

**INTERIM TECHNICAL EVALUATION REPORT (TER)
FIELD EVALUATION OF THE
FOCALPOINT HIGH PERFORMANCE MODULAR
BIOFILTRATION SYSTEM**

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EXECUTIVE SUMMARY

Summary

On October 28, 2014, ACF Environmental of Richmond, Virginia authorized Civil & Environmental Consultants, Inc. (CEC) to perform a full-scale field test to assess the water quality performance of the FocalPoint High Performance Modular Biofiltration System (HPMBS). This study was conducted at the warehouse facility owned by Civil & Environmental Consultants, Inc. (CEC) on Campbells Run Road in Pittsburgh, Pennsylvania.

CEC provides consulting services specializing in Best Management Practices (BMP) evaluation and product research and development. CEC was contracted by ACF Environmental to assist with the Quality Assurance Project Plan (QAPP) development, based on Technology Assessment Protocol Evaluation (TAPE), and execution of this study. The project focuses on the design, execution, and review of the field study to assess the hydraulic and pollutant-removal performance of the FocalPoint system.

Technology

The FocalPoint HPMBS is a specialized system utilizing biofiltration media for the treatment of stormwater runoff from impervious surfaces. The FocalPoint system was developed by Convergent Water Technologies of Houston, Texas. The modular treatment system, containing biologically active biofiltration media, is used as a complete, integrated system with a demanding specification that insures functionality performance and maintainability. With rigorous quality assurance standards and post construction in-situ infiltration verification, FocalPoint HPMBS guarantees performance.

The installation of the FocalPoint system and initiation of data collection was completed in July 2015. The construction and installation of the FocalPoint was performed by a third party contractor, Exact Storm of Richmond, VA. The data collection goal for the project is to retrieve

water quality samples for a minimum of 20 qualifying storm events, with completion of the data collection phase by the spring of 2016.

Rainfall

For the study period to date (164 Julian Days) there were 57 of days with measurable precipitation and a total rainfall depth of 18.24 inches observed at the site.

Water Quality Performance

The FocalPoint system in this TAPE level field study was sized to treat a 1-inch runoff volume (WQv) prior to bypass from 0.25-acre impervious parking lot. The resulting filter bed area to drainage area ratio is 0.40% and the ponding volume above the system is approximately 20% of the WQv.

Of these rainfall events, twelve (12) events were classified as qualifying storm events, as defined by the QAPP (i.e., qualifying storm event of 0.15-inch or greater rainfall total). From these 12 storm events, there has been an average 31% reduction in runoff volume through the FocalPoint system for the given storms monitored to date.

Stormwater runoff bypassed during 1 of event, consequently the system treated > 95% of the total runoff generated at the site.

Water quality performance is summarized in the table below (Table 1ES). A narrative description of the pollutant removal efficiencies is included herein:

**TABLE 1ES.
SUMMARY OF REMOVAL EFFICIENCIES
FOR PRIMARY CONSTITUENTS OF CONCERN –
SUSPENDED SEDIMENT (TSS), TOTAL PHOSPHORUS (TP),
TOTAL NITROGEN (TN)**

Study Protocol	Constituents	% Removal Concentration Based, for the event mean ^A	% Removal Mass Based, for the event mean	Bootstrap 95% CI for mean [LCL, UCL] Concentration Based	Bootstrap 95% CI for mean [LCL, UCL] Mass Based	% Removal, Lab Based Column Study ^B
TAPE	Suspended Sediment (TSS)	86 (n=12)	88 (n=11)	[65.1, 85.7]	[82.1, 91.3]	91.2
TAPE	Total Phosphorus (TP)	52 (n=7)	59 (n=7)	[30.6, 57.9]	[45.7, 62.9]	66
TAPE	Total Nitrogen (TN) ^C	95 (n=6)	97 (n=6)	[59.7, 86.6]	[67.5, 89.6]	48.5

^A Flow-weighted composite samples were collected and the composite sample concentration is defined as a volume-weighted average of the individual samples. Therefore the Event Mean Concentration (EMC) flow-weighted composite samples is the concentration of a composite sample.

^B CEC Assessment of suspended solids and nutrient attenuation by the Virginia mixture of FocalPoint Biofiltration System via column testing, October 2014

^C For this study period there were no measureable removals of nitrates. The reduction in TN is derived from the attenuation of the Kjeldahl Nitrogen portion of the influent concentrations

Of the 12 qualifying storm events, 12 events qualified for assessing suspended solids removal efficiencies. Relative to TSS, the influent concentrations measured from the test site range from 4.9 to 238 mg/L. For the 20-100 mg/L influent range, the measured effluent TSS does meet the TAPE-required upper 95% confidence limit about the mean effluent concentration of less than or equal to 20 mg/L (data calculations from the study produced a 16.8 mg/L upper confidence limit concentration via bootstrapping; 14.5 mg/L upper confidence limit for the median from Q-Q plots). For influent TSS in the range of 100-200 mg/L, three events to date, the TAPE minimum 80% removal efficiency requirement is met with a mass loading-based 95% lower confidence limit of 90.5%, as calculated via bootstrapping. There was one event with an influent TSS concentration above 200 mg/L (238 mg/L from December 14, 2015) for which 80% removal was achieved on a concentration mass load basis.

For nitrogen-based compounds, removal efficiencies for TKN and nitrate are given. Of the 12 qualifying storm events, 6 events qualified for assessing TKN removal efficiencies and 8 events for nitrate removal efficiencies. Removal efficiencies calculated for TKN produced a lower 95% confidence limit of 50.7% based on Probability Plots (Q-Q plots). Removal efficiencies for nitrate are very low (negative lower 95% confidence limit values) and nitrate attenuation is not anticipated to occur within bioretention systems due to redox conditions that are unfavorable to denitrification associated with a lack of adequate subsurface detention time, and, often, a limited organic carbon source.

Of the 12 qualifying storm events, seven events qualified for assessing TP. Influent TP concentration ranged from 0.121 mg/L to 0.424 mg/L and fell within the TAPE criteria for TP. The bootstrapped lower 95% confidence limit for the mean for this study to date is 45.7% on a mass loading basis (41.7% for the 95% lower confidence limit about the median based on the more applicable Probability Plot method for data sets $n < 20$). The mean concentration and mass load reductions were 52% and 59%, respectively, with one (concentration based) and two (mass based) events producing greater than 60% removal.

Of the 12 qualifying storm events, five events qualified for assessing dissolved Cu removal efficiencies, nine events qualified for assessing dissolved Zn removal efficiencies, and six events qualified for assessing dissolved Pb removal efficiencies. The bootstrapped lower 95% confidence limit for the mean for this study is 16.8% on a mass loading basis for total Cu (5.5% for the 95% lower confidence limit about the median based on the more applicable Probability Plot method for data sets $n < 20$). The bootstrapped lower 95% confidence limit for the mean for this study is 47.2% on a mass loading basis for total Zn (41.5% for the 95% lower confidence limit about the median based on the more applicable Probability Plot method for data sets $n < 20$). Total Pb reductions through the FocalPoint system resulted in bootstrapped lower 95% confidence limit for the mean for this study is 29.4% on a mass loading basis for total Pb (18.6% for the 95% lower confidence limit about the median based on the more applicable Probability Plot method for data sets $n < 20$).

The calculated p-values derived from the paired group comparison tests for the influent versus effluent concentrations are the same as the p-values derived for the influent versus effluent mass loadings, except for suspended solids, nitrate and total copper. The constituents with statistically significant decreases from influent to effluent, based on both concentrations and mass loadings, include suspended solids (TSS), TP, TN as represented by TKN, total Zn and total Pb.

