

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

FINAL REPORT

Prepared for
Kitsap County

Prepared by
Herrera Environmental Consultants, Inc.



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Prepared for
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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 bioretention soil media (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 (TP), ortho-phosphorus (ortho-P), and total and dissolved copper (total and dissolved Cu). 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.

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 wood 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-coated 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 total water volume used for flushing was 361.8 liters which is equivalent to one water year in the Seattle area with a bioretention surface area of 6.7 percent of the contributing area.

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.

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.

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 total water volume used for flushing was 93.8 liters which is equivalent to approximately 26 percent of a water year in the Seattle area with a bioretention surface area of 6.7 percent of the contributing area.

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 K_{sat} 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 condition.

INTRODUCTION

The 2012 Western Washington Stormwater Management Manual (Ecology 2014) requires that the default bioretention soil mix (BSM) in western Washington contains a mixture of 60% sand and 40% compost by volume. Monitoring data from several studies conducted in the 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 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). Project partners included Kitsap County (the grant recipient) and an advisory group with representation from the following entities: Kitsap County, Ecology, City of Seattle, City of Redmond, and Washington Department of Transportation. Geosyntec Consultants served as a technical advisor to the study and provided third party review of study deliverables. Seattle University provided laboratory space, faculty support and students to assist with conducting experiments.

This study had four primary objectives:

1. Select individual bioretention media components and analyze the potential of those components to leach N, P, and Cu.
2. Analyze media blends developed from components identified in objective 1 for the ability to capture and retain N, P, Cu, and other stormwater pollutants of concern when exposed to flushing and dosing regimes in columns (the ability of the media blends to germinate vegetation was also assessed).
3. Develop recommendations for updating current BSM media guidelines for improved capture and retention of N, P, and Cu based on leaching, pollutant retention, hydraulic considerations, cost, and sustainability criteria.
4. Identify unresolved water quality and hydraulic performance issues from this study that may warrant future evaluation.

At the onset of this study, a Quality Assurance Project Plan (QAPP) (Herrera 2014b) was prepared to describe the procedures that would be used to meet these study objectives. One revision of this QAPP (Herrera 2014c) was subsequently prepared to document modifications to these procedures; for reference, this later version of the QAPP is reproduced in Appendix A.

This document was prepared by Herrera to summarize the results from the study and is organized as follows:

Study Background describes the need for the media research.

Study Design and Methodology including modifications to the procedures identified in the original QAPP or procedures not fully documented in both versions of the QAPP.

Results are presented and discussed in relation to the primary study objectives identified above and organized by contaminant type.

Discussion of results is organized by media blends.

Conclusion and Recommendations summarize findings and future research needs.

STUDY BACKGROUND

The current Washington State, Phase I Municipal Stormwater Permit (effective August 1, 2013) requires the use of low impact development (LID) practices as the first option for managing stormwater where feasible. Bioretention is the most widely applicable and flexible Best Management Practice (BMP) in the suite of LID practices. Bioretention facilities are shallow landscaped depressions with a designed soil mix and plants adapted to the local climate and soil moisture conditions. Sized to receive stormwater from a small contributing area, these systems are designed to more closely mimic natural forested conditions where healthy soil structure and vegetation promote the infiltration, storage, filtration, and slow release of stormwater flows. When used in a typical LID application, bioretention areas are designed as small-scale, dispersed systems that are integrated into the site as a landscape amenity (see Figure 1).



Figure 1. Typical Bioretention Swales (from City of Seattle and Kitsap County)

Pursuant to the 2012 Western Washington Stormwater Management Manual (Ecology 2014), the default BSM used to construct bioretention facilities in western Washington should contain a mixture of 60% sand and 40% compost. While bioretention systems constructed with this BSM have been shown to provide good water quality treatment for many contaminants (e.g., sediment, zinc, hydrocarbons, and likely bacteria), regional research indicates N, P, and Cu may also be exported from these systems (Herrera 2014a, 2015). Both the compost and sand used in the BSM have been shown to be potential sources for these pollutants (Herrera 2014a).

Bioretention systems may include under-drains, especially in areas with soils that are less suitable for infiltration. In these cases, a portion of the treated runoff is discharged back into the stormwater conveyance system rather than infiltrated. Export of N, P, and Cu is of particular concern for bioretention installations with under-drains that discharge to receiving waters. In addition, export of these pollutants is also a concern for bioretention installations

with or without under-drains when located over shallow groundwater or in proximity to phosphorus and nitrogen sensitive receiving waters.

To address this concern, this study was implemented to study new materials that may improve BSM performance for the capture and retention of N, P, and Cu. Because each BSM component has specific flow and pollutant capture characteristics that influence hydraulic conductivity and water quality treatment performance for specific contaminants (Pitt and Clark 2010), this study first analyzed each media component for leaching potential of N, P and Cu. Media blends comprised of those components were then tested in columns to assess the flushing and pollutant capture capability for multiple pollutants. More detailed information on the experimental design for this study is provided in the next section and the QAPP (Appendix A).

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 hydraulic conductivity and support plants.
3. Combine components at various ratios, place in column arrays, 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 D 2434.
4. Dose the best performing 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.

As discussed previously, a QAPP was prepared at the onset of this study (Herrera 2014b) to provide detailed descriptions of the procedures to be used for these tasks. A revised version of the QAPP was subsequently prepared to document modifications to these procedures (Herrera 2014c). For reference, this later version of the QAPP is reproduced in Appendix A. A summary of the changes made to the original QAPP is also provided below. In addition, procedures used in the study but not fully documented in either version of the QAPP are also summarized.

Revisions to QAPP

The following three changes were made to the original QAPP (Herrera 2014b) that was prepared for the study:

- The water distribution system for the flushing and dosing experiments was initially designed to operate by gravity through orifices in the bottom of a distribution tank. To improve the accuracy of the distribution system, the final design included peristaltic pumps to deliver water during these experiments (see additional detail below on the related calibration regime).
- Bacteria and particle size distribution were eliminated from the parameter list due to budget constraints.

- The initial sampling regime indicated the mixing tanks and distribution lines would be cleaned between dosing experiments. However, stormwater containing various contaminants was used for the dosing tests. Based on previous experiments with similar delivery systems residual contaminants in the mixing tanks and distribution lines from previous dosing were judged to not significantly influence concentrations of target contaminants in subsequent dosing. Accordingly, the tanks and distribution lines were not cleaned between dosing experiments and no rinsate blanks were collected.

These changes are reflected in the revised version of the QAPP that is reproduced in Appendix A.

Summary Documentation of Procedures

The subsections below provide a summary of the experimental design and documentation of procedures that were added later in the study by the Advisory group and not provided in the original and revised versions of the QAPP (Herrera 2014c, b) for the study. The following subsections include:

- Survey and Selection of Media Components
- Synthetic Precipitation Leaching Protocol Extraction
- Column Array for Dosing and Flushing Experiments
- Flushing Experiments
- Hydraulic Conductivity Measurements
- Plant Growth and Media Physical Properties
- Data Analysis Procedures

Survey and Selection of Media Components

A rapid survey of the scientific literature was performed to identify candidate media components for this study in each of the following categories: bulk aggregates (e.g., sands) and bulk organic materials (e.g., compost) that comprise the majority of the media blends; and mineral and organic additives which provide specific pollutant capture and/or hydraulic characteristics, and comprise less of the overall volume. The following information, when available, was assembled for each media component through this survey:

- | | |
|-----------------------------------|--|
| • Material composition | • Quantity for cost estimate |
| • Source or manufacturing process | • Estimated Percentage Use in BSM (low) |
| • Vendor | • Estimated Percentage Use in BSM (high) |
| • Source location | • Target pollutants |
| • Unit cost | • Treatment mechanisms |
| | • Performance notes |

See Appendix K for a complete list of media candidates.

With input from the project Advisory group, a subset of media components was subsequently prioritized for further analyses in this study using these criteria:

- Treatment performance: includes potential for both leaching and estimates of pollutant capture capability from the literature.
- Sustainability: includes availability, transportation requirements, manufacturing and/or extraction processes.
- Cost: media components with lower unit costs were prioritized in the selection process. Cost was considered along with the above criteria to attain the best balance of cost to optimum performance. See Appendix M for media blend cost per cubic yard.

Synthetic Precipitation Leaching Protocol Extraction

The leaching potential for N, P, and Cu for selected media components was assessed using Synthetic Precipitation Leaching Protocol (EPA Method 1312). The analysis was performed at Analytical Resources Inc. (ARI) an Ecology certified laboratory. Parameters analyzed for the SPLP analysis are contaminants flushed from sand and compost in previous studies (Herrera 2014a, 2015) and consisted of: total nitrogen, nitrate-nitrite, total phosphorus, ortho-phosphorus, and total and dissolved copper using two procedures:

- Metals: weak acid (H₂SO₄/HNO₃) extraction using a pH recommended for western U.S.
- Nutrients: deionized water extraction.

A 0.7 micron filter was used in the SPLP extraction procedure for copper to isolate the dissolved fraction.

At least two mineral, two organic, and two amendments were selected from the SPLP analysis using the following criteria:

1. Maximum extraction concentrations: Cu ≤ 5 µg/L; N₀₃-N₀₂ ≤ 0.1 mg/L; and TP ≤ 0.1 mg/L.
2. If none of the components initially selected meet these criteria, additional components will be considered for SPLP analysis.
3. If none of the components initially or subsequently selected meet these criteria, then components with the lowest concentrations will be selected and proprietary and non-proprietary components will be considered for use as a polishing layer to reduce effluent concentrations from the media blends comprised of the components with the lowest SPLP concentrations.

Column Array for Flushing and Dosing Experiments

Twenty four columns for flushing and dosing experiments were constructed at the Seattle University Engineering Laboratory. The columns were built using polyvinyl chloride (PVC) with an 8 inch (20.3 cm) diameter and a height of 36 inches (91.4 cm). Each column includes a 1 inch (2.54 cm) slotted under-drain placed at the bottom of the column (Figure 2). The inside of the column walls were roughened to minimize preferential flow between the media and the column wall. Media components meeting SPLP, cost and sustainability criteria above were combined into media blends (see description in Results section) and placed in the columns for subsequent flushing and dosing experiments. The media depth was 18 inches (45.7 cm) with a 12-inch (30.5 cm) aggregate bedding layer placed under the media to provide a final filter before discharge through the under-drain pipe.

Peristaltic pumps were installed to deliver water to the columns during the experiments. The peristaltic pumps were calibrated by repeated test runs to compare the volume delivered by each pump to a target volume. With each repeated test run, the output of the individual pumps was iteratively adjusted until the pump delivered the target volume within the stated accuracy (± 10 percent maximum error). The pumps were calibrated at the beginning and mid-experiment for the flushing experiments and re-calibrated to the maximum delivery rate for the last two dosing experiments.



Key

- 1: 200 gallon (757 liter) cone bottom HDPE mixing tank.
- 2: mixer (10 hp electric motor with 8-inch propeller).
- 3: 15 gallon (189 liter) cone bottom HDPE distribution tank.
- 4: peristaltic pumps (Chem-Tech XP series, model XP080LALX).
- 5: PVC columns.

Figure 2. Column Array for Flushing and Dosing Experiments

After initial calibration, the maximum error for an individual pump was 6.84 percent (mean error for all pumps was 3.03 percent and maximum percent difference was 6.41). After mid-experiment calibration, the maximum error for an individual pump was 5.92 percent (mean error for all pumps was 2.60 percent and maximum percent difference was 7.32). Maximum percent error at maximum delivery rate was 1.82 percent (mean error for all pumps was 0.69 percent and maximum percent difference was 2.46). See Appendix B for peristaltic pump calibration records.

Flushing Experiments

Media components selected from the SPLP analysis were combined, by volume, into media blends, placed in columns, and flushed with deionized water. Deionized water was supplied through a 9-inch Portable Exchange Mixed Bed Deionized Tank filter with a 200,000 ohm output. The filtered water was delivered directly to the distribution tank and distributed to each column by peristaltic pump (Figure 2).

Approximately 13.4 liters of stormwater was applied to each column for the first two flushing events. This is equivalent to 1.32 inches or the 6-month, 24-hour storm in Seattle area for each event. Approximately 26.8 liters of stormwater was applied to each column for the last two high flush events (equivalent to 2.43 inches of precipitation for each event). The drainage to bioretention area ratio used to the flushing volume was 15 to 1 (bioretention area approximately 6.7 percent of the contributing area). The total volume applied to each column approximates the volume delivered to a bioretention area in the Seattle area for 1 water year (October 1 through September 30) given the above sizing factor. See QAPP in Appendix A for specific sizing criteria.

After flushing, the same media columns were dosed with stormwater collected from City of Redmond catch basins. Collected stormwater was augmented with sediment and/or reagent grade salts for a sub-set of events to increase concentrations of target analytes. See Results section for information on influent chemistry. Approximately 13.4 liters of stormwater was applied to each column for the first three dosing events. This is equivalent to 1.32 inches or the 6-month, 24-hour storm in Seattle area for each event. Approximately 26.8 liters of stormwater was applied to each column for the last two high-dose events (equivalent to 2.43 inches of precipitation for the Seattle area for each event). The drainage to bioretention area ratio used to the flushing volume was 15 to 1 (bioretention area approximately 6.7 percent of the contributing area).

Hydraulic Conductivity

Two methods were used to evaluate saturated hydraulic conductivity (Ksat). As described in the QAPP for the study (Appendix A), falling head Ksat tests were performed for every column at the beginning of the flushing experiments. In addition, constant head permeability tests were also performed by Shannon and Wilson using American Society for Testing and Materials (ASTM) D2434. This additional testing was performed to provide Ksat test values comparable to previous media analyses.

To achieve similar compaction within each column, media was added in 6 inch (15 cm) lifts and each lift compacted by dropping a 2.0 kg (4.41 lb) disc 3 times from a distance of 6 inches (15 cm) above each lift. Media moisture was not measured, but all media was placed at similar moisture condition. Again, hydraulics and associated measurements necessary to provide detailed procedures for hydraulics experiments were beyond the scope of this project.

Plant Germination and Media Physical Properties

Plant germination, media porosity and cation exchange capacity were evaluated at Soil Control Lab in Watsonville California. The specific analyses performed are described in the following subsections.

Plant Germination

Plant germination tests were performed to determine if the media blends would germinate plants (i.e. confirm the media components do not contain growth inhibitors or toxins) and maintain plant health subsequent to germination. These tests were performed using cucumber, rye, and corn following procedures from Test Methods for the Examination of Composting and Compost (TMECC) 05.05-A (Cucumber Bioassay).

Porosity

Porosity was assessed to determine available pore space for water holding capacity in the media blends. To perform these tests, samples of the media blends were placed in a cylinder of a known volume and weight and then soaked in water until all organic matter was saturated and all pore spaces filled. Based on the dry weight of sample and the water in the cylinder, the total porosity was determined at the specific compaction for the media blend. Water was subsequently drained from the cylinder for two hours and collected. The water remaining in the sample pores was then used to approximate the water remaining at field capacity for the media blend.

Cation Exchange Capacity

The cation exchange capacity (CEC) of the media blends was evaluated as a measure of the media's capability to exchange and sorb cations (primarily metals). This analysis was conducted using CEC peat method 973.09 AOAC 15th edition (pg 39).

Carbon Nitrogen Ratio

The carbon nitrogen ratio (C/N) of the media blends was analyzed to compare their carbon and nitrogen balance relative to values considered appropriate for typical bioretention plants in western Washington. This analysis was conducted using a Leco CHN analyzer and TMECC 04.02-D (Total Nitrogen by Combustion) and 04.01-A (Organic Carbon).

Organic Matter

The amount of organic matter (OM) in the media blends was tested because OM influences water holding capacity, CEC and media structure. This analysis was conducted using TMECC 05.07-A (Loss on Ignition).

Data Analysis Procedures

Two-factor analysis of variance (ANOVA) tests were used to compare effluent concentrations across the media treatments in both the flushing and dosing experiments. These tests were specifically performed to identify media treatments with superior performance relative to others in each of these experiments.

For the flushing experiments, one factor was the media treatment and the other factor was the cumulative volume flushed through each column (samples were collected at the first, sixth, twelfth, and nineteenth flushing events; see additional detail in the *Results* section). For the dosing experiments, one factor was the media treatment and the other factor was the influent concentration (high and low; see additional detail in the *Results* section).

Because an ANOVA test is considered a parametric procedure, there are several underlying assumptions that must be met when this approach is used; most notably, the data must have a normal distribution and each treatment group must have an equal variance. After visual assessment using boxplot distributions, the effluent concentration data for many of the treatments were found to be non-normal distributions. Accordingly, the ANOVA tests for all parameters were performed on the ranks of the data following guidance provide in Helsel and Hirsh (2002). Each test indicated whether there was a significant difference in effluent concentration due to one or both of the factors, and the interaction of the two. Where a significant difference in effluent concentration was detected due to the media treatment factor in both the flushing and dosing experiments, follow-up Tukey multiple comparison tests were performed to determine which specific media treatments had different effluent concentrations relative to the others. Statistical significance in all these tests was assessed based on an alpha (α) level of 0.05.

Graphical summaries using box plots were also prepared for both the flushing and dosing experiments to facilitate comparisons of effluent concentrations (flushing and dosing) and pollutant percent removal (dosing only). Using these box plots, the following summary statistics are provided:

- The lower and upper whiskers show the minimum and maximum values of the data, respectively
- The lower and upper edges of the box show the 25th and 75th percentile values of the data, respectively
- The horizontal line through the box show the 50th percentile (median) of the data.

Results from the Tukey multiple comparison tests described above are also summarized in these box plots using letters shown on the top of each box. Specifically, boxes with the same letter have effluent concentrations that are not significantly different.

The reduction (in percent) in pollutant concentration during each individual experiment (ΔC) was calculated as:

$$\Delta C = 100 \times \frac{(C_{in} - C_{eff})}{C_{in}}$$

where: C_{in} = composite influent pollutant concentration

C_{eff} = composite effluent pollutant concentration for each treatment

RESULTS

This section presents results from the four primary tasks that were performed for this study to develop improved bioretention media for N, P, and Cu retention and capture. Results are organized to include separate sections for each of the following study components:

- Survey of potential media components
- Synthetic Precipitation Leaching Protocol Results
- Flushing Experiments Results
- Dosing Experiment Results
- Hydraulic Conductivity Evaluation Results
- Plant Growth and Media Physical Properties Results

Because total suspended solids (TSS), nitrate-nitrite, total phosphorus (TP), ortho-phosphorus (ortho-P), Cu (total and dissolved), and Zn (total and dissolved) are the primary pollutants of interest for this study, the presentation of results in this section focuses exclusively on these parameters. Information on this subset of parameters and all other measured analytical parameters is also provided in the following supporting appendices to this section where applicable:

- Appendix C Quality Assurance Review Summary
- Appendix D Quality Assurance Review Worksheets
- Appendix E Synthetic Precipitation Leaching Protocol Results
- Appendix F Graphical Summaries for Flushing Experiment Results
- Appendix G Tabular Summaries for Flushing Experiment Results
- Appendix H Graphical Summaries for Dosing Experiment Results
- Appendix I Tabular Summaries for Dosing Experiment Results
- Appendix J Description of Media Components for Study

Results in Appendices F through I are organized alphabetically by parameter name as follows:

- Alkalinity
- Cadmium, Dissolved
- Cadmium, Total
- Calcium
- Chloride
- Copper, Dissolved
- Copper, Total
- Dissolved Organic Carbon
- Hardness
- Lead, Dissolved
- Lead, Total
- Magnesium
- Nitrate + Nitrite
- Ortho-Phosphorus
- Potassium
- Sodium
- Sulfate
- Total Kjeldahl Nitrogen
- Total Phosphorus
- Total Suspended Solids
- Zinc, Dissolved
- Zinc, Total

Appendix L provides the reports that were received from the analytical laboratory for each parameter of the study.

Survey and Selection of Media Components

A rapid survey of technical bulletins and scientific literature (see reference list at the end of Appendix K) was performed to identify candidate media components for this study in each of the following categories: bulk aggregates (e.g., sands) and bulk organic materials (e.g., compost) that comprise the majority of the media blends; and mineral and organic additives which provide specific pollutant capture and/or hydraulic characteristics, and comprise less of the overall volume. Candidate media components identified through this survey are shown in Appendix K.

Based on criteria identified in the Study Design and Methodology section, the following media components from Appendix K were identified for the SPLP extractions described in the next subsection:

- Bulk aggregate
 - Corliss pipe bedding
 - Corliss utility sand
 - Crushed brick fines
 - Eastern OR iron sand
 - Lava sand
 - Miles Canyon sand
 - Rhyolite sand
 - Volcanic sand
 - Washed sand
- Bulk organic
 - Land Recovery Inc. compost
 - Cedar Grove compost
 - Cedar Grove special compost
 - Coco coir pith
 - Coco peat
 - Dakota peat
 - iron-coated wood chip
- Mineral Additive
 - Activated alumina
 - Diatomaceous earth
 - Oyster shells
 - Zeolite
- Organic Additive
 - High carbon wood ash AS 100+ mesh
 - High carbon wood ash PD 100+ mesh
 - Biochar
 - Granular Activated Carbon 1230AWaGranular Activated Carbon 1230AWb
 - Granular Activated Carbon 824BC

Samples of the selected media components were subsequently collected from suppliers by Herrera staff; where possible, these samples were collected from multiple locations in material stockpiles and composited for analysis.

Synthetic Precipitation Leaching Protocol Results

SPLP extractions were performed on the 26 prospective media components identified from the survey results described in the previous subsection. These extractions were subsequently analyzed for total nitrogen, nitrate-nitrite, TP, ortho-P, and total and dissolved copper. Appendix E provides summary tables from these analyses organized by media component (bulk aggregate, bulk organic, mineral additive, and organic additive) and parameter. These summary tables rank the observed leaching of each parameter from lowest to highest for each media component; lower ranks indicated lower leaching potential. The individual rankings for each parameter are also summed to provide an overall rank of leaching potential.

These rankings were then used to select media components included for further testing as part of media blends. The components selected represented materials with the lowest or near lowest rankings for leaching potential; however, availability and cost also influenced selection. For example, rhyolite sand had a slightly better (lower) overall rank than washed sand; however, availability of rhyolite sand is limited for this region and cost was significantly higher than washed sand.

- Media components selected for the media blends for the column tests include: Bulk aggregate: volcanic sand (vs) and washed sand (ws).

Selection criteria: both volcanic and washed sand ranked lowest overall for leaching potential and are locally available.

- Bulk organic: iron-coated wood chips (fe), coconut coir pith (cp), Cedar Grove compost, and Land Recovery Inc. compost.

Selection criteria: iron-coated wood chips ranked lowest for leaching potential, are locally available and contained iron for phosphorus capture; coconut coir pith ranked slightly higher than coco peat, but has very high water holding capacity and does not contain peat (a material potentially excavated from environmentally sensitive areas); Cedar Grove compost was selected for the 60sand/40comp because this is the compost commonly used for the current BSM specification; and Land Recovery Inc. compost was selected because this material is yard waste feed stock only and had not been tested before this study.

- Mineral additives: diatomaceous earth (de) and activated alumina.

Selection criteria: diatomaceous earth and activated alumina ranked lowest overall for leaching potential; diatomaceous earth has very high water holding capacity; while expensive, activated alumina is material with high phosphorus binding capability.

- Organic additive: 1230AW granular activated charcoal (gac), high-carbon wood ash (ash) and activated bone char.

Selection criteria: 1230AW granular activated charcoal and high carbon wood ash (PD 100+ mesh) ranked lowest overall for leaching potential; granular activated charcoal 824BC ranked higher for overall leaching potential, but was selected for specific copper binding capability.

Activated alumina and granular activated charcoal 824BC were selected specifically for phosphorus and copper binding capability as a polishing layer under media containing 90 percent volcanic sand and 10 percent compost (see Table 10 below for media treatments). The polishing layer is placed under the media as the aggregate filter around the under-drain and as a final filter to capture phosphorus and copper leaching from the compost.

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 by volume is summarized in Table 10.

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 fly 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 wood 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-coated wood chips

gac: granular activated charcoal

vs: volcanic sand

ws: washed sand

p-layer: polishing layer

NA: not applicable

Flushing Experiments Results

Flushing experiments were performed to evaluate potential pollutant leaching from the media treatments. For these experiments, each of the 8 media treatments identified in Table 10 were replicated 3 times in the 24 column array (see description above) using a random block design per the project QAPP (Appendix A). Each column was then 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. Sample collection occurred over a two day period; twelve of the

24 columns were sampled the first day and the remaining twelve the second day. A sample was also collected from an influent monitoring port each day for a total of 26 samples per sampling event (12 effluent samples plus 1 influent sample the first day; and 12 effluent samples plus 1 influent sample the second day).

Results from the flushing experiments are presented below for the eight priority pollutants identified previously. Flushing experiment results for all the measured analytical parameters are also summarized in Appendices F and G.

Total Suspended Solids

Figure 3 on page 21 provides line plots showing median effluent concentrations of TSS for each treatment by percent water year and boxplots showing effluent concentration distributions across all sampled flushing events. Table 11 on page 31 also presents the raw data and summary statistics for TSS from each flushing event.

TSS influent concentrations were below the reporting limit (1.1 milligrams per liter [mg/L]) for all sampled flushing events. In general, all treatments followed a typical flushing pattern of decreasing TSS concentration as flushing progressed. Two exceptions to this trend were a slight increase in median concentrations from the first to second flush for the 70vs/20fe/10de and 70vs/20fe/10ash treatments.

Notably, the TSS concentrations for the 90vs/10comp/p-layer dropped rapidly to very low effluent concentrations after the first flush. Median effluent concentrations for all four sampling events were not considerably different across treatments except for 70vs/20cp/10de (significantly higher) and 90vs/10comp/p-layer (significantly lower).

The best performing media reach the TAPE target of less than 20 mg/l TSS within ½ a year and include: 70ws/20cp/10ash, 70vs/20cp/10ash and the 90vs/10comp/p-layer media. Media that reduce TSS concentrations to under 20 mg/l within a year are: 70vs/20cp/10gac, and 60sand/40comp.

Nitrate+Nitrite

Nitrate+nitrite influent concentrations varied among flushing events possibly due to contamination within the water delivery system (Table 12, page 33). The first two events were at or near the reporting limit (0.010 and 0.012 mg/L respectively) for all columns. For the third event, influent concentrations increased from 0.012 to 0.017 mg/L from the first day (first set of columns) to the second day (second set of columns). Influent concentrations varied during the fourth event as well with the first set of columns receiving 0.035 mg/L and the second 0.016 mg/L.

For the 60sand/40comp control, the median nitrate+nitrite effluent concentration for all sampled events was significantly higher than all other treatments except the 90vs/10comp/p-layer treatment (see Figure 4 and Table 12, pages 22 and 33). For the first sampled nitrate+nitrite flushing event, the median effluent concentration (18.6 mg/L) of the 60sand/40comp control was 3 orders of magnitude higher than the treatments not containing compost (e.g. 0.02 mg/L for the 70vs/20cp/10ash treatment). While the nitrate+nitrite effluent concentrations in the 60sand/40comp decreased from the first to final sampled

flushing event, the median concentration remained significantly higher than all other treatments for all events (5.339 mg/L compared to 0.017 mg/L for the 70vs/20cp/10ash).

Total Phosphorus

TP influent concentrations were below the reporting limit (0.008 mg/L) for all flushing events (Table 13, page 35). The median TP effluent concentration for the 60sand/40comp control (1.28 mg/L) was significantly higher than all other treatments (e.g. 0.117 mg/L for 10vs/20cp/10gac). Flushing performance varied statistically among treatments (Figure 5, page 23); however, the treatments containing iron-coated wood chips, and coco-coir pith with granular activated charcoal or high-carbon fly ash generally exhibited slightly lower median effluent concentrations than the other treatments (e.g. 0.277 mg/L for the 10vs/20fe/10de and 0.117 mg/L for the 70vs/20cp/10gac). Flushing of total phosphorus from the 60sand/40comp treatment followed a pattern observed in other field monitoring where concentrations increase over time before decreasing (Herrera 2014a, 2015). Two other treatments (70vs/20fe/10de and 70ws/20cp/10ash) exhibited very slight increases in effluent concentrations from the first to second flushing events and then decreased as flushing progressed. Effluent concentrations for the 90vs/10comp/p-layer treatment were initially high (similar to the 60sand/40comp) but dropped significantly (levels similar to the non-compost treatments) after the first sampling event. All other treatments followed a typical flushing pattern of decreasing effluent concentrations over time.

Ortho Phosphorus

Ortho-P influent concentrations were below the reporting limit (0.004 mg/L) for all flushing events (Table 14, page 37). The initial median ortho-P effluent concentration for the 60sand/40comp control was significantly higher than all other treatments (0.425 mg/L compared to 0.057 mg/L for the 70vs/20cp/10ash) and remained higher for all flushing experiments. Flushing performance varied statistically among treatments (Figure 6, page 24). However, the treatments containing iron-coated wood chips, and coco-coir pith with granular activated charcoal or high-carbon fly ash generally exhibited slightly lower median effluent concentrations than the other treatments (e.g. 0.028 mg/L for the 10vs/20fe/10de and 0.021 mg/L for the 70vs/20cp/10gac).

Flushing of ortho-P from the 60sand/40comp treatment followed a pattern observed in other research and field monitoring where concentrations increase over time before decreasing (Figure 6). Two other treatments (70vs/20fe/10ash and 70ws/20cp/10ash) exhibited slight increases in effluent concentrations from the first to second flushing events and then decreased as flushing progressed. All other treatments followed a typical flushing pattern of decreasing effluent concentrations over time.

Total Copper

Total Cu influent concentrations varied slightly among flushing events (Table 15, page 39). The first event was below the reporting limit (0.5 micrograms per liter [$\mu\text{g/L}$]) for all columns. For the second, third, and fourth events influent concentrations varied from 0.5 to 0.9 $\mu\text{g/L}$ from the first day (first set of columns) to the second day (second set of columns).

The median effluent concentration for 60sand/40comp control (16.4 $\mu\text{g/L}$) was significantly higher than all other treatments except the 70vs/20fe/10ash (Table 15). Flushing

performance varied among treatments (Figure 7, page 25); however, the treatments containing coco-coir, granular activated charcoal or high-carbon fly ash generally exhibited slightly lower effluent concentrations than the other treatments (4.4 µg/L for the 70vs/20cp/10gac compared to 13.0 µg/L for the 70vs/20fe/10ash).

Median effluent concentration for the 60sand/40comp control were very high (43.5 µg/L) compared to the best performer (70ws/20cp/10ash at 7.8 µg/L) for the initial flushing event. Effluent concentrations then dropped rapidly to levels 2-3 times higher than the treatments with the lowest concentrations. Two treatments (70vs/20fe/10ash and 70ws/20cp/10ash) exhibited slight increases in effluent concentrations from the first to second flushing events and then decreased as flushing progressed. All other treatments followed a typical flushing pattern of decreasing effluent concentrations over time.

Dissolved Copper

Dissolved Cu influent concentrations were below the reporting limit (0.5 µg/L) for all flushing events (Table 16, page 41). The initial median effluent concentration (38.4 µg/L) for the 60sand/40comp control was approximately 5 to 50 times higher than the other treatments (e.g. 2.2 µg/L for the 70vs/20cp/10ash). The median effluent concentration for the 60sand/40comp then fell rapidly to approximately 3-10 times that of the other treatments (e.g. 11.4 µg/L compared to 1.3 µg/L for the 70vs/20cp/10ash). The median dissolved Cu effluent concentration for the 60sand/40comp control was significantly higher than all other treatments (Figure 8, page 26). Flushing performance varied considerably among treatments; however, the treatments containing coco-coir, granular activated charcoal or high-carbon fly ash generally exhibited small, but significantly, lower effluent concentrations than the other treatments.

Total Zinc

Total Zn influent concentrations were below the reporting limit (4 µg/L) for all but the first half of the third flushing event (5 µg/L) (Table 17, page 43). The median effluent concentration for the 60sand/40comp control was significantly higher (13.5 µg/L) than all other treatments (Figure 9, page 27). In general, all other treatment median effluent concentrations were similar with low concentration initially and then declining to at or below the reporting limit by the second sampling event.

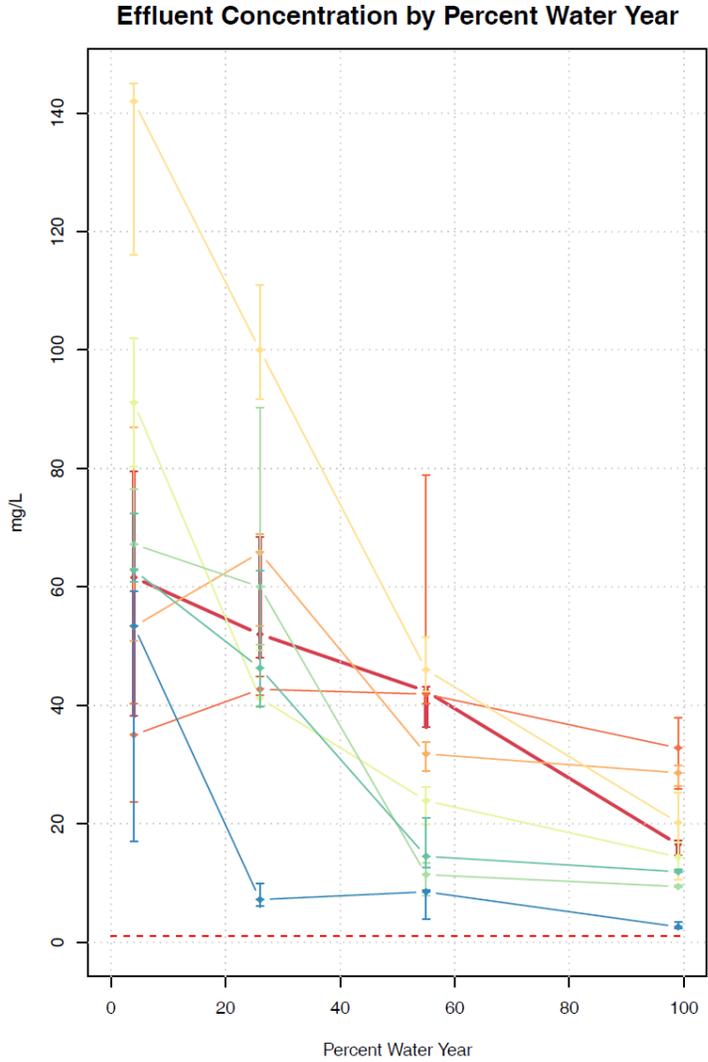
An unusually high effluent concentration (96 µg/L) was observed for the 70vs/20cp/10gac treatment during the second flushing event. Field or lab quality control data did not indicate there was a problem for this sample; however, the measurement lies far outside the pattern of all other measurements for total Zn and should be viewed with caution.

Dissolve Zinc

Dissolved Zn influent concentrations were below reporting limit (4 µg/L) for all flushing events (Table 18, page 45). The median dissolved Zn effluent concentration for the 60sand/40comp control and 90vs/10comp/p-layer treatment were significantly higher than all other treatments (Figure 10, page 28). All other median effluent concentrations were not significantly different and near or below reporting limits from the initial to final flush.

Flushing Experiments Results - Plots

Total Suspended Solids



- 60/40
- 70vs/20fe/10de
- 70vs/20fe/10dash
- 70vs/20cp/10de
- 70vs/20cp/10gac
- 70vs/20cp/10dash
- 70vs/20cp/10dash
- 90vs/10comp/player
- Reporting Limit (1.1 mg/L)

Two-Way ANOVA on Effluent (ranks)
 Treatment p-value : 2.13e-18 ***
 Sample Event p-value : 2.01e-29 ***
 Interaction p-value : 6.44e-12 ***

Effluent Concentration by Treatment

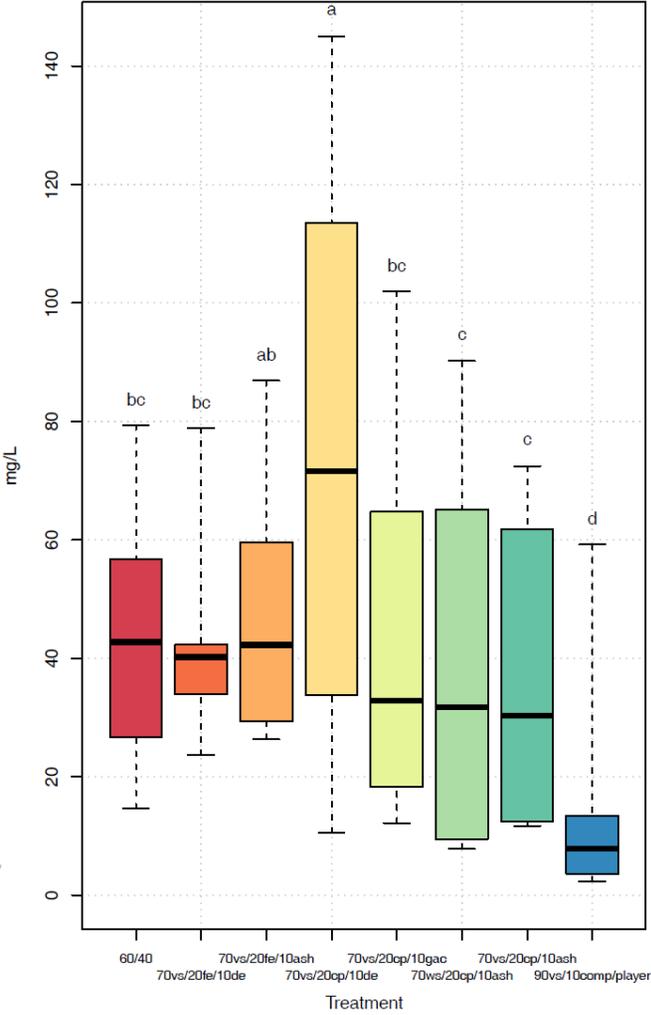


Figure 3. Flushing Experiment Effluent Concentration Trend Lines and Distributions by Media Treatment for Total Suspended Solids.

Nitrate + Nitrite

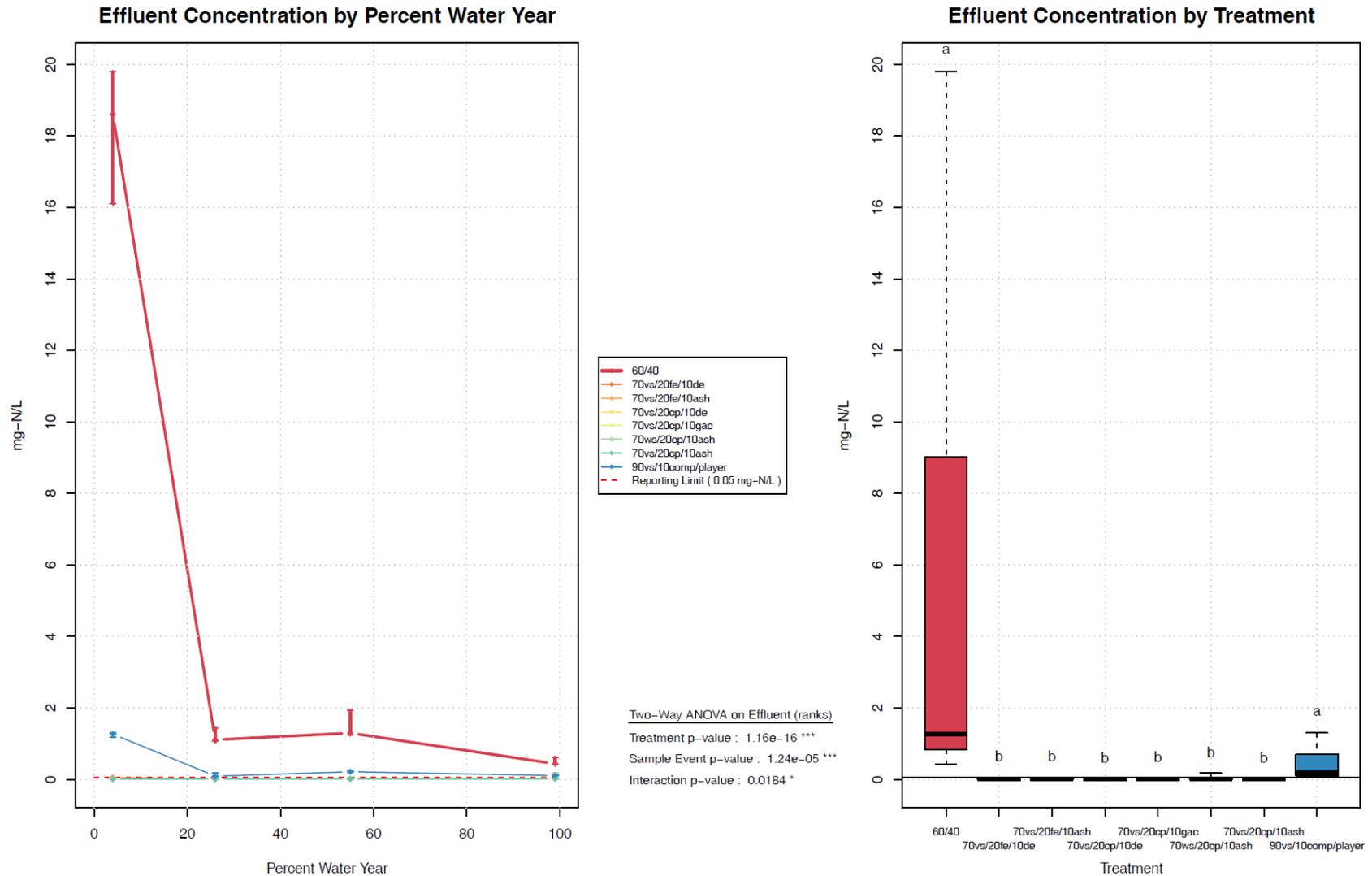


Figure 4. Flushing Experiment Effluent Concentration Trend Lines and Distributions by Media Treatment for Nitrate+Nitrite.

Total Phosphorus

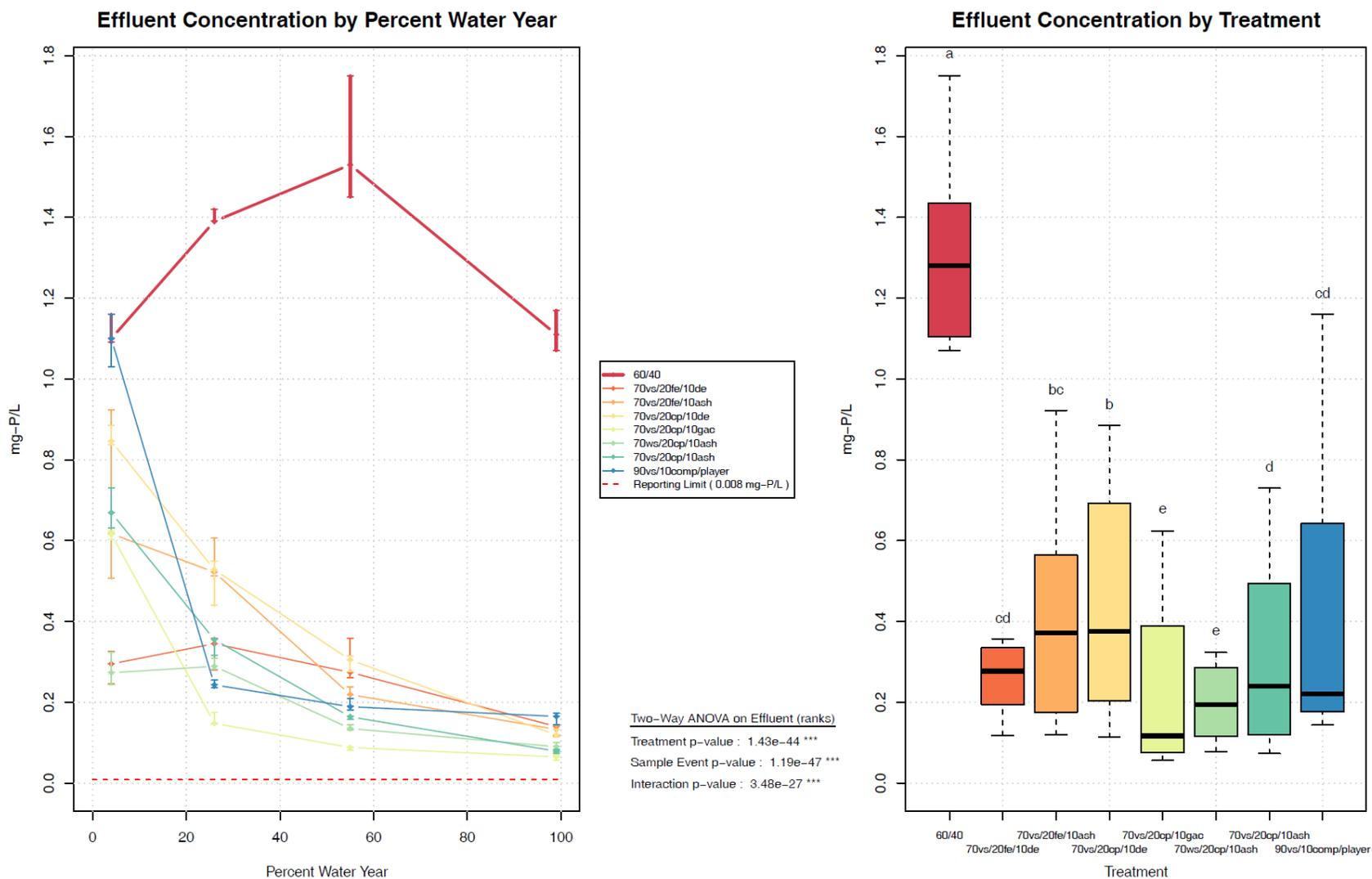


Figure 5. Flushing Experiment Effluent Concentration Trend Lines and Distributions by Media Treatment for Total Phosphorus.

Ortho-Phosphorus

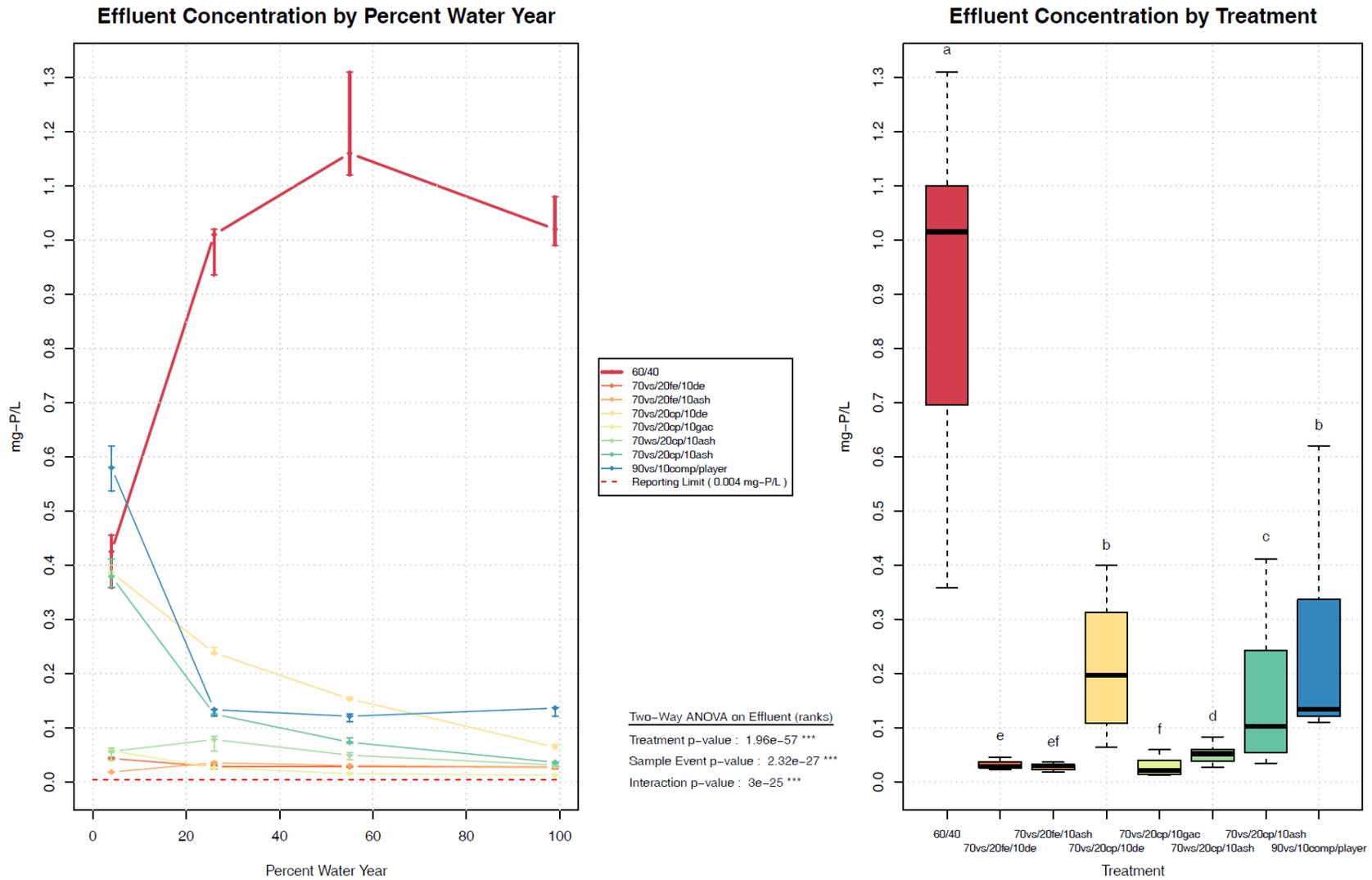


Figure 6. Flushing Experiment Effluent Concentration Trend Lines and Distributions by Media Treatment for Ortho Phosphorus.

Total Copper

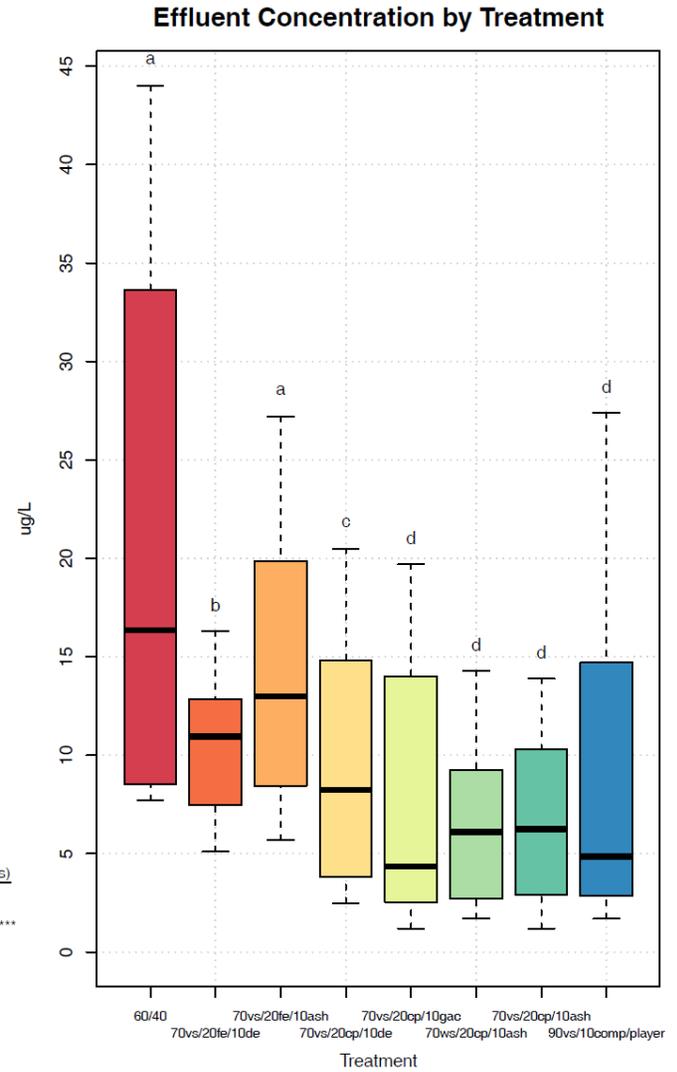
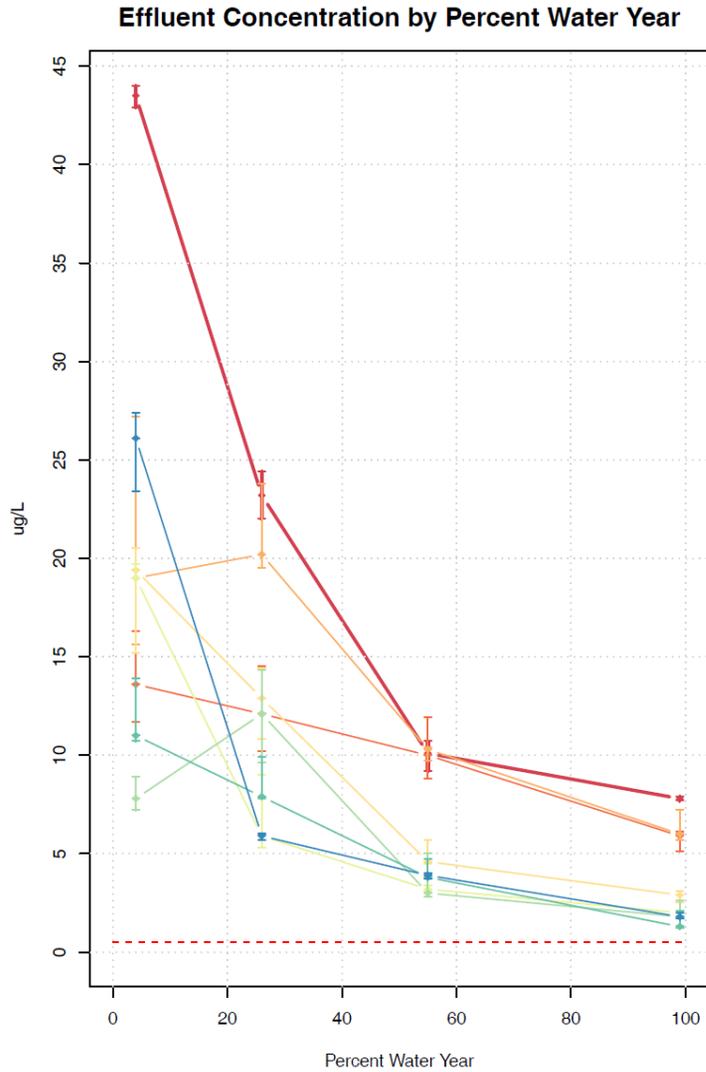


Figure 7. Flushing Experiment Effluent Concentration Trend Lines and Distributions by Media Treatment for Total Copper.

Dissolved Copper

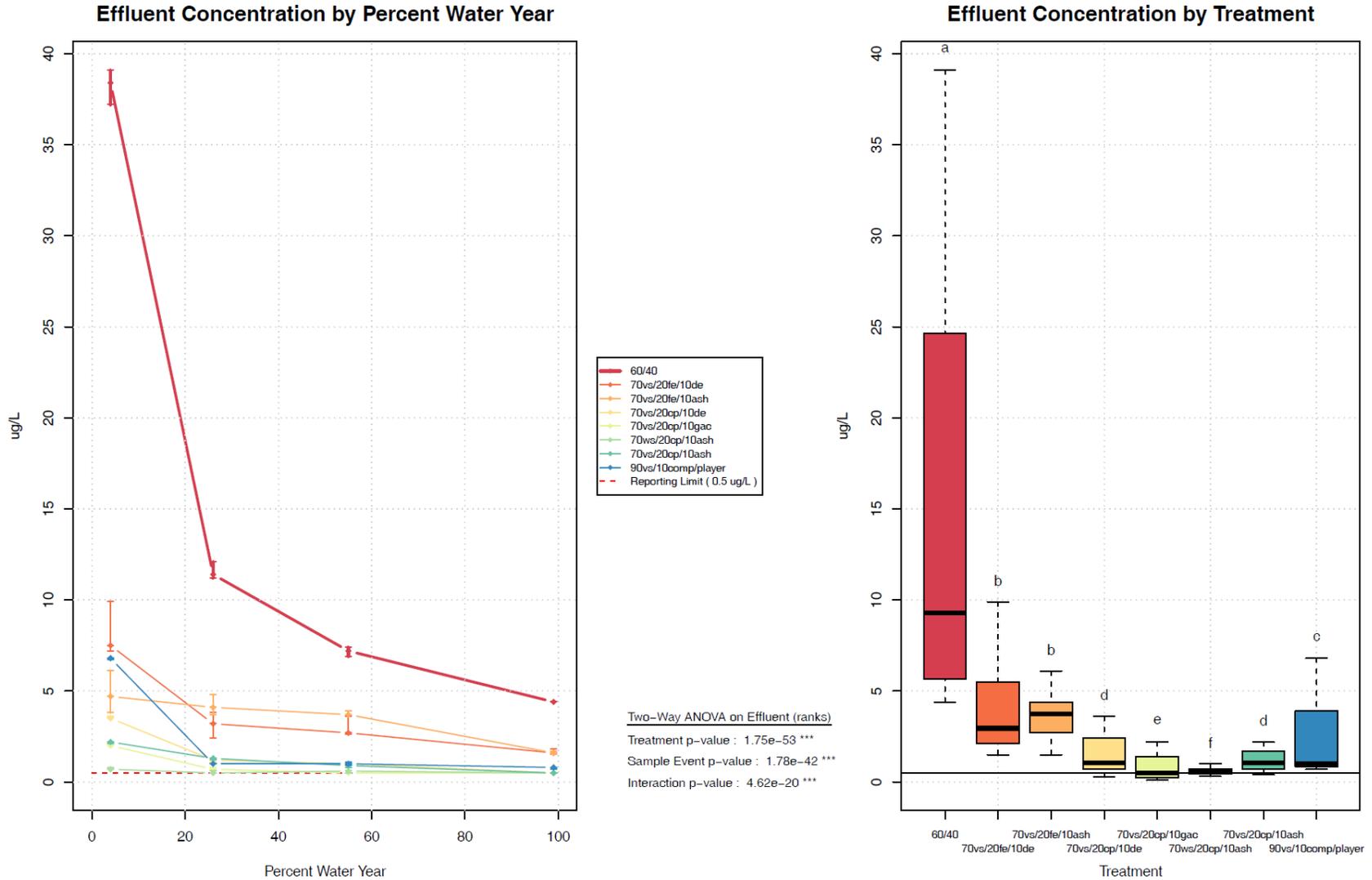


Figure 8. Flushing Experiment Effluent Concentration Trend Lines and Distributions by Media Treatment for Dissolved Copper.

