THE CITY OF
POMONA
Public Works Department

April 9, 2019

Deborah J. Smith
Executive Officer
California Regional Water Quality Control Board
Los Angeles Region
320 West 4th Street, Suite 200
Los Angeles, CA 90013

Attention: Mr. Ivar Ridgeway

SUBJECT: SUBMITTAL OF OLDCASTE INFRASTRUCTURE BIOPOD SYSTEM EQUIVELANCY ANALYSIS AND DESIGN CRITERIA FOR REVIEW AND APPROVAL

Dear Ms. Smith:

The NPDES Municipal Separate Storm Sewer System Permit Order No. R4-2012-0175 (Permit) requires biofiltration Best Management Practices (BMPs) to be designed in accordance with the design specifications provided in Attachment H of the Permit. Alternatively, if the proposed project design does not meet the specifications outlined in Attachment H, an approval can be sought from the Regional Water Quality Control Board's Executive Officer for use of an alternative design.

The City of Pomona is seeking approval for use of the Biopod System, manufactured by Oldcastle Infrastructure, as an alternative design to the specifications outlined in Attachment H of the Permit. We have enclosed an Equivalency Analysis and Design Criteria report for the Biopod System prepared for Oldcastle Infrastructure, by Geosyntec Consultants.

If you have any questions or require additional information, please contact Rae Beimer at (714) 788-6936 or via email Rae_Beimer@ci.pomona.ca.us. We look forward to your review and approval of these biofiltration systems for use in the City of Pomona, pursuant to the Permit.

Sincerely,

Rene Guerrero, P.E.
City of Pomona
Interim Public Works Director

Enclosures

1. Equivalency Analysis and Design Criteria for the Biopod System

EQUIVALENCY ANALYSIS AND DESIGN CRITERIA for BIOPOD SYSTEM

Pursuant to:

Los Angeles County MS4 Permit
(Order R4-2012-0175)

Prepared for

Oldcastle Infrastructure, a CRH Company

Prepared by

Geosyntec
consultants
engineers | scientists | innovators

621 SW Morrison Street, Suite 600
Portland, Oregon 97205

February 2019

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1 INTRODUCTION

The Los Angeles County MS4 Permit (Order No. R4-2012-0175) (MS4 Permit) requires that new development and redevelopment projects infiltrate 100 percent of the Stormwater Quality Design volume (SWQDv) on-site as the preferred approach unless technical infeasibility or alternative approaches apply (Provision 7.c). When it is not technically feasible to fully infiltrate the SWQDv, the MS4 Permit allows for on-site biofiltration to be used if it meets the specific criteria in Attachment H of the MS4 Permit. The MS4 Permit also allows for the Los Angeles County Regional Water Quality Control Board (Regional Board) Executive Officer to approve alternate biofiltration design criteria.

The purpose of this report is to develop a design basis for the Oldcastle BioPod system such that these systems will provide equivalent performance to biofiltration BMPs as defined in Attachment H of the MS4 Permit. This report is intended to serve as technical support for requests to the Executive Officer of the Regional Board for approval of alternative design criteria for BioPod systems. This report describes the basis for evaluating equivalency, details the design approach and equivalency criteria for BioPod systems to achieve equivalent performance to conventional biofiltration, and provides the supporting rationales for these equivalency criteria.

The remainder of this report is organized as follows:

Section 2 – BMP Descriptions (Conventional Biofiltration and BioPod)

Section 3 – Basis and Methodology for Evaluating Equivalency

Section 4 – BioPod Design Approach and Equivalency Criteria

Section 5 – Discussion and Conclusions

Section 6 – References

Appendix A – Design Assumptions for Conventional Biofiltration

Appendix B – SWMM Modeling Methodology and Assumptions

Appendix C – Datasets and Analysis Methods for Pollutant Treatment Evaluation

Appendix D – Results of BMP Treatment Performance Evaluation

2 BMP DESCRIPTIONS

2.1 Conventional Biofiltration

Biofiltration (also known as bioretention with underdrain) consists of shallow landscaped depressions that capture and filter stormwater runoff through engineered media. These facilities function as soil and plant-based filtration systems that remove pollutants through a variety of physical, biological, and chemical treatment processes. Biofiltration facilities normally consist of a ponding area, mulch layer, soils, and plantings (Figure 1). An optional gravel layer added below the planting soil coupled with an upturned elbow (or similar hydraulic control approach) can provide additional storage volume for infiltration. As stormwater passes through the planting soil pollutants are filtered, adsorbed, and biodegraded by the soil media, microorganisms living in the soil and optional gravel layer, and plants. Conventional biofiltration is typically designed as a "volume-based" BMP, meaning that is it sized based on capture of the runoff from a specific size of storm event (the SWQDv).

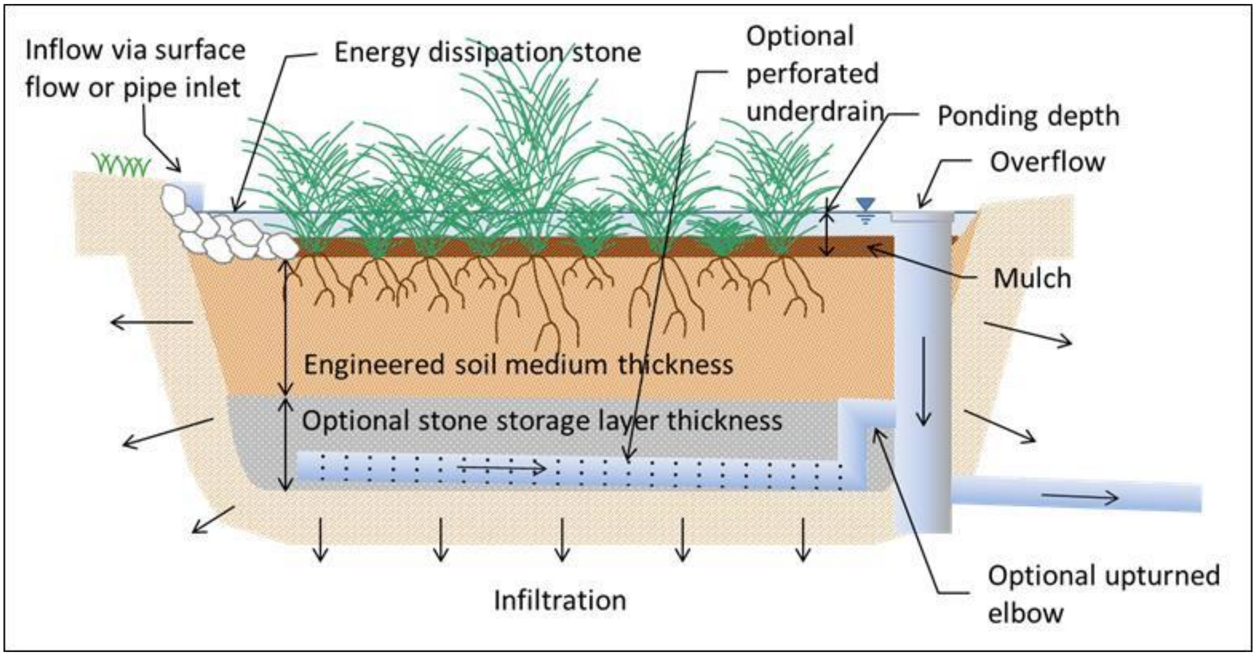

Figure 1: Cross sections of typical biofiltration system

2.2 <u>BioPod</u>

BioPod consists of engineered media topped with mulch and housed in a precast concrete structure. The unit (from bottom to top) contains 6 inches of gravel, 18 inches of media, 2 inches of mulch, and 6 inches of head space. A 4-inch underdrain pipe is embedded in the gravel layer with an orifice cap to control the rate of treated discharge. The orifice cap provides flow control for treated water passing through the system, limiting the rate at which water moves though the media. Systems are configured to provide either an internal or external bypass for flow rates that exceed the system treatment capacity. Figure 2 shows a typical internal bypass configuration.

There are two key components of the BioPod system that contribute to pollutant removal: mulch and engineered filter media. Vegetation and/or other system biota can enhance treatment. In contrast to conventional biofiltration, the media filtration rates of BioPod systems are substantially higher, and therefore the footprint of these systems tends to be substantially smaller than conventional biofiltration systems. As a result of smaller footprints, the amount of volume reduction (via infiltration and evapotranspiration) that is typically observed in these systems when not coupled with infiltration systems tends to be relatively low. Because these systems provide relatively limited ponded water volume above the surface of the media, they are typically sized as "flow-based" BMPs based on a design intensity of rainfall rather than "volume-based" BMPs based on a design storm depth. However, the volume in the system upstream of the discharge structure provides some equalization of peak inflow rates.

The BioPod technology has a General Use Level Designation (GULD) approval for Basic (TSS), Enhanced (dissolved metals), and Phosphorus treatment by the Washington State Technology Assessment Protocol – Ecology (TAPE) program. This approval is provided for reference only. The equivalency analysis presented in this report is based on an independent evaluation of BioPod performance data and modeling results. It is not contingent on approvals in other jurisdictions.

Figure 2: Typical BioPod Configuration

3 METHODOLOGY FOR EVALUATING EQUIVALENCY

3.1 Basis for Equivalency

The equivalency of BioPod to conventional biofiltration as described in Attachment H of the MS4 Permit was evaluated based on the following factors that influence pollutant load reduction performance of stormwater BMPs:

- **Capture efficiency:** The percent of long-term stormwater runoff volume that is treated by the BMP vs. bypassed.
- **Volume reduction:** The percent of long-term stormwater runoff volume that is removed from the system via infiltration or evapotranspiration and does not discharge directly to the storm sewer or surface waters.
- **Concentration reduction:** The difference in contaminant concentration between the raw stormwater runoff and the BMP-treated stormwater runoff.

The equivalency analysis consisted of three parts:

1) The baseline performance of conventional biofiltration was estimated, including representative estimates of capture efficiency, volume reduction, and concentration reduction provided by conventional designs.
2) Sizing criteria were developed for BioPod (with supplemental infiltration systems if needed) such that BioPod would provide equivalent performance to conventional biofiltration.
3) A design methodology for BioPod was developed to ensure consistent application of the equivalent sizing criteria in the design of BioPod systems.

3.2 Methods and Assumptions for Establishing Baseline for Conventional Biofiltration Performance

3.2.1 Hydrologic Performance (Capture Efficiency and Volume Reduction)

Attachment H of the MS4 Permit specifies several criteria that influence the hydrologic performance of the conventional biofiltration BMPs:

- 6 to 18-inch ponding area above media
- Optional layer of mulch
- 2 to 3 feet of engineered filter media (2 feet typical) with a design infiltration rate of 5 to 12 inches/hour; the Attachment H specification calls for a mix of 60 to 80% fine sand and 20 to 40% compost
- Gravel storage layer below the bioretention media to promote infiltration
- Underdrain placed near the top of the gravel layer (or an infiltration sump otherwise provided via an equivalent hydraulic control approach) in cases where underlying soil allows incidental infiltration
- Underdrain discharge to the storm drain system
- Capacity (including stored and filtered water) adequate to biofilter 150 percent of the portion of the SWQDv not reliably retained (i.e., infiltrated or evapotranspired).

Within the bounds established by these criteria, a range of actual conventional biofiltration designs could result as a function of site infiltration conditions as well as designer and local jurisdiction preferences. An example of potential design variability is illustrated in Appendix A. For this analysis, representative design assumptions were developed within the range of potential design assumptions. These assumptions are also presented in Appendix A with supporting rationales. Long-term continuous simulation modeling was conducted using EPA SWMM 5.1 with 18 years of 5-minute resolution precipitation data, as described in Appendix B, to estimate the long-term capture efficiency and volume reduction of the baseline biofiltration design scenario for a range of site infiltration rates. Table 1 describes the baseline hydrologic performance of biofiltration BMPs.

Table 1. Conventional Biofiltration Hydrologic Performance

Site Soil Infiltration Rate, in/hr	Long-Term Capture Efficiency (percent of total runoff volume)	Long-Term Volume Reduction (percent of total runoff volume) (ET + Infiltration)
0	92 to 94%[1] (93% capture is representative)	4%
0.01		5%
0.05		11%
0.15		21%
0.30[2]		34%

1 - Capture efficiency varies slightly as a function of soil infiltration rate (and associated differences in design profile) and land use imperviousness. These differences are relatively minor and are less important than the variability in performance that may result from different design approaches and maintenance conditions that may be encountered. Therefore, a single baseline value of 93 percent long-term capture was used in this analysis.

2 - A maximum soil infiltration rate of 0.3 inches per hour was evaluated because for soil infiltration rates greater than 0.3 inches per hour the MS4 Permit requires that infiltration be evaluated.

3.2.2 Concentration Reduction

Pollutant concentration reduction performance for baseline biofiltration was evaluated based on analysis of bioretention with underdrain studies in the International Stormwater BMP Database. Analyses were conducted based on a screened subset of studies that were considered most representative of MS4 Permit Attachment H design criteria (16 studies). Additionally, four peer-reviewed research studies (Davis 2007; Li and Davis 2009; David et al., 2011; Gilbreath et al. 2012) not contained in the International BMP Database were added to the sample pool for analysis. Two of these studies were conducted in the San Francisco Bay area based on biofiltration design standards and media specifications very similar to Attachment H of the Los Angeles MS4 Permit. The two other additional studies were included due to their similarity to the MS4 Permit Attachment H design criteria. Note that this is the same set of conventional biofiltration studies that were considered in the Filterra Equivalency Analysis (Geosyntec Consultants, 2015) and MWS Linear Equivalency Analysis (Geosyntec Consultants, 2018). The resulting number of studies is adequate to estimate representative concentration reduction performance of conventional biofiltration.

Concentration reduction performance was characterized using a moving window bootstrapping method (Leisenring et al., 2009; see details in Appendix C) that accounts for the influence of influent concentration on effluent concentration and characterizes the relative uncertainty in performance estimates within each range of influent quality. Both the median and mean summary statistics were evaluated using these methods. Additionally, literature on the influence of biofiltration design variables on performance was summarized to support the criteria that were used to select the 20 BMP studies that were included in the screened dataset. The pollutant treatment evaluation was based on total suspended solids, total phosphorus, total copper, and total zinc. Influent concentrations characteristic of single family, multi family, commercial, and light industrial land uses were applied to estimate effluent concentrations and concentration change.

Generally, biofiltration provides good removal of TSS, moderate removal of copper and zinc, and generally shows export of phosphorus. Details about pollutant treatment analyses are provided in Appendix C, and results of these analyses are provided in Appendix D.

3.3 BioPod Analysis to Determine Equivalent Design Criteria

This section provides information on how BioPod performance was analyzed to determine the conditions under which these systems provide equivalent performance to conventional biofiltration.

3.3.1 Capture Efficiency

Capture efficiency by BioPod is a function of the tributary area and runoff coefficient of the tributary area, the time of concentration of the associated watershed, and the design precipitation intensity used to size the BioPod. A fully impervious catchment was used for all simulations. Continuous simulation with EPA SWMM 5.1 using the same 18 years of 5-minute resolution precipitation data as was used for conventional biofiltration (and as described in Appendix B) was used to determine the effect of time of concentration and BioPod sizing criteria on capture efficiency. The effect of time of concentration was determined by changing the modeled width (and associated path length) of a one-acre catchment to match a range of time of concentrations. The BioPod system was represented as a small storage unit matching the profile of the BioPod system with a head-dependent rating curve for treated outflow. Pore space in the BioPod media was modeled with a porosity of 0.4. Because of the outlet control orifice downstream of the media, the media pores will fill and serve as equalization storage in the system. The storage unit footprint area and treated flowrates were scaled linearly to represent different design precipitation intensities. The details of this analysis are provided in Appendix B. Figure 3 presents the results of the simulations.