1.0 INTRODUCTION

On October 28, 2014, ACF Environmental of Richmond, Virginia authorized Civil & Environmental Consultants, Inc. (CEC) to perform a full-field scale test to assess the hydraulic and water quality performance of the FocalPoint High Performance Modular Biofiltration System (HPMBS).

CEC provides consulting services specializing in Best Management Practices (BMP) evaluation and product research and development. CEC was contracted by ACF Environmental to assist with the Quality Assurance Project Plan (QAPP) development and execution of this study. The project focuses on the design, execution, and technical review of the field study to assess the hydraulic and pollutant-removal performance of the FocalPoint. The purpose of the QAPP is to document the type and quality of data needed for the project and to characterize the systems effectiveness with a given level of statistical confidence in removing pollutants from stormwater runoff and to compare test results with various regulatory goals, such as TAPE performance goals. This test protocol also assesses the systems maintainability, reliability, and longevity.

The FocalPoint HPMBS is a specialized system utilizing biofiltration media for the treatment of stormwater runoff from impervious surfaces. The FocalPoint system was developed by Convergent Water Technologies of Houston, Texas. The modular treatment system, containing biologically active biofiltration media, is used as a complete, integrated system with a demanding specification that insures functionality performance and maintainability. With rigorous quality assurance standards and post construction in-situ infiltration verification, FocalPoint HPMBS guarantees performance.

FocalPoint is a scalable biofiltration system which combines the efficiency of high flow rate engineered media with the durability and modularity of a highly pervious, open cell underdrain/storage/infiltration system. The system employs a 3-foot cross-section that includes a 3-inch layer of mulch, 18-inch biofiltration media, 6 inches of washed bridging stone, and 9-inches underdrain wrapped in an open-mesh microgrid (See Figure 1 below).

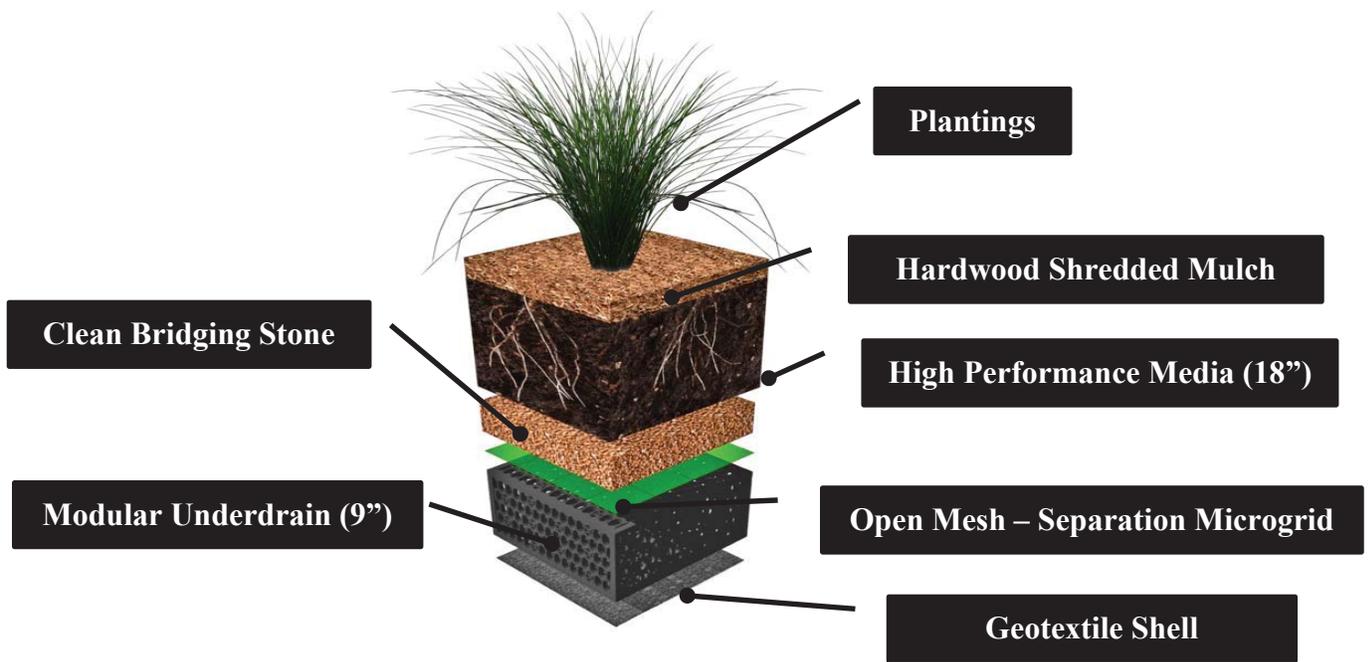


Figure 1 FocalPoint HPMBS System Components

Analytical services for all pollutants were provided by ESC Lab Sciences (ESC) located in Mt. Juliet, Tennessee. ESC is accredited under the National Environmental Laboratory Accreditation Program (NELAP). For this project, specific parameters of interest for evaluation include Total Phosphorous (TP), Total Kjeldahl Nitrogen (TKN-N), Nitrate-Nitrogen (NO₃-N), Total Suspended Solids (TSS), Total Copper (Cu), Total Lead (Pb), and Total Zinc (Zn).

This study was conducted at the warehouse facility owned by Civil & Environmental Consultants, Inc. on Campbells Run Road in Pittsburgh, Pennsylvania. The construction of the FocalPoint system and installation of the data collection and monitoring equipment was completed in July 2015. The construction and installation of the FocalPoint was performed by Exact Stormwater. The goal of the project is to retrieve water quality samples for a minimum of 20 qualifying storm events.

This Technical Evaluation Report (TER) summarizes the interim results of this study.

2.0 TECHNOLOGY DESCRIPTION

2.1 PHYSICAL DESCRIPTION

FocalPoint is a modular, high performance biofiltration system that often works in tandem with other integrated management practices (IMP). Contaminated stormwater runoff enters the biofiltration bed through energy dissipation/pretreatment device such as a conveyance swale, rock/stone surround, level spreader, or Rain Guardian Turret before it reaches the 3-inch layer of aged, double-shredded hardwood mulch on the surface of the biofiltration media.

As the water passes through the mulch layer, most of the larger sediment particles and heavy metals are removed through sedimentation and chemical reactions with the organic material in the mulch. Water passes through the biofiltration media where the finer particles are removed and numerous chemical reactions take place to immobilize and capture pollutants in the media.

The cleansed water passes into the underdrain/storage system and remaining flows are directed to a storm sewer system or other appropriate discharge point. Once the pollutants are in the media, bacteria begin to break down and metabolize the materials and the plants begin to uptake and metabolize the pollutants. Some pollutants such as heavy metals, which are chemically bound to organic particles in the mulch, are released over time as the organic matter decomposes to release the metals to the feeder roots of the plants and the cells of the bacteria in the media where they remain and are recycled. Other pollutants such as phosphorus are chemically bound to the media particles and released slowly back to the plants and bacteria and used in their metabolic processes. Nitrogen goes through a variety of very complex biochemical processes where it can ultimately end up in the plant/bacteria biomass, turned to nitrogen gas or dissolves back into the water column as nitrates depending on soil temperature, pH and the availability of oxygen. The pollutants ultimately are retained in the mulch, media and biomass with some passing out of the system into the air or back into the water.