Total Zinc

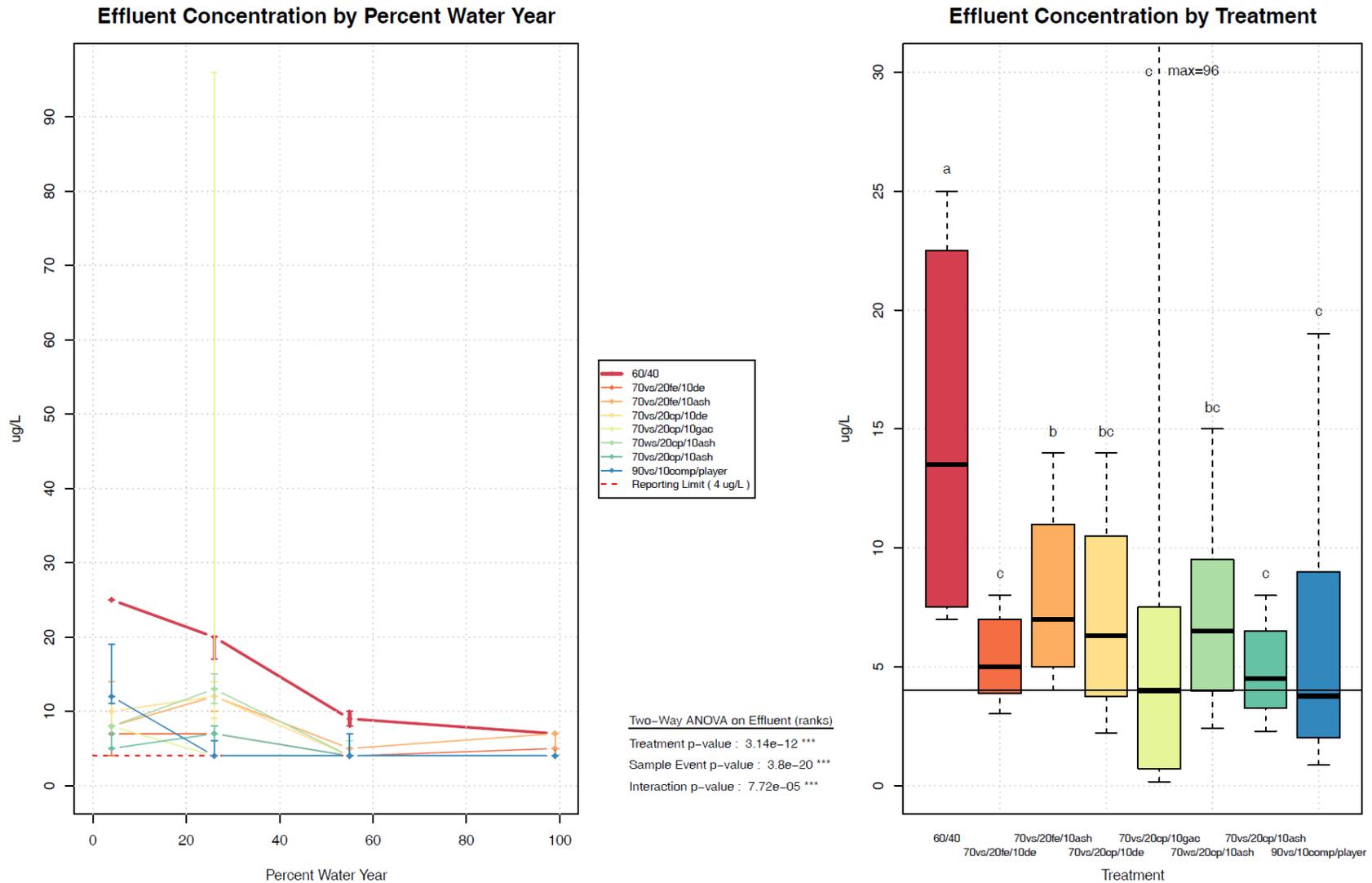


Figure 9. Flushing Experiment Effluent Concentration Trend Lines and Distributions by Media Treatment for Total Zinc.

Dissolved Zinc

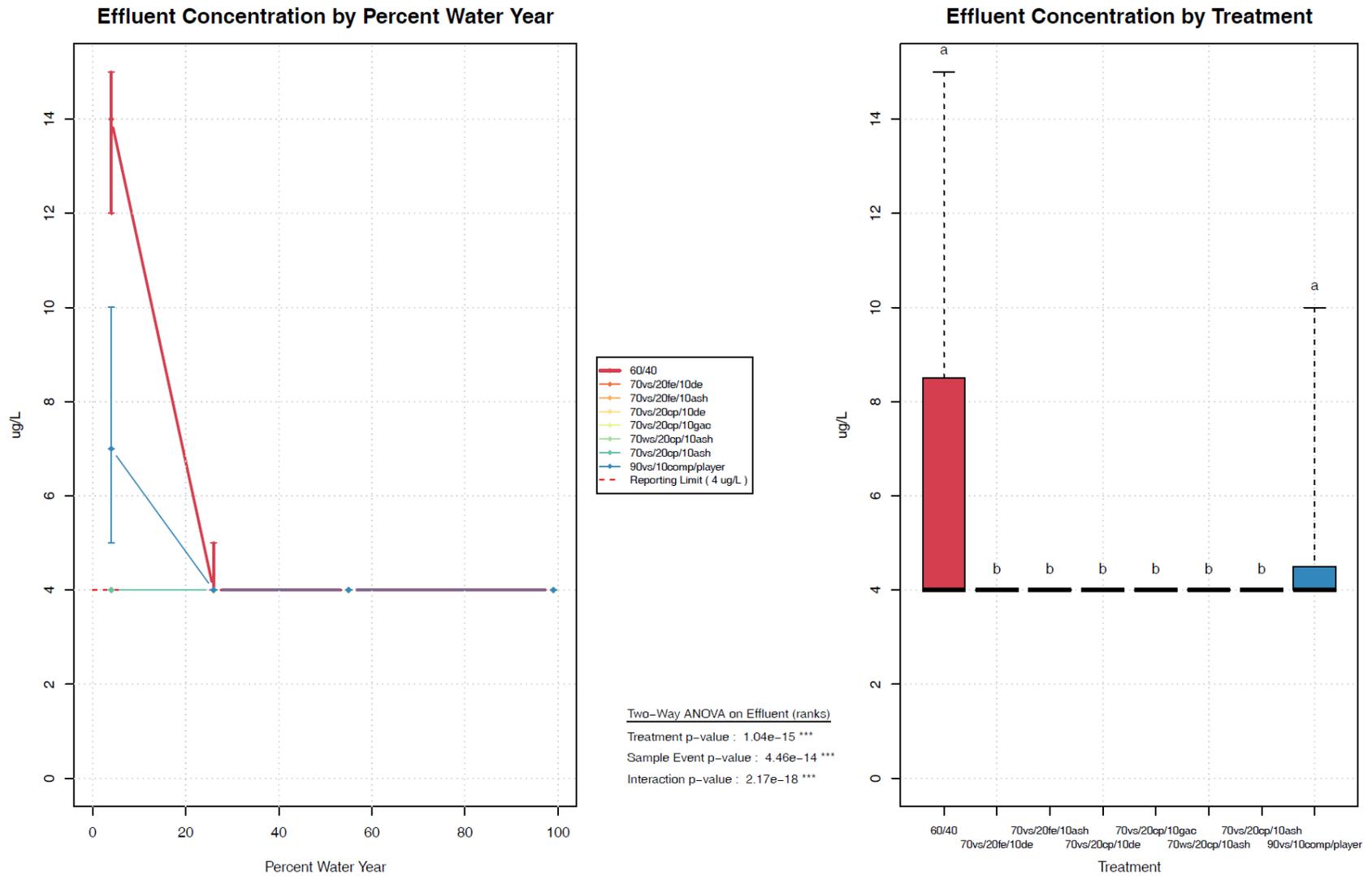


Figure 10. Flushing Experiment Effluent Concentration Trend Lines and Distributions by Media Treatment for Dissolved Zinc.

Flushing Experiments Results - Tables

Table 11. Flushing Experiment Raw Data and Summary Statistics for Total Suspended Solids.

Flushing Event ^a	Flushing Volume/Column (liters)	Percent Water Year	Flow Rate (L/hour)	Influent (mg/L)	Flag	60sand/40comp (mg/L)	Flag	70vs/20fe/10de (mg/L)	Flag	70vs/20fe/10ash (mg/L)	Flag	70vs/20cp/10de (mg/L)	Flag	70vs/20cp/10gac (mg/L)	Flag	70ws/20cp/10ash (mg/L)	Flag	70vs/20cp/10ash (mg/L)	Flag	90vs/10comp/p-layer (mg/L)	Flag
1	13.4	0.04	6.7	1.1	U	61.6		35		50.8		145		102		76.4		72.4		17	
						79.4		40.2		53.3		142		80.2		63		60.8		59.2	
						38.2		23.7		86.9		116		91.1		67.2		62.8		53.4	
6	13.4	0.26	6.7	1.1	U	52		42.7		65.8		100		41.2		60		39.7		6	
						68.4		44.8		53.3		91.7		49.3		50.2		46.3		9.8	
						48		41.6		68.9		111		39.6		90.2		62.7		7.2	
12	26.8	0.55	6.7	1.1	U	42.4		78.9		28.8		51.5		19.8		13.4		20.9		8.8	
						43.1		40.2		33.7		42.3		26.1		7.8		14.5		8.5	
						36.3		41.9		31.8		46		23.9		11.4		12.5		3.9	
19	26.8	0.99	6.7	1.1	U	14.6		37.8		29.8		10.5		12.2		9.6		11.7		2.6	
						16.5		25.8		28.6		20.2		16.8		9.4		11.9		2.3	
						17.1		32.8		26.3		25.2		14.4		9.3		12.3		3.4	
Min				1.1		14.6		23.7		26.3		10.5		12.2		7.8		11.7		2.3	
Max				1.1		79.4		78.9		86.9		145.0		102.0		90.2		72.4		59.2	
Mean				1.1		43.1		40.5		46.5		75.1		43.1		39.0		35.7		15.2	
Median				1.1		42.8		40.2		42.3		71.6		32.9		31.8		30.3		7.9	

^a The first sample collection occurred on the 1st flushing event, the second sample collection on the 6th flushing event, the third sample collection on the 12th flushing event, and the final sample collection occurred on the 19th flushing event.

Add convention for non-detect
 L/hour: liters per hour
 mg/L: milligrams per liter
 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

Table 12. Flushing Experiment Raw Data and Summary Statistics for Nitrate-Nitrite.

Flushing Event ^a	Flushing Volume/ Column (liters)	Percent Water Year	Flow Rate (L/hour)	Influent (mg/L)	Flag	60sand/ 40comp (mg/L)	Flag	70vs/20fe/ 10de (mg/L)	Flag	70vs/20fe/ 10ash (mg/L)	Flag	70vs/20cp/ 10de (mg/L)	Flag	70vs/20cp/ 10gac (mg/L)	Flag	70ws/20cp/ 10ash (mg/L)	Flag	70vs/20cp/ 10ash (mg/L)	Flag	90vs/ 10comp/ p-layer (mg/L)	Flag
1	13.4	0.04	6.7	0.010	U	19.8		0.05	U	0.02	U	0.01	U	0.01	U	0.01	U	0.01	U	1.17	
						18.6		0.05	U	0.01	U	0.02	U	0.01	U	0.01	U	0.02	U	1.27	
						16.1		0.01	U	0.05	U	0.01	U	0.025		0.012		0.01	U	1.3	
6	13.4	0.26	6.7	0.012	J	1.11		0.01	U	0.01	U	0.012	J	0.01	U	0.015	J	0.01	J	0.07	J
						1.43		0.01	U	0.01	U	0.014	J	0.012	J	0.014	J	0.01	U	0.182	J
						1.06		0.012	J	0.012	J	0.013	J	0.01	U	0.012	J	0.01	U	0.094	J
12	26.8	0.55	6.7	0.012	J	1.3		0.01	U	0.017	J	0.01	U	0.015	J	0.015	J	0.016	J	0.226	J
				0.017		1.25		0.023	J	0.015	J	0.02	J	0.015	J	0.015	J	0.021	J	0.202	J
						1.94		0.011	J	0.01	U	0.011	J	0.028	J	0.018	J	0.019	J	0.216	J
19	26.8	0.99	6.7	0.035	J	0.439		0.023	J	0.012	J	0.023	J	0.018	J	0.025	J	0.021	J	0.113	J
				0.016		0.415		0.019	J	0.013	J	0.023	J	0.021	J	0.018	J	0.017	J	0.096	J
						0.623		0.019	J	0.02	J	0.021	J	0.024	J	0.177	J	0.018	J	0.111	J
Min				0.010		0.415		0.010		0.010		0.010		0.010		0.010		0.010		0.070	
Max				0.035		19.800		0.050		0.050		0.023		0.028		0.177		0.021		1.300	
Mean				0.017		5.339		0.021		0.017		0.016		0.017		0.028		0.015		0.421	
Median				0.014		1.275		0.016		0.013		0.014		0.015		0.015		0.017		0.192	

^a The first sample collection occurred on the 1st flushing event, the second sample collection on the 6th flushing event, the third sample collection on the 12th flushing event, and the final sample collection occurred on the 19th flushing event.

L/hour: liters per hour
 mg/L: milligrams per liter
 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

Table 13. Flushing Experiment Raw Data and Summary Statistics for Total Phosphorus.

Flushing Event ^a	Flushing Volume/Column (liters)	Percent Water Year	Flow Rate (L/hour)	Influent (mg/L)	Flag	60sand/40comp (mg/L)	Flag	70vs/20fe/10de (mg/L)	Flag	70vs/20fe/10ash (mg/L)	Flag	70vs/20cp/10de (mg/L)	Flag	70vs/20cp/10gac (mg/L)	Flag	70ws/20cp/10ash (mg/L)	Flag	70vs/20cp/10ash (mg/L)	Flag	90vs/10comp/p-layer (mg/L)	Flag
1	13.4	0.04	6.7	0.008	U	1.16		0.295		0.506		0.885		0.616		0.273		0.73		1.03	
						1.1		0.325		0.617		0.846		0.603		0.243		0.669		1.1	
						1.09		0.245		0.922		0.837		0.624		0.323		0.631		1.16	
6	13.4	0.26	6.7	0.008	U	1.42		0.357		0.606		0.549		0.146		0.282		0.356		0.235	
						1.39		0.345		0.522		0.439		0.175		0.289		0.315		0.243	
						1.39		0.28		0.512		0.528		0.148		0.309		0.355		0.255	
12	26.8	0.55	6.7	0.008	U	1.53		0.357		0.209		0.313		0.08		0.13		0.158		0.208	
						1.45		0.26		0.238		0.276		0.088		0.135		0.165		0.18	
						1.75		0.274		0.219		0.305		0.088		0.144		0.164		0.189	
19	26.8	0.99	6.7	0.008	U	1.11		0.14		0.133		0.113		0.056		0.1		0.073		0.165	
						1.07		0.118		0.142		0.119		0.07		0.09		0.079		0.144	
						1.17		0.144		0.12		0.132		0.065		0.078		0.083		0.172	
Min				0.008		1.070		0.118		0.120		0.113		0.056		0.078		0.073		0.144	
Max				0.008		1.750		0.357		0.922		0.885		0.624		0.323		0.730		1.160	
Mean				0.008		1.303		0.262		0.396		0.445		0.230		0.200		0.315		0.423	
Median				0.008		1.280		0.277		0.372		0.376		0.117		0.194		0.240		0.222	

^a The first sample collection occurred on the 1st flushing event, the second sample collection on the 6th flushing event, the third sample collection on the 12th flushing event, and the final sample collection occurred on the 19th flushing event.

L/hour: liters per hour
 mg/L: milligrams per liter
 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

Table 14. Flushing Experiment Raw Data and Summary Statistics for Ortho-Phosphorus.

Flushing Event ^a	Flushing Volume/ Column (liters)	Percent Water Year	Flow Rate (L/hour)	Influent (mg/L)	Flag	60sand/ 40comp (mg/L)	Flag	70vs/20fe/ 10de (mg/L)	Flag	70vs/20fe/ 10ash (mg/L)	Flag	70vs/20cp/ 10de (mg/L)	Flag	70vs/20cp/ 10gac (mg/L)	Flag	70ws/20cp/ 10ash (mg/L)	Flag	70vs/20cp/ 10ash (mg/L)	Flag	90vs/ 10comp/ p-layer (mg/L)	Flag
1	13.4	0.04	6.7	0.004	U	0.425		0.042		0.018		0.399		0.057		0.039		0.411		0.580	
						0.358		0.045		0.018		0.386		0.054		0.056		0.379		0.536	
						0.455		0.043		0.018		0.376		0.059		0.062		0.359		0.620	
6	13.4	0.26	6.7	0.004	U	1.010		0.030		0.035		0.248		0.026		0.057		0.124		0.133	
						0.935		0.028		0.036		0.238		0.025		0.083		0.125		0.121	
						1.020		0.023		0.034		0.236		0.026		0.078		0.125		0.134	
12	26.8	0.55	6.7	0.004	U	1.160		0.031		0.030		0.150		0.015		0.040		0.071		0.125	
						1.120		0.028		0.030		0.153		0.014		0.054		0.081		0.110	
						1.310		0.026		0.030		0.157		0.016		0.049		0.073		0.121	
19	26.8	0.99	6.7	0.004	U	1.020		0.027		0.026		0.064		0.014		0.027		0.036		0.136	
						0.990		0.027		0.028		0.064		0.012		0.036		0.036		0.120	
						1.080		0.024		0.027		0.067		0.012		0.031		0.034		0.137	
Min				0.004		0.358		0.023		0.018		0.064		0.012		0.027		0.034		0.110	
Max				0.004		1.310		0.045		0.036		0.399		0.059		0.083		0.411		0.620	
Mean				0.004		0.907		0.031		0.028		0.212		0.028		0.051		0.155		0.239	
Median				0.004		1.015		0.028		0.029		0.197		0.021		0.052		0.103		0.134	

^a The first sample collection occurred on the 1st flushing event, the second sample collection on the 6th flushing event, the third sample collection on the 12th flushing event, and the final sample collection occurred on the 19th flushing event.

L/hour: liters per hour
 mg/L: milligrams per liter
 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\

Table 15. Flushing Experiment Raw Data and Summary Statistics for Total Copper.

Flushing Event ^a	Flushing Volume/Column (liters)	Percent Water Year	Flow Rate (L/hour)	Influent (µg/L)	Flag	60sand/40comp (µg/L)	Flag	70vs/20fe/10de (µg/L)	Flag	70vs/20fe/10ash (µg/L)	Flag	70vs/20cp/10de (µg/L)	Flag	70vs/20cp/10gac (µg/L)	Flag	70ws/20cp/10ash (µg/L)	Flag	70vs/20cp/10ash (µg/L)	Flag	90vs/10comp/p-layer (µg/L)	Flag
1	13.4	0.04	6.7	0.5	U	44		13.6		15.6		15.2		19		8.9	J	11		23.4	13.4
						43.5		16.3		19		20.5		19		7.8	J	13.9		26.1	
						42.9		11.7		27.2		19.4		19.7		7.2	J	10.7		27.4	
6	13.4	0.26	6.7	0.9	J	22		14.5		23.8		14.4		5.9	J	14.3		9.9		5.7	13.4
				0.6	J	24.4		12.1		19.5		10.8		9	J	12.1		7.8	J	6	
						23.2		10.2		20.2		12.9		5.3	J	9.6		7.9	J	5.9	
12	26.8	0.55	6.7	0.5	U	10.7		11.9		9.7		4.6	J	3.1	J	2.8	J	3.8	J	3.7	26.8
				0.6	J	9.2	J	8.8	J	10.4		5.7		3.4	J	5	J	4.7	J	4	
						10.1		10		10.3		4.5	J	3.2	J	3	J	3.7	J	3.9	
19	26.8	0.99	6.7	0.9	J	7.7	J	5.9	J	5.7	J	2.5	J	2	J	1.7	J	1.2	J	2	26.8
				0.5	U	7.9	J	5.1	J	7.2	J	2.9	J	1.2	J	2.6	J	2.1	J	1.7	
						7.8	J	6.1	J	6	J	3.1	J	2	J	1.8	J	1.3	J	1.8	
Min				0.5		7.7		5.1		5.7		2.5		1.2		1.7		1.2		1.7	
Max				0.9		44.0		16.3		27.2		20.5		19.7		14.3		13.9		27.4	
Mean				0.6		21.1		10.5		14.6		9.7		7.7		6.4		6.5		9.3	
Median				0.6		16.4		11.0		13.0		8.3		4.4		6.1		6.3		4.9	

^a The first sample collection occurred on the 1st flushing event, the second sample collection on the 6th flushing event, the third sample collection on the 12th flushing event, and the final sample collection occurred on the 19th flushing event.

L/hour: liters per hour
 µg/L: micrograms per liter
 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

Table 16. Flushing Experiment Raw Data and Summary Statistics for Dissolved Copper.

Flushing Event ^a	Flushing Volume/Column (liters)	Percent Water Year	Flow Rate (L/hour)	Influent (µg/L)	Flag	60sand/40comp (µg/L)	Flag	70vs/20fe/10de (µg/L)	Flag	70vs/20fe/10ash (µg/L)	Flag	70vs/20cp/10de (µg/L)	Flag	70vs/20cp/10gac (µg/L)	Flag	70ws/20cp/10ash (µg/L)	Flag	70vs/20cp/10ash (µg/L)	Flag	90vs/10comp/p-layer (µg/L)	Flag
1	13.4	0.04	6.7	0.5	U	38.4		7.2		3.8	J	3.5	J	2	J	0.7	J	2.2	J	6.7	
						39.1		9.9		4.7	J	3.6	J	2	J	0.7	J	2.2	J	6.8	
						37.2		7.5		6.1		3.5	J	2.2	J	0.8	J	2.1	J	6.8	
6	13.4	0.26	6.7	0.5	U	11.4		3.8	J	4.8	J	1.1	J	0.6	J	0.5	J	1.2	J	1	J
						11.2		3.2	J	3.7	J	1.2	J	0.7	J	0.6	J	1.3	J	1	J
						12.1		2.4	J	4.1	J	1.3	J	0.8	J	0.5	J	1.3	J	1	J
12	26.8	0.55	6.7	0.5	U	7.2		3.6	J	3.7	J	1	J	0.5	U	1	J	0.9	J	1	J
						6.9		2.6	J	3.7	J	0.9	J	0.5	U	0.5	J	0.9	J	1.1	J
						7.4		2.7	J	3.9	J	1	J	0.5	U	0.6	J	0.8	J	0.9	J
19	26.8	0.99	6.7	0.5	U	4.4	J	1.6	J	1.6	J	0.5	U	0.5	U	0.5	U	0.5	U	0.8	J
						4.4	J	1.5	J	1.5	J	0.5	U	0.5	U	0.5	U	0.5	U	0.8	J
						4.4	J	1.8	J	1.7	J	0.5	U	0.5	U	0.5	U	0.5	U	0.7	J
Min				0.5		6.9		2.4		3.7		0.9		0.5		0.5		0.8		0.9	
Max				0.5		39.1		9.9		6.1		3.6		2.2		1.0		2.2		6.8	
Mean				0.5		19.0		4.8		4.3		1.9		1.1		0.7		1.4		2.9	
Median				0.5		11.4		3.6		3.9		1.2		0.7		0.6		1.3		1.0	

^a The first sample collection occurred on the 1st flushing event, the second sample collection on the 6th flushing event, the third sample collection on the 12th flushing event, and the final sample collection occurred on the 19th flushing event.

L/hour: liters per hour
 µg/L: micrograms per liter
 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

Table 17. Flushing Experiment Raw Data and Summary Statistics for Total Zinc.

Flushing Event ^a	Flushing Volume/Column (liters)	Percent Water Year	Flow Rate (L/hour)	Influent (µg/L)	Flag	60sand/40comp (µg/L)	Flag	70vs/20fe/10de (µg/L)	Flag	70vs/20fe/10ash (µg/L)	Flag	70vs/20cp/10de (µg/L)	Flag	70vs/20cp/10gac (µg/L)	Flag	70ws/20cp/10ash (µg/L)	Flag	70vs/20cp/10ash (µg/L)	Flag	90vs/10comp/p-layer (µg/L)	Flag
1	13.4	0.04	6.7	4	U	25		7		7		8		7		8		5		12	
						25		7		8		11		8		8		7		19	
						25		4		14		10		8		7		5		11	
6	13.4	0.26	6.7	4	U	17		8		12		14		4		15		8		4	U
						20		6		10		9		96		13		7		6	
						20		7		14		12		4		11		6		4	U
12	26.8	0.55	6.7	5		9		4	U	4		4		4	U	4	U	4	U	7	
				4	U	8		4	U	5		4	U	4		6		4		4	U
						10		5		5		4	U	4	U	4	U	4	U	4	U
19	26.8	0.99	6.7	4	U	7		5		5		4	U	4	U	4	U	4	U	4	U
						7		4	U	7		4	U	4	U	4	U	4	U	4	U
						7		5		7		4	U	4	U	4	U	4	U	4	U
Min			4		7.0		4.0		4.0		4.0		4.0		4.0		4.0		4.0		
Max			5		25.0		8.0		14.0		14.0		96.0		15.0		8.0		19.0		
Mean			4.2		15.0		5.5		8.2		7.3		12.6		7.3		5.2		6.9		
Median			4		13.5		5.0		7.0		6.0		4.0		6.5		4.5		4.0		

^a The first sample collection occurred on the 1st flushing event, the second sample collection on the 6th flushing event, the third sample collection on the 12th flushing event, and the final sample collection occurred on the 19th flushing event.

L/hour: liters per hour
 µg/L: micrograms per liter
 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

Table 18. Flushing Experiment Raw Data and Summary Statistics for Dissolved Zinc.

Flushing Event ^a	Flushing Volume/Column (liters)	Percent Water Year	Flow Rate (L/hour)	Influent (µg/L)	Flag	60sand/40comp (µg/L)	Flag	70vs/20fe/10de (µg/L)	Flag	70vs/20fe/10ash (µg/L)	Flag	70vs/20cp/10de (µg/L)	Flag	70vs/20cp/10gac (µg/L)	Flag	70ws/20cp/10ash (µg/L)	Flag	70vs/20cp/10ash (µg/L)	Flag	90vs/10comp/p-layer (µg/L)	Flag
1	13.4	0.04	6.7	4	U	15		4	U	4	U	4	U	4	U	4	U	4	U	5	
						12		4	U	4	U	4	U	4	U	4	U	4	U	10	
						14		4	U	4	U	4	U	4	U	4	U	4	U	7	
6	13.4	0.26	6.7	4	U	4	U	4	U	4	U	4	U	4	U	4	U	4	U	4	U
						4	U	4	U	4	U	4	U	4	U	4	U	4	U	4	U
						5		4	U	4	U	4	U	4	U	4	U	4	U	4	U
12	26.8	0.55	6.7	4	U	4	U	4	U	4	U	4	U	4	U	4	U	4	U	4	U
						4	U	4	U	4	U	4	U	4	U	4	U	4	U	4	U
						4	U	4	U	4	U	4	U	4	U	4	U	4	U	4	U
19	26.8	0.99	6.7	4	U	4	U	4	U	4	U	4	U	4	U	4	U	4	U	4	U
						4	U	4	U	4	U	4	U	4	U	4	U	4	U	4	U
						4	U	4	U	4	U	4	U	4	U	4	U	4	U	4	U
Min				4		4		4		4		4		4		4		4		4	
Max				4		15		4		4		4		4		4		4		10	
Mean				4		7		4		4		4		4		4		4		5	
Median				4		4		4		4		4		4		4		4		4	

^a The first sample collection occurred on the 1st flushing event, the second sample collection on the 6th flushing event, the third sample collection on the 12th flushing event, and the final sample collection occurred on the 19th flushing event.

L/hour: liters per hour
 µg/L: micrograms per liter
 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

Dosing Experiment Results

Dosing experiments were performed to evaluate the pollutant capture potential of the media treatments. For these experiments, each of the 8 media treatments identified in Table 10 (page 16) were replicated 3 times in the 24 column array (see description above) using a randomized block design per the project QAPP (Appendix A). Each column was then dosed on five occasions with natural stormwater or natural stormwater augmented with reagent grade chemicals to attain target concentration ranges identified in the project QAPP. The natural stormwater used in these experiments was obtained from a catch basin that collects runoff from the City of Redmond Maintenance and Operations Center located on Northeast 76th Street in Redmond, Washington. Chemicals added to attain target concentrations are as follows: Sil-Co-Sil 106 to introduce TSS; potassium phosphate to introduce phosphorus; copper sulfate to introduce Cu; and zinc chloride to introduce Zn. See additional details in the subsections below.

Results from the dosing experiments are presented in separate subsections below for the eight priority pollutants identified previously. Dosing experiment results for all the measured analytical parameters are also summarized in Appendices H and I. In addition, a concluding subsection compares performance of the individual treatments to performance goals identified in Ecology's Technology Assessment Protocol-Ecology (TAPE) guidelines for approving emerging stormwater treatment systems (Ecology 2011).

Total Suspended Solids

Figure 11 (on page 52) shows the distribution of TSS effluent concentrations and percent removal by treatment. Table 19 (on page 61) also presents the raw data and summary statistics for TSS from each dosing event.

For the first and final sampling events, no Sil-Co-Sil 106 was introduced to the mixing tank and influent TSS concentrations were at levels found in the collected stormwater. Sil-Co-Sil 106 was added to the collected stormwater for the second, third and fourth events. An unusually high TSS level occurred in the second half of the fourth event (205 mg/L for day two compared to 72.8 mg/L for day one) and was likely due to residual material in the water delivery system.

In general, percent removal varied across experiments and treatments from export to 50 to 90 percent removal. The exception to this was the 60sand/40comp control and 90vs/10comp/p-layer treatment. Percent removal for both were good across all influent concentrations with the 60sand/60comp achieving 39 to 84 percent and 90vs/10comp/p-layer consistently achieving above 90 percent removal for all influent concentrations. Other than the first experiment, the 70ws/20cp/10ash also performed well with percent removal from 89-93 percent for the second, third and fourth experiments.

Most median effluent concentrations (for all experiments) were in a range of approximately 15 to 30 mg/L. The exception was the 90vs/10comp/p-layer treatment with effluent concentrations consistently below 5 mg/L except for the one experiment with a high influent concentration (205 mg/L) where the effluent concentration increased to approximately 9 mg/L.

Nitrate+Nitrite

No nitrogen was added for any of the dosing events so influent concentrations for nitrate+nitrite were always at levels found in the collected stormwater (Table 20, page 63). Influent concentrations were relatively high for the first three events (approximately 1-2 mg/L) and lower (0.2-0.5 mg/L) for the last two experiments.

In general, percent removal for nitrate+nitrite varied across experiments and treatments from export to 90 percent plus removal (Figure 12 and Table 20, page 53 and page 63). Three treatments achieve consistently high percent reductions (60-99 percent) across all influent concentration levels: 70vs/20cp/10gac, 70vs/20cp/10ash and 70ws/20cp/10ash. The 60sand/40comp control consistently exported nitrate+nitrite. Median effluent concentration for 60sand/40comp control was also significantly higher than all other treatments. While high, the initial effluent concentrations for these experiments (16.7 mg/L) was much lower than the initial effluent concentrations (approximately 100mg/L) found in previous field monitoring (Herrera 2014a, 2015). There were no significant differences in median effluent concentrations for the other treatments (Figure 12).

Total Phosphorus

Influent concentrations for TP were at levels found in the collected stormwater for the first, second, fourth, and final experiments. Dissolved phosphorus was added to the stormwater for the third event in the form of potassium phosphate.

In general, percent removal for TP varied across experiments and treatments from export to 90 percent plus removal (Figure 13 and Table 21, pages 54 and 65). Median percent removal for all treatments except the 60sand/40comp control generally fell in a range of 20-70 percent.

The median effluent concentration for the 60sand/40comp control was significantly higher than all other treatments and the media exported TP in all but one experiment (Figure 13). All other treatment median effluent concentrations were not significantly different.

Ortho Phosphorus

Influent concentrations for ortho-P were at levels found in the collected stormwater for the first, second, third, and final experiments. Dissolved phosphorus was added to the stormwater for the fourth event in the form of potassium phosphate. Note that the influent concentration for the second set of columns on day two of sample event 4 was elevated (1.13 mg/L) compared to day one (0.071 mg/L). The higher influent concentration could bias the result of that set of columns to higher percent removal.

In general, percent removal varied across experiments and treatments from export to 90 percent plus removal (Figure 14 and Table 22, pages 55 and 67). Median percent removal for all treatments except the 60sand/40comp and the 90vs/10comp/p-layer generally fell in a range of 10-80 percent. The percent removal for the 60sand/40comp was dramatically less than the better performing blends with all experiments showing negative percent removal (export). For example, the percent export for the 60sand/40comp was -634 percent while the best performer had 85 percent removal in the third experiment

The median effluent concentration for the 60sand/40comp control was significantly higher than all other treatments and the media exported ortho-P in all experiments (Figure 14). Other treatments including 70vs/20fe/10de, 70vs/20fe/10de and 90vs/10comp/p-layer also exported ortho-P in some experiments including those with low and higher influent concentrations.

Total Copper

Influent concentrations for total Cu were at levels found in the collected stormwater for the first, second and final experiments. Dissolved copper was added to the stormwater for the third and fourth event in the form of copper sulfate.

In general, percent removal varied across experiments and treatments from export to 90 percent plus removal (Figure 15 and Table 23, pages 56 and 69). Median percent removal for all treatments except the 70vs/20fe/10de and 70vs/20fe/10ash generally fell in a range of 10-70 percent for the lower dose experiments and 90 plus percent removal for the one high-dose experiment.

The 70vs/20fe/10de and 70vs/20fe/10ash treatments exported total Cu in all but one lower-dose experiment and the median effluent concentrations were high (approximately 20-40 µg/L) for both of those treatments. Effluent concentrations for the 60sand/40comp control fell in the range of 10-20 µg/L, while the other treatments fell in the range of 3-13 µg/L for the lower-dose experiments.

Dissolved Copper

Influent concentrations for dissolved Cu were at levels found in the collected stormwater for the first, second and final experiments. Dissolved copper was added to the stormwater for the third and fourth event in the form of copper sulfate.

In general, percent removal varied across experiments and treatments from export to 90 percent plus removal (Figure 16 and Table 24, pages 57 and 71). Median percent removal for all treatments except the 60sand/40comp, 70vs/20fe/10de and 70vs/20fe/10ash treatments generally fell in a range of 10-80 percent.

The 60sand/40comp, 70vs/20fe/10de and 70vs/20fe/10ash treatments consistently exported dissolved Cu in all but the high-dose experiments. The median effluent concentrations were high (approximately 10-40 µg/L) for the 70vs/20fe/10de and 70vs/20fe/10ash treatments. Effluent concentrations for the 60sand/40comp were approximately 10 µg/L, while the other treatments fell in the range of 1-8 µg/L for the lower-dose experiments.

Dissolved Cu influent concentrations were increased to very high levels for event 4 for two reasons: first to test dissolved Cu capture capability at high influent concentrations; and secondly (and more importantly) determine if there is flushing or export of dissolved Cu for event 5 with influent concentrations returned to low concentrations. The best performers reduced the high influent concentrations significantly (7.7 µg/L for the 70ws/20cp/10ash, 9.0 µg/L for the 70vs/20cp/10de and 12.0 µg/L for the 70vs/20cp/10gac). When influent concentrations were reduced (approximately 8 µg/L) effluent concentrations for the best performers (treatments containing coco coir pith, gac, high carbon wood ash and

diatomaceous earth) remained low (3.7 to 5.7 µg/L) showing no signs of dissolved Cu flushing or export.

Total Zinc

Influent concentrations for total Zn were at levels found in the collected stormwater for the first, second and final experiments. Dissolved Zn was added to the stormwater for the third and fourth event in the form of zinc chloride.

In general, percent removal was high across all experiments and treatments, and median percent removal for all treatments was high as well (Figure 17 and Table 25, pages 58 and 73). Effluent concentrations for all treatments were consistently low ranging from approximately 4-14 µg/L and many treatments were at or below reporting limits (4 µg/L) for both the lower-dose and high-dose experiments.

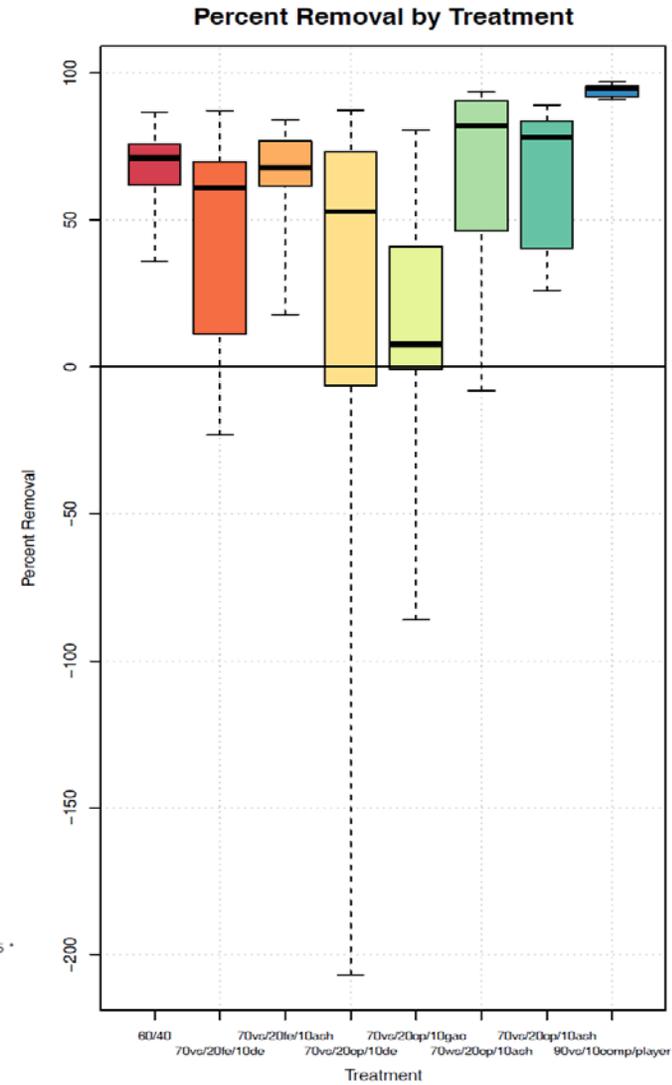
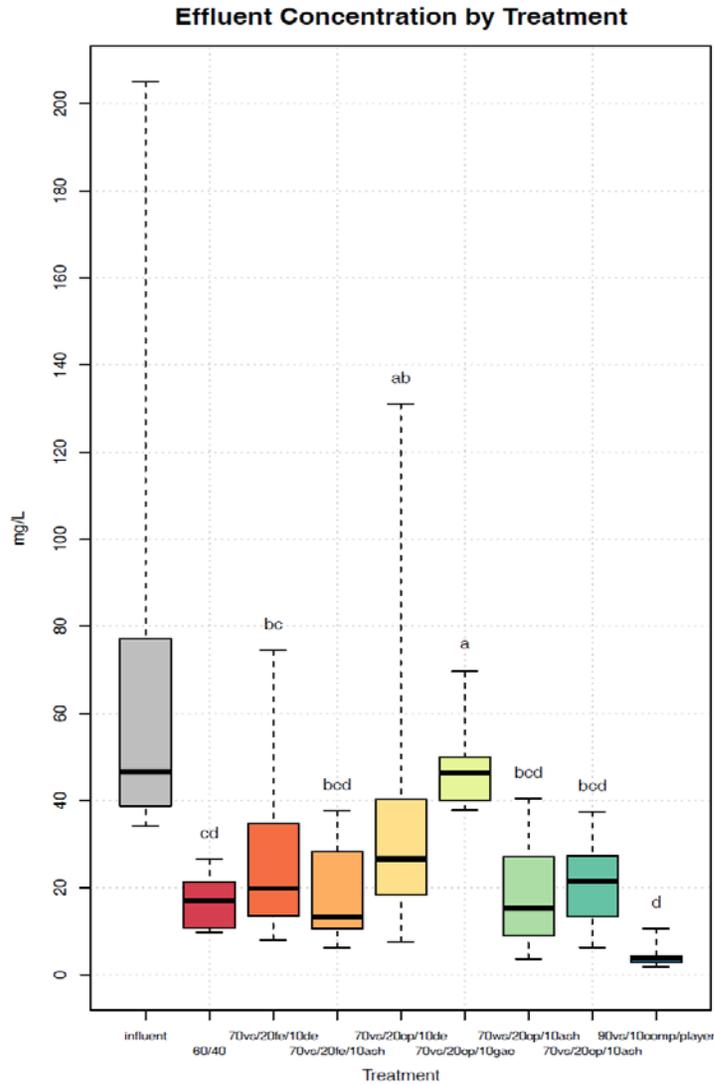
Dissolved Zinc

Influent concentrations for dissolved Zn were at levels found in the collected stormwater for the first, second and final experiments. Dissolved Zn was added to the stormwater for the third and fourth event in the form of zinc chloride.

In general, percent removal was high across experiments and treatments, and median percent removal for all treatments was high as well (80-90 percent) (Figure 18 and Table 26, pages 59 and 75). Median effluent concentrations for all treatments were consistently low ranging from approximately 4-5 µg/L and most treatments were at or below reporting limits (4 µg/L) for both the lower-dose and high-dose experiments.

Dosing Experiments Results - Plots

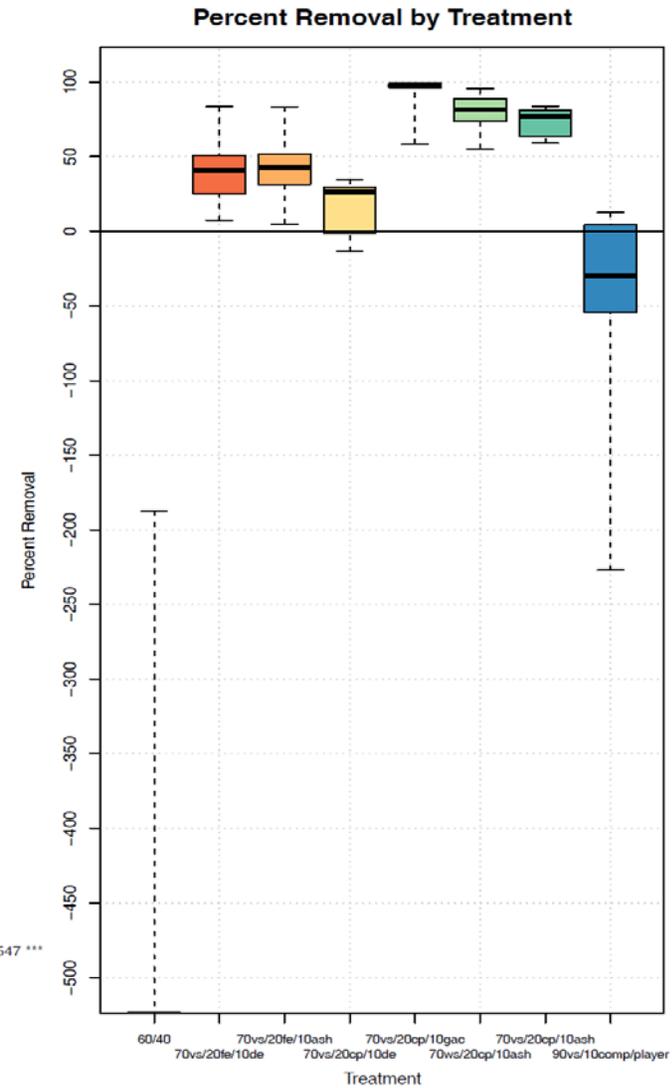
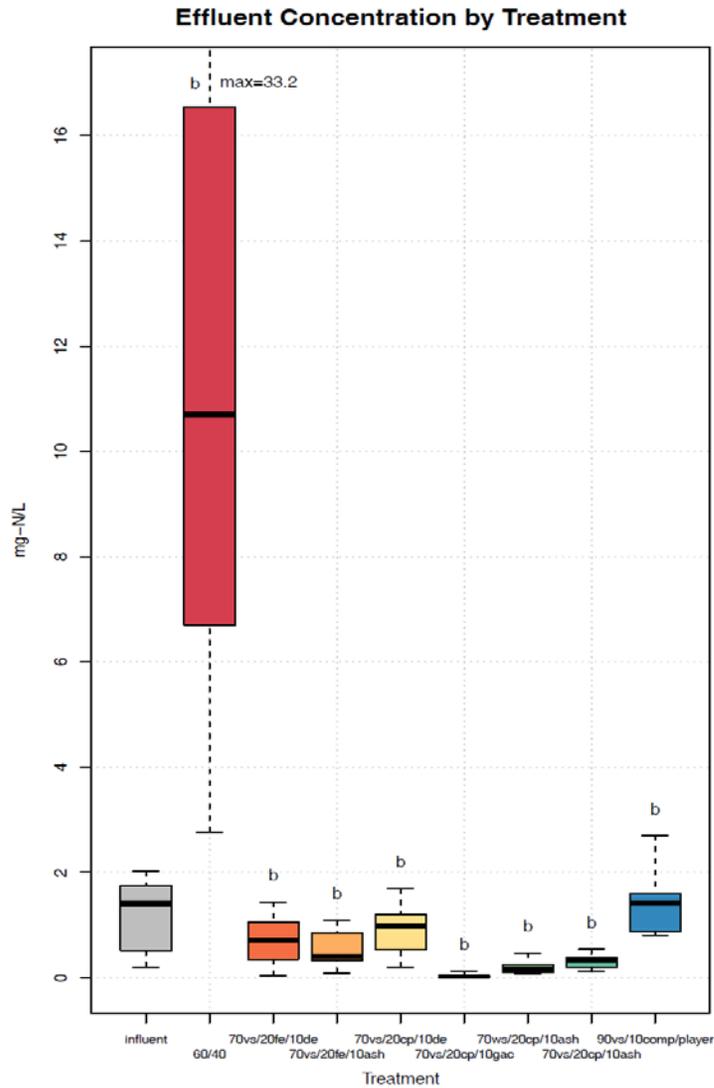
Total Suspended Solids



Two-Way ANOVA on Removal (ranks)
 Treatment p-value : 2.1e-14 ***
 Influent Concentration p-value : 0.0115 *
 Interaction p-value : 0.000356 ***

Figure 11. Dosing Experiment Effluent Concentration and Percent Removal Distributions by Treatment for Total Suspended Solids.

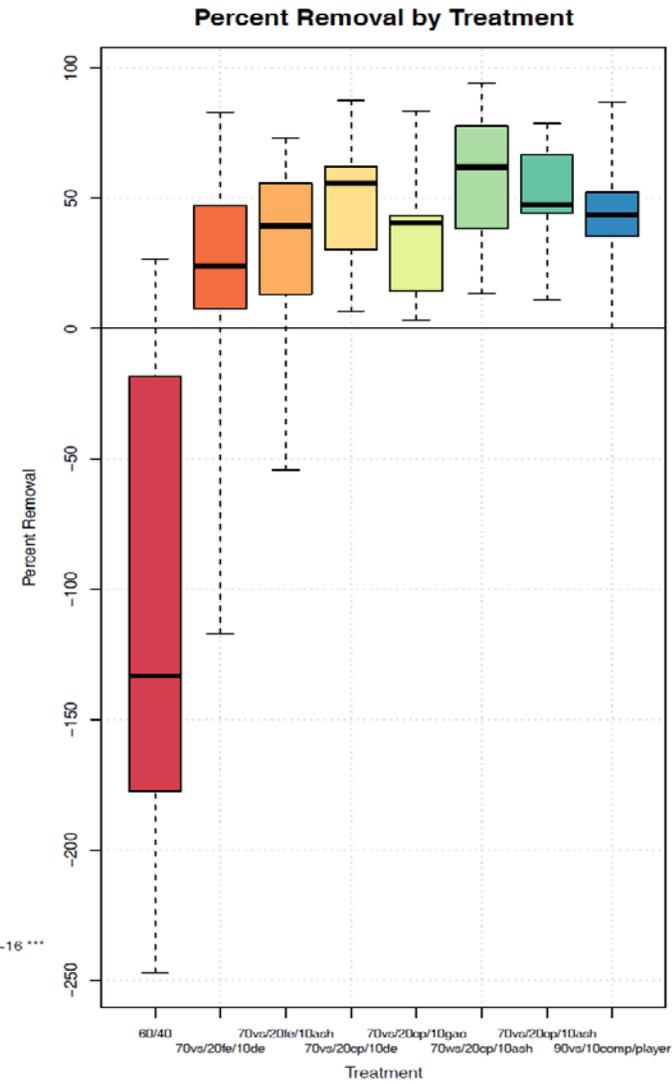
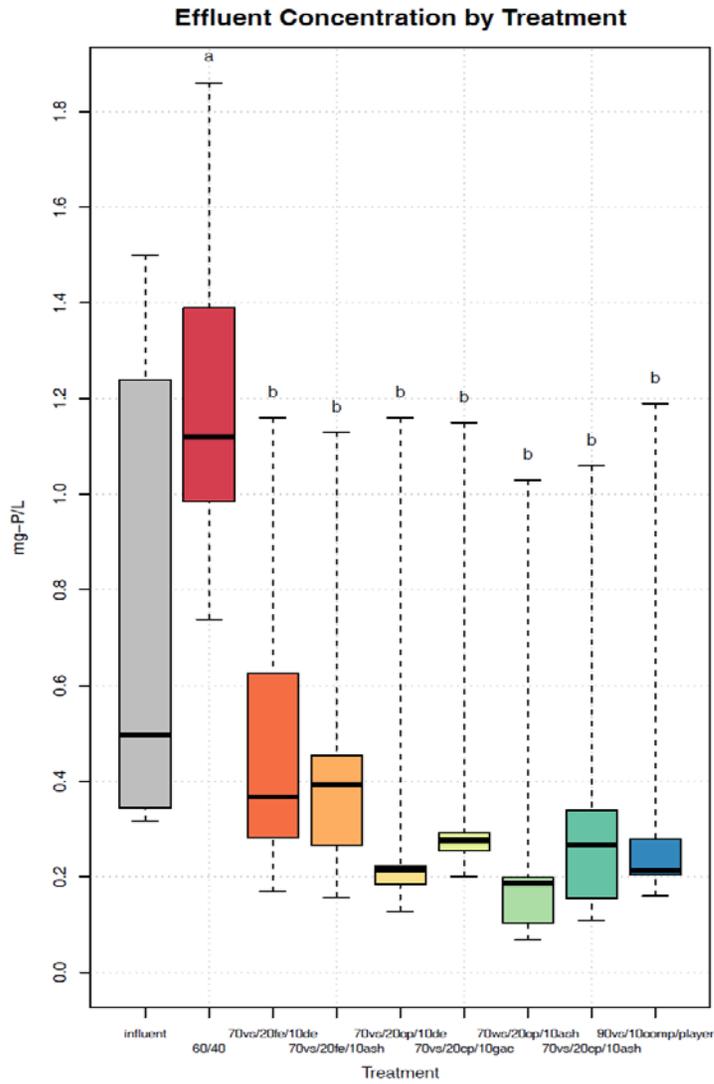
Nitrate + Nitrite



Two-Way ANOVA on Removal (ranks)
 Treatment p-value : 1.16e-48 ***
 Influent Concentration p-value : 0.000547 ***
 Interaction p-value : 0.45

Figure 12. Dosing Experiment Effluent Concentration and Percent Removal Distributions by Treatment for Nitrate+Nitrite.

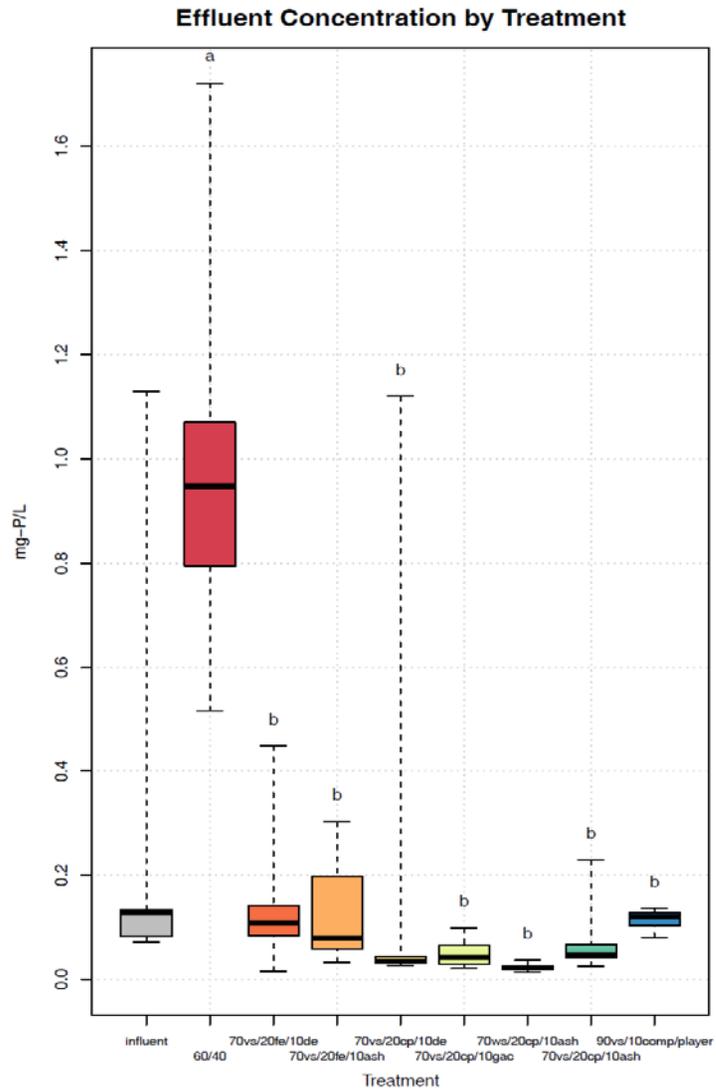
Total Phosphorus



Two-Way ANOVA on Removal (ranks)
 Treatment p-value : 3.14e-14 ***
 Influent Concentration p-value : 9.96e-16 ***
 Interaction p-value : 0.0648 .

Figure 13. Dosing Experiment Effluent Concentration and Percent Removal Distributions by Treatment for Total Phosphorus.

Ortho-Phosphorus



Two-Way ANOVA on Removal (ranks)
 Treatment p-value : 4.4e-32 ***
 Influent Concentration p-value : 0.075 .
 Interaction p-value : 8.81e-14 ***

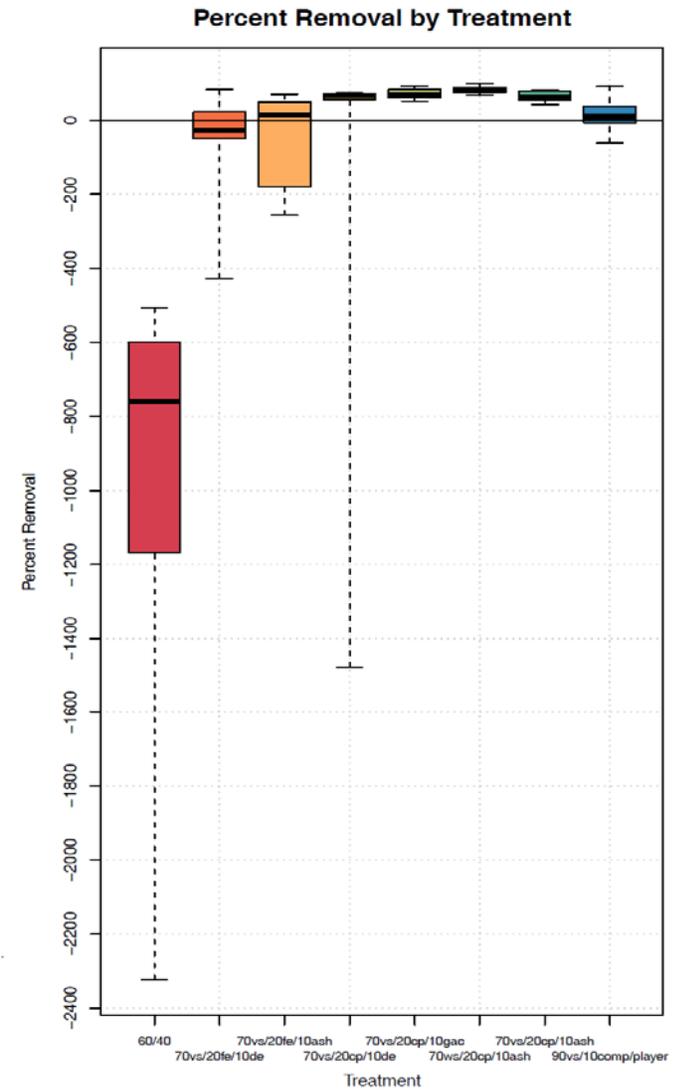
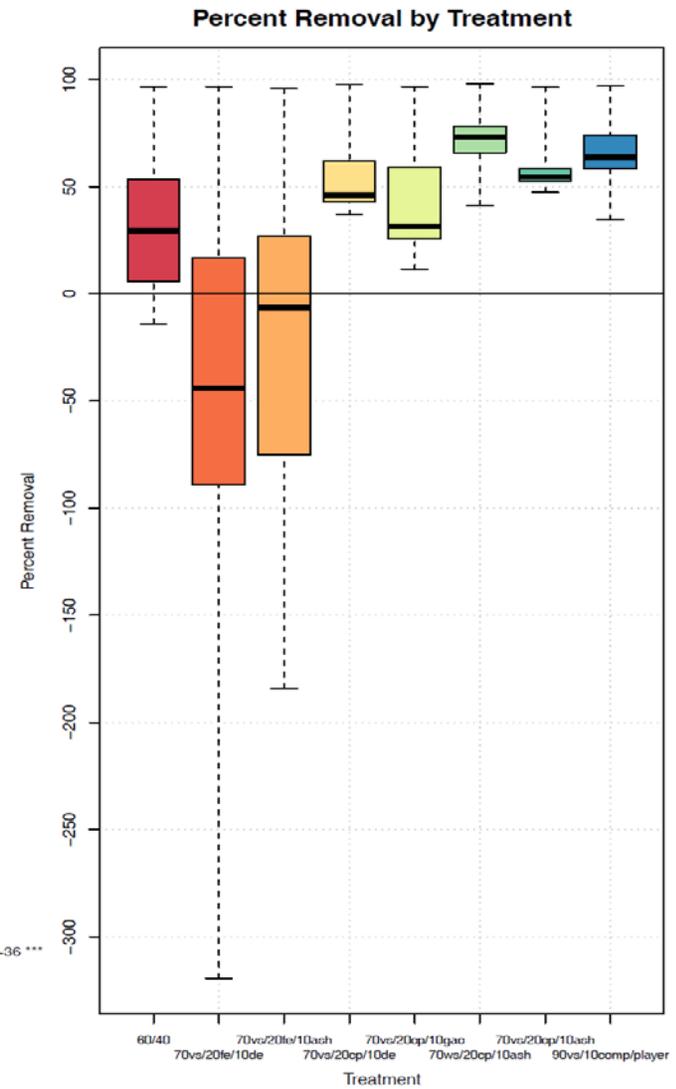
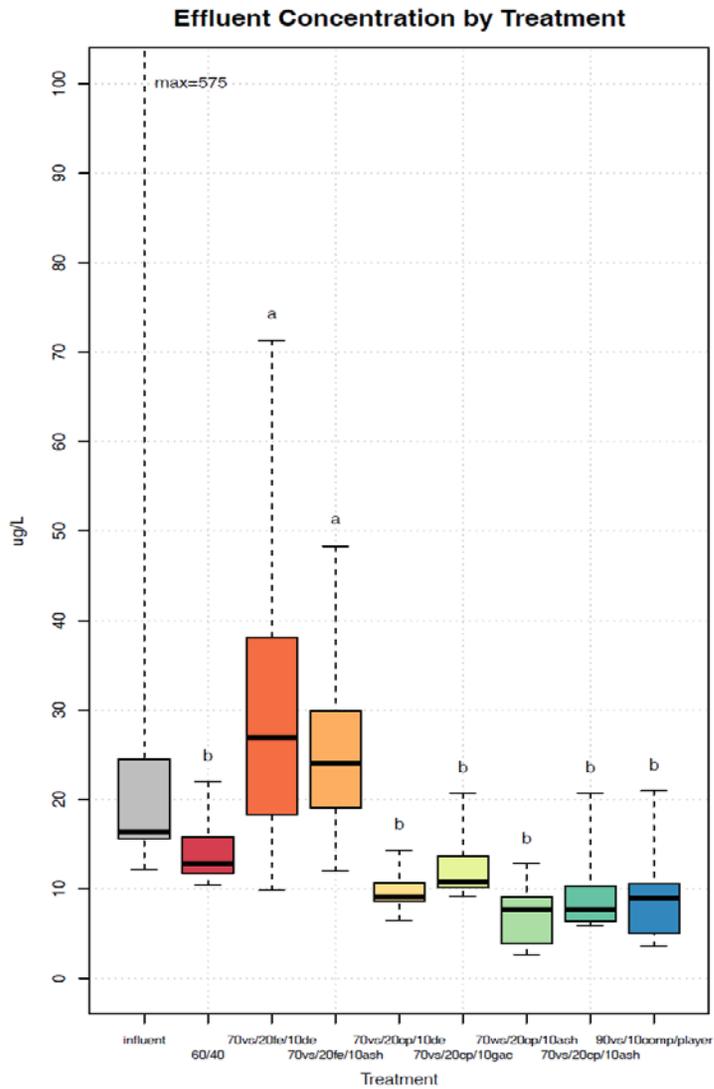


Figure 14. Dosing Experiment Effluent Concentration and Percent Removal Distributions by Treatment for Ortho Phosphorus.