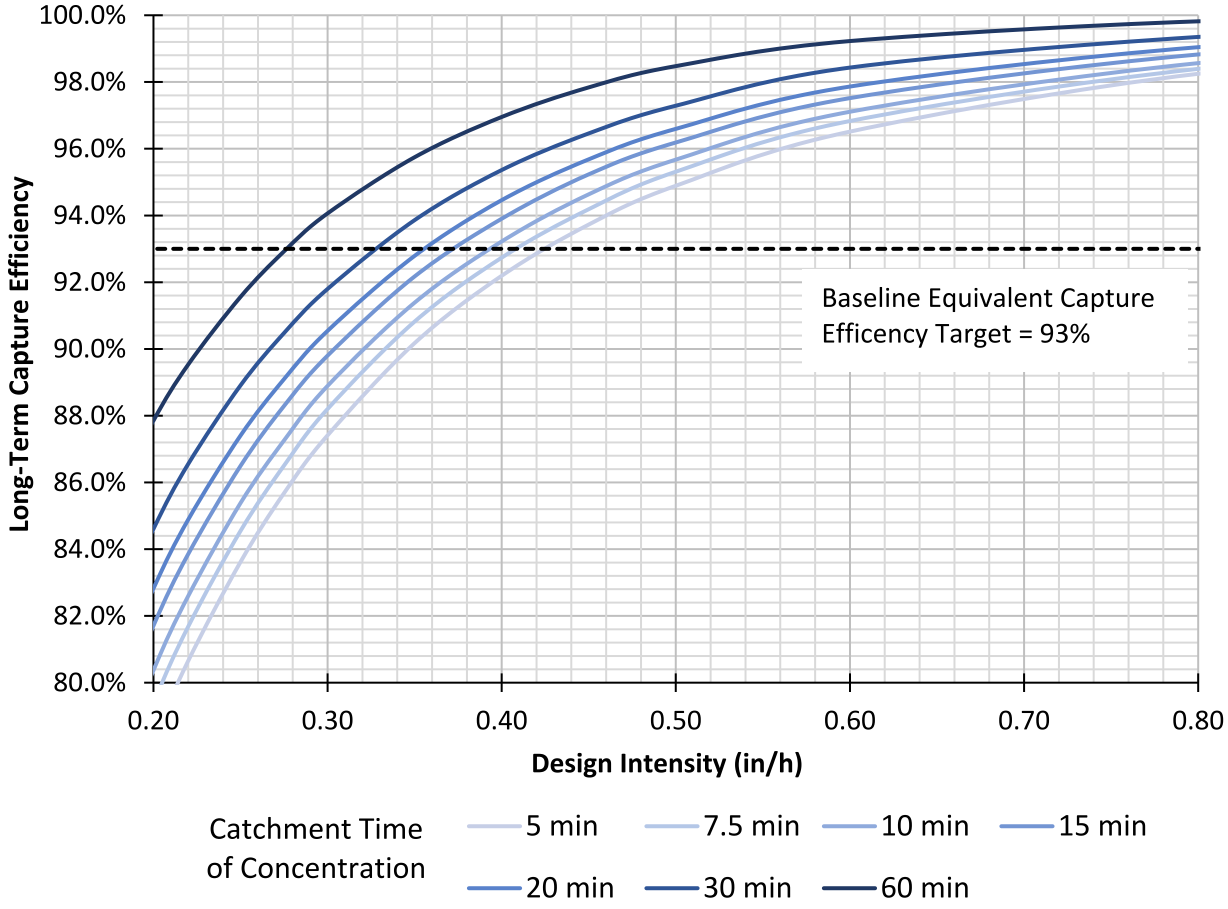

Figure 3: BioPod Long-Term Capture Efficiency based on Design Intensity and Time of Concentration

3.3.2 Volume Reduction (BioPod and Supplemental Infiltration Storage)

Volume reduction through BioPod is minor due to the small surface area and impermeable floor of the treatment unit. Supplemental infiltration components may need to be added, either upstream, downstream, or underneath the BioPod, to provide volume reduction equivalent to what conventional biofiltration would typically achieve under the same site conditions. Volume reduction is a function of the storage volume provided and the infiltration rate of the underlying soil. EPA SWMM 5.1 was used to conduct long-term continuous simulation to model supplemental infiltration compartments to determine the magnitude of volume reduction that would be provided if these were paired with a BioPod unit. A range of soil infiltration values were used to determine the long-term volume reduction of a supplemental infiltration compartment based upon the volume of the infiltration component. Infiltration component sizing was based on various fractions of the SWQDv. The details of this analysis are presented in Appendix B, and results are presented in Figure 4.

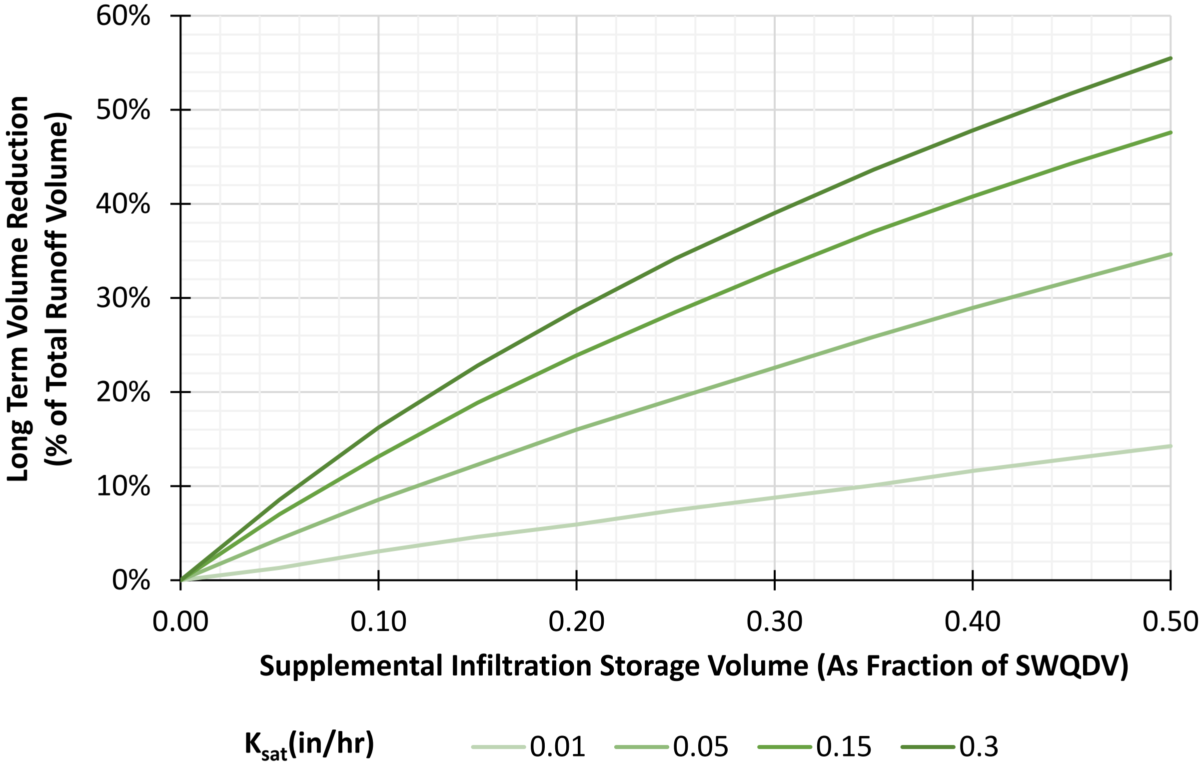

Figure 4: Volume Reduction Provided by a Supplemental Infiltration Compartment

3.3.3 Pollutant Treatment

BioPod performance data were analyzed using the same moving window bootstrapping methods used for conventional biofiltration. Data from a third-party study in Washington state were utilized in this analysis. This analysis sought to determine whether BioPod performance is reasonably similar to the treatment performance of conventional biofiltration BMPs under representative ranges of influent quality. The MS4 permit does not prescribe the suite of pollutants that need to be considered in evaluating equivalency. Therefore, this equivalency analysis was based on the suite of pollutants that were available, including TSS, total copper, total zinc, and total phosphorus.

The water quality equivalency analysis, as described in Appendices C and D, indicates that BioPod has similar or superior pollutant removal performance compared to conventional biofiltration. The bullets below summarize the findings of the analysis:

- **Total Suspended Sediment:** Both BioPod and conventional biofiltration performed well for TSS, although BioPod provided consistently better removal performance than conventional biofiltration. For conventional biofiltration TSS removal efficiencies were greater than 75% for all evaluated land use influent concentrations except for multi-family residential (55%), while for BioPod efficiencies were greater than 90% for all evaluated land uses except multi-family residential (83%).

- **Metals (Copper and Zinc):** BioPod showed slightly better performance for all representative influent concentrations, and notably better performance for some land uses for zinc reductions. Conventional biofiltration exhibited removal efficiencies generally greater than 40% for copper and 70% for zinc, while BioPod exhibited removal efficiencies generally greater than 50% for copper and 80% for zinc for all evaluated land use influent concentrations.
- **Phosphorus:** For influent concentrations below 0.5 mg/L conventional biofiltration exported phosphorus. Superior phosphorus removal performance was evident for BioPod, with removal efficiencies generally exceeding 75% for all evaluated land use influent concentrations. This is likely a function of the low nutrient media included in the system.

Given these findings, BioPod are expected to provide similar or better pollutant concentration reduction across the representative site conditions considered. Notably, BioPod does not exhibit phosphorus export as is consistently observed in conventional biofiltration similar to Attachment H criteria. The monitored system did not include vegetation. The addition of vegetation, which is included in some BioPod configurations, could result in enhanced treatment performance compared to the data collected in the third-party Washington state study.

3.3.4 Additional Capture In Lieu of Volume Reduction

For BioPod applications with minor deficiencies in volume reduction compared to conventional biofiltration, an alternative option to supplemental infiltration is to provide treatment of long-term runoff in excess of the 93% capture efficiency required for equivalency with conventional biofiltration.

As a simple approach for minor volume reduction deficiencies, the pollutant treatment performance of BioPod systems for TSS was used. Based on a representative removal efficiency of 80 percent (actual performance may be higher), a BMP must treat and discharge 5 parts of water for every 4 parts of water that would be lost to infiltration or ET. This means that for every 1 percent of volume reduction deficit, 1.25 percent of long-term volume must be treated. This translates to 0.25 percent additional capture for every 1 percent of volume reduction deficit. This concept is illustrated in Figure 5. Calculations of required additional capture efficiency are provided in Table 2.

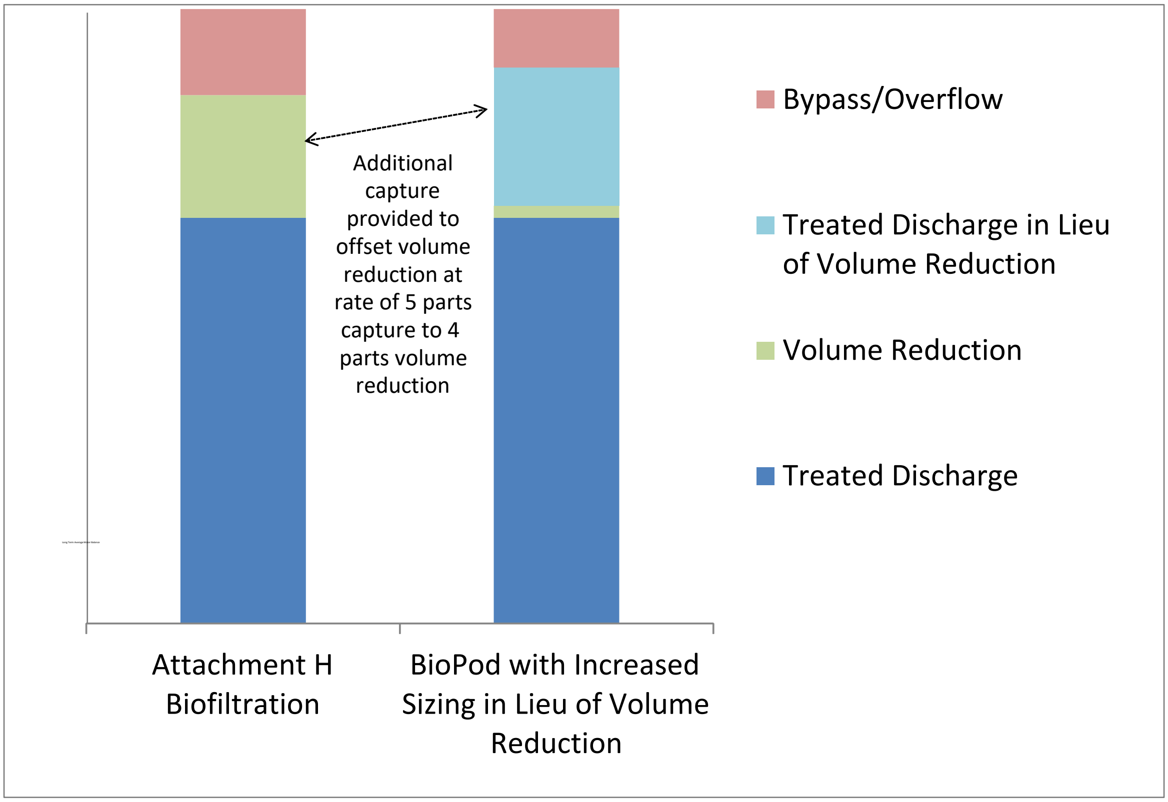

Figure 5. Illustration of Additional Capture in Lieu of Volume Reduction (Not to scale)

Table 2. Additional Capture Efficiency in Lieu of Volume Reduction

Site Soil Infiltration Rate, in/hr	Attachment H Biofiltration Long-Term Volume Reduction[1, 2]	BioPod Long-Term Volume Reduction[1] (ET only)	Volume Reduction Deficit	Additional Required Capture Efficiency in Lieu of Volume Reduction[3]	Adjusted Target Capture Efficiency
0	3.9%	1%	2.9%	0.7%	93.7%
0.01	5.2%	1%	4.2%	1.1%	94.1%
0.05	10.5%	1%	9.5%	2.4%	95.4%
0.15	21.4%	1%	20.4%	5.1%	98.1%
0.30	33.7%	1%	32.7%	8.2%	N/A

1 – Based on modeling of ET from pores and standing water.

2 – Includes infiltration losses, where feasible

3 – Required additional capture calculated at a rate of 1 part additional for every 4-parts volume reduction deficit.

4 DESIGN METHODOLOGY AND EQUIVALENCY CRITERIA

This section explains how to apply the equivalency relationships developed in Section 3. Applying this design methodology is expected to result in equivalent treatment to a conventional biofiltration basin as described in Appendix H of the MS4 Permit.