The System is comprised of the following elements:

Open Cell Underdrain: A modular, high infiltration rate ‘flat pipe’ underdrain/storage system which is designed to directly infiltrate or exfiltrate water through its surface. The modular underdrain overcomes the limited collection capacity of traditional stone and pipe underdrains. A 95% open surface area collects water significantly faster and can be extended below for additional volume.

Separation Layer: A wide aperture mesh layer is utilized to prevent bridging stone from entering the underdrain system. The separation layer utilizes the concept of ‘bridging’ to separate the biofiltration media from the underdrain without the use of geotextile fabrics. The use of geotextile fabrics within an infiltration device can lead to clogging; by eliminating the need for a geotextile fabric, the potential for clogging is greatly reduced.

High Flow Media: The advanced high flow rate engineered soils utilizes physical, chemical and biological mechanisms of the soil, plant and microbe complex, to remove pollutants found in stormwater runoff. Infiltration rates at 100 inches per hour overcome the challenges of clogging and flooding and minimize space requirements.

Mulch: Shredded, hardwood mulch acts as a pre-treatment mechanism by preventing trash, sediments and particles from entering the system. Removal and replacement of mulch is necessary only every 6-12 months and is the only maintenance requirement for the entire system. Maintenance cycles may be extended with the implementation of upstream pretreatment.

Plants: Native Plants are best suited as they adjust well to periodic droughts and temperature extremes. The media contains 10% by volume peat moss. Over the years the decaying mulch, roots, fungi, bacteria and organic inputs from stormwater runoff add to the organic mix as it evolves as more natural soil strata. Soil moisture is maintained through the use of peat moss and mulch.

The hydraulic capacity of the system is limited by the biofiltration media which is designed to operate at 100 in/hr. All other components have greater hydraulic capacity.

2.2 SITE REQUIREMENTS

The following sections provides a list of common site requirements

Necessary soil characteristics: There are typically no requirements for the native soils surrounding the system and we use a non-woven geotextile separation layer and underdrain. If the system is designed to exfiltrate\infiltrate into native soils, appropriate design considerations are given with respect to infiltration bed sizing.

Pretreatment: Pretreatment of runoff entering a FocalPoint HPMBs is necessary to trap coarse sediment particles before they reach and prematurely close the filter bed. Pretreatment measures must be designed to dissipate velocities and spread water out over a 2 to 4 ft. width. Many pretreatment options are available and include manufactured systems like the RainGuardian or non-propriety systems like stone aprons\diaphragms, grass filter stripes and level lip spreaders.

Hydraulic grade line requirements: All low impact development or environmental site design practices such as FocalPoint HPMBs are constrained by the invert elevation of the existing conveyance system to which the system discharges (i.e., the bottom elevation needed to tie the underdrain from the FocalPoint HPMBs into the storm drain system. In general, 3.5 ft. of elevation above this invert is needed to accommodate the required ponding and filter system depths. If the system does not include an underdrain or if an inverted or elevated underdrain design is used, less hydraulic head may be required.

Ponding depth: The recommended surface ponding depth is 6 to 12 inches and is ideal for streetscape, mostly permeably tree boxes and stormwater planters. Minimum and maximum surface ponding depths are 3 inches and 18 inches, respectively. When greater ponding depths are utilized the design must consider safety issues; for example, fencing requirements, aesthetics, viability and survival of plants and erosion and scour of side slopes. It should be noted these same considerations are typical of traditional low flow bioretention practices.

Side Slopes: Typically 3:1 or flatter. In highly urbanized or space constrained areas, a drop curb design or precast panel wall structure can be used to create a stable, vertical side wall.

These drop curb designs should not exceed a vertical drop of more than 12 inches, unless safety precautions such as railing, walls, grating, etc. are included.

Depth to groundwater: The system should be separated from the water table to ensure that groundwater does not inundate the filter bed. A separation distance of 2 feet is recommended between bottom of excavated FocalPoint HPMBS area and the seasonally high ground water table.

Utility requirements: The system is typically drained to a conventional a close pipe drainage system or can be piped directly to a conveyance channel or drainage course.

Applications: The manufacturer of FocalPoint HPMBS recommends the technology for the following land uses: Roadways, high-use sites, commercial, industrial, residential runoff areas. Greater than 600 FocalPoint HPMBS have been successfully installed across the United States with a high density in the Mid-Atlantic, Northeast and Southwest regions. Included below is a list of references with names and telephone numbers who have successfully implemented FocalPoint HPMBS into their projects.

Town of Falmouth
Department of Public Works
271 Falmouth Rd
Falmouth, ME 04105
Mr. Jay Reynolds
207-699-5374

Harris County Government
Engineering Department
1001 Preston, 7th Floor
Houston, TX 77002
Mr. John Blount, P.E.
713-755-6888

City of Houston
Engineering Services Section
611 Walker St
Houston, TX 77002
Ms. Kathlie Jeng-Bullock, P.E.
832-395-2511

Sebago Technics
City of South Portland Consulting Engineer
75 John Roberts Rd, Suite 1A
South Portland, ME 04106
Mr. Dan Riley, P.E.
207-200-2100

Ransom Environmental
City of Portland Consulting Engineer
400 Commercial St, Suite 404
Portland, ME 04101
Mr. John Mahoney, P.E.
207-772-2891

Highpoint Engineering
Canton Corporate Place
45 Dan Road, Suite 140
Canton, MA 02021
Mr. Michael Fabbiano, P.E.
781.770.0970

2.3 SIZING METHODOLOGY

The FocalPoint HPMBS is a low impact development or environmental site design practice that uses a higher hydraulic conductivity factor than traditional low flow bioretention practices. It's modular, flexible and scalable "outside the box" design provides civil site designers virtually an endless supply of solutions.

The FocalPoint HPMBS is sized to treat the water quality volume (WQv) as determined by a qualified project engineer per the local, state or federal regulations. The system dynamically stores, treats and discharges (either pipe conveyance or infiltrate) the WQv prior to bypass.

ACF Environmental has technical engineering staff to provide sizing assistance to engineers/designers and has developed a sizing calculator/tool (*ACF FP and RT Calculator version 1.8*). The calculator takes the WQv and distributes the volume using a Type I, Type II or III TR-55 storm distribution to produce an inflow hydrograph (expressed in volumetric terms). The output from the calculator is a filter bed area (measured in square feet) and storage volume above media bed that ensures the WQv passes through the system prior to overflow. The system in this TAPE level field study was sized using this calculator and results in a ratio of 0.40% (44 sq. ft. of filter bed area to 10,890 sq. ft. of impervious area) and ponding volume of 20% of the WQv.

High flow media systems such as FocalPoint HPMBS have an estimated drawdown time between 0.25 and 0.30 hrs. This is significantly less than that required for WQv requirements; therefore, it should be used as part of a system of practices that capture, store and slowly release the required volume of runoff at rates meeting channel protection flow criteria.

Where the system includes an infiltration component, Rev may be addressed as well. Because FocalPoint HPMBS are often distributed about a site, it allows for Rev to be distributed across a site as much as practical to mimic natural conditions.

The minimum size FocalPoint HPMBS from a constructability and practical limit standpoint is 20 sq. ft. The smallest constructible width or length dimension is 2 ft. There are no limits on the width to length ratio.

The system has a design life equal to or great than traditional low flow bioretention facilities and is estimated to be 20-25 years.

The specific media flow rate (i.e., design velocity) of the FocalPoint HPMBS is 1 gpm/SF.

