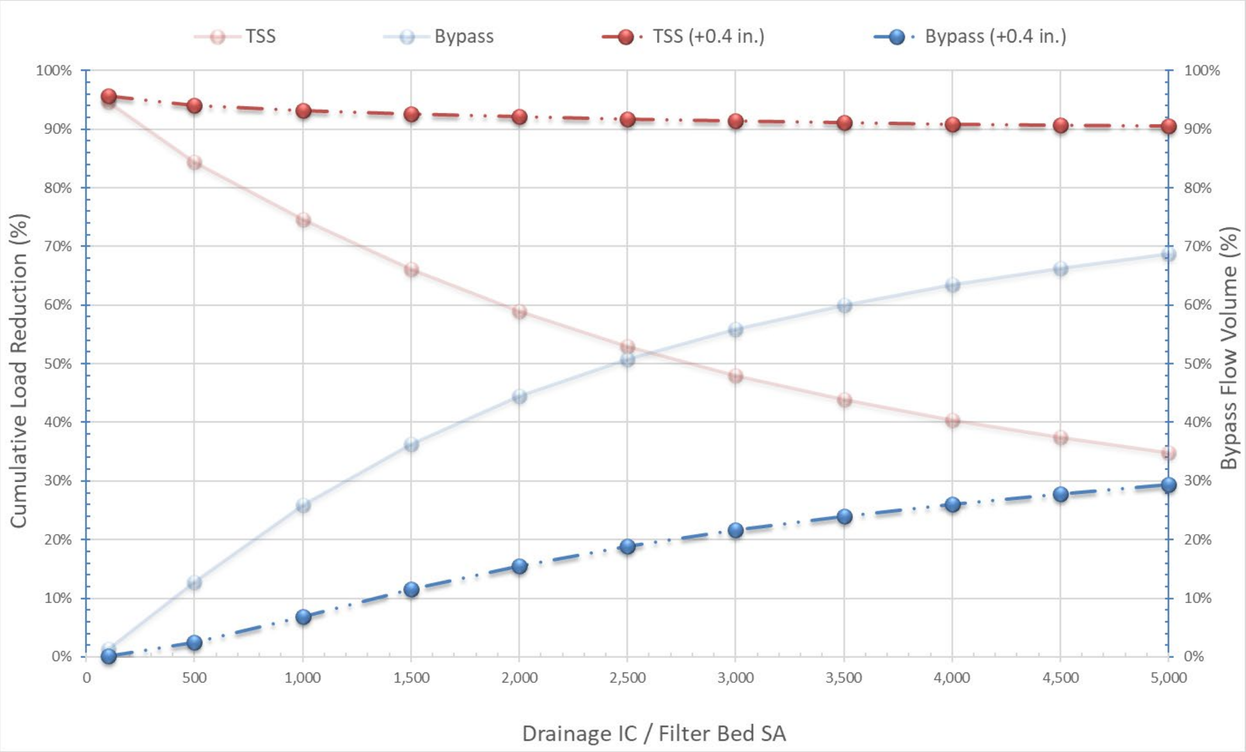


Figure 4-5. The HFR biofilter's cumulative TSS load reduction curve with an extra 0.4 inches of runoff storage from the impervious area.