Step 1: Characterize Site and Determine Key Attributes

The first steps in developing an equivalent design are to assess the location-specific characteristics of each proposed BioPod:

- Delineate the drainage area to the BioPod.
- Estimate the imperviousness of the tributary area; use this value to estimate a runoff coefficient for the drainage area using a method acceptable to the local jurisdiction.
- Calculate the drainage area time of concentration (T_c) using methods acceptable to the local jurisdiction.
- Determine local 85th percentile, 24-hour precipitation depth for the project location. This should be determined from the Los Angeles County 85th percentile precipitation isohyetal map (http://dpw.lacounty.gov/wrd/hydrologygis/). If the isohyetal map gives a value less than 0.75 in, use 0.75 in, per the MS4 Permit.
- Calculate the site “scaling factor” (f) as the ratio of the project-specific 85th percentile, 24-hour storm event to the LAX 85th percentile, 24-hour storm event (1.0”).
- Determine the long-term reliable infiltration rate of the soils underlying the future BMP location using appropriate methods, subject to the approval of the reviewing agency.

This information is applied in the following steps.

Step 2: Select Design Approach for BioPod for Equivalent Long-Term Performance

BioPod must be designed to provide equivalent capture efficiency to conventional biofiltration. Additionally, because BioPod systems do not allow for infiltration, the design of BioPod must mitigate for deficiency in volume reduction compared to conventional biofiltration. Two options are available for meeting this requirement:

> **Option A:** Provide a supplemental infiltration chamber either upstream, downstream, or underneath of the BioPod unit. This is feasible in any condition where infiltration is allowable but supplemental BMPs are necessary.
>
> **Option B:** Increase the size of the BioPod unit to provide a higher capture efficiency in lieu of infiltration. This is most feasible when soils have very low permeability or infiltration is infeasible for other reasons, such that conventional BMPs would achieve relatively little incidental infiltration and therefore volume reduction.

Note that both options may not be feasible for a specific site. Step 3A provides guidance on Option A; Step 3B provides guidance on Option B.

Step 3A: BioPod Sizing with Supplemental Infiltration Storage (Option A)

This option involves selecting a BioPod model that achieves equivalent long-term capture efficiency to conventional biofiltration and sizing a supplemental infiltration system to achieve equivalent long-term volume reduction.

1. Based on the Tc from Step 1, select the required design precipitation intensity to achieve equivalent long-term capture efficiency.

Table 3: Design Precipitation Intensity to Achieve Equivalent Long-Term Capture Efficiency (supplemental infiltration provided separately)

Time of Concentration (min)	Design Precipitation Intensity (in/hr)
5	0.43
7.5	0.41
10	0.39
15	0.37
20	0.36
30	0.33
60	0.28

2. Apply the Rational Method (Equation 1) to determine the design flowrate (Q) required for the BioPod.

$$Q = CiA \times (\frac{1\,ft}{12\,in}) \times (\frac{1\,h}{3600\,s}) \times f \tag{1}$$

Where,

Q = design flow rate (cfs)
C = runoff coefficient
i = design precipitation intensity (in/hr)
A = catchment area (ft^2)
f = site scaling factor

3. Consult Table 4 to select a BioPod model that equals or exceeds the required treatment flowrate. As shown in Table 4, internal bypass configurations have lower treatment flowrates than external bypass configuration for a given vault size because of the portion of the vault area that is occupied by the internal bypass structure.

Table 4: BioPod Model Sizing and Specifications

Model Name[(1)]	Vault Size	Internal Bypass[(1)] Surface Area (ft²)	Internal Bypass[(1)] Treatment Flowrate (cfs)[(2)]	External Bypass Surface Area (ft²)	External Bypass Treatment Flowrate (cfs)[(2)]
X-44Y-Z	4' x 4'	12.9	0.046	16.0	0.057
X-46.5Y-Z	4' x 6.5'	22.9	0.081	26.0	0.092
X-48Y-Z	4′ x 8′	28.9	0.102	32.0	0.113
X-413Y-Z*	4′ x 13′	48.9	0.173	52.0	0.184
X-415Y-Z*	4′ x 15′	56.9	0.201	60.0	0.213
X-417Y-Z*	4′ x 17′	64.9	0.230	68.0	0.241
X-419Y-Z*	4′ x 19′	72.9	0.258	76.0	0.269
X-421Y-Z*	4′ x 21′	80.9	0.286	84.0	0.298
X-66Y-Z	6' x 6'	32.9	0.116	36.0	0.128
X-68Y-Z	6′ x 8′	44.9	0.159	48.0	0.170
X-612Y-Z	6' x 12'	68.9	0.244	72.0	0.255
X-88Y-Z	8′ x 8′	60.9	0.216	64.0	0.227
X-812Y-Z	8′ x 12′	92.9	0.329	96.0	0.340
X-816Y-Z	8′ x 16′	124.9	0.442	128.0	0.453

(1) Model name listed here includes indicators for project-specific configuration and alignment. X, Y, and Z are placeholders that will be used to indicate BioPod configuration, internal or external bypass, and inlet alignment, respectively. Other sizes may be available as well.
(2) Internal Bypass Peak Flow Capacity = 2.0 cfs, all sizes.
(3) Based on WA Ecology GULD approval for basic, enhanced, & phosphorus treatment at 1.6 gpm/ft^2.
* Only available in Planter Configuration

4. Multiply the site-specific SWQDv for the BioPod drainage area by the required supplemental infiltration storage volume fraction in Table 5. This table assumes that the supplemental infiltration basin will be 2.0 ft in depth. Shallower or deeper storage would require different sizing factors. Supplemental calculations could be provided to demonstrate that an alternative storage configuration would provide equivalent long-term volume reduction. Note that for long-term reliable infiltration rates greater than 0.3 in/hr full infiltration of the SWQDv must be considered.

Table 5: Supplemental Infiltration Volume for Equivalent Long-Term Volume Reduction

Estimated Long-Term Reliable Infiltration Rate below Site, inches per hour	Long-Term Volume Reduction Deficit, % of Long-Term Runoff	Required Supplemental Infiltration Storage Volume as Fraction of Local SWQDv, unitless[1,2]
0	3%	Not feasible; See Option B
0.01	4%	0.14
0.05	10%	0.11
0.15	20%	0.17
0.3	33%	0.24

1 – Values are not expected to follow a continually increasing trend.

2 - A 2.0-foot effective storage depth is assumed for supplemental storage.

Step 3B: BioPod Sizing for Excess Capture in Lieu of Volume Reduction

This option involves increasing the size of BioPod to achieve a higher level of capture efficiency in lieu of providing supplemental volume reduction.

1. Use Table 6 to determine the adjusted design rainfall intensity. For times of concentration less than 5 min, round up to 5 min. Interpolation between values in this table would be permissible.
2. Apply the Rational Method (Equation 1) to determine the design flowrate (Q) required for the BioPod.
3. Select a BioPod Model from Table 4 to provide the required treatment flowrate.

Table 6: Adjusted Design Intensity to Provide Additional Capture In Lieu of Volume Reduction (Option B)

Time of Concentration (min)	**Reliable Infiltration Rate at Site**			
	0 in/hr (ET only) Capture Efficiency Target = 93.7%	**0.01 in/hr** Capture Efficiency Target = 94.1%	**0.05 in/hr** Capture Efficiency Target = 95.4%	**0.15 in/hr** Capture Efficiency Target = 98.1%
	Adjusted BioPod Design Precipitation Intensities, in/hr			
5	0.45	0.47	0.53	0.78
7.5	0.43	0.45	0.51	0.76
10	0.42	0.43	0.49	0.74
15	0.39	0.41	0.46	0.69
20	0.38	0.39	0.44	0.64
30	0.35	0.36	0.40	0.57
60	0.29	0.30	0.34	0.47

5 DISCUSSION AND CONCLUSIONS

5.1 Key Observations and Findings

5.1.1 Capture Efficiency and Volume Reduction

Overall, if BioPod units are designed based on the methodology and criteria presented in Section 4 and effectively operated and maintained, these systems are expected to result in similar performance compared to conventional biofiltration. The following bullets summarize key findings from this analysis:

- The baseline level of capture efficiency and volume reduction provided by conventional biofiltration BMPs, if effectively designed per Attachment H of the MS4 Permit, is relatively high. This establishes a relatively high baseline standard for BioPod systems to meet in providing equivalent performance.
- Design variation for conventional biofiltration are permitted by MS4 Permit Attachment H criteria and local implementation guidance. These variations result in variations in hydrologic performance. Additionally, variations in operations and maintenance conditions over time (i.e., decline in media rates, reduction in active storage volume from sedimentation) are also expected to influence performance.
- It is possible to design BioPod units to match the capture efficiency of conventional biofiltration BMPs. This requires larger sizes of BioPod units than was required for treatment control BMPs under the previous MS4 Permit. This also requires a commitment to regular maintenance consistent with BioPod standard maintenance requirements.
- BioPod units alone are not expected to match the volume reduction performance provided by effectively designed conventional biofiltration. However, it is possible for BioPod systems to mitigate for deficiency in volume reduction via either a supplemental infiltration basin or by increasing the size of the BioPod unit to increase capture efficiency, thereby providing equivalent TSS load reductions.

5.1.2 Water Quality Treatment

The water quality equivalency analysis, as described in Appendices C and D, indicates that BioPod achieves similar or better pollutant removal performance compared to conventional biofiltration. This is summarized in Section 3.3.3 above. Notably, BioPod has not exhibited phosphorus export as is consistently observed in conventional biofiltration systems that include compost similar to Attachment H criteria. BioPod does not include compost.

5.2 Reliability and Limitations

There are several uncertainties that could influence the reliability of the findings presented in this report. These are addressed in the paragraphs below.

> **Modeled hydrologic performance estimates.** Performance estimates were based on models which were not calibrated. This introduces some uncertainty. However, this uncertainty was mitigated by applying identical input parameters and modeling approaches for conventional

biofiltration and BioPod units, as appropriate. This has the effect of offsetting most sources of bias.

Treatment performance estimates for conventional biofiltration. Treatment performance estimates were based on peer reviewed studies from the International Stormwater BMP Database and other peer-reviewed third party studies that were selected to be representative of the BMPs being compared. Due to the limited documentation of these studies, it was not possible to quantitatively evaluate whether performance estimates are specifically representative of the MS4 Permit's Attachment H guidelines. Additionally, performance has been observed to vary greatly from site to site, indicative of the importance of design factors such as sizing, media composition, and sources of media components. The conventional biofiltration datasets analyzed are believed to provide reliable information about the range of potential performance that may be expected from conventional biofiltration in Los Angeles County; however, they are not intended to be used as a predictive tool for any one variation of biofiltration design. Reliability of these data was improved through the application of robust statistical methods that account for the influence of influent concentration and provide a quantification of uncertainty.

Treatment performance estimates for BioPod units. BioPod units have been evaluated in a third-party field study with representative stormwater conditions; however, this site was not in Los Angeles County. Additionally, the sample size of BioPod datasets is still somewhat low in comparison to conventional biofiltration BMPs. These factors are mitigated to a large extent by the standardized design that accounts for differences in rainfall intensity and ensures consistency in treatment processes. These factors improve the transferability of findings between regions. Additionally, the reliability of BioPod performance data was improved by applying the same robust statistical methods as used for conventional biofiltration, which helps adjust for differences in influent quality between studies.

TSS removal as a surrogate for additional capture in lieu of volume reduction. For small deficiencies in volume reduction, a TSS treatment removal rate of 80 percent was used to calculate required additional capture efficiency in lieu of volume reduction. A multi-parameter approach would be more complex and would need to account for the export of nutrients in conventional biofiltration as well as variability in treatment performance with influent contraction. Given that this approach is only intended to offset minor volume reduction (up to about 20%), this is considered a reasonable approach.

Sensitivity to site conditions. The effectiveness of volume reduction processes is particularly sensitive to estimates of a BMPs underlying infiltration rate. It is often not possible to anticipate with certainty what the long-term infiltration rate will be after construction. This limitation is largely mitigated for this analysis because the uncertainty in infiltration rate influences the design and performance of conventional biofiltration and BioPod with supplemental infiltration storage similarly. Additionally, estimating the BMP location infiltration rate is now a standard part of developing a BMP plan for a site, so the reliability of approaches for developing this estimate should improve with time.

Variability in design and construction process. The analyses and criteria presented in this report assume that the BMPs will be designed, constructed, and maintained according to typical standards and manufacturer guidelines. It is inherent that the design of conventional biofiltration BMPs provides a greater degree of freedom and associated professional judgment as part of preparing design calculations, design drawings, and specifications than proprietary BMPs such as BioPod units use. This introduces a wider potential range of resulting designs for conventional biofiltration: some may perform better than average, some may perform worse. In comparison, there is likely to be substantially less variability in the design and construction of BioPod units as compared to biofiltration BMPs.

Sensitivity to operations and maintenance. Both types of systems are susceptible to decline in performance over time. **Neither BMP type will continue to function as designed if not regularly and effectively maintained.**

Overall, the analyses are believed to result in reliable design assumptions. Where substantial uncertainties exist, these are mostly offset for the purpose of estimating equivalency, because they affect both conventional biofiltration and BioPod similarly.

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APPENDIX A – CONVENTIONAL BIOFILTRATION DESIGN ASSUMPTIONS FOR PERFORMANCE MODELING

The following criteria from the MS4 Permit Attachment H were important for evaluating pollutant load reduction performance of "conventional biofiltration" scenarios:

- 6 to 18-inch ponding area above media
- Optional layer of mulch
- 2 to 3 feet of engineered filter media (2 feet typical) with a design infiltration rate of 5 to 12 inches/hour; the Attachment H specification calls for a mix of 60 to 80% fine sand and 20 to 40% compost
- Gravel storage layer below the bioretention media to promote infiltration
- Underdrain placed near the top of the gravel layer (or an infiltration sump otherwise provided via an equivalent hydraulic control approach) in cases where underlying soil infiltration rates allow
- Underdrain discharge to the storm drain
- Total physical water storage volume sized to be equal to at least the stormwater quality design volume (SWQDv = runoff volume from the 85th percentile, 24-hour storm event)
- Capacity (including stored and filtered water) adequate to biofilter 150 percent of the portion of the SWQDv not reliably retained.

Within the bounds established by these criteria, a range of actual biofiltration designs could result as a function of site infiltration conditions as well as designer and local jurisdiction preferences. An example of potential design variability is illustrated in Table A.1 below. For this analysis, representative design assumptions were developed within the range of potential design assumptions. These assumptions are also presented in Table A.1 with supporting rationales.

