ANALYSIS OF BIORETENTION SOIL MEDIA FOR IMPROVED NITROGEN, PHOSPHOROUS AND COPPER RETENTION

FINAL REPORT

Prepared for
Kitsap County

Prepared by
Herrera Environmental Consultants, Inc.

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EXECUTIVE SUMMARY

Monitoring data from several studies conducted in the western Washington region (Herrera 2014a, 2015) indicate that some pollutants are exported from bioretention systems using the default BSM, most notably nitrogen (N), phosphorus (P), and copper (Cu). To address this concern, Herrera Environmental Consultants (Herrera) implemented a study in partnership with Kitsap County to improve BSM performance for the capture and retention of these pollutants. This study was funded by the Washington State Department of Ecology (Ecology) through the Municipal Stormwater Grants of Statewide and Regional Significance program (2013–2015 biennium).

Study Design and Methodology

Four primary tasks were performed in this study to analyze bioretention media components and blends for N, P, and Cu retention and capture:

1. Conduct a survey of potential bioretention media components based on pollutant capture capability, cost, availability, and sustainability. Select individual media components from survey and project partner input.
2. Conduct Synthetic Precipitation Leaching Protocol (SPLP Method 1312) to determine N, P, and Cu leaching potential. Select the media components that minimize leaching potential, provide adequate (>1.0 inch/hour) hydraulic conductivity and support plants.
3. Combine components at various ratios, place in 8 inch (20.3 cm) diameter by 36 inch (91.4 cm) tall columns, flush the media blends with deionized water, and assess the effluent for N, P, Cu, and other stormwater pollutants of concern. Assess the hydraulic conductivity of the media blends during the flushing experiments using falling head tests in the columns and ASTM 2434.
4. Dose the media columns with natural stormwater that is spiked (if necessary) with reagent grade chemicals to attain pre-determined concentrations. Assess the effluent concentrations of N, P, Cu, and other stormwater pollutants of concern.

Results

Survey and Selection of Media Components

SPLP extractions were performed on the 26 prospective media components identified from the survey results. These extractions were subsequently analyzed for total nitrogen, nitrate-nitrite, total phosphorus, ortho-phosphorus, and total and dissolved copper. Media components were ranked from lowest to highest, lower ranks indicated lower leaching potential. Media components selected for the media blends in the column tests include:

- Bulk aggregate: volcanic sand (vs) and washed sand (ws).
- Bulk organic: iron-coated wood chips (fe) and coconut coir pith (cp).
- Mineral additives: diatomaceous earth (de) and activated alumina.
- Organic additive: 1230AW granular activated charcoal (gac), high-carbon wood ash (ash) and activated bone char.

Based on best professional judgment, selected media components were combined in a series of media treatments designed to minimize pollutant flushing and maximize pollutant capture performance. Composition of each media treatment is summarized in Table 1.

Table 1. Composition of Media Treatments Used in Flushing and Dosing Experiments.

Media Treatment Name[a]	Bulk Aggregate	Bulk Organic	Mineral Additive	Organic Additive
60sand/40comp[b]	60% sand	40% compost[d]	NA	NA
70vs//20fe/10de	70% volcanic sand	20% iron-coated wood chips	10% diatomaceous earth	NA
70vs/20fe/10ash	70% volcanic sand	20% iron-coated wood chips	NA	10% high carbon wood ash
70vs/20cp/10de	70% volcanic sand	20% coconut coir pith	10% diatomaceous earth	NA
70vs/20cp/10gac	70% volcanic sand	20% coconut coir pith	NA	10% granulated activated charcoal[f]
70ws/20cp/10ash	70% washed sand	20% coconut coir pith	NA	10% high carbon fly ash
70vs/20cp/10ash	70% volcanic sand	20% coconut coir pith	NA	10% high carbon wood ash
90vs/10comp/p-layer[c]	90% volcanic sand	10% compost[e]	see footnote "c"	see footnote "c"

[a] Naming conventions for media treatments used throughout this document.
[b] Media treatment used default BSM specifications from the 2012 Western Washington Stormwater Management Manual (Ecology 2014) to serve as a control.
[c] Media treatment included a polishing layer consisting of volcanic sand, activated alumina, and bone char.
[d] Cedar Grove compost
[e] Land Recovery Incorporated Compost
[f] 1230AW (acid wash) coconut granular activated charcoal

ash: high-carbon fly ash
cp: coconut coir pith
de: diatomaceous earth
fe: iron-fused wood chips
gac: granular activated charcoal
vs: volcanic sand
ws: washed sand
p-layer: polishing layer
NA: not applicable

Flushing Experiments

Experiments were performed to evaluate potential pollutant flushing from the media treatments. Each of the 24 columns were flushed 19 times with deionized water over a one month period (once per day excluding weekends). Samples were collected on four occasions corresponding to the first, sixth, twelfth, and nineteenth flushing events.