Media specifications ensure adequate media quality all the time. The physical and chemical properties of are included below:

Composition and Characteristics	
Sand – Fine	< 5%
Sand – Medium	10% - 15%
Sand – Coarse	15% - 25%
Sand – Very Coarse	40% - 45%
Gravel	10% - 20%
Infiltration Rate	>100 inches per hour
Peat Moss*	5% - 15%
* Peat Moss Specification	
Listed by Organic Materials Review Institute	
100% natural peat (no composted, sludge, yard or leaf waste)	
Total Carbon >85%	
Carbon to Nitrogen Ratio 15:1 to 23:1	
Lignin Content 49% to 52%	
Humic Acid >18%	
pH 6.0 to 7.0	
Moisture Content 30% to 50%	
95% to 100% passing 2.0mm sieve	
> 80% passing 1.0mm sieve	

2.4 INSTALLATION

Installation of FocalPoint HPMBS requires conventional labor and equipment associated with site earthwork and drainage utility activities. The base of excavation shall be smooth, level and free of lumps or debris, and compacted unless infiltration of storm water into subgrade is desired. A thin layer (3") of compacted base material is recommended to establish a level working platform (may not be needed in sandy soils). If the base of the excavation is pumping or appears excessively soft, a geotechnical engineer should be consulted for advice. In many cases, a stabilization geotextile and 6" of compactable material that drains well will be sufficient to amend the bearing capacity of the soil.

Most applications require 8 oz. Non-Woven Geotextile or equivalent nonwoven geotextile with a nominal weight of 8 oz. per square yard to line the excavation to separate in situ soils and the FocalPoint HPMBS (note: applications requiring water to infiltrate the in situ sub-soils should use a bridging stone rather than geotextile to provide a separation layer between the FocalPoint HPMBS and the in situ soils). Geotextile, when utilized, should be placed on the bottom and up the sides of the excavation. Absolutely no geotextiles should be used in the water column. If an impermeable liner is specified, it shall be installed according to supplier's instructions and recommendations.

Specified backfill material must be free from lumps, debris and any sharp objects that could penetrate the geotextile. Material is used for backfill along the sides of the system as indicated in engineering detail drawings.

Cleanup and Protection during Ongoing Construction Activity

- A. Perform cleaning during the installation and upon completion of the work.
- B. Remove from site all excess materials, debris, and equipment. Repair any damage to adjacent materials and surfaces resulting from installation.

- C.** If surrounding drainage area is not fully stabilized, a protective covering of geotextile fabric should be securely placed to protect the Biofiltration Media.
- D.** Construction phase erosion and sedimentation controls shall be placed to protect the inlet(s) to the Biofiltration System. Excessive sedimentation, particularly prior to establishment of plants may damage the HPMBS.
- E.** Strictly follow supplier's guidelines with respect to protection of the HPMBS between Installation and Commissioning phases.

Commissioning

- F.** Commissioning should only be carried out once the contributing drainage area is fully stabilized. If Commissioning must be carried out sooner, it is imperative that appropriate erosion and sediment controls be placed to prevent the entry of excessive sediment/pollutant loads into the system.
- G.** Commissioning entails removing the protective covering from the Biofiltration Media, planting the plant material in accordance with the approved drawings, and placing mulch if specified.
 - 1. Dig planting holes the depth of the root ball and two to three times as wide as the root ball. Wide holes encourage horizontal root growth that plants naturally produce.
 - 2. With trees, you must ensure you are not planting too deep. Don't dig holes deeper than root balls. The media should be placed at the root collar, not above the root collar. Otherwise the stem will be vulnerable to disease.
 - 3. Strictly follow supplier's planting guidance.
- H.** Cover the exposed root ball top with mulch. Mulch should not touch the plant base because it can hold too much moisture and invite disease and insects. Evenly place 3 inches of double-shredded hardwood mulch (if

specified) on the surface of the media.

- I. Plantings shall be watered-in at installation and temporary irrigations shall be provided, if specified.

2.5 OPERATION AND MAINTENANCE REQUIREMENTS

All stormwater treatment systems require maintenance for effective operation. This necessity is often incorporated in your property's permitting process as a legally binding operation and maintenance agreement. Other reasons for maintenance include:

- Avoid legal challenges from your jurisdiction's maintenance enforcement program.
- Prolong the lifespan of your FocalPoint HPMBS.
- Avoid costly repairs.
- Help reduce pollutant loads leaving your property.

Simple maintenance of the FocalPoint HPMBS is required to continue effective pollutant removal from stormwater runoff before any discharge into downstream waters. This procedure will also extend the longevity of the living biofiltration system. The unit will recycle and accumulate pollutants within the biomass, but may also be subjected to other materials entering the surface of the system. This may include trash, silt and leaves etc. which will be contained above the mulch and/or biofiltration media layer. Too much silt may inhibit the FocalPoint's HPMBS flowrate, which is a primary reason for system maintenance. Removal of accumulated silt/sediment and/or replacement of the mulch layer (when specified), is an important activity that prevents over accumulation of such silt/sediment.

Convergent Water Technologies and/or its Value-Added Reseller (VAR) include a 1-year maintenance plan with each system purchased. Annual included maintenance consists of two (2) scheduled maintenance visits. Additional maintenance may be necessary depending on sediment and trash loading (by Owner or at additional cost). The start of the maintenance plan begins when the system is activated for full operation. Full operation is defined as when the site is

appropriately stabilized, the unit is installed and activated (by VAR), i.e., when mulch (if specified) and plantings are added.

Activation should be avoided until the site is fully stabilized (full landscaping, grass cover, final paving and street sweeping completed). Maintenance visits are scheduled seasonally; the spring visit aims to clean up after winter loads including salts and sands. The fall visit helps the system by removing excessive leaf litter. A first inspection to determine if maintenance is necessary should be performed at least twice annually after storm events of greater than (1) one inch total depth (subject to regional climate). Refer to Appendix J for the maintenance checklist for specific conditions that indicate if maintenance is necessary.

It has been found that in regions which receive between 30-50 inches of annual rainfall, (2) two visits are generally required. Regions with less rainfall often only require (1) one visit per annum. Varying land uses can affect maintenance frequency.

Some sites may be subjected to extreme sediment or trash loads, requiring more frequent maintenance visits. This is the reason for detailed notes of maintenance actions per unit, helping the VAR/Maintenance contractor and Owner predict future maintenance frequencies, reflecting individual site conditions. Owners must promptly notify the VAR/Maintenance contractor of any damage to the plant(s), which constitute(s) an integral part of the biofiltration technology. Owners should also advise other landscape or maintenance contractors to leave all maintenance of the FocalPoint HPMBS to the VAR/Maintenance contractor (i.e. no pruning or fertilizing).

Each maintenance visit consists of the following simple tasks (detailed instructions below).

1. Inspection of FocalPoint HPMBS and surrounding area
2. Removal of debris, trash and mulch
3. Mulch replacement
4. Plant health evaluation (including measurements) and pruning or replacement as necessary
5. Clean area around FocalPoint HPMBS
6. Complete paperwork, including date stamped photos of the tasks listed above.

Ideal tools include: camera, bucket, shovel, broom, pruners, hoe/rake, and tape measure. Appropriate Personal Protective Equipment (PPE) should be used in accordance with local or company procedures. This may include impervious gloves where the type of trash is unknown, high visibility clothing and barricades when working in close proximity to traffic and also safety hats and shoes.

2.6 RELIABILITY

This section of the TER describes the following, if applicable.