Table A.1 Biofiltration Design Assumptions from Various Sources and Selected Representative Design Assumptions

Design Assumption	**Design References**					**Selected Representative Design Assumption**	**Rationale for Selected Design Assumption**
	MS4 Permit Attachment H	Los Angeles County LID Manual, static method	Los Angeles County LID Manual, routing method	City of Los Angeles LID Manual	Ventura County TGM		
Ponding Depth, ft	0.5 to 1.5	0.5 to **1.5**	0.5 to **1.5**	0.5 to **1.5**	0.5 to **1.5**	1.5	Many designers will utilize deepest depth allowable because of space efficiency.
Media Depth, ft	2 to 3	**2** to 3	**2** to 3	**2** to 3	**2** to 3	2	Typical design approach is to use minimum depth due to cost of media.
Gravel “sump” depth below underdrain, ft	Not specified; narrative	Not specified, narrative	Not specified, narrative	At least 1 foot; up to **2** feet if soils allow incidental infiltration	**0.5** minimum below underdrain	Depth that would drain in 24 hours. For example, 1.5 ft if site infiltration rate estimated at just less than 0.3 in/hr	Approach produces a reasonable design that considers infiltration rates; Attachment H states that volume infiltrated within 24 hours can be considered retained.
Media Filtration Rate, in/hr	5 to 12	**5** to 12	**5** to 12	**5** to 12	1 to 12 **(5)**	5	Representative of long-term operation after some clogging
Allowable Routing Period for Biofiltration Treatment, hrs	Not specified	Routing is not part of simple method	Allows routing of **24-hour** design hydrograph from LA County HydroCalc model	**3** hours, unless using a routing model	Depth up to ponding depth (**1.5 ft**) can be considered routed	6 hours[1]	Based on evaluation of storm durations for events similar to design event. See footnote 1.
Resulting Footprint Factor at 0.3 in/hr Infiltration Rate, in/hr (% of impervious area)	Not enough information to calculate	5 to 10%	1.4%	2.4% (1.4% with routing similar to LA County)	2.8%	2.0%	Calculated based on assumptions.

Note: where a range of guidance is allowed, the bolded number indicates the value that was used in calculations. The design values were selected based on developing the most economical and space-efficient design that meets the applicable criteria.

1 – The allowable routing period was estimated based on the typical storm duration associated with events similar to the 85th percentile, 24-hour storm depth (1.0 inches at LAX). This was estimated in two ways. For days with precipitation totals between 0.9 and 1.1 inches, the total number of hours with rainfall was tabulated (average = 11 hours; 10th percentile = 6 hours). This does not consider dry periods between hours with rainfall, therefore is somewhat conservative in estimating the time available for routing biofiltered water during a given day. For unique precipitation events, separated by 6-hour dry period (potentially spanning across breaks in calendar days), with precipitation totals between 0.9 and 1.1 inches, the total storm durations were tabulated (average = 16 hours; 10th percentile = 7 hours). Based on this analysis, a 6-hour routing period is defensible and conservative in estimating the amount of water that can be routed through a biofiltration system during typical storm events similar to the design storm event.

APPENDIX B – SWMM MODELING METHODOLOGY AND ASSUMPTIONS

The relative performance of BioPod and conventional biofiltration was determined using the following data inputs and modeled site conditions:

- Rainfall: Los Angeles International Airport, 2000-2018, ASOS
- ET: CIMIS Zone 4
- Catchment imperviousness: 100%
- Catchment slope: 3%
- Area: 1 acre

For conventional biofiltration the sizing and design criteria described in Appendix A were followed, including underlying soil infiltration rates of 0, 0.01, 0.05, 0.15, and 0.30 in/hr.

For BioPod, all combinations of the following sizing and design criteria were evaluated:

- Time of concentration: 5, 7.5, 10, 15, 20, 30, and 60 min
- Design rainfall intensity: 20 values spanning 0.02 - 1.00 in/hr

Supplemental infiltration compartments were evaluated using the following sizing and design criteria:

- Time of concentration: 5 min (not a sensitive parameter for a volume-based BMP)
- Unit depth: 2 ft
- Underlying soil infiltration rate: 0.01, 0.05, 0.15, and 0.30 in/hr
- Percent of runoff depth, using the 24-hr, 85th percentile rainfall depth: 10 increments spanning 5% -50%.

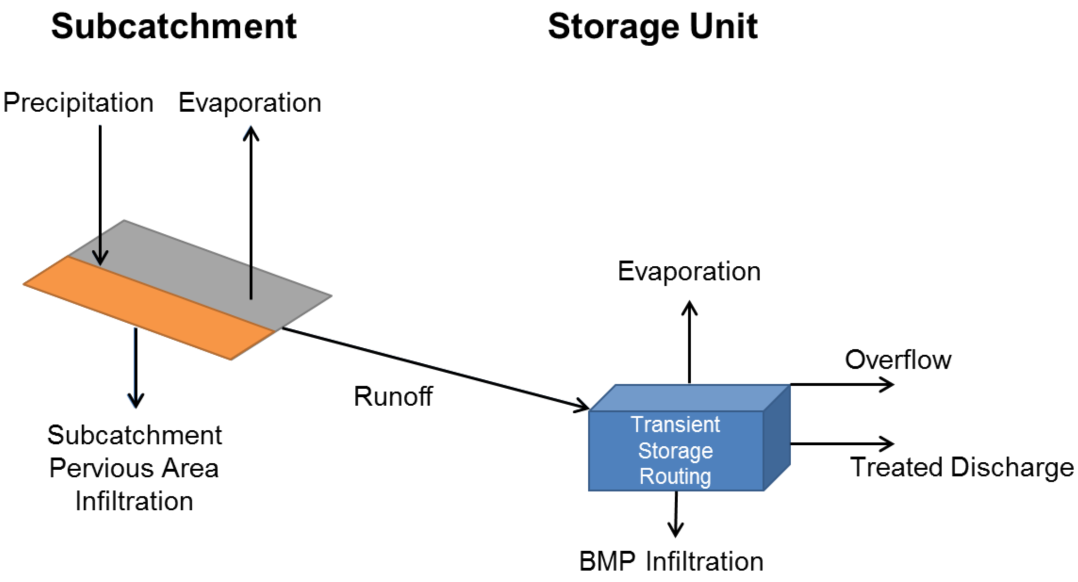
Overview of SWMM Analysis Framework

SWMM was used to estimate the long-term capture efficiency and volume reduction from conventional biofiltration and BioPod for each scenario. SWMM simulates surface runoff, evaporation, infiltration, and flow routing. A conceptual representation of the SWMM model framework used for this analysis is provided in Figure B.1. Within this framework, parameters were adjusted for each scenario to account for soil condition and BMP sizing and design attributes.

In SWMM, subcatchment elements are used to generate a runoff hydrograph. Input data defining the surface characteristics include subcatchment area, imperviousness, width, depression storage, surface roughness, surface slope, and infiltration parameters. SWMM performs a mass balance of inflows and outflows to determine runoff from a subcatchment. The inflows to this mass balance are precipitation and any runoff directed from another subcatchment. The outflows from the mass balance include evaporation, infiltration, and runoff. The runoff parameters assumed for this analysis are discussed in this Appendix.

A variety of hydraulic flow routing elements exist in SWMM, but fundamentally the program includes nodes (i.e., storage units, manholes, and outfalls) and links (i.e., conduits, pipes, pumps, weirs, orifices, and outlets). For traditional biofiltration, a storage unit was used to represent the storage and routing attributes of BMPs. The elements defining the storage volume and related discharge were adjusted based on the various sizing and design criteria evaluated in the equivalency scenarios, the details of which are discussed in this Appendix. For BioPod a storage unit was also used to represent the storage and routing attributes, with a transverse weir to represent the overflow structure and an outlet with a simplified head-dependent outflow curve to represent the underdrain and orifice cap. The supplemental infiltration storage compartment was also modeled as a storage unit and included seepage loss.

SWMM was run in continuous simulation mode over an 18-year period (January 2000-March 2018). A continuous hydrograph of runoff was generated and routed through the model representations of BMPs. The results were tracked and reported in terms of long-term runoff volume, long-term volume lost in the BMP, long-term volume bypassing or overflowing the BMP, and long-term volume treated in the BMP. The 18-year period of record was selected based on the availability of high quality 5-minute resolution precipitation data, which are important for representing urban catchments with a short time of concentration. To ensure comparability, the same forcing data (rainfall, ET) were applied to conventional biofiltration scenarios and BioPod scenarios.



Capture Efficiency (fraction of runoff) = 1- (Overflow/Runoff)

Volume Reduction (fraction of runoff) = 1- (Treated Discharge + Overflow)/(Runoff)

Figure B.1. Schematic SWMM modeling framework in support of equivalency analysis

Meteorological Inputs

Precipitation

Long-term modeling used 5-minute data obtained from the Automated Surface Observation System (ASOS). This data was compared to National Climatic Data Center (NCDC) hourly precipitation data to ensure quality, as NCDC data sets undergo a greater level of quality review than ASOS data sets. While the NCDC data spans 1948-2015 and the ASOS model spans only 2000-2018, the ASOS data was selected over the NCDC data because the improved temporal resolution is important for small catchments. Both ASOS and NCDC rainfall data were obtained from gauges located at Los Angeles International Airport.

Comparison of NCDC and ASOS data resulted in the elimination of 14 ASOS data points (for a total of 70 minutes of data out of the 17+ years of available) that were determined to be clearly erroneous. Otherwise, ASOS and NCDC data agreed well. The 85th percentile, 24-hour depth was determined using NCDC data for days with rainfall greater than 0.1 inches. This value was slightly higher for the NCDC data (1.01”) than for the ASOS data (0.94”), which can be attributed to the difference in the length of available data sets (Table B.1).

Table B.1: LAX Storm Water Quality Design Volume

Data	Gauge Location	85th Percentile 24-Hour Depth (in)
NCDC (1948-2015)	Los Angeles Airport (045114)	1.01
ASOS (2000-2018)	Los Angeles Airport (KLAX)	0.94

Evapotranspiration

Evapotranspiration (ET) values for Zone 4 as defined in the California Irrigation Management Information System (CIMIS) were used for all SWMM models (Table B.2). ET values used in the model were set to 60% of the reference ET values to account for mixed urban conditions and shading conditions based on guidance provided by CIMIS (CDWR, 2015). ET values have little influence on modeled outputs in SWMM.

Table B.2: CIMIS Zone 4 Evapotranspiration Values

Month	Evapotranspiration Rate (in/month)	Evapotranspiration Rate (in/day)	60% Evapotranspiration Rate (in/day)
January	1.86	0.05	0.06
February	2.24	0.08	0.08
March	3.41	0.12	0.11
April	4.5	0.17	0.15
May	5.27	0.22	0.17

Month	Evapotranspiration Rate (in/month)	Evapotranspiration Rate (in/day)	60% Evapotranspiration Rate (in/day)
June	5.7	0.26	0.19
July	5.89	0.28	0.19
August	5.58	0.25	0.18
September	4.5	0.19	0.15
October	3.41	0.13	0.11
November	2.4	0.07	0.08
December	1.86	0.05	0.06

Runoff Parameters

The key SWMM parameters used to estimate surface runoff from the impervious catchment are subcatchment area, width, depression storage, surface roughness, and surface slope. The majority of surface characteristics were kept constant for both BMP systems and across all land use types. For BioPod simulations the width parameter (defines the overland flow length for runoff to travel), was adjusted to reflect differences in time of concentration. Drainage widths were set to correspond with times of concentration of 5, 7.5, 10, 15, 20, 30, and 60 minutes in a 1-acre catchment via Equation B.1 (Table B.3):

$$T_c = \frac{0.93 \times L^{0.6} \times n^{0.6}}{I^{0.4} \times S^{0.3}} \tag{B.1}$$

Where,

T_c= time of concentration (min)
L = length (ft)
n = Manning’s n (0.012, corresponding to impervious surface Manning’s n)
S = Slope (ft/ft) (0.03)
I = intensity (in/hr; set to the 85th percentile rainfall intensity at the corresponding time of concentration, as determined by ASOS data; Table B.3)

Table B.3: Rainfall Intensities Used to Determine Catchment Width

Time of Concentration (min)	85th Percentile Rainfall Intensity (in/hr)	Path Length Associated with Tc (ft)	SWMM Catchment Width to Represent Tc (ft)
5	0.24	92	474
7.5	0.24	181	241
10	0.24	292	149
15	0.20	508	86
20	0.18	765	57
30	0.16	1391	31
60	0.12	3644	12

Infiltration over the catchment was not modeled because the scenarios considered only 100 percent impervious catchments. This was done for both conventional biofiltration and BioPod simulations. Runoff coefficients are applied as part of the design process.

Table B.4: EPA SWMM Parameters Used to Model BMPs

SWMM Runoff Parameters	**Units**	**Values**	**Source/Rationale**
Wet time step	seconds	150	Set to 50% of the time steps of precipitation input data (300 seconds)
Dry time step	seconds	14,400	Equivalent to 4 hours.
Period of Record		January 2000-March 2018	Availability of ASOS data
Percent of Impervious Area	percent	100	Representative of typical fully developed area draining to BioPod; actual imperviousness would be used by designer to calculate runoff coefficient.
Impervious Manning's n	unitless	0.012	James and James, 2000
Drainage area	acres	1	Hypothetical for purpose of analysis
Width	feet	*Conventional biofiltration:* 174 ft *BioPod:* Variable to represent different time of concentrations (Table B.3)	*Conventional biofiltration:* Typical assumption for urban drainage patterns (equates to 250-ft path length). Performance of volume-based BMPs is not sensitive to catchment width. *BioPod:* Calculated as described above.

SWMM Runoff Parameters	Units	Values	Source/Rationale
Slopes	ft/ft	0.03 (represents average of roofs, landscaping, and streets)	Professional judgment; actual slope would be used by designer to calculate Tc.
Evaporation	in / month	60% of reference ET values (Table B.4)	CIMIS (CWDR, 2015)
Depression storage, impervious	inches	0.02	James and James, 2000

Supplemental Infiltration Unit

Catchment parameters were kept the same for supplemental infiltration unit modeling as for BioPod runoff modeling (Table B.5). Catchment width was kept constant for all runs, using the conservative value associated with a time of concentration of 5 minutes. The unit was modeled with a constant depth and a total volume based upon a fraction of the SWQDv (Table B.1) (equal to the runoff from a 1.0” event).

Table B.5: EPA SWMM Parameters Used to Model Supplemental Infiltration

SWMM Runoff Parameters	Units	Values	Source/Rationale
Catchment Width	feet	473.6	Width of a 1 ac catchment with a 5 min time of concentration
Storage Unit Depth	ft	2.0	Typical value
Storage Unit Saturated Hydraulic Conductivity (in/hr)	in/hr	Varies by site condition: 0.01, 0.05, 0.1, 0.15, and 0.30	Allows for analysis of different underlying soil types

BMP Representation

Conventional Biofiltration

Conventional biofiltration was simulated using a storage unit with outlets to represent infiltration losses (if present) and treated discharge, and a weir to simulate overflow/bypass. The elevations of these elements within the storage unit were used to represent the design profiles of these systems. Storage compartments were divided in to: evaporation storage (i.e., water stored in soil that is not freely drained); infiltration storage (i.e., water stored below the lowest outlet that can either infiltrate or evapotranspirate only); and freely drained storage (i.e., water that can drain through the underdrains of the system at a rate controlled by the media hydraulic conductivity).

Sizing criteria for the conventional biofiltration system was based on the runoff from the 85th percentile, 24-hour storm depth (1.0 inches for LAX). For each scenario, this depth was applied to the catchment area to compute an estimated runoff volume. Storage profiles for the conventional biofiltration system were established to represent typical profiles for conventional biofiltration, consistent with what is required by Attachment H of the MS4 Permit, which are presented in Appendix A of this report. The storage profiles included equivalent storage volumes provided in the ponding depth, media depth (divided between ET storage and freely drained storage), gravel layer, and placement of the underdrain system specific to the site conditions. Based on the equivalent storage depth in these profiles and the design storm runoff volume, the required footprints were calculated. For gravel, a porosity of 0.4 in/in was assumed. For media, a porosity of 0.4 in/in was assumed, divided as 0.15 in/in soil suction storage (i.e. ET storage) and 0.25 in/in freely drained storage. The profiles used for this analysis and the typical footprints are presented in Table B.6.