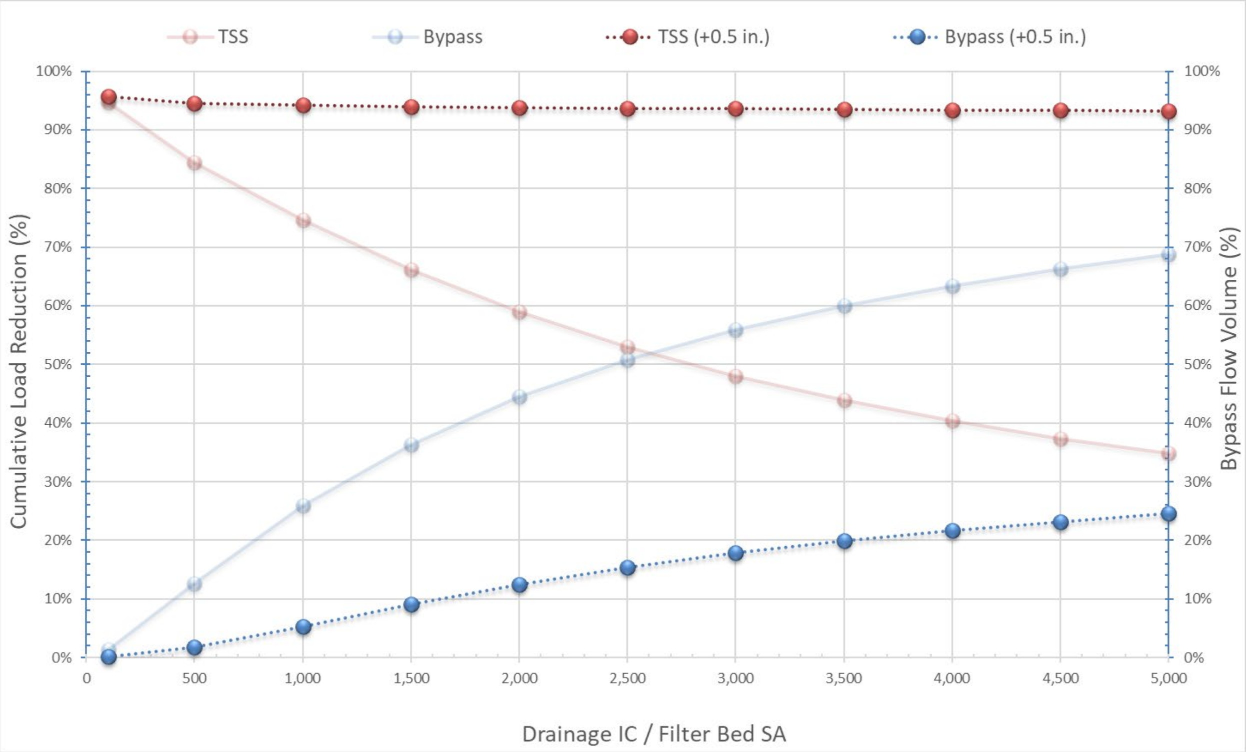


Figure 4-6. The HFR biofilter's cumulative TSS load reduction curve with an extra 0.5 inches of runoff storage from the impervious area.

4.2 TP Performance Curves

Six performance curves for TP were developed covering a range of IC/SA, both with and without additional surface storage (see Table 4-2 and Figure 4-7 through Figure 4-12). This surface storage temporarily holds the runoff from the impervious drainage area, allowing it to flow through the media.

An IC/SA ratio of 100 results in a TP load reduction of 40% and effectively captures nearly all surface runoff from the impervious drainage area. In contrast, a ratio of 5,000 reduces the TP load by only 14%, as approximately 70% of the surface runoff bypasses the system untreated. However, if temporary storage is designed upstream of the system to capture 0.5 inches of runoff depth from the impervious drainage area, the larger ratio of 5,000 can achieve a TP load reduction of 35%.

Figure 4-13 demonstrates that adding one foot of sub-surface storage to an open bottom with an infiltration rate of 2.41 inches per hour significantly increases TP reduction from 40% to 72% when the IC/SA ratio is 100. However, for a large IC/SA ratio of 5,000, the improvement in TP reduction is minimal, increasing only from 35% to 37%. This limited increase is due to the much larger drainage area compared to the sub-surface storage beneath the filter media.

The performance curves indicate that the reduction in TP decreases as the IC/SA ratio increases, primarily due to a rise in the untreated bypass flow. Additionally, these curves suggest that TP reduction can be enhanced by increasing both surface storage and subsurface storage with an open bottom. This configuration helps to reduce the amount of untreated bypass flow and allows the water stored in the under-drain to further infiltrate into the surrounding native soil.