The 60sand/40comp control flushed high concentrations of nitrate+nitrite, TP, Ortho-P, and dissolved Cu. These results are consistent with previous studies (Herrera 2014a, 2015) performed on this BSM and indicate the compost fraction is the predominant source of these pollutants.

All the treatments generally exhibited some initial flushing of TP, Ortho-P and dissolved Cu; however, concentrations were initially lower and rapidly declined relative to those for the 60sand/40comp control. Flushing of TP and Ortho-P from the 60sand/40comp control actually increased substantially before decreasing.

The treatment containing 10 percent compost with a polishing layer (70vs/10comp/p-layer) also flushed elevated levels of nitrogen and phosphorus compared to treatments not containing compost; however, concentrations were lower than the 60sand/40comp control.

In general, treatments containing the coco coir pith and either GAC or high carbon wood ash were the best performers for reducing pollutant flushing. The additive, (GAC or high carbon wood ash) that provides the most benefit in these blends is not known.

Summary results for the flushing experiments are provided below in Table 2 through Table 5. Treatments are arranged from lowest to highest median effluent concentration.

Table 2. Flushing Experiment Effluent Concentration Summary Statistics for Total Suspended Solids.

Rank	Treatment	Units	Median Influent Concentration	Median Effluent Concentration
1	90vs/10comp/player	mg/L	1.1	7.85
2	70vs/20cp/10ash	mg/L	1.1	30.3
3	70ws/20cp/10ash	mg/L	1.1	31.8
4	70vs/20cp/10gac	mg/L	1.1	32.85
5	70vs/20fe/10de	mg/L	1.1	40.2
6	70vs/20fe/10ash	mg/L	1.1	42.25
7	60/40	mg/L	1.1	42.75
8	70vs/20cp/10de	mg/L	1.1	71.6

Treatments are arranged from lowest to highest median effluent concentration.

Table 3. Flushing Experiment Effluent Concentration Summary Statistics for Nitrate+Nitrite.

Rank	Treatment	Units	Median Influent Concentration	Median Effluent Concentration
1	70vs/20fe/10de	mg-N/L	0.014	0.012
2	70vs/20fe/10ash	mg-N/L	0.014	0.012
3	70vs/20cp/10de	mg-N/L	0.014	0.013
4	70vs/20cp/10ash	mg-N/L	0.014	0.015
5	70vs/20cp/10gac	mg-N/L	0.014	0.015
6	70ws/20cp/10ash	mg-N/L	0.014	0.015
7	90vs/10comp/player	mg-N/L	0.014	0.192
8	60/40	mg-N/L	0.014	1.275

Treatments are arranged from lowest to highest median effluent concentration.

Table 4. Flushing Experiment Effluent Concentration Summary Statistics for Ortho-Phosphorus.				
Rank	**Treatment**	**Units**	**Median Influent Concentration**	**Median Effluent Concentration**
1	70vs/20cp/10gac	mg-P/L	0.004	0.021
2	70vs/20fe/10de	mg-P/L	0.004	0.028
3	70vs/20fe/10ash	mg-P/L	0.004	0.029
4	70ws/20cp/10ash	mg-P/L	0.004	0.052
5	70vs/20cp/10ash	mg-P/L	0.004	0.103
6	90vs/10comp/player	mg-P/L	0.004	0.134
7	70vs/20cp/10de	mg-P/L	0.004	0.197
8	60/40	mg-P/L	0.004	1.015

Treatments are arranged from lowest to highest median effluent concentration.