For estimating long-term volume reduction and baseline capture efficiency, the entire pore volume was assumed to be immediately available. However, because water takes time to travel through the soil column, it is possible for a biofiltration BMP to overflow before the entire soil poor volume is utilized. Based on analysis of flow monitoring data, Davis et al. (2011) found that the volume immediately available within a storm is better represented by the bowl volume (surface ponding) and the freely drained pores within the root zone (approximately the top 1 foot of soil). To check whether this condition influenced long term capture efficiency, parallel model runs were conducted where the storage volume equaled the bowl volume plus freely drained pores in the soil root zone, and the drawdown time was adjusted for only this volume. The result was that this condition reduced capture efficiency by approximately 2 percent. This indicates that this condition controls performance relatively rarely but is not negligible.

Table B.6 Summary of Conventional Biofiltration Profiles

Infiltration Rate, in/hr	Retention Sump Depth (as gravel depth)[1], ft	Effective Water Storage in Retention Sump (ft)	Media Depth, ft	Effective Water Storage in Media[2], ft	Ponding Depth, ft	Total Effective Water Depth (ft)	Approximate Footprint Sizing Factor (Los Angeles)[3]
0.3	1.5	0.60	2	0.8	1.5	2.9	1.9%
0.15	0.75	0.30	2	0.8	1.5	2.6	2.1%
0.05	0.25	0.10	2	0.8	1.5	2.4	2.2%
0.01	0.05	0.02	2	0.8	1.5	2.32	2.3%
0	0	0.00	2	0.8	1.5	2.3	2.3%

1 Sump storage was determined based on the depth of water that would infiltrate in 24 hours based on guidance provided in Attachment H.

2 Media storage depth represented as 0.3 ft suction storage and 0.5 ft freely drained storage.

3 Expressed as BMP footprint as percent of tributary area.

BioPod

BioPod primarily operates as a flow-based BMP, however it has a small amount of storage in soil pores and headspace that provides some flow equalization. Units were modeled using a storage unit with an overflow weir and an underflow outlet with a simplified head-dependent rating curve.

Calculations were conducted to develop the model representation for a 4’ x 6.5’ base unit with internal bypass, which has a media footprint of 23 ft^2.

The storage unit attributes were developed based on a unit profile (bottom to top) consisting of a 6-inch gravel subdrain containing a 4-inch perforated pipe, 18 inches of media, 2 inches of mulch, and 6 inches of ponding. It was assumed that the media, gravel, and mulch all had a porosity of 0.4 in/in, and that the treated discharge rate in the base unit was controlled by a 1.5-inch diameter orifice cap, with the orifice located at the invert of the perforated subdrain. The media saturated hydraulic conductivity is approximately 400 in/h. This is controlled to a maximum filtration rate of approximately 154 in/h (1.6 gpm/ft^2) by the outlet control orifice cap. The calculated treated discharge rate for the base unit was scaled to other BioPod sizing increments using a scaling factor.

The discharge rate was calculated based on an orifice equation with adjustments for head loss through the media. An iterative calculation was used to determine the appropriate discharge rate for the base unit using the orifice equation (Equation B.2), with a head loss adjustment based on Darcy’s Law (Equation B.3):

$$Q = C_d A \sqrt{2gh} \qquad \text{(B.2)}$$

Where,

C_d = 0.62 for a sharp opening

A = area of orifice in $ft^2 = pi*r^2$ (The base unit has an orifice diameter of 1.5 inches, corresponding to an area of 0.012 ft^2)
g = acceleration due to gravity (32.2 ft/s^2)
h = head on orifice centerline minus head loss through the media (ft)

And head loss through the media was calculated as:

$$\Delta h = \frac{q * \Delta l}{K} \tag{B.3}$$

Where,
q = effective discharge rate (in/h) (head dependent)
K = hydraulic conductivity of the media (in/h) (400 in/h)
h = hydraulic head
l = length of travel (depth of media, ft) (20 inches)

This calculation was performed to determine the discharge rate at two water levels: fully saturated media with full ponding (6”), and fully saturated media with no ponding. The discharge rate between these points was assumed to follow a linear function. The resulting stage-discharge relationships for the base 4’ x 6.5’ unit are shown in Table B.7.

Table B.7 Head-Dependent Discharge Rates for 4’ x 6.5’ BioPod Unit with Internal Bypass

Condition	Effective Head (ft)	q (in/h)	Q (cfs)
Full ponding, saturated media	1.8	154	0.082
No ponding, saturated media	1.3	131	0.070

Next, twenty increments of design intensities ranging from 0.02 inches/hour up to 1.0 inches/hour were established to represent a range of potential BioPod sizing criteria to achieve equivalency. For each scenario, the design intensity was applied to the catchment area and imperviousness to calculate the runoff flowrate using the Rational Method Equation (Equation B.4).

$$Q = CiA \tag{B.4}$$

Where,

Q = flow rate (ft^3/s)
C = runoff coefficient (0.90)
i = rainfall intensity (ft/s)
A = catchment area (43,560 ft^2, corresponding to 1 acre)

The necessary BioPod treatment area corresponding to each rainfall design intensity was then calculated using the TAPE-approved flow rate of 1.6 gal/min*ft^2.

A scaling factor was calculated by dividing the treatment surface area of the design unit by the treatment surface area of the base unit. Finally, the head-dependent discharge rates for the design unit were calculated by multiplying each of the two head-dependent discharge rates calculated for the base unit by the design unit scaling factor.

For example, if the rainfall intensity increment resulted in a design flowrate of 0.30 cfs (142 gpm), then the base unit would have a media surface area of 89 ft^2 (142 gpm / 1.6 gpm/ft^2). Because the base unit has a media surface area of 23 ft^2, the scaling factor would be 3.87 (89 ft ^{2} / 23 ft^2). This scaling factor would then be applied to the discharge rates computed for the base unit, resulting in a treated discharge rate of 0.30 cfs (3.87 * 0.082 cfs) at full ponding depth, and 0.26 cfs (3.87 * 0.070 cfs) when the media is fully saturated, but there is no ponding.

Supplemental Infiltration Unit

Supplemental infiltration was modeled as a storage unit with a pervious underlying soil and an outlet. The infiltration unit was sized based on a percentage of the runoff volume from the 85th percentile, 24-hour depth. Every combination of ten sizes of basin (5%-50% of the SWQDv in 5% increments) and four infiltration rates (0.01, 0.05, 0.15, and 0.30 in/hr) were modeled. The depth of the unit was assumed to be 2 feet.

APPENDIX C – DATASETS AND ANALYSIS METHODS FOR POLLUTANT TREATMENT EVALUATION

Data Development and Analysis Framework

BMP performance is a function of BMP type, BMP design parameters, influent water quality characteristics, and other factors. As part of the BioPod equivalency analysis it was necessary to develop a statistical description of BMP performance that accounted for the difference between conventional biofiltration and BioPod, and for the influence of land use runoff quality (i.e., BMP influent quality) on expected BMP performance. The data development and analysis framework used for this project included four steps:

1) Compile and review data from monitoring studies of conventional biofiltration systems; then screen these studies to identify studies that are reasonably representative of conventional biofiltration designs that would meet the MS4 Permit requirements, focusing on factors that would influence treated effluent quality.
2) Compile and review monitoring data from full-scale BioPod monitoring studies.
3) Apply a common statistical analysis framework to analyze the data from both datasets.
4) Determine representative land use runoff quality.
5) Based on results from step 3 and 4, estimate the effluent quality expected for conventional biofiltration compared to BioPod for each pollutant for a range of land use-based influent quality.

Compilation and Screening of Conventional Biofiltration Studies

Note, this analysis is equivalent to the analysis conducted as part of evaluating Filterra equivalency (Geosyntec, 2015). Based on review of the International BMP Database, limited new information about conventional biofiltration performance was available at the time of publication. It is possible that 2 to 3 additional studies are available that would have similar design parameters to Attachment H of the MS4 Permit. New data from two to three new studies would be unlikely to influence findings from the 21 studies that were used in the 2015 Filterra equivalency analysis, therefore this previous assessment of baseline performance was not revised.

As of 2015, the International Stormwater BMP Database (www.bmpdatabase.org) included storm event monitoring data from 28 peer-reviewed studies of bioretention BMPs with underdrains. These data were used as the primary source for characterizing the treatment performance of conventional biofiltration BMPs in this study. In addition to the 28 studies from the International BMP Database, four peer-reviewed research studies (Davis 2007; Li and Davis 2009; David et al., 2011; Gilbreath et al. 2012) not contained in the International BMP Database were added to the sample pool for analysis. Two of these studies were conducted in the San Francisco Bay area, which has biofiltration design standards and media specifications nearly identical to Attachment H of the Los Angeles MS4 Permit. The two other additional studies were included due to their similarity to Attachment H design criteria and the rigor of their analytical methods.

Screening Process for Developing Conventional Biofiltration Sample Pool

In general, the bioretention BMPs in the International BMP Database are representative of the range of designs that could meet the MS4 Permit Attachment H requirements. Most of the bioretention studies in the BMP Database were completed between 2000 and 2015, and have typically been designed, constructed, and/or monitored under the supervision of experienced researchers. Many of these systems have been designed with BMP profiles (i.e., ponding depth, media depth), media filtration rates, and media composition that are similar to the criteria in Attachment H. However, where design attributes indicated that performance would be expected to be poorer than Attachment H designs and/or representativeness could not be evaluated, these studies were screened out of the analysis pool for this study. Systems that were expected to achieve similar or better performance than a typical BMP designed per Attachment H were kept in the pool; this is a conservative approach when evaluating BioPod equivalency because it tends to establish a higher baseline for comparison than if these BMPs were excluded.

Screening criteria were developed based on professional judgment as informed by review of literature and BMP performance studies. Our understanding of the influence of design parameters on bioretention performance was informed by studies in the BMP Database (see various summary reports at www.bmpdatabase.org), a recent evaluation by Roseen and Stone (2013), and review of recent bioretention media research in Washington State. A summary of the relevant findings is provided in the paragraphs below.

Roseen and Stone (2013) conducted an evaluation of biofiltration performance to determine how design criteria and media composition influence performance. As part of their research, they compiled site, design, and performance data for 80 field bioretention systems and 114 lab columns/mesocosms. Data from the International BMP Database were included in this pool as well as other research studies. Performance data were compiled as study summaries (e.g., study median influent, effluent, and removal efficiency). Roseen and Stone then utilized design information to categorize systems into groups based on common combinations of factors. They then conducted a statistical evaluation of how performance was influenced by design factors such as presence/absence of mulch layers, use of compost in media, infiltration rate of media, ratio of tributary to biofiltration area, presence/absence of pretreatment, presence/absence of internal storage layers, etc. Roseen and Stone found that the presence of compost in mixes strongly influences the variability in performance and potential export of pollutants, including phosphorus, nitrogen, and copper. Systems without compost and/or with a high fraction of sand tended to provide the most consistent and best performance for these pollutants. Systems with an internal water storage zone tended to perform better for nutrients than systems without an internal water storage zone. Finally, they found that media flowrate and depth of media bed tended to have an influence on performance. Beyond these findings, the influence of other parameters was less conclusive.

Recent bioretention studies, many in Washington State (Herrera 2014b, 2015a, 2015b), have identified the potential severity of pollutant export of nitrogen, phosphorus, and copper from conventional biofiltration systems and have evaluated the potential sources of these issues. This research also found that some sand products can also contain elevated levels of phosphorus and copper. These studies are relevant because the standard biofiltration media specifications for Western Washington are very similar to Attachment H, calling for 60 to 65 percent sand and 35 to 40 percent compost. It should also be noted that the compost certification criteria in Washington State (Washington Department of Ecology, 2014) allow for half as much metals content as allowed in the Attachment H specification, therefore should theoretically have less potential for export of metals than compost meeting the Attachment H specification.

Based on these literature findings and best professional judgment, the following criteria were applied as part of screening bioretention studies:

- Systems with media filtration rates substantially higher than 12 inches per hour were excluded – while higher rate media has been found to provide good performance in some cases, the general trends observed by Roseen and Stone (2013) indicated a decline in performance for some parameters with increased filtration rates.
- Systems with sizing factors (BMP area as fraction of tributary area) substantially smaller than the 3 to 5 percent (20:1 to 30:1 ratio of tributary area to BMP area) were excluded – this parameter is related to media filtration rate and is an indicator of the degree of hydraulic loading.
- Systems that were observed to have very infrequent underdrain discharge (i.e., mostly infiltration) were excluded – for these designs, the effluent that was sampled for water quality was likely not representative of the entire storm event.
- Systems with internal water storage zones were kept in the pool of data; these systems are believed to provide better control of nutrients than systems without internal water storage; Attachment H does not require internal water storage to be provided.
- Based on the findings of Roseen and Stone (2013) as well as recent research in Washington State, mixes with less compost and a higher fraction of sand than the Attachment H specification were kept in the sample pool because they are believed to provide more reliable performance and less potential for export of pollutants on average than a 70-30 sand/compost mix.
- Systems that contained media with experimental components were excluded.
- Finally, systems were excluded if there was not enough design information reported to be able to evaluate representativeness, and/or any other factors were noted by the original study researchers that were believed to contribute to poorer performance than average. For example, some studies were noted as underperforming studies due to construction issues, premature clogging, etc.

Overall, the screening that was applied is believed to improve the representativeness of the sample pool and generally increase the average performance of the sample pool compared to the entire pool of studies contained in the International BMP Database. As discussed above, establishing a higher baseline level of performance for conventional biofiltration is conservative in the context of this evaluation.

Screening Results

Table C.2 summarizes the number of data points for each constituent before and after applying screening to remove unrepresentative studies.

Table C.2. Summary of Data Points by Parameter for Conventional Biofiltration BMPs

Constituent	Number of Screened Data Pairs	Number of Unscreened Data Pairs
Total Suspended Solids	234	354
Total Phosphorus	242	384
Total Copper	190	216
Total Zinc	200	252

Inventory of Bioretention Studies and Screening Results/Rationales

Table C.4 (located at the end of this Appendix) provides an inventory of studies of bioretention with underdrains from the International BMP Database, screening results, and brief rationales for screening.

BioPod Monitoring Study

BioPod performance was assessed using data from a monitoring study performed from November 2016 through May 2017. The data from this study mostly covered the range of influent pollutant concentrations for the representative Los Angeles land uses, though the lowest influent total copper concentration in this study (14 µg/L) was slightly higher than the total copper concentration for Los Angeles residential land uses. The monitoring study was based on a full-scale field application, was conducted by a third-party entity (Herrera, 2018), and employed flow-weighted influent and effluent sampling of a representatively sized BioPod system under actual storm events.

This monitoring study followed the Washington State Technology Acceptance Protocol-Ecology (TAPE) certification requirements. Storm event sampling of a BioPod system was conducted at the Ship Canal Test Facility (SCTF) in Seattle, WA, located in the Interstate 5 right-of-way beneath the north side of the Lake Union Ship Canal Bridge. The sample results reported by the original researchers were used in this evaluation. A total of 17 samples were collected and analyzed for each of TSS, total phosphorus, total copper, and total zinc removal.