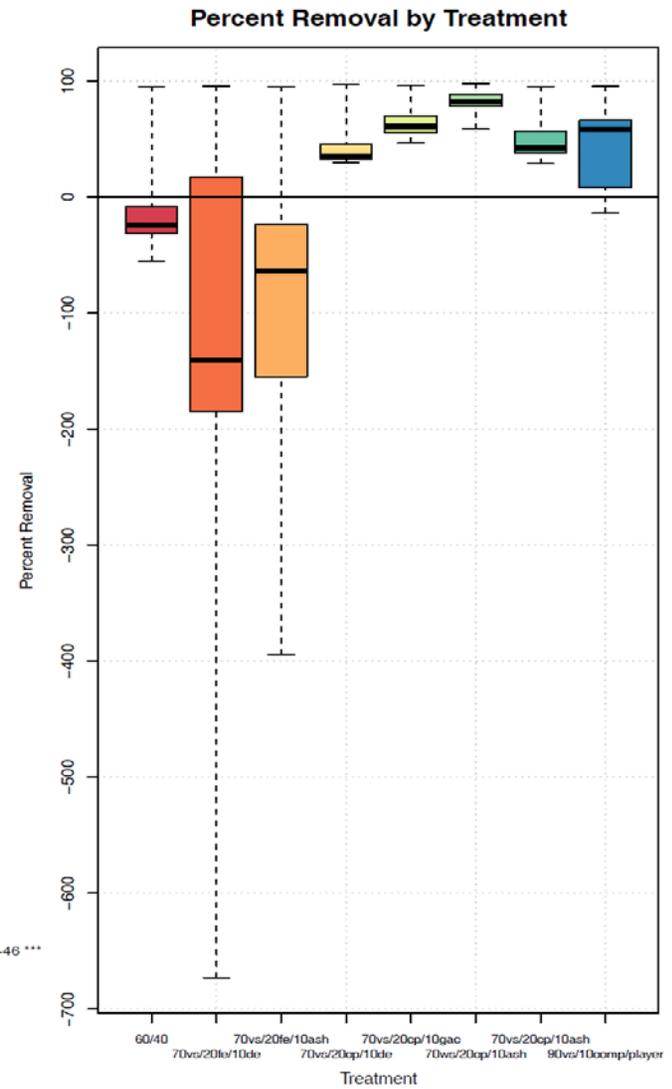
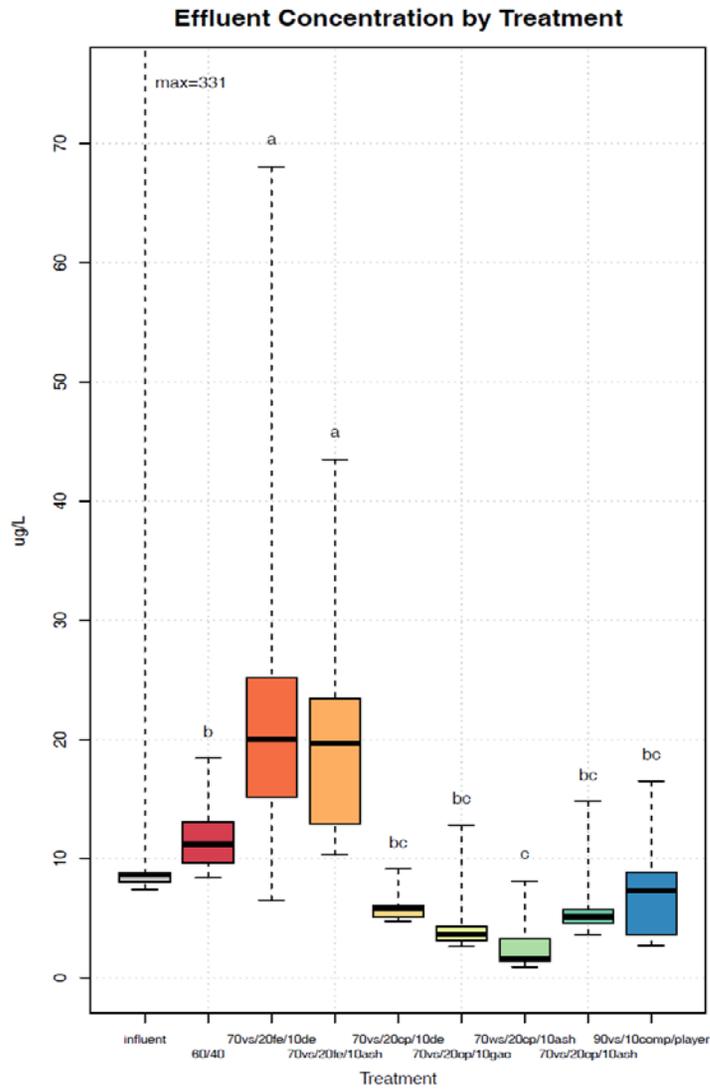
Total Copper



Two-Way ANOVA on Removal (ranks)
 Treatment p-value : 6.47e-26 ***
 Influent Concentration p-value : 4.96e-36 ***
 Interaction p-value : 1.31e-05 ***

Figure 15. Dosing Experiment Effluent Concentration and Percent Removal Distributions by Treatment for Total Copper

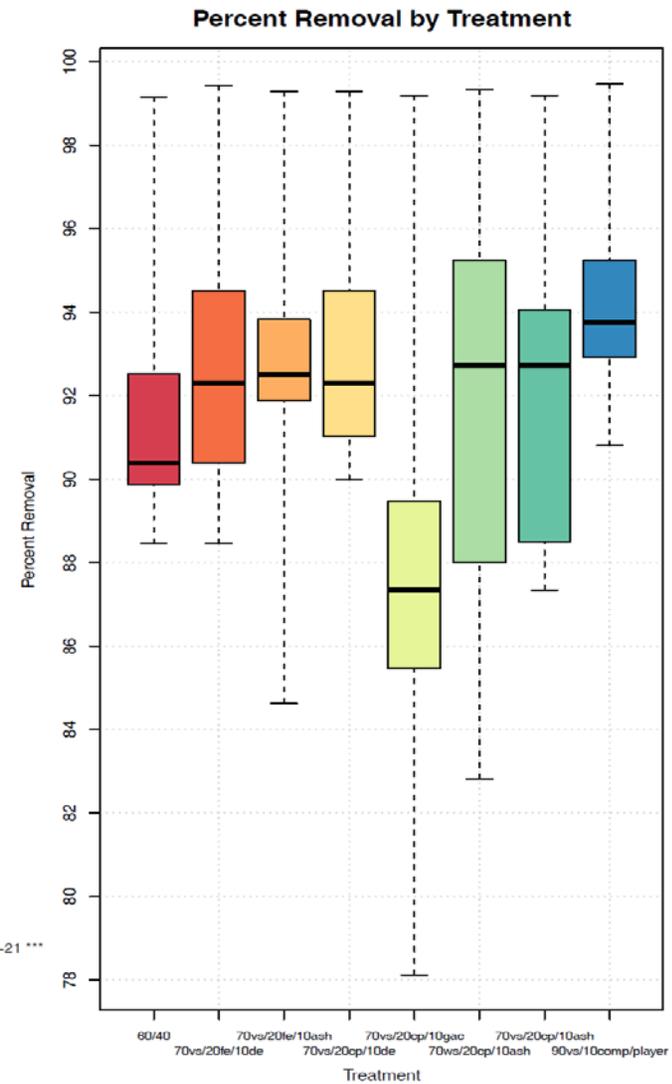
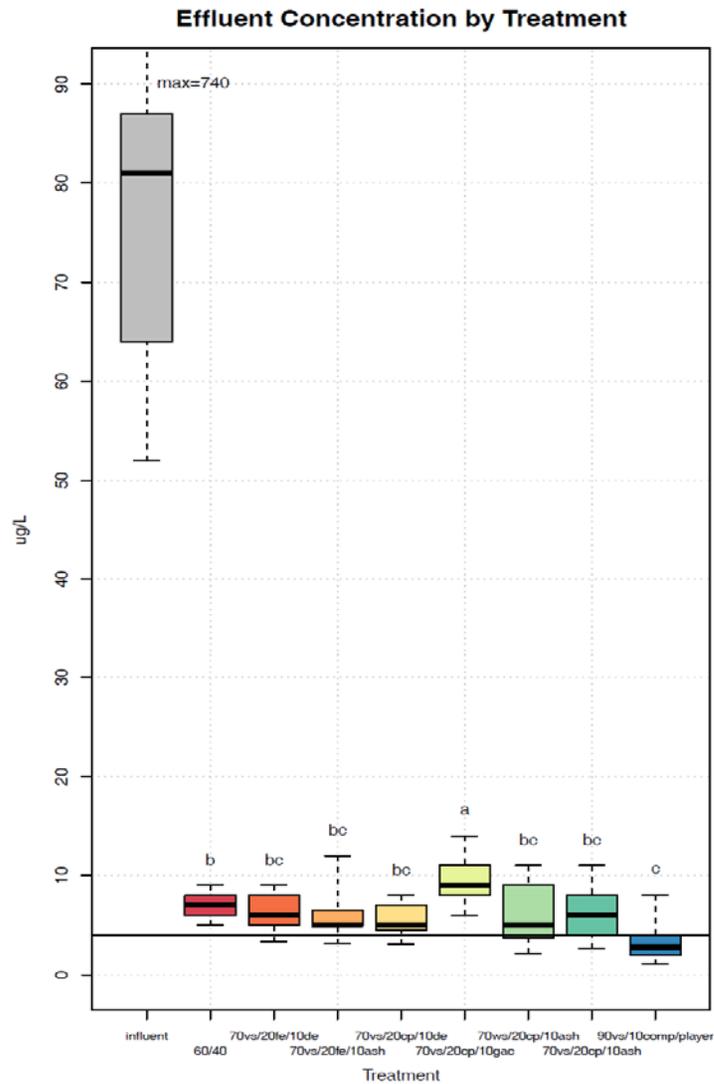
Dissolved Copper



Two-Way ANOVA on Removal (ranks)
 Treatment p-value : 4.95e-38 ***
 Influent Concentration p-value : 3.09e-46 ***
 Interaction p-value : 3.98e-11 ***

Figure 16. Dosing Experiment Effluent Concentration and Percent Removal Distributions by Treatment for Dissolved Copper.

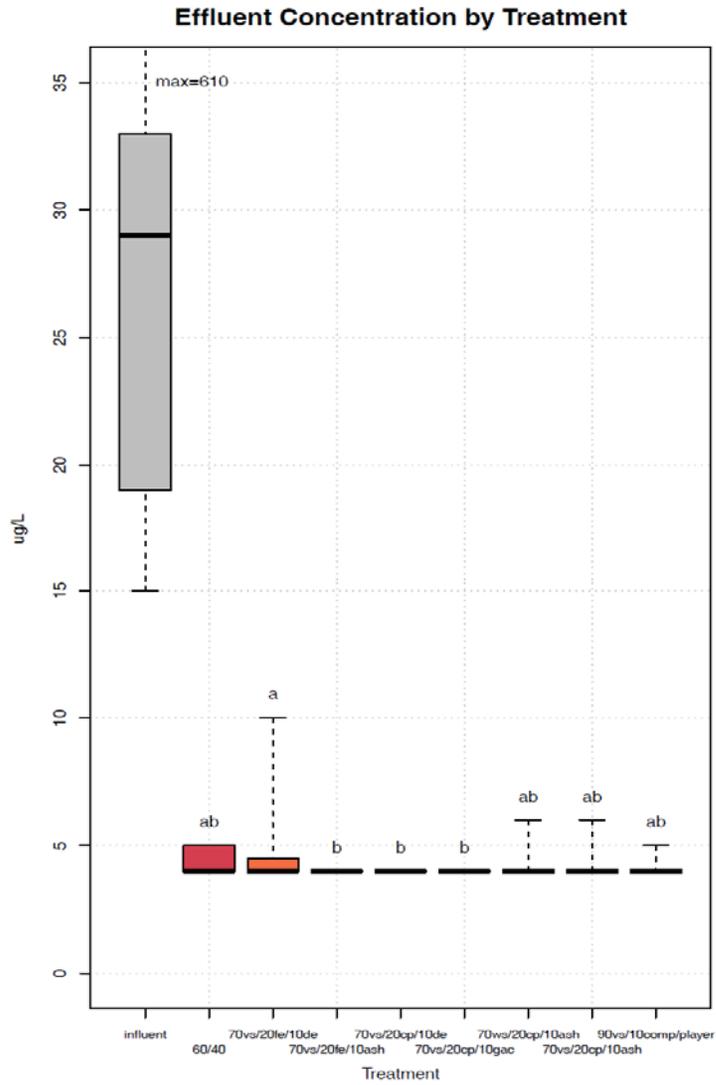
Total Zinc



Two-Way ANOVA on Removal (ranks)
 Treatment p-value : 1.42e-07 ***
 Influent Concentration p-value : 1.94e-21 ***
 Interaction p-value : 0.367

Figure 17. Dosing Experiment Effluent Concentration and Percent Removal Distributions by Treatment for Total Zinc.

Dissolved Zinc



Two-Way ANOVA on Removal (ranks)
 Treatment p-value : 0.123
 Influent Concentration p-value : 3.62e-17 ***
 Interaction p-value : 0.998

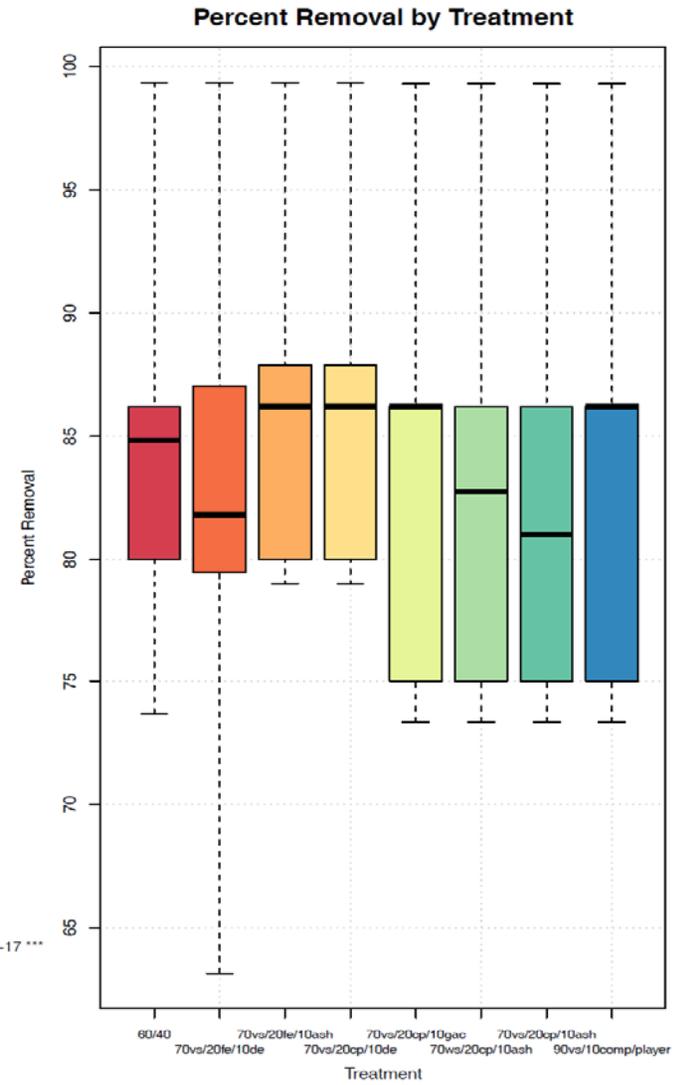


Figure 18. Dosing Experiment Effluent Concentration and Percent Removal Distributions by Treatment for Dissolved Zinc.

Dosing Experiments Results - Tables

Table 19. Dosing Experiment Raw Data and Summary Statistics for Total Suspended Solids (mg/L).

Sample Event 1	Dosing Volume/Column (liters)	Flow Rate (L/hour)	9/25/2014					9/26/2014				
			Influent	60/40	70vs/20fe/10de	70vs/20fe/10ash	70vs/20cp/10de	Influent	70vs/20cp/10gac	70ws/20cp/10ash	70vs/20cp/10ash	90vs/10comp/p-layer
	13.4	6.7	34.1	10.4	28	6.4	41.4	37.4	69.6	32	14.1	3.2
	13.4	6.7		20.9	8	11	49		46.4	37.6	22.3	2.6
	13.4	6.7		21.9	10.2	10.4	44.5		56.5	40.4	27.3	3
Average				17.7	15.4	9.3	45.0		57.5	36.7	21.2	2.9
Median				20.9	10.2	10.4	44.5		56.5	37.6	22.3	3.0
Percent Reduction				39	70	70	-30		-51	-1	40	92
Sample Event 2	Dosing Volume/Column (liters)	Flow Rate (L/hour)	10/1/2014					10/2/2014				
			Influent	60/40	70vs/20fe/10de	70vs/20fe/10ash	70vs/20cp/10de	Influent	70vs/20cp/10gac	70ws/20cp/10ash	70vs/20cp/10ash	90vs/10comp/p-layer
	13.4	6.7	38.8	11.8	11.8	6.2	18.2	40.8	38.6	4.1	6.3	1.8
	13.4	6.7		10.6	19.1	13.3	7.6		37.7	3.6	7.2	3.7
	13.4	6.7		21.8	15.1	9.4	11.3		38.3	9.3	7.6	1.9
Average				14.7	15.3	9.6	12.4		38.2	5.7	7.0	2.5
Median				11.8	15.1	9.4	11.3		38.3	4.1	7.2	1.9
Percent Reduction				70	61	76	71		6	90	82	95
Sample Event 3	Dosing Volume/Column (liters)	Flow Rate (L/hour)	10/15/2014					10/16/2014				
			Influent	60/40	70vs/20fe/10de	70vs/20fe/10ash	70vs/20cp/10de	Influent	70vs/20cp/10gac	70ws/20cp/10ash	70vs/20cp/10ash	90vs/10comp/p-layer
	13.4	6.7	77.2	12	9.9	13.3	18.8	81.5	49.6	8.3	14.9	2.5
	13.4	6.7		10.4	19.8	28.3	9.7		46.6	8.6	20.6	4.3
	13.4	6.7		22.3	28.5	17.2	18.5		50.4	14.7	13.3	3.5
Average				14.9	19.4	19.6	15.7		48.9	10.5	16.3	3.4
Median				12.0	19.8	17.2	18.5		49.6	8.6	14.9	3.5
Percent Reduction				84	74	78	76		39	89	82	96
Sample Event 4	Dosing Volume/Column (liters)	Flow Rate (L/hour)	10/29/2014					10/30/2014				
			Influent	60/40	70vs/20fe/10de	70vs/20fe/10ash	70vs/20cp/10de	Influent	70vs/20cp/10gac	70ws/20cp/10ash	70vs/20cp/10ash	90vs/10comp/p-layer
	26.8	11.1	72.8	17	25.4	28	34.4	205	44	13.4	no sample	10.6
	26.8	11.1		18.2	74.5	37.6	26.6		39.9	17.2	22.3	9.6
	26.8	11.1		26.5	69.4	34.8	35.7		40.3	15.3	26.2	7.3
Average				20.6	56.4	33.5	32.2		41.4	15.3	24.3	9.2
Median				18.2	69.4	34.8	34.4		40.3	15.3	24.3	9.6
Percent Reduction				75	5	52	53		80	93	88	95
Sample Event 5	Dosing Volume/Column (liters)	Flow Rate (L/hour)	12/10/2014					12/11/2014				
			Influent	60/40	70vs/20fe/10de	70vs/20fe/10ash	70vs/20cp/10de	Influent	70vs/20cp/10gac	70ws/20cp/10ash	70vs/20cp/10ash	90vs/10comp/p-layer
	26.8	11.1	42.7	9.7	18.3	16.4	39.1	50.5	53	23.9	37.1	3.7
	26.8	11.1		11	52.6	35.1	25.2		48.8	30.3	28	4.1
	26.8	11.1		16.9	40.9	12.1	131		44	17.2	37.4	4.5
Average				12.5	37.3	21.2	65.1		48.6	23.8	34.2	4.1
Median				11.0	40.9	16.4	39.1		48.8	23.9	37.1	4.1
Percent Reduction				74	4	62	8		3	53	27	92

L/hour: liters per hour
 mg/L: milligrams per liter
 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

Table 20. Dosing Experiment Raw Data and Summary Statistics for Nitrate Nitrite (mg/L).

Sample Event 1	Dosing Volume/Column (liters)	Flow Rate (L/hour)	9/25/2014					9/26/2014				
			Influent	60/40	70vs/20fe/10de	70vs/20fe/10ash	70vs/20cp/10de	Influent	70vs/20cp/10gac	70ws/20cp/10ash	70vs/20cp/10ash	90vs/10comp/p-layer
	13.4	6.7	1.83	16.4	1.44	0.354	1.2	2.02	0.03	0.468	0.327	2.7
	13.4	6.7		16.7	1.09	0.306	1.21		0.019	0.146	0.36	2.62
	13.4	6.7		33.2	0.362	1.08	1.23		0.023	0.347	0.347	2.53
Average				22.1	0.964	0.580	1.213		0.024	0.320	0.345	2.617
Median				16.7	1.090	0.354	1.210		0.023	0.347	0.347	2.620
Percent Reduction				-813	40	81	34		99	83	83	-30
Sample Event 2	Dosing Volume/Column (liters)	Flow Rate (L/hour)	10/1/2014					10/2/2014				
			Influent	60/40	70vs/20fe/10de	70vs/20fe/10ash	70vs/20cp/10de	Influent	70vs/20cp/10gac	70ws/20cp/10ash	70vs/20cp/10ash	90vs/10comp/p-layer
	13.4	6.7	1.34	8.36	1.01	0.595	0.986	1.48	0.024	0.277	0.543	1.42
	13.4	6.7		10.9	0.769	0.684	0.96		0.012	0.074	0.375	1.48
	13.4	6.7		7.61	0.707	0.73	0.984		0.023	0.174	0.28	1.42
Average				9.0	0.829	0.670	0.977		0.020	0.175	0.399	1.440
Median				8.4	0.769	0.684	0.984		0.023	0.174	0.375	1.420
Percent Reduction				-524	43	49	27		98	88	75	4
Sample Event 3	Dosing Volume/Column (liters)	Flow Rate (L/hour)	10/15/2014					10/16/2014				
			Influent	60/40	70vs/20fe/10de	70vs/20fe/10ash	70vs/20cp/10de	Influent	70vs/20cp/10gac	70ws/20cp/10ash	70vs/20cp/10ash	90vs/10comp/p-layer
	13.4	6.7	1.72	10.7	1.3	0.985	1.69	1.75	0.028	0.327	0.362	1.62
	13.4	6.7		19.6	1.1	0.977	1.2		0.028	0.083	0.339	1.53
	13.4	6.7		4.94	0.934	1.09	1.23		0.037	0.194	0.366	1.57
Average				11.7	1.111	1.017	1.373		0.031	0.201	0.356	1.573
Median				10.7	1.100	0.985	1.230		0.028	0.194	0.362	1.570
Percent Reduction				-522	36	43	28		98	89	79	10
Sample Event 4	Dosing Volume/Column (liters)	Flow Rate (L/hour)	10/29/2014					10/30/2014				
			Influent	60/40	70vs/20fe/10de	70vs/20fe/10ash	70vs/20cp/10de	Influent	70vs/20cp/10gac	70ws/20cp/10ash	70vs/20cp/10ash	90vs/10comp/p-layer
	26.8	11.1	0.518	6.1	0.48	0.334	0.523	0.561	0.016	0.216	no sample	0.842
	26.8	11.1		12.1	0.384	0.383	0.529		0.019	0.097	0.201	0.851
	26.8	11.1		2.77	0.336	0.409	0.574		0.025	0.164	0.198	0.88
Average				7.0	0.400	0.375	0.542		0.020	0.159	0.200	0.858
Median				6.1	0.384	0.383	0.529		0.019	0.164	0.200	0.851
Percent Reduction				-1078	26	26	-2		97	71	64	-52
Sample Event 5	Dosing Volume/Column (liters)	Flow Rate (L/hour)	12/10/2014					12/11/2014				
			Influent	60/40	70vs/20fe/10de	70vs/20fe/10ash	70vs/20cp/10de	Influent	70vs/20cp/10gac	70ws/20cp/10ash	70vs/20cp/10ash	90vs/10comp/p-layer
	26.8	11.1	0.205	7.3	0.093	0.093	0.233	0.295	0.123	0.133	0.121	0.808
	26.8	11.1		25	0.034	0.149	0.197		0.027	0.071	0.116	0.884
	26.8	11.1		5.91	0.082	0.195	0.222		0.035	0.095	0.117	0.965
Average				12.7	0.070	0.146	0.217		0.062	0.100	0.118	0.886
Median				7.3	0.082	0.149	0.222		0.035	0.095	0.117	0.884
Percent Reduction				-3461	60	27	-8		88	68	60	-200

L/hour: liters per hour
 mg/L: milligrams per liter
 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

Table 21. Dosing Experiment Raw Data and Summary Statistics for Total Phosphorus (mg/L).

Sample Event 1	Dosing Volume/Column (liters)	Flow Rate (L/hour)	9/25/2014					9/26/2014				
			Influent	60/40	70vs/20fe/10de	70vs/20fe/10ash	70vs/20cp/10de	Influent	70vs/20cp/10gac	70ws/20cp/10ash	70vs/20cp/10ash	90vs/10comp/p-layer
	13.4	6.7	0.317	0.739	0.241	0.417	0.219	0.324	0.291	0.142	0.18	0.205
	13.4	6.7		0.8	0.285	0.489	0.223		0.263	0.2	0.171	0.213
	13.4	6.7		1.1	0.688	0.192	0.213		0.264	0.199	0.156	0.204
Average				0.880	0.405	0.366	0.218		0.273	0.180	0.169	0.207
Median				0.800	0.285	0.417	0.219		0.264	0.199	0.171	0.205
Percent Reduction				-152	10	-32	31		19	39	47	37
Sample Event 2	Dosing Volume/Column (liters)	Flow Rate (L/hour)	10/1/2014					10/2/2014				
			Influent	60/40	70vs/20fe/10de	70vs/20fe/10ash	70vs/20cp/10de	Influent	70vs/20cp/10gac	70ws/20cp/10ash	70vs/20cp/10ash	90vs/10comp/p-layer
	13.4	6.7	1.24	0.911	1.06	1.13	0.986	1.19	1.14	0.981	1.06	0.921
	13.4	6.7		0.986	1.16	1.12	1.16		1.15	1.02	1.06	1.19
	13.4	6.7		1.83	1.13	1.03	0.899		1.13	1.03	1.02	0.98
Average				1.242	1.117	1.093	1.015		1.140	1.010	1.047	1.030
Median				0.986	1.130	1.120	0.986		1.140	1.020	1.060	0.980
Percent Reduction				20	9	10	20		4	14	11	18
Sample Event 3	Dosing Volume/Column (liters)	Flow Rate (L/hour)	10/15/2014					10/16/2014				
			Influent	60/40	70vs/20fe/10de	70vs/20fe/10ash	70vs/20cp/10de	Influent	70vs/20cp/10gac	70ws/20cp/10ash	70vs/20cp/10ash	90vs/10comp/p-layer
	13.4	6.7	0.344	0.982	0.169	0.257	0.133	0.351	0.211	0.068	0.118	0.16
	13.4	6.7		1.12	0.367	0.274	0.132		0.2	0.089	0.117	0.186
	13.4	6.7		1.19	0.564	0.157	0.128		0.209	0.101	0.108	0.204
Average				1.097	0.367	0.229	0.131		0.207	0.086	0.114	0.183
Median				1.120	0.367	0.257	0.132		0.209	0.089	0.117	0.186
Percent Reduction				-226	-7	25	62		40	75	67	47
Sample Event 4	Dosing Volume/Column (liters)	Flow Rate (L/hour)	10/29/2014					10/30/2014				
			Influent	60/40	70vs/20fe/10de	70vs/20fe/10ash	70vs/20cp/10de	Influent	70vs/20cp/10gac	70ws/20cp/10ash	70vs/20cp/10ash	90vs/10comp/p-layer
	26.8	11.1	1.45	1.45	0.246	0.411	0.19	1.5	0.276	0.086	no sample	0.203
	26.8	11.1		1.86	0.414	0.393	0.178		0.248	0.106	0.339	0.197
	26.8	11.1		1.57	0.488	0.413	0.205		0.259	0.106	0.32	0.216
Average				1.627	0.383	0.406	0.191		0.261	0.099	0.330	0.205
Median				1.570	0.414	0.411	0.190		0.259	0.106	0.330	0.203
Percent Reduction				-8	71	72	87		83	93	78	86
Sample Event 5	Dosing Volume/Column (liters)	Flow Rate (L/hour)	12/10/2014					12/11/2014				
			Influent	60/40	70vs/20fe/10de	70vs/20fe/10ash	70vs/20cp/10de	Influent	70vs/20cp/10gac	70ws/20cp/10ash	70vs/20cp/10ash	90vs/10comp/p-layer
	26.8	11.1	0.494	1.12	0.279	0.284	0.215	0.5	0.295	0.186	0.273	0.25
	26.8	11.1		1.33	0.356	0.274	0.224		0.281	0.199	0.26	0.281
	26.8	11.1		1.19	0.289	0.212	0.218		0.289	0.19	0.277	0.276
Average				1.213	0.308	0.257	0.219		0.288	0.192	0.270	0.269
Median				1.190	0.289	0.274	0.218		0.289	0.190	0.273	0.276
Percent Reduction				-141	41	45	56		42	62	45	45

L/hour: liters per hour
mg/L: milligrams per liter
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

Table 22. Dosing Experiment Raw Data and Summary Statistics for Ortho Phosphorus (mg/L).

Sample Event 1	Dosing Volume/Column (liters)	Flow Rate (L/hour)	9/25/2014					9/26/2014				
			Influent	60/40	70vs/20fe/10de	70vs/20fe/10ash	70vs/20cp/10de	Influent	70vs/20cp/10gac	70ws/20cp/10ash	70vs/20cp/10ash	90vs/10comp/p-layer
	13.4	6.7	0.085	0.516	0.015	0.266	0.03	0.126	0.025	0.014	0.027	0.132
	13.4	6.7		0.56	0.122	0.303	0.028		0.021	0.019	0.028	0.127
	13.4	6.7		0.824	0.448	0.064	0.027		0.023	0.022	0.025	0.137
Average				0.633	0.195	0.211	0.028		0.023	0.018	0.027	0.132
Median				0.560	0.122	0.266	0.028		0.023	0.019	0.027	0.132
Percent Reduction				-559	-44	-213	67		82	85	79	-5
Sample Event 2	Dosing Volume/Column (liters)	Flow Rate (L/hour)	10/1/2014					10/2/2014				
			Influent	60/40	70vs/20fe/10de	70vs/20fe/10ash	70vs/20cp/10de	Influent	70vs/20cp/10gac	70ws/20cp/10ash	70vs/20cp/10ash	90vs/10comp/p-layer
	13.4	6.7	0.073	0.674	0.018	0.114	0.032	0.082	0.029	0.021	0.046	0.125
	13.4	6.7		0.79	0.077	0.08	0.032		0.037	0.027	0.047	0.12
	13.4	6.7		1.06	0.112	0.033	0.031		0.03	0.021	0.042	0.133
Average				0.841	0.069	0.076	0.032		0.032	0.023	0.045	0.126
Median				0.790	0.077	0.080	0.032		0.030	0.021	0.046	0.125
Percent Reduction				-982	-5	-10	56		63	74	44	-52
Sample Event 3	Dosing Volume/Column (liters)	Flow Rate (L/hour)	10/15/2014					10/16/2014				
			Influent	60/40	70vs/20fe/10de	70vs/20fe/10ash	70vs/20cp/10de	Influent	70vs/20cp/10gac	70ws/20cp/10ash	70vs/20cp/10ash	90vs/10comp/p-layer
	13.4	6.7	0.13	0.8	0.074	0.112	0.036	0.134	0.042	0.025	0.048	0.121
	13.4	6.7		0.97	0.166	0.077	0.034		0.04	0.037	0.05	0.109
	13.4	6.7		0.895	0.292	0.041	0.033		0.051	0.033	0.047	0.128
Average				0.888	0.177	0.077	0.034		0.044	0.032	0.048	0.119
Median				0.895	0.166	0.077	0.034		0.042	0.033	0.048	0.121
Percent Reduction				-588	-28	41	74		69	75	64	10
Sample Event 4	Dosing Volume/Column (liters)	Flow Rate (L/hour)	10/29/2014					10/30/2014				
			Influent	60/40	70vs/20fe/10de	70vs/20fe/10ash	70vs/20cp/10de	Influent	70vs/20cp/10gac	70ws/20cp/10ash	70vs/20cp/10ash	90vs/10comp/p-layer
	26.8	11.1	0.071	1.08	0.108	0.214	0.05	1.13	0.097	0.016	no sample	0.102
	26.8	11.1		1.72	0.096	0.183	0.063		0.085	0.022	0.229	0.092
	26.8	11.1		1.38	0.106	0.238	1.12		0.099	0.02	0.204	0.119
Average				1.393	0.103	0.212	0.411		0.094	0.019	0.217	0.104
Median				1.380	0.106	0.214	0.063		0.097	0.020	0.217	0.102
Percent Reduction				-1844	-49	-201	11		91	98	81	91
Sample Event 5	Dosing Volume/Column (liters)	Flow Rate (L/hour)	12/10/2014					12/11/2014				
			Influent	60/40	70vs/20fe/10de	70vs/20fe/10ash	70vs/20cp/10de	Influent	70vs/20cp/10gac	70ws/20cp/10ash	70vs/20cp/10ash	90vs/10comp/p-layer
	26.8	11.1	0.134	0.948	0.091	0.076	0.043	0.145	0.058	0.018	0.068	0.08
	26.8	11.1		1.15	0.161	0.039	0.044		0.061	0.025	0.067	0.098
	26.8	11.1		0.983	0.12	0.053	0.042		0.069	0.022	0.066	0.104
Average				1.027	0.124	0.056	0.043		0.063	0.022	0.067	0.094
Median				0.983	0.120	0.053	0.043		0.061	0.022	0.067	0.098
Percent Reduction				-634	10	60	68		58	85	54	32

L/hour: liters per hour
mg/L: milligrams per liter
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

Table 23. Dosing Experiment Raw Data and Summary Statistics for Total Copper (µg/L).

Sample Event 1	Dosing Volume/Column (liters)	Flow Rate (L/hour)	9/25/2014					9/26/2014				
			Influent	60/40	70vs/20fe/10de	70vs/20fe/10ash	70vs/20cp/10de	Influent	70vs/20cp/10gac	70ws/20cp/10ash	70vs/20cp/10ash	90vs/10comp/p-layer
	13.4	6.7	17	12.8	14.6	43.1	10.7	15.8	13.3	6.6	6.4	4.6
	13.4	6.7		12	24.5	48.3	10.6		14	8.9	7.3	6.5
	13.4	6.7		11.3	71.3	18.1	10.7		11.4	9.3	7.5	5.1
Average				12.0	36.8	36.5	10.7		12.9	8.3	7.1	5.4
Median				12.0	24.5	43.1	10.7		13.3	8.9	7.3	5.1
Percent Reduction				29	-44	-154	37		16	44	54	68
Sample Event 2	Dosing Volume/Column (liters)	Flow Rate (L/hour)	10/1/2014					10/2/2014				
			Influent	60/40	70vs/20fe/10de	70vs/20fe/10ash	70vs/20cp/10de	Influent	70vs/20cp/10gac	70ws/20cp/10ash	70vs/20cp/10ash	90vs/10comp/p-layer
	13.4	6.7	12.2	11.8	9.8	22.3	6.9	13.2	10.1	2.7	6.1	3.8
	13.4	6.7		13.9	18.3	20.2	6.5		9.2	3.7	6.4	4.8
	13.4	6.7		12.8	26.9	12	6.7		9.2	3.4	5.9	5.2
Average				12.8	18.3	18.2	6.7		9.5	3.3	6.1	4.6
Median				12.8	18.3	20.2	6.7		9.2	3.4	6.1	4.8
Percent Reduction				-5	-50	-66	45		30	74	54	64
Sample Event 3	Dosing Volume/Column (liters)	Flow Rate (L/hour)	10/15/2014					10/16/2014				
			Influent	60/40	70vs/20fe/10de	70vs/20fe/10ash	70vs/20cp/10de	Influent	70vs/20cp/10gac	70ws/20cp/10ash	70vs/20cp/10ash	90vs/10comp/p-layer
	13.4	6.7	15.6	14.3	14.2	28.3	8.8	15.6	12.1	3.6	7.9	3.6
	13.4	6.7		17.4	39.2	26.4	8.4		10.4	4.2	8.2	9
	13.4	6.7		14.3	64.9	15.2	9		10.7	4.1	7.4	10.2
Average				15.3	39.4	23.3	8.7		11.1	4.0	7.8	7.6
Median				14.3	39.2	26.4	8.8		10.7	4.1	7.9	9.0
Percent Reduction				8	-151	-69	44		31	74	49	42
Sample Event 4	Dosing Volume/Column (liters)	Flow Rate (L/hour)	10/29/2014					10/30/2014				
			Influent	60/40	70vs/20fe/10de	70vs/20fe/10ash	70vs/20cp/10de	Influent	70vs/20cp/10gac	70ws/20cp/10ash	70vs/20cp/10ash	90vs/10comp/p-layer
	26.8	11.1	546	22	18.4	31.9	13.6	575	20.7	11.6	no sample	18.2
	26.8	11.1		19.2	33.1	26.1	13.2		19	12.8	20.7	20.2
	26.8	11.1		20.4	45.4	24	14.3		19	12.5	20.6	21
Average				20.5	32.3	27.3	13.7		19.6	12.3	20.7	19.8
Median				20.4	33.1	26.1	13.6		19.0	12.5	20.7	20.2
Percent Reduction				96	94	95	98		97	98	96	96
Sample Event 5	Dosing Volume/Column (liters)	Flow Rate (L/hour)	12/10/2014					12/11/2014				
			Influent	60/40	70vs/20fe/10de	70vs/20fe/10ash	70vs/20cp/10de	Influent	70vs/20cp/10gac	70ws/20cp/10ash	70vs/20cp/10ash	90vs/10comp/p-layer
	26.8	11.1	23.4	11.4	23.7	31.4	8.8	24.5	10.8	8.4	10.7	10.8
	26.8	11.1		11.7	36.2	20	9.1		10.1	8.3	10.2	10.3
	26.8	11.1		10.4	37	14.2	9.5		10	7.7	10.3	9.6
Average				11.2	32.3	21.9	9.1		10.3	8.1	10.4	10.2
Median				11.4	36.2	20.0	9.1		10.1	8.3	10.3	10.3
Percent Reduction				51	-55	15	61		59	66	58	58

L/hour: liters per hour
 mg/L: milligrams per liter
 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

Table 24. Dosing Experiment Raw Data and Summary Statistics for Dissolved Copper (µg/L).

Sample Event 1	Dosing Volume/Column (liters)	Flow Rate (L/hour)	9/25/2014					9/26/2014				
			Influent	60/40	70vs/20fe/10de	70vs/20fe/10ash	70vs/20cp/10de	Influent	70vs/20cp/10gac	70ws/20cp/10ash	70vs/20cp/10ash	90vs/10comp/p-layer
			13.4	6.7	8.8	10.6	6.5	38.5	5	8.6	2.6	0.9
13.4	6.7		9.6	21.7	43.5	4.7		2.6	1.2	4.6	3.6	
13.4	6.7		9.5	68	14.4	4.9		3.4	1.1	3.6	3.6	
Average				9.9	32.1	32.1	4.9		2.9	1.1	4.0	3.5
Median				9.6	21.7	38.5	4.9		2.6	1.1	3.7	3.6
Percent Reduction				-9	-147	-338	44		70	87	57	58
Sample Event 2	Dosing Volume/Column (liters)	Flow Rate (L/hour)	10/1/2014					10/2/2014				
			Influent	60/40	70vs/20fe/10de	70vs/20fe/10ash	70vs/20cp/10de	Influent	70vs/20cp/10gac	70ws/20cp/10ash	70vs/20cp/10ash	90vs/10comp/p-layer
			13.4	6.7	8.6	11.6	7.9	21	5.4	7.4	2.9	1.4
13.4	6.7		12.6	16.3	19.2	5.8		2.8	1.6	4.6	3.6	
13.4	6.7		11.6	22.6	10.3	5.9		3.3	1.6	4.2	4.1	
Average				11.9	15.6	16.8	5.7		3.0	1.5	4.5	3.6
Median				11.6	16.3	19.2	5.8		2.9	1.6	4.6	3.6
Percent Reduction				-35	-90	-123	33		61	78	38	51
Sample Event 3	Dosing Volume/Column (liters)	Flow Rate (L/hour)	10/15/2014					10/16/2014				
			Influent	60/40	70vs/20fe/10de	70vs/20fe/10ash	70vs/20cp/10de	Influent	70vs/20cp/10gac	70ws/20cp/10ash	70vs/20cp/10ash	90vs/10comp/p-layer
			13.4	6.7	8.7	11.2	12.8	23.1	5.9	8.8	3.4	1.3
13.4	6.7		13.5	34.5	19.6	6.1		4.7	1.7	5.2	8.2	
13.4	6.7		10.8	56.4	11.1	6		3.9	1.6	5.2	8.6	
Average				11.8	34.6	17.9	6.0		4.0	1.5	5.1	6.5
Median				11.2	34.5	19.6	6.0		3.9	1.6	5.2	8.2
Percent Reduction				-29	-297	-125	31		56	82	41	7
Sample Event 4	Dosing Volume/Column (liters)	Flow Rate (L/hour)	10/29/2014					10/30/2014				
			Influent	60/40	70vs/20fe/10de	70vs/20fe/10ash	70vs/20cp/10de	Influent	70vs/20cp/10gac	70ws/20cp/10ash	70vs/20cp/10ash	90vs/10comp/p-layer
			26.8	11.1	331	18.4	14	25.9	9	297	11.7	7
26.8	11.1		17	20	19.8	9.1		12	8.1	14.5	15.9	
26.8	11.1		16.4	27	17	9		12.8	7.7	14.8	16.5	
Average				17.3	20.3	20.9	9.0		12.2	7.6	14.7	15.4
Median				17.0	20.0	19.8	9.0		12.0	7.7	14.7	15.9
Percent Reduction				95	94	94	97		96	97	95	95
Sample Event 5	Dosing Volume/Column (liters)	Flow Rate (L/hour)	12/10/2014					12/11/2014				
			Influent	60/40	70vs/20fe/10de	70vs/20fe/10ash	70vs/20cp/10de	Influent	70vs/20cp/10gac	70ws/20cp/10ash	70vs/20cp/10ash	90vs/10comp/p-layer
			26.8	11.1	7.6	9.6	19.1	23.7	4.9	8	3.6	3.3
26.8	11.1		9.5	23.3	11.1	5.1		3.7	3.2	5.7	9.1	
26.8	11.1		8.4	18.3	11.4	5.1		3.8	2.8	5.2	7.3	
Average				9.2	20.2	15.4	5.0		3.7	3.1	5.5	8.3
Median				9.5	19.1	11.4	5.1		3.7	3.2	5.7	8.4
Percent Reduction				-25	-151	-50	33		54	60	29	-5

L/hour: liters per hour
mg/L: milligrams per liter
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

Table 25. Dosing Experiment Raw Data and Summary Statistics for Total Zinc (µg/L).

Sample Event 1	Dosing Volume/Column (liters)	Flow Rate (L/hour)	9/25/2014					9/26/2014				
			Influent	60/40	70vs/20fe/10de	70vs/20fe/10ash	70vs/20cp/10de	Influent	70vs/20cp/10gac	70ws/20cp/10ash	70vs/20cp/10ash	90vs/10comp/p-layer
	13.4	6.7	80	8	6	6	8	64	14	8	6	4
	13.4	6.7		9	7	6	8		14	11	7	4
	13.4	6.7		7	9	5	8		12	11	8	4
Average				8	7	6	8		13	10	7	4
Median				8	7	6	8		14	11	7	4
Percent Reduction				90	91	93	90		78	83	89	94
Sample Event 2	Dosing Volume/Column (liters)	Flow Rate (L/hour)	10/1/2014					10/2/2014				
			Influent	60/40	70vs/20fe/10de	70vs/20fe/10ash	70vs/20cp/10de	Influent	70vs/20cp/10gac	70ws/20cp/10ash	70vs/20cp/10ash	90vs/10comp/p-layer
	13.4	6.7	52	5	5	4	4	55	8	4	4	4
	13.4	6.7		6	5	5	4		7	4	4	4
	13.4	6.7		6	4	4	4		8	4	4	4
Average				6	5	4	4		8	4	4	4
Median				6	5	4	4		8	4	4	4
Percent Reduction				88	90	92	92		85	93	93	93
Sample Event 3	Dosing Volume/Column (liters)	Flow Rate (L/hour)	10/15/2014					10/16/2014				
			Influent	60/40	70vs/20fe/10de	70vs/20fe/10ash	70vs/20cp/10de	Influent	70vs/20cp/10gac	70ws/20cp/10ash	70vs/20cp/10ash	90vs/10comp/p-layer
	13.4	6.7	82	7	5	7	5	84	11	4	5	4
	13.4	6.7		8	7	6	4		9	4	5	4
	13.4	6.7		8	4	5	5		9	5	4	4
Average				8	5	6	5		10	4	5	4
Median				8	5	6	5		9	4	5	4
Percent Reduction				90	94	93	94		89	95	94	95
Sample Event 4	Dosing Volume/Column (liters)	Flow Rate (L/hour)	10/29/2014					10/30/2014				
			Influent	60/40	70vs/20fe/10de	70vs/20fe/10ash	70vs/20cp/10de	Influent	70vs/20cp/10gac	70ws/20cp/10ash	70vs/20cp/10ash	90vs/10comp/p-layer
	26.8	11.1	700	6	8	5	5	740	9	5	no sample	4
	26.8	11.1		7	9	7	5		7	5	6	4
	26.8	11.1		6	4	5	5		6	5	7	4
Average				6	7	6	5		7	5	7	4
Median				6	8	5	5		7	5	7	4
Percent Reduction				99	99	99	99		99	99	99	99
Sample Event 5	Dosing Volume/Column (liters)	Flow Rate (L/hour)	12/10/2014					12/11/2014				
			Influent	60/40	70vs/20fe/10de	70vs/20fe/10ash	70vs/20cp/10de	Influent	70vs/20cp/10gac	70ws/20cp/10ash	70vs/20cp/10ash	90vs/10comp/p-layer
	26.8	11.1	78	5	8	12	6	87	10	11	10	6
	26.8	11.1		8	9	8	7		9	8	10	6
	26.8	11.1		7	6	5	7		11	10	11	8
Average				7	8	8	7		10	10	10	7
Median				7	8	8	7		10	10	10	6
Percent Reduction				91	90	90	91		89	89	89	93

L/hour: liters per hour
 mg/L: milligrams per liter
 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

Table 26. Dosing Experiment Raw Data and Summary Statistics for Dissolved Zinc (µg/L).

Sample Event 1	Dosing Volume/Column (liters)	Flow Rate (L/hour)	9/25/2014					9/26/2014				
			Influent	60/40	70vs/20fe/10de	70vs/20fe/10ash	70vs/20cp/10de	Influent	70vs/20cp/10gac	70ws/20cp/10ash	70vs/20cp/10ash	90vs/10comp/p-layer
	13.4	6.7	19	5	4	4	4	15	4	4	4	4
	13.4	6.7		4	4	4	4		4	4	4	4
	13.4	6.7		4	7	4	4		4	4	4	4
Average				4	5	4	4		4	4	4	4
Median				4	4	4	4		4	4	4	4
Percent Reduction				79	79	79	79		73	73	73	73
Sample Event 2	Dosing Volume/Column (liters)	Flow Rate (L/hour)	10/1/2014					10/2/2014				
			Influent	60/40	70vs/20fe/10de	70vs/20fe/10ash	70vs/20cp/10de	Influent	70vs/20cp/10gac	70ws/20cp/10ash	70vs/20cp/10ash	90vs/10comp/p-layer
	13.4	6.7	20	4	4	4	4	16	4	4	4	4
	13.4	6.7		4	4	4	4		4	4	4	4
	13.4	6.7		4	4	4	4		4	4	4	4
Average				4	4	4	4		4	4	4	4
Median				4	4	4	4		4	4	4	4
Percent Reduction				80	80	80	80		75	75	75	75
Sample Event 3	Dosing Volume/Column (liters)	Flow Rate (L/hour)	10/15/2014					10/16/2014				
			Influent	60/40	70vs/20fe/10de	70vs/20fe/10ash	70vs/20cp/10de	Influent	70vs/20cp/10gac	70ws/20cp/10ash	70vs/20cp/10ash	90vs/10comp/p-layer
	13.4	6.7	29	5	4	4	4	29	4	5	4	4
	13.4	6.7		4	4	4	4		4	6	5	4
	13.4	6.7		4	10	4	4		4	4	6	5
Average				4	6	4	4		4	5	5	4
Median				4	4	4	4		4	5	5	4
Percent Reduction				86	86	86	86		86	83	83	86
Sample Event 4	Dosing Volume/Column (liters)	Flow Rate (L/hour)	10/29/2014					10/30/2014				
			Influent	60/40	70vs/20fe/10de	70vs/20fe/10ash	70vs/20cp/10de	Influent	70vs/20cp/10gac	70ws/20cp/10ash	70vs/20cp/10ash	90vs/10comp/p-layer
	26.8	11.1	610	4	4	4	4	580	4	4	no sample	4
	26.8	11.1		4	4	4	4		4	4	4	4
	26.8	11.1		4	4	4	4		4	4	4	4
Average				4	4	4	4		4	4	4	4
Median				4	4	4	4		4	4	4	4
Percent Reduction				99	99	99	99		99	99	99	99
Sample Event 5	Dosing Volume/Column (liters)	Flow Rate (L/hour)	12/10/2014					12/11/2014				
			Influent	60/40	70vs/20fe/10de	70vs/20fe/10ash	70vs/20cp/10de	Influent	70vs/20cp/10gac	70ws/20cp/10ash	70vs/20cp/10ash	90vs/10comp/p-layer
	26.8	11.1	33	5	6	4	4	29	4	4	4	4
	26.8	11.1		5	5	4	4		4	4	4	4
	26.8	11.1		5	4	4	4		4	4	4	4
Average				5	5	4	4		4	4	4	4
Median				5	5	4	4		4	4	4	4
Percent Reduction				85	85	88	88		86	86	86	86

L/hour: liters per hour
 mg/L: milligrams per liter
 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

Comparison of Research Results to TAPE Performance Targets

To provide some context for evaluating the performance of the individual treatments, statistical analyses were performed to compare the results from this study to applicable performance goals specified in Ecology’s TAPE guidelines (Ecology 2011) for basic, enhanced, and phosphorus treatment (see Table 27). The statistical analyses involved the computation of bootstrapped lower confidence intervals around the mean percent removal for TSS, TP, dissolved Zn, and dissolved Cu (Table 28). In addition, a bootstrapped upper confidence limit was also computed around the mean effluent concentration for TSS (Table 29). Note that not all sampling events met TAPE influent guidelines, and as a result, some sample sizes are small. For example, Total phosphorus dosing events 1, 3 and 5 met TAPE guidelines, however events 2 and 4 exceeded influent concentrations and were not used. These values were then compared to the performance goals identified in Table 27 to determine if specific treatments were performing at acceptable levels in accordance with the TAPE guidelines. However, it should be noted that this is an applied research study that did not follow TAPE guidelines for data collection which require testing of full-scale systems. Accordingly, the following provides only a general estimate of treatment performance within the context of the TAPE guidelines.

Performance Goal	Influent Range	Criteria
Basic Treatment	20-100 mg/L TSS	Effluent goal ≤ 20 mg/L TSS ^a
	100-200 mg/L TSS	$\geq 80\%$ TSS removal ^b
	> 200 mg/L TSS	$> 80\%$ TSS removal ^b
Enhanced (Dissolved Metals) Treatment	Dissolved copper 0.005–0.02 mg/L	Must meet basic treatment goal and exhibit $> 30\%$ dissolved copper removal ^b
	Dissolved zinc 0.02–0.3 mg/L	Must meet basic treatment goal and exhibit $> 60\%$ dissolved zinc removal ^b
Phosphorus Treatment	Total phosphorus (TP) 0.1 to 0.5 mg/L	Must meet basic treatment goal and exhibit $\geq 50\%$ TP removal ^b

Source: Ecology (2011).

^a The upper 95 percent confidence interval around the mean effluent concentration for the treatment system being evaluated must be lower than this performance goal to meet the performance goal with the required 95 percent confidence.

^b The lower 95 percent confidence interval around the mean removal efficiency for the treatment system being evaluated must be higher than this performance goal to meet the performance goal with the required 95 percent confidence.

mg/L = milligrams per liter

Note: Only samples falling in the TAPE influent ranges were used for Zn, Cu and TP calculations. All influent concentrations for TSS fell within the 20-100 mg/L range except for the second set of columns during sample event 4 which was 205 mg/L.

Results from this comparison show only the 90vs/10comp/p-layer treatment met the separate performance targets for basic treatment that are based on percent removal and effluent concentration. None of the treatments met the performance target for phosphorus treatment while all of the treatments met the enhanced treatment performance target for dissolved zinc. Finally, all of the following treatments met the enhanced treatment performance target for dissolved Zn and Cu:

- 70vs/20cp/10de
- 70vs/20cp/10gac
- 70ws/20cp/10ash
- 70vs/20cp/10ash

Table 28. Bootstrapped Lower 95 Percent Confidence Interval Around the Mean Removal Efficiency (%).

Parameter	60/40	70vs/ 20fe/ 10de	70vs/ 20fe/ 10ash	70vs/ 20cp/ 10de	70vs/ 20cp/ 10gac	70ws/ 20cp/ 10ash	70vs/ 20cp/ 10ash	90vs/ 10comp/ p-layer
Total Suspended Solids	59.8	30.3	58.0	-9.3	- 4.7	48.6	52.5	93.0
Total Phosphorus	- 205.7	- 30.2	0.0	42.3	25.9	52.6	48.6	39.8
Dissolved Zinc	84.2	76.1	86.5	86.5	86.2	82.8	82.8	84.5
Dissolved Copper	- 33.5	- 307.2	- 198.9	33.2	55.5	72.7	37.5	19.1

Bootstrapped confidence limits were calculated using n=15 for each treatment and 5000 bootstrap iterations.

Negative numbers indicate export.

Bold values meet performance targets identified in TAPE for the respective parameter.

Table 29. Bootstrapped Upper 95 Percent Confidence Interval Around the Mean Effluent Concentration (mg/L).

Parameter	60/40	70vs/ 20fe/ 10de	70vs/ 20fe/ 10ash	70vs/ 20cp/ 10de	70vs/ 20cp/ 10gac	70ws/ 20cp/ 10ash	70vs/ 20cp/ 10ash	90vs/ 10comp/ p-layer
Total Suspended Solids	18.5	37.9	23.3	47.3	50.4	23.3	24.7	5.6

Bootstrapped confidence limits were calculated using n=15 for each treatment and 5000 bootstrap iterations.

Negative numbers indicate export.

Bold values meet performance targets identified in TAPE for the respective parameter.

Hydraulic Conductivity Evaluation Results

Two different tests were conducted to evaluate Ksat: 1) column falling head procedure; and 2) ASTM D2434 (Standard Test Method for Permeability of Granular Soils) conducted by Shannon and Wilson. See Sampling and Data Analysis Procedures section above for details.

For an individual measurement, the column falling head tests results ranged from a high rate of 195 inches per hour (in/hr) (497.28 centimeters per hour [cm/hr]) for the 60sand/40comp control to a low of 43.06 in/hr (109.38 cm/hr) for the 70ws/20cp/10ash treatment. Mean rates ranged from a high of 161.20 in/hr (409.46 cm/hr) for the 60sand/40comp control to a low of 56.48 in/hr (143.45 cm/hr) for the 70ws/20cp/10ash treatment. Figure 19 shows mean Ksat rates for the column falling head tests by treatment.

For an individual measurement, Ksat rates from the ASTM D2434 tests ranged from a high rate of 196.00 in/hr (497.84.52 cm/hr) for the 90vs/10comp/p-layer treatment to a low of 4.00 in/hr (10.16 cm/hr) for the 70vs/20cp/10de treatment. Mean rates ranged from a high of 148.00 in/hr (375.92 cm/hr) for the 90vs/10comp/p-layer treatment to a low of 32.00 in/hr (81.28 cm/hr) for the 70ws/20cp/10ash treatment. Figure 20 shows mean Ksat rates from ASTM constant head tests by treatment. Note that the ASTM constant head test was not performed on the 60san/40comp control.