Table 4-2. Performance curves for the long-term (8 years) cumulative load reduction of TP in the HFR biofilter system with and without extra storage

IC/SA Ratio	TP Reduction (%)	Additional storage upstream of the device				
		0.1 inch	0.2 inch	0.3 inch	0.4 inch	0.5 inch
100	39.8%	40.1%	40.2%	40.2%	40.3%	40.3%
500	34.4%	36.4%	37.3%	37.9%	38.3%	38.4%
1,000	30.1%	33.6%	35.4%	36.5%	37.3%	37.8%
1,500	26.5%	31.3%	33.7%	35.3%	36.4%	37.2%
2,000	23.5%	29.3%	32.2%	34.2%	35.6%	36.7%
2,500	21.0%	27.5%	30.9%	33.2%	35.0%	36.3%
3,000	19.0%	26.1%	29.8%	32.4%	34.4%	35.9%
3,500	17.3%	24.8%	28.8%	31.7%	33.9%	35.6%
4,000	15.9%	23.7%	28.0%	31.1%	33.5%	35.4%
4,500	14.7%	22.7%	27.3%	30.5%	33.2%	35.2%
5,000	13.7%	21.9%	26.7%	30.1%	32.9%	35.1%

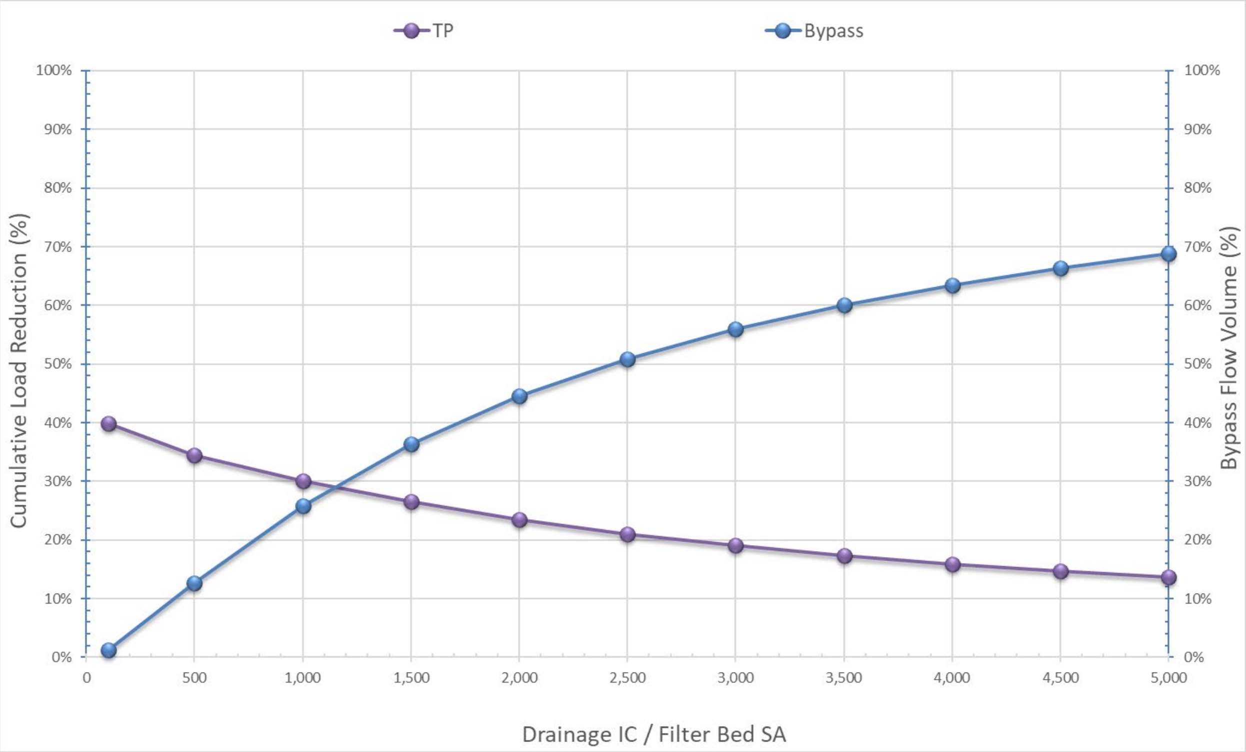


Figure 4-7. The HFR biofilter's cumulative TP load reduction curve without extra storage.