Data Analysis Method

The most common ways to characterize BMP performance include (1) removal efficiency (percent removal) in various forms, and (2) effluent probability. In general, the effluent probability approach is recommended for evaluating BMP performance and applying BMP performance to pollutant load models (Geosyntec and Wright Water, 2009). This method involves conducting a statistical comparison of influent and effluent quality to determine if effluent is significantly different from influent. If effluent is significantly different from influent, then the effluent quality is characterized by a statistical distribution developed from all effluent data points. Probability plots are prepared indicating the probability that a certain effluent quality is achieved.

However, to isolate differences in performance between two BMP types, the effluent probability method requires the assumption that the influent quality was similar between the studies of the two BMP types being compared. This assumption is generally reliable for categorical analysis of BMPs in the International BMP Database because of the large number of studies in most categories in the Database. However, when comparing BMP types with a relatively limited number of study sites (such as the BioPod dataset), this assumption may not be reliable.

To address these challenges and help ensure a valid comparison between conventional biofiltration and BioPod, a moving bootstrap method (Leisenring et al., 2009) was applied to both datasets. This method characterizes influent-effluent relationships such that the BMPs compared do not need to have been studied under conditions with similar influent quality. In this approach, all data pairs are used to form the total sample population. Then for each increment of influent quality, a subsample of the overall population is formed including only those data pairs that lie within a certain span of the selected influent quality. Applying bootstrap principles (Singh and Xie, 2008), the median or mean and the confidence interval around the median or mean is computed. Then a new increment of influent quality is selected, and the process is repeated with a new subsample population until a statistical description of effluent quality has been developed for each increment of influent quality over the range of the data. A minimum span of 5 was set for calculation of confidence intervals.

Resulting tables and plots from this analysis are presented in Appendix D.

Land Use Stormwater Quality Inputs and Assumptions

Representative stormwater runoff concentrations for the land use condition used in this analysis were developed based on the land use stormwater quality monitoring data reported in the Los Angeles County 1994-2000 Integrated Receiving Water Impacts Report and Los Angeles County 2000-2001 Stormwater Monitoring Report (LA County 2000; LA County 2001). The median and mean runoff quality values from this dataset were used as representative influent water quality conditions for evaluating BMP performance. These concentrations represent only one land use monitoring station in one geographic area; actual conditions for a given drainage area in a given region are anticipated to vary. Beyond the range of water quality presented in this table, this analysis did not attempt to characterize the uncertainty/variability in runoff water quality. This simplification is considered appropriate for evaluating equivalency in BMP performance.

Land use runoff quality is reported in Appendix D.

Table C.4. Inventory of conventional biofiltration studies from the International BMP Database and screening rationale

Source	Site Name	Sponsoring Entity	State	City	Selected?	Selection/Rejection Reasons
Int. BMP Database	Rocky Mount Grassed Bioretention Cell 1	North Carolina State	NC	Rocky Mount	Yes	Aligns with Att. H; Has internal water storage zone and underdrain
Int. BMP Database	Rocky Mount Mulch/Shrub Bioretention Cell 1	North Carolina State	NC	Rocky Mount	Yes	Aligns with Att. H; Has internal water storage zone and underdrain
Int. BMP Database	CHS_BioFilter	The Thomas Jefferson Planning District Commission	VA	Charlottesville	Yes	Aligns with Att. H; Has internal water storage zone, underdrain, and mulch layer (0.25 feet)
Int. BMP Database	Parks & Forestry Bioretention	City of Overland Park	KS	Overland Park	Yes	Aligns with Att. H; Has internal water storage zone, underdrain, and mulch layer
Int. BMP Database	Bioretention 6	Johnson County	KS	Shawnee	Yes	Aligns with Att. H; Has internal water storage zone and underdrain
Int. BMP Database	G2	North Carolina State	NC	Greensboro	Yes	Aligns with Att. H; Has underdrain, and mulch layer (7-10 cm)
Int. BMP Database	G1	North Carolina State	NC	Greensboro	Yes	Aligns with Att. H; Has underdrain, and mulch layer (7-10 cm)
Int. BMP Database	L1	North Carolina State	NC	Louisburg	Yes	Aligns with Att. H; Appropriate loading ratio
Int. BMP Database	Bioretention 3B	Johnson County	KS	Shawnee	Yes	Aligns with Att. H; Has internal water storage zone and underdrain
Int. BMP Database	Parking Lot Bioretention Cell	City of Fort Collins	CO	Fort Collins	Yes	Aligns with Att. H; Has internal water storage zone and mulch layer
Int. BMP Database	Bioretention Cells	Johnson County SMP	KS	Overland Park	Yes	Aligns with Att. H; Has internal water storage zone, underdrain, and mulch layer
Int. BMP Database	Bioretention Cell	Johnson County SMP	KS	Overland Park	Yes	Aligns with Att. H; Has internal water storage zone and underdrain

Source	Site Name	Sponsoring Entity	State	City	Selected?	Selection/Rejection Reasons
Int. BMP Database	Bioretention System (D1)	UNH/Cooperative Institute for Coastal and Estuarine Environmental Technology	NH	Durham	Yes	Aligns with Att. H; Has pretreatment, internal water storage zone, underdrain, and mulch layer
Int. BMP Database	UDFCD Rain Garden	Urban Drainage and Flood Control District	CO	Lakewood	Yes	Aligns with Att. H; Has internal water storage zone, underdrain, and compost layer
Int. BMP Database	Hal Marshall Bioretention Cell	City of Charlotte, North Carolina	NC	Charlotte	Yes	Aligns with Att. H; Has underdrain, and mulch layer
Int. BMP Database	Rocky Mount Grassed Bioretention Cell 2	The Cooperative Institute for Coastal and Estuarine Environmental Technology	NC	Rocky Mountain	Yes	Aligns with Att. H; Has internal water storage zone and underdrain
Li and Davis (2009)	Bioretention Cell 1	Prince George's County Department of Environmental Resources/ U of MD	MD	College Park	Yes	Aligns with Att. H
Li and Davis (2009)	Bioretention Cell 2	Prince George's County Department of Environmental Resources/U of MD	MD	Silver Spring	Yes	Aligns with Att. H
Davis (2007)	Bioretention Cell 1	Prince George's County Department of Environmental Resources/U of MD	MD	College Park	Yes	Aligns with Att. H
David et al. (2011)	Daly City Library Rain Gardens	San Francisco Estuary Institute	CA	Daly City	Yes	Aligns with Att. H
Gilbreath et al. (2012)	San Pablo Ave Green Streets	San Francisco Estuary Institute	CA	El Cerrito	Yes	Aligns with Att. H
Int. BMP Database	Bioretention Area	Virginia Department of Conservation and Recreation	VA	Charlottesville	No	Not enough design info provided
Int. BMP Database	Small Cell	North Carolina Department of Transportation	NC	Knightdale	No	Infiltration rate low; noted to be underperforming BMP by study researchers
Int. BMP Database	BRC_B	North Carolina State	NC	Nashville	No	Infiltration too low and undersized
Int. BMP Database	North cell	North Carolina State	NC	Raleigh	No	Media very different from Att. H
Int. BMP Database	WA Ecology Embankment at SR 167 MP 16.4	Washington State Dept. of Transportation	WA	Olympia	No	Linear design; lateral flow; not representative of typical biofiltration design

Source	Site Name	Sponsoring Entity	State	City	Selected?	Selection/Rejection Reasons
Int. BMP Database	Bioretention Cell	Delaware Department of Transportation	DE	Dover	No	Design is very different from Att. H
Int. BMP Database	East 44th St. Pond	City of Tacoma	WA	Tacoma	No	No design data
Int. BMP Database	Tree Filter	UNH/Cooperative Institute for Coastal and Estuarine Environmental Technology	NH	Durham	No	Design is very different from Att. H
Int. BMP Database	BRC_A	North Carolina State University	NC	Raleigh	No	Infiltration rate very low; noted to be a partially clogged/failing system
Int. BMP Database	Cub Run Bioretention	Fairfax County	VA	Fairfax	No	No design data provided
Int. BMP Database	South cell	North Carolina State University (BAE)	NC	Raleigh	No	Design is very different from Att. H
Int. BMP Database	R Street	City of Tacoma	WA	Tacoma	No	No design data provided

APPENDIX D – RESULTS OF POLLUTANT TREATMENT DATA ANALYSIS

The data analysis methods described in Appendix C were applied to the datasets described in Appendix C. The following pages present tabular and graphical results of this analysis.

Table D.1 compares the mean and median summary statistics and confidence intervals from the moving window bootstrap analysis between the conventional biofiltration datasets and the BioPod datasets. The screened dataset refers to the 20 studies described in Appendix C that were considered representative of MS4 Permit Attachment criteria. The unscreened dataset includes all bioretention studies available in the International BMP Database as of 2015. These datasets are described in Appendix C.

Figure D.1 shows plots of the data analysis results based on the median statistic. Figure D.2 shows plots of the data analysis results based on the mean statistic.

Table D.1 Summary Statistics of Moving Window Bootstrap Analysis – Conventional Biofiltration and BioPod

Median Statistics

Land Use	Pollutant	Units	Median Representative Runoff Quality	Traditional Biofiltration Effluent (Screened)			Traditional Biofiltration Effluent (Unscreened)			BioPod Effluent		
				Median	95th Percentile UCL on Median	Removal Efficiency	Median	95th Percentile UCL on Median	Removal Efficiency	Median	95th Percentile UCL on Median	Removal Efficiency
Commercial	TSS	mg/L	53	12	13.7	77%	11	12	79%	4.0	4.1	92%
	Total Phosphorus	mg/L	0.27	**0.46**	0.55	-70%	0.26	0.37	4%	0.043	0.051	84%
	Copper	µg/L	22	12	15	45%	12	14	45%	8.8	9.5	60%
	Zinc	µg/L	192	35	44	82%	36	40	81%	18.9	29	90%
High Density Single Family Residential	TSS	mg/L	61	12	15	80%	12	13	80%	4.0	4.1	93%
	Total Phosphorus	mg/L	0.32	**0.47**	0.55	-47%	0.28	0.43	13%	0.047	0.051	85%
	Copper	µg/L	11	5.3	5.9	52%	5.3	6.4	52%	5.1	5.1	54%
	Zinc	µg/L	66	20	27	70%	18	26	73%	13	13	81%
Light Industrial	TSS	mg/L	129	16	18	88%	16	18	88%	4.0	5.0	97%
	Total Phosphorus	mg/L	0.3	**0.47**	0.55	-57%	0.27	0.42	10%	0.046	0.051	85%
	Copper	µg/L	21	12	15	43%	12	13.85	43%	8.3	9.0	60%
	Zinc	µg/L	366	35	44	90%	36	40	90%	21	30	94%
Multi-family Residential	TSS	mg/L	24	10.8	12.5	55%	9.9	9.9	59%	4.0	4.0	83%
	Total Phosphorus	mg/L	0.14	**0.39**	0.45	-179%	**0.21**	0.25	-50%	0.035	0.044	75%
	Copper	µg/L	12	5.6	6.1	53%	5.6	6.6	53%	5.1	5.1	58%
	Zinc	µg/L	89	20	27	78%	18	26	80%	17	19.4	81%

Mean Statistics

Land Use	Pollutant	Units	Mean Representative Runoff Quality	Traditional Biofiltration Effluent (Screened)			Traditional Biofiltration Effluent (Unscreened)			BioPod Effluent		
				Mean	95th Percentile UCL on Mean	Removal Efficiency	Mean	95th Percentile UCL on Mean	Removal Efficiency	Mean	95th Percentile UCL on Mean	Removal Efficiency
Commercial	TSS	mg/L	66	28	49	58%	25	39	62%	5.00	8.65	92%
	Total Phosphorus	mg/L	0.39	**0.8**	1.3	-105%	**0.65**	1	-67%	0.05	0.05	88%
	Copper	µg/L	39	19	29	51%	16	24	59%	13.87	20.20	64%
	Zinc	µg/L	241	65	145	73%	59	108	76%	22.76	25.51	91%
High Density Single Family Residential	TSS	mg/L	95	28	49	71%	25	39	74%	6.14	12.17	94%
	Total Phosphorus	mg/L	0.39	**0.8**	1.3	-105%	**0.65**	1	-67%	0.05	0.05	88%
	Copper	µg/L	15	13	21	13%	13	19	13%	5.62	5.77	63%
	Zinc	µg/L	79	33	50	58%	32	46	59%	16.01	19.70	80%
Light Industrial	TSS	mg/L	240	46	105	81%	40	87	83%	8.66	13.51	96%
	Total Phosphorus	mg/L	0.41	**0.8**	1.3	-95%	**0.65**	1	-59%	0.05	0.05	89%
	Copper	µg/L	32	19	29	41%	16	24	50%	12.35	14.46	61%
	Zinc	µg/L	639	NA	NA	NA	59	108	91%	27.07	29.21	96%
Multi-family Residential	TSS	mg/L	46	18	28	61%	18	27	61%	5.00	6.30	89%
	Total Phosphorus	mg/L	0.2	**0.8**	1.3	-300%	**0.6**	1	-200%	0.04	0.05	80%
	Copper	µg/L	12	10	15	17%	9	14	25%	5.09	5.09	58%
	Zinc	µg/L	146	45	90	69%	32	46	78%	22.76	25.51	84%

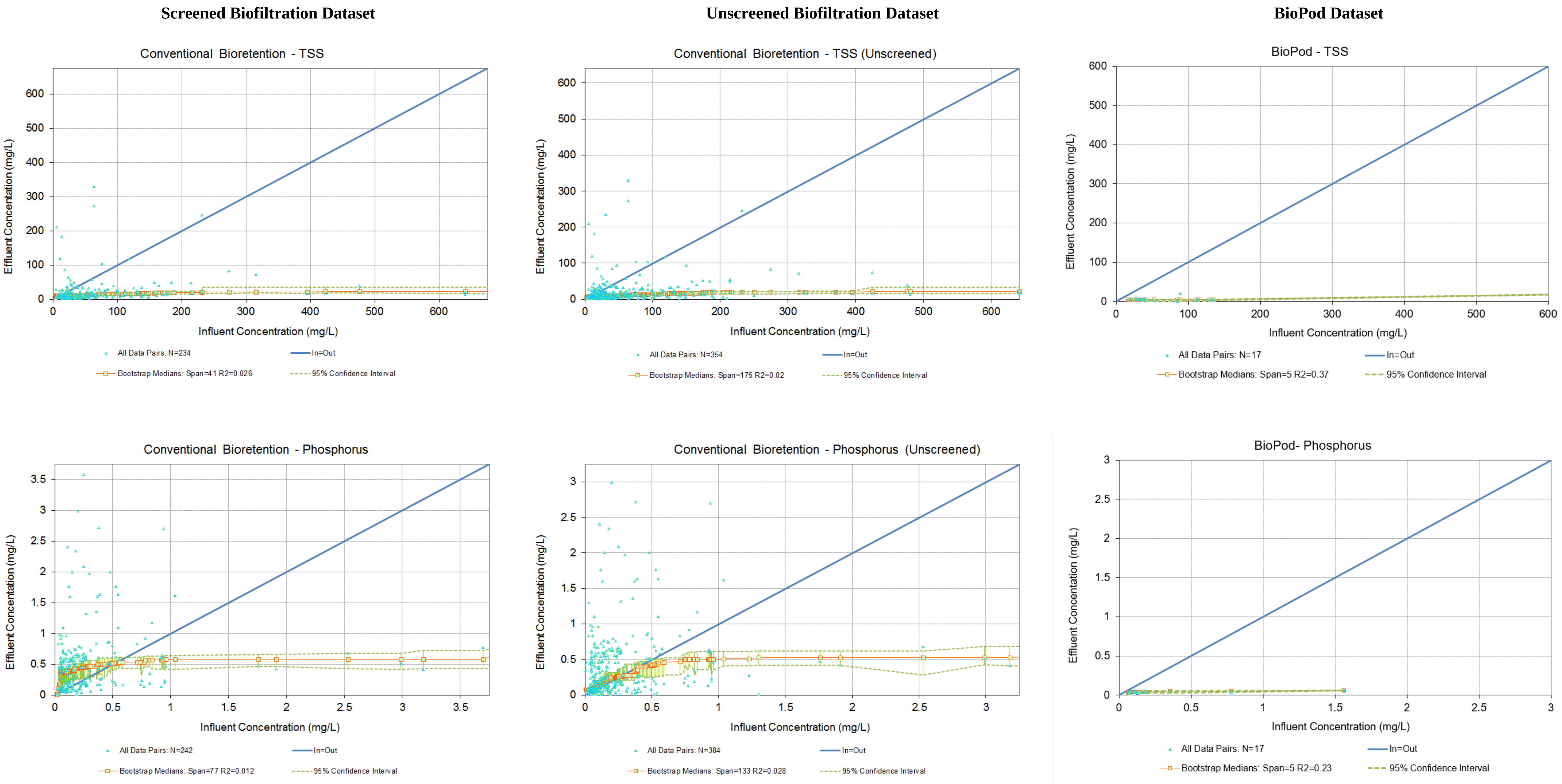
NA: Average values could not be computed because the land use average influent was outside the range of influent observed in monitoring studies.