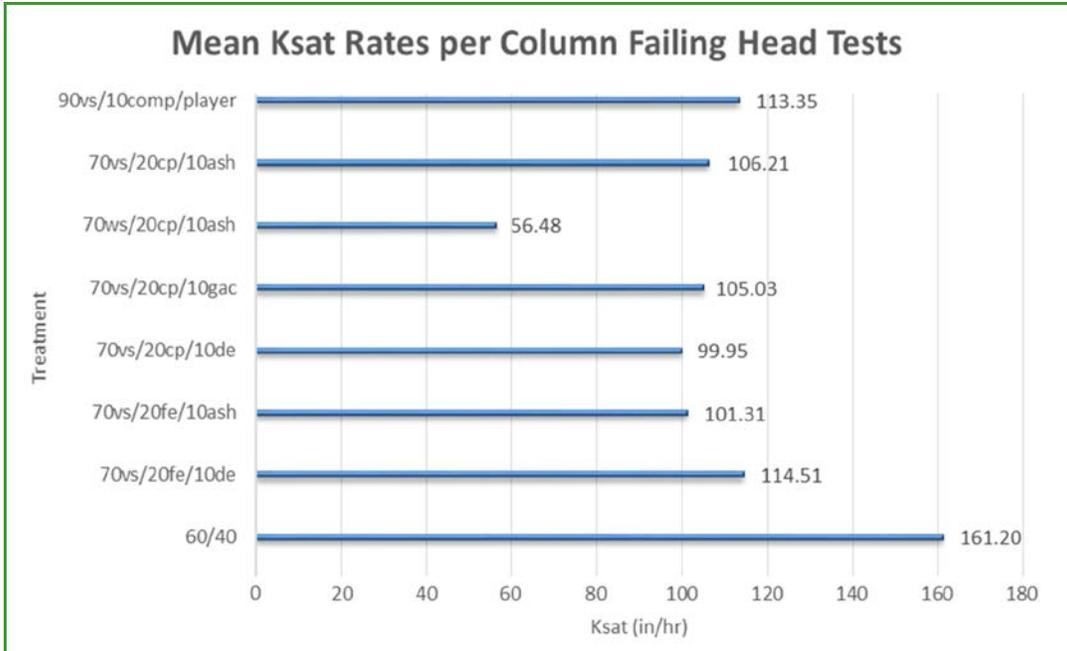


Figure 19. Mean Ksat Rates for Column Failing Head Tests

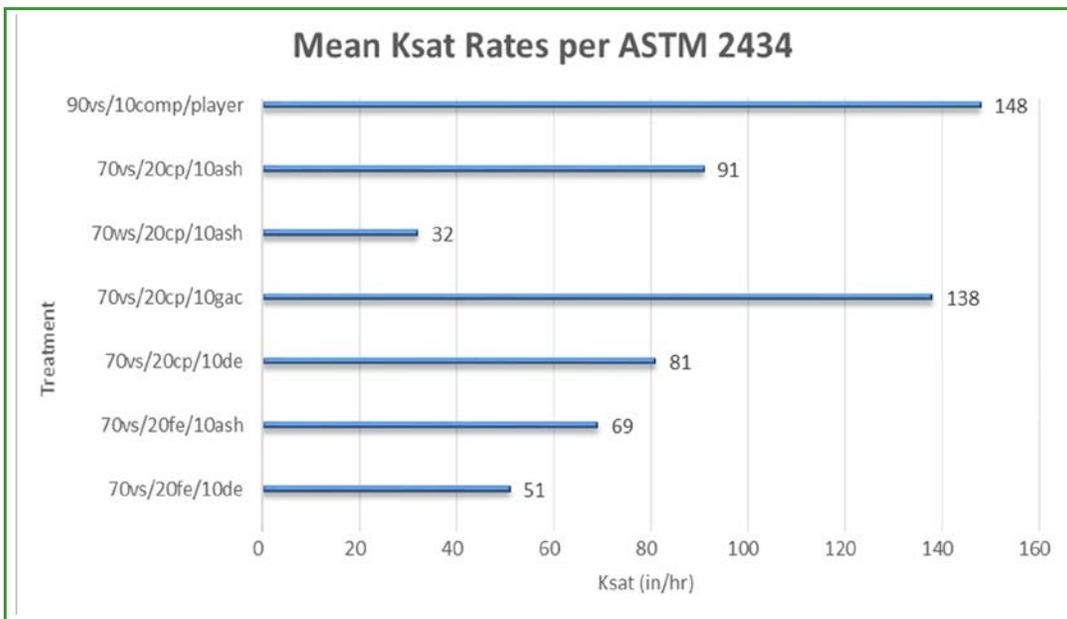


Figure 20. Mean Ksat Rates for ASTM 2434 Tests

Plant Growth and Media Physical Properties Results

Several of the media treatments were sent to Soil Control Labs in California to assess the physical and chemical characteristics of the media. The 60sand/40comp was not submitted for testing because extensive testing has been conducted on this mix in previous studies.

As anticipated the media treatments have low organic matter content. However typical organic matter content for the 60sand/40comp falls in the range of 3 to 6 percent, so the organic matter range of 1.7 to 3.4 shows reasonable alignment with previous analysis. (see Table 30).

Treatment	CEC (meq/100 grams dry soil)	Organic Matter (percent)	Porosity (percent)	
			Total Water Filled	After 2-hr Drain-Down
70vs/20fe/10de	1.7	2.5	47.6	44.8
70vs/20fe/10ash	2.3	1.7	49.0	44.0
70vs/20cp/10de	2.4	2.0	52.7	50.5
70vs/20cp/10gac	1.8	2.7	57.2	52.2
70ws/20cp/10ash	2.9	3.4	48.9	46.5
90vs/10comp/p-layer	1.4	1.7	52.3	48.7

Meq: milliequivalents

The cation exchange capacity (CEC) is also low and below the recommended 5 meq/100grams dry soil for treatment media (Ecology, 2014). Note that the method used for this analysis is CEC Peat (973.09 AOAC15th Edition); however, there are other methods that may produce varying results. Porosity and water holding capacity are high in all treatments as anticipated with the selection of media components known to have high porosity. The carbon nitrogen ratio is not reported given unusual results and possible laboratory error.

The plant germination and growth tests use three species of plants (cucumber, barley and clover) in small pots and controlled indoor growing conditions. Table 31 shows the average percent germination and height for all three plant species arranged by germination then height from highest to lowest value. All media germinated plants. While no clear pattern emerges for specific treatments the media containing compost was the best performer.

Treatment	Germination (%)	Height (cm)
90vs/10comp/player	94.4	8.2
70vs/20cp/10gac	91.1	6.7
70vs/20fe/10de	88.9	5.7
70ws/20cp/10ash	87.8	7.4
70vs/20fe/10ash	86.7	8.1
70vs/20cp/10de	85.5	8.3

DISCUSSION

The following provides a discussion of the flushing and dosing results organized by media blend treatment. For this discussion the treatments have been grouped under separate subsections by bulk organic material as follows:

Control: includes 60/40 treatment

Iron Coated Woodchips: includes 70vs/20fe/10de and 70vs/20fe/10ash treatments

Coco coir pith: 70ws/20cp/10ash, 70vs/20cp/10ash, 70vs/20cp/10gac and 70vs/20cp/10de treatments

Compost with polishing layer: 90vs/10comp/p-layer treatment

60sand/40comp Control

The 60sand/40comp is the media blend currently prescribed in the SWMMWW, the Stormwater Management Manual for Eastern Washington (SWMMEW) and the Low Impact Development Technical Guidance Manual for Puget Sound. This blend was used as a control or benchmark to compare flushing and dosing performance of the new treatments.

The 60sand/40comp control performed poorly compared to the other treatments in the flushing experiments; especially for nitrate+nitrite, TP, ortho-P, and dissolved Cu. This is consistent with previous studies (Herrera 2014a, 2015) that have examined the performance of this BSM. For example, in the first sampled nitrate+nitrite flushing event, the median effluent concentration (18.6 mg/L) for the 60sand/40comp control was 3 orders of magnitude higher than the treatments not containing compost (e.g. 0.02 mg/L for the 70vs/20cp/10ash treatment).

As with the flushing experiments, the 60sand/40comp control generally performed poorly compared to other treatments in the dosing experiments. Nitrate+nitrite, ortho-P and dissolved Cu were consistently exported from the 60sand/40comp control and median effluent concentrations were significantly higher than those for all other treatments. In particular, median effluent concentrations for nitrate+nitrite and ortho-P were often an order of magnitude higher than concentrations observed for the other treatments. These results indicate compost is a significant source of pollutant flushing for this subset of pollutants.

The 60sand/40comp treatment was in the middle of the performance range for TSS capture at 71 percent removal for all dosing experiments.

70vs/20fe/10de and 70vs/20fe/10ash Treatments

These blends used fine wood chips coated with iron for the bulk organic material. The additives were then varied (diatomaceous earth and high carbon wood ash) to compare performance.

Both blends performed similarly in the flushing tests. Median effluent concentrations for nitrate+nitrite and ortho-P for all events were near or the lowest concentrations of all treatments. Dissolved Cu performance was not quite as good with median effluent concentrations for all events at 3.6 and 3.9 µg/L compared to the better performers with median effluent concentrations at or below 1 µg/L.

For the dosing experiments both of these blends did not perform well compared to the best media blends. NO₃-NO₂ and ortho-P median effluent concentrations for all events were higher, but not significantly higher than all treatments except the 60sand/40comp control. Percent removal for NO₃-NO₂ was less than, and at times half of, the better performers for many experiments. The iron component of the woods chips was included to capture ortho-P; however, for most experiments ortho-P was exported from these blends. Dissolved Cu was also exported from these blends for all but the high-dose experiment. The dissolved Cu effluent concentrations were high (up to 43.5 µg/L) initially and declined in subsequent dosing, but remained high compared to the better performers.

TSS median percent removal was in the middle of the performance range at 61 percent for the 70vs/20fe/10de and 68 percent for the 70vs/20fe/10ash for all dosing experiments.

While the source and mechanisms are not understood, the iron-coated chips appear to be a source of dissolved Cu and did not provide an adequate level of ortho-P capture.

70vs/20cp/10de, 70vs/20cp/10gac, 70vs/20cp/10ash, and 70ws/20cp/10ash Treatments

Coconut coir pith was used in 4 of the 8 blends because of the high water holding capacity and desirable structure for plant growth. For the coconut coir pith blends, diatomaceous earth, granular activated charcoal and high carbon wood ash were also included for water holding capacity, high surface area and water treatment capabilities reported in the literature.

The coconut coir pith treatments were the best performers in the flushing experiments. Of the four treatments, the blends with high carbon wood ash and granular activated charcoal were the top performers in this group. While the blends containing high carbon wood ash and granular activated charcoal performed very well in all experiments for nitrate-nitrite, ortho-P and dissolved Cu, the blend containing diatomaceous earth had poorer results for ortho-P.

These blends were also top performers in the dosing experiments. Again, the blends containing high carbon wood ash and granular activated charcoal performed very well in all experiments for nitrate-nitrite, ortho-P and dissolved Cu; however, the blend containing diatomaceous earth had higher effluent concentrations and poorer percent removal (ranging from slight export to 34 percent) for nitrate-nitrite.

While the mechanisms are not understood, the coir and granular activated charcoal or high carbon wood ash media are successfully capturing nitrate+nitrite ions. In other studies of bioretention media performance in this region, nitrate+nitrite ions have proven to be exceptionally difficult to remove from stormwater by sorption or complexation mechanisms and have only been successfully removed through biological de-nitrification.

TSS median percent removal for this class of materials varied considerably. The 70ws/20cp/10ash and 70vs/20cp/10ash were near the top of the performance range at 78 and 82 percent respectively. However, the 70vs/20cp/10gac was the poorest performer with an overall median removal of 8 percent.

90vs/10comp/p-layer Treatment

The 90vs/10comp/p-layer was the only other treatment with compost besides the 60sand/40comp control. The polishing layer was added in an attempt to retain compost as the primary bulk organic material, but eliminate export of nitrogen, phosphorus and copper. Accordingly, compost was reduced to a minimum while attempting to retain enough organic material for water holding capacity and other plant growth characteristics. A polishing layer was then incorporated under the media as an aggregate filter using activated alumina for capturing phosphate and bone char for capturing copper.

The 90vs/10comp/p-layer treatment had mixed performance for nitrogen, phosphorus and copper flushing. Median effluent concentrations for nitrate+nitrite and ortho-P were 0.192 and 0.134 mg/L, respectively, for all events (the second highest concentrations after the 60sand/40comp control). The median effluent concentration for dissolved Cu across all flushing events was very low at 1.0 µg/L. For nitrate+nitrite and ortho-P, the 90vs/10comp/p-layer treatment median effluent concentrations for all events was significantly higher than all other treatments.

The 90vs/10comp/p-layer treatment exhibited poor percent removal for nitrate+nitrite (-200 to 10 percent) and median effluent concentrations were relatively high (0.851-2.62 mg/L) in the dosing experiments. Percent removal for ortho-P was also generally poor (-52-32 percent) for the lower-dose experiments and median effluent concentrations moderate (0.098-0.132 mg/L). In general the 90vs/10comp/p-layer treatment performed better for capturing particulate contaminants (presumably because of the very good TSS capture characteristic) and relatively poorly for dissolved contaminants.

The 90vs/10comp/p-layer treatment was the top performer for TSS capture, indicating the polishing layer (consisting of a finer sand mix) may provide a higher performance filter for mineral and organic particulates than the Type 26 material used in the other treatments.

Plant Growth and Media Physical Properties

The physical and chemical analysis of the media treatments present some unusual results and generally no clear performance pattern. The low CEC (1.4 to 2.9 meq/100grams dry soil) suggest poor treatment capability for cations; however, treatment capability in the dosing experiments with the coco coir pith and high-carbon wood ash or granular activated charcoal

indicate very good pollutant capture for positive ions. The carbon nitrogen ratio is not reported given unusual results and possible laboratory error.

All media germinated plants. While no clear pattern emerges for specific treatments the media containing compost was the best performer for germination and plant height.

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. However, longer-term tests with plants specific to bioretention systems are required to adequately assess the media for supporting healthy plant growth.

CONCLUSIONS AND RECOMMENDATIONS

This study was implemented to improve BSM performance for the capture and retention of nitrogen, phosphorus, and copper. To meet this goal, the study involved separate experiments to first identify media components and blends with reduced potential for leaching these pollutants. Follow-up experiments were then performed to quantify the pollutant capture performance of the media blends. 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. Export concentrations were often 1-2 orders of magnitude higher. 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. 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.
- The treatment containing 10 percent compost with a polishing layer (90vs/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. Nitrate+nitrite and ortho-P pollutant capture performance in the dosing experiments for the 90vs/10comp/p-layer treatment was better than the 60sand/40comp control, but significantly poorer than the better performers not containing compost. The p-layer treatment did, however, perform relatively well overall for dissolved Cu with an overall median effluent concentration of 3.85 µg/L compared the best performer at and overall median effluent concentration of 1.6 µg/L. 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.
- The treatments containing iron coated woodchips leached dissolved Cu during the dosing experiments; therefore, the treatment capability for copper was poor. This leaching pattern was not observed during the flushing experiments. The addition of this component to the media blends also did not substantially improve treatment performance for phosphorus as originally intended.
- 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. Note that the carbon nitrogen ratio is not reported given unusual results and possible laboratory error.

Based on these conclusions, the following suite of recommendations are provided to further improve media treatment performance and develop an improved BSM specification for incorporation in subsequent updates to the SWMMWW and SWMMEW. These recommendations are presented in a stepwise sequence to: 1) identify and optimize a preferred BSM; 2) investigate the availability of the associated components and conduct full-scale testing, and 3) develop necessary resources for updating the SWMMWW and SWMMEW.

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. At present, Ksat rates for the treatments containing coco coir pith and washed or volcanic sands range from approximately 32 to 161 inches/hour depending on the test used and specific treatment tested. These high Ksat rates likely contribute to reduced treatment performance for particulate bound pollutants. At present, the treatments containing coir coco pith and washed or volcanic sands do not appear to meet treatment goals identified in the TAPE guidelines for basic treatment; however, 70vs/20cp/10de, 70vs/20cp/10gac, 70ws/20cp/10ash and 70vs/20cp/10ash meet enhanced treatment for dissolved Cu and Zn. To optimize hydrologic and water quality treatment performance for TSS and TP, additional laboratory and pilot scale studies are recommended to develop media blends with lower Ksat rates or determine the feasibility of using outlet controls to restrict flows through the media.
- 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. These studies could be performed in tandem with the studies from the previous recommendation.

- Compost is a key component of the default BSM for promoting plant growth. This study has shown treatments that incorporate coir coco pith provide superior treatment performance relative to those containing compost. Furthermore, 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.
 - 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 can be made available in sufficient quantities to meet expected demand. When making this determination, the analysis should incorporate 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 and SWMMEW
 - Once a preferred treatment is identified, guidelines for consistency and quality control should be developed for the individual components and subsequent blend to ensure 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 condition.

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APPENDIX A

Quality Assurance Project Plan

QUALITY ASSURANCE PROJECT PLAN

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

Prepared for
Kitsap County

Prepared by
Herrera Environmental Consultants, Inc.



QUALITY ASSURANCE PROJECT PLAN

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

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November 21, 2014

Title and Approval Sheet

Title: Quality Assurance Project Plan: Analysis of Bioretention Media for Improved Nitrogen, Phosphorus and Copper Retention

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Date: March 25, 2014 Rev.

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1. INTRODUCTION

The current Washington State, Phase I municipal National Pollutant Discharge Elimination System (NPDES) stormwater permit (effective August 1, 2013) requires the use of low impact development (LID) practices as the first option for managing stormwater where feasible. Bioretention is the most widely applicable and flexible Best Management Practice (BMP) in the suite of LID practices. Bioretention systems may include under-drains, especially in areas with soils that are less suitable for infiltration. In these cases, a portion of the treated runoff is discharged back into the stormwater conveyance system rather than infiltrated. While bioretention can provide very good water quality treatment for many contaminants (e.g., sediment, zinc, hydrocarbons, and likely bacteria), regional and national research indicates nitrogen (N), phosphorus (P), and copper (Cu) may be exported from these systems.

This project, funded by Grants of Regional and Statewide Significance (GRSS) through Washington State Department of Ecology (Ecology), will support continued coordination among State and local jurisdictions that are developing and implementing bioretention systems, and with input from those partners, testing of individual bioretention components and media mixtures to improve retention of N, P, and Cu. The findings have broad regional application across all Phase I and II jurisdictions for application of new NPDES Permit requirements and for protecting freshwater resources in western and eastern Washington.

Each environmental study conducted by or for Ecology must have an approved Quality Assurance Project Plan (QAPP) describing the objectives of the study and the procedures to follow to achieve those objectives. The following QAPP was prepared in accordance with Ecology's *Guidelines for Preparing Quality Assurance Project Plans* (Ecology 2004), and documents sample collection, processing, and analysis procedures to ensure that resulting data are scientifically and legally defensible. This document is organized as follows:

- Background
- Project Description
- Organization and Schedule
- Quality Objectives
- Experimental Design
- Sampling Procedures
- Measurement Procedures
- Quality Control
- Data Management Procedures

- Audits and Reports
- Data Verification and Validation
- Data Quality Assessment
- References

2. BACKGROUND

This section provides a description of the bioretention media study and briefly summarizes the results of previous laboratory testing and field monitoring.

2.1. Technology Description

Bioretention facilities are shallow landscaped depressions with a designed soil mix and plants adapted to the local climate and soil moisture conditions that receive stormwater from a small contributing area. These systems are designed to more closely mimic natural forested conditions where healthy soil structure and vegetation promote the infiltration, storage, filtration, and slow release of stormwater flows. Within the low Impact development approach, bioretention areas are designed as small-scale, dispersed systems that are integrated into the site as a landscape amenity (see Figure 1).

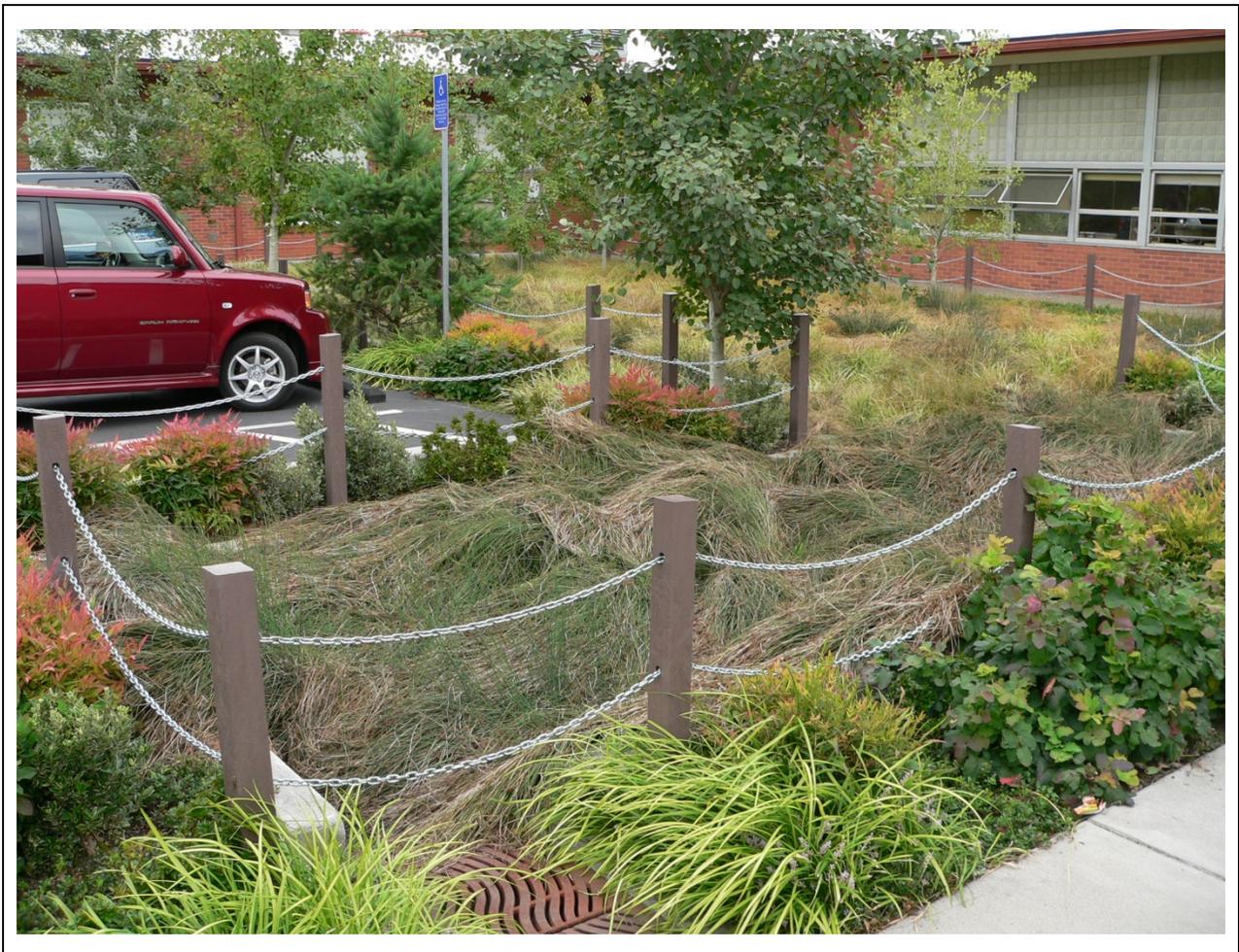


Figure 1. Typical Bioretention Application.

2.2. Results of Previous Studies

While bioretention can provide very good water quality treatment for many contaminants (e.g., sediment, zinc, hydrocarbons, and likely bacteria), regional and national research indicates nitrogen (N), phosphorus (P), and copper (Cu) may be exported from these systems (Herrera 2012; Jonasson et al. 2010; Trowsdale and Simcock 2011). The sources of N, P, and Cu can come from various materials including compost, mineral aggregates, and natural and engineered amendments (Herrera 2012; Pitt and Clark 2010). Export of N, P, and Cu is of particular concern for bioretention installations with under-drains that discharge to receiving waters and bioretention installations with or without under-drains located over shallow groundwater or in proximity to phosphorus and nitrogen sensitive receiving waters. Each media component has specific flow and pollutant capture characteristics that influence hydraulic conductivity and water quality treatment performance for specific contaminants. Accordingly, each media component and the media blend require analysis to understand the interaction of the components and the treatment capability for multiple pollutants (Pitt and Clark 2010).

3. PROJECT DESCRIPTION

The goal of this project is to improve bioretention soil media (BSM) performance and application for capture and retention of N, P, and Cu while retaining the current high level of water quality treatment performance for other stormwater pollutants of concern demonstrated in regional BSM research.

To accomplish the above goal, the project has three objectives:

- Analyze the amount of N, P, and Cu leached from individual bioretention soil media components using weak acid and deionized water extraction
- Analyze media blends for the ability to capture and retain N, P, Cu, and other stormwater pollutants of concern when exposed to flushing and dosing regimes in columns (the ability of the media blends to support vegetation will also be assessed)
- Develop recommendations for updating current BSM media guidelines for improved capture and retention of N, P, and Cu based on leaching, pollutant retention, hydraulic, cost, and sustainability criteria (see criteria below)
- Identify unresolved water quality and hydraulic performance issues from this study that may warrant future evaluation

Qualitative criteria for media component and media blends include:

- **Leaching:** media components that leach the minimum amount of N, P, and Cu will be considered first for testing in the media blends
- **Pollutant retention:** media blends that meet pollutant reduction efficiencies in Table 11 will be considered best performers. Media blends that also reduce dissolved Cu below 10 µg/L will be considered optimal
- **Hydraulic performance:** media blends that have a saturated hydraulic conductivity (Ksat) greater than 4 inches/hour will be considered optimal. No maximum Ksat will be targeted (see Section 6.1.3 for Ksat details)
- **Sustainability:** includes availability, transportation requirements, manufacturing and/or extraction processes
- **Cost:** media components with the minimum cost per unit used in the media blends will be considered first for testing in media blends. Cost will be considered along with the above criteria to attain the best balance of cost to optimum performance.

Optimizing bioretention media to best manage these contaminants will provide the region and state with a high performance and affordable water quality treatment practice that captures multiple pollutants of concern and is adaptable to rural, suburban, and ultra-urban settings. The project will support continued coordination among State and local jurisdictions that are

developing and implementing bioretention systems, and with input from those partners, refine and conduct testing of individual bioretention components and media mixtures to improve retention of N, P, and Cu.

Systematically evaluating, describing, and improving the water quality treatment capabilities of bioretention will support western and eastern Washington NPDES permittees implement permit requirements and programs by:

- Providing a scientific basis for determining the appropriate design of bioretention media
- Refining and expanding the application of an effective flow control and water quality treatment tool for meeting Minimum Requirements 5, 6, and 7 in Appendix 1 of the permit
- Developing recommendations for updating “Design Criteria for Custom Bioretention Soil Mixes,” the “Default Bioretention Soil Media,” and the default bioretention soil mix infiltration rate/correction factor presented in Section 7.4 of Volume V of the 2012 Stormwater Management Manual for Western Washington
- Develop recommendations for updating bioretention soil media in the 2012 Low Impact Development Technical Guidance Manual for Puget Sound
- Improving design review and permitting of bioretention with updated design criteria

4. ORGANIZATION AND SCHEDULE

The bioretention media study is funded by the 2013-15 Biennial Municipal Stormwater GRSS funding program. The GRSS provides support for Phase I and Phase II local governments to implement their stormwater management programs pursuant to requirements of the NPDES stormwater permit. Herrera Environmental Consultants, Inc. (Herrera) is the technical lead and will design and conduct the media evaluation in cooperation with project partners. Analytical Resources Inc. will provide analytical laboratory services for the water quality analysis. Project organization and personnel for this study are identified in Table 1.

Title	Name	Affiliation
Client Project Manager	Chris May	Kitsap County
Test Site Contact	Phil Thompson	Seattle University
Herrera Principal-in-Charge	Joy Michaud	Herrera
Herrera Project Co-Manager	John Lenth	Herrera
Herrera Project Co-Manager and Technical Lead	Curtis Hinman	Herrera
Herrera Water Quality Data Quality Assurance Lead	Gina Catarra	Herrera
Herrera Technical Support	Dylan Ahearn	Herrera
Herrera Data Management Lead	Kristen Matsumura	Herrera
Herrera Field Sampling Support	Alex Svendsen	Herrera
Analytical Laboratory Quality Assurance Officer	Mark Harris	Analytical Resources, Inc.

Project partners include: Kitsap County, City of Seattle, City of Redmond, Seattle University, Washington Department of Transportation, and Washington Department of Ecology.

4.1. Responsibilities

4.1.1.1. Client Project Manager - Chris May

Chris May will oversee project progress and review and comment on the technical work and deliverables. He will be the primary point of contact for Kitsap County.

4.1.1.2. Test Site Contact - Phil Thompson

Phil Thompson will coordinate access and set-up of laboratory space and students to assist with sampling for the column study at Seattle University. He will review the laboratory modifications necessary to facilitate experiments at the site to ensure that it is consistent with the project requirements.

4.1.1.3. Herrera Principal-in-Charge - Joy Michaud

Joy Michaud will provide senior quality assurance review of technical work and deliverables throughout all phases of the project.

4.1.1.4. Herrera Project Co-Manager - John Lenth

John Lenth will coordinate all technical work related to this project in accordance with the associated budget and schedule.

4.1.1.5. Herrera Project Co-Manager and Technical Lead - Curtis Hinman

Curtis Hinman will direct all technical work and coordinate all field work related to this project including laboratory column experimental design.

4.1.1.6. Herrera Water Quality Data Quality Assurance Lead - Gina Catarra

Gina Catarra will independently review water quality data entry (laboratory reports compared to electronic files) and will review quality assurance worksheets to determine appropriate response actions to any quality assurance issues.

4.1.1.7. Herrera Technical Support - Dylan Ahearn

Dylan Ahearn will provide technical support for experimental design. He will also perform a final quality assurance review on these data to assess their accuracy and determine their usability for subsequent analysis related to system performance evaluations.

4.1.1.8. Herrera Data Management Lead - Kristen Matsumura

Kristen Matsumura will coordinate data management and assist with statistical analysis as needed.

4.1.1.9. Herrera Field Sampling Support - Alex Svendsen

Alex Svendsen will: setup column arrays; assist with equipment maintenance; collect flow and water quality data; track quality assurance, including preliminary review of laboratory data, document sample collection procedures and quality assurance/quality control measures; and maintain field records. He will also work with Seattle University students to demonstrate proper water delivery and sample collection techniques.

4.1.1.10. Analytical Laboratory Quality Assurance Officer - Mark Harris

Mark Harris will: track samples and results in the laboratory; provide properly cleaned sample bottles with appropriate preservatives; evaluate laboratory compliance with this QAPP and laboratory quality assurance plan; report discrepancies to the Herrera Project Manager; and transmit laboratory results to the Herrera Project Manager.

4.2. Contacts

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4.3. Schedule

The estimated project schedule for the bioretention media study is outlined in Table 2.

Project Milestone	Date Completed
Draft QAPP for project partner review	February 20, 2014
Select media components	February 28, 2014
Final QAPP	February 28, 2014
Complete leaching analysis of media components	May 15, 2014
Complete flushing analysis of media blends	June 30, 2014
Complete dosing analysis of media blends	August 29, 2014
Complete data analysis	November 15, 2014
Complete preliminary report	December 15, 2014
Complete final report with media recommendations	January 30, 2015

5. QUALITY OBJECTIVES

The goal of this QAPP is to ensure that data collected through this study are scientifically accurate and legally defensible. To meet this goal, the collected data will be evaluated using the following quality assurance objectives:

- **Precision:** A measure of the variability in the results of replicate measurements due to random error
- **Bias:** The systematic or persistent distortion of a measurement process which causes errors in one direction (i.e., the expected measurement is different from the true value)
- **Representativeness:** The degree to which the data accurately describe the conditions being evaluated based on the selected sampling locations, sampling frequency, and sampling methods
- **Completeness:** The amount of data obtained from the measurement system
- **Comparability:** The ability to compare data from the current project to data from other similar projects, regulatory requirements, and historical data

Method Quality Objectives (MQOs) are performance or acceptance criteria that are established for each of these quality assurance objectives. The specific MQOs that have been identified for this project are described below and summarized in Table 3.

5.1. Precision

Precision will be assessed using laboratory and field duplicates. Precision for laboratory duplicates will be ± 25 percent relative percent difference (RPD) for TSS, ± 10 percent for pH, ± 35 percent for bacteria, and ± 20 percent for all other water quality parameters. Precision for field duplicates will be ± 15 percent RPD for pH and ± 25 percent for all other water quality parameters. In all cases, the RPD of duplicate samples will be calculated using the following equation:

$$RPD = \frac{(C_1 - C_2) \times 100\%}{(C_1 + C_2) / 2}$$

where: RPD = relative percent difference

C_1 = larger of two values

C_2 = smaller of two value

The relative percent difference will be less than or equal to the indicated percentages for values greater than 5 times the reporting limit and ± 2 times the reporting limit for values less than or equal to 5 times the reporting limit.

Table 3. Method Quality Objectives for Water Quality Data.

Parameter	Reporting Limit	Units	Method Blank	Rinsate Blank	Control Standard Recovery	Matrix Spike Recovery	Laboratory Duplicate RPD ^a
Total suspended solids	1.0	mg/L	<RL	<2 x RL	90 - 110%	NA	≤20% or ± 2 x RL
pH	NA	std. units	<RL	NA	NA	NA	≤10% or ± 2 x RL
TKN	1.0	mg/L	<RL	<2 x RL	90 - 110%	75 - 125%	≤20% or ± 2 x RL
Nitrate-nitrite	0.01	mg/L	<RL	<2 x RL	90 - 110%	75 - 125%	≤20% or ± 2 x RL
Total phosphorus	0.008	mg/L	<RL	<2 x RL	90 - 110%	75 - 125%	≤20% or ± 2 x RL
Ortho-phosphorus	0.004	mg/L	<RL	<2 x RL	90 - 110%	75 - 125%	≤20% or ± 2 x RL
DOC	1.5	mg/L	<RL	<2 x RL	90 - 110%	75 - 125%	≤20% or ± 2 x RL
Hardness	0.33	mg/L	<RL	NA	90 - 110%	75 - 125%	≤20% or ± 2 x RL
Cadmium, dissolved	0.1	µg/L	<RL	<2 x RL	80 – 120%	75 - 125%	≤20% or ± 2 x RL
Cadmium, total							
Copper, dissolved	0.5	µg/L	<RL	<2 x RL	80 – 120%	75 - 125%	≤20% or ± 2 x RL
Copper, total							
Zinc, dissolved	4	µg/L	<RL	<2 x RL	80 – 120%	75 - 125%	≤20% or ± 2 x RL
Zinc, total							
Potassium	500	µg/L	<RL	<2 x RL	80 – 120%	75 - 125%	≤20% or ± 2 x RL
Sodium	500	µg/L	<RL	<2 x RL	80 – 120%	75 - 125%	≤20% or ± 2 x RL
Sulfate	2.0	mg/L	<RL	<2 x RL	90 - 110%	75 - 125%	≤20% or ± 2 x RL
Chloride	1.0	mg/L	<RL	<2 x RL	90 - 110%	75 - 125%	≤20% or ± 2 x RL
Alkalinity	1.0	mg/L	<RL	<2 x RL	90 - 110%	NA	≤20% or ± 2 x RL
Fecal Coliform bacteria	1	CFU/100 mL	<RL	NA	NA	NA	≤35% or ± 2 x RL

^a The relative percent difference will be less than or equal to the indicated percentage for values greater than 5 times the reporting limit, and ± 2 times the reporting limit for values less than or equal to 5 times the reporting limit.

CFU / 100 mL

mg/L = milligrams per liter.

µg/L = micrograms per liter.

std. units = standard units.

RL = reporting limit.

RPD = relative percent difference.

NA = not applicable.

5.2. Bias

Bias will be assessed based on analyses of method blanks, matrix spikes, and control standards. Method blank values will not exceed the reporting limit. The percent recovery of matrix spikes will be ± 25 percent for total phosphorus, ortho-phosphorus, hardness, and total and dissolved metals. Duplicate matrix spikes will also be run on a portion of the samples. The laboratory control sample recovery will be ± 10 percent for TSS, total phosphorus, ortho-phosphorus, hardness, and total and dissolved metals. Percent recovery for matrix spikes will be calculated using the following equation:

$$\%R = \frac{(S - U) \times 100\%}{C_{sa}}$$

where: %R = percent recovery
S = measured concentration in spike sample
U = measured concentration in un-spiked sample
C_{sa} = actual concentration of spike added

If the analyte is not detected in the un-spiked sample, then a value of zero will be used in the equation.

Percent recovery for control standards will be calculated using the following equation:

$$\%R = \frac{(M) \times 100\%}{T}$$

where: %R = percent recovery
M = measured value
T = true value

5.3. Representativeness

Flushing and dosing experiments will be conducted in eight-inch columns. A maximum of eight media treatment sets will be selected consisting of various proportions of selected media components. The treatment will be replicated a minimum of three times and placed in a random block design. Flushing and dosing experiments will be based on typical bioretention surface area to contributing area ratios. Flushing and dosing volumes will be based on the Ecology water quality treatment design storm (see Experimental Design below). Data from five sampling events is considered adequate to meet sampling program objectives.

5.4. Completeness

A minimum of 95 percent of the samples submitted to the laboratory will be judged valid. An equipment checklist and Chain of Custody forms will be used to prevent loss of data resulting from missing containers, inoperable delivery and collection apparatus or sample delivery.

5.5. Comparability

Standard sampling procedures, analytical methods, units of measurement, and reporting limits will be applied to meet the goal of data comparability. The results will be tabulated in standard spreadsheets to facilitate analysis and comparison with comparable bioretention media studies.

6. EXPERIMENTAL DESIGN

This section of the QAPP provides information on the study design including: overall approach and phases of the study, testing site and description of the column arrays, water delivery and water sampling.

6.1. Study Approach by Task

Overall the study approach is designed to optimize bioretention media for N, P, and Cu capture. There are four primary tasks to the study:

1. Conduct a rapid 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 hydraulic conductivity and support plants.
3. Combine components at various ratios, place in column arrays, flush the media blends with deionized water, and assess the effluent for N, P, Cu, and other stormwater pollutants of concern. Hydraulic conductivity of the media blends will be assessed during the flushing experiments.
4. Dose the best performing media columns with natural stormwater spiked (if necessary) with reagent grade chemicals to attain pre-determined concentrations. Assess the effluent for N, P, Cu, and other stormwater pollutants of concern.

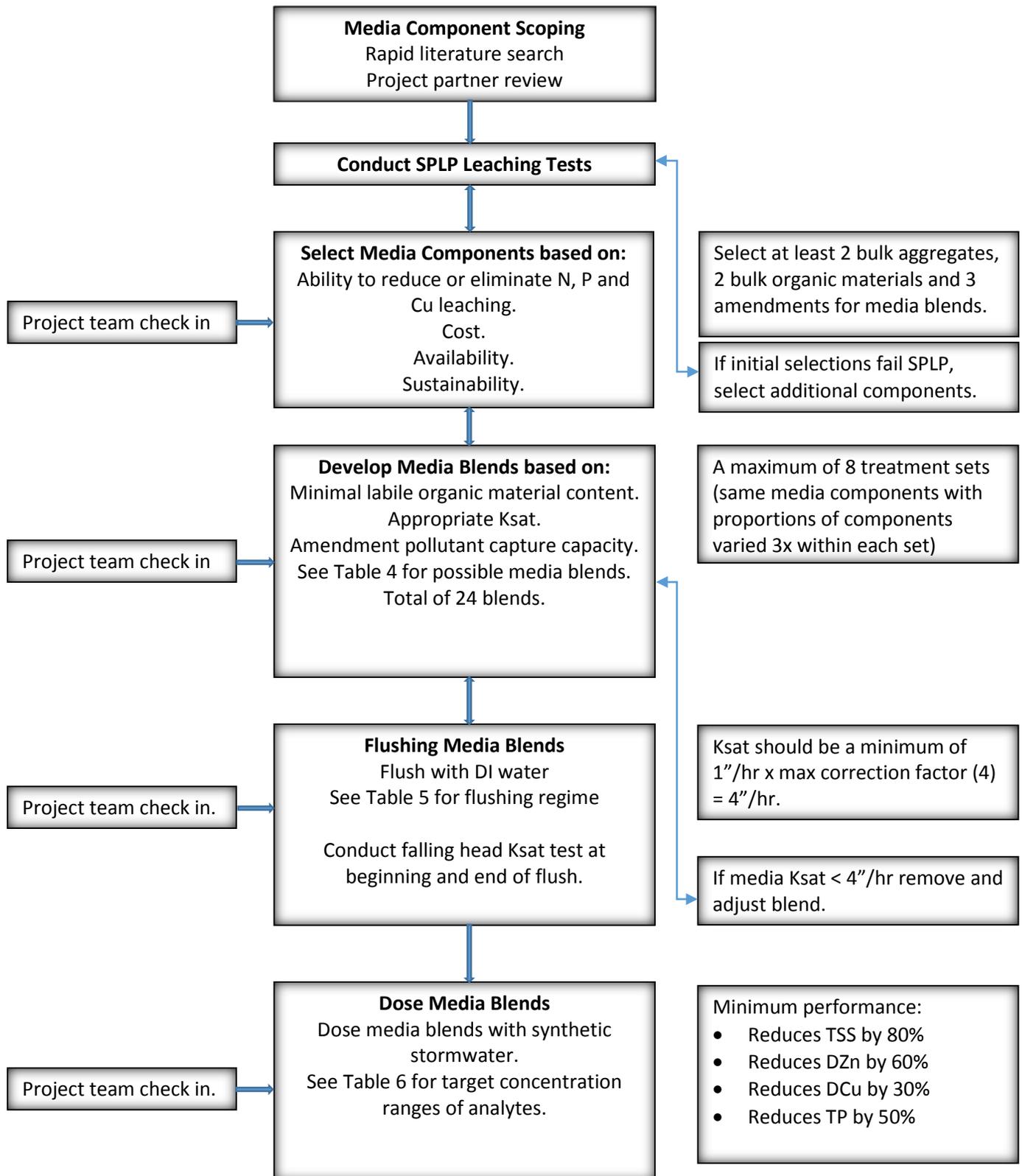
See Figure 2 for a summary of the study approach.

6.1.1. *Rapid Survey of Media Components*

A rapid survey of the scientific literature and project partner review will provide a basis for selecting the best component candidates based on their treatment effectiveness for the target stormwater pollutants of concern. Additionally, practical considerations will include availability, sustainability and cost. A broad range of bioretention media components will be considered and included in the survey.

The media components will be organized into a matrix organized in three categories: bulk aggregate media (e.g., sands); bulk organic materials (e.g., compost) that comprise the majority of the media blends; and amendments which provide specific pollutant capture and/or hydraulic characteristics, and comprise less of the overall volume. A minimum of eight bioretention media components (e.g., three bulk aggregates, three amendments, and two bulk organic materials) will be selected based on minimal leaching and pollutant capture in previous research, availability, and cost.

Figure 2. Summary of the Bioretention Media Study Approach.



6.1.2. Media Component Leaching Tests

The leaching potential for N, P, and Cu for selected media components will be assessed using SPLP. The analysis will be performed at Analytical Resources Inc. (ARI) an Ecology certified laboratory. The SPLP analysis will be conducted for total nitrogen, nitrate-nitrite, total phosphorus, ortho-phosphorus, and total and dissolved copper using two procedures:

- Metals - weak acid (H₂SO₄/HNO₃) extraction using a pH recommended for western U.S.
- Nutrients - deionized water extraction

Suppliers will be identified for media components selected from the survey process described in Section 6.1.1. Samples of the selected media components will then be collected from suppliers and, where possible, samples will be collected by Herrera staff from multiple locations in material stockpiles and composited for analysis.

At least two mineral, two organic, and two amendments will be selected from the SPLP analysis using the following criteria: Cu ≤ 5 µg/L; NO₃-NO₂ ≤ 0.1 mg/L; and TP ≤ 0.1 mg/L. If none of the components initially selected meet these criteria, additional components will be considered for SPLP analysis. If none of the components initially or subsequently selected meet these criteria, then components with the lowest concentrations will be selected and proprietary and non-proprietary components will be considered for use as a polishing layer to reduce effluent concentrations from the media blends comprised of the components with the lowest SPLP concentrations. Results will be reviewed by the project partners to consider SPLP analysis, and media component cost and sustainability for final recommendations.

One SPLP analysis will be conducted per media component; accordingly, no statistical analysis will be performed on the leaching results.

6.1.3. Combine Components and Flush Media in Columns

Media components meeting criteria in Section 6.1.2 from the SPLP analysis will be combined into media blends, placed in polyvinyl chloride (PVC) columns, and flushed with deionized water at the Seattle University Engineering Laboratory. The media depth will be 18 inches (45.7 cm) and a 12-inch (30.5 cm) aggregate bedding layer will be placed under the media to provide a final filter before discharge through the under-drain pipe. The columns will be 8 inches (20.3 cm) diameter and 36 inches (91.4 cm) tall. A maximum of eight treatment sets will be selected. Each treatment set will consist of the same media components. Within each treatment set, proportions of the components will be varied to maximize the number of media tested and screening of potential blends with optimum pollutant capture characteristics. Additionally, polishing layers (aggregate and amendment layer beneath the media blend used as a final filter and bedding for the under-drain) will be selected. See Table 4 for possible media and polishing layer blends.

The proportions of media components in each blend will be selected for the appropriate gradation and density to minimize migration of fine fractions and organic material and prevent excessively high or low hydraulic conductivity and desired pollutant capture. The

Table 4. Possible Media Blends for Flushing and Dosing Experiments.

Column	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	
Component																									
Amendment 1	5	10	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0	0	0	
Amendment 2	0	0	0	5	10	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0	0	
Amendment 3	0	0	0	0	0	0	5	10	15	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0	
Amendment 4	0	0	0	0	0	0	0	0	0	5	10	15	15	15	15	15	15	15	15	15	0	0	0	5	
Organic 1	10	10	10	10	10	10	10	10	10	10	10	10	5	15	0	0	0	0	0	0	10	10	10	10	
Organic 2	0	0	0	0	0	0	0	0	0	0	0	0	0	10	5	15	15	15	15	15	0	0	0	0	
Aggregate 1	85	80	75	85	80	75	85	80	75	85	80	75	80	70	75	80	70	0	0	0	85	85	85	85	
Aggregate 2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	70	0	0	0	0	0	0	
Aggregate 3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	70	0	0	0	0	0	
Aggregate 4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	70	0	0	0	0	
Polishing Layer	no	no	no	no	no	no	no	no	no	no	no	no	no	no	no	no	no	no	no	no	yes	yes	yes	yes	
Total	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	
	compare amendments																								
													compare organics												
																	compare aggregates								
																						compare polishing			

minimum target for hydraulic conductivity is 4 inches/hour (4 inch/hour x the maximum correction factor for BSM of 0.25 = 1 inch/hour or Ecology's recommended minimum saturated hydraulic conductivity (Ksat) for BSM). No maximum hydraulic conductivity will be targeted. Coefficient of Uniformity, Guidelines for Filter Media in Biofiltration Systems (FAWB 2009), and best professional judgment will be used to estimate proper gradation.

Flushing experiment hydraulic load will be based on typical bioretention surface area to contributing area ratios (see below). The bioretention surface area will be 6.7 percent (drainage to bioretention area ratio of 15/1) of the contributing area and the contributing area effectiveness will be 0.9 (i.e., 90 percent of precipitation depth delivered from contributing area to bioretention area).

Flushing equivalent precipitation depth will be based on the Ecology water quality treatment design storm. The flushing experiments will be conducted using two loading rates (phases) to provide a conservative test of effluent quality. The first two flushing tests (Phase 1) will use the Ecology water quality treatment design storm. The effective precipitation depth will be increased (doubled) for the second two flushing tests (Phase 2). See Table 5 for the equivalent precipitation depth and flushing volumes applied. The flushing regime will be as follows:

- Target depth for Phase 1 flushing experiments: 1.32 inches of equivalent precipitation (the 6-month, 24-hour storm for the Seattle area)
- Per column flushing volume for Phase 1 will be approximately 13.4 liters per sampling event.

Flushing volume is determined by the following:

$$(\text{Column Area} \times \text{Drainage Area Ratio} \times \text{Runoff Ratio} \times \text{Bypass}) / 61.02$$

where: Column Area = 50.264 in²
 Drainage to Bioretention Area Ratio = 15/1
 Runoff Ratio = 0.9
 Bypass = 0.91
 61.02 = conversion for cubic inches to liters

- Target depth for Phase 2 flushing experiments: 2.68 inches equivalent precipitation
- Per column flushing volume for Phase 2 will be approximately 26.8 liters per sampling event.
- Columns will be allowed to drain down for a minimum of 24 hours between flushing experiments.
- Sampling event duration: flushing experiment duration will be determined by volume of water delivered (bioretention to contributing area ratio, effective precipitation and influent flow rate). Initial estimate for event duration is approximately 4 hours.

- Sample event coverage: the entire storm volume will be collected and one sub-sample per sampling event will be collected for each column.
- Influent concentrations: Deionized water will be used for the flushing experiments.

Event	Day	Volume applied (liters/column)	Equivalent Storm size (in)	Cumulative Rain (in)	Percent Water Year (Seattle)
Test 1 (Phase 1)	1	13.4	1.32	1.32	4
Flush 1	3	13.4	1.32	2.64	7
Flush 2	5	13.4	1.32	3.96	11
Flush 3	7	13.4	1.32	5.28	15
Flush 4	9	13.4	1.32	6.6	18
Flush 5	11	13.4	1.32	7.92	22
Test 2 (Phase 1)	13	13.4	1.32	9.24	26
Flush 8	15	13.4	1.32	10.56	29
Flush 9	17	13.4	1.32	11.88	33
Flush 10	19	13.4	1.32	13.2	37
Flush 11	21	13.4	1.32	14.52	40
Flush 12	23	26.8	2.64	17.16	48
Test 3 (Phase 2)	25	26.8	2.64	19.8	55
Flush 13	27	26.8	2.64	22.44	62
Flush 14	29	26.8	2.64	25.08	70
Flush 15	31	26.8	2.64	27.72	77
Flush 16	33	26.8	2.64	30.36	84
Flush 17	35	26.8	2.64	33	92
Test 4 (Phase 2)	37	26.8	2.64	35.64	99

Hydraulic conductivity will also be assessed during the flushing test (see Section 7.2.1.3 for details). If any media blends do not meet minimum Ksat requirements (4 inches/hour or 10 cm/hour) during the first three flushing events, that media blend will be removed and replaced with new media.

Effluent from the flushing experiments will be analyzed for contaminants listed in Table 6 below.

6.1.4. Dose Media Blends in Columns

Following flushing, the same media treatments will be dosed with natural stormwater or natural stormwater augmented with reagent grade chemicals to attain target concentration ranges at the Seattle University Engineering Laboratory (see Table 6 for target concentrations).

Analyte	Target Concentration	Range
TSS	75 mg/L	50-200 mg/L
Hardness	no target	no target
Dissolve organic carbon	no target	no target
Total Cd	0.3 µg/L	0.3-1.0 µg/L
Dissolved Cd	0.2 µg/L	0.2-1.0 µg/L
Total Cu	20.0 µg/L	10.0-50.0 µg/L
Dissolved Cu	7.0 µg/L	5.0-20.0 µg/L
Total Zn	150.0 µg/L	100.0-500.0 µg/L
Dissolved Zn	50 µg/L	2.0-300.0 µg/L
TKN	1.0 mg/L	0.6-2.0 mg/L
NO ₃ +NO ₂	0.3 mg/L	0.1-1.0 mg/L
Total phosphorus	0.25 mg/L	0.1-0.5 mg/L
Ortho-phosphorus	0.035 mg/L	0.02-0.1 mg/L
Potassium	no target	no target
Sodium	no target	no target
Sulfate	no target	no target
Chloride	no target	no target
Alkalinity	no target	no target

Dosing experiment hydraulic and contaminant load will be based on typical bioretention surface area to contributing area ratios. Dosing equivalent precipitation depth will be based on the Ecology water quality treatment design storm. The dosing regime will be as follows:

- Target depth for Phase 1 dosing experiments: 1.32 inches of equivalent precipitation
- Total dosing volume for Phase 1 will be approximately 13.4 liters per sampling event
- Target depth for Phase 2 dosing experiments: 2.64 inches equivalent precipitation
- Total dosing volume for Phase 2 will be approximately 26.8 liters per sampling event
- Columns will be allowed to drain down for a minimum of 24 hours between dosing experiments
- Sampling event duration: dosing experiment duration will be determined by volume of water delivered (bioretention to contributing area ratio, effective precipitation and influent flow rate). Initial estimate for event duration is approximately 4 hours.
- Sample event coverage: the entire storm volume will be collected and one sub-sample per sampling event will be collected for each column
- Influent concentrations: to the extent possible, influent concentrations will be within concentration ranges designated in Table 6

Dosing experiment hydraulic and contaminant load will be based on typical bioretention surface area to contributing area ratios. Bioretention surface area will be 5 percent of the contributing area and the contributing area effectiveness will be 0.9 (i.e., 90 percent of precipitation depth delivered from contributing area to bioretention area). See Section 6.1.3 hydraulic load calculation.

Effluent from the dosing experiments will be analyzed for contaminants listed in Table 6.

6.2. Sampling Process Design

The study will include collection of bioretention media samples and subsequent hydrologic and water quality experiments to evaluate the performance of those components and media blends. Separate sections below describe the sampling process design that will be used in conjunction with each of these sampling elements.

6.2.1. Media Component Sample Collection

Individual bioretention media component samples will be collected from suppliers or local material stockpiles. Local material stockpiles of some media components are not currently available. For these materials, regional suppliers will provide samples for the study. Media component samples that are available from local stockpiles will be collected from multiple locations in those stockpiles and composited for analysis (see Section 7.2 for sampling details).

6.2.2. Media Component Blending

Once collected, media components will be blended in proportions selected for the appropriate gradation and density to minimize migration of fine fractions and organic material and prevent excessively high or low hydraulic conductivity and desired pollutant capture. Media amendments will be added to the blends to achieve specific N, P, and Cu capture objectives. The appropriate quantity of media amendments added to each blend will be estimated based on the following simple load analysis:

$$\text{Load}_c + \text{Load}_{\text{mfi}} + \text{Load}_{\text{mft}} \leq \text{pollutant capture capacity of amendment}$$

where:

Load_c = N, P, and Cu load from contributing area

Load_{mfi} = initial media flushing load of N, P, and Cu

Load_{mft} = long-term media flushing load of N, P, and Cu

6.2.3. Hydraulic Monitoring

Influent and effluent volumes will be monitored to determine flow delivery rates, hydraulic and contaminant loading into the media columns, and effluent quantity from the media columns.

Flow will be delivered by pump from a mixing tank to a distribution tank elevated above the columns. Peristaltic pumps will deliver water to each column from a distribution manifold connected to the distribution tank. A maximum 6-inch ponding depth will be maintained for the slowest media blend by adjusting the peristaltic pump flow rate to the column and

installing an outlet with an invert at 6 inches above the media surface. Note: ponding depths will vary by media blend due to variation in media gradation and organic material content. If necessary valves will be used at the column end of the delivery lines for fine adjustment of the flow rates.

6.2.3.1. Influent Flow Volume Monitoring

Influent flow volume will be monitored by applying a known volume to the columns through pump and distribution system. The distribution system will be calibrated by adjusting the flow rate of the peristaltic pumps and collecting the entire volume from each pump for each calibration to confirm delivered volume. Pumps will be adjusted until the desired flow rate is achieved. The variation among distribution lines will be no more 20 percent.

6.2.3.2. Effluent Flow Volume Monitoring

The entire effluent volume will be collected for each flushing and dosing sampling event. Each sample will be collected in a pre-weighed container, the sample and container weighed and the container weight subtracted to determine whole sample volume. See Figure 3 for a schematic of the column and delivery and collection array.

6.2.3.3. Saturated Hydraulic Conductivity

Saturated hydraulic conductivity will be estimated for each media blend during the flushing experiments using a falling head test (see Section 7.2.1.3 for details).

6.2.4. Water Quality Sampling

This section describes sampling equipment for influent and effluent water quality sampling as well as sampling methodology, parameters, and duration.

6.2.4.1. Influent Water Quality Sampling

For the flushing and dosing experiments, influent samples will be collected from an influent monitoring port (IMP). The distribution tank manifold will incorporate an extra distribution port and a peristaltic pump will direct influent water from that port to a collection container without passing through a media column. The whole IMP sample will be collected and sub-sampled using the same procedure for the media column effluent.

6.2.4.2. Effluent Water Quality Sampling

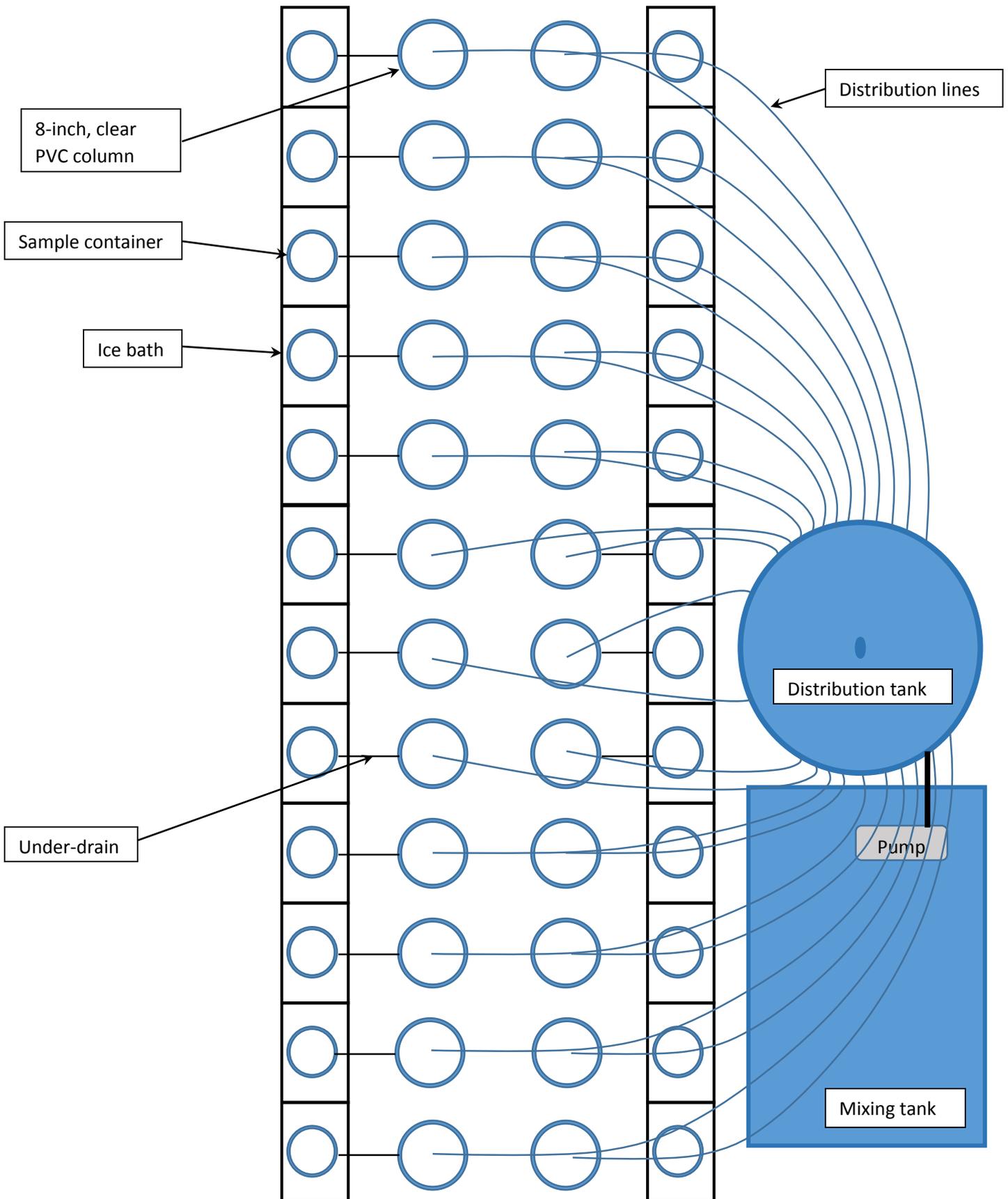
The entire effluent volume will be collected for each flushing and dosing sampling event. Each whole sample will be churn-split at the laboratory.

6.2.4.3. Sampling Methodology

While the study is not evaluating the performance of full-scale treatment systems, TAPE methodologies will be used where applicable. Two out of the five sampling methods listed in the TAPE guidelines (Ecology 2011) will be used for this study:

- **Method 1 - Composite sampling:** This sampling method will be used for all of the flushing and dosing sampling to generate EMCs used to determine whether the treatment system meets Ecology's performance goals.