Table 5. Flushing Experiment Effluent Concentration Summary Statistics for Dissolved Copper.				
Rank	**Treatment**	**Units**	**Median Influent Concentration**	**Median Effluent Concentration**
1	70vs/20cp/10gac	ug/L	0.5	0.5
2	70ws/20cp/10ash	ug/L	0.5	0.6
3	90vs/10comp/player	ug/L	0.5	1.0
4	70vs/20cp/10de	ug/L	0.5	1.1
5	70vs/20cp/10ash	ug/L	0.5	1.1
6	70vs/20fe/10de	ug/L	0.5	3.0
7	70vs/20fe/10ash	ug/L	0.5	3.8
8	60/40	ug/L	0.5	9.3

Treatments are arranged from lowest to highest median effluent concentration.

Dosing Experiments

Dosing experiments were performed to evaluate the pollutant capture potential of the media treatments. Each of the 24 columns were dosed on five occasions with natural stormwater or natural stormwater augmented with reagent grade chemicals to attain target concentration ranges.

The 60sand/40comp control flushed high concentrations of nitrate+nitrite, TP, Ortho-P, and dissolved Cu during the dosing phase of the experiments as well. Pollutant capture performance for the other treatment with compost (70vs/10comp/p-layer) was better than the 60sand/40comp control, but poorer than the best performers not containing compost.

In general, treatments containing the coco coir pith and either GAC or high carbon wood ash were the best performers for capturing pollutants. The additive (GAC or high carbon wood ash) that provides the most benefit in these blends is not known.

Summary results for the dosing experiments are provided below in Table 6 through Table 9. Treatments are arranged from lowest to highest median effluent concentration. Note that dosing event 4 is not included in the summary statistics for dissolved Cu because influent concentrations were much higher (approximately 300 µg/L) compared to approximately 8 µg/L for all other experiments.

Table 6. Dosing Experiment Effluent Concentration Summary Statistics for Total Suspended Solids.				
Rank	Treatment	Units	Median Influent Concentration	Median Effluent Concentration
1	90vs/10comp/player	mg/L	83.04	3.7
2	70vs/20fe/10ash	mg/L	53.12	13.3
3	70ws/20cp/10ash	mg/L	83.04	15.3
4	60/40	mg/L	53.12	16.9
5	70vs/20fe/10de	mg/L	53.12	19.8
6	70vs/20cp/10ash	mg/L	83.04	21.45
7	70vs/20cp/10de	mg/L	53.12	26.6
8	70vs/20cp/10gac	mg/L	83.04	46.4

Treatments are arranged from lowest to highest median effluent concentration.

Table 7. Dosing Experiment Effluent Concentration Summary Statistics for Nitrate+Nitrite.				
Rank	Treatment	Units	Median Influent Concentration	Median Effluent Concentration
1	70vs/20cp/10gac	mg-N/L	1.22	0.025
2	70ws/20cp/10ash	mg-N/L	1.22	0.164
3	70vs/20cp/10ash	mg-N/L	1.22	0.333
4	70vs/20fe/10ash	mg-N/L	1.12	0.409
5	70vs/20fe/10de	mg-N/L	1.12	0.707
6	70vs/20cp/10de	mg-N/L	1.12	0.984
7	90vs/10comp/player	mg-N/L	1.22	1.42
8	60/40	mg-N/L	1.12	10.7

Treatments are arranged from lowest to highest median effluent concentration.

Table 8. Dosing Experiment Effluent Concentration Summary Statistics for Ortho-Phosphorus.				
Rank	Treatment	Units	Median Influent Concentration	Median Effluent Concentration
1	70ws/20cp/10ash	mg-P/L	0.323	0.022
2	70vs/20cp/10de	mg-P/L	0.088	0.034
3	70vs/20cp/10gac	mg-P/L	0.323	0.042
4	70vs/20cp/10ash	mg-P/L	0.323	0.048
5	70vs/20fe/10ash	mg-P/L	0.088	0.080
6	70vs/20fe/10de	mg-P/L	0.088	0.108
7	90vs/10comp/player	mg-P/L	0.323	0.120
8	60/40	mg-P/L	0.088	0.948

Treatments are arranged from lowest to highest median effluent concentration.