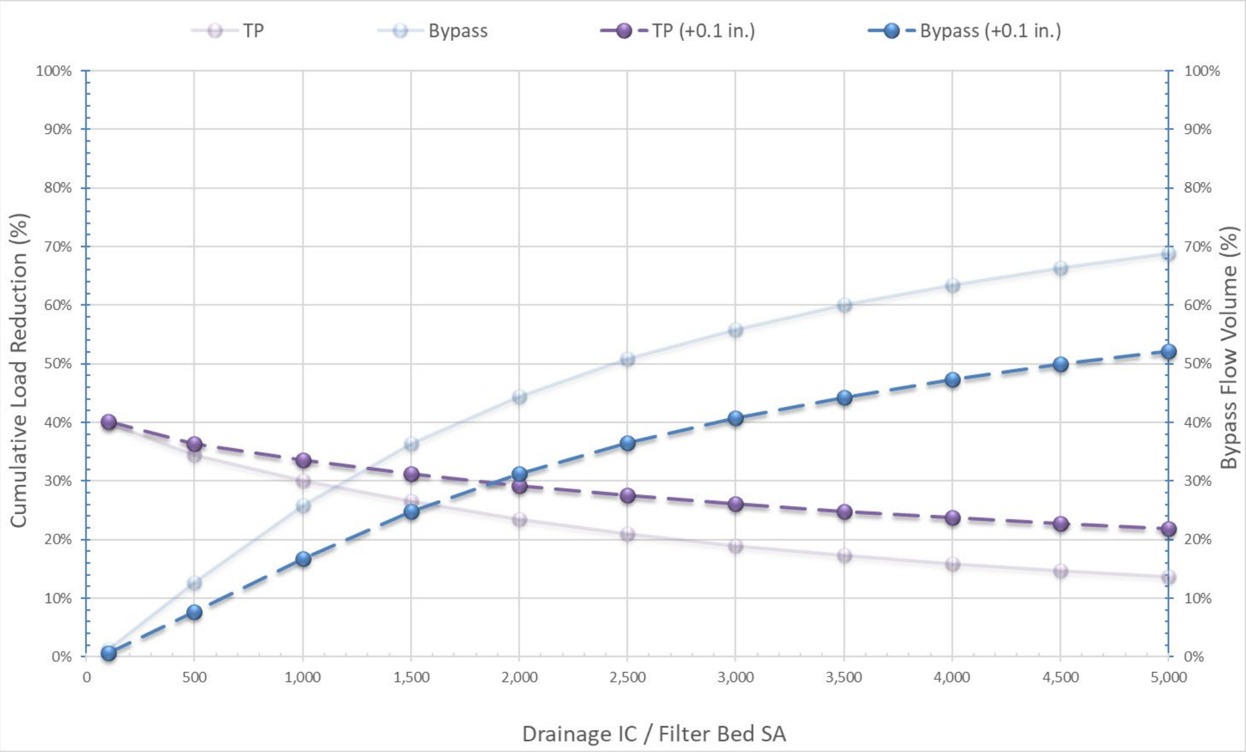


Figure 4-8. The HFR biofilter's cumulative TP load reduction curve with an extra 0.1 inches of runoff storage from the impervious area.