- When designed and installed correctly, the FocalPoint HPMBS can be impacted by sedimentation and lack of maintenance.
- As evident in this study, there are no readily observed circumstances where the system can add, transform or release accumulated pollutants.
- The media is comprised of inert sand and peat. Peat is an accumulation of naturally decomposed organic matter. Based on this information the filter medium is not expected to decompose. The potential for slime/bacteria growth is very low and has not been observed in the system.
- Pretreatment is suggested and will increase reliability and reduce the impact of heavy or fine sediment loadings.
- Underperformance is diagnosed with visual inspection and hydraulic conductivity testing. Visual inspection of the vegetation, high water marks and drain down time after storm subsidence will expose underperformance. These items are treated with routine maintenance of the mulch layer. The top 6 inches of media can be removed if significant clogging or underperformance is observed and lastly full media depth restoration if the system has outlasted its functional design life.

- The system is commissioned with a one year warranty.
- Initial and on-going user support is provided as follows:

Vendor does not charge for the following

- Upfront design/specification and technical support
- Education and training to specifier's, installers, owners and regulators
- First year of maintenance
- Hydraulic conductivity warranty in the first year

Vendor does charge for the following

- Extended maintenance and warranty plans

3.0 SAMPLING PROCEDURES

3.1 SITE INFORMATION

Data for this study was collected over the course of multiple storm events between July 2015 and December 2015 from an urban site incorporating a full-scale FocalPoint HPMBS located in Pittsburgh, Pennsylvania. The system was installed within the 15 ft. x 70 ft. grassed segment located at the entrance to the CEC warehouse along the north portion of the property facing Campbells Run Road (4315 Campbells Run Road, Pittsburgh, PA 15205). Runoff from the crown of Campbells Run Road also flows back towards the south into the grassed area. The total watershed to the test area is approximately 10,890 ft².

The FocalPoint system was constructed by excavating the grassed portion of the CEC lot to accommodate approximately an 11 ft. x 4 ft. (44 ft²) filter bed with a ponding volume above 220 ft³. A bottom layer of crushed stone was placed initially to provide a level base for the high-performance modular underdrain/storage system. An 8-inch diameter Schedule 40 PVC pipe was installed at the bottom, extending from the modular underdrain to the effluent collection manhole. A 2 ft. x 2 ft. plastic or gum rubber anti-seep collar was installed around the non-perforated pipe immediately downstream of the modular underdrain with soil compacted around the full extent of the collar and pipe. A layer of open-mesh microgrid was installed over the modular underdrain followed by a 6-inch layer of washed, bridging stone over the microgrid. Next, an 18-inch layer of high-performance biofiltration media was placed over the bridging stone. A 3-inch layer of clean, double shredded hardwood mulch was placed over the biofiltration media to complete the system. A mixture of grass plugs and shrubs were planted in the bioretention prior to the initiation of testing.

3.2 MONITORING EQUIPMENT

Stormwater flow measurements along with influent and effluent stormwater sampling were carried out using Teledyne ISCO portable automatic samplers equipped with Teledyne ISCO acoustic (Doppler) flow meters positioned at both the influent and effluent manholes. The

acoustic flow meters' area-velocity sensors trigger sampling based on the head variations detected behind the weir and corresponding flow rates.

A collection trough at the interface of the asphalt pavement and the grassed area adjacent to the road was constructed to convey the influent from the parking lot to the v-notch weir (inside the influent manhole). Water then passes into the top surface zone of the bioretention area. The Teledyne ISCO flow meter sensor and low-flow strainer of the sampler was positioned within the weir trough. A Solinst Levelogger 3100 transducer with barometric compensation and datalogging capabilities was anchored over the mulch surface to measure head fluctuations and infiltration rates of the media. Sharp crested trapezoidal weir was constructed with the invert positioned several inches above (minimum of 6 inches) the FocalPoint surface for passing flows above the design runoff/rainfall event. A second transducer was installed at the overflow weir to measure when overflows occur.

The 8-inch PVC effluent pipe from the FocalPoint was sloped to a collection manhole where the flow-meter sensor and low-flow strainer were positioned behind a v-notch weir. The effluent pipe from the sampling manhole was directed to the north to discharge via gravity into the storm sewer.

The equipment used in this study was pre-calibrated by the manufacturer or supplier. All monitoring equipment is re-calibrated when necessary and as recommended by the manufacturer. The stormwater collection trough, weirs and overflow channel/pipe were inspected at least weekly for obstructions prior to the next sampling event. Automatic samplers, flow meters transducers, and pumps were inspected at least monthly to ensure the equipment was effectively operating. All routine maintenance for the automatic samplers and flow meters strictly adhered to the Teledyne ISCO maintenance manual provided with the equipment.

3.3 STORMWATER SAMPLES COLLECTION AND HANDLING

Flow-proportional composite sampling was used for this study for both influent and effluent flows. Flow-proportional composite sampling is the extraction of sample aliquots on a fixed-volume interval (sampling trigger volumes) and immediately mixing the sample aliquot within a

single 4-gallon composite container located within the ISCO automatic sampler unit. The samplers and flow meters were equipped with data logging capabilities in order to record flows and trigger volume-paced sampling. The flow volume increments chosen for programming the samplers were by determined using hydrologic modeling of the test watershed. Flow-composited sampling was programmed to cover at least 70% of the storm volume during each event. Transducer logging was programmed to take readings every 1 minute.

The time and date stamps for all data-loggers associated with the automatic samplers, flow meters, and transducers were synchronized prior to initiating sampling activities. Periodic field checks were carried out to ensure time and date stamps for all monitoring equipment was synchronized. Sandbags, Erosion Eels, or other portable diversion devices were used to divert runoff that is extraneous to the test watershed away from the testing area. The data-logging rain gage was installed during construction of the bioretention area to record site specific rainfall information. An as-built survey of the testing area was performed prior to initiating the sampling operations and is provided in Appendix E.

After each storm event, the samplers were inspected to determine how much, if any, sample volume was taken in the influent and effluent composite containers. If there was less than the required sample size for the analysis of the targeted constituents plus a single duplicate of each constituent, the sample was discarded. After removal of the sample contents, the containers were flushed with distilled water and allowed to dry before being reinstalled in the sampler.

3.4 QUALITY CRITERIA FOR FIELD SAMPLING

This section addresses quality objectives for precision, bias, sample representativeness, data completeness, and data comparability. Additional information regarding quality control criteria is available in the QAPP in Appendix D

Precision -To assess precision in the field, stormwater field duplicates were collected every qualifying storm event for influent and effluent composite samples submitted to the laboratory for analysis.

Bias - Defining and following standardized sampling methods such as those set forth in this QAPP minimizes error due to bias. Bias in field procedures was measured by collecting one field blank for each qualifying storm sample collection event. Additionally, bias was reduced by regularly calibrating field equipment per the recommendation schedule set forth by each manufacturer and consistently following field procedures described in this QAPP. Equipment was calibrated by the manufacturers prior to installation in the field study.

Representative Sampling and Data Comparability - To ensure representativeness of the data, composite stormwater samples were collected at inlet and outlet sample points that best represent pollutant constituents in the influent stormwater and treated effluent. Consistent and standard sampling procedures as set forth in this QAPP were followed. The inlet and outlet sample points were selected to ensure well-mixed samples that are representative of the storm conditions are collected.

Data Completeness – The required amount of valid data obtained from this project shall include representative influent and effluent composite samples from at least 20 qualifying storms. The length of the study period will be extended until the minimum number of acceptable qualifying storms is achieved.