Figure 3. Schematic of the Water Delivery, Column and Collection Array.



- Method 5 - In situ sampling: pH measurements will be collected in situ using a hand held field meter.

6.2.4.4. Sampling Parameters

This Study will include the following parameters:

- Total suspended solids (TSS)
- pH
- Dissolved organic carbon (DOC)
- Total phosphorus
- Ortho-Phosphorus
- Total Kjeldahl nitrogen (TKN)
- Nitrate-nitrite
- Total and dissolved cadmium, copper and zinc
- Hardness
- Sodium and potassium
- Sulfate
- Chloride
- Alkalinity

6.2.4.5. Experiment Duration

A minimum of four composite samples for all treatments will be collected for the flushing experiments and five composite samples for the dosing experiments over a period of approximately 3 months.

7. SAMPLING PROCEDURES

This section of the QAPP describes laboratory sampling procedures necessary to ensure the quality and representativeness of the collected samples. This section includes information on laboratory safety, flow monitoring, and water sampling.

7.1. Laboratory Safety Procedures

Laboratory experiments will be conducted at Seattle University (SU). Personnel will follow safety requirements for SU as outlined in their laboratory procedures.

7.2. Obtain and Sample Media Components

Individual media components selected from the survey process described in Section 6.1.1 will be collected from producers or suppliers of those materials. For suppliers not located in this region, representatives will be contacted by Herrera staff and samples collected and shipped by the suppliers. For local suppliers with bulk aggregate or organic materials, Herrera staff will collect samples on-site from various representative locations in those material piles and composite into a single sample. Samples will be collected using stainless steel scoops, mixed in stainless steel bowls, and composited into plastic containers. All containers will be pre-cleaned using the following process: liquinox detergent rinse, deionized water rinse, 10 percent hydrochloric acid rinse, and a final rinse with deionized water.

7.3. Hydraulic Monitoring

7.3.1. Influent Flow Volume Monitoring

For the flushing and dosing experiments, influent flow volume will be monitored by applying a known volume to the columns through pump and distribution system. The distribution system will be calibrated by adjusting the flow rate of the peristaltic pumps and collecting the entire volume from each pump for each calibration to confirm delivered volume. Pumps will be adjusted until the desired flow rate is achieved. The variation among distribution lines will be no more 20 percent (\pm 10 percent from the target flow volume).

During the first flushing test, flow rate to the columns will start low (approximately 5 in/hr or 12.7 cm/hr) and increased until a maximum ponding depth of 6 inches (15.24 cm) is maintained for the media with the slowest hydraulic conductivity. This flow rate will be used for all dosing experiments. All overflow through the column outlets (invert located 6 inches above media surface) will be collected and re-delivered to the same column.

7.3.2. Effluent Flow Volume Monitoring

The entire effluent volume will be collected for each flushing and dosing sampling event in a pre-weighed container and the sample and container weighed to determine whole sample volume. The sample weight will recorded and converted to liters.

7.3.3. Saturated Hydraulic Conductivity

Saturated hydraulic conductivity will be evaluated for each media blend. At the beginning and end of the flushing regime and between flushing sample collection, falling head tests will be conducted using the following procedure:

- At the end of the flush and while there is still water ponded on the surface of the media, close the under-drain valve
- Fill the column until there is 6 inches of ponded water
- Open the valve and time until water is no longer visible on the media surface

7.4. pH Monitoring

The pH and temperature of each sample will be measured with a calibrated field meter when effluent samples are collected in the laboratory at Seattle University. The pH electrode will be immersed in the sample container and the measurement recorded when the meter indicates a stable reading.

7.5. Water Quality Sampling

This section discusses column array set-up, lab forms, sample containers and preservation, sample identification and labeling, and chain of custody forms.

7.5.1. Column Array Setup

Twenty four columns will be constructed and placed at the Seattle University Engineering Laboratory. The clear PVC columns will be 8 inch (20.3 cm) diameter and 36 inches (91.4 cm) tall and include a 1 inch (2.54 cm) slotted under-drain placed at the bottom of the column. The inside of the column walls will be roughened to minimize preferential flow between the media and the column wall.

Media proportions will be determined by volume and each component volume weighed to determine mass for future calculations. Component volumes and mass will be measured in calibrated, pre-weighed containers and the components thoroughly mixed in 5 gallon buckets.

The drainage layer and media blends will be placed in each column in 6-inch (15-cm) lifts and compacted with a disc dropped from the same height and for the same number of blows to attain similar compaction across all columns.

Flow into the media columns will be mixed and delivered from a mixing tank by pump to a distribution tank elevated above the columns (see Section 7.2.1 for calibration). Diffusors (and if necessary valves) will be attached to the column end of each distribution line to prevent particle sorting and promote even distribution of influent flow across the media surface.

7.5.2. Influent Water Sampling

Thirteen distribution ports will be placed at the bottom of the distribution tank. Twelve ports will distribute flow, by peristaltic pump, to the media and the thirteenth will be used to

sample influent water quality. Half of the columns will be sampled at one time and half immediately after (that or the next day). Influent water will be collected in a 24.6-liter glass containers placed in a tub of ice. The whole sample will be delivered to the laboratory where samples for each analyte will be obtained using a churn splitter.

7.5.3. *Effluent Water Sampling*

Effluent water will be collected in 24.6 liter glass containers placed in a tub of ice. All water from the sampling event will be collected and delivered to the laboratory where samples for each analyte will be obtained using a churn splitter. See sections below for Sample Handling, Delivery, and Processing.

Photos will be taken of each effluent sample to record effluent color.

7.5.4. *Laboratory Forms*

For each experiment, personnel will record the following information on a standardized field form before and after sampling:

- Date
- Time of sample collection, measurement, or observation
- Name(s) of field personnel present
- All cleaning and preparation procedures
- Any calibration procedures and findings
- Sample volume collected in sample bottles
- Duration of experiment (start of inflow to end of effluent volume collection)
- Unusual conditions (e.g., odor, color, turbidity, equipment leaks or spills)
- Modifications of, or unusual, sampling procedures
- Any miscellaneous factors that might influence samples

7.5.5. *Sample Containers and Preservation*

The analytical laboratory will clean the 24.6 liter sample bottles. Spare sample bottles will be carried by personnel conducting the testing in case of breakage or possible contamination. Sample containers and preparation will follow Code of Federal Regulations [40 CFR 136] guidelines. Refer to Table 6 in the *Measurement Procedures* section for information on recommended sample containers.

7.5.6. *Sample Identification and Labeling*

All sample containers will be labeled with the following information, using waterproof labels and indelible ink and placed on dry sample container lids:

- Column/sample ID
- Date of sample collection (month/day/year)
- Time of sample collection (military format)

7.5.7. *Chain-of-Custody*

After samples have been obtained and the collection procedures properly documented, a written record of the chain-of-custody of each sample will be completed by laboratory personnel to ensure that samples have not been tampered with or compromised in any way and to track the requested analysis for the analytical laboratory. Information necessary in the chain-of-custody includes:

- Name(s) of field personnel
- Date and time of sample collection
- Location of sample collection
- Printed names, signatures and contact information of field personnel and laboratory personnel handling the samples
- Laboratory analysis requested and control information (e.g., duplicate or spiked samples) and any special instructions (e.g., time sensitive analyses)

Sample custody will be tracked in the laboratory through the entire analytical process, and the signed chain-of-custody forms and analytical results returned to the Herrera project manager. The Herrera monitoring lead will record the date and time of sample deliveries for the project file.

7.5.8. *Sample Delivery*

Immediately after collection samples will be clearly labeled and delivered to ARI in Tukwila, Washington. Samples will be capped to prevent contamination and kept on ice to maintain a temperature of 6 degrees C or less. At ARI samples will be churn split into bottles prepared by ARI.

8. MEASUREMENT PROCEDURES

Laboratory analytical procedures will follow methods approved by the US Environmental Protection Agency (EPA) (APHA et al. 1992, 1998; US EPA 1983, 1984). These methods provide reporting limits that are below the state and federal regulatory criteria or guidelines and will allow direct comparison of the analytical results with these criteria. Preservation methods, analytical methods, reporting limits, and sample holding times are presented in Table 7.

Samples for parameters requiring filtration (i.e., ortho-phosphorus, dissolved copper, and dissolved zinc) will be delivered to the laboratory within 4 hours of their collection. Upon their receipt, laboratory personnel will immediately filter and preserve these samples.

ARI, the laboratory identified for this project, is certified by Ecology and participates in audits and inter-laboratory studies by Ecology and EPA. These performance and system audits have verified the adequacy of the laboratory's standard operating procedures, which include preventive maintenance and data reduction procedures.

The laboratory will report the analytical results within 30 days of receipt of the samples. The laboratory will provide sample and quality control data in standardized reports suitable for evaluating the project data. The reports will also include a case narrative summarizing any problems encountered in the analyses.

Table 7. Methods and Detection Limits for Water Quality Analyses

Analyte	Analytical Method	Method Number ^a	Holding Time ^b	Sample Container	Preservation	Reporting Limit	Units
Total suspended solids	Gravimetric	SM 2540 D	7 days	HDPE	Cool, ≤6°C	1.0	mg/L
pH	Meter	SM 4500 H+B	15 minutes	HDPE	Cool, ≤6°C	NA	std. units
TKN	Colorimetric	SM4500-Norg D	28 days	HDPE	Cool, ≤6°C; H ₂ SO ₄ to pH<2	1.0	mg/L
Nitrate-nitrite	Colorimetric	SM 4500 NO ₃ I	48 hours	HDPE	Cool, ≤6°C	0.01	mg/L
Total phosphorus	Colorimetric	EPA 365.2	28 days	HDPE	Cool, ≤6°C; H ₂ SO ₄ to pH<2	0.008	mg/L
Ortho-phosphorus	Colorimetric	EPA 365.2	48 hours	HDPE	Filter, Cool, ≤6°C	0.004	mg/L
DOC	Combustion	SM5310B	24 hours (filter), 28 days (total)	Amber Glass	Filter, Cool, ≤6°C; H ₂ SO ₄ to pH<2	1.5	mg/L
Hardness	Calculation	EPA 6010	6 months	HDPE	Cool, ≤6°C	0.33	mg/L
Cadmium, dissolved	ICP-MS	EPA 200.8	24 hours, filter 6 months	HDPE	Filter, Cool, ≤6°C; HNO ₃ to pH<2	0.1	µg/L
Copper, dissolved						0.5	
Zinc, dissolved						4	
Cadmium, total						0.1	
Copper, total			0.5				
Zinc, total			4				
Potassium			500				
Sodium			500				
Sulfate	Colorimetric	SM 4500 SO ₄ G	28 days	HDPE	Cool, ≤6°C	2.0	mg/L
Chloride	Colorimetric	SM 4500 CL E	28 days	HDPE	Cool, ≤6°C	1.0	mg/L
Alkalinity	Titration	SM 2320 B	14 days	HDPE	Cool, ≤6°C, sodium thiosulfate	1.0	mg/L
Fecal Coliform bacteria	Membrane filtration	SM 9222 D	6 hours	Corning	Cool, ≤6°C	1	CFU/100 mL

^a SM method numbers are from APHA et al. (1998); EPA method numbers are from US EPA (1983, 1984). The 18th edition of Standard Methods for the Examination of Water and Wastewater (APHA et al. 1992) is the current legally adopted version in the Code of Federal Regulations (CFR). However, the 20th edition provides additional guidance on certain key items. For this reason, the 20th edition is referenced in this table as the best available guidance. An equivalent standard method can be substituted.

^b Holding time specified in EPA guidance or referenced in Standard Methods for equivalent method

9. QUALITY CONTROL

This section includes information on field quality assurance/quality control (QA/QC) and laboratory quality control.

9.1. Field Quality Control

This section summarizes the QA/QC procedures that laboratory personnel will implement to evaluate sample contamination and sampling precision and to maintain and calibrate monitoring equipment.

9.1.1. *Rinsate Blanks*

For the flushing tests, columns will be randomly selected and three rinsate blanks collected at the beginning of the study, after decontaminating the equipment, and toward the end of the study.

Stormwater containing various contaminants will be used for the dosing tests. Residuals in the mixing and distribution tanks and the distribution lines from previous dosing should not significantly influence concentrations of target contaminants in subsequent dosing. Accordingly, the tanks and distribution lines will not be cleaned between dosing experiments and no rinsate blanks collected since the delivery system is contaminated at acceptable levels.

9.1.2. *Bottle Blanks*

One sample bottle blank will be collected at the beginning of the flushing experiments and one at the beginning and end of the dosing experiments. The bottle blank will be collected by filling sample bottles with reagent-grade water using a similar volume collected during column experiments.

9.1.3. *Equipment Maintenance and Calibration*

Maintenance procedures and frequencies are summarized in Table 9. Calibration activities will be documented on standardized field forms.

9.2. Laboratory Quality Control

This section summarizes the quality control procedures the laboratory will perform and report with the analytical results. Accuracy of the laboratory analyses will be verified using blank analyses, duplicate analyses, laboratory control spikes and matrix spikes in accordance with the EPA methods employed. Analytical Resources, Inc. will be responsible for conducting internal quality control and quality assurance measures in accordance with their own quality assurance plans. The required frequency for quality control procedures and evaluation criteria are summarized in Table 8.

Table 8. Anticipated Number of Samples and Associated Quality Assurance Requirements.

Parameter	Sample Type	Sample Events	Number of Columns	Total Number of Samples	Rinsate Blanks	Method Blanks	Control Standard	Matrix Spike	Lab Duplicates	Bottle Blanks
Total suspended solids	Whole sample composite	9		216	16	1/sample event	1/sample event	NA	1/sample event	2
pH	In situ	9	24	216	NA	NA	NA	NA	NA	NA
TKN	Whole sample composite	9	24	216	16	1/sample event	1/sample event	1/sample event	1/sample event	2
Nitrate-nitrite	Whole sample composite	9	24	216	16	1/sample event	1/sample event	1/sample event	1/sample event	2
Total phosphorus	Whole sample composite	9	24	216	16	1/sample event	1/sample event	1/sample event	1/sample event	2
Ortho-phosphorus	Whole sample composite	9	24	216	16	1/sample event	1/sample event	1/sample event	1/sample event	2
DOC	Whole sample composite	9	24	216	16	1/sample event	1/sample event	1/sample event	1/sample event	2
Hardness	Whole sample composite	9	24	216	16	1/sample event	1/sample event	1/sample event	1/sample event	2
Cadmium, dissolved	Whole sample composite	9	24	216	16	1/sample event	1/sample event	1/sample event	1/sample event	2
Cadmium, total	Whole sample composite	9	24	216	16	1/sample event	1/sample event	1/sample event	1/sample event	2
Copper, dissolved	Whole sample composite	9	24	216	16	1/sample event	1/sample event	1/sample event	1/sample event	2
Copper, total	Whole sample composite	9	24	216	16	1/sample event	1/sample event	1/sample event	1/sample event	2

Table 8 (continued). Anticipated Number of Samples and Associated Quality Assurance Requirements.

Parameter	Sample Type	Sample Events	Number of Columns	Total Number of Samples	Rinsate Blanks	Method Blanks	Control Standard	Matrix Spike	Lab Duplicates	Bottle Blanks
Zinc, dissolved	Whole sample composite	9	24	216	16	1/sample event	1/sample event	1/sample event	1/sample event	2
Zinc, total	Whole sample composite	9	24	216	16	1/sample event	1/sample event	1/sample event	1/sample event	2
Potassium	Whole sample composite	9	24	216	16	1/sample event	1/sample event	1/sample event	1/sample event	2
Sodium	Whole sample composite	9	24	216	16	1/sample event	1/sample event	1/sample event	1/sample event	2
Sulfate	Whole sample composite	9	24	216	16	1/sample event	1/sample event	1/sample event	1/sample event	2
Chloride	Whole sample composite	9	24	216	16	1/sample event	1/sample event	1/sample event	1/sample event	2
Alkalinity	Whole sample composite	9	24	216	16	1/sample event	1/sample event	1/sample event	1/sample event	2

NA = not applicable.

Equipment	Item	Procedure	Minimum Frequency
Influent delivery system	Distribution tank	Check for debris, flush with deionized water	Each dosing experiment
	Distribution lines	Check for debris, flush with deionized water	Each dosing experiment
pH laboratory meter	Calibration	Calibrate in accordance with manufacturer's instructions	Before and after each use

Water quality results will first be reviewed at the laboratory for errors or omissions. Laboratory quality control results will be reviewed by the laboratory to verify compliance with acceptance criteria. The laboratory will also validate the results by examining the completeness of the data package to determine whether method procedures and laboratory quality assurance procedures were followed. The review, verification, and validation by the laboratory will be documented in a case narrative that accompanies the analytical results.

Data will be reviewed and validated within 7 days of receiving the results from the laboratory. This review will be performed to ensure that all data are consistent, correct and complete, and that all required quality control information has been provided. Specific quality control elements for the data (see Table 3) will also be examined to determine if MQOs for the project have been met.

Results from these data validation reviews will be summarized in quality assurance worksheets (see example in Appendix A) that are prepared for each sample batch. The Herrera project manager and Herrera quality assurance lead for water quality data will be jointly responsible for identifying and initiating corrective action. Values associated with minor quality control problems will be considered estimates and assigned *J* qualifiers. Values associated with major quality control problems will be rejected and qualified with an *R*. Estimated values may be used for evaluation purposes, but rejected values will not be used. The following sections describe in detail the data validation procedures for quality control.

10. DATA MANAGEMENT PROCEDURES

Analytical Resources, Inc. will report the analytical results within 30 days of receipt of the samples. The laboratory will provide sample and quality control data in standardized reports that are suitable for evaluating the project data. These reports will include all quality control results associated with the data. The reports will also include a case narrative summarizing any problems encountered in the analyses, corrective actions taken, changes to the referenced method, and an explanation of data qualifies.

Laboratory data will be entered into the project database for all subsequent data management and archiving tasks. Herrera's quality assurance lead for water quality data will perform an independent review to ensure that the data were entered without error. Specifically, 10 percent of the sample values will be randomly selected for rechecking and crosschecking with laboratory reports. If errors are detected, they will be corrected, and then an additional 10 percent will be selected for validation. This process will be repeated until no errors are found in the data.

All sample volume pH data will be entered manually into a project database within 24 hours of sample collection.

11. AUDITS AND REPORTS

This section provides information on audits and reports that will be part of this monitoring program.

11.1. Audits

Audits performed for water quality data will occur within 7 business days of receiving results from the laboratory. This review will be performed to ensure that all data are consistent, correct, and complete, and that all required quality control information has been provided. Specific quality control elements for the data (see Table 3) and raw data will also be examined to determine if the MQOs for the project have been met. Results from these audits will be documented in QA worksheets (see Appendix B) that will be prepared for each batch of samples.

In the event that a potential QA issue is identified through these audits, Herrera's data quality assurance lead will review the data to determine if any response actions are required. Response actions in this case might include the collection of additional samples, reanalysis of existing samples if not yet past holding time, or advising the laboratory that methodologies or QA/QC procedures need to be improved.

11.2. Reports

Herrera will prepare a preliminary and final report for project partner (including Ecology) review.

12. DATA VERIFICATION AND VALIDATION

Data verification and validation will be performed on the water quality data that are collected through the duration of this project. The specific procedures that will be used to verify and validate each type of data are described in the following sections.

12.1. Verification and Validation Methods for Water Quality Data

Data will be reviewed and audited within seven business days of receiving the results from the laboratory. This review will be performed to ensure that all data are consistent, correct and complete, and that all required quality control information has been provided. Specific quality control elements for the data (see tables 3 and 8) will also be examined to determine if the MQOs for the project have been met. Results from these data validation reviews will be summarized in quality assurance worksheets that are prepared for each sample batch (see Appendix B). Values associated with minor quality control problems will be considered estimates and assigned *J* qualifiers. Values associated with major quality control problems will be rejected and qualified *R*. Estimated values may be used for evaluation purposes, while rejected values will not be used. The following sections describe in detail the data validation procedures for these quality control elements:

- Completeness
- Methodology
- Holding times
- Method and rinsate blanks
- Reporting limits
- Duplicates
- Matrix spikes
- Control standards
- Sample representativeness

12.1.1. Completeness

Completeness will be assessed by comparing valid sample data with this quality assurance project plan and the chain-of-custody records. Completeness will be calculated by dividing the number of valid values by the total number of values. If less than 95 percent of the samples submitted to the laboratory are judged to be valid, then more samples will be collected until at least 95 percent are judged to be valid.

12.1.2. Methodology

Methodologies for analytical procedures will follow US EPA approved methods (APHA et al. 1992, 1998; US EPA 1983, 1984) specified in Table 7. Field procedures will follow the

methodologies described in this QAPP. Any deviations from these methodologies must be approved by Ecology and documented in an addendum to this QAPP. Deviations that are deemed unacceptable will result in rejected values (R) and will be corrected for future analyses.

12.1.3. Holding Times

Holding times for each analytical parameter in this study are summarized in Table 7. Holding time compliance will be assessed by comparing sample collection dates and times to filtration (pre-filtration) and analytical (post-filtration or total) dates and times. Sample collection times will be based on the date and time that the last aliquot was collected, but start of sampling date and time will be recorded as well.

12.1.3.1. Pre-Filtration Holding Times

Samples requiring filtration should be filtered within 12 hours of collection of the last aliquot. US EPA requires that dissolved metals and ortho-phosphorus should be filtered within 15 minutes of the collection of the last aliquot. Meeting this holding time goal would be difficult for this project. Consequently, dissolved metals and soluble reactive phosphorus samples that are filtered within 12 hours will be flagged as estimated values (J). Dissolved metals and soluble reactive phosphorus samples that are filtered after this 12-hour limit will be considered rejected (R).

12.1.3.2. Post-Filtration or Total Holding Times

- For analytes with holding times in excess of 7 days:
 - Data from samples that exceed the specified maximum post-filtration holding times by less than 48 hours will be considered estimates (J). Data from samples that exceed the maximum post-filtration holding times by more than 48 hours will be rejected values (R).
- For analytes with holding equal to or less than 7 days:
 - Data from samples that exceed the specified maximum post-filtration holding times by less than 24 hours will be considered estimates (J). Data from samples that exceed the maximum post-filtration holding times by more than 24 hours will be rejected values (R).

12.1.4. Method Blanks

Method blank values will be compared to the MQOs that have been identified for this project (see Table 3). If an analyte is detected in a method blank at or below the reporting limit, no action will be taken. If blank concentrations are greater than the reporting limit, the associated data will be labeled with a *U* (in essence increasing the reporting limit for the affected samples), and associated project samples within 5 times the de facto reporting limit will be flagged with a *J* (G. Grepogrove, Manchester Laboratory, personal communication, September 4, 2007). In each of these cases, the de facto reporting limit for that analyte will be recorded along with the raw data, equipment will be decontaminated, and samples will be rerun if possible.

12.1.5. *Rinsate Blanks*

Rinsate blank concentrations will be compared to the MQOs that have been identified for this project (see Table 3). If concentrations are detected in the rinsate blanks that exceed 2 times the reporting limit, then associated sample tubing will be cleaned or replaced and associated samples collected since the previous rinsate blank that are within 5 times the new reporting limit will be flagged with a J.

12.1.6. *Reporting Limits*

Both raw values and reporting limits will be presented in each laboratory report. If the proposed reporting limits are not met by the laboratory, the laboratory will be requested to reanalyze the samples or revise the method, if time permits. Proposed reporting limits for this project are summarized in Table 7.

12.1.7. *Duplicates*

Duplicate results exceeding the MQOs for this project (see Table 3) will be recorded in the raw data tables, and noted in the quality assurance worksheets; and associated values will be flagged as estimates (*J*). If the objectives are severely exceeded (such as more than twice the objective), then associated values will be rejected (*R*).

12.1.8. *Matrix Spikes*

Matrix spike results exceeding the MQOs for this project (see Table 3) will be noted in the quality assurance worksheets, and associated values will be flagged as estimates (*J*). However, if the percent recovery exceeds the MQOs and a value is less than the reporting limit, the result will not be flagged as an estimate. Non-detected values will be rejected (*R*) if the percent recovery is less than 30 percent.

12.1.9. *Control Standards*

Control standard results exceeding the MQOs for this project (see Table 3) will be noted in the quality assurance worksheets, and associated values will be flagged as estimates (*J*). If the objectives are severely exceeded (such as more than twice the objective), then associated values will be rejected (*R*).

13. DATA QUALITY ASSESSMENT

Separate subsections herein describe the procedures that will be used to assess the usability of the data and analyze the data.

13.1. Data Usability Assessment

The Herrera quality assurance officer will provide an independent review of the water quality QC data from each sampling event using the MQOs that have been identified in this QAPP. The results will be presented in a water quality data quality assessment report (see *Audits and Reports* section). The data quality assessment report will summarize quality control results, identify when data quality objectives were not met, and discuss the resulting limitations (if any) on the use or interpretation of the data. Specific quality assurance information that will be noted in the data quality assessment report includes the following:

- Changes in and deviations from the QAPP
- Results of performance or system audits
- Significant quality assurance problems and recommended solutions
- Data quality assessment results in terms of precision, bias, representativeness, completeness, comparability, and reporting limits
- Discussion of whether the quality assurance objectives were met, and the resulting impact on decision-making
- Limitations on use of the measurement data

13.2. Data Analysis Procedures

Data analysis will be performed to document the performance of the bioretention media for pollutant removal efficiencies and relative to treatment goals that are specified in the TAPE guidelines (Ecology 2011) for basic, enhanced, phosphorus and metals. Separate sub-sections below describe the specific data analysis procedures that will be applied to meet these objectives.

13.2.1. Evaluation of Treatment Performance

To evaluate the treatment performance of the various bioretention media, the following data compilations and analyses will be generated from the sampling results:

- Sampling event data will be reviewed to determine if goals for representativeness that are specified in the Quality Objectives section of this QAPP were met.
- Flushing potential will be calculated for each parameter from each flushing event

- Pollutant removal efficiency will be calculated for each parameter from each dosing event

Each of these activities is described in more detail below.

13.2.1.1. Sampling Event Data

Using the compiled sampling data, a summary table will be prepared with the following data from each column experiment:

- Experiment ID or number
- Location
- Antecedent dry period
- Experiment duration
- Influent and effluent water volume
- Presence/absence of bypass

This information will be compared to sample collection guidelines that are specified in the *Quality Objectives* section of this QAPP to evaluate the overall representativeness of the compiled data.

13.2.1.2. Statistical Comparisons of Influent and Effluent Pollutant Concentrations

Statistical analyses will be performed to determine whether there are significant differences in pollutant concentrations between the influent and effluent of each media blend across individual sampling events. The specific null hypothesis (H_0) and alternative hypothesis (H_a) for these analyses are as follows:

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

H_a : Effluent concentrations are less than influent concentrations.

To evaluate these hypotheses, a 2-tailed Wilcoxon signed-rank test (Helsel and Hirsch 2002) will be used to compare the influent and effluent performance data. (The Wilcoxon signed-rank test is a nonparametric analogue to the paired t-test.) Statistical significance will be assessed based on an alpha (α) level of 0.1.

A Freidman test will be used to evaluate if there is significant differences in reducing pollutant concentrations among the media blends.

13.2.1.3. Pollutant Removal Efficiency Calculations

Pursuant to guidance from Ecology (2008), pollutant reduction efficiencies for each bioretention media will be estimated using the three methods described below.

Method #1: Individual Experiment Reduction in Pollutant Concentration

The reduction (in percent) in pollutant concentration during each individual experiment (ΔC) will be calculated as:

$$\Delta C = 100 \times \frac{(C_{in} - C_{eff})}{C_{in}}$$

where: C_{in} = composite influent pollutant concentration

C_{eff} = composite effluent pollutant concentration for each treatment

For TSS and total phosphorus, the median percent reduction in concentrations and associated 95 percent confidence interval about the median will be estimated using a bootstrapping approach (Helsel and Hirsch 2002). The lower confidence interval about the median for each parameter will then be used to determine whether the treatment goals identified above for basic and phosphorus treatment have been met. Specifically, if the lower confidence limit is higher than the specified removal efficiency goals for each treatment category, it can be concluded that the treatment goal was met with the required 95 percent confidence that is specified in Ecology (2008).

Method #2: Aggregate Pollutant Loading Reduction

The aggregate reduction (in percent) in pollutant load for all experiments (ΔL_{agg}) will be calculated as:

$$\Delta L_{agg} = 100 \times \frac{\left(\sum_{i=1}^n (C_{i,in} * V_i) - \sum_{i=1}^n (C_{i,eff} * V_i) \right)}{\sum_{i=1}^n (C_{i,in} * V_i)}$$

where: $C_{i,in}$ = influent pollutant concentration for experiment i

V_i = water volume applied for experiment i

$C_{i,eff}$ = composite effluent pollutant concentration of each treatment

n = number of experiments

Method #3: Individual Storm Reduction in Pollutant Loading

Pollutant load reduction (in percent) in individual experiments (ΔL) will be calculated as:

$$\Delta L = 100 \times \frac{((C_{in} \times V) - (C_{eff} \times V))}{(C_{in} \times V)}$$

where: C_{in} = composite influent pollutant concentration

V_i = water volume applied for experiment i

C_{eff} = composite effluent pollutant concentration

Like the Method #1 calculations above, the median percent reduction in loads for TSS and total phosphorus will be estimated using a bootstrapping approach along with the associated 95 percent confidence interval about the median (Helsel and Hirsch 2002). The lower confidence interval about the median will then be compared to the treatment goals identified above for basic and phosphorus treatment to determine if they have been met with the required 95 percent confidence that is specified in Ecology (2008).

13.2.2. Statistical Evaluation of Performance Goals

Statistical analyses will be performed to determine whether the collected data demonstrate that the media blends meet applicable performance goals specified in the TAPE guidelines (Ecology 2011) for basic, enhanced, and phosphorus treatment (see Table 11). The statistical analysis will involve the computation of bootstrapped confidence intervals around the mean effluent concentration or pollutant removal efficiency. Bootstrapping offers a distribution-free method for computing confidence intervals around a measure of central tendency (Efron and Tibshirani 1993). The generality of bootstrapped confidence intervals means they are well-suited to non-normally distributed data or datasets not numerous enough for a powerful test of normality (Porter et al. 1997).

Performance Goal	Influent Range	Criteria
Basic Treatment	20-100 mg/L TSS	Effluent goal ≤ 20 mg/L TSS ^a
	100-200 mg/L TSS	$\geq 80\%$ TSS removal ^b
	>200 mg/L TSS	$>80\%$ TSS removal ^b
Enhanced (Dissolved Metals) Treatment	Dissolved copper 0.003 – 0.2 mg/L	Must meet basic treatment goal and exhibit $>30\%$ dissolved copper removal ^b
	Dissolved zinc 0.02 – 0.3 mg/L	Must meet basic treatment goal and exhibit $>60\%$ dissolved zinc removal ^b
Phosphorus Treatment	Total phosphorus (TP) 0.1 to 0.5 mg/L	Must meet basic treatment goal and exhibit $\geq 50\%$ TP removal ^b

Source: Ecology (2011).

^a The upper 95 percent confidence interval around the mean effluent concentration for the treatment system being evaluated must be lower than this performance goal to meet the performance goal with the required 95 percent confidence.

^b The lower 95 percent confidence interval around the mean removal efficiency for the treatment system being evaluated must be higher than this performance goal to meet the performance goal with the required 95 percent confidence.

mg/L - milligrams per liter

Cu - copper

TP - total phosphorus

TSS - total suspended solids

Zn - zinc

In its simplest form, bootstrapping a summary statistic of a dataset of sample size n consists of drawing n elements from the dataset randomly with replacement and equal probabilities of drawing any element. The statistic of interest is then calculated on this synthetic dataset, and the process is repeated for many repetitions. Repetition generates a distribution of

possible values for the statistic of interest. Percentiles of this distribution are confidence intervals of the statistic. For example, if the mean is calculated for 1,000 synthetic datasets, after sorting the replications, the result for ranks 25 and 975 are the lower and upper 95 percent confidence intervals, respectively, around the mean.

For basic, enhanced, and phosphorus treatment with goals that are expressed as a minimum removal efficiency (i.e., 80 percent TSS removal, 30 percent dissolved copper removal, 60 percent dissolved zinc removal, and 50 percent TP removal), bootstrapping will be used to compute the 95 percent confidence interval around the mean removal efficiency for each parameter. The lower 95 percent confidence limit will then be compared to the applicable performance goal. If the lower confidence limit is higher than the treatment goal, it can be concluded that the media blend met the performance goal with the required 95 percent confidence.

For the basic treatment with goal that is expressed as a maximum effluent concentration (i.e., 20 mg/L TSS), bootstrapping will be used to compute the 95 percent confidence interval around the mean effluent concentration. The upper 95 percent confident limit will then be compared to the applicable performance goal. If the upper confidence limit is lower than the treatment goal, it can be concluded that the media blend met the performance goal with the required 95 percent confidence.

14. REFERENCES

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APPENDIX A

Quality Assurance Worksheet



HERRERA Data Quality Assurance Worksheet

Project Name/No./Client: _____

Laboratory/Parameters: _____

Sample Date/Sample ID: _____

By _____

Date _____ Page 1 of 1

Checked: initials _____

date _____

Parameter	Completeness/ Methodology	Holding Times (days)		Blanks/ Reporting Limit	Matrix Spikes/ Surrogate Recovery (%)		Lab Control Samples Recovery (%)		Lab Duplicates RPD (%)		Field Duplicates RPD (%)		Instrument Calibration/ Performance	ACTION
		Reported	Goal		Reported	Goal	Reported	Goal	Reported	Goal ¹	Reported	Goal ¹	OK	

¹ If the sample or duplicate value is less than five times the reporting limit, then the difference is calculated rather than the RPD and the QA objective is that the difference shall not exceed 2 times the reporting limit instead of the number indicated in the objective column.

NA – not applicable or not available

NC – not calculable due to one or more values below the detection limit

NS – field duplicate not sampled.

APPENDIX B

Peristaltic Pump Calibration Records

Table B-1. Initial (Pre-Experiment) Pump Calibration at 52% for 30 Minutes

Pump	Error (%)	Pump Adjustment (%)	Run 1 (mL)	Run 2 (mL)	Run3 (mL)	Run4 (mL)	Run5 (mL)	Stated Value ^a (mL)	Percent Error Run 1	Percent Error Run 2	Percent Error Run 3	Percent Error Run 4	Percent Error Run 5
1	-0.31	16.23	3260	3310	3320	3310	3350	3276.00	-0.49	1.04	1.34	1.04	2.26
2	-0.16	8.40	3420	3465	3140	3300	3305	3276.00	4.40	5.77	-4.15	0.73	0.89
3	-0.24	12.34	3250	3290	3225	3350	3290	3276.00	-0.79	0.43	-1.56	2.26	0.43
4	-0.17	9.01	3270	3310	3340	3385	3400	3276.00	-0.18	1.04	1.95	3.33	3.79
5	-0.36	18.47	3240	3310	3300	3370	3400	3276.00	-1.10	1.04	0.73	2.87	3.79
6	-0.32	16.55	3350	3350	3300	3405	3460	3276.00	2.26	2.26	0.73	3.94	5.62
7	-0.27	14.28	3240	3300	3360	3390	3370	3276.00	-1.10	0.73	2.56	3.48	2.87
8	-0.42	21.79	3210	3240	3230	3140	3330	3276.00	-2.01	-1.10	-1.40	-4.15	1.65
9	-0.31	16.13	3410	3455	3210	3420	3445	3276.00	4.09	5.46	-2.01	4.40	5.16
10	-0.33	17.21	3330	3330	3245	3340	3355	3276.00	1.65	1.65	-0.95	1.95	2.41
11	-0.30	15.68	3240	3250	3270	3310	3335	3276.00	-1.10	-0.79	-0.18	1.04	1.80
12	-0.27	14.17	3215	3280	3270	3240	3340	3276.00	-1.86	0.12	-0.18	-1.10	1.95
13	-0.29	15.12	3420	3420	3370	3475	3500	3276.00	4.40	4.40	2.87	6.07	6.84
Mean			3296.54	3331.54	3275.38	3341.15	3375.38		0.63	1.70	-0.02	1.99	3.03
Pump			Min. to Attain 13.4 L										
1			123.31	121.45	121.08	121.45	120.00						
2			117.54	116.02	128.03	121.82	121.63						
3			123.69	122.19	124.65	120.00	122.19						
4			122.94	121.45	120.36	118.76	118.24						
5			124.07	121.45	121.82	119.29	118.24						
6			120.00	120.00	121.82	118.06	116.18						
7			124.07	121.82	119.64	118.58	119.29						
8			125.23	124.07	124.46	128.03	120.72						
9			117.89	116.35	125.23	117.54	116.69						
10			120.72	120.72	123.88	120.36	119.82						
11			124.07	123.69	122.94	121.45	120.54						
12			125.04	122.56	122.94	124.07	120.36						
13			117.54	117.54	119.29	115.68	114.86						
Mean			116.20	120.72	122.78	120.39	119.13						

^a Manufacturer stated value at 52% cycle time

Peristaltic pump calibration notes:

Application: Determine accuracy of peristaltic pumps compared to manufacturer stated value at 52% cycle time and 30 minute run time.

Method: determine percent difference between manufacturers' stated value and measured value from accuracy checks at 52 percent cycle timing. Multiply percent difference (error) by 52 percent or use pump delivery rate table to determine percent change to attain stated value.

Analysis performed by: Curtis Hinman

Date: 6-30-14

Table B-2. Mid-Experiment Pump Calibration at 52% for 30 Minutes.

Pump	Run 1 (mL)	Run 2 (mL)	Run3 (mL)	Run4 (mL)	Stated Value ^a (mL)	Percent Error Run 1	Percent Error Run 2	Percent Error Run 3	Percent Error Run 4
1	3540	3170	3510	3260	3276.00	8.06	-3.24	7.14	-0.49
2	3670	3290	3590	3365	3276.00	12.03	0.43	9.58	2.72
3	3420	3300	3465	3230	3276.00	4.40	0.73	5.77	-1.40
4	3590	3360	3595	3360	3276.00	9.58	2.56	9.74	2.56
5	3560	3210	3500	3390	3276.00	8.67	-2.01	6.84	3.48
6	3700	3400	3585	3390	3276.00	12.94	3.79	9.43	3.48
7	3495	3180	3400	3355	3276.00	6.68	-2.93	3.79	2.41
8	3585	3360	3580	3455	3276.00	9.43	2.56	9.28	5.46
9	3740	3525	3600	3470	3276.00	14.16	7.60	9.89	5.92
10	3590	3300	3545	3350	3276.00	9.58	0.73	8.21	2.26
11	3450	3440	3530	3290	3276.00	5.31	5.01	7.75	0.43
12	3560	3360	3610	3400	3276.00	8.67	2.56	10.20	3.79
13	4525	3160	3350	3380	3276.00	38.13	-3.54	2.26	3.17
Mean	3648.08	3311.92	3527.69	3361.15		11.36	1.10	7.68	2.60
Pump	Min. to Attain 13.4 L								
1	113.56	126.81	114.53	123.31					
2	109.54	122.19	111.98	119.47					
3	117.54	121.82	116.02	124.46					
4	111.98	119.64	111.82	119.64					
5	112.92	125.23	114.86	118.58					
6	108.65	118.24	112.13	118.58					
7	115.02	126.42	118.24	119.82					
8	112.13	119.64	112.29	116.35					
9	107.49	114.04	111.67	115.85					
10	111.98	121.82	113.40	120.00					
11	116.52	116.86	113.88	122.19					
12	112.92	119.64	111.36	118.24					
13	88.84	127.22	120.00	118.93					
Mean	105.50	121.51	114.01	119.65					

^a Manufacturers' stated value at 52% cycle time

Peristaltic pump calibration notes:

Application: Determine accuracy of peristaltic pumps compared to manufacturer stated value at 52% cycle time and 30 minute run time.

Method: determine percent difference between stated value and measured value from accuracy checks at 52 percent cycle timing.

Multiply percent difference (error) by 52 percent or use pump delivery rate table to determine percent change to attain stated value.

Analysis performed by: Curtis Hinman

Date: 9-4, 9-17, and 9/24/14

Table B-3. Mid-Dosing Experiment Pump Calibration at 100% for 30 Minutes.

Pump	Error (%)	Pump Adjustment (%)	Run 1 (mL)	Pump Adjustment (%)	Run 2 (mL)	Pump Adjustment (%)	Run 3 (mL)	Pump Adjustment (%)	Run 4 (mL)	Pump Adjustment (%)	Stated ^a Value (mL)	Percent Error Run 1	Percent Error Run 2	Percent Error Run 3	Percent Error Run 4
1	-2.59	-2.59	5530	0	5595	0	5585	0	5600	0	5500.00	0.55	1.73	1.55	1.82
2	-22.09	-22.09	5060	8	5840	6	5495	0	5520	0	5500.00	-8.00	6.18	-0.09	0.36
3	-4.59	-4.59	5355	2	5575	0	5570	0	5580	0	5500.00	-2.64	1.36	1.27	1.45
4	-21.82	-21.82	4905	11	5855	6	5400	1	5570	0	5500.00	-10.82	6.45	-1.82	1.27
5	-3.09	-3.09	5500	0	5590	0	5600	1	5470	0	5500.00	0.00	1.64	1.82	-0.55
6	-3.55	-3.55	5550	0	5590	0	5620	1	5475	0	5500.00	0.91	1.64	2.18	-0.45
7	-16.73	-16.73	4980	9	5680	3	5595	0	5600	0	5500.00	-9.45	3.27	1.73	1.82
8	-8.14	-8.14	5315	3	5680	3	5535	0	5540	0	5500.00	-3.36	3.27	0.64	0.73
9	-16.09	-16.09	5140	6	5630	2	5550	0	5600	0	5500.00	-6.55	2.36	0.91	1.82
10	-14.91	-14.91	5010	8	5660	2	5660	0	5555	0	5500.00	-8.91	2.91	2.91	1.00
11	-13.09	-13.09	4900	10	5800	2	5670	3	5485	0	5500.00	-10.91	5.45	3.09	-0.27
12	-10.91	-10.91	5140	6	5655	2	5655	0	5530	0	5500.00	-6.55	2.82	2.82	0.55
13	-17.00	-17.00	5110	7	5610	2	5860	0	5465	0	5500.00	-7.09	2.00	6.55	-0.64
Minimum			4900		5575		5400		5465						
Maximum			5530		5840		5585		5600						
Mean			5191.92		5673.85		5599.62		5537.69			-5.60	3.16	1.81	0.69
Time to Attain 26.8 L (minutes)															
	145.39				143.70				143.96						143.57
	158.89				137.67				146.31						145.65
	150.14				144.22				144.34						144.09
	163.91				137.32				148.89						144.34
	146.18				143.83				143.57						146.98
	144.86				143.83				143.06						146.85
	161.45				141.55				143.70						143.57
	151.27				141.55				145.26						145.13
	156.42				142.81				144.86						143.57
	160.48				142.05				142.05						144.73
	164.08				138.62				141.80						146.58
	156.42				142.18				142.18						145.39
	157.34				143.32				137.20						147.12
Mean			155.14		141.74				143.63						145.20

^a Manufacturer stated value at 100% cycle time

Peristaltic pump calibration notes:

Application: Determine accuracy of peristaltic pumps compared to manufacturer stated value at 100% cycle time and 30 minute run time.

Method: determine percent difference between stated value and measured value from accuracy checks at 100% cycle timing.

Multiply percent difference (error) by 100 percent (1) or use pump delivery rate table to determine percent change to attain stated value.

Analysis performed by: Curtis Hinman

Date: 10-23-14

APPENDIX C

Quality Assurance Review Summary

Herrera Environmental Consultants, Inc.

Memorandum

To John Lenth, Herrera Environmental Consultants
cc Curtis Hinman, Herrera Environmental Consultants
From Gina Catarra, Herrera Environmental Consultants
Date March 23, 2015
Subject Bioretention Media Study Data Quality Assurance Review

This memorandum presents a review of data quality for a total of 243 water samples (including rinsate blank, influent and split samples) collected between July 7, 2014 and December 11, 2014 during the flushing and dosing experiments for the bioretention media study project. Samples were analyzed by Analytical Resources, Inc., of Tukwila, Washington for the following parameters:

- Total suspended solids using Standard Method 2540D
- Hardness using Standard Method 2340B
- Dissolved organic carbon using EPA method 9060
- Total phosphorus using EPA method 365.2
- Ortho-phosphorus using EPA method 365.2
- Total Kjeldahl nitrogen using EPA method 351.2
- Nitrate-nitrite using EPA method 353.2
- Total and dissolved metals (cadmium, copper, lead, and zinc) using EPA method 200.8
- Sodium and potassium using EPA method 6010C
- Sulfate using EPA method 375.2
- Chloride using EPA method 325.2
- Alkalinity using Standard Method 2320

The laboratory's performance was reviewed in accordance with the quality control (QC) criteria outlined in the *Analysis of Bioretention Soil Media for Improved Nitrogen, Phosphorus, and Copper Retention Quality Assurance Project Plan (QAPP)* (Herrera 2014).

Quality control data summaries submitted by the laboratory were reviewed; raw data were not submitted by the laboratory. Data Quality assurance worksheets summarizing the quality assurance and quality control (QA/QC) review were completed for each sampling event and are included as Appendix D of the Final Report. Data Qualifiers (flags) were added to the sample results in the database. Data validation results are summarized for Flushing and Dosing Experiments below followed by definitions of data qualifiers.

Flushing Experiments

In general, the flushing experiment data quality for all parameters was found to be acceptable based on reporting limit, method blank, control standard, matrix spike, laboratory duplicate, and field duplicate criteria. Data were qualified based on holding time and rinsate blank exceedances, as described below.

EPA method 365.2 requires field filtering within 15 minutes of the last aliquot. Whole samples were collected for this study and churn split at the laboratory; consequently, filtering was not performed in the field and typically occurred 2 or more hours after sample collection. Therefore, all ortho-phosphorus data were qualified as estimated (flagged J).

A total of four rinsate blanks were collected during the flushing experiments. Sample results were qualified as estimated (flagged J) if the rinsate blank result was greater than 2 times the reporting limit and the sample results was within 5 times the rinsate blank result. Due to rinsate blank contamination, 65 dissolved copper results, 55 total copper results, and 58 nitrate-nitrite results were qualified as estimated (flagged J).

The flushing experiment data are considered acceptable as qualified.

Dosing Experiments

In general, the dosing experiment data quality for all parameters was found to be acceptable based on holding time, reporting limit, rinsate blank, control standard, matrix spike, laboratory duplicate, and field duplicate criteria. Due to method blank contamination, one nitrate-nitrite result was qualified as estimated. In addition, one sample container was broken by the laboratory and not analyzed for any of the parameters.

EPA method 365.2 requires field filtering within 15 minutes of the last aliquot. Whole samples were collected for this study and churn split at the laboratory; consequently, filtering was not

performed in the field and typically occurred 2 or more hours after sample collection. Therefore, all ortho-phosphorus data were qualified as estimated (flagged J).

The flushing experiment data are considered acceptable as qualified.

Definition of Data Qualifiers

The following data qualifier definitions are taken from the QAPP (Herrera 2014).

J The associated value is an estimated quantity.

References

Herrera. 2014. Analysis of Bioretention Soil Media for Improved Nitrogen, Phosphorus and Copper Retention Quality Assurance Project Plan. Prepared for Kitsap County by Herrera Environmental Consultants, Seattle, Washington

APPENDIX D

Data Quality Assurance Worksheets

Table D-1. Data Quality Assurance Worksheet: Flushing Experiments (7-7-14 Flushing Event)

Columns: 33, 42, 73, 12, 21, 72, 52, 53, 83, 22, 51, 82

Entry date 9/5/2014

Page 1 of 1

Laboratory/Parameters: pH, TSS, DOC, total and dissolved metals, TP, Ortho-P, TKN, NO3-NO2, BLM ions (see QAPP)

Checked by: Gina Catarra

Sample Date/Sample ID/Lab ID: 7-7-14 /S14-05757-0026 thru S14-05757-0038/ARI YQ68

Sample collection time: 14:00

Parameter	Completeness/Methodology	Pre-filter Holding Time		Total Holding Time		Lab Method Blanks/Reporting Limit		Surrogate Recovery (% Recovery)		Matrix Spikes (% Recovery)		Lab Duplicates (RPD) ^b		Field Duplicates (RSDp)		Rinsate Blanks		Lab Control Standard (% Recovery)		Action
		Reported	Goal	Reported	Goal	Reported	Goal	Reported	Goal	Reported	Goal	Reported	Goal	Reported	Goal	Reported	Goal	Reported	Goal	
Total Suspended Solids	SM 2540D	NA	NA	1	7dy	OK	≤1.0 mg/L	NA	NA	NA	NA	OK (LCS/LCS D + dup)	≤20%or±2xRL	NA	≤35%	ND	≤2xRL	OK	±20	None
Hardness ^a	SM2340-C	NA	NA	7	6mo	OK	≤1.0mg/L ^a	NA	NA	OK	±25	OK	≤20%or±2xRL	NA	≤35%	ND	≤2xRL	OK	±20	None
DOC	EPA 9060	OK	15min‡	2	28 dy	OK	≤1.5mg/L	NA	NA	OK	±25	OK	≤20%or±2xRL	NA	≤35%	ND	≤2xRL	OK (SRM)	±20	None
Total Phosphorus	EPA 365.2	NA	NA	2	28dy	OK	≤0.008mg/L	NA	NA	OK	±25	OK	≤20%or±2xRL	NA	≤35%	ND	≤2xRL	OK (SRM)	±20	None
Ortho P	EPA 365.2	OK	15min‡	1	2dy	OK	≤0.004mg/L	NA	NA	OK	±25	OK	≤20%or±2xRL	NA	≤35%	ND	≤2xRL	OK (SRM)	±20	None
TKN	EPA 351.2	NA	NA	10	28dy	OK	≤1.0 mg/L	NA	NA	OK	±25	OK (LCS/LCS D + dup)	≤20%or±2xRL	NA	≤35%	ND	≤2xRL	OK (LCS + SRM)	±20	None
Nitrate + Nitrite	EPA 353.2	OK	48hr	1	28dy	OK	≤0.01 mg/L	NA	NA	OK	±25	OK	≤20%or±2xRL	NA	≤35%	ND	≤2xRL	OK (SRM)	±20	None
Sulfate	EPA375-2	NA	NA	7	28dy	OK	≤2.0 mg/L	NA	NA	OK	±25	OK	≤20%or±2xRL	NA	≤35%	ND	≤2xRL	OK (SRM)	±20	None
Chloride	EPA 325.2	NA	NA	2	28dy	OK	≤1.0 mg/L	NA	NA	OK	±25	OK	≤20%or±2xRL	NA	≤35%	ND	≤2xRL	OK (SRM)	±20	None
Alkalinity	SM 2320	NA	NA	10	14dy	NA	≤1.0mg/L	NA	NA	NA	NA	OK	≤20%or±2xRL	NA	≤35%	ND	≤2xRL	OK (SRM)	±20	None
Total metals	EPA 200.8 / 6010C	NA	NA	3,7	180 dy	OK	0.1 – 50 µg/L	NA	NA	OK	±25	OK	≤20%or±2xRL	NA	≤35%	Ca – ND,70 Cu – 1.8/1.9 Zn – 6/6	≤2xRL	OK	±20	Rinsate blanks for Ca and Zn Ok – less than 2xRL. All Cu results >5X RB, no flags added.
Dissolved metals	EPA 200.8 / 6010C	OK	15min‡ (dissolved)	3,7	180 dy	OK	0.1-500 µg/L	NA	NA	OK	±25	OK	≤20%or±2xRL	NA	≤35%	Cu – 1.2/1.1 Zn – 5/5	≤2xRL	OK	±20	Rinsate blanks for Zn Ok – less than 2XRL. For Cu “J” flag -0032, -0033, -0035, -0036, -0037

^a as CaCO3

^b The relative percent difference (RPD) must be less than or equal to the indicated percentage for values that are greater than 5 times the reporting limit. RPD must be within ±2 times the reporting limit for values that are less than or equal to 5 times the reporting limit.

^c EPA requires field filtering within 15 min of collection of the last aliquot. This is generally not feasible with flow weighted composite sampling.

Table D-2. Data Quality Assurance Worksheet: Flushing Experiments (7-8-14 Flushing Event)

Table D-2. Data Quality Assurance Worksheet: Flushing Experiments (7-8-14 Flushing Event)																				
Columns: 11,32,63,31,61,62,13,43,71,41,23,81,43,61															Entry date		9/5/2014		Page 1 of 1	
Laboratory/Parameters: pH, TSS, DOC, total and dissolved metals, TP, Ortho-P, TKN, NO3-NO2, BLM ions (see QAPP)															Checked by:		Gina Catarra			
Sample Date/Sample ID/Lab ID: 7-8-14 /S14-05757-0039 thru S14-05757-0053/ARI YQ70															Sample collection time:		14:37			
Parameter	Completeness/Methodology	Pre-filter Holding Time		Total Holding Time		Lab Method Blanks/Reporting Limit		Surrogate Recovery (% Recovery)		Matrix Spikes (% Recovery)		Lab Duplicates (RPD) ^b		Field Duplicates (RSDp)		Rinsate Blanks		Lab Control Standard (% Recovery)		Action
		Reported	Goal	Reported	Goal	Reported	Goal	Reported	Goal	Reported	Goal	Reported	Goal	Reported	Goal	Reported	Goal	Reported	Goal	
Total Suspended Solids	SM 2540D	NA	NA	1	7dy	OK	≤1.0 mg/L	NA	NA	NA	NA	OK (LCS/LCS D + dup)	≤20%or±2xRL	NA	≤35%	ND	≤2xRL	OK	±20	None
Hardness ^a	SM2340-C	NA	NA	7	180dy	OK	≤1.0mg/L ^a	NA	NA	OK	±25	OK	≤20%or±2xRL	NA	≤35%	ND	≤2xRL	OK	±20	None
DOC	EPA 9060	OK	15min‡	1	28 dy	OK	≤1.5mg/L	NA	NA	OK	±25	OK	≤20%or±2xRL	NA	≤35%	ND	≤2xRL	OK (SRM)	±20	None
Total Phosphorus	EPA 365.2	NA	NA	1	28dy	OK	≤0.008mg/L	NA	NA	OK	±25	OK	≤20%or±2xRL	NA	≤35%	ND	≤2xRL	OK (SRM)	±20	None
Ortho P	EPA 365.2	OK	15min‡	2	2dy	OK	≤0.004mg/L	NA	NA	OK	±25	OK	≤20%or±2xRL	NA	≤35%	ND	≤2xRL	OK (SRM)	±20	None
TKN	EPA 351.2	NA	NA	9	28dy	OK	≤1.0 mg/L	NA	NA	OK	±25	OK (LCS/LCS D + dup)	≤20%or±2xRL	NA	≤35%	ND	≤2xRL	OK (LCS + SRM)	±20	None
Nitrate + Nitrite	EPA 353.2	OK	48hr	3	28dy	OK	≤0.01 mg/L	NA	NA	OK	±25	OK	≤20%or±2xRL	NA	≤35%	ND	≤2xRL	OK (SRM)	±20	None
Sulfate	EPA375-2	NA	NA	6	28dy	OK	≤2.0 mg/L	NA	NA	OK	±25	OK	≤20%or±2xRL	NA	≤35%	ND	≤2xRL	OK (SRM)	±20	None
Chloride	EPA 325.2	NA	NA	2	28dy	OK	≤1.0 mg/L	NA	NA	OK	±25	OK	≤20%or±2xRL	NA	≤35%	ND	≤2xRL	OK (SRM)	±20	None
Alkalinity	SM 2320	NA	NA	10	14dy	NA	≤1.0mg/L	NA	NA	NA	NA	OK	≤20%or±2xRL	NA	≤35%	ND	≤2xRL	OK (SRM)	±20	None
Total metals	EPA 200.8 / 6010C	NA	NA	3,7	180 dy	OK	0.1 – 50 µg/L	NA	NA	OK	±25	OK	≤20%or±2xRL	NA	≤35%	Ca – ND,70 Cu – 1.8/1.9 Zn – 6/6	≤2xRL	OK	±20	Rinsate blanks for Ca and Zn Ok – less than 2xRL. For Cu “J” flag -0042, -0043, -0044.
Dissolved metals	EPA 200.8 / 6010C	OK	15min‡ (dissolved)	3,7	180 dy	OK	0.1-500 µg/L	NA	NA	OK	±25	OK	≤20%or±2xRL	NA	≤35%	Cu – 1.2/1.1 Zn – 5/5	≤2xRL	OK	±20	Rinsate blanks for Zn Ok – less than 2XRL. For Cu “J” flag all except -0048, -0049, -0050, -0051

^a as CaCO3

^b The relative percent difference (RPD) must be less than or equal to the indicated percentage for values that are greater than 5 times the reporting limit. RPD must be within ±2 times the reporting limit for values that are less than or equal to 5 times the reporting limit.

^c EPA requires field filtering within 15 min of collection of the last aliquot. This is generally not feasible with flow weighted composite sampling.

Table D-3. Data Quality Assurance Worksheet: Flushing Experiments (7-16-14 Flushing Event)

Columns: 33, 42, 73, 12, 21, 72, 52, 53, 83, 22, 51, 82

Laboratory/Parameters: pH, TSS, DOC, total and dissolved metals, TP, Ortho-P, TKN, NO3-NO2, BLM ions (see QAPP)

Sample Date/Sample ID/Lab ID: 7-16-14 /S14-05757-0054 thru S14-05757-0066/ARI YR79

Entry date 9/26/2014

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Checked by: Gina Catarra

Sample collection time: 12:47

Parameter	Completeness/Methodology	Pre-filter Holding Time		Total Holding Time		Lab Method Blanks/Reporting Limit		Surrogate Recovery (% Recovery)		Matrix Spikes (% Recovery)		Lab Duplicates (RPD) ^b		Field Duplicates (RSDp)		Rinsate Blanks		Lab Control Standard (% Recovery)		Action
		Reported	Goal	Reported	Goal	Reported	Goal	Reported	Goal	Reported	Goal	Reported	Goal	Reported	Goal	Reported	Goal	Reported	Goal	
Total Suspended Solids	SM 2540D	NA	NA	1	7dy	OK	≤1.0 mg/L	NA	NA	NA	NA	OK (LCS/LCS D + dup)	≤20%or±2xRL	NA	≤35%	NA	≤2xRL	OK	±20	None
Hardness ^a	SM2340-C	NA	NA	6	6mo	OK	≤1.0mg/L ^a	NA	NA	OK	±25	OK	≤20%or±2xRL	NA	≤35%	NA	≤2xRL	OK	±20	None
DOC	EPA 9060	OK	15min [‡]	1	28 dy	OK	≤1.5mg/L	NA	NA	OK	±25	OK	≤20%or±2xRL	NA	≤35%	NA	≤2xRL	OK (SRM)	±20	None
Total Phosphorus	EPA 365.2	NA	NA	7	28dy	OK	≤0.008mg/L	NA	NA	OK	±25	OK	≤20%or±2xRL	NA	≤35%	NA	≤2xRL	OK (SRM)	±20	None
Ortho P	EPA 365.2	OK	15min [‡]	1	2dy	OK	≤0.004mg/L	NA	NA	OK	±25	OK	≤20%or±2xRL	NA	≤35%	NA	≤2xRL	OK (SRM)	±20	None
TKN	EPA 351.2	NA	NA	13	28dy	OK	≤1.0 mg/L	NA	NA	OK	±25	OK (LCS/LCS D + dup)	≤20%or±2xRL	NA	≤35%	NA	≤2xRL	OK (LCS + SRM)	±20	None
Nitrate + Nitrite	EPA 353.2	OK	48hr	10	28dy	OK	≤0.01 mg/L	NA	NA	OK	±25	OK	≤20%or±2xRL	NA	≤35%	NA	≤2xRL	OK (SRM)	±20	"J" results for -0059, -0062 thru -0066 due to final rinsate blanks.
Sulfate	EPA375-2	NA	NA	15	28dy	OK	≤2.0 mg/L	NA	NA	OK	±25	OK	≤20%or±2xRL	NA	≤35%	NA	≤2xRL	OK (SRM)	±20	None
Chloride	EPA 325.2	NA	NA	8	28dy	OK	≤1.0 mg/L	NA	NA	OK	±25	OK	≤20%or±2xRL	NA	≤35%	NA	≤2xRL	OK (SRM)	±20	None
Alkalinity	SM 2320	NA	NA	2	14dy	NA	≤1.0mg/L	NA	NA	NA	NA	OK	≤20%or±2xRL	NA	≤35%	NA	≤2xRL	OK (SRM)	±20	None
Total metals	EPA 200.8 / 6010C	NA	NA	5	180 dy	OK	0.1 – 50 µg/L	NA	NA	OK	±25	OK	≤20%or±2xRL	NA	≤35%	NA	≤2xRL	OK	±20	Rinsate blanks for Ca and Zn Ok – less than 2xRL. For Cu "J" flag -0066.
Dissolved metals	EPA 200.8 / 6010C	OK	15min [‡] (dissolved)	5, 6	180 dy	OK / Lead = 0.1	0.1-500 µg/L	NA	NA	OK	±25	OK	≤20%or±2xRL	NA	≤35%	NA	≤2xRL	OK	±20	No flag for MB because reported MB value equaled the RL, per the QAPP. Rinsate blanks for Zn Ok – less than 2XRL. For Cu "J" flag -0057 through -0065

^a as CaCO3

^b The relative percent difference (RPD) must be less than or equal to the indicated percentage for values that are greater than 5 times the reporting limit. RPD must be within ±2 times the reporting limit for values that are less than or equal to 5 times the reporting limit.

^c EPA requires field filtering within 15 min of collection of the last aliquot. This is generally not feasible with flow weighted composite sampling.

Table D-4. Data Quality Assurance Worksheet: Flushing Experiments (7-17-14 Flushing Event)

Columns: 11,32,63,31,61,62,13,43,71,41,23,81

Entry date 9/26/2014

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Laboratory/Parameters: pH, TSS, DOC, total and dissolved metals, TP, Ortho-P, TKN, NO3-NO2, BLM ions (see QAPP)

Checked by: Gina Catarra

Sample Date/Sample ID/Lab ID: 7-17-14 /S14-05757-0067 thru S14-05757-0079/ARI YS10

Sample collection time: 14:23

Parameter	Completeness/ Methodology	Pre-filter Holding Time		Total Holding Time		Lab Method Blanks/ Reporting Limit		Surrogate Recovery (% Recovery)		Matrix Spikes (% Recovery)		Lab Duplicates (RPD) ^b		Field Duplicates (RSDp)		Rinsate Blanks		Lab Control Standard (% Recovery)		Action
		Reported	Goal	Reported	Goal	Reported	Goal	Reported	Goal	Reported	Goal	Reported	Goal	Reported	Goal	Reported	Goal	Reported	Goal	
Total Suspended Solids	SM 2540D	NA	NA	1	7dy	OK	≤1.0 mg/L	NA	NA	NA	NA	OK (LCS/LCS D + dup)	≤20%or±2xRL	NA	≤35%	NA	≤2xRL	OK	±20	None
Hardness ^a	SM2340-C	NA	NA	7	6mo	OK	≤1.0mg/L ^a	NA	NA	OK	±25	OK	≤20%or±2xRL	NA	≤35%	NA	≤2xRL	OK	±20	None
DOC	EPA 9060	OK	15min‡	1	28 dy	OK	≤1.5mg/L	NA	NA	OK	±25	OK	≤20%or±2xRL	NA	≤35%	NA	≤2xRL	OK (SRM)	±20	None
Total Phosphorus	EPA 365.2	NA	NA	5	28dy	OK	≤0.008mg/L	NA	NA	OK	±25	OK	≤20%or±2xRL	NA	≤35%	NA	≤2xRL	OK (SRM)	±20	None
Ortho P	EPA 365.2	OK	15min‡	1	2dy	OK	≤0.004mg/L	NA	NA	OK	±25	OK	≤20%or±2xRL	NA	≤35%	NA	≤2xRL	OK (SRM)	±20	None
TKN	EPA 351.2	NA	NA	12	28dy	OK	≤1.0 mg/L	NA	NA	OK	±25	OK (LCS/LCS D + dup)	≤20%or±2xRL	NA	≤35%	NA	≤2xRL	OK (LCS + SRM)	±20	None
Nitrate + Nitrite	EPA 353.2	OK	48hr	8	28dy	OK	≤0.01 mg/L	NA	NA	OK	±25	OK	≤20%or±2xRL	NA	≤35%	NA	≤2xRL	OK (SRM)	±20	"J" results for -0068, -0070 thru -0073, and -0076 thru -0079 for final rinsate blank
Sulfate	EPA375-2	NA	NA	14	28dy	OK	≤2.0 mg/L	NA	NA	OK	±25	OK	≤20%or±2xRL	NA	≤35%	NA	≤2xRL	OK (SRM)	±20	None
Chloride	EPA 325.2	NA	NA	6	28dy	OK	≤1.0 mg/L	NA	NA	OK	±25	OK	≤20%or±2xRL	NA	≤35%	NA	≤2xRL	OK (SRM)	±20	None
Alkalinity	SM 2320	NA	NA	1	14dy	NA	≤1.0mg/L	NA	NA	NA	NA	OK	≤20%or±2xRL	NA	≤35%	NA	≤2xRL	OK (SRM)	±20	None
Total metals	EPA 200.8 / 6010C	NA	NA	5,7	180 dy	OK	0.1 – 50 µg/L	NA	NA	OK	±25	OK	≤20%or±2xRL	NA	≤35%	NA	≤2xRL	OK	±20	For Cu "J" results for -0067 thru -0069, and -0074 thru -0079 due to initial rinsate blank.
Dissolved metals	EPA 200.8 / 6010C	OK	15min‡ (dissolved)	5,7	180 dy	OK / Lead = 0.1	0.1-500 µg/L	NA	NA	OK	±25	OK	≤20%or±2xRL	NA	≤35%	NA	≤2xRL	OK	±20	For Cu "J" results for -0067 thru -0078 due to initial rinsate blank.

^a as CaCO3

^b The relative percent difference (RPD) must be less than or equal to the indicated percentage for values that are greater than 5 times the reporting limit. RPD must be within ±2 times the reporting limit for values that are less than or equal to 5 times the reporting limit.

^c EPA requires field filtering within 15 min of collection of the last aliquot. This is generally not feasible with flow weighted composite sampling.

Table D-5. Data Quality Assurance Worksheet: Flushing Experiments (7-28-14 Flushing Event)

Columns: 33, 42, 73, 12, 21, 72, 52, 53, 83, 22, 51, 82

Laboratory/Parameters: pH, TSS, DOC, total and dissolved metals, TP, Ortho-P, TKN, NO3-NO2, BLM ions (see QAPP)

Sample Date/Sample ID/Lab ID: 7-28-14 /S14-05757-0080 thru S14-05757-0092/ARI YU11

Entry date 10/2/2014

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Checked by: Gina Catarra

Sample collection time: 13:40

Parameter	Completeness/ Methodology	Pre-filter Holding Time		Total Holding Time		Lab Method Blanks/ Reporting Limit		Surrogate Recovery (% Recovery)		Matrix Spikes (% Recovery)		Lab Duplicates (RPD) ^b		Field Duplicates (RSDp)		Rinsate Blanks		Lab Control Standard (% Recovery)		Action
		Reported	Goal	Reported	Goal	Reported	Goal	Reported	Goal	Reported	Goal	Reported	Goal	Reported	Goal	Reported	Goal	Reported	Goal	
Total Suspended Solids	SM 2540D	NA	NA	1	7dy	OK	≤1.0 mg/L	NA	NA	NA	NA	OK (LCS/LCS D + dup)	≤20%or±2xRL	NA	≤35%	NA	≤2xRL	OK	±20	None
Hardness ^a	SM2340-C	NA	NA	8	6mo	OK	≤1.0mg/L ^a	NA	NA	OK	±25	OK	≤20%or±2xRL	NA	≤35%	NA	≤2xRL	OK	±20	None
DOC	EPA 9060	OK	15min‡	2	28 dy	OK	≤1.5mg/L	NA	NA	OK	±25	OK	≤20%or±2xRL	NA	≤35%	NA	≤2xRL	OK (SRM)	±20	None
Total Phosphorus	EPA 365.2	NA	NA	1	28dy	OK	≤0.008mg/L	NA	NA	OK	±25	OK	≤20%or±2xRL	NA	≤35%	NA	≤2xRL	OK (SRM)	±20	None
Ortho P	EPA 365.2	OK	15min‡	1	2dy	OK	≤0.004mg/L	NA	NA	OK	±25	OK	≤20%or±2xRL	NA	≤35%	NA	≤2xRL	OK (SRM)	±20	None
TKN	EPA 351.2	NA	NA	10	28dy	OK	≤1.0 mg/L	NA	NA	OK	±25	OK (LCS/LCS D + dup)	≤20%or±2xRL	NA	≤35%	NA	≤2xRL	OK (LCS + SRM)	±20	None
Nitrate + Nitrite	EPA 353.2	OK	48hr	8	28dy	OK	≤0.01 mg/L	NA	NA	OK	±25	OK	≤20%or±2xRL	NA	≤35%	NA	≤2xRL	OK (SRM)	±20	"J" results for -0084 thru -0087, and -0090 thru -0092 due to final rinsate blanks.
Sulfate	EPA375-2	NA	NA		28dy		≤2.0 mg/L		NA		±25		≤20%or±2xRL		≤35%	NA	≤2xRL	OK (SRM)	±20	Not Reported
Chloride	EPA 325.2	NA	NA		28dy		≤1.0 mg/L		NA		±25		≤20%or±2xRL		≤35%	NA	≤2xRL	OK (SRM)	±20	Not Reported
Alkalinity	SM 2320	NA	NA	2	14dy	NA	≤1.0mg/L	NA	NA	NA	NA	OK	≤20%or±2xRL	NA	≤35%	NA	≤2xRL	OK (SRM)	±20	None
Total metals	EPA 200.8 / 6010C	NA	NA	3,8	180 dy	OK	0.1 – 50 µg/L	NA	NA	OK	±25	Cu RPD=36 (-0089)	≤20%or±2xRL	NA	≤35%	NA	≤2xRL	OK	±20	Rinsate blanks for Ca and Zn Ok – less than 2xRL. For Cu "J" flag -0081, -0084, -0089 to -0091. Dup RPD exceeded 20%, "J" result for -0089 only.
Dissolved metals	EPA 200.8 / 6010C	OK	15min‡ (dissolved)	3,4	180 dy	OK	0.1-500 µg/L	NA	NA	OK	±25	OK	≤20%or±2xRL	NA	≤35%	NA	≤2xRL	OK	±20	Rinsate blanks for Zn Ok – less than 2XRL. For Cu "J" flag -0083 to -0091

^a as CaCO3

^b The relative percent difference (RPD) must be less than or equal to the indicated percentage for values that are greater than 5 times the reporting limit. RPD must be within ±2 times the reporting limit for values that are less than or equal to 5 times the reporting limit.

^c EPA requires field filtering within 15 min of collection of the last aliquot. This is generally not feasible with flow weighted composite sampling.

Table D-6. Data Quality Assurance Worksheet: Flushing Experiments (7-29-14 Flushing Event)

Columns: 11,32,63,31,61,62,13,43,71,41,23,81

Laboratory/Parameters: pH, TSS, DOC, total and dissolved metals, TP, Ortho-P, TKN, NO3-NO2, BLM ions (see QAPP)

Sample Date/Sample ID/Lab ID: 7-29-14 /S14-05757-0093 thru S14-05757-0105/ARI YU18

Entry date 10/2/2014

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Checked by: Gina Catarra

Sample collection time: No time specified

Parameter	Completeness/Methodology	Pre-filter Holding Time		Total Holding Time		Lab Method Blanks/Reporting Limit		Surrogate Recovery (% Recovery)		Matrix Spikes (% Recovery)		Lab Duplicates (RPD) ^b		Field Duplicates (RSDp)		Rinsate Blanks		Lab Control Standard (% Recovery)		Action
		Reported	Goal	Reported	Goal	Reported	Goal	Reported	Goal	Reported	Goal	Reported	Goal	Reported	Goal	Reported	Goal	Reported	Goal	
Total Suspended Solids	SM 2540D	NA	NA	2	7dy	OK	≤1.0 mg/L	NA	NA	NA	NA	OK (LCS/LCS D + dup)	≤20%or±2xRL	NA	≤35%	NA	≤2xRL	OK	±20	None
Hardness ^a	SM2340-C	NA	NA	8	6mo	OK	≤1.0mg/L ^a	NA	NA	OK	±25	OK	≤20%or±2xRL	NA	≤35%	NA	≤2xRL	OK	±20	None
DOC	EPA 9060	OK	15min‡	2	28 dy	OK	≤1.5mg/L	NA	NA	OK	±25	OK	≤20%or±2xRL	NA	≤35%	NA	≤2xRL	OK (SRM)	±20	None
Total Phosphorus	EPA 365.2	NA	NA	7	28dy	OK	≤0.008mg/L	NA	NA	OK	±25	OK	≤20%or±2xRL	NA	≤35%	NA	≤2xRL	OK (SRM)	±20	None
Ortho P	EPA 365.2	OK	15min‡	<1	2dy	OK	≤0.004mg/L	NA	NA	OK	±25	OK	≤20%or±2xRL	NA	≤35%	NA	≤2xRL	OK (SRM)	±20	None
TKN	EPA 351.2	NA	NA	9	28dy	OK	≤1.0 mg/L	NA	NA	OK	±25	OK (LCS/LCS D + dup)	≤20%or±2xRL	NA	≤35%	NA	≤2xRL	OK (LCS + SRM)	±20	None
Nitrate + Nitrite	EPA 353.2	OK	48hr	7	28dy	OK	≤0.01 mg/L	NA	NA	OK	±25	OK	≤20%or±2xRL	NA	≤35%	NA	≤2xRL	OK (SRM)	±20	"J" flag all results due to final rinsate blank.
Sulfate	EPA375-2	NA	NA		28dy		≤2.0 mg/L		NA		±25		≤20%or±2xRL		≤35%	NA	≤2xRL	OK (SRM)	±20	Not Reported
Chloride	EPA 325.2	NA	NA		28dy		≤1.0 mg/L		NA		±25		≤20%or±2xRL		≤35%	NA	≤2xRL	OK (SRM)	±20	Not Reported
Alkalinity	SM 2320	NA	NA	1	14dy	NA	≤1.0mg/L	NA	NA	NA	NA	OK	≤20%or±2xRL	NA	≤35%	NA	≤2xRL	OK (SRM)	±20	None
Total metals	EPA 200.8 / 6010C	NA	NA	6,8	180 dy	OK	0.1 – 50 µg/L	NA	NA	OK	±25	Cu RPD=27 (-0099)	≤20%or±2xRL	NA	≤35%	NA	≤2xRL	OK	±20	Rinsate blanks for Ca and Zn Ok – less than 2xRL. For Cu "J" flag all results. Dup Cu RPD=27, "J" flag - 0099 only.
Dissolved metals	EPA 200.8 / 6010C	OK	15min‡ (dissolved)		180 dy	OK	0.1-500 µg/L	NA	NA	OK	±25	OK	≤20%or±2xRL	NA	≤35%	NA	≤2xRL	OK	±20	Rinsate blanks for Zn Ok – less than 2XRL. For Cu "J" flag -0096 thru -0104.

^a as CaCO3

^b The relative percent difference (RPD) must be less than or equal to the indicated percentage for values that are greater than 5 times the reporting limit. RPD must be within ±2 times the reporting limit for values that are less than or equal to 5 times the reporting limit.

^c EPA requires field filtering within 15 min of collection of the last aliquot. This is generally not feasible with flow weighted composite sampling.

Table D-7. Data Quality Assurance Worksheet: Flushing Experiments (8-6-14 Flushing Event)

Columns: 33,42,79,12,21,72,52,52,83,22,51,82

Laboratory/Parameters: pH, TSS, DOC, total and dissolved metals, TP, Ortho-P, TKN, NO3-NO2, BLM ions (see QAPP)

Sample Date/Sample ID/Lab ID: 8-6-14 /S14-05757-0106 thru S14-05757-0118/ARI YV14

Entry date 10/2/2014

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Checked by: Gina Catarra

Sample collection time: No time specified

Parameter	Completeness/Methodology	Pre-filter Holding Time		Total Holding Time		Lab Method Blanks/Reporting Limit		Surrogate Recovery (% Recovery)		Matrix Spikes (% Recovery)		Lab Duplicates (RPD) ^b		Field Duplicates (RSDp)		Rinsate Blanks		Lab Control Standard (% Recovery)		Action
		Reported	Goal	Reported	Goal	Reported	Goal	Reported	Goal	Reported	Goal	Reported	Goal	Reported	Goal	Reported	Goal	Reported	Goal	
Total Suspended Solids	SM 2540D	NA	NA	1	7dy	OK	≤1.0 mg/L	NA	NA	NA	NA	OK (LCS/LCS D + dup)	≤20%or±2xRL	NA	≤35%	NA	≤2xRL	OK	±20	None
Hardness ^a	SM2340-C	NA	NA	5	6mo	OK	≤1.0mg/L ^a	NA	NA	OK	±25	OK	≤20%or±2xRL	NA	≤35%	NA	≤2xRL	OK	±20	None
DOC	EPA 9060	OK	15min‡	1	28 dy	OK	≤1.5mg/L	NA	NA	OK	±25	OK	≤20%or±2xRL	NA	≤35%	NA	≤2xRL	OK (SRM)	±20	None
Total Phosphorus	EPA 365.2	NA	NA	13	28dy	OK	≤0.008mg/L	NA	NA	OK	±25	OK	≤20%or±2xRL	NA	≤35%	NA	≤2xRL	OK (SRM)	±20	None
Ortho P	EPA 365.2	OK	15min‡	1	2dy	OK	≤0.004mg/L	NA	NA	OK	±25	OK	≤20%or±2xRL	NA	≤35%	NA	≤2xRL	OK (SRM)	±20	None
TKN	EPA 351.2	NA	NA	8	28dy	OK	≤1.0 mg/L	NA	NA	OK	±25	OK (LCS/LCS D + dup)	≤20%or±2xRL	NA	≤35%	NA	≤2xRL	OK (LCS + SRM)	±20	None
Nitrate + Nitrite	EPA 353.2	OK	48hr	1	28dy	OK	≤0.01 mg/L	NA	NA	OK	±25	OK	≤20%or±2xRL	NA	≤35%	NA	≤2xRL	OK (SRM)	±20	"J" results -0106 thru -0118 due to final rinsate blank.
Sulfate	EPA375-2	NA	NA		28dy		≤2.0 mg/L		NA		±25		≤20%or±2xRL		≤35%	NA	≤2xRL	OK (SRM)	±20	Not Requested
Chloride	EPA 325.2	NA	NA		28dy		≤1.0 mg/L		NA		±25		≤20%or±2xRL		≤35%	NA	≤2xRL	OK (SRM)	±20	Not Requested
Alkalinity	SM 2320	NA	NA		14dy		≤1.0mg/L		NA		NA		≤20%or±2xRL		≤35%	NA	≤2xRL	OK (SRM)	±20	Not Requested
Total metals	EPA 200.8 / 6010C	NA	NA	5	180 dy	OK	0.1 – 50 µg/L	NA	NA	OK	±25	OK	≤20%or±2xRL	NA	≤35%	NA	≤2xRL	OK	±20	Rinsate blanks for Ca and Zn Ok – less than 2xRL. For Cu "J" flag all results.
Dissolved metals	EPA 200.8 / 6010C	OK	15min‡ (dissolved)	5	180 dy	OK	0.1-500 µg/L	NA	NA	OK	±25	OK	≤20%or±2xRL	NA	≤35%	NA	≤2xRL	OK	±20	Rinsate blanks for Zn Ok – less than 2xRL. For Cu "J" flag -0106 thru -0114.

^a as CaCO3

^b The relative percent difference (RPD) must be less than or equal to the indicated percentage for values that are greater than 5 times the reporting limit. RPD must be within ±2 times the reporting limit for values that are less than or equal to 5 times the reporting limit.

^c EPA requires field filtering within 15 min of collection of the last aliquot. This is generally not feasible with flow weighted composite sampling.

Table D-8. Data Quality Assurance Worksheet: Flushing Experiments (8-7-14 Flushing Event)

Columns: 11,32,63,31,61,62,13,43,71,41,23,81

Laboratory/Parameters: pH, TSS, DOC, total and dissolved metals, TP, Ortho-P, TKN, NO3-NO2, BLM ions (see QAPP)

Sample Date/Sample ID/Lab ID: 8-7-14 /S14-05757-0119 thru S14-05757-0131/ARI YV35

Entry date 10/2/2014

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Checked by: Gina Catarra

Sample collection time: No time specified

Parameter	Completeness/Methodology	Pre-filter Holding Time		Total Holding Time		Lab Method Blanks/Reporting Limit		Surrogate Recovery (% Recovery)		Matrix Spikes (% Recovery)		Lab Duplicates (RPD) ^b		Field Duplicates (RSDp)		Rinsate Blanks		Lab Control Standard (% Recovery)		Action
		Reported	Goal	Reported	Goal	Reported	Goal	Reported	Goal	Reported	Goal	Reported	Goal	Reported	Goal	Reported	Goal	Reported	Goal	
Total Suspended Solids	SM 2540D	NA	NA	1	7dy	OK	≤1.0 mg/L	NA	NA	NA	NA	OK (LCS/LCS D + dup)	≤20%or±2xRL	NA	≤35%	NA	≤2xRL	OK	±20	None
PSD	TAPE App F	NA	NA		7dy		0.1microns	NA	NA	NA	NA		≤20%	NA	≤35%		≤2xRL		NA	Not Requested
Hardness ^a	SM2340-C	NA	NA	11	6mo	OK	≤1.0mg/L ^a	NA	NA	OK	±25	OK	≤20%or±2xRL	NA	≤35%	NA	≤2xRL	OK	±20	None
DOC	EPA 9060	OK	15min‡	<1	28 dy	OK	≤1.5mg/L	NA	NA	OK	±25	OK	≤20%or±2xRL	NA	≤35%	NA	≤2xRL	OK (SRM)	±20	None
Total Phosphorus	EPA 365.2	NA	NA	12	28dy	OK	≤0.008mg/L	NA	NA	OK	±25	DUP = 22% meets lab QC limits	≤20%or±2xRL	NA	≤35%	NA	≤2xRL	OK (SRM)	±20	None
Ortho P	EPA 365.2	OK	15min‡	1	2dy	OK	≤0.004mg/L	NA	NA	OK	±25	OK	≤20%or±2xRL	NA	≤35%	NA	≤2xRL	OK (SRM)	±20	None
TKN	EPA 351.2	NA	NA	6	28dy	OK	≤1.0 mg/L	NA	NA	OK	±25	OK (LCS/LCS D + dup)	≤20%or±2xRL	NA	≤35%	NA	≤2xRL	OK (LCS + SRM)	±20	None
Nitrate + Nitrite	EPA 353.2	OK	48hr	1	28dy	OK	≤0.01 mg/L	NA	NA	OK	±25	OK	≤20%or±2xRL	NA	≤35%	NA	≤2xRL	OK (SRM)	±20	"J" results for -0119 thru -0131 due to final rinsate blanks.
Sulfate	EPA375-2	NA	NA		28dy		≤2.0 mg/L		NA		±25		≤20%or±2xRL		≤35%	NA	≤2xRL	OK (SRM)	±20	Not Requested
Chloride	EPA 325.2	NA	NA		28dy		≤1.0 mg/L		NA		±25		≤20%or±2xRL		≤35%	NA	≤2xRL	OK (SRM)	±20	Not Requested
Alkalinity	SM 2320	NA	NA		14dy		≤1.0mg/L		NA		NA		≤20%or±2xRL		≤35%	NA	≤2xRL	OK (SRM)	±20	Not Requested
Total metals	EPA 200.8 / 6010C	NA	NA	6,11	180 dy	ZN=12 (RL=4)	0.1 – 50 µg/L	NA	NA	OK	±25	OK	≤20%or±2xRL	NA	≤35%	NA	≤2xRL	OK	±20	ZN in MB okay – all samples ND for AN. Rinsate blanks for Ca and Zn Ok – less than 2xRL. For Cu "J" flag -0119 thru -0130.
Dissolved metals	EPA 200.8 / 6010C	OK	15min‡ (dissolved)	6	180 dy	OK	0.1-500 µg/L	NA	NA	OK	±25	OK	≤20%or±2xRL	NA	≤35%	NA	≤2xRL	OK	±20	Rinsate blanks for Zn Ok – less than 2XRL. For Cu "J" flag -0128 thru -0130.

^a as CaCO3

^b The relative percent difference (RPD) must be less than or equal to the indicated percentage for values that are greater than 5 times the reporting limit. RPD must be within ±2 times the reporting limit for values that are less than or equal to 5 times the reporting limit.

^c EPA requires field filtering within 15 min of collection of the last aliquot. This is generally not feasible with flow weighted composite sampling.

Table D-9. Data Quality Assurance Worksheet: Flushing Experiments (8-13-14 Rinsate Blanks)

Columns: NA (Rinsate Blanks)

Entry date 10/2/2014

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Laboratory/Parameters: pH, TSS, DOC, total and dissolved metals, TP, Ortho-P, TKN, NO3-NO2, BLM ions (see QAPP)

Checked by: Gina Catarra

Sample Date/Sample ID/Lab ID: 8-13-14 /S14-05757-0132 and S14-05757-0133/ARI YW14 (Rinsate Blanks)

Sample collection time: No time specified

Parameter	Completeness/Methodology	Pre-filter Holding Time		Total Holding Time		Lab Method Blanks/Reporting Limit		Surrogate Recovery (% Recovery)		Matrix Spikes (% Recovery)		Lab Duplicates (RPD) ^b		Field Duplicates (RSDp)		Rinsate Blanks		Lab Control Standard (% Recovery)		Action
		Reported	Goal	Reported	Goal	Reported	Goal	Reported	Goal	Reported	Goal	Reported	Goal	Reported	Goal	Reported	Goal	Reported	Goal	
Total Suspended Solids	SM 2540D	NA	NA	1	7dy	OK	≤1.0 mg/L	NA	NA	NA	NA	OK (LCS/LCS D + dup)	≤20%or±2xRL	NA	≤35%	ND	≤2xRL	OK	±20	None
pH	EPA 150.1	NA	NA	OK	15 min		NA	NA	NA	NA	NA	OK	≤10%	NA	≤35%	5.00/4.96	NA	OK	NA	None
Hardness ^a	SM2340-C	NA	NA	5	6mo	OK	≤1.0mg/L ^a	NA	NA	OK	±25	OK	≤20%or±2xRL	NA	≤35%		≤2xRL	OK	±20	None
DOC	EPA 9060	OK	15min [‡]	<1	28 dy	OK	≤1.5mg/L	NA	NA	OK	±25	OK	≤20%or±2xRL	NA	≤35%	ND	≤2xRL	OK (SRM)	±20	None
Total Phosphorus	EPA 365.2	NA	NA	12	28dy	OK	≤0.008mg/L	NA	NA	OK	±25	DUP = 22% meets lab QC limits	≤20%or±2xRL	NA	≤35%	ND	≤2xRL	OK (SRM)	±20	None
Ortho P	EPA 365.2	OK	15min [‡]	1	2dy	OK	≤0.004mg/L	NA	NA	OK	±25	OK	≤20%or±2xRL	NA	≤35%	ND	≤2xRL	OK (SRM)	±20	None
TKN	EPA 351.2	NA	NA	6	28dy	OK	≤1.0 mg/L	NA	NA	OK	±25	OK (LCS/LCS D + dup)	≤20%or±2xRL	NA	≤35%	ND	≤2xRL	OK (LCS + SRM)	±20	None
Nitrate + Nitrite	EPA 353.2	OK	48hr	1	28dy	OK	≤0.01 mg/L	NA	NA	OK	±25	OK	≤20%or±2xRL	NA	≤35%	0.025/0.059	≤2xRL	OK (SRM)	±20	Rinsate blank out of control.
Sulfate	EPA375-2	NA	NA		28dy		≤2.0 mg/L		NA		±25		≤20%or±2xRL		≤35%		≤2xRL	OK (SRM)	±20	Not Requested
Chloride	EPA 325.2	NA	NA		28dy		≤1.0 mg/L		NA		±25		≤20%or±2xRL		≤35%		≤2xRL	OK (SRM)	±20	Not Requested
Alkalinity	SM 2320	NA	NA		14dy		≤1.0mg/L		NA		NA		≤20%or±2xRL		≤35%		≤2xRL	OK (SRM)	±20	Not Requested
Total metals	EPA 200.8 / 6010C	NA	NA	2,5	180 dy	OK	0.1 – 50 µg/L	NA	NA	OK	±25	OK	≤20%or±2xRL	NA	≤35%	Zn – 5/5	≤2xRL	OK	±20	Rinsate blanks for Zn Ok – less than 2xRL.
Dissolved metals	EPA 200.8 / 6010C	OK	15min [‡] (dissolved)	1	180 dy	OK	0.1-500 µg/L	NA	NA	OK	±25	OK	≤20%or±2xRL	NA	≤35%	Zn – 4/ND	≤2xRL	OK	±20	Rinsate blank for Zn Ok – less than 2XRL.

^a as CaCO3

^b The relative percent difference (RPD) must be less than or equal to the indicated percentage for values that are greater than 5 times the reporting limit. RPD must be within ±2 times the reporting limit for values that are less than or equal to 5 times the reporting limit.

^c EPA requires field filtering within 15 min of collection of the last aliquot. This is generally not feasible with flow weighted composite sampling.

Table D-10. Data Quality Assurance Worksheet: Dosing Experiments (9-25-14 Water)

Columns: 33,42,73,12,21,72,52,53,83,22,51,82

Laboratory/Parameters: TSS, hardness, DOC, total and dissolved metals, TP, Ortho-P, TKN, NO3-NO2, BLM ions (see QAPP)

Sample Date/Sample ID/Lab ID: 9-25-14 /S14-05757-0135 thru S14-05757-0148/ARI ZB73

Entry date 12/2/2014

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Checked by: Gina Catarra

Sample collection time: No time specified

Parameter	Completeness/ Methodology	Pre-filter Holding Time		Total Holding Time		Lab Method Blanks/ Reporting Limit		Surrogate Recovery (% Recovery)		Matrix Spikes (% Recovery)		Lab Duplicates (RPD) ^b		Field Duplicates (RSDp)		Rinsate Blanks		Lab Control Standard (% Recovery)		Action
		Reported	Goal	Reported	Goal	Reported	Goal	Reported	Goal	Reported	Goal	Reported	Goal	Reported	Goal	Reported	Goal	Reported	Goal	
Total Suspended Solids	SM 2540D	NA	NA	1	7dy	OK	≤1.0 mg/L	NA	NA	NA	NA	OK (LCS/LCSD + dup)	≤20%or±2xRL	NA	≤35%	OK	≤2xRL	OK	±20	None
PSD	TAPE App F	NA	NA		7dy		0.1microns	NA	NA	NA	NA		≤20%	NA	≤35%		≤2xRL		NA	Not Requested
Hardness ^a	SM2340-C	NA	NA	11	6mo	OK	≤1.0mg/L ^a	NA	NA	OK	±25	OK	≤20%or±2xRL	NA	≤35%	OK	≤2xRL	OK	±20	None
DOC	EPA 9060	OK	15min‡	5	28 dy	OK	≤1.5mg/L	NA	NA	OK	±25	OK	≤20%or±2xRL	NA	≤35%	OK	≤2xRL	OK (SRM)	±20	None
Total Phosphorus	EPA 365.2	NA	NA	5	28dy	OK	≤0.008mg/L	NA	NA	OK	±25	OK	≤20%or±2xRL	NA	≤35%	OK	≤2xRL	OK (SRM)	±20	None
Ortho P	EPA 365.2	OK	15min‡	1	2dy	OK	≤0.004mg/L	NA	NA	NA	±25	OK	≤20%or±2xRL	NA	≤35%	OK	≤2xRL	OK (SRM)	±20	None
TKN	EPA 351.2	NA	NA	<1	28dy	OK	≤1.0 mg/L	NA	NA	OK	±25	OK (LCS/LCSD + dup)	≤20%or±2xRL	NA	≤35%	OK	≤2xRL	OK (LCS + SRM)	±20	None
Nitrate+ nitrite	EPA 353.2	OK	48hr	1	28dy	OK	≤0.01 mg/L	NA	NA	OK	±25	OK	≤20%or±2xRL	NA	≤35%	0.013 (all samples <5X)	≤2xRL	OK (SRM)	±20	None
Sulfate	EPA375-2	NA	NA	13	28dy	OK	≤2.0 mg/L	NA	NA	OK	±25	OK	≤20%or±2xRL	NA	≤35%	OK	≤2xRL	OK (SRM)	±20	None
Chloride	EPA 325.2	NA	NA	9	28dy	OK	≤1.0 mg/L	NA	NA	OK	±25	OK	≤20%or±2xRL	NA	≤35%	OK	≤2xRL	OK (SRM)	±20	None
Alkalinity	SM 2320	NA	NA	1	14dy	OK	≤1.0mg/L	NA	NA	NA	NA	OK	≤20%or±2xRL	NA	≤35%	OK	≤2xRL	OK (SRM)	±20	None
Total metals	EPA 200.8 / 6010C	NA	NA	7	180 dy	OK	0.1 – 50 µg/L	NA	NA	OK	±25	OK	≤20%or±2xRL	NA	≤35%	OK	≤2xRL	OK	±20	None
Dissolved metals	EPA 200.8 / 6010C	OK	15min‡ (dissolved)	5,7	180 dy	OK	0.1-500 µg/L	NA	NA	OK	±25	OK	≤20%or±2xRL	NA	≤35%	OK	≤2xRL	OK	±20	None

^a as CaCO3

^b The relative percent difference (RPD) must be less than or equal to the indicated percentage for values that are greater than 5 times the reporting limit. RPD must be within ±2 times the reporting limit for values that are less than or equal to 5 times the reporting limit.

^c EPA requires field filtering within 15 min of collection of the last aliquot. This is generally not feasible with flow weighted composite sampling.

Table D-11. Data Quality Assurance Worksheet: Dosing Experiments (9-26-14 Water)

Columns: 11,32,63,31,61,62,13,43,71,41,23,81

Laboratory/Parameters: TSS, hardness, DOC, total and dissolved metals, TP, Ortho-P, TKN, NO3-NO2, BLM ions (see QAPP)

Sample Date/Sample ID/Lab ID: 9-26-14 /S14-05757-0149 thru S14-05757-0162/ARI ZB93

Entry date 12/2/2014

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Checked by: Gina Catarra

Sample collection time: No time specified

Parameter	Completeness/Methodology	Pre-filter Holding Time		Total Holding Time		Lab Method Blanks/Reporting Limit		Surrogate Recovery (% Recovery)		Matrix Spikes (% Recovery)		Lab Duplicates (RPD) ^b		Field Duplicates (RSDp)		Rinsate Blanks		Lab Control Standard (% Recovery)		Action
		Reported	Goal	Reported	Goal	Reported	Goal	Reported	Goal	Reported	Goal	Reported	Goal	Reported	Goal	Reported	Goal	Reported	Goal	
Total Suspended Solids	SM 2540D	NA	NA	3	7dy	OK	≤1.0 mg/L	NA	NA	NA	NA	OK (LCS/LCSD + dup)	≤20%or±2xRL	NA	≤35%	OK	≤2xRL	OK	±20	None
PSD	TAPE App F	NA	NA		7dy		0.1microns	NA	NA	NA	NA		≤20%	NA	≤35%		≤2xRL		NA	Not Requested
Hardness ^a	SM2340-C	NA	NA	7	6mo	OK	≤1.0mg/L ^a	NA	NA	OK	±25	OK	≤20%or±2xRL	NA	≤35%	OK	≤2xRL	OK	±20	None
DOC	EPA 9060	OK	15min‡	3	28 dy	OK	≤1.5mg/L	NA	NA	OK	±25	OK	≤20%or±2xRL	NA	≤35%	OK	≤2xRL	OK (SRM)	±20	None
Total Phosphorus	EPA 365.2	NA	NA	3	28dy	OK	≤0.008mg/L	NA	NA	OK	±25	OK	≤20%or±2xRL	NA	≤35%	OK	≤2xRL	OK (SRM)	±20	None
Ortho P	EPA 365.2	OK	15min‡	<1	2dy	OK	≤0.004mg/L	NA	NA	OK	±25	OK	≤20%or±2xRL	NA	≤35%	OK	≤2xRL	OK (SRM)	±20	None
TKN	EPA 351.2	NA	NA	3	28dy	OK	≤1.0 mg/L	NA	NA	OK	±25	OK (LCS/LCSD + dup)	≤20%or±2xRL	NA	≤35%	OK	≤2xRL	OK (LCS + SRM)	±20	None
Nitrate + Nitrite	EPA 353.2	OK	48hr	<1	28dy	OK	≤0.01 mg/L	NA	NA	OK	±25	OK	≤20%or±2xRL	NA	≤35%	0.013 (<2xRL)	≤2xRL	OK (SRM)	±20	None
Sulfate	EPA375-2	NA	NA	13	28dy	OK	≤2.0 mg/L	NA	NA	OK	±25	OK	≤20%or±2xRL	NA	≤35%	OK	≤2xRL	OK (SRM)	±20	None
Chloride	EPA 325.2	NA	NA	8	28dy	OK	≤1.0 mg/L	NA	NA	OK	±25	OK	≤20%or±2xRL	NA	≤35%	OK	≤2xRL	OK (SRM)	±20	None
Alkalinity	SM 2320	NA	NA	3	14dy	OK	≤1.0mg/L	NA	NA	NA	NA	OK	≤20%or±2xRL	NA	≤35%	OK	≤2xRL	OK (SRM)	±20	None
Total metals	EPA 200.8 / 6010C	NA	NA	8	180 dy	OK	0.1 – 50 µg/L	NA	NA	OK	±25	OK	≤20%or±2xRL	NA	≤35%	OK	≤2xRL	OK	±20	None
Dissolved metals	EPA 200.8 / 6010C	OK	15min‡ (dissolved)	7,8	180 dy	OK	0.1-500 µg/L	NA	NA	OK	±25	OK	≤20%or±2xRL	NA	≤35%	OK	≤2xRL	OK	±20	None

^a as CaCO3

^b The relative percent difference (RPD) must be less than or equal to the indicated percentage for values that are greater than 5 times the reporting limit. RPD must be within ±2 times the reporting limit for values that are less than or equal to 5 times the reporting limit.

^c EPA requires field filtering within 15 min of collection of the last aliquot. This is generally not feasible with flow weighted composite sampling.

Table D-12. Data Quality Assurance Worksheet: Dosing Experiments (10-1-14 Water)

Columns: 33,42,73,12,21,72,52,53,83,22,51,82

Laboratory/Parameters: TSS, hardness, DOC, total and dissolved metals, TP, Ortho-P, TKN, NO3-NO2, BLM ions (see QAPP)

Sample Date/Sample ID/Lab ID: 10-1-14 /S14-05757-0163 thru S14-05757-0175/ARI ZC76

Entry date 12/2/2014

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Checked by: Gina Catarra

Sample collection time: No time specified

Parameter	Completeness/ Methodology	Pre-filter Holding Time		Total Holding Time		Lab Method Blanks/ Reporting Limit		Surrogate Recovery (% Recovery)		Matrix Spikes (% Recovery)		Lab Duplicates (RPD) ^b		Field Duplicates (RSDp)		Rinsate Blanks		Lab Control Standard (% Recovery)		Action
		Reported	Goal	Reported	Goal	Reported	Goal	Reported	Goal	Reported	Goal	Reported	Goal	Reported	Goal	Reported	Goal	Reported	Goal	
Total Suspended Solids	SM 2540D	NA	NA	1	7dy	OK	≤1.0 mg/L	NA	NA	NA	NA	OK (LCS/LCSD + dup)	≤20%or±2xRL	NA	≤35%	OK	≤2xRL	OK	±20	None
PSD	TAPE App F	NA	NA		7dy		0.1microns	NA	NA	NA	NA		≤20%	NA	≤35%		≤2xRL		NA	Not Requested
Hardness ^a	SM2340-C	NA	NA	6	6mo	OK	≤1.0mg/L ^a	NA	NA	OK	±25	OK	≤20%or±2xRL	NA	≤35%	OK	≤2xRL	OK	±20	None
DOC	EPA 9060	OK	15min [‡]	<1	28 dy	OK	≤1.5mg/L	NA	NA	OK	±25	OK	≤20%or±2xRL	NA	≤35%	OK	≤2xRL	OK (SRM)	±20	None
Total Phosphorus	EPA 365.2	NA	NA	3	28dy	OK	≤0.008mg/L	NA	NA	OK	±25	OK	≤20%or±2xRL	NA	≤35%	OK	≤2xRL	OK (SRM)	±20	None
Ortho P	EPA 365.2	OK	15min [‡]	2	2dy	0.004 (OK)	≤0.004mg/L	NA	NA	NA	±25	OK	≤20%or±2xRL	NA	≤35%	OK	≤2xRL	OK (SRM)	±20	Flag -0166 "J" due to MB contamination
TKN	EPA 351.2	NA	NA	2	28dy	OK	≤1.0 mg/L	NA	NA	OK	±25	OK (LCS/LCSD + dup)	≤20%or±2xRL	NA	≤35%	OK	≤2xRL	OK (LCS + SRM)	±20	None
Nitrate + Nitrite	EPA 353.2	OK	48hr	1	28dy	OK	≤0.01 mg/L	NA	NA	OK	±25	OK	≤20%or±2xRL	NA	≤35%	0.013 (all samples <5X)	≤2xRL	OK (SRM)	±20	None
Sulfate	EPA375-2	NA	NA		28dy		≤2.0 mg/L		NA		±25		≤20%or±2xRL		≤35%		≤2xRL		±20	Not requested
Chloride	EPA 325.2	NA	NA		28dy		≤1.0 mg/L		NA		±25		≤20%or±2xRL		≤35%		≤2xRL		±20	Not requested
Alkalinity	SM 2320	NA	NA		14dy		≤1.0mg/L		NA		NA		≤20%or±2xRL		≤35%		≤2xRL		±20	Not requested
Total metals	EPA 200.8 / 6010C	NA	NA	5	180 dy	OK	0.1 – 50 µg/L	NA	NA	OK	±25	OK	≤20%or±2xRL	NA	≤35%	OK	≤2xRL	OK	±20	None
Dissolved metals	EPA 200.8 / 6010C	OK	15min [‡] (dissolved)	5	180 dy	OK	0.1-500 µg/L	NA	NA	OK	±25	OK	≤20%or±2xRL	NA	≤35%	OK	≤2xRL	OK	±20	None

^a as CaCO₃

^b The relative percent difference (RPD) must be less than or equal to the indicated percentage for values that are greater than 5 times the reporting limit. RPD must be within ±2 times the reporting limit for values that are less than or equal to 5 times the reporting limit.

^c EPA requires field filtering within 15 min of collection of the last aliquot. This is generally not feasible with flow weighted composite sampling.

Table D-13. Data Quality Assurance Worksheet: Dosing Experiments (10-2-14 Water)

Columns: 11,32,63,31,61,62,13,43,71,41,23,81

Laboratory/Parameters: TSS, hardness, DOC, total and dissolved metals, TP, Ortho-P, TKN, NO3-NO2, BLM ions (see QAPP)

Sample Date/Sample ID/Lab ID: 10-2-14 /S14-05757-0176 thru S14-05757-0189/ARI ZC98, ZD08

Entry date 12/2/2014

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Checked by: Gina Catarra

Sample collection time: No time specified

Parameter	Completeness/ Methodology	Pre-filter Holding Time		Total Holding Time		Lab Method Blanks/ Reporting Limit		Surrogate Recovery (% Recovery)		Matrix Spikes (% Recovery)		Lab Duplicates (RPD) ^b		Field Duplicates (RSDp)		Rinsate Blanks		Lab Control Standard (% Recovery)		Action
		Reported	Goal	Reported	Goal	Reported	Goal	Reported	Goal	Reported	Goal	Reported	Goal	Reported	Goal	Reported	Goal	Reported	Goal	
Total Suspended Solids	SM 2540D	NA	NA	1	7dy	OK	≤1.0 mg/L	NA	NA	NA	NA	OK (LCS/LCSD + dup)	≤20%or±2xRL	NA	≤35%	OK	≤2xRL	OK	±20	None
PSD	TAPE App F	NA	NA		7dy		0.1microns	NA	NA	NA	NA		≤20%	NA	≤35%		≤2xRL		NA	Not Requested
Hardness ^a	SM2340-C	NA	NA	6,1	6mo	OK	≤1.0mg/L ^a	NA	NA	OK	±25	OK	≤20%or±2xRL	NA	≤35%	OK	≤2xRL	OK	±20	None
DOC	EPA 9060	OK	15min‡	1	28 dy	OK	≤1.5mg/L	NA	NA	OK	±25	OK	≤20%or±2xRL	NA	≤35%	OK	≤2xRL	OK (SRM)	±20	None
Total Phosphorus	EPA 365.2	NA	NA	3	28dy	OK	≤0.008mg/L	NA	NA	OK	±25	OK	≤20%or±2xRL	NA	≤35%	OK	≤2xRL	OK (SRM)	±20	None
Ortho P	EPA 365.2	OK	15min‡	1	2dy	OK	≤0.004mg/L	NA	NA	OK	±25	OK	≤20%or±2xRL	NA	≤35%	OK	≤2xRL	OK (SRM)	±20	None
TKN	EPA 351.2	NA	NA	1	28dy	OK	≤1.0 mg/L	NA	NA	OK	±25	OK (LCS/LCSD + dup)	≤20%or±2xRL	NA	≤35%	OK	≤2xRL	OK (LCS + SRM)	±20	None
Nitrate + Nitrite	EPA 353.2	OK	48hr	1	28dy	0.022 (-0189) OK	≤0.01 mg/L	NA	NA	OK	±25	OK	≤20%or±2xRL	NA	≤35%	0.013 (<2xRL)	≤2xRL	OK (SRM)	±20	None
Sulfate	EPA375-2	NA	NA		28dy		≤2.0 mg/L		NA		±25		≤20%or±2xRL		≤35%		≤2xRL		±20	Not Requested
Chloride	EPA 325.2	NA	NA		28dy		≤1.0 mg/L		NA		±25		≤20%or±2xRL		≤35%		≤2xRL		±20	Not Requested
Alkalinity	SM 2320	NA	NA		14dy		≤1.0mg/L		NA		NA		≤20%or±2xRL		≤35%		≤2xRL		±20	Not Requested
Total metals	EPA 200.8 / 6010C	NA	NA	6,1	180 dy	OK	0.1 – 50 µg/L	NA	NA	OK	±25	OK	≤20%or±2xRL	NA	≤35%	OK	≤2xRL	OK	±20	None
Dissolved metals	EPA 200.8 / 6010C	OK	15min‡ (dissolved)	6	180 dy	OK	0.1-500 µg/L	NA	NA	OK	±25	OK	≤20%or±2xRL	NA	≤35%	OK	≤2xRL	OK	±20	None

^a as CaCO3

^b The relative percent difference (RPD) must be less than or equal to the indicated percentage for values that are greater than 5 times the reporting limit. RPD must be within ±2 times the reporting limit for values that are less than or equal to 5 times the reporting limit.

^c EPA requires field filtering within 15 min of collection of the last aliquot. This is generally not feasible with flow weighted composite sampling.

Table D-14. Data Quality Assurance Worksheet: Dosing Experiments (10-15-14 Water)

Columns: 33,42,73,12,21,72,52,53,83,22,51,82

Laboratory/Parameters: TSS, hardness, DOC, total and dissolved metals, TP, Ortho-P, TKN, NO3-NO2, BLM ions (see QAPP)

Sample Date/Sample ID/Lab ID: 10-15-14 /S14-05757-0196 thru S14-05757-0208/ARI ZF22

Entry date 12/2/2014

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Checked by: Gina Catarra

Sample collection time: No time specified

Parameter	Completeness/Methodology	Pre-filter Holding Time		Total Holding Time		Lab Method Blanks/Reporting Limit		Surrogate Recovery (% Recovery)		Matrix Spikes (% Recovery)		Lab Duplicates (RPD) ^b		Field Duplicates (RSDp)		Rinsate Blanks		Lab Control Standard (% Recovery)		Action
		Reported	Goal	Reported	Goal	Reported	Goal	Reported	Goal	Reported	Goal	Reported	Goal	Reported	Goal	Reported	Goal	Reported	Goal	
Total Suspended Solids	SM 2540D	NA	NA	1	7dy	OK	≤1.0 mg/L	NA	NA	NA	NA	OK (LCS/LCSD + dup)	≤20%or±2xRL	NA	≤35%	OK	≤2xRL	OK	±20	None
PSD	TAPE App F	NA	NA		7dy		0.1microns	NA	NA	NA	NA		≤20%	NA	≤35%		≤2xRL		NA	Not Requested
Hardness ^a	SM2340-C	NA	NA	9	6mo	OK	≤1.0mg/L ^a	NA	NA	OK	±25	OK	≤20%or±2xRL	NA	≤35%	OK	≤2xRL	OK	±20	None
DOC	EPA 9060	OK	15min‡	7	28 dy	OK	≤1.5mg/L	NA	NA	OK	±25	OK	≤20%or±2xRL	NA	≤35%	OK	≤2xRL	OK (SRM)	±20	None
Total Phosphorus	EPA 365.2	NA	NA	2	28dy	OK	≤0.008mg/L	NA	NA	OK	±25	OK	≤20%or±2xRL	NA	≤35%	OK	≤2xRL	OK (SRM)	±20	None
Ortho P	EPA 365.2	OK	15min‡	1	2dy	OK	≤0.004mg/L	NA	NA	OK	±25	OK	≤20%or±2xRL	NA	≤35%	OK	≤2xRL	OK (SRM)	±20	None
TKN	EPA 351.2	NA	NA	9	28dy	OK	≤1.0 mg/L	NA	NA	OK	±25	OK (LCS/LCSD + dup)	≤20%or±2xRL	NA	≤35%	OK	≤2xRL	OK (LCS + SRM)	±20	None
Nitrate + Nitrite	EPA 353.2	OK	48hr	7	28dy	OK	≤0.01 mg/L	NA	NA	OK	±25	OK	≤20%or±2xRL	NA	≤35%	0.013 (all samples <5X)	≤2xRL	OK (SRM)	±20	None
Sulfate	EPA375-2	NA	NA		28dy		≤2.0 mg/L		NA		±25		≤20%or±2xRL		≤35%		≤2xRL		±20	Not requested
Chloride	EPA 325.2	NA	NA		28dy		≤1.0 mg/L		NA		±25		≤20%or±2xRL		≤35%		≤2xRL		±20	Not requested
Alkalinity	SM 2320	NA	NA		14dy		≤1.0mg/L		NA		NA		≤20%or±2xRL		≤35%		≤2xRL		±20	Not requested
Total metals	EPA 200.8 / 6010C	NA	NA	8,9	180 dy	OK	0.1 – 50 µg/L	NA	NA	OK	±25	OK	≤20%or±2xRL	NA	≤35%	OK	≤2xRL	OK	±20	None
Dissolved metals	EPA 200.8 / 6010C	OK	15min‡ (dissolved)	7	180 dy	OK	0.1-500 µg/L	NA	NA	OK	±25	OK	≤20%or±2xRL	NA	≤35%	OK	≤2xRL	OK	±20	None

^a as CaCO3

^b The relative percent difference (RPD) must be less than or equal to the indicated percentage for values that are greater than 5 times the reporting limit. RPD must be within ±2 times the reporting limit for values that are less than or equal to 5 times the reporting limit.

^c EPA requires field filtering within 15 min of collection of the last aliquot. This is generally not feasible with flow weighted composite sampling.

Table D-15. Data Quality Assurance Worksheet: Dosing Experiments (10-16-14 Water)

Columns: 11,32,63,31,61,62,13,43,71,41,23,81

Laboratory/Parameters: TSS, hardness, DOC, total and dissolved metals, TP, Ortho-P, TKN, NO3-NO2, BLM ions (see QAPP)

Sample Date/Sample ID/Lab ID: 10-16-14 /S14-05757-0209 thru S14-05757-0221/ARI ZF53 / 10-22-14 / S14-05757-0223 / ZG66

Entry date 12/2/2014

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Checked by: Gina Catarra

Sample collection time: No time specified

Parameter	Completeness/Methodology	Pre-filter Holding Time		Total Holding Time		Lab Method Blanks/Reporting Limit		Surrogate Recovery (% Recovery)		Matrix Spikes (% Recovery)		Lab Duplicates (RPD) ^b		Field Duplicates (RSDp)		Rinsate Blanks		Lab Control Standard (% Recovery)		Action
		Reported	Goal	Reported	Goal	Reported	Goal	Reported	Goal	Reported	Goal	Reported	Goal	Reported	Goal	Reported	Goal	Reported	Goal	
Total Suspended Solids	SM 2540D	NA	NA	1	7dy	OK	≤1.0 mg/L	NA	NA	NA	NA	OK (LCS/LCSD + dup)	≤20%or±2xRL	NA	≤35%	OK	≤2xRL	OK	±20	None
PSD	TAPE App F	NA	NA		7dy		0.1microns	NA	NA	NA	NA		≤20%	NA	≤35%		≤2xRL		NA	Not Requested
Hardness ^a	SM2340-C	NA	NA	8,6	6mo	OK	≤1.0mg/L ^a	NA	NA	OK	±25	OK	≤20%or±2xRL	NA	≤35%	OK	≤2xRL	OK	±20	None
DOC	EPA 9060	OK	15min [‡]	4,2	28 dy	OK	≤1.5mg/L	NA	NA	OK	±25	OK	≤20%or±2xRL	NA	≤35%	OK	≤2xRL	OK (SRM)	±20	None
Total Phosphorus	EPA 365.2	NA	NA	1	28dy	OK	≤0.008mg/L	NA	NA	OK	±25	OK	≤20%or±2xRL	NA	≤35%	OK	≤2xRL	OK (SRM)	±20	None
Ortho P	EPA 365.2	OK	15min [‡]	<1,2	2dy	OK	≤0.004mg/L	NA	NA	OK	±25	OK	≤20%or±2xRL	NA	≤35%	OK	≤2xRL	OK (SRM)	±20	None
TKN	EPA 351.2	NA	NA	8,2	28dy	OK	≤1.0 mg/L	NA	NA	OK	±25	OK (LCS/LCSD + dup)	≤20%or±2xRL	NA	≤35%	OK	≤2xRL	OK (LCS + SRM)	±20	None
Nitrate + Nitrite	EPA 353.2	OK	48hr	6,2	28dy	OK	≤0.01 mg/L	NA	NA	OK	±25	OK	≤20%or±2xRL	NA	≤35%	0.013 (<2xRL)	≤2xRL	OK (SRM)	±20	None
Sulfate	EPA375-2	NA	NA		28dy		≤2.0 mg/L		NA		±25		≤20%or±2xRL		≤35%		≤2xRL		±20	Not Requested
Chloride	EPA 325.2	NA	NA		28dy		≤1.0 mg/L		NA		±25		≤20%or±2xRL		≤35%		≤2xRL		±20	Not Requested
Alkalinity	SM 2320	NA	NA		14dy		≤1.0mg/L		NA		NA		≤20%or±2xRL		≤35%		≤2xRL		±20	Not Requested
Total metals	EPA 200.8 / 6010C	NA	NA	6,5	180 dy	OK	0.1 – 50 µg/L	NA	NA	OK	±25	OK	≤20%or±2xRL	NA	≤35%	OK	≤2xRL	OK	±20	None
Dissolved metals	EPA 200.8 / 6010C	OK	15min [‡] (dissolved)	6,5	180 dy	OK	0.1-500 µg/L	NA	NA	OK	±25	OK	≤20%or±2xRL	NA	≤35%	OK	≤2xRL	OK	±20	None

^a as CaCO3

^b The relative percent difference (RPD) must be less than or equal to the indicated percentage for values that are greater than 5 times the reporting limit. RPD must be within ±2 times the reporting limit for values that are less than or equal to 5 times the reporting limit.

^c EPA requires field filtering within 15 min of collection of the last aliquot. This is generally not feasible with flow weighted composite sampling.

Table D-16. Data Quality Assurance Worksheet: Dosing Experiments (10-29-14 Water)

Columns: 33,42,73,12,21,72,52,53,83,22,51,82

Laboratory/Parameters: TSS, hardness, DOC, total and dissolved metals, TP, Ortho-P, TKN, NO3-NO2, BLM ions (see QAPP)

Sample Date/Sample ID/Lab ID: 10-29-14 /S14-05757-0231 thru S14-05757-0243/ARI ZH77

Entry date 12/2/2014

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Checked by: Gina Catarra

Sample collection time: No time specified

Parameter	Completeness/Methodology	Pre-filter Holding Time		Total Holding Time		Lab Method Blanks/Reporting Limit		Surrogate Recovery (% Recovery)		Matrix Spikes (% Recovery)		Lab Duplicates (RPD) ^b		Field Duplicates (RSDp)		Rinsate Blanks		Lab Control Standard (% Recovery)		Action
		Reported	Goal	Reported	Goal	Reported	Goal	Reported	Goal	Reported	Goal	Reported	Goal	Reported	Goal	Reported	Goal	Reported	Goal	
Total Suspended Solids	SM 2540D	NA	NA	1	7dy	OK	≤1.0 mg/L	NA	NA	NA	NA	OK (LCS/LCSD + dup)	≤20%or±2xRL	NA	≤35%	OK	≤2xRL	OK	±20	None
PSD	TAPE App F	NA	NA		7dy		0.1microns	NA	NA	NA	NA		≤20%	NA	≤35%		≤2xRL		NA	Not Requested
Hardness ^a	SM2340-C	NA	NA	6	6mo	OK	≤1.0mg/L ^a	NA	NA	OK	±25	OK	≤20%or±2xRL	NA	≤35%	OK	≤2xRL	OK	±20	None
DOC	EPA 9060	OK	15min [‡]	1	28 dy	OK	≤1.5mg/L	NA	NA	OK	±25	OK	≤20%or±2xRL	NA	≤35%	OK	≤2xRL	OK (SRM)	±20	None
Total Phosphorus	EPA 365.2	NA	NA	6	28dy	OK	≤0.008mg/L	NA	NA	OK	±25	OK	≤20%or±2xRL	NA	≤35%	OK	≤2xRL	OK (SRM)	±20	None
Ortho P	EPA 365.2	OK	15min [‡]	1	2dy	OK	≤0.004mg/L	NA	NA	OK	±25	OK	≤20%or±2xRL	NA	≤35%	OK	≤2xRL	OK (SRM)	±20	None
TKN	EPA 351.2	NA	NA	7	28dy	OK	≤1.0 mg/L	NA	NA	OK	±25	OK (LCS/LCSD + dup)	≤20%or±2xRL	NA	≤35%	OK	≤2xRL	OK (LCS + SRM)	±20	None
Nitrate + Nitrite	EPA 353.2	OK	48hr	1	28dy	OK	≤0.01 mg/L	NA	NA	OK	±25	OK	≤20%or±2xRL	NA	≤35%	0.013 (all samples <5X)	≤2xRL	OK (SRM)	±20	None
Sulfate	EPA375-2	NA	NA		28dy		≤2.0 mg/L		NA		±25		≤20%or±2xRL		≤35%		≤2xRL		±20	Not requested
Chloride	EPA 325.2	NA	NA		28dy		≤1.0 mg/L		NA		±25		≤20%or±2xRL		≤35%		≤2xRL		±20	Not requested
Alkalinity	SM 2320	NA	NA		14dy		≤1.0mg/L		NA		NA		≤20%or±2xRL		≤35%		≤2xRL		±20	Not requested
Total metals	EPA 200.8 / 6010C	NA	NA	6	180 dy	OK	0.1 – 50 µg/L	NA	NA	OK	±25	OK	≤20%or±2xRL	NA	≤35%	OK	≤2xRL	OK	±20	None
Dissolved metals	EPA 200.8 / 6010C	OK	15min [‡] (dissolved)	6	180 dy	OK	0.1-500 µg/L	NA	NA	OK	±25	OK	≤20%or±2xRL	NA	≤35%	OK	≤2xRL	OK	±20	None

^a as CaCO₃

^b The relative percent difference (RPD) must be less than or equal to the indicated percentage for values that are greater than 5 times the reporting limit. RPD must be within ±2 times the reporting limit for values that are less than or equal to 5 times the reporting limit.

^c EPA requires field filtering within 15 min of collection of the last aliquot. This is generally not feasible with flow weighted composite sampling.

Table D-17. Data Quality Assurance Worksheet: Dosing Experiments (10-30-14 Water)

Columns: 11,32,63,31,61,62,43,71,41,23,81

Laboratory/Parameters: TSS, hardness, DOC, total and dissolved metals, TP, Ortho-P, TKN, NO3-NO2, BLM ions (see QAPP)

Entry date 12/2/2014

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Checked by: Gina Catarra

Sample Date/Sample ID/Lab ID: 10-30-14 /S14-05757-0244 thru S14-05757-0256 (no -0250) /ARI ZI14 / 10-30-14 / S14-05757-0257 / Z124

Sample collection time: No time specified

Parameter	Completeness/Methodology	Pre-filter Holding Time		Total Holding Time		Lab Method Blanks/Reporting Limit		Surrogate Recovery (% Recovery)		Matrix Spikes (% Recovery)		Lab Duplicates (RPD) ^b		Field Duplicates (RSDp)		Rinsate Blanks		Lab Control Standard (% Recovery)		Action
		Reported	Goal	Reported	Goal	Reported	Goal	Reported	Goal	Reported	Goal	Reported	Goal	Reported	Goal	Reported	Goal	Reported	Goal	
Total Suspended Solids	SM 2540D	NA	NA	1	7dy	OK	≤1.0 mg/L	NA	NA	NA	NA	OK (LCS/LCSD + dup)	≤20%or±2xRL	NA	≤35%	OK	≤2xRL	OK	±20	None
PSD	TAPE App F	NA	NA		7dy		0.1microns	NA	NA	NA	NA		≤20%	NA	≤35%		≤2xRL		NA	Not Requested
Hardness ^a	SM2340-C	NA	NA	6	6mo	OK	≤1.0mg/L ^a	NA	NA	OK	±25	OK	≤20%or±2xRL	NA	≤35%	OK	≤2xRL	OK	±20	None
DOC	EPA 9060	OK	15min‡	6,4	28 dy	OK	≤1.5mg/L	NA	NA	OK	±25	OK	≤20%or±2xRL	NA	≤35%	OK	≤2xRL	OK (SRM)	±20	None
Total Phosphorus	EPA 365.2	NA	NA	5	28dy	OK	≤0.008mg/L	NA	NA	OK	±25	OK	≤20%or±2xRL	NA	≤35%	OK	≤2xRL	OK (SRM)	±20	None
Ortho P	EPA 365.2	OK	15min‡	<1	2dy	OK	≤0.004mg/L	NA	NA	OK	±25	OK	≤20%or±2xRL	NA	≤35%	OK	≤2xRL	OK (SRM)	±20	None
TKN	EPA 351.2	NA	NA	6	28dy	OK	≤1.0 mg/L	NA	NA	OK	±25	OK (LCS/LCSD + dup)	≤20%or±2xRL	NA	≤35%	OK	≤2xRL	OK (LCS + SRM)	±20	None
Nitrate+ nitrite	EPA 353.2	OK	48hr	6	28dy	OK	≤0.01 mg/L	NA	NA	OK	±25	OK	≤20%or±2xRL	NA	≤35%	0.013 (<2xRL)	≤2xRL	OK (SRM)	±20	None
Sulfate	EPA375-2	NA	NA		28dy		≤2.0 mg/L		NA		±25		≤20%or±2xRL		≤35%		≤2xRL		±20	Not Requested
Chloride	EPA 325.2	NA	NA		28dy		≤1.0 mg/L		NA		±25		≤20%or±2xRL		≤35%		≤2xRL		±20	Not Requested
Alkalinity	SM 2320	NA	NA		14dy		≤1.0mg/L		NA		NA		≤20%or±2xRL		≤35%		≤2xRL		±20	Not Requested
Total metals	EPA 200.8 / 6010C	NA	NA	5	180 dy	OK	0.1 – 50 µg/L	NA	NA	OK	±25	OK	≤20%or±2xRL	NA	≤35%	OK	≤2xRL	OK	±20	None
Dissolved metals	EPA 200.8 / 6010C	OK	15min‡ (dissolved)	5	180 dy	OK	0.1-500 µg/L	NA	NA	OK	±25	OK	≤20%or±2xRL	NA	≤35%	OK	≤2xRL	OK	±20	None

^a as CaCO3

^b The relative percent difference (RPD) must be less than or equal to the indicated percentage for values that are greater than 5 times the reporting limit. RPD must be within ±2 times the reporting limit for values that are less than or equal to 5 times the reporting limit.

^c EPA requires field filtering within 15 min of collection of the last aliquot. This is generally not feasible with flow weighted composite sampling.

Table D-18. Data Quality Assurance Worksheet: Dosing Experiments (12-10-14 Water)

Columns: 33,42,73,12,21,72,52,53,83,22,51,82

Laboratory/Parameters: TSS, hardness, DOC, total and dissolved metals, TP, Ortho-P, TKN, NO3-NO2, BLM ions (see QAPP)

Sample Date/Sample ID/Lab ID: 12-10-14 /S14-05757-0258 thru S14-05757-0270/ARI ZJ87

Entry date 1/12/2015

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Checked by: Gina Catarra

Sample collection time: No time specified

Parameter	Completeness/ Methodology	Pre-filter Holding Time		Total Holding Time		Lab Method Blanks/ Reporting Limit		Surrogate Recovery (% Recovery)		Matrix Spikes (% Recovery)		Lab Duplicates (RPD) ^b		Field Duplicates (RSDp)		Rinsate Blanks		Lab Control Standard (% Recovery)		Action
		Reported	Goal	Reported	Goal	Reported	Goal	Reported	Goal	Reported	Goal	Reported	Goal	Reported	Goal	Reported	Goal	Reported	Goal	
Total Suspended Solids	SM 2540D	NA	NA	2	7dy	OK	≤1.0 mg/L	NA	NA	NA	NA	OK (LCS/LCSD + dup)	≤20%or±2xRL	NA	≤35%	OK	≤2xRL	OK	±20	None
PSD	TAPE App F	NA	NA		7dy		0.1microns	NA	NA	NA	NA		≤20%	NA	≤35%		≤2xRL		NA	Not Requested
Hardness ^a	SM2340-C	NA	NA	6	6mo	OK	≤1.0mg/L ^a	NA	NA	OK	±25	OK	≤20%or±2xRL	NA	≤35%	OK	≤2xRL	OK	±20	None
DOC	EPA 9060	OK	15min [‡]	2	28 dy	OK	≤1.5mg/L	NA	NA	OK	±25	OK	≤20%or±2xRL	NA	≤35%	OK	≤2xRL	OK (SRM)	±20	None
Total Phosphorus	EPA 365.2	NA	NA	20	28dy	OK	≤0.008mg/L	NA	NA	OK	±25	OK	≤20%or±2xRL	NA	≤35%	OK	≤2xRL	OK (SRM)	±20	None
Ortho P	EPA 365.2	OK	15min [‡]	1	2dy	OK	≤0.004mg/L	NA	NA	OK	±25	OK	≤20%or±2xRL	NA	≤35%	OK	≤2xRL	OK (SRM)	±20	None
TKN	EPA 351.2	NA	NA	19	28dy	OK	≤1.0 mg/L	NA	NA	OK	±25	OK (LCS/LCSD + dup)	≤20%or±2xRL	NA	≤35%	OK	≤2xRL	OK (LCS + SRM)	±20	None
Nitrate+ nitrite	EPA 353.2	OK	48hr	1	28dy	OK	≤0.01 mg/L	NA	NA	74	±25	OK	≤20%or±2xRL	NA	≤35%	0.015 (<2XRL)	≤2xRL	OK (SRM)	±20	MS rec (74%) marginally outside of control limit, no flag because all other criteria met.
Sulfate	EPA375-2	NA	NA	5	28dy	OK	≤2.0 mg/L	NA	NA	OK	±25	OK	≤20%or±2xRL	NA	≤35%	OK	≤2xRL	OK (SRM)	±20	None
Chloride	EPA 325.2	NA	NA	2	28dy	OK	≤1.0 mg/L	NA	NA	OK	±25	OK	≤20%or±2xRL	NA	≤35%	OK	≤2xRL	OK (SRM)	±20	None
Alkalinity	SM 2320	NA	NA	7	14dy	OK	≤1.0mg/L	NA	NA	NA	NA	OK	≤20%or±2xRL	NA	≤35%	OK	≤2xRL	OK (SRM)	±20	None
Total metals	EPA 200.8 / 6010C	NA	NA	6	180 dy	OK	0.1 – 50 µg/L	NA	NA	OK	±25	OK	≤20%or±2xRL	NA	≤35%	ZN=4 (<2XRL)	≤2xRL	OK	±20	None
Dissolved metals	EPA 200.8 / 6010C	OK	15min [‡] (dissolved)	6	180 dy	OK	0.1-500 µg/L	NA	NA	OK	±25	OK	≤20%or±2xRL	NA	≤35%	OK	≤2xRL	OK	±20	None

^a as CaCO3

^b The relative percent difference (RPD) must be less than or equal to the indicated percentage for values that are greater than 5 times the reporting limit. RPD must be within ±2 times the reporting limit for values that are less than or equal to 5 times the reporting limit.

^c EPA requires field filtering within 15 min of collection of the last aliquot. This is generally not feasible with flow weighted composite sampling.

Table D-19. Data Quality Assurance Worksheet: Dosing Experiments (12-11-14 Water)

Columns: 11,32,63,31,61,62,43,71,41,23,81

Laboratory/Parameters: TSS, hardness, DOC, total and dissolved metals, TP, Ortho-P, TKN, NO3-NO2, BLM ions (see QAPP)

Sample Date/Sample ID/Lab ID: 12-11-14 /S14-05757-0271 thru S14-05757-0284 /ARI ZO32

Entry date 1/12/2015

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Checked by: Gina Catarra

Sample collection time: No time specified

Parameter	Completeness/ Methodology	Pre-filter Holding Time		Total Holding Time		Lab Method Blanks/ Reporting Limit		Surrogate Recovery (% Recovery)		Matrix Spikes (% Recovery)		Lab Duplicates (RPD) ^b		Field Duplicates (RSDp)		Rinsate Blanks		Lab Control Standard (% Recovery)		Action
		Reported	Goal	Reported	Goal	Reported	Goal	Reported	Goal	Reported	Goal	Reported	Goal	Reported	Goal	Reported	Goal	Reported	Goal	
Total Suspended Solids	SM 2540D	NA	NA	4	7dy	OK	≤1.0 mg/L	NA	NA	NA	NA	OK (LCS/LCSD + dup)	≤20%or±2xRL	NA	≤35%	OK	≤2xRL	OK	±20	None
PSD	TAPE App F	NA	NA		7dy		0.1microns	NA	NA	NA	NA		≤20%	NA	≤35%		≤2xRL		NA	Not Requested
Hardness ^a	SM2340-C	NA	NA	7	6mo	OK	≤1.0mg/L ^a	NA	NA	OK	±25	OK	≤20%or±2xRL	NA	≤35%	OK	≤2xRL	OK	±20	None
DOC	EPA 9060	OK	15min [‡]	1	28 dy	OK	≤1.5mg/L	NA	NA	OK	±25	OK	≤20%or±2xRL	NA	≤35%	OK	≤2xRL	OK (SRM)	±20	None
Total Phosphorus	EPA 365.2	NA	NA	19	28dy	OK	≤0.008mg/L	NA	NA	OK	±25	OK	≤20%or±2xRL	NA	≤35%	OK	≤2xRL	OK (SRM)	±20	None
Ortho P	EPA 365.2	OK	15min [‡]	1	2dy	OK	≤0.004mg/L	NA	NA	OK	±25	OK	≤20%or±2xRL	NA	≤35%	OK	≤2xRL	OK (SRM)	±20	None
TKN	EPA 351.2	NA	NA	18	28dy	OK	≤1.0 mg/L	NA	NA	OK	±25	OK (LCS/LCSD + dup)	≤20%or±2xRL	NA	≤35%	OK	≤2xRL	OK (LCS + SRM)	±20	None
Nitrate+ nitrite	EPA 353.2	OK	48hr	1	28dy	OK	≤0.01 mg/L	NA	NA	OK	±25	OK	≤20%or±2xRL	NA	≤35%	0.015 (<2xRL)	≤2xRL	OK (SRM)	±20	None
Sulfate	EPA375-2	NA	NA	4	28dy	OK	≤2.0 mg/L	NA	NA	OK	±25	OK	≤20%or±2xRL	NA	≤35%	OK	≤2xRL	OK (SRM)	±20	None
Chloride	EPA 325.2	NA	NA	1	28dy	OK	≤1.0 mg/L	NA	NA	OK	±25	OK	≤20%or±2xRL	NA	≤35%	OK	≤2xRL	OK (SRM)	±20	None
Alkalinity	SM 2320	NA	NA	6	14dy	OK	≤1.0mg/L	NA	NA	NA	NA	OK	≤20%or±2xRL	NA	≤35%	OK	≤2xRL	OK (SRM)	±20	None
Total metals	EPA 200.8 / 6010C	NA	NA	5	180 dy	OK	0.1 – 50 µg/L	NA	NA	OK	±25	OK	≤20%or±2xRL	NA	≤35%	ZN=4 (<2xRL)	≤2xRL	OK	±20	None
Dissolved metals	EPA 200.8 / 6010C	OK	15min [‡] (dissolved)	5-11	180 dy	OK	0.1-500 µg/L	NA	NA	OK	±25	OK	≤20%or±2xRL	NA	≤35%	OK	≤2xRL	OK	±20	None

^a as CaCO3

^b The relative percent difference (RPD) must be less than or equal to the indicated percentage for values that are greater than 5 times the reporting limit. RPD must be within ±2 times the reporting limit for values that are less than or equal to 5 times the reporting limit.

^c EPA requires field filtering within 15 min of collection of the last aliquot. This is generally not feasible with flow weighted composite sampling.

APPENDIX E

Synthetic Precipitation Leaching Protocol Results

Table E-1. Mineral Bulk SPLP Extraction Results.

Sample Date	Sample ID (Herrera)	Rank	Sample Component	Sample Treatment Type	Units	Data Qualifier	Parameter	Value	Sample Component	Overall Rank
4/28/2014	S14-05757-0003	1	volcanic sand	mineral bulk	mg/L	U	TKN	1.0	volcanic sand	12
4/28/2014	S14-05757-0004	1	Corliss utility sand	mineral bulk	mg/L	U	TKN	1.0	rhyolite sand	12
4/28/2014	S14-05757-0005	1	Corliss pipe bedding	mineral bulk	mg/L	U	TKN	1.0	crushed brick fines	13
4/28/2014	S14-05757-0007	1	rhyolite sand	mineral bulk	mg/L	U	TKN	1.0	washed sand	13
4/28/2014	S14-05757-0008	1	Miles Canyon sand	mineral bulk	mg/L	U	TKN	1.0	eastern OR iron sand	15
4/28/2014	S14-05757-0009	1	crushed brick fines	mineral bulk	mg/L	U	TKN	1.0	Miles Canyon sand	17
5/12/2014	S14-05757-0016	1	eastern OR iron sand	mineral bulk	mg/L	U	TKN	1.0	Corliss pipe bedding	19
5/12/2014	S14-05757-0017	1	lava sand	mineral bulk	mg/L	U	TKN	1.0	Corliss utility sand	20
5/12/2014	S14-05757-0018	1	washed sand	mineral bulk	mg/L	U	TKN	1.0	laval sand	23
Sample Date	Sample ID (Herrera)	Rank	Sample Component	Sample Treatment Type	Units	Data Qualifier	Parameter	Value		
4/28/2014	S14-05757-0003	1	volcanic sand	mineral bulk	mg/L		Nitrate-Nitrite	0.023		
5/12/2014	S14-05757-0016	2	eastern OR iron sand	mineral bulk	mg/L		Nitrate-Nitrite	0.024		
5/12/2014	S14-05757-0018	3	washed sand	mineral bulk	mg/L		Nitrate-Nitrite	0.024		
4/28/2014	S14-05757-0008	4	Miles Canyon sand	mineral bulk	mg/L		Nitrate-Nitrite	0.021		
5/12/2014	S14-05757-0017	5	lava sand	mineral bulk	mg/L		Nitrate-Nitrite	0.037		
4/28/2014	S14-05757-0005	6	Corliss pipe bedding	mineral bulk	mg/L		Nitrate-Nitrite	0.02		
4/28/2014	S14-05757-0004	7	Corliss utility sand	mineral bulk	mg/L		Nitrate-Nitrite	0.029		
4/28/2014	S14-05757-0007	8	rhyolite sand	mineral bulk	mg/L		Nitrate-Nitrite	0.604		
4/28/2014	S14-05757-0009	9	crushed brick fines	mineral bulk	mg/L		Nitrate-Nitrite	2.46		
Sample Date	Sample ID (Herrera)	Rank	Sample Component	Sample Treatment Type	Units	Data Qualifier	Parameter	Value		
4/28/2014	S14-05757-0009	1	crushed brick fines	mineral bulk	mg/L		Ortho-Phosphorus	0.012		
4/28/2014	S14-05757-0007	2	rhyolite sand	mineral bulk	mg/L		Ortho-Phosphorus	0.015		
4/28/2014	S14-05757-0003	3	volcanic sand	mineral bulk	mg/L		Ortho-Phosphorus	0.03		
4/28/2014	S14-05757-0008	4	Miles Canyon sand	mineral bulk	mg/L		Ortho-Phosphorus	0.046		
5/12/2014	S14-05757-0018	5	washed sand	mineral bulk	mg/L		Ortho-Phosphorus	0.12		
4/28/2014	S14-05757-0004	6	Corliss utility sand	mineral bulk	mg/L		Ortho-Phosphorus	0.136		
4/28/2014	S14-05757-0005	7	Corliss pipe bedding	mineral bulk	mg/L		Ortho-Phosphorus	0.144		
5/12/2014	S14-05757-0017	8	lava sand	mineral bulk	mg/L		Ortho-Phosphorus	0.305		
5/12/2014	S14-05757-0016	9	eastern OR iron sand	mineral bulk	mg/L		Ortho-Phosphorus	0.424		
Sample Date	Sample ID (Herrera)	Rank	Sample Component	Sample Treatment Type	Units	Data Qualifier	Parameter	Value		
4/28/2014	S14-05757-0007	1	rhyolite sand	mineral bulk	mg/L		Dissolved Cu	0.0009		
4/28/2014	S14-05757-0009	2	crushed brick fines	mineral bulk	mg/L		Dissolved Cu	0.002		
5/12/2014	S14-05757-0018	4	washed sand	mineral bulk	mg/L		Dissolved Cu	0.005		
4/28/2014	S14-05757-0005	5	Corliss pipe bedding	mineral bulk	mg/L		Dissolved Cu	0.0054		
4/28/2014	S14-05757-0004	6	Corliss utility sand	mineral bulk	mg/L		Dissolved Cu	0.0055		
4/28/2014	S14-05757-0003	7	volcanic sand	mineral bulk	mg/L		Dissolved Cu	0.0058		
4/28/2014	S14-05757-0008	8	Miles Canyon sand	mineral bulk	mg/L		Dissolved Cu	0.0095		
5/12/2014	S14-05757-0017	9	lava sand	mineral bulk	mg/L		Dissolved Cu	0.014		

Table E-2. Organic Bulk SPLP Extraction Results.

Sample Date	Sample ID (Herrera)	Rank	Sample Component	Sample Treatment Type	Units	Data Qualifier	Parameter	Value	Sample Component	Overall Rank
4/28/2014	S14-05757-0010	1	iron-coated wood chips	organic bulk	mg/L	U	TKN	1.0	iron-coated wood chips	6
4/28/2014	S14-05757-0015	1	Coco peat	organic bulk	mg/L	U	TKN	1.0	Coco peat	8
7/16/2014	S14-05757-0024	1	Coco coir pith	organic bulk	mg/L	U	TKN	1.0	Coco coir pith	12
7/16/2014	S14-05757-0025	2	Land Recovery Inc. compost	organic bulk	mg/L		TKN	5.4	Dakota Peat	13
4/28/2014	S14-05757-0002	3	Dakota Peat	organic bulk	mg/L		TKN	6.4	Land Recovery Inc. compost	18
5/12/2014	S14-05757-0020	4	Cedar Grove special compost	organic bulk	mg/L		TKN	20.0	Cedar Grove special compost	22
5/12/2014	S14-05757-0019	5	Cedar Grove compost	organic bulk	mg/L		TKN	24.0	Cedar Grove compost	22
Sample Date	Sample ID (Herrera)	Rank	Sample Component	Sample Treatment Type	Units	Data Qualifier	Parameter	Value		
4/28/2014	S14-05757-0010	1	iron-coated wood chips	organic bulk	mg/L	U	Nitrate-Nitrite	0.01		
4/28/2014	S14-05757-0015	2	Coco peat	organic bulk	mg/L		Nitrate-Nitrite	0.017		
7/16/2014	S14-05757-0024	3	Coco coir pith	organic bulk	mg/L		Nitrate-Nitrite	0.037		
7/16/2014	S14-05757-0025	4	Land Recovery Inc. compost	organic bulk	mg/L		Nitrate-Nitrite	0.188		
5/12/2014	S14-05757-0019	5	Cedar Grove compost	organic bulk	mg/L		Nitrate-Nitrite	0.674		
5/12/2014	S14-05757-0020	6	Cedar Grove special compost	organic bulk	mg/L		Nitrate-Nitrite	0.727		
4/28/2014	S14-05757-0002	7	Dakota Peat	organic bulk	mg/L		Nitrate-Nitrite	20.4		
Sample Date	Sample ID (Herrera)	Rank	Sample Component	Sample Treatment Type	Units	Data Qualifier	Parameter	Value		
4/28/2014	S14-05757-0010	1	iron-coated wood chips	organic bulk	mg/L		Ortho-Phosphorus	0.006		
4/28/2014	S14-05757-0002	2	Dakota Peat	organic bulk	mg/L		Ortho-Phosphorus	0.125		
4/28/2014	S14-05757-0015	3	Coco peat	organic bulk	mg/L		Ortho-Phosphorus	0.459		
7/16/2014	S14-05757-0024	4	Coco coir pith	organic bulk	mg/L		Ortho-Phosphorus	0.662		
5/12/2014	S14-05757-0020	5	Cedar Grove special compost	organic bulk	mg/L		Ortho-Phosphorus	5.08		
5/12/2014	S14-05757-0019	6	Cedar Grove compost	organic bulk	mg/L		Ortho-Phosphorus	6.5		
7/16/2014	S14-05757-0025	7	Land Recovery Inc. compost	organic bulk	mg/L		Ortho-Phosphorus	7.84		
Sample Date	Sample ID (Herrera)	Rank	Sample Component	Sample Treatment Type	Units	Data Qualifier	Parameter	Value		
4/28/2014	S14-05757-0002	1	Dakota Peat	organic bulk	mg/L		Dissolved Cu	0.0009		
4/28/2014	S14-05757-0015	2	Coco peat	organic bulk	mg/L		Dissolved Cu	0.0009		
4/28/2014	S14-05757-0010	3	iron-coated wood chips	organic bulk	mg/L		Dissolved Cu	0.0012		
7/16/2014	S14-05757-0024	4	Coco coir pith	organic bulk	mg/L		Dissolved Cu	0.0017		
7/16/2014	S14-05757-0025	5	Land Recovery Inc. compost	organic bulk	mg/L		Dissolved Cu	0.0101		
5/12/2014	S14-05757-0019	6	Cedar Grove compost	organic bulk	mg/L		Dissolved Cu	0.024		
5/12/2014	S14-05757-0020	7	Cedar Grove special compost	organic bulk	mg/L		Dissolved Cu	0.024		

Table E-3. Mineral Additive SPLP Extraction Results.

Sample Date	Sample ID (Herrera)	Rank	Sample Component	Sample Treatment Type	Units	Data Qualifier	Parameter	Value	Sample Component	Overall Rank
4/28/2014	S14-05757-0001	1	diatomaceous earth	mineral additive	mg/L	U	TKN	1.0	diatomaceous earth	6
4/28/2014	S14-05757-0006	1	zeolite	mineral additive	mg/L	U	TKN	1.0	activated alumina	8
4/28/2014	S14-05757-0013	1	activated alumina	mineral additive	mg/L	U	TKN	1.0	oyster shells	9
5/12/2014	S14-05757-0021	1	oyster shells	mineral additive	mg/L	U	TKN	1.0	zeolite	11
Sample Date	Sample ID (Herrera)	Rank	Sample Component	Sample Treatment Type	Units	Data Qualifier	Parameter	Value		
4/28/2014	S14-05757-0001	1	diatomaceous earth	mineral additive	mg/L		Nitrate-Nitrite	0.092		
4/28/2014	S14-05757-0013	2	activated alumina	mineral additive	mg/L		Nitrate-Nitrite	0.44		
5/12/2014	S14-05757-0021	3	oyster shells	mineral additive	mg/L		Nitrate-Nitrite	0.746		
4/28/2014	S14-05757-0006	4	zeolite	mineral additive	mg/L		Nitrate-Nitrite	0.741		
Sample Date	Sample ID (Herrera)	Rank	Sample Component	Sample Treatment Type	Units	Data Qualifier	Parameter	Value		
4/28/2014	S14-05757-0013	1	activated alumina	mineral additive	mg/L	U	Ortho-Phosphorus	0.004		
5/12/2014	S14-05757-0021	2	oyster shells	mineral additive	mg/L		Ortho-Phosphorus	0.028		
4/28/2014	S14-05757-0001	3	diatomaceous earth	mineral additive	mg/L		Ortho-Phosphorus	0.032		
4/28/2014	S14-05757-0006	4	zeolite	mineral additive	mg/L		Ortho-Phosphorus	0.043		
Sample Date	Sample ID (Herrera)	Rank	Sample Component	Sample Treatment Type	Units	Data Qualifier	Parameter	Value		
4/28/2014	S14-05757-0001	1	diatomaceous earth	mineral additive	mg/L		Dissolved Cu	0.0013		
4/28/2014	S14-05757-0006	2	zeolite	mineral additive	mg/L		Dissolved Cu	0.0018		
5/12/2014	S14-05757-0021	3	oyster shells	mineral additive	mg/L	U	Dissolved Cu	0.002		
4/28/2014	S14-05757-0013	4	activated alumina	mineral additive	mg/L		Dissolved Cu	0.0023		

Table E-4. Organic Additive SPLP Extraction Results.

Sample Date	Sample ID (Herrera)	Rank	Sample Component	Sample Treatment Type	Units	Data Qualifier	Parameter	Value	Sample Component	Overall Rank
4/28/2014	S14-05757-0011	1	High carbon wood ash PD 100+ mesh	organic additive	mg/L	U	TKN	1.0	High carbon wood ash PD 100+ mesh	7
4/28/2014	S14-05757-0012	1	High carbon wood ash AS 100+ mesh	organic additive	mg/L	U	TKN	1.0	GAC 1230AWb ²	8
4/28/2014	S14-05757-0014	1	GAC 1230AWa	organic additive	mg/L	U	TKN	1.0	GAC 1230AWa ¹	9
6/11/2014	S14-05757-0022	1	GAC 824BC	organic additive	mg/L	U	TKN	1.0	High carbon wood ash AS 100+ mesh	12
7/16/2014	S14-05757-0023	1	GAC 1230AWb	organic additive	mg/L	U	TKN	1.0	Biochar	16
7/16/2014	S14-05757-0022a	2	Biochar	organic additive	mg/L		TKN	2.0	GAC 824BC	18
Sample Date	Sample ID (Herrera)	Rank	Sample Component	Sample Treatment Type	Units	Data Qualifier	Parameter	Value		
7/16/2014	S14-05757-0023	1	GAC 1230AWb	organic additive	mg/L		Nitrate-Nitrite	0.016		
4/28/2014	S14-05757-0011	2	High carbon wood ash PD 100+ mesh	organic additive	mg/L		Nitrate-Nitrite	0.021		
4/28/2014	S14-05757-0014	3	GAC 1230AWa	organic additive	mg/L		Nitrate-Nitrite	0.034		
7/16/2014	S14-05757-0022a	4	Biochar	organic additive	mg/L		Nitrate-Nitrite	0.068		
4/28/2014	S14-05757-0012	5	High carbon wood ash AS 100+ mesh	organic additive	mg/L		Nitrate-Nitrite	0.118		
6/11/2014	S14-05757-0022	6	GAC 824BC	organic additive	mg/L		Nitrate-Nitrite	0.119		
Sample Date	Sample ID (Herrera)	Rank	Sample Component	Sample Treatment Type	Units	Data Qualifier	Parameter	Value		
7/16/2014	S14-05757-0023	1	GAC 1230AWb	organic additive	mg/L		Ortho-Phosphorus	0.155		
4/28/2014	S14-05757-0014	2	GAC 1230AWa	organic additive	mg/L		Ortho-Phosphorus	0.434		
4/28/2014	S14-05757-0011	3	High carbon wood ash PD 100+ mesh	organic additive	mg/L		Ortho-Phosphorus	0.518		
4/28/2014	S14-05757-0012	4	High carbon wood ash AS 100+ mesh	organic additive	mg/L		Ortho-Phosphorus	0.706		
6/11/2014	S14-05757-0022	5	GAC 824BC	organic additive	mg/L		Ortho-Phosphorus	2.78		
7/16/2014	S14-05757-0022a	6	Biochar	organic additive	mg/L		Ortho-Phosphorus	14.9		
Sample Date	Sample ID (Herrera)	Rank	Sample Component	Sample Treatment Type	Units	Data Qualifier	Parameter	Value		
4/28/2014	S14-05757-0011	1	High carbon wood ash PD 100+ mesh	organic additive	mg/L	U	Dissolved Cu	0.0005		
4/28/2014	S14-05757-0012	2	High carbon wood ash AS 100+ mesh	organic additive	mg/L	U	Dissolved Cu	0.0005		
4/28/2014	S14-05757-0014	3	GAC 1230AWa	organic additive	mg/L	U	Dissolved Cu	0.0005		
7/16/2014	S14-05757-0022a	4	Biochar	organic additive	mg/L	U	Dissolved Cu	0.0005		
7/16/2014	S14-05757-0023	5	GAC 1230AWb	organic additive	mg/L		Dissolved Cu	0.0006		
6/11/2014	S14-05757-0022	6	GAC 824BC	organic additive	mg/L		Dissolved Cu	0.002		

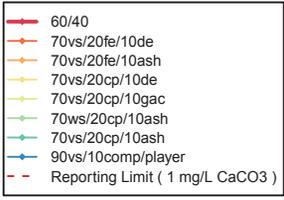
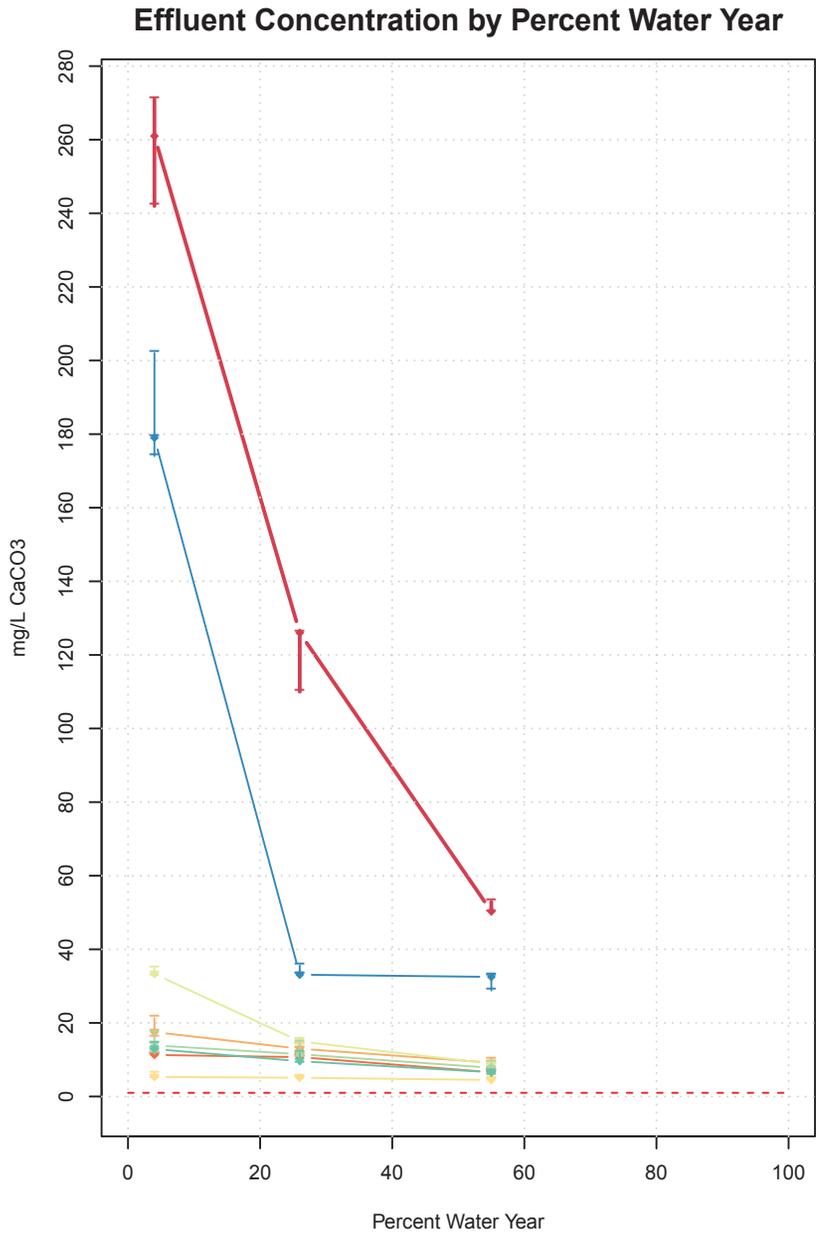
¹ GAC 1230AW = sample from old material (Olympia study)

² GAC 1230AW = sample from new material (sent from Charcoal House)

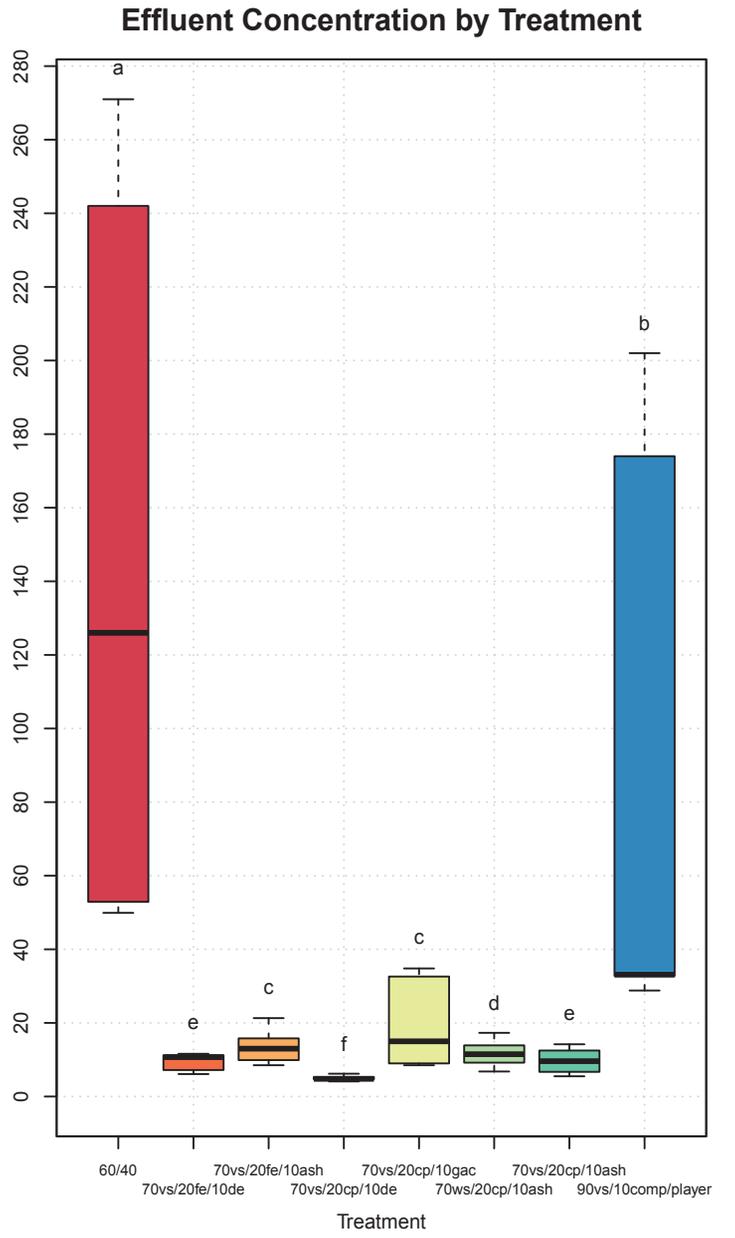
APPENDIX F

Graphical Summaries for Flushing Experiment Results

Alkalinity

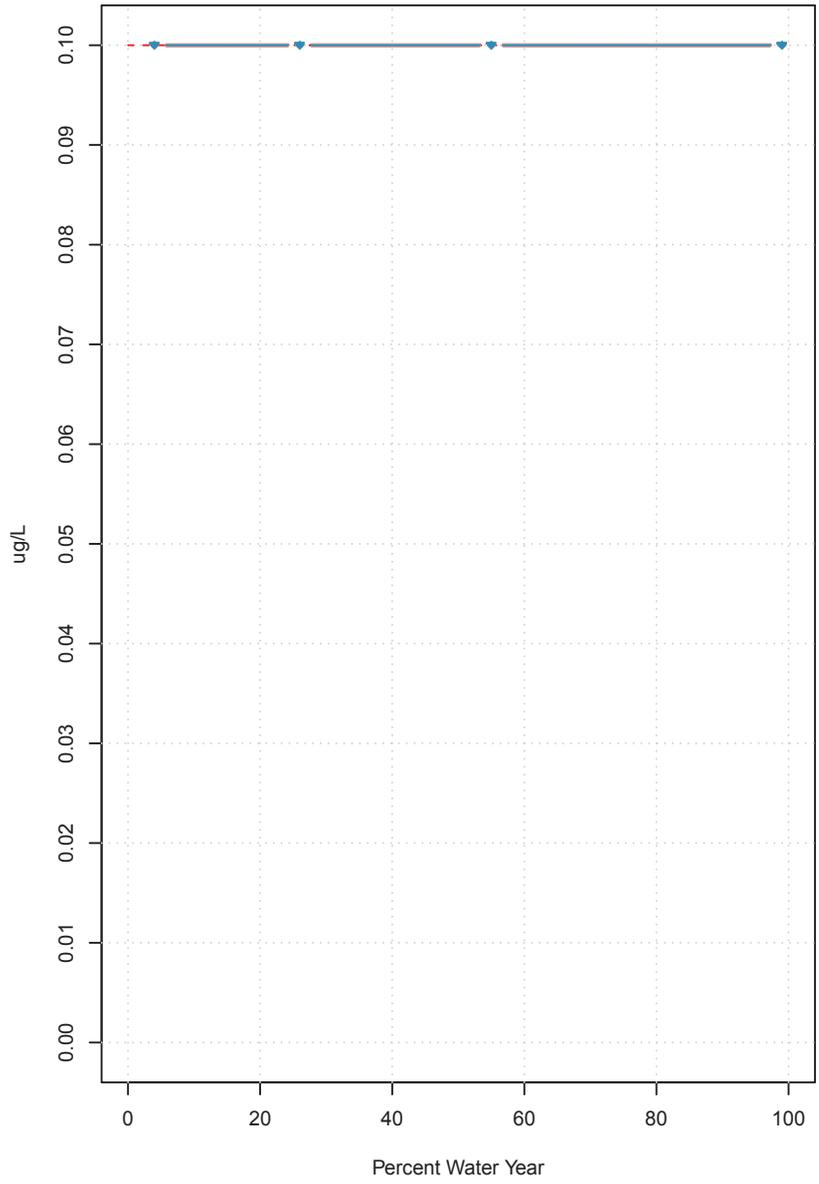


Two-Way ANOVA on Effluent (ranks)
 Treatment p-value : 1.66e-35 ***
 Sample Event p-value : 3.18e-23 ***
 Interaction p-value : 1.27e-07 ***



Dissolved Cadmium

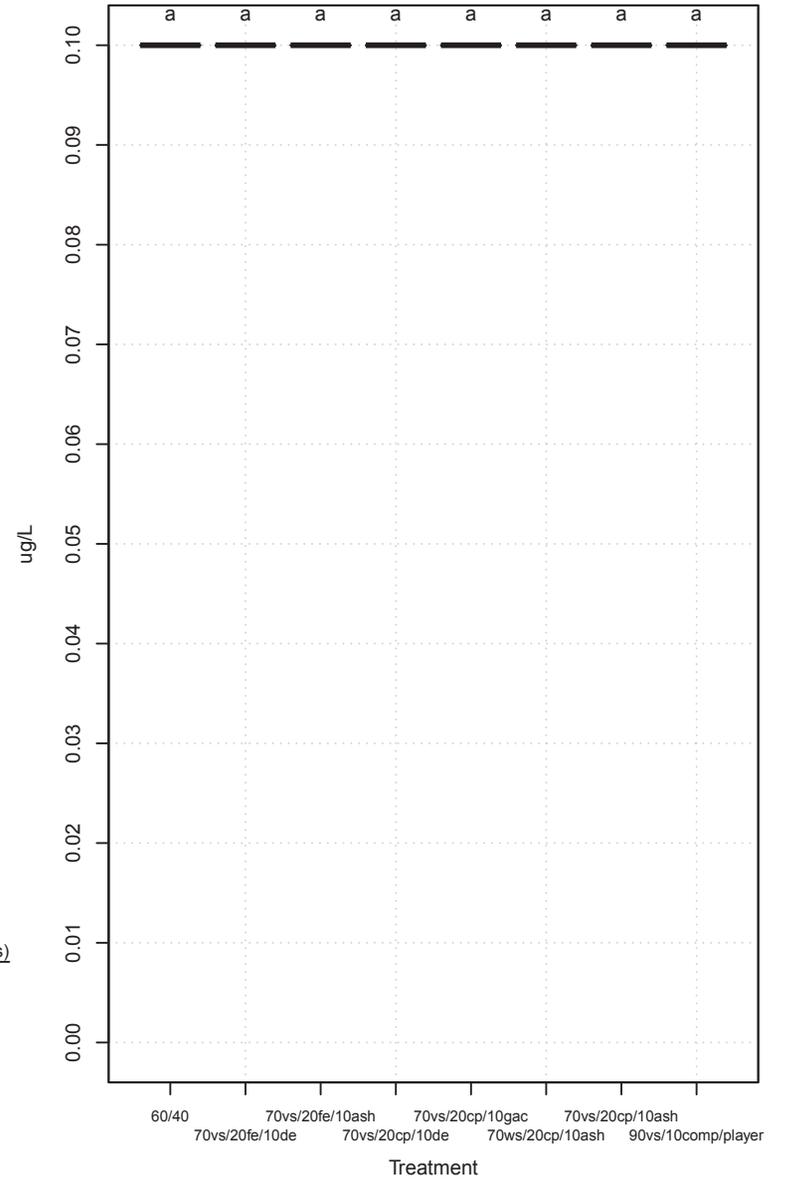
Effluent Concentration by Percent Water Year



- 60/40
- 70vs/20fe/10de
- 70vs/20fe/10ash
- 70vs/20cp/10de
- 70vs/20cp/10gac
- 70vs/20cp/10ash
- 70vs/20cp/10ash
- 90vs/10comp/player
- Reporting Limit (0.1 ug/L)

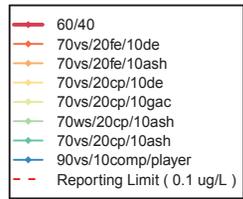
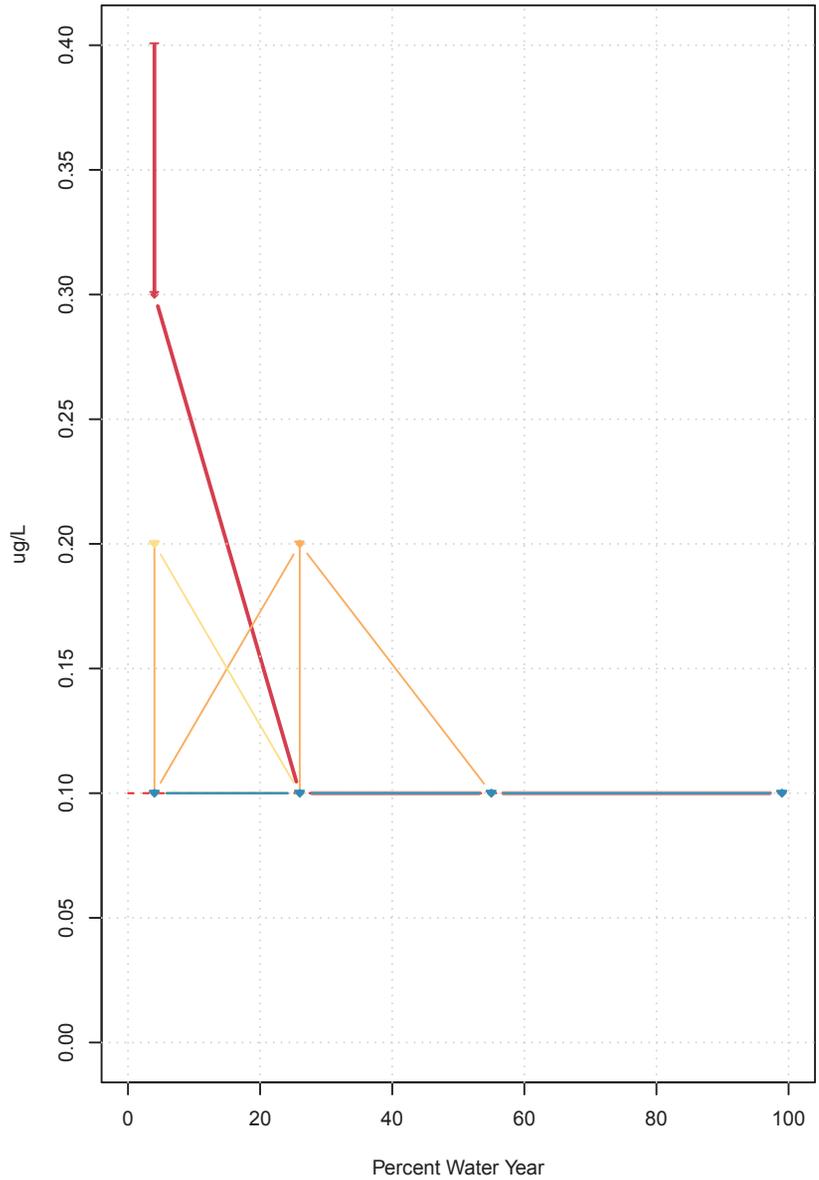
Two-Way ANOVA on Effluent (ranks)
 Treatment p-value : 0.44
 Sample Event p-value : 0.399
 Interaction p-value : 0.476

Effluent Concentration by Treatment



Total Cadmium

Effluent Concentration by Percent Water Year



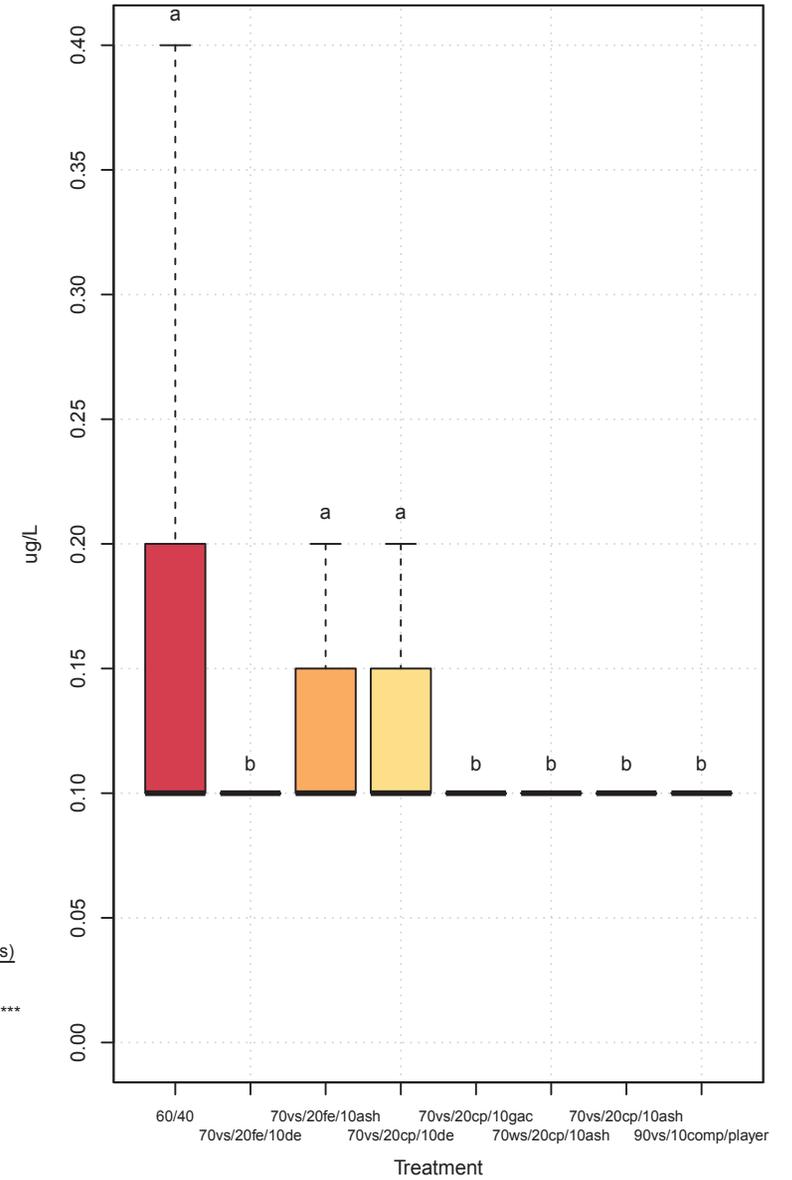
Two-Way ANOVA on Effluent (ranks)

Treatment p-value : 1.42e-08 ***

Sample Event p-value : 1.96e-10 ***

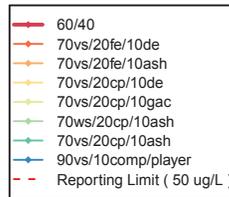
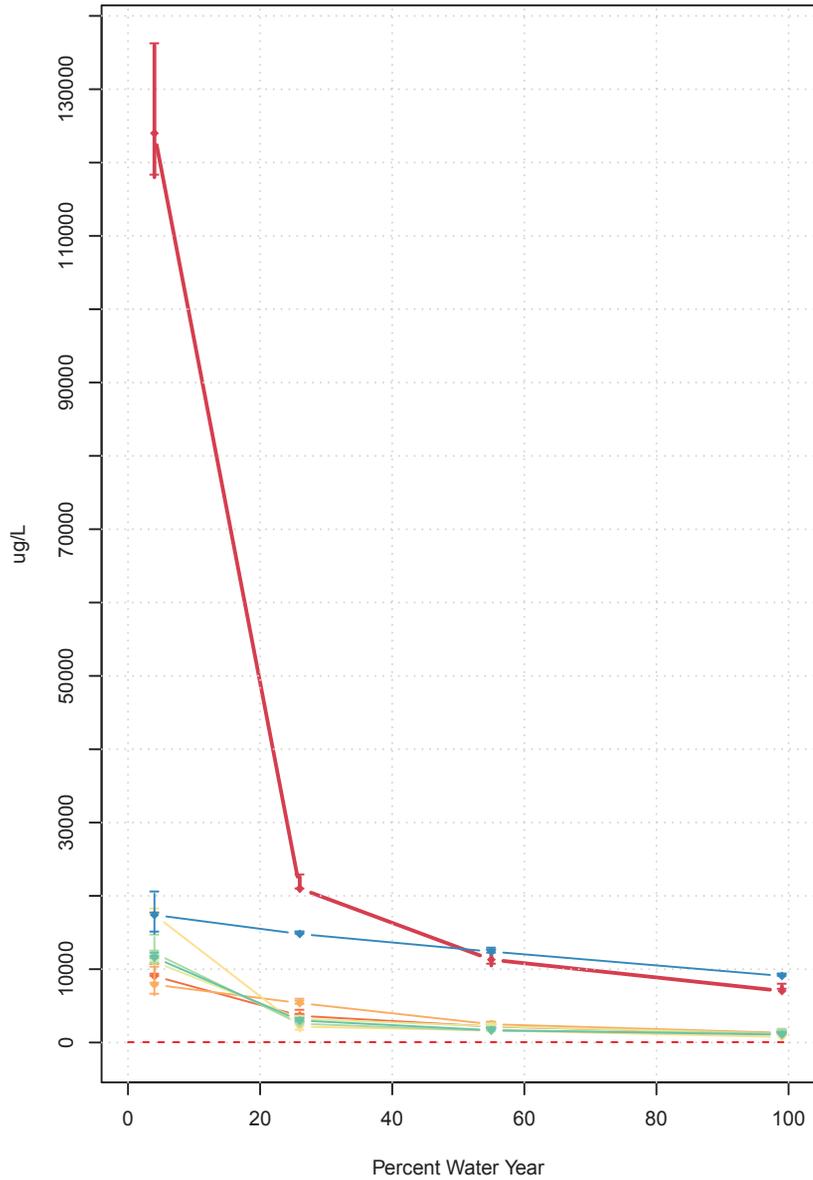
Interaction p-value : 3.64e-13 ***

Effluent Concentration by Treatment



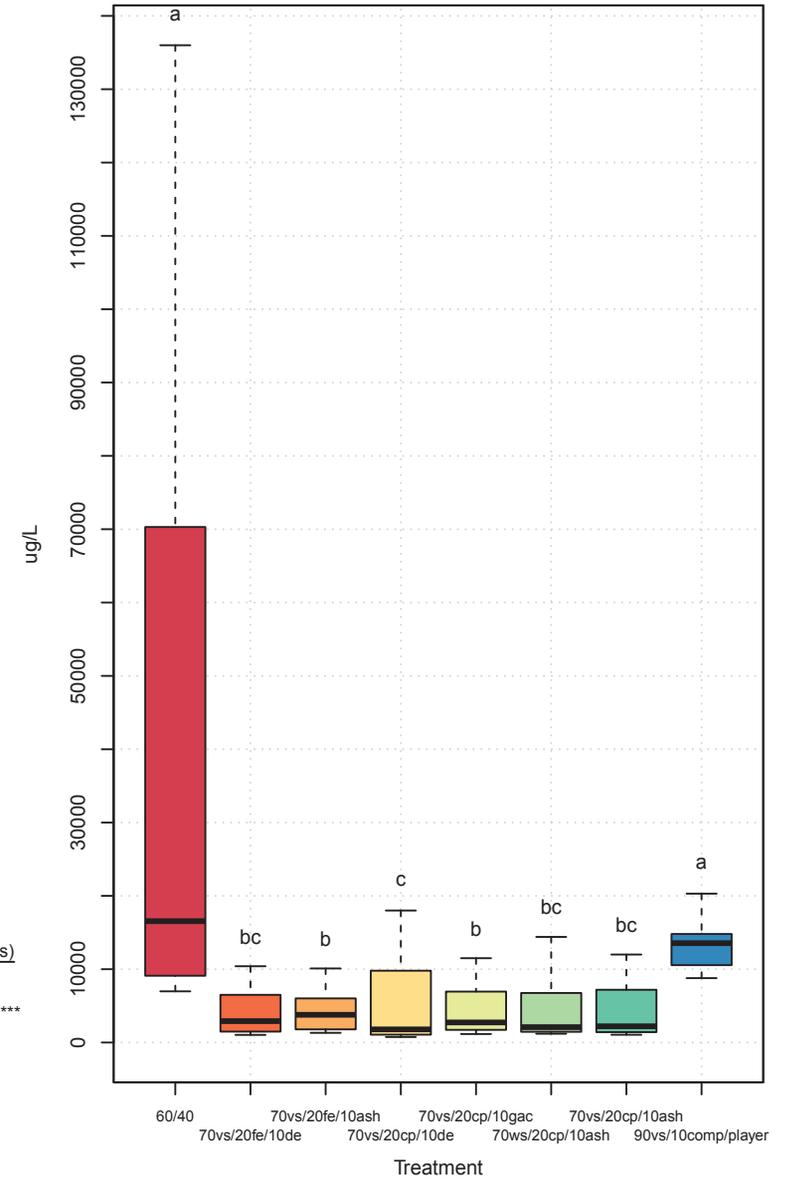
Total Calcium

Effluent Concentration by Percent Water Year



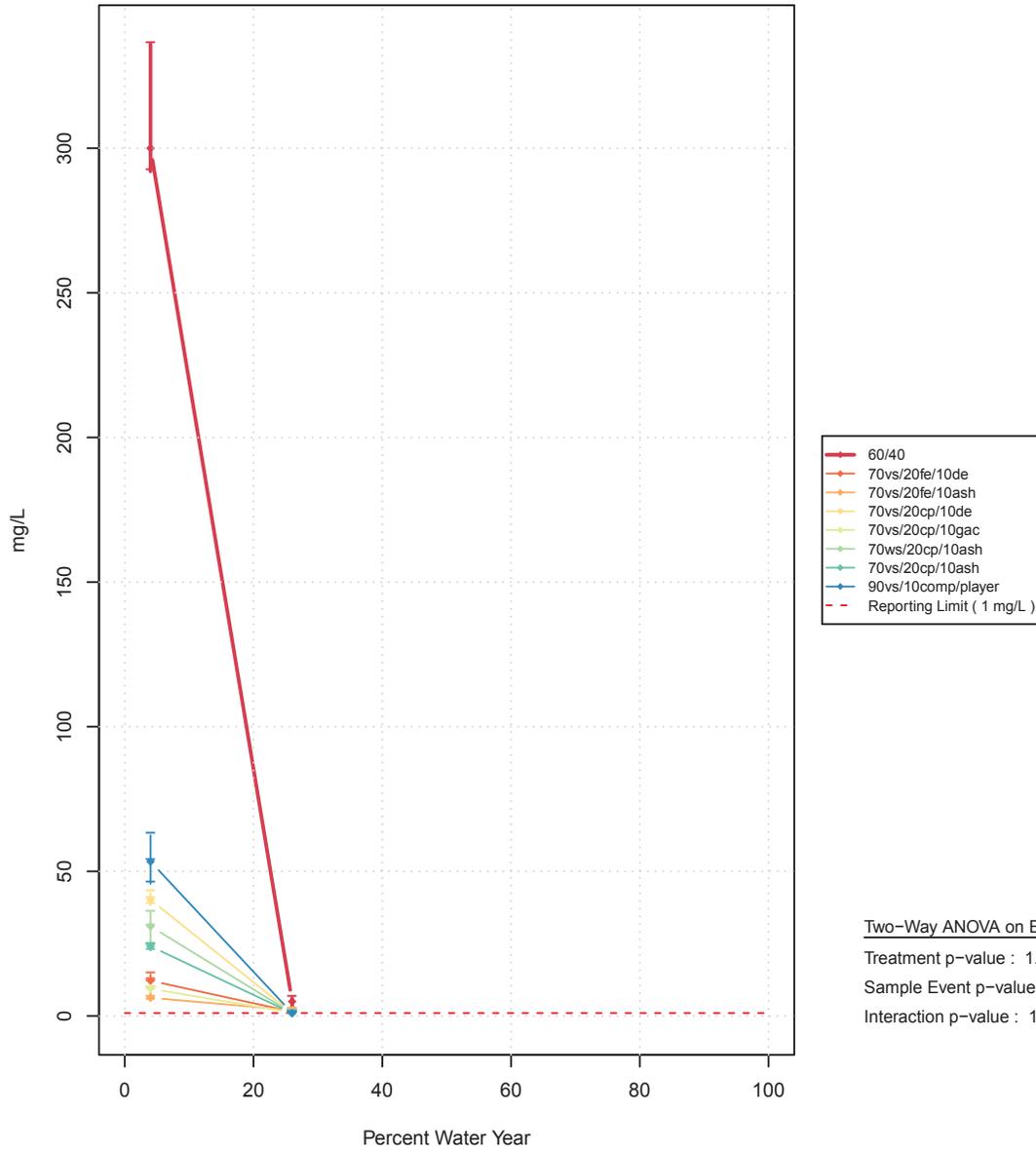
Two-Way ANOVA on Effluent (ranks)
 Treatment p-value : 1.86e-46 ***
 Sample Event p-value : 1.53e-52 ***
 Interaction p-value : 3.3e-21 ***

Effluent Concentration by Treatment

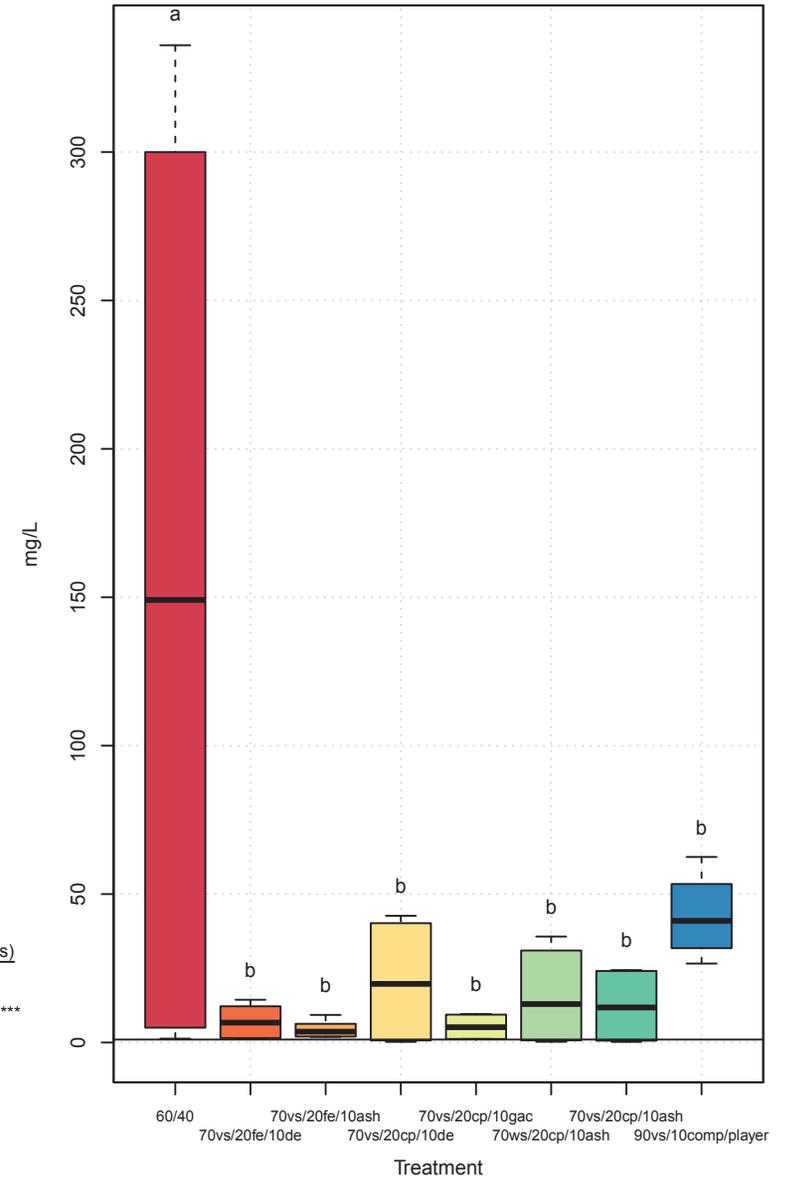


Chloride

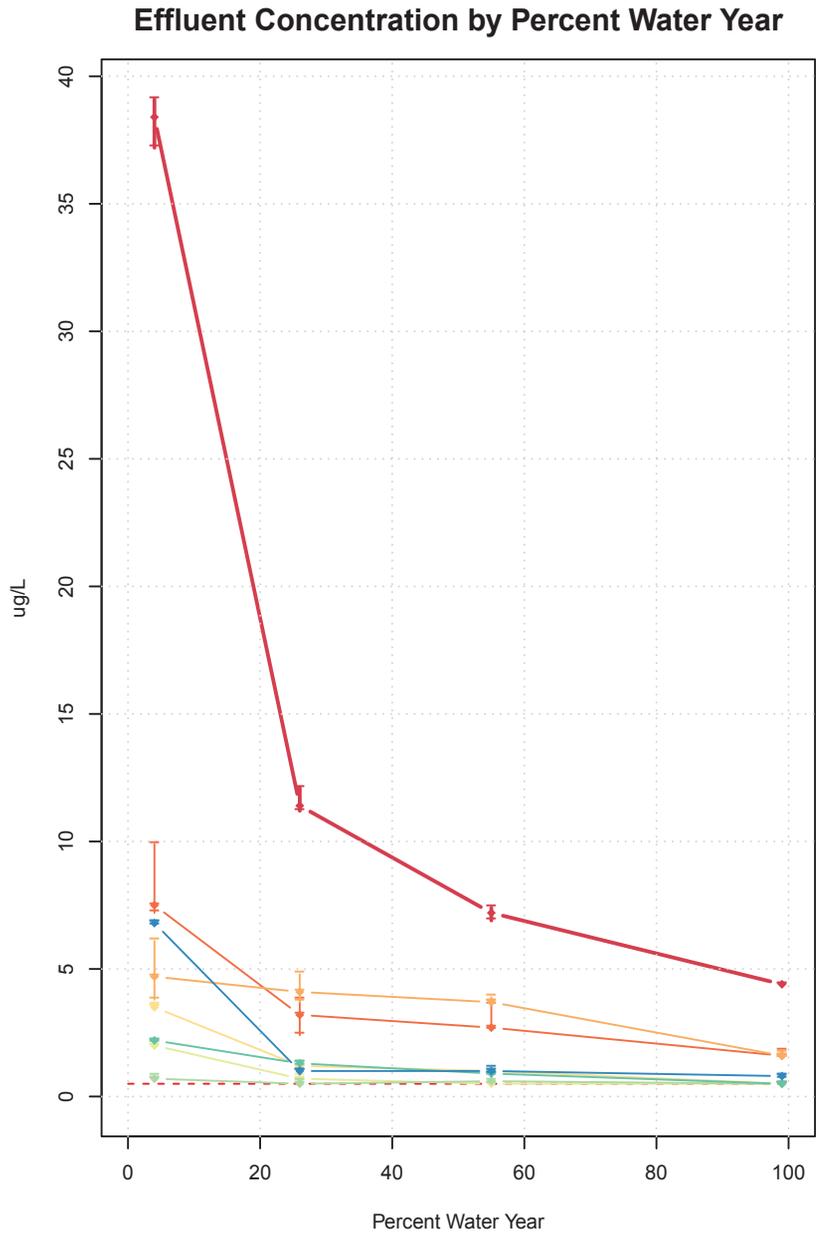
Effluent Concentration by Percent Water Year



Effluent Concentration by Treatment

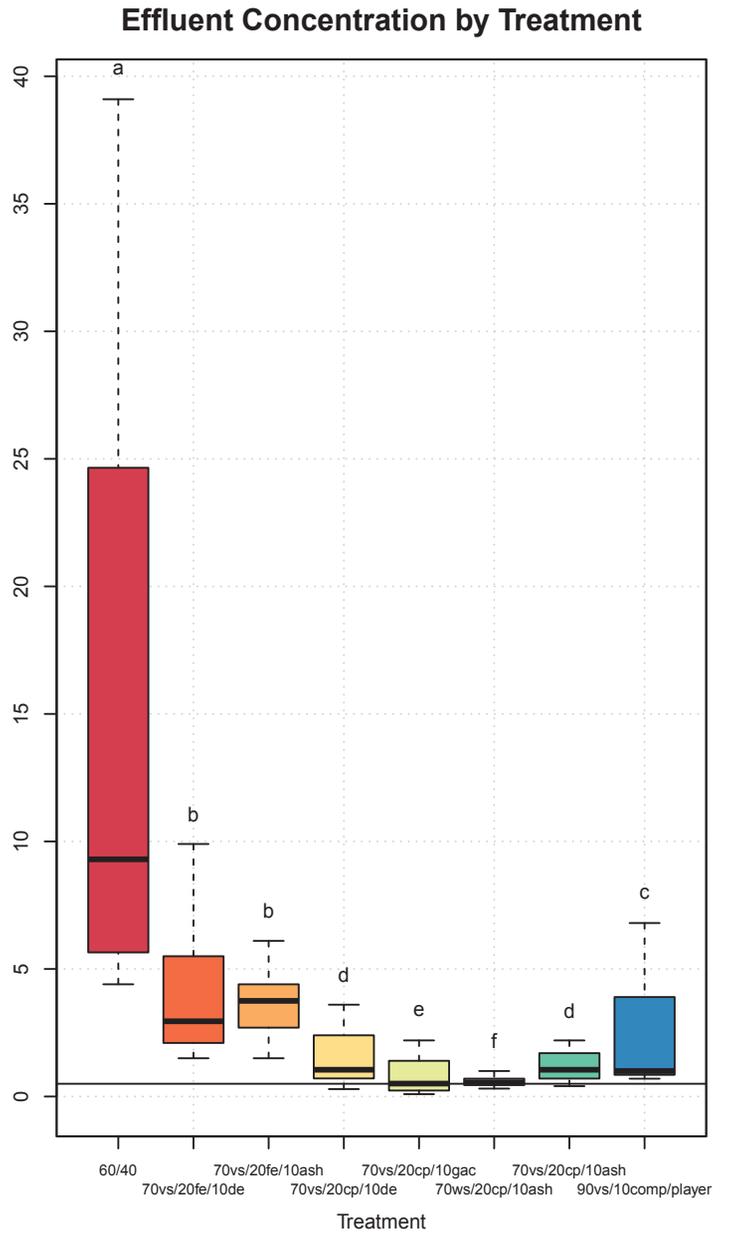


Dissolved Copper

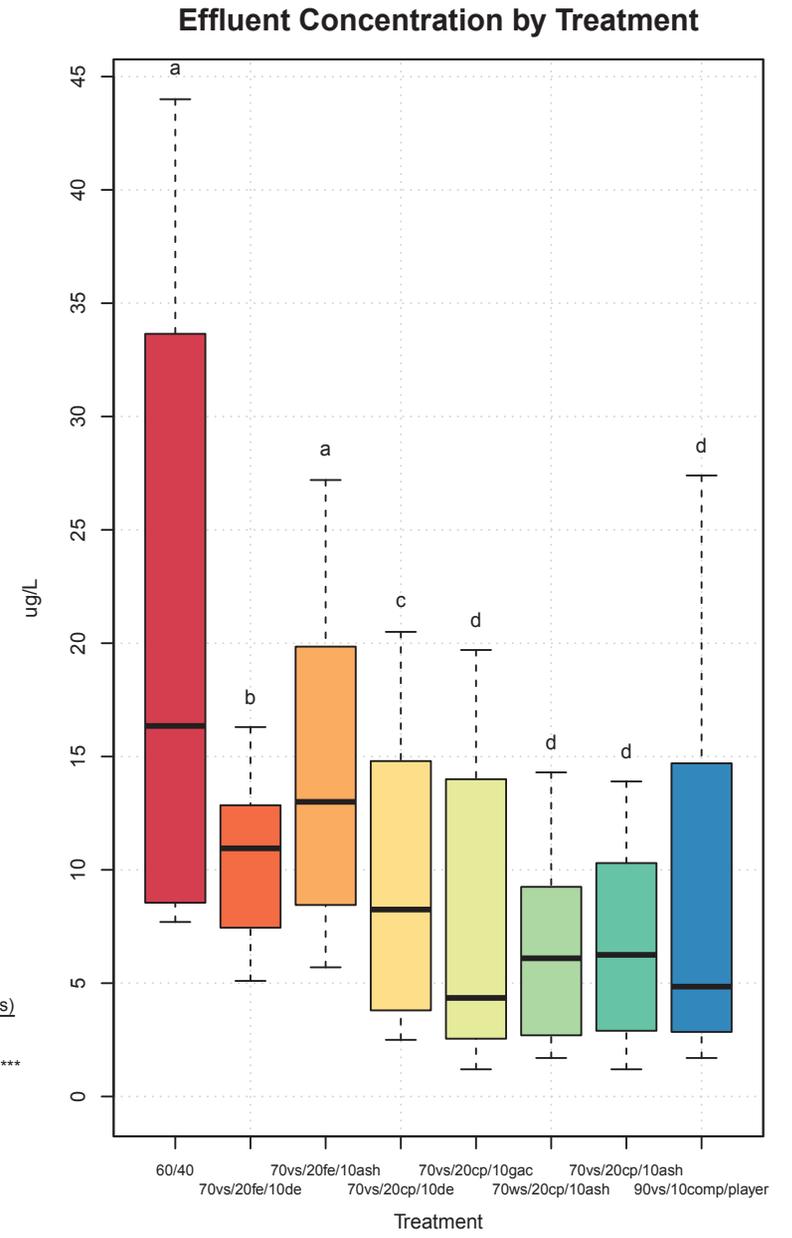
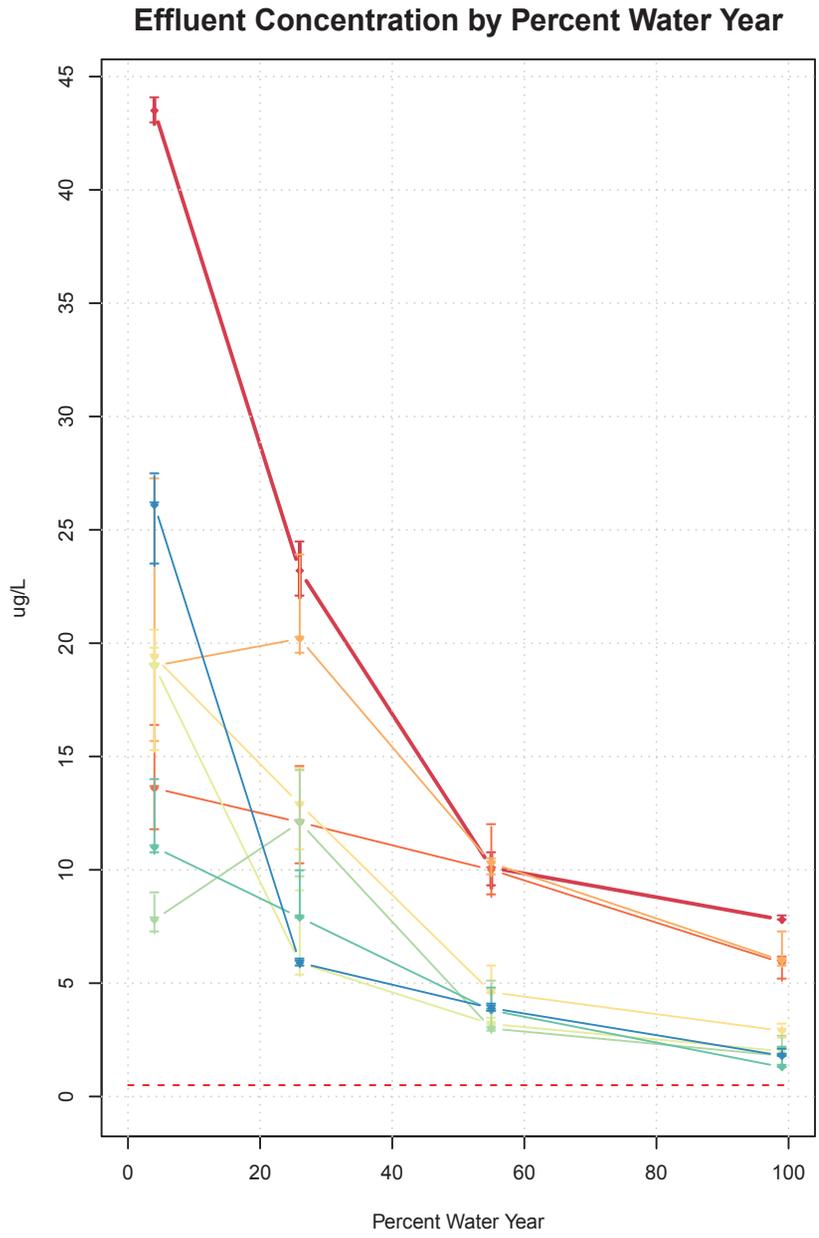


- 60/40
- 70vs/20fe/10de
- 70vs/20fe/10ash
- 70vs/20cp/10de
- 70vs/20cp/10gac
- 70vs/20cp/10ash
- 70vs/20cp/10ash
- 90vs/10comp/player
- Reporting Limit (0.5 ug/L)

Two-Way ANOVA on Effluent (ranks)
 Treatment p-value : 1.75e-53 ***
 Sample Event p-value : 1.78e-42 ***
 Interaction p-value : 4.62e-20 ***

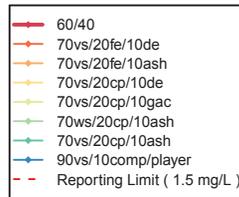
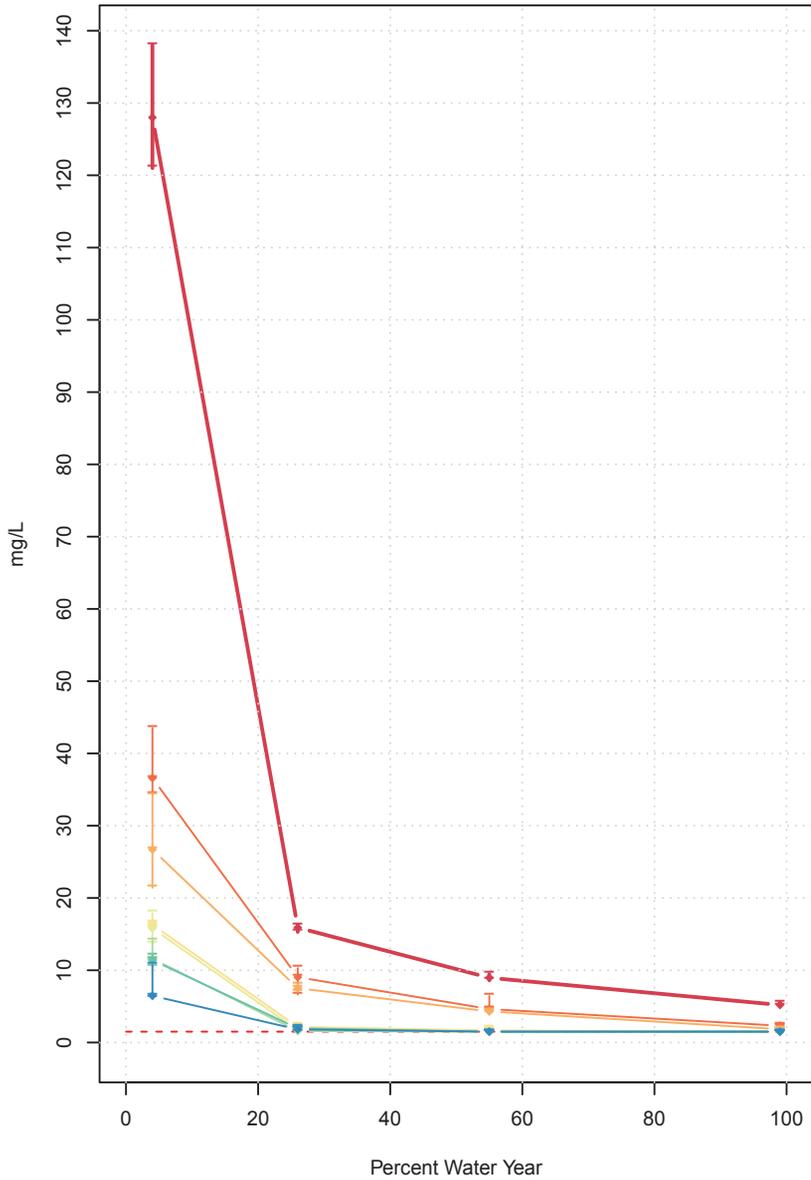


Total Copper



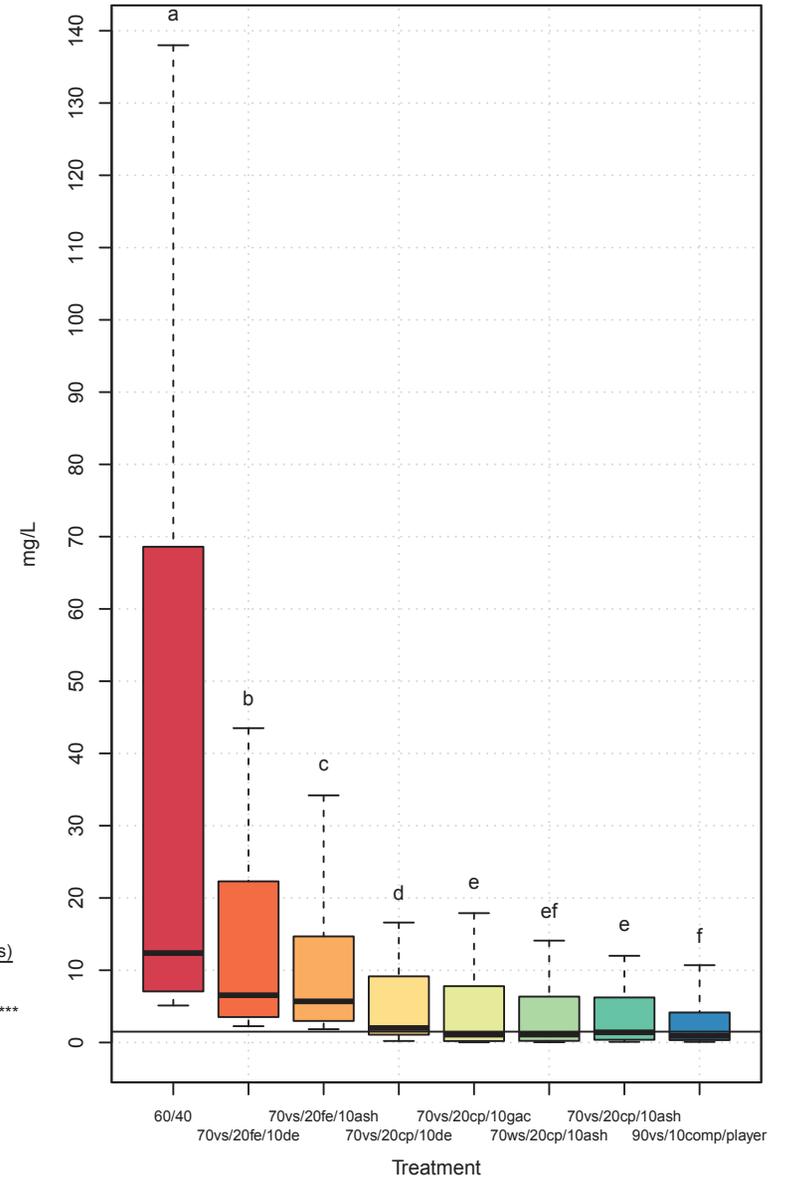
Dissolved Organic Carbon

Effluent Concentration by Percent Water Year

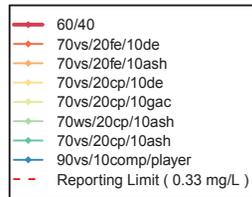
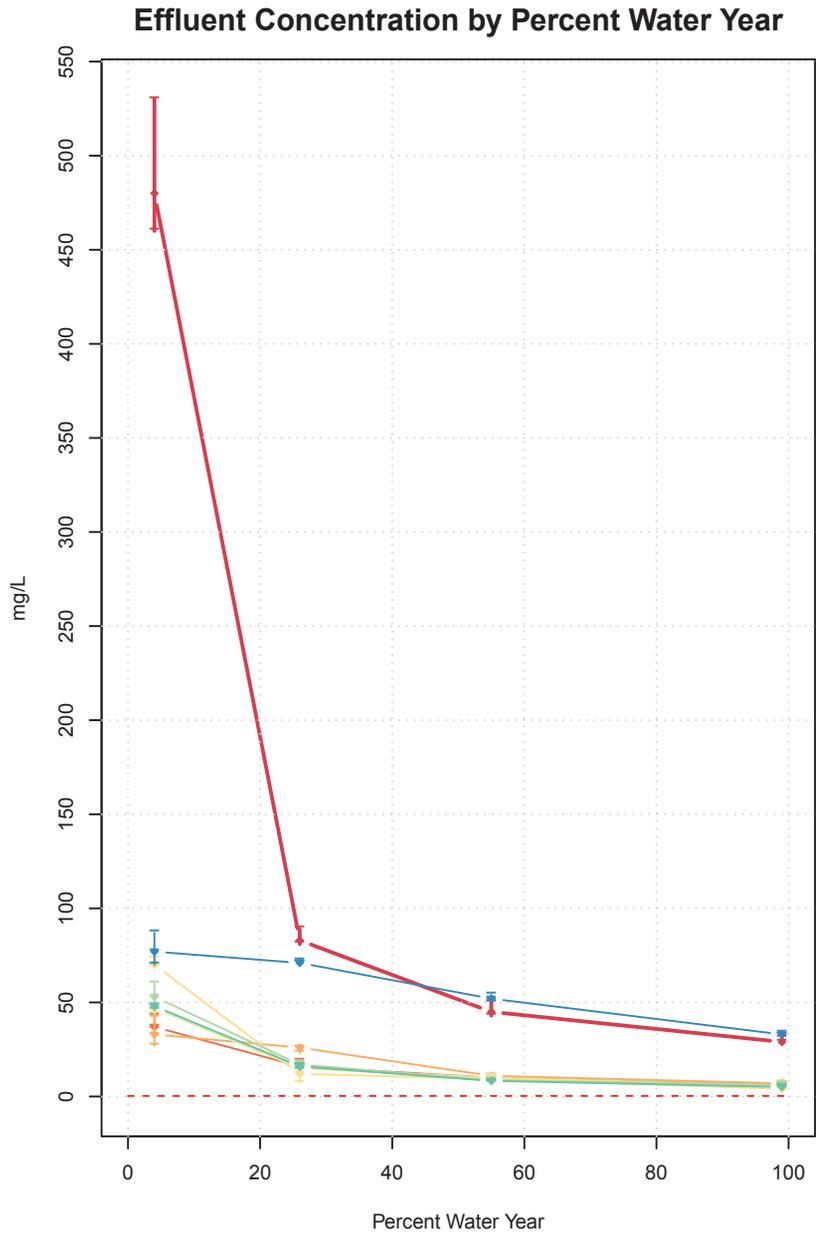


Two-Way ANOVA on Effluent (ranks)
 Treatment p-value : 1.2e-43 ***
 Sample Event p-value : 7.86e-54 ***
 Interaction p-value : 5.63e-14 ***

Effluent Concentration by Treatment

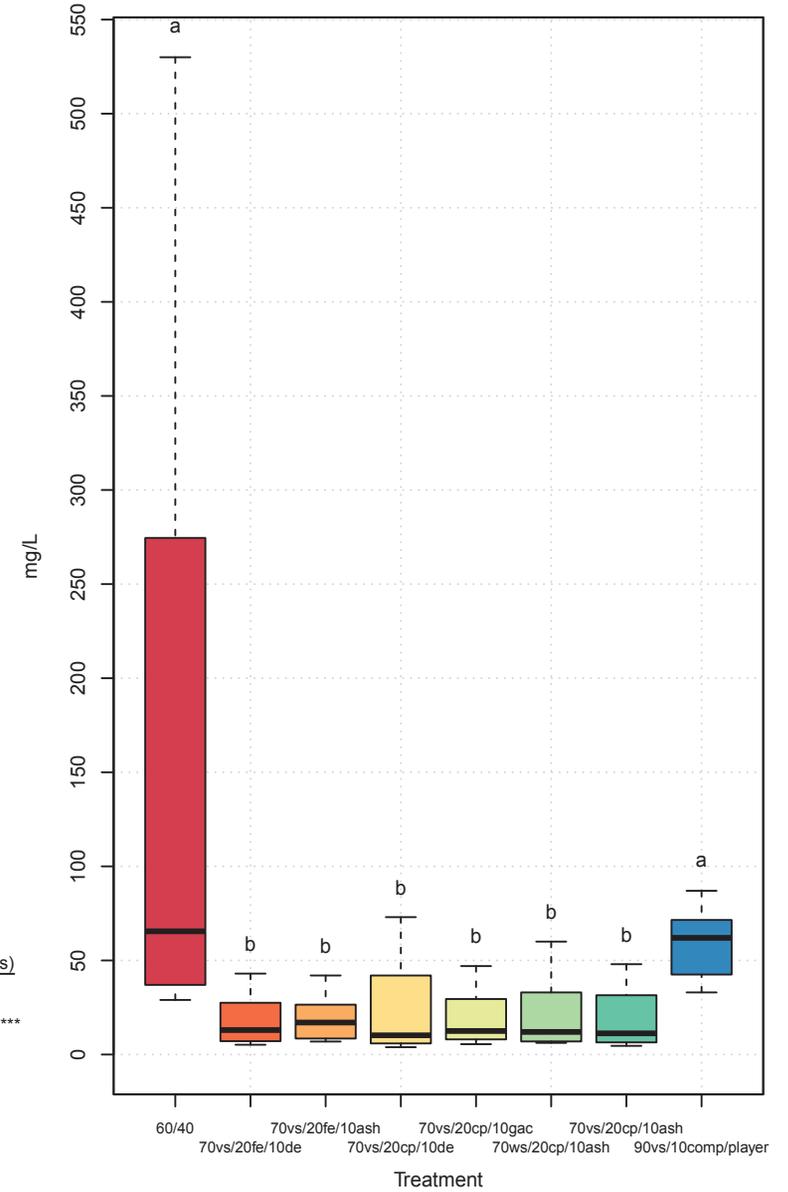


Hardness



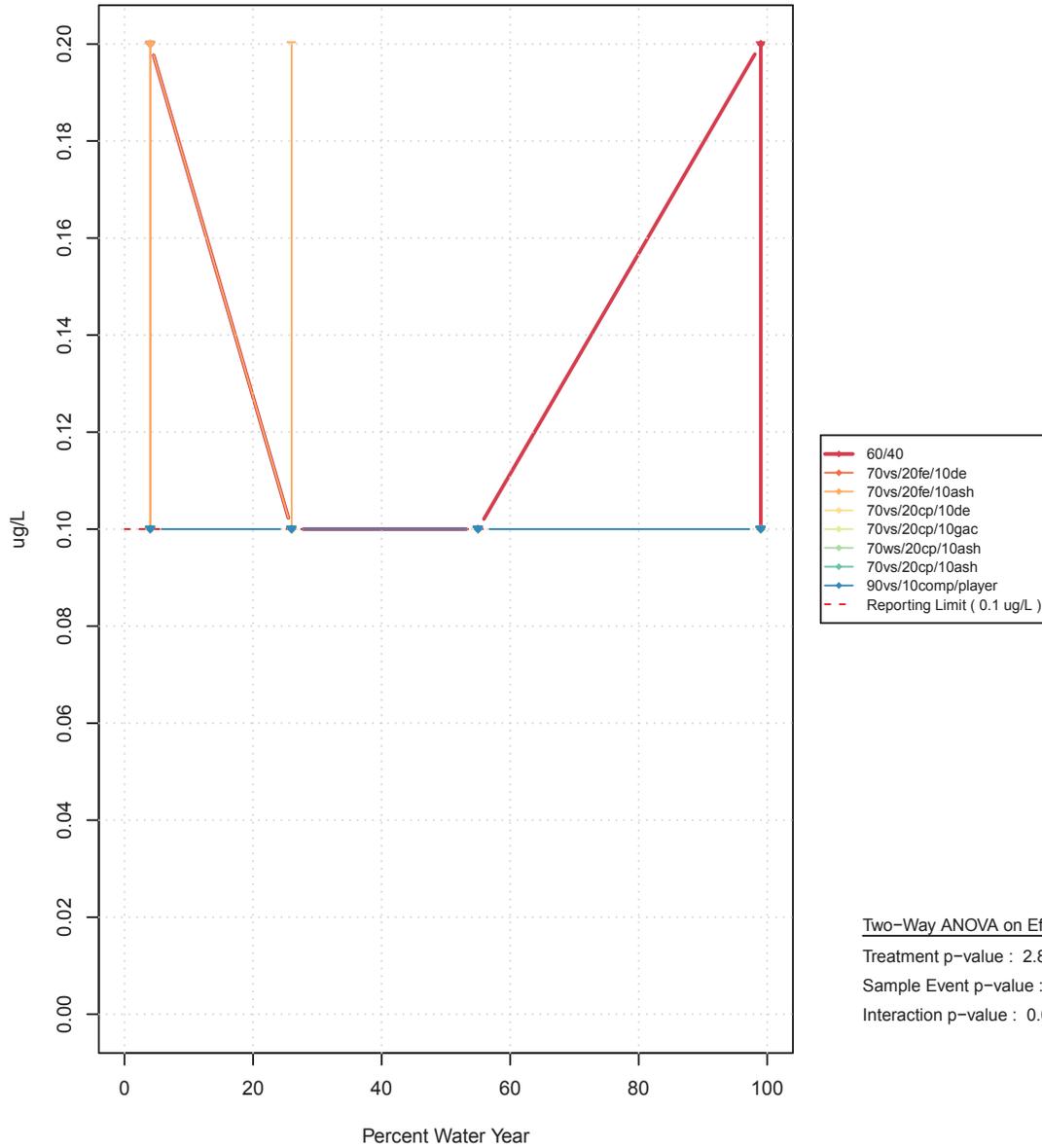
Two-Way ANOVA on Effluent (ranks)
 Treatment p-value : 5.41e-46 ***
 Sample Event p-value : 1.37e-52 ***
 Interaction p-value : 1.65e-18 ***

Effluent Concentration by Treatment

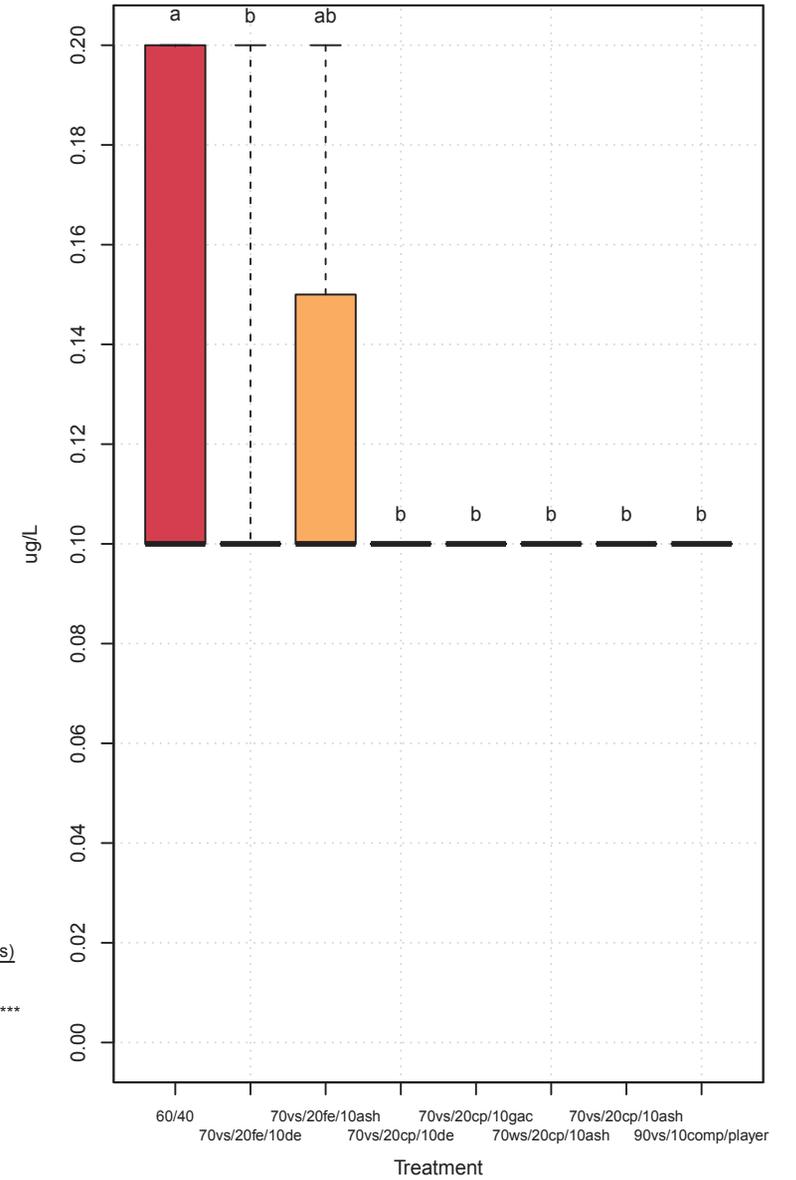


Dissolved Lead

Effluent Concentration by Percent Water Year

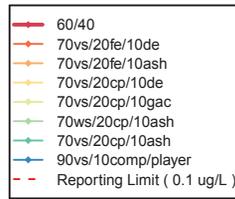
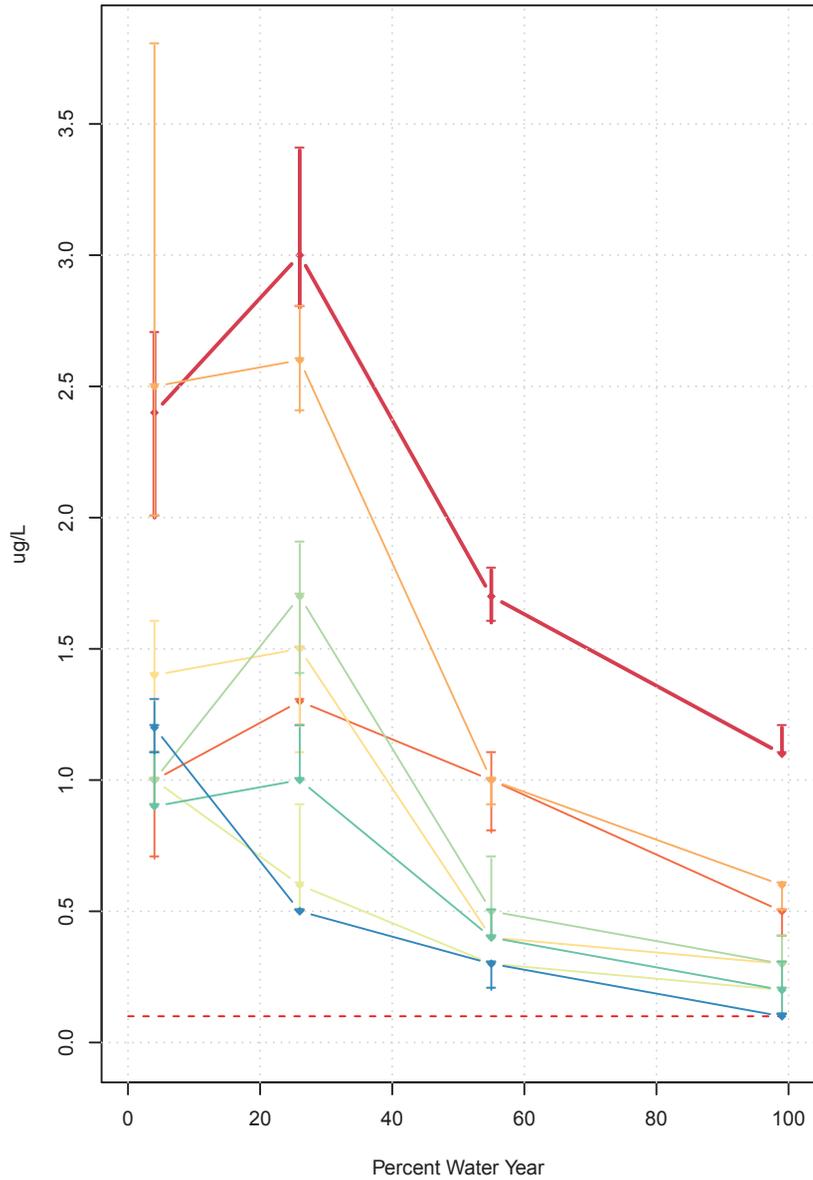


Effluent Concentration by Treatment



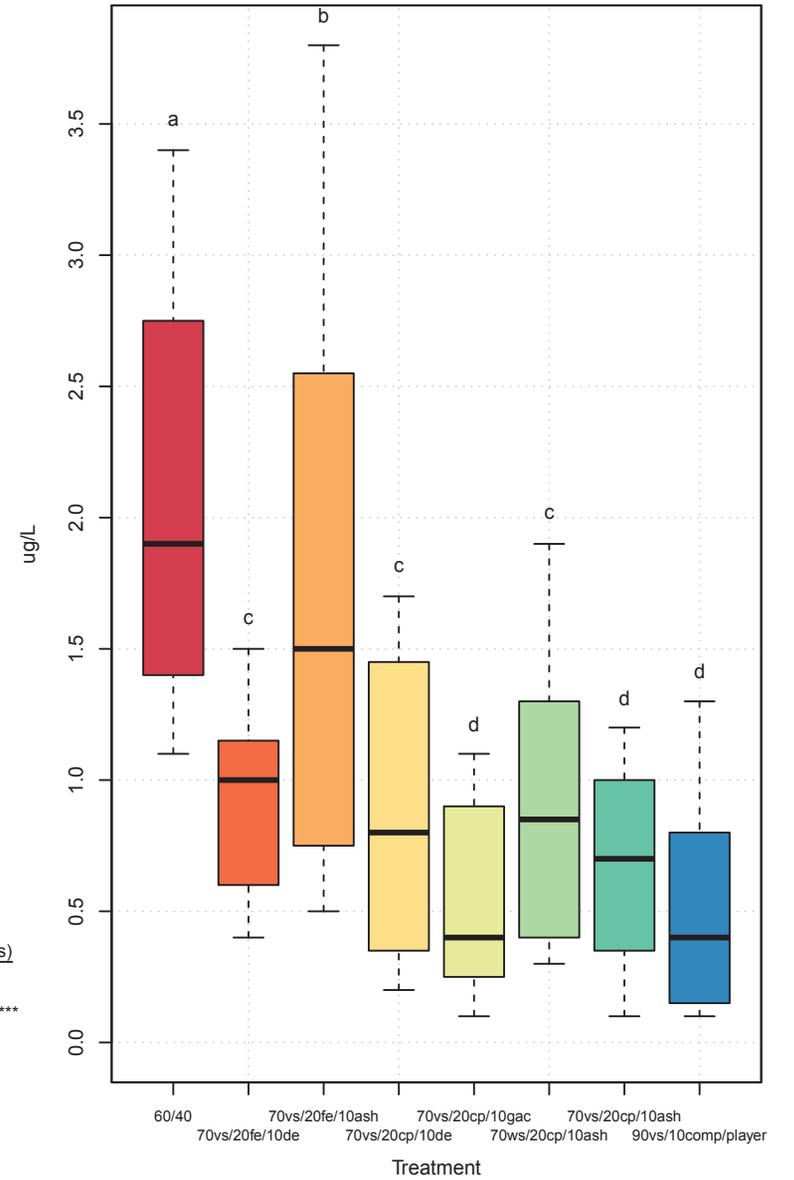
Total Lead

Effluent Concentration by Percent Water Year



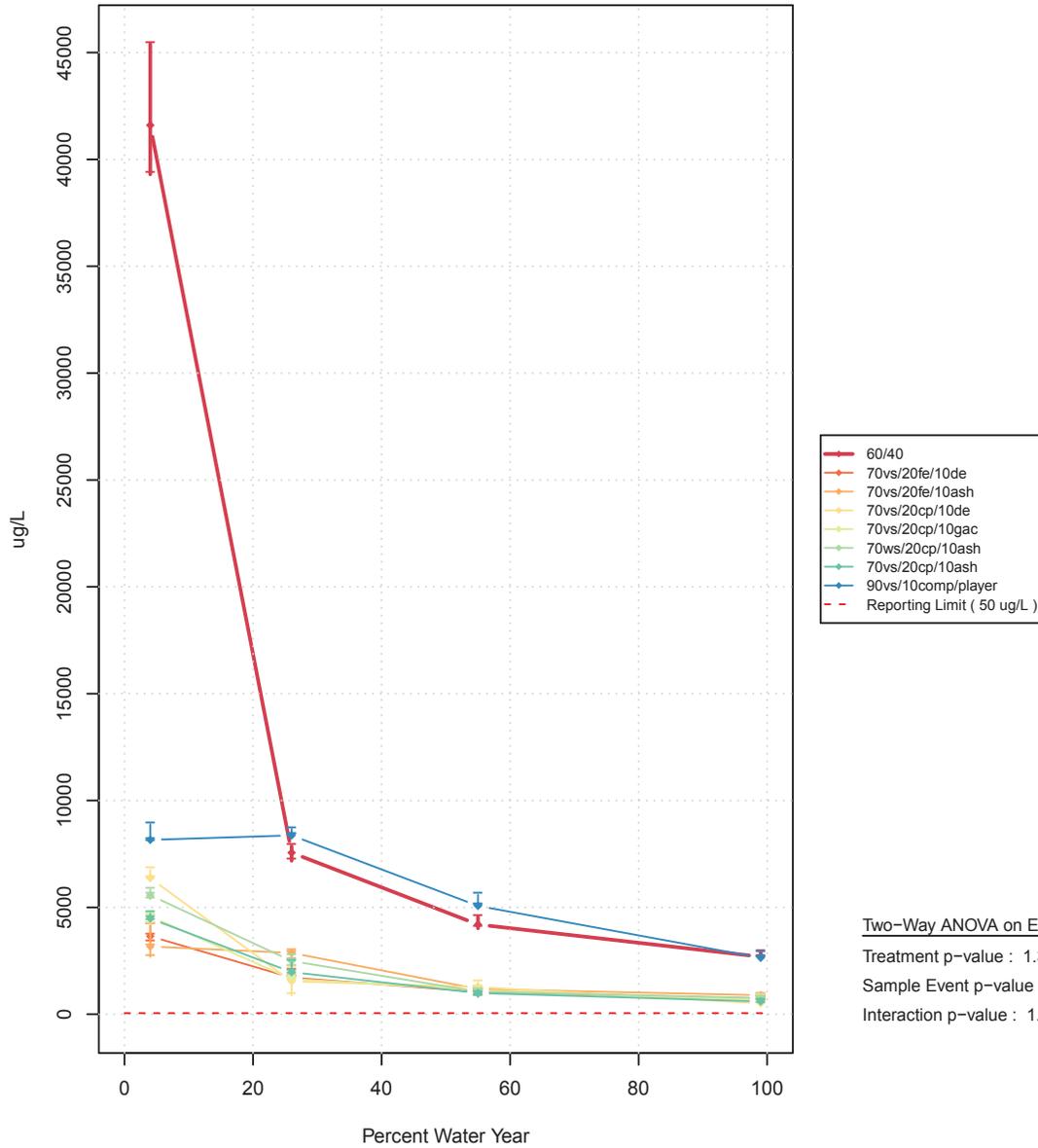
Two-Way ANOVA on Effluent (ranks)
 Treatment p-value : 1.53e-33 ***
 Sample Event p-value : 7.84e-39 ***
 Interaction p-value : 3.92e-12 ***

Effluent Concentration by Treatment

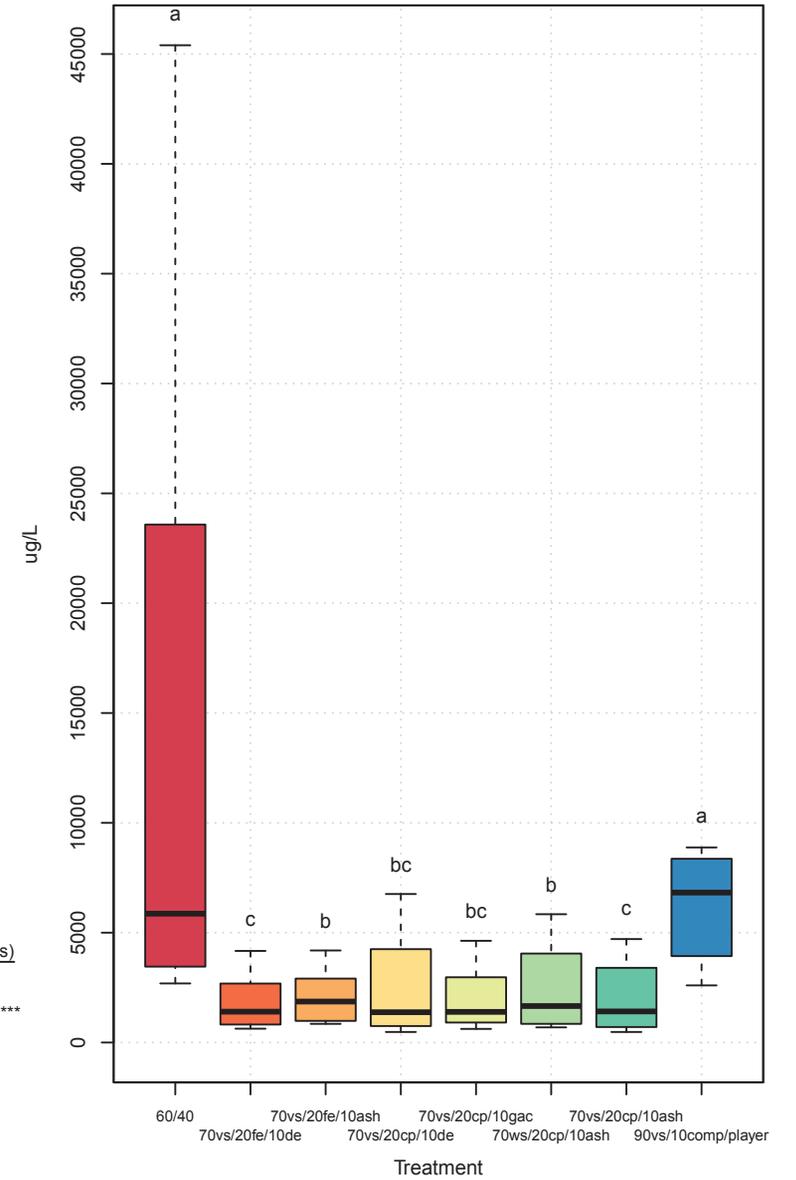


Total Magnesium

Effluent Concentration by Percent Water Year

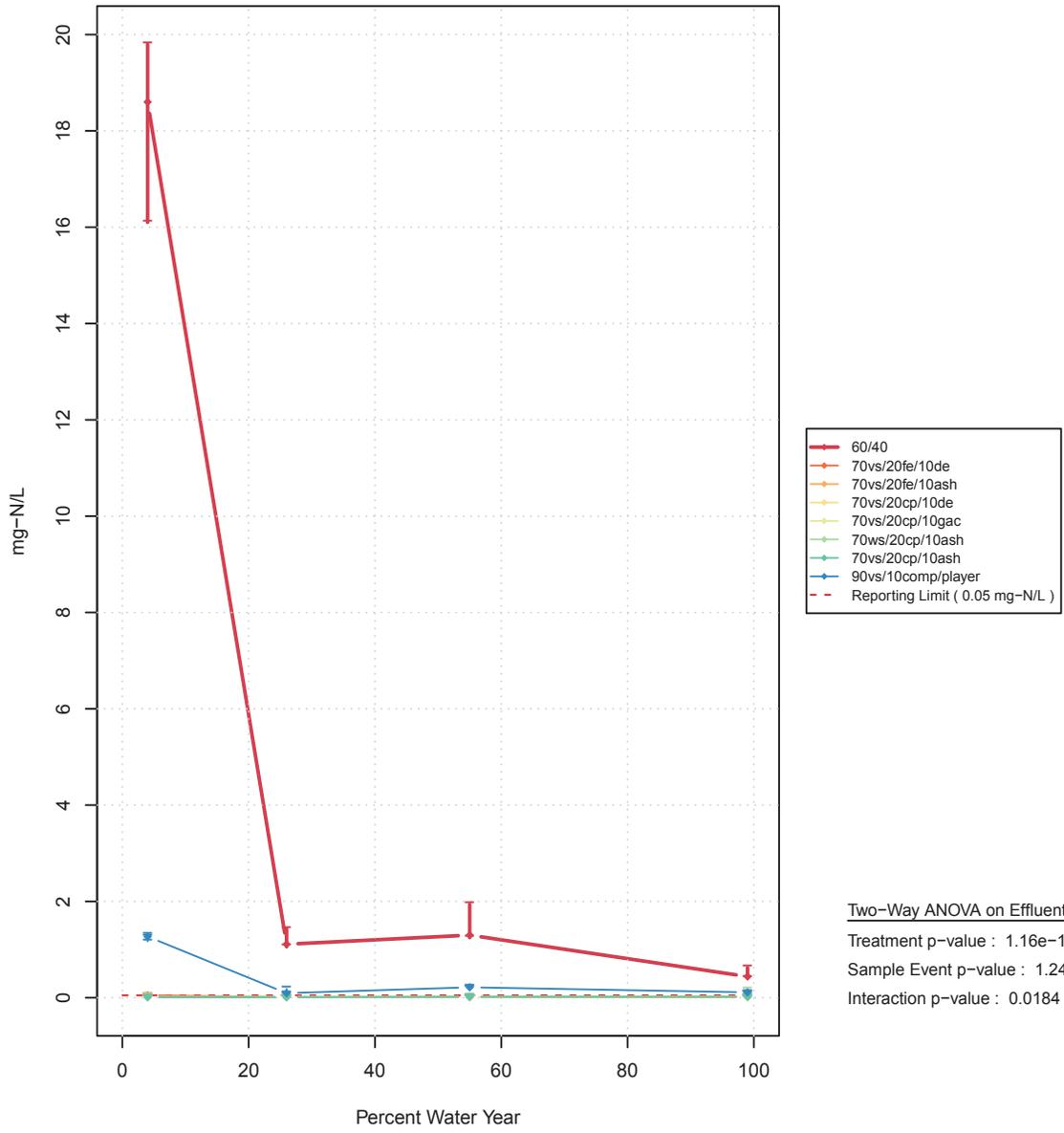


Effluent Concentration by Treatment

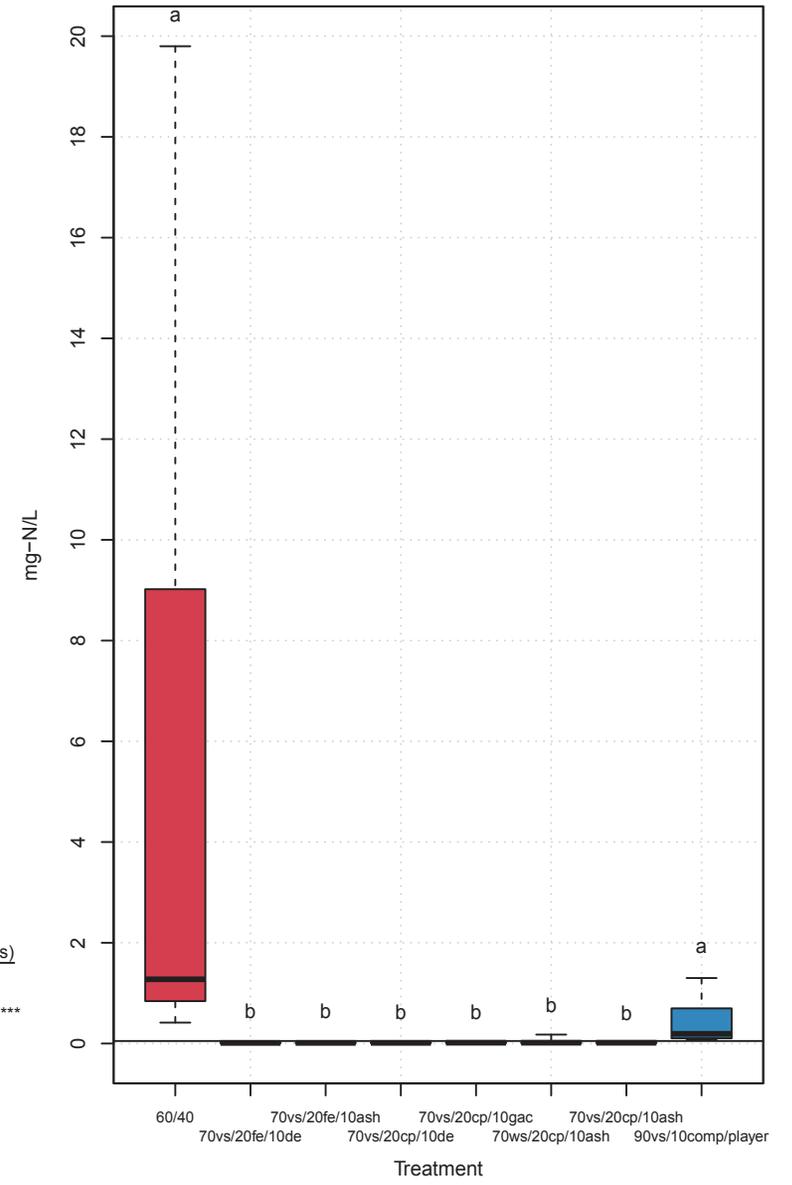


Nitrate + Nitrite

Effluent Concentration by Percent Water Year