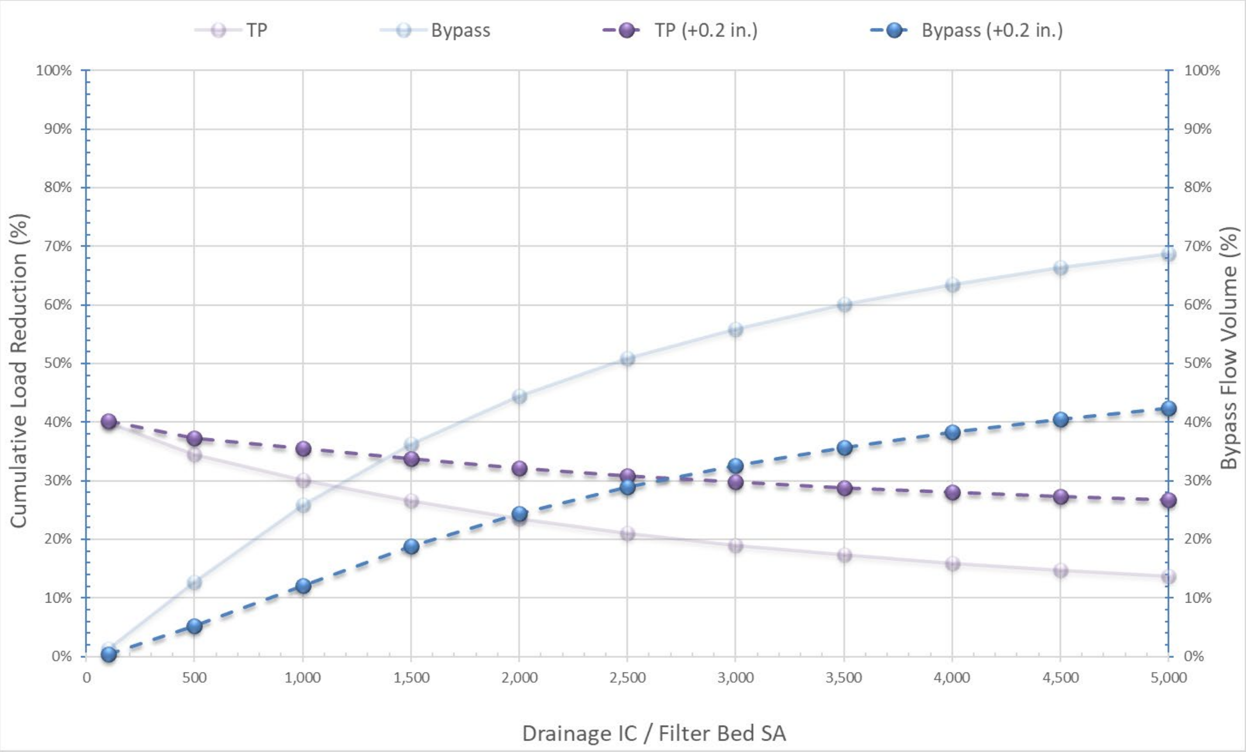


Figure 4-9. The HFR biofilter's cumulative TP load reduction curve with an extra 0.2 inches of runoff storage from the impervious area.

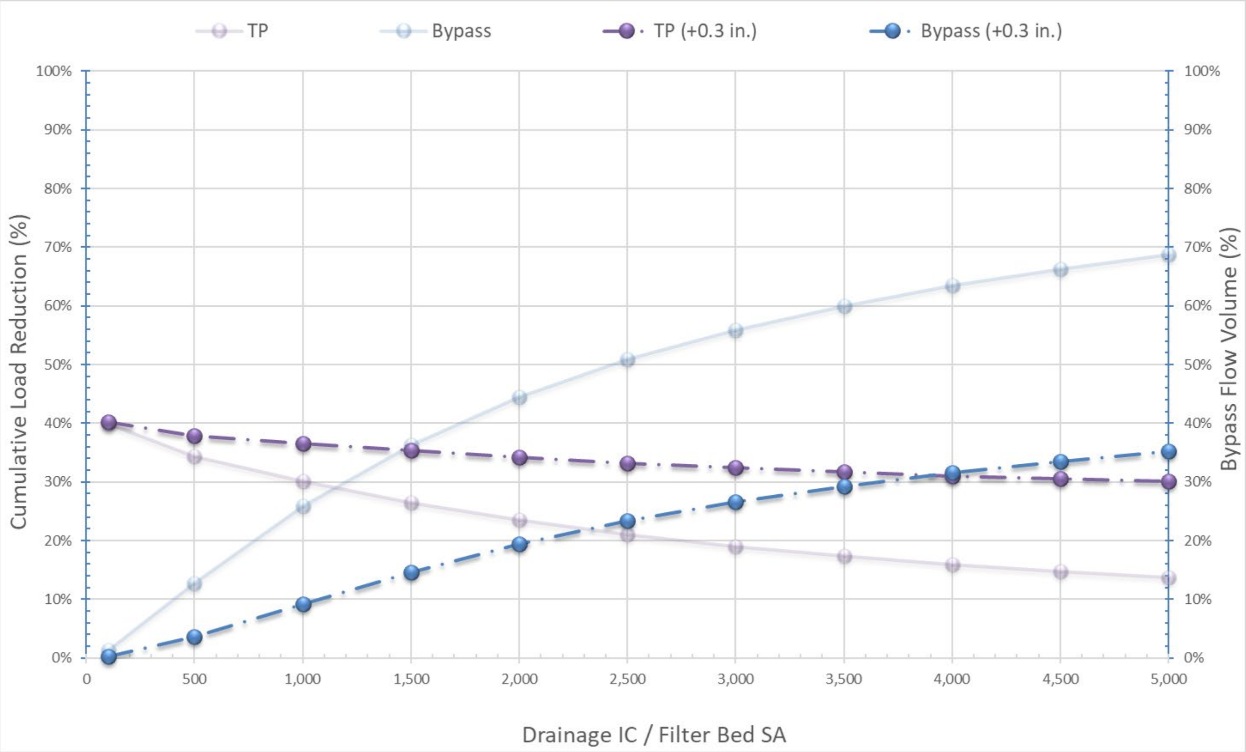


Figure 4-10. The HFR biofilter's cumulative TP load reduction curve with an extra 0.3 inches of runoff storage from the impervious area.