4.0 DATA SUMMARIES AND ANALYSIS

This section includes a summary of the storm event data and an Individual Storm Report (ISR) for each sampled storm event summarizing storm, hydrologic and pollutant data.

**TABLE 2
STORM EVENT SUMMARY**

Storm ID	Event 1	Event 2	Event 3	Event 4	Event 5	Event 6	Event 7	Event 8	Event 9	Event 10	Event 11	Event 12
Location	Campbells Run											
Storm Depth (inches)	0.66	0.57	4.03	0.41	0.46	1.95	0.3	0.89	0.21	0.56	0.34	0.36
Antecedent dry period (days)	1.60	7.97	0.77	5.99	1.96	2.77	4.86	3.49	4.71	2.19	0.22	0.67
Storm duration (hours)	20.22	19.15	19.35	1.78	11.08	21.75	8.08	14.33	9.63	11.23	7.88	16.82
Influent volume of water (gallons)	2278.83	1771.83	30225.45	1956.37	1291.62	9380.27	1396.59	2899.05	340.26	828.61	575.51	409.34
Effluent volume of water (gallons)	1100.38	898.08	100857.74	1499.33	636.44	4265.24	835.03	819.96	416.84	1002.48	453.22	333.25
Bypass volume of water (gallons)	0	0	unk	0	0	0	0	0	0	0	0	0
Peak flow rate through treatment system (gpm)	127.52	26.65	2051.74	131.36	12.98	161.04	78.45	24.33	7.51	5.95	15.00	8.83
Influent peak flow rate (gpm)	127.52	26.65	193.45	131.36	12.98	161.04	78.45	24.33	7.51	4.82	15.00	8.83
Effluent peak flow rate (gpm)	72.35	18.36	2051.74	71.27	6.58	37.21	38.68	10.44	7.51	5.95	10.96	6.32
Average flow rate through treatment system	1.88	1.54	84.40	18.28	1.94	7.01	2.88	3.37	1.81	1.49	1.22	0.41
Average influent flow rate (gpm)	1.88	1.54	25.29	18.28	1.94	7.01	2.88	3.37	1.48	1.23	1.22	0.41
Average effluent flow rate (gpm)	0.91	0.78	84.40	14.01	0.95	3.19	1.72	0.95	1.81	1.49	0.96	0.33
Number of influent aliquots	6	4	93	6	4	29	4	9	3	7	5	3
Number of effluent aliquots	6	5	146	9	4	27	5	4	8	19	9	6
Percentage of influent storm volume sampled	79%	73%	100%	88%	77%	98%	69%	88%	62%	72%	70%	53%
Percentage of effluent storm volume sampled	74%	73%	100%	86%	83%	95%	76%	62%	82%	94%	83%	72%

5.0 OPERATION AND MAINTENANCE INFORMATION

No maintenance has been performed on the FocalPoint HPMBS at the time of this interim report. Maintenance will be performed by ACF Environmental, if necessary, in accordance with manufacturer's recommendations. As no maintenance has been performed at the time of this report, no maintenance records have been generated.

6.0 DISCUSSION

6.1 STATISTICAL ANALYSES

There have been 12 storm events that have been sampled to date. All of these 12 events are classified as qualifying storm events, as defined by the QAPP for this research (i.e., qualifying storm event of 0.15-inch or greater rainfall total). From these 12 storm events, there has been an average 31% reduction in runoff volume through the FocalPoint system for the given storms monitored to date.

There were several constituents, namely the nutrients and metals, having influent concentrations below the reporting limit for the given constituent. These data were removed from the qualifying data sets for statistical analyses.

The following is a summary of the statistical analyses for the qualifying data sets. Statistical software packages used for this research include NCSS, Minitab®, and MATLAB®

Pollutant removal efficiency calculations

Removal efficiencies were calculated for each measured constituent using both methods presented below since there are water losses in some storm events within the bioretention system, where influent volume is more than effluent volume, and there are also some events where there are no measured losses from influent to effluent.

Method #1: Individual storm reduction in pollutant concentration

The reduction in pollutant concentration during each individual storm is calculated as:

$$\frac{A - B}{A} \times 100$$

where:

A = flow-proportional influent concentration

B = flow-proportional effluent concentration

Method #2: Individual storm reduction in pollutant mass loading

The reduction in pollutant loading during each individual storm is calculated as:

$$\frac{C - D}{C} \times 100$$

where:

C = (Storm flow-proportional influent concentration) x (Storm influent volume)

D = (Storm flow-proportional effluent concentration) x (Storm effluent volume)

Statistical evaluation of performance goals

The ranges for influent TSS collected to date are from 4.9 mg/L to 238 mg/L. The TAPE performance goal for TSS calls for influent in the range of 20 to 100 mg/L to achieve an effluent concentration < 20 mg/L TSS as determined by the upper 95% confidence limit about the mean. For influent TSS in the range of 100-200 mg/L, the removal efficiency must be greater than or equal to 80% as determined using the lower 95% confidence interval about the mean efficiency. For influent TSS in the range >200 mg/L, the removal efficiency must be greater than 80% as determined using the lower 95% confidence interval about the mean efficiency.

The TAPE performance goal for enhanced treatment assumes that the system treats storm water with TP influent concentrations ranging from 0.1 to 0.5 mg/L. The influent TP concentrations from all storm events sampled to date fell within acceptable TAPE ranges.

The TAPE performance goal for enhanced treatment assumes that the system treats storm water with dissolved Zn influent concentrations ranging from 0.02 to 0.3 mg/L, and dissolved Cu influent concentrations ranging from 0.003 to 0.02 mg/L. Total Cu and total Zn are being analyzed for this study. The influent total Zn and total Cu concentrations from all storm events sampled to date fell within acceptable TAPE ranges for dissolved metal constituents. Event 2 influent total Zn is slightly higher than the 0.3 mg/L dissolved upper limit at 0.37 mg/L.

Basic descriptive statistics for influent and effluent water quality are given in Table S1 on a concentration basis and Table S2 on a mass loading basis.

Table S1. Basic descriptive statistics for constituent concentrations

Constituent	N sample size	Mean Influent (mg/L)	*Mean Effluent (mg/L)	Median Influent (mg/L)	*Median Effluent (mg/L)	Influent Std. Dev. (mg/L)	*Effluent Std. Dev. (mg/L)
Suspended Solids	12	84.4	11.4	49.9	9.4	74.8	8.0
TP	7	0.21	0.1	0.18	0.1	0.1	0.01
TKN	6	8.89	0.39	1.46	0.31	18.11	0.18
Total Cu	5	0.013	0.01	0.014	0.01	0.002	0
Total Zn	9	0.14	0.05	0.09	0.05	0.096	0.01
Total Pb	6	0.007	0.005	0.007	0.005	0.003	0.001

*Censored effluent data replaced with the reporting limit value

Table S2. Basic descriptive statistics for constituent mass loadings

Constituent	N sample size	Mean Influent (mg)	*Mean Effluent (mg)	Median Influent (mg)	*Median Effluent (mg)	Influent Std. Dev. (mg)	*Effluent Std. Dev. (mg)
Suspended Solids	**11	394,680	45,733	321,907	27,653	375,007	41,089
TP	7	758.8	313.4	567.7	339.9	533.1	176.9
TKN	6	44,285	1,212	4,490	904	96,939	915
Total Cu	5	70.7	33.1	74.4	34.0	48.0	17.2
Total Zn	9	788	156	668	155	788	83
Total Pb	6	29.1	13.1	19.4	8.5	29.2	8.8