Red bold indicates median or mean effluent concentrations are greater than influent concentration. This is indicative of the potential for pollutant export.

Blue indicates upper confidence interval of effluent concentration is greater than the influent concentration. This is not a conclusive indicator but is provided for reference.

[1] Minimum tested influent concentration (14 µg/L for copper) was greater than representative runoff quality. In these cases, the bootstrap-predicted effluent associated with the minimum tested influent concentration was used.

Figure D.1 Moving Window Bootstrap Plots of Medians



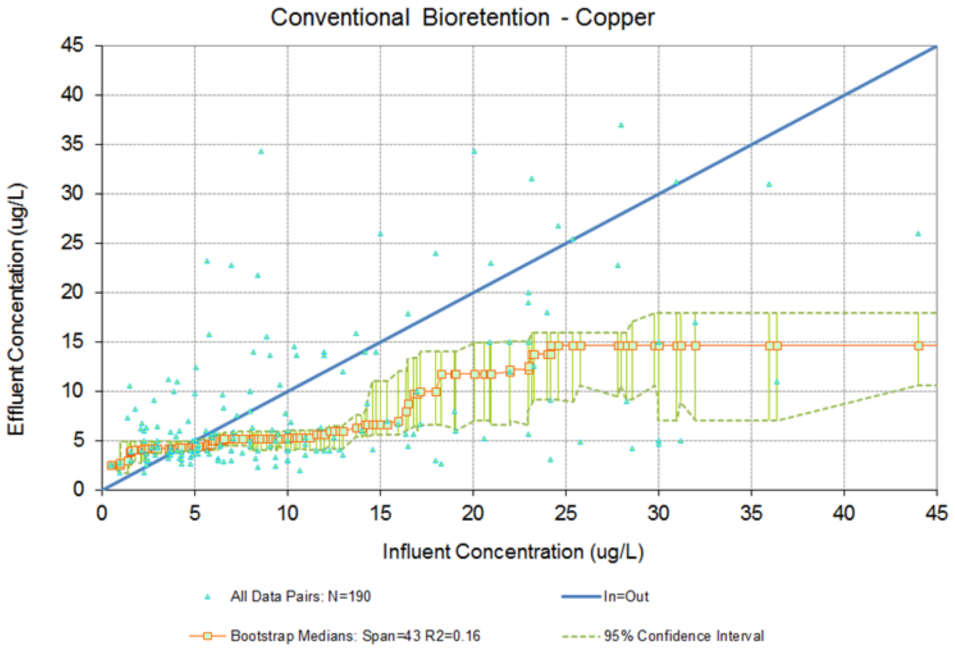
Screened Biofiltration Dataset

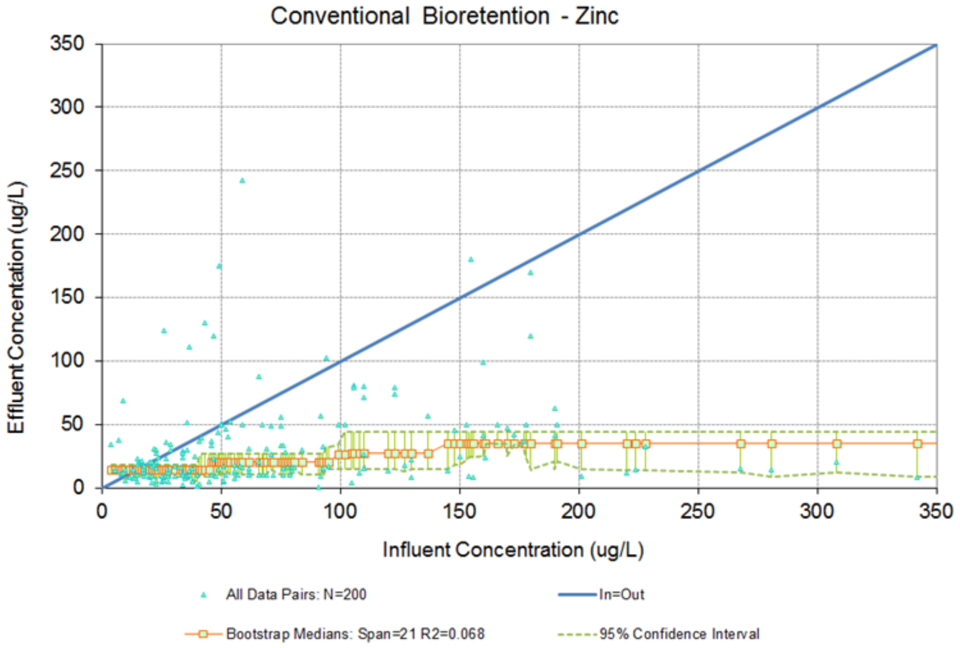
Unscreened Biofiltration Dataset

BioPod Dataset

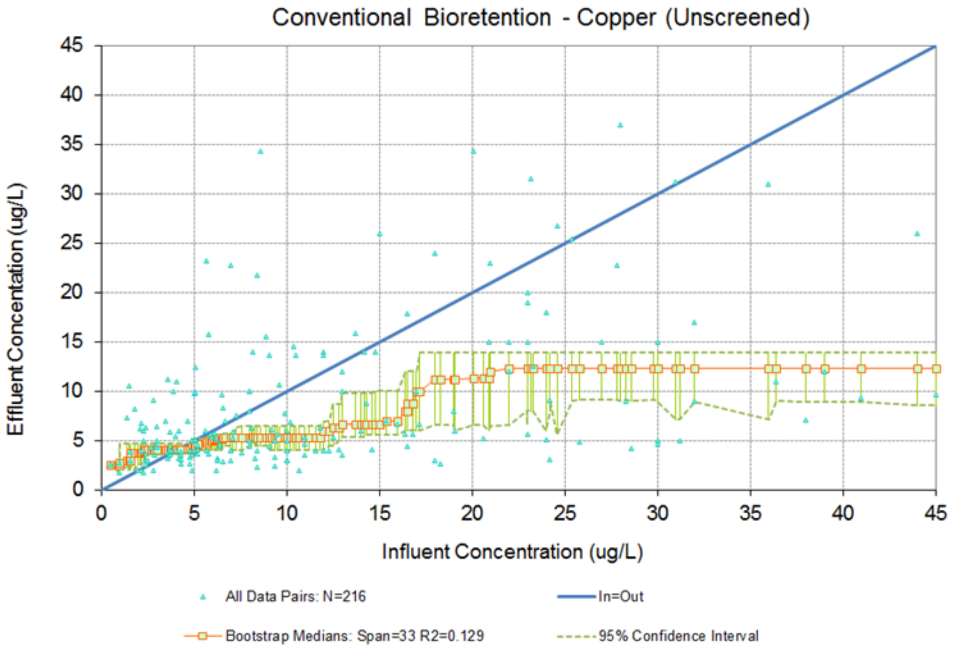
Figure D.1 Moving Window Plots of Medians (Cont.)