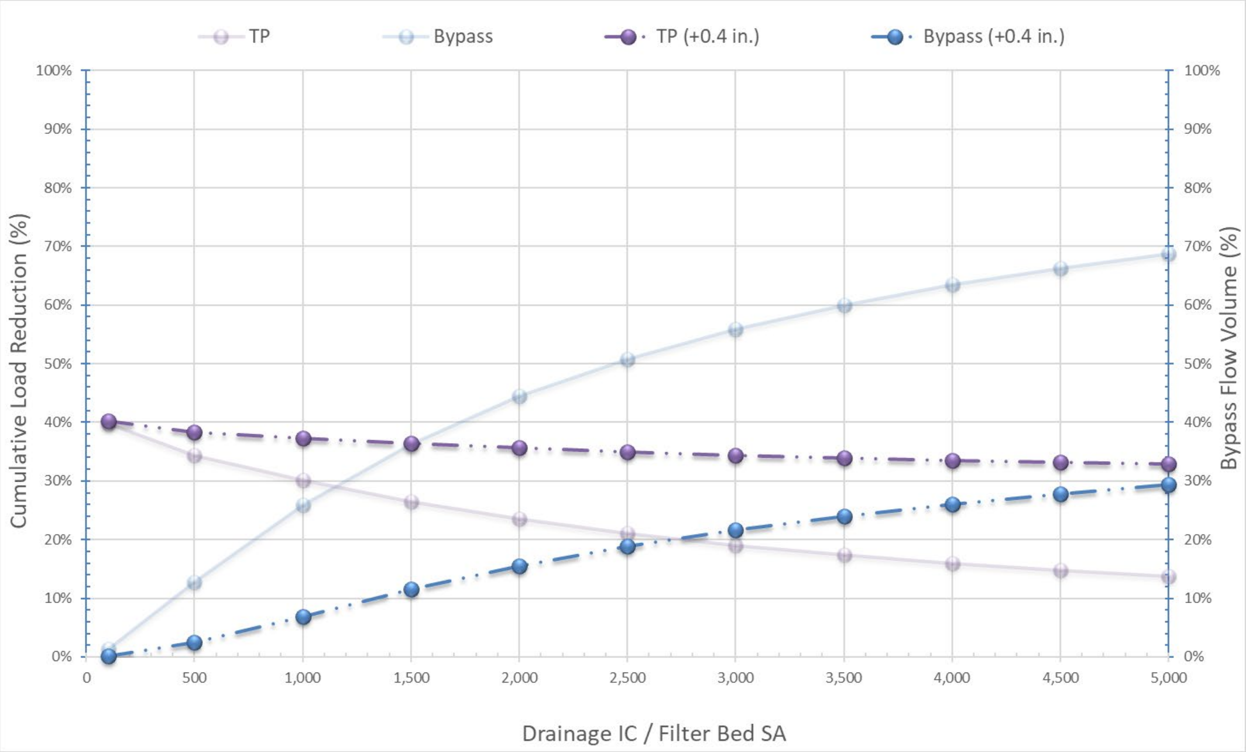


Figure 4-11. The HFR biofilter's cumulative TP load reduction curve with an extra 0.4 inches of runoff storage from the impervious area.