*Censored effluent data replaced with the reporting limit value

**Event 3 influent and effluent volumes were not collected due to instrument error

Based on distribution fitting of the pollutant removal efficiency data, about half of all of the data sets have a skewed distribution (e.g., Weibull or lognormal), with the remaining, small data sets fitting either a logistic or normal distribution the best. 95% confidence intervals for both the mean and the median are presented herein since the median better represents the central tendency of the data from skewed distributions. In addition, while bootstrapping results for confidence intervals are presented herein based on the TAPE protocol requirement, bootstrapping is not the most accurate method for the development of confidence intervals for the mean and median for data sets < 20. Therefore, in addition to presenting the bootstrapping confidence interval results,

95% confidence intervals for the median have also been calculated from Probability Plots (or Q-Q Plots) of the given constituent data sets, fitting each removal efficiency data set for each constituent to the best-fit distribution. All of the removal efficiency data sets currently have less than 20 efficiencies. The probability plot method produces more accurate confidence intervals for data sets < 20 (Helsel, 2015).

Refer to Tables S3 and S4 for 95% confidence intervals for concentration-based and mass-loading-based removal efficiencies, respectively, for each constituent. For nitrogen-based compounds, removal efficiency for TKN is given. Removal efficiencies calculated for TKN produced a lower 95% confidence limit of 50.7% based on Probability Plots (Q-Q plots).

Table S3: 95% confidence intervals (CI) about the mean and median for concentration-based removal efficiencies (%)

Constituent	Probability Plot 95% CI for Median [LCL, UCL]	Bootstrap 95% CI for Median [LCL, UCL]	Bootstrap 95% CI for Mean [LCL, UCL]
Suspended Solids	[62.3, 89.5]	[57.8, 91.8]	[65.1, 85.7]
TP	[22.4, 60.4]	[21.9, 56.5]	[30.6, 57.9]
TKN	[50.7, 86.0]	[53.2, 92.2]	[59.7, 86.6]
Total Cu	[7.1, 50.5]	[17.4, 33.3]	[14.4, 29.5]
Total Zn	[34.4, 67.0]	[35.4, 77.6]	[40.5, 65.9]
Total Pb	[6.9, 52.0]	[9.7, 55.0]	[16.9, 47.4]

LCL- Lower confidence limit; UCL – Upper confidence limit

Table S4: 95% confidence intervals (CI) about the mean and median for mass-loading-based removal efficiencies (%)

Constituent	Probability Plot 95% CI for Median [LCL, UCL]	Bootstrap 95% CI for Median [LCL, UCL]	Bootstrap 95% CI for Mean [LCL, UCL]
Suspended Solids	[81.1, 93.0]	[76.8, 94.3]	[82.1, 91.3]
TP	[41.7, 69.0]	[52.7, 66.7]	[45.7, 62.9]
TKN	[60.0, 92.9]	[62.2, 93.9]	[67.5, 89.6]
Total Cu	[5.5, 65.5]	[-1.2, 67.8]	[16.8, 57.6]
Total Zn	[41.5, 81.6]	[33.5, 88.7]	[47.2, 77.3]
Total Pb	[18.6, 57.1]	[22.9, 68.5]	[29.4, 60.0]

LCL- Lower confidence limit; UCL – Upper confidence limit

Relative to TSS, the influent concentrations measured from the test site range from 4.9 to 238 mg/L. For the 20-100 mg/L influent range, the measured effluent TSS does meet the TAPE-required upper 95% confidence limit about the mean effluent concentration of less than or equal to 20 mg/L (data calculations from the study produced a 16.8 mg/L upper confidence limit concentration via bootstrapping; 14.5 mg/L upper confidence limit for the median from Q-Q plots). For influent TSS in the range of 100-200 mg/L, three events to date, the TAPE minimum 80% removal efficiency requirement is met with a mass loading-based 95% lower confidence limit of 90.5%, as calculated via bootstrapping. Note: Bootstrapping is recommended for sample sizes of $n > 20$. A better estimate for small data sets is via Probability Plots to estimate the confidence intervals about the median for skewed data such as these. There is currently not enough data to determine the lower 95% confidence limit about the median using Probability Plots for the three sample sets. There was only one event with an influent TSS concentration above 200 mg/L (238 mg/L from December 14, 2015).

For TP, the TAPE requirement for a minimum 50% removal efficiency for the lower 95% confidence limit about the mean is not satisfied at this point in the study. The bootstrapped lower 95% confidence limit for the mean is 45.7% on a mass loading basis (41.7% for the 95% lower confidence limit about the median based on the more applicable Probability Plot method for data sets $n < 20$).

For dissolved Cu, the TAPE requires a minimum 30% removal efficiency for the lower 95% confidence limit about the mean. However, this study is measuring total Cu. The bootstrapped lower 95% confidence limit for the mean for this study is 16.8% on a mass loading basis for total Cu (5.5% for the 95% lower confidence limit about the median based on the more applicable Probability Plot method for data sets $n < 20$).

For dissolved Zn, the TAPE requires a minimum 60% removal efficiency for the lower 95% confidence limit about the mean. However, this study is measuring total Zn. The bootstrapped lower 95% confidence limit for the mean for this study is 47.2% on a mass loading basis for total Zn (41.5% for the 95% lower confidence limit about the median based on the more applicable Probability Plot method for data sets $n < 20$).

Total Pb reductions through the FocalPoint system resulted in a bootstrapped lower 95% confidence limit for the mean for this study of 29.4% on a mass loading basis for total Pb (18.6% for the 95% lower confidence limit about the median based on the more applicable Probability Plot method for data sets $n < 20$).

Statistical comparisons of influent and effluent pollutant concentrations and mass loadings

Interim results of paired group comparisons for influent versus effluent concentrations and mass loadings are presented in Table S5 and Table S6, respectively. Statistical analyses have been performed to determine whether there are significant differences in pollutant concentrations and mass loadings between the influent and effluent stations for each individual, qualifying storm event. The specific null hypothesis (H_0) and alternative hypothesis (H_a) utilized for these analyses were as follows:

H_0 : Effluent pollutant concentrations are equal to or greater than influent concentrations.

H_a : Effluent concentrations are less than influent concentrations.

For suspended solids and nitrate data where there are no censored values, a 1-tailed Wilcoxon signed-rank test was used to compare the influent and effluent water quality. The Wilcoxon signed-rank test is a nonparametric analogue to the paired t-test for testing differences in group medians. Statistical significance was assessed based on an alpha (α) level (Type I error) of 0.05. For nutrients and metals data, effluent data for many of the paired data sets are left-censored. Therefore, the Sign Test was used for censored data sets. The Sign Test determines whether paired values from one group are generally higher or lower than the other group (Helsel and Hirsch, 2002). Due to its paired structure, the Sign Test can be used when there is one reporting limit or censored value per paired data couple (Helsel, 2012). In addition, for censored effluent data sets, the 1-tailed Wilcoxon signed-rank test for differences in medians was also performed after replacing each censored effluent value with the respective reporting limit for the given constituent.

The calculated p-values derived from the group comparison tests for the influent versus effluent concentrations are the same as the p-values derived for the influent versus effluent mass loadings except for suspended solids, nitrate and total copper. The constituents with statistically

significant decreases from influent to effluent, based on both concentrations and mass loadings, include suspended solids, TP, TKN, total Zn and total Pb.

Table S5: Paired group comparisons for influent vs effluent concentrations, $\alpha=0.05$

Constituent	# of Sample Pairs**	Test Method	p-Value	Reject Null Hypothesis, Ho?
Suspended Solids	12	1-tailed Wilcoxon signed-rank	0.0002	Yes
TP	7	Sign Test	0.0078	Yes
TP	7	1-tailed Wilcoxon signed-rank*	0.0078	Yes
TKN	6	Sign Test	0.0156	Yes
TKN	6	1-tailed Wilcoxon signed-rank*	0.0156	Yes
Total Cu	5	Sign Test	0.0313	Yes (marginal)
Total Cu	5	1-tailed Wilcoxon signed-rank*	<0.05	Yes (marginal)
Total Zn	9	Sign Test	0.002	Yes
Total Zn	9	1-tailed Wilcoxon signed-rank*	0.002	Yes
Total Pb	6	Sign Test	0.0156	Yes
Total Pb	6	1-tailed Wilcoxon signed-rank*	0.0156	Yes

*Censored effluent data replaced with the reporting limit value

** Based on qualifying storms

Table S6: Paired group comparisons for influent vs effluent mass loadings, $\alpha=0.05$

Constituent	# of Sample Pairs**	Test Method	p-Value	Reject Null Hypothesis, Ho?
Suspended Solids	11 ^	1-tailed Wilcoxon signed-rank	0.0005	Yes
TP	7	Sign Test	0.0078	Yes
TP	7	1-tailed Wilcoxon signed-rank*	0.0078	Yes
TKN	6	Sign Test	0.0156	Yes
TKN	6	1-tailed Wilcoxon signed-rank*	0.0156	Yes
Total Cu	5	Sign Test	0.1875	No
Total Cu	5	1-tailed Wilcoxon signed-rank*	0.0625	No
Total Zn	9	Sign Test	0.002	Yes
Total Zn	9	1-tailed Wilcoxon signed-rank*	0.002	Yes
Total Pb	6	Sign Test	0.0156	Yes
Total Pb	6	1-tailed Wilcoxon signed-rank*	0.0156	Yes

*Censored effluent data replaced with the reporting limit value

** Based on qualifying storms

^Event 3 influent and effluent volumes were not collected due to instrument error

Even with the small sample sizes, there were several constituent paired group comparisons where the null hypothesis was rejected. With the Type I error set at 0.05, this means there is only a 5% chance that these detected, statistically significant decreases in constituent concentrations and mass loadings are due to random error. The statistical significance of these reductions in constituent concentrations and mass loadings from influent to effluent will be more conclusive and defensible with a larger sample size.

Flow Rate Determination

Based on flow-proportional composite sampling performed as part of this research, aliquot-weighted flow rates for each storm event were determined by averaging the influent flow rate at the time each aliquot was collected for each storm. Refer to Table S7 for aliquot-weighted flows per storm event.

Table S7: Aliquot-weighted influent rates for each storm event

Rain Event	Average Flow of Each (gpm)	Average Ponding Depth above Mulch (inches)
1	39.5	0.69
2	3.4	0.74
3	69.1	2.52
4	61.4	1.08
5	6.7	0.80
6	31.7	1.12
7	36.0	0.95
8	10.3	0.90
9	4.3	0.85
10	3.0	0.87
11	7.0	0.91
12	7.0	1.01

Pollutant removal as a function of flow rate

Linear regression analysis to evaluate pollutant removal performance as a function of influent flow rate for all constituents was performed for this interim report. The linear regression analysis is designed to determine whether the treatment performance increases, decreases, or remains unchanged as a function of influent flow rate.

7.0 CONCLUSIONS

In the fall of 2014, ACF Environmental of Richmond, VA authorized Civil & Environmental Consultants, Inc. (CEC) to perform a full-scale test to assess the water quality performance of the FocalPoint High Performance Modular Biofiltration System (HPMBS). The FocalPoint system full-scale, field trial in Pittsburgh has performed as anticipated to date, with reductions in influent storm water volumes, suspended solids, nutrients, and metals.

For the study period to date (164 Julian Days) there were 57 of days with measurable precipitation and a total rainfall depth of 18.24 inches observed at the site. Of these rainfall events twelve (12) events were qualifying storm events, as defined by the QAPP (i.e., qualifying storm event of 0.15-inch or greater rainfall total). From these 12 storm events, there has been an average 31% reduction in runoff volume through the FocalPoint system for the given storms monitored to date.

Of the 12 qualifying storm events, 12 events qualified for assessing suspended solids removal efficiencies. Relative to TSS, the influent concentrations measured from the test site range from 4.9 to 238 mg/L. For the 20-100 mg/L influent range, the measured effluent TSS does meet the TAPE-required upper 95% confidence limit about the mean effluent concentration of less than or equal to 20 mg/L (data calculations from the study produced a 16.8 mg/L upper confidence limit concentration via bootstrapping; 14.5 mg/L upper confidence limit for the median from Q-Q plots). For influent TSS in the range of 100-200 mg/L, three events to date, the TAPE minimum 80% removal efficiency requirement is met with a mass loading-based 95% lower confidence limit of 90.5%, as calculated via bootstrapping. There was one event with an influent TSS concentration above 200 mg/L (238 mg/L from December 14, 2015) for which 80% removal was achieved on a concentration mass load basis

For nitrogen-based compounds, removal efficiencies for TKN and nitrates are given. Of the 12 qualifying storm events, 6 events qualified for assessing TKN removal efficiencies and 8 events for nitrate removal efficiencies. Removal efficiencies calculated for TKN produced a lower 95% confidence limit of 50.7% based on Probability Plots (Q-Q plots). Removal efficiencies for

nitrates are very low (negative lower 95% confidence limit values) and nitrate attenuation is not anticipated to occur within bioretention systems due to redox conditions that are unfavorable to denitrification associated with a lack of adequate subsurface detention time, and, often, a limited organic carbon source.

Of the 12 qualifying storm events, 7 events qualified for assessing TP. The bootstrapped lower 95% confidence limit for the mean for this study is 45.7% on a mass loading basis (41.7% for the 95% lower confidence limit about the median based on the more applicable Probability Plot method for data sets $n < 20$).

Of the 12 qualifying storm events, 5 events qualified for assessing dissolved Cu removal efficiencies, 9 events qualified for assessing dissolved Zn removal efficiencies, and 6 events qualified for assessing dissolved Pb removal efficiencies. The bootstrapped lower 95% confidence limit for the mean for this study is 16.8% on a mass loading basis for total Cu (5.5% for the 95% lower confidence limit about the median based on the more applicable Probability Plot method for data sets $n < 20$). The bootstrapped lower 95% confidence limit for the mean for this study is 47.2% on a mass loading basis for total Zn (41.5% for the 95% lower confidence limit about the median based on the more applicable Probability Plot method for data sets $n < 20$). Total Pb reductions through the FocalPoint system resulted in bootstrapped lower 95% confidence limit for the mean for this study is 29.4% on a mass loading basis for total Pb (18.6% for the 95% lower confidence limit about the median based on the more applicable Probability Plot method for data sets $n < 20$).

The calculated p-values derived from the paired group comparison tests for the influent versus effluent concentrations are the same as the p-values derived for the influent versus effluent mass loadings, except for suspended solids, nitrates and total copper. The constituents with statistically significant decreases from influent to effluent, based on both concentrations and mass loadings, include suspended solids (TSS), TP, TKN, total Zn and total Pb..

8.0 REFERENCES

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