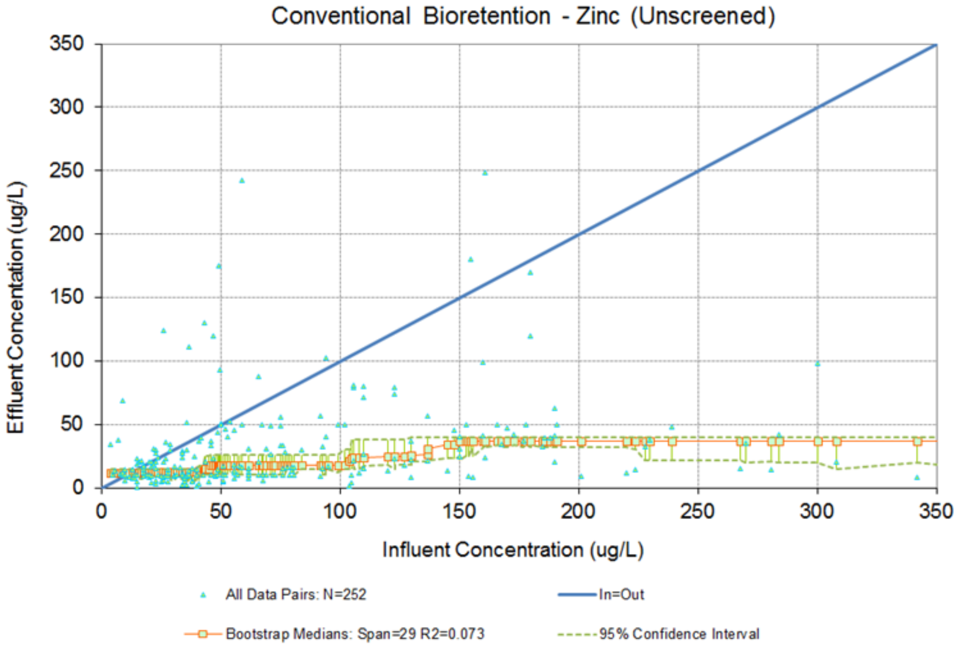
Screened Biofiltration Dataset



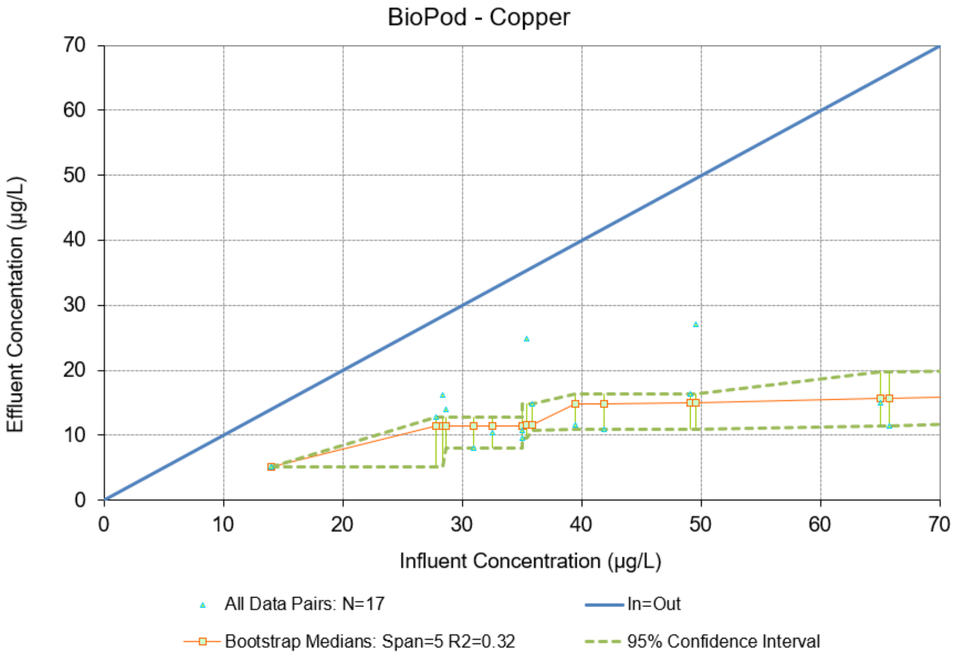


Unscreened Biofiltration Dataset





BioPod Dataset



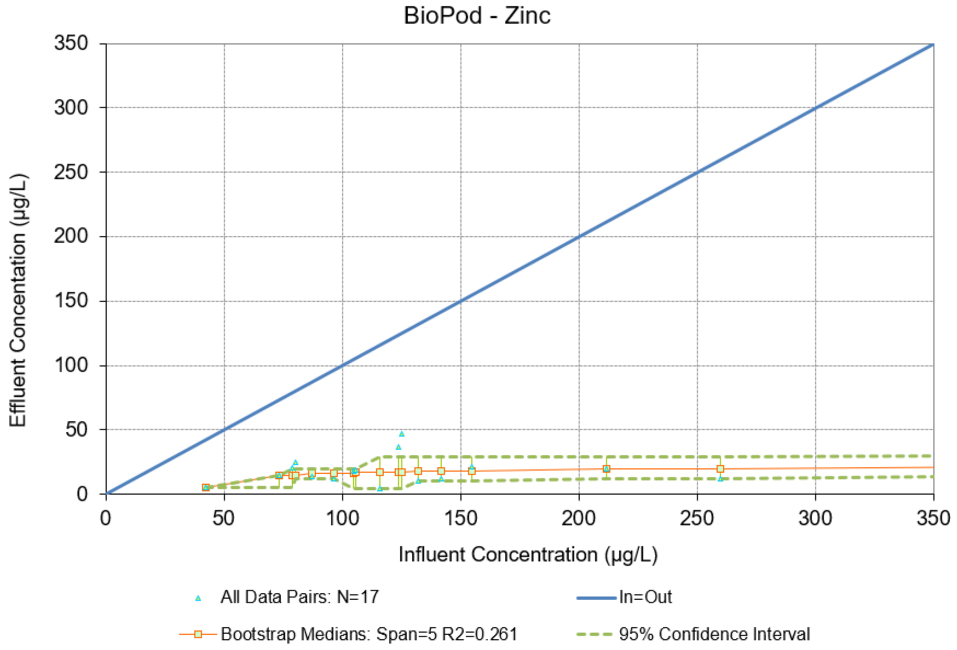
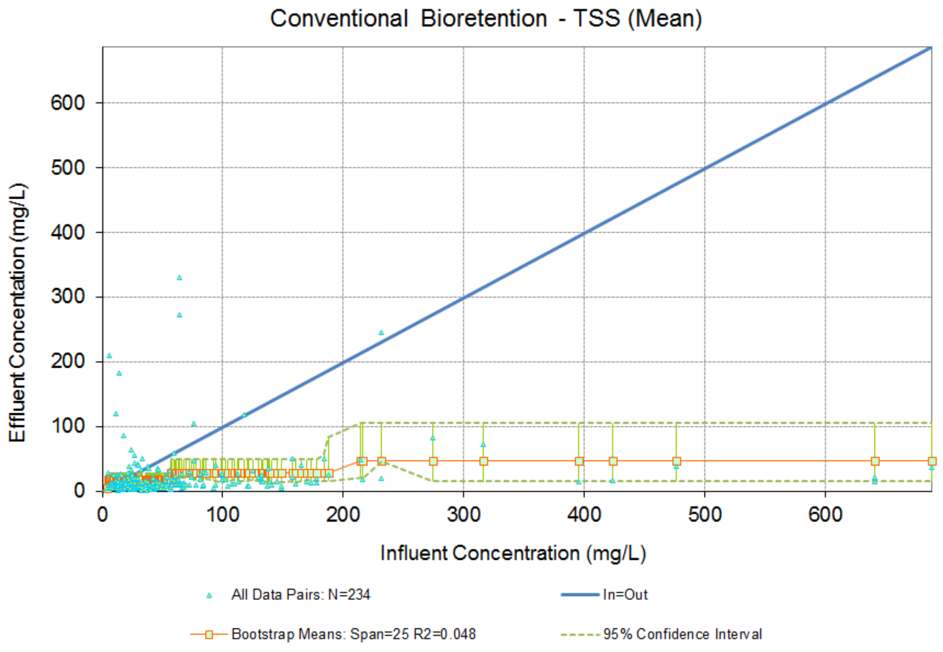
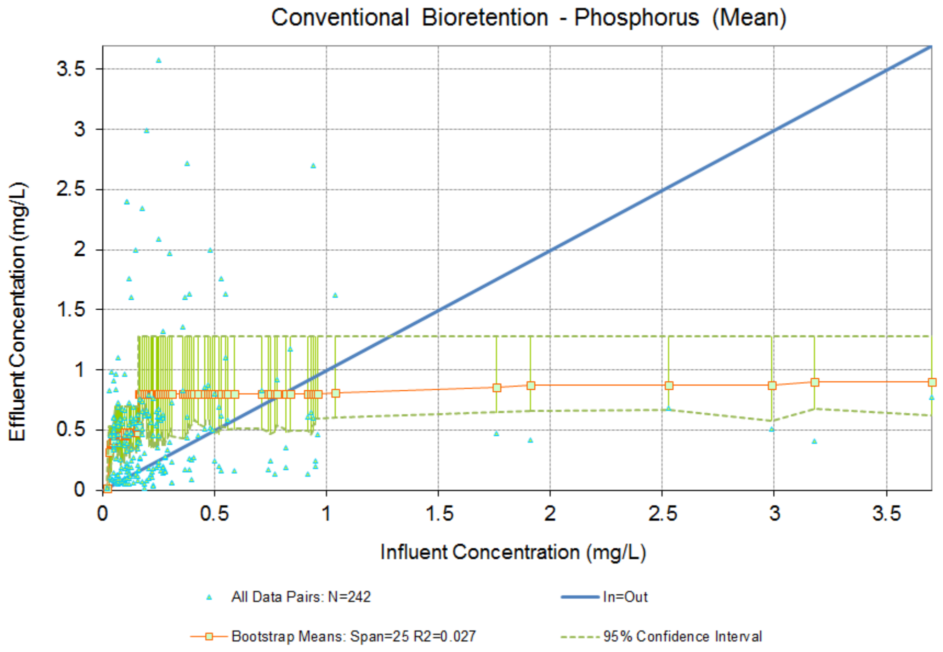


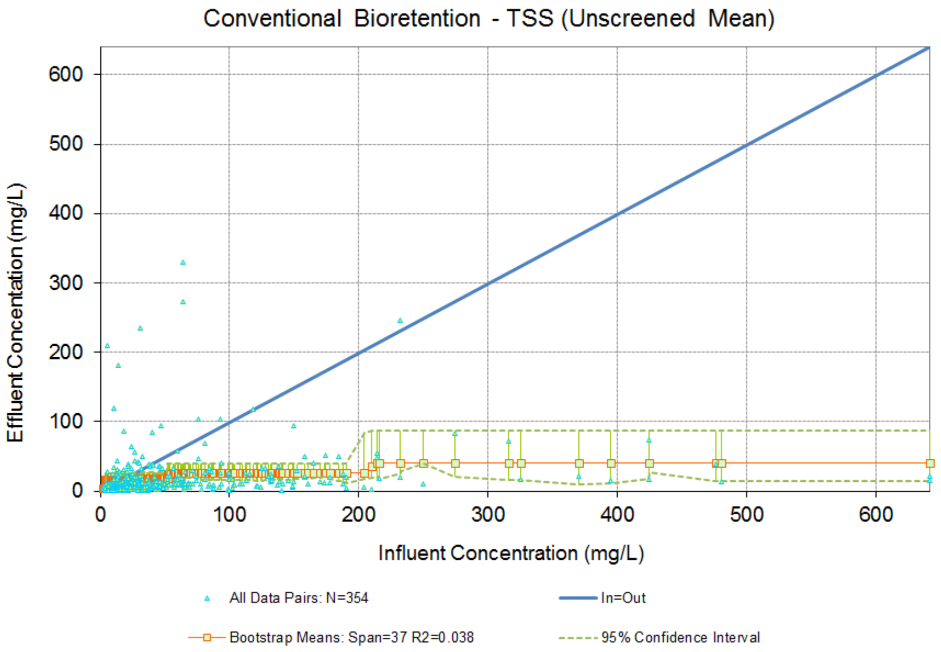
Figure D.2 Moving Window Bootstrap Plots of Means

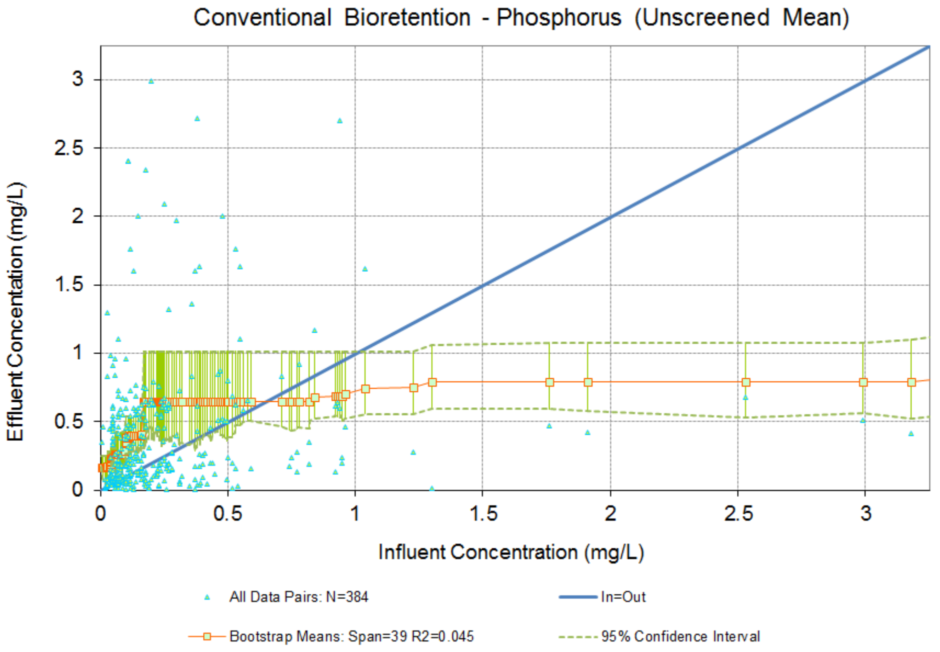
Screened Biofiltration Dataset



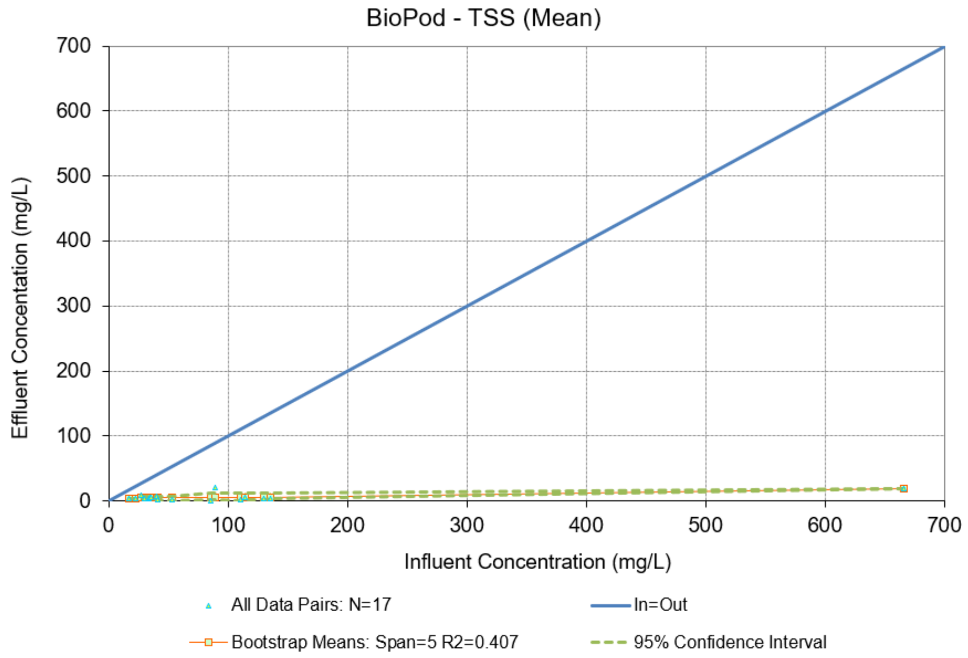


Unscreened Biofiltration Dataset





BioPod Dataset



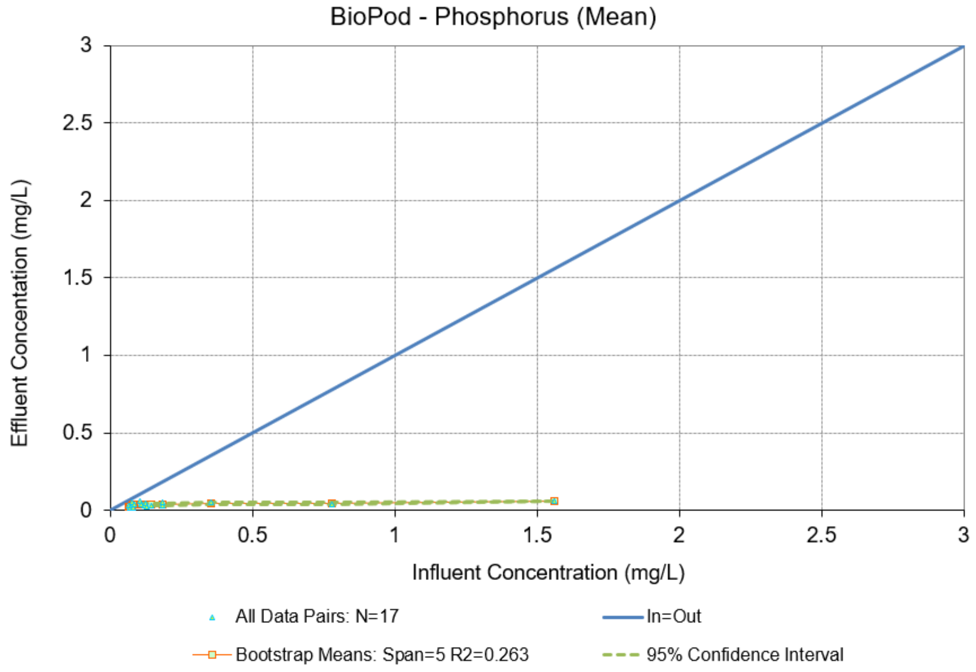
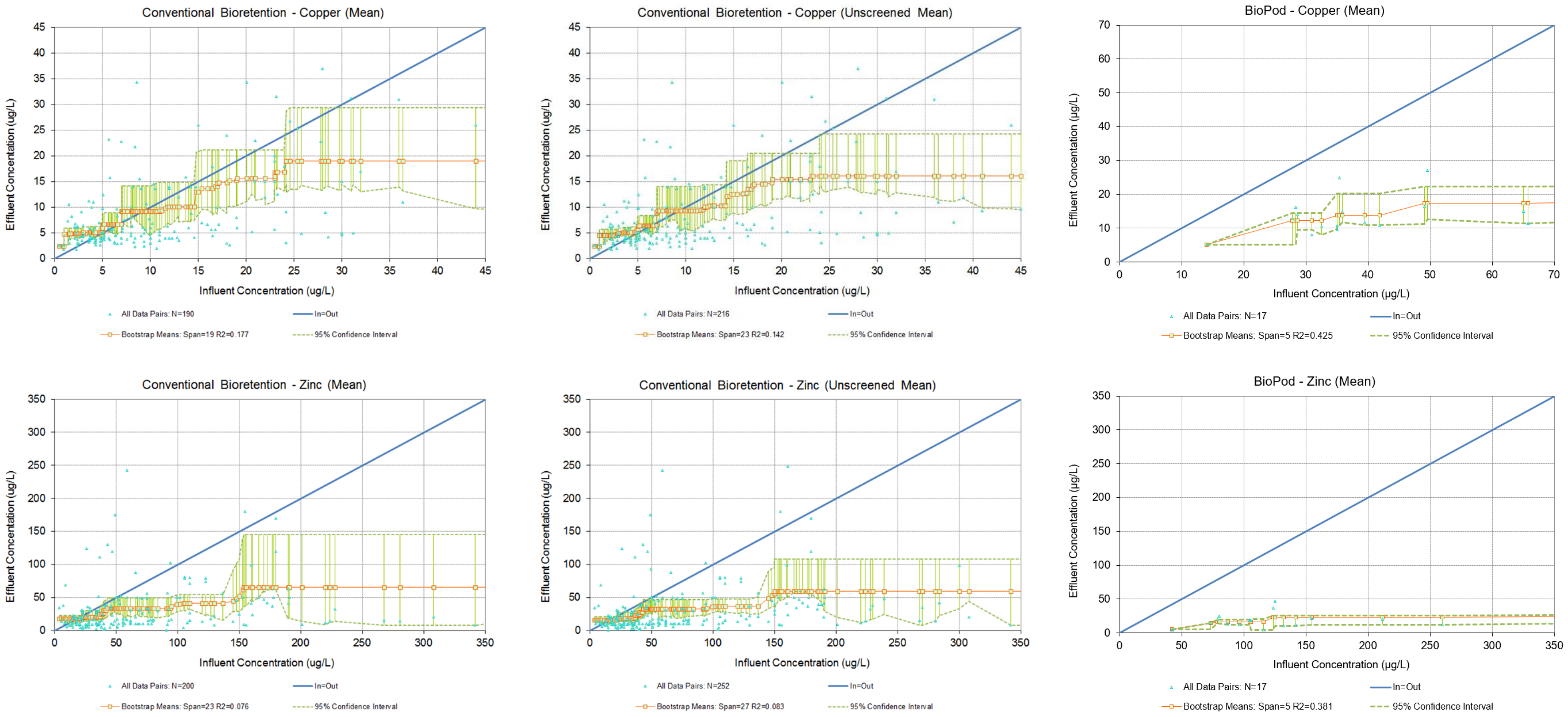


Figure D.2 Moving Window Plots of Means (Cont.)



Screened Biofiltration Dataset

Unscreened Biofiltration Dataset

BioPod Dataset