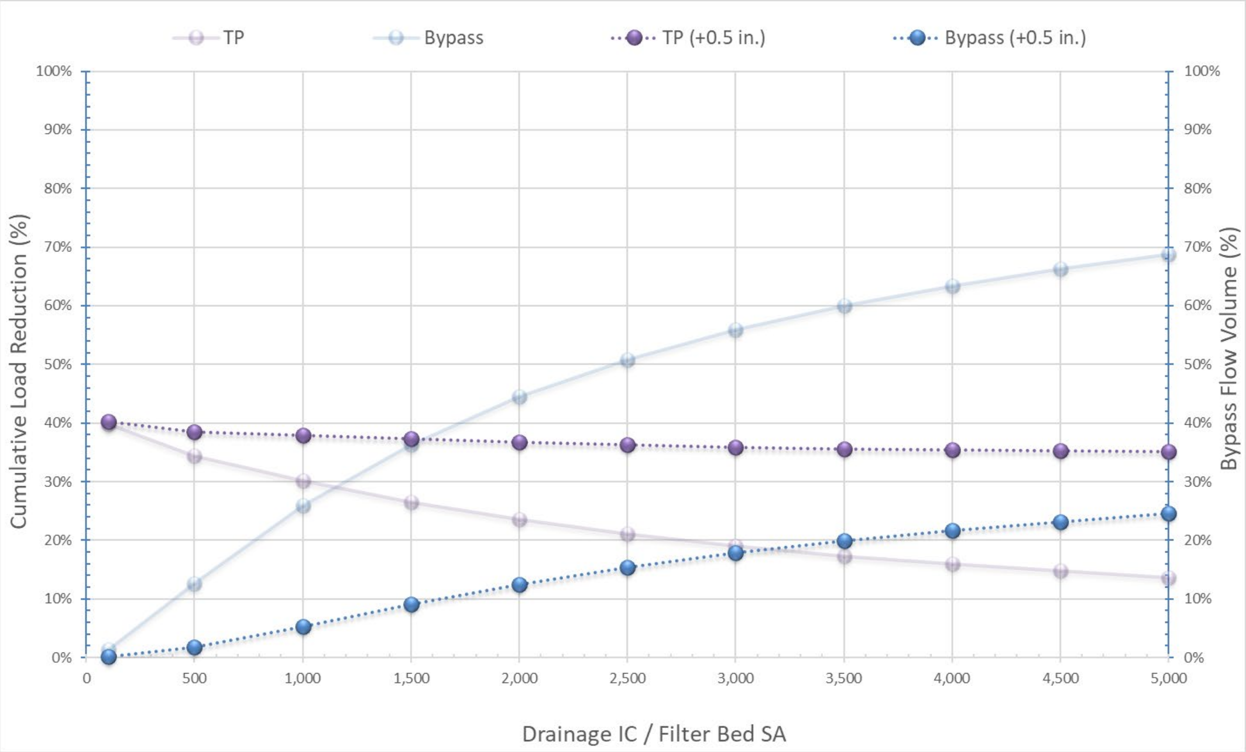


Figure 4-12. The HFR biofilter's cumulative TP load reduction curve with an extra 0.5 inches of runoff storage from the impervious area.

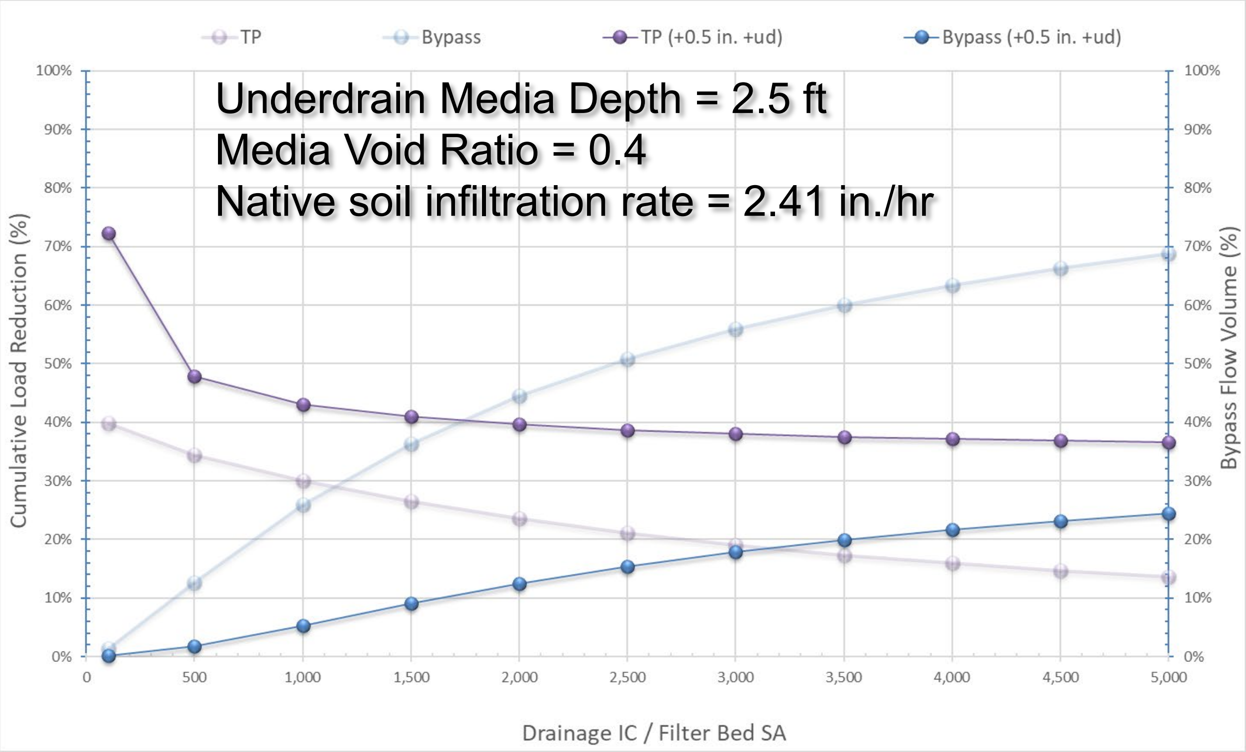


Figure 4-13. The HFR biofilter's cumulative TP load reduction curve with an extra 0.5 inches of runoff storage from the impervious area and 1 foot of underdrain storage, with a native soil infiltration rate of 2.41 in./hr.

5 CONCLUSION AND RECOMMENDATIONS

The performance curves for High Flow Rate (HFR) biofiltration systems were developed based on a range of impervious cover (IC) drainage area to filter bed surface area (SA) ratios. These curves estimate the long-term cumulative reduction of total phosphorus (TP) and total suspended solids (TSS) for an industry-standard vertical design profile. They assume a well-designed system where infiltrated stormwater is fully drained through the underdrain pipe outlet, without accounting for infiltration losses to surrounding or underlying native soils.

In addition to these baseline curves, supplementary performance curves were developed to evaluate the impact of increased upstream storage capacities on pollutant reduction. These additional curves reflect cumulative performance improvements linked to providing extra storage volumes equivalent to 0.1-inch, 0.2-inch, 0.3-inch, 0.4-inch, and 0.5-inch of runoff depth from the impervious drainage area. Incorporating upstream storage substantially enhances the system's overall performance by allowing for greater retention and treatment of stormwater within the biofilter, thereby reducing the likelihood of untreated flow bypassing the system.

When applying these curves, it is important to recognize their limitations. They do not represent a single design storm event or account for reductions specific to particularly dry or wet seasons. Instead, they reflect long-term cumulative load reductions across various storm sizes and antecedent moisture conditions. The curves are valid only for the design specifications used in their development, including the IC/SA ratio, filter media flow rate, and additional storage capacity. Deviations from these parameters may result in performance discrepancies.

Additionally, HFR system effectiveness relies on proper maintenance—regular inspections and upkeep are essential to prevent clogging, maintain permeability, and sustain pollutant removal efficiency. The inspection and maintenance schedule for stormwater treatment devices depends on system efficiency and pollutant loading from the drainage basin. Routine maintenance ensures optimal performance and prevents clogging or reduced filtration capacity. Typical tasks include removing accumulated trash and leaves, replacing the mulch layer, and raking the top three inches of underlying filtration media to prevent compaction. Fresh mulch is then applied to enhance filtration and pollutant absorption.

Future research should explore additional scenarios to optimize HFR biofilter performance. Key areas of study include varying underdrain storage capacity to assess its impact on stormwater retention and gradual release, evaluating the influence of different native soil infiltration rates, and analyzing how adjustments to filter media flow rates affect pollutant removal and hydraulic efficiency. A more comprehensive approach would involve examining combinations of these variables to understand their collective impact on system performance. By studying these scenarios, future research can refine biofilter design guidelines, improve predictive modeling, and enhance stormwater treatment effectiveness across diverse site conditions.

6 REFERENCES

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