Table 9. Dosing Experiment Effluent Concentration Summary Statistics for Dissolved Copper.				
Rank	**Treatment**	**Units**	**Median Influent Concentration**	**Median Effluent Concentration**
1	70ws/20cp/10ash	ug/L	8.2	1.6
2	70vs/20cp/10gac	ug/L	8.2	3.4
5	90vs/10comp/player	ug/L	8.2	3.85
3	70vs/20cp/10ash	ug/L	8.2	4.8
4	70vs/20cp/10de	ug/L	8.43	5.25
6	60/40	ug/L	8.43	10.7
7	70vs/20fe/10ash	ug/L	8.43	19.4
8	70vs/20fe/10de	ug/L	8.43	20.4

Treatments are arranged from lowest to highest median effluent concentration.

Conclusions and Recommendations

Based on the results from these experiments, the following major study conclusions were identified:

- The 60sand/40comp control exported statistically higher concentrations of nitrate+nitrite, TP, Ortho-P, and dissolved Cu compared to the non-compost treatments during the flushing and dosing phases. As a result, the capability of the 60/40 media to treat nitrate+nitrite, TP, Ortho-P, and dissolved Cu was substantially reduced.

- All the treatments generally exhibited some initial flushing of TP, Ortho-P and dissolved Cu; however, concentrations were initially lower and rapidly declined relative to those for the 60sand/40comp control. Flushing of TP and ortho-P from the 60sand/40comp control actually increased substantially before decreasing.

- Pollutant capture performance in the dosing experiments for the 70vs/10comp/p-layer treatment was better than the 60sand/40comp control, but significantly poorer than the better performers not containing compost. The 70vs/10comp/p-layer treatment was the best performer for TSS capture, likely due the finer texture of the polishing layer compared to the Type 26 drainage layer used in all other treatments.

- In general, treatments containing the coco coir pith and either GAC or high carbon wood ash were the best performers with regard to pollutant flushing and pollutant capture. The additive (GAC or high carbon wood ash) that provides the most benefit in these blends is not clear.

- Ksat rates for all the treatments tested were extremely high (ranging from 32 to 161 inches/hour). Performance for TSS and particulate bound pollutants may be improved with media blends having lower Ksat rates; however, optimizing treatment performance based on this aspect of media design was outside the scope of this study.

- All media germinated plants and exhibited high water holding capacity and low organic matter content as anticipated. However, no clear plant growth performance pattern emerged for specific treatments. The plant germination tests provide a first look at the media to confirm there are no toxins inhibiting germination and that plants grow during the two week test.

Based on these conclusions, the following recommendations are provided to further improve the treatment performance and develop an improved specification for BSM.

1. Identify and optimize a preferred BSM:

    - The study results indicate the treatments containing the coco coir pith are generally the best performers out of all the treatments evaluated. However, further work is necessary to optimize the hydrologic performance of BSMs containing this component and the sands used in the experiments.

    - The study results also indicated that GAC and high carbon wood ash increase treatment performance for several pollutants; however, it is not clear which component provides the most benefit. Therefore, additional lab and pilot scale studies are recommended to obtain more data on the performance of these media components.

    - Results from this study suggest treatments that incorporate coir coco pith will germinate plants. However, more detailed studies on plant establishment and health are recommended to confirm the capability of these media to support healthy plants in a bioretention setting.

    - Ongoing research by Washington State University (WSU) has shown that stormwater treated through bioretention systems is significantly less toxic to Coho salmon and other aquatic organisms relative to untreated stormwater. To date, these studies have largely focused on bioretention systems using the default BSM containing 60% sand and 40% compost or 60% sand, 15% compost and other additives. To ensure bioretention systems will continue to provide protection for aquatic organisms, this toxicological research should be expanded to investigate alternative treatments identified through this study and future studies.

2. Investigate the availability of BSM components and conduct full-scale testing

    - Once candidate treatments are identified, conduct analysis to confirm all the individual components are available in sufficient quantities to meet expected demand and assess other factors such as cost, source location, manufacturing processes, sustainability, and patent infringement.

    - Due to the presence of data artifacts that may be introduced through pilot scale studies, the preferred treatment(s) should also be subject to full-scale testing to confirm the expected performance.

3. Develop necessary resources for updating the SWMMWW

- Once a preferred treatment is identified, guidelines for consistency and quality control should be developed for the individual components and subsequent blend to ensure the expected performance.
- Based on the Ksat rate for the preferred treatment (or use of an outlet control) update sizing criteria to ensure constructed systems will provide adequate treatment for the design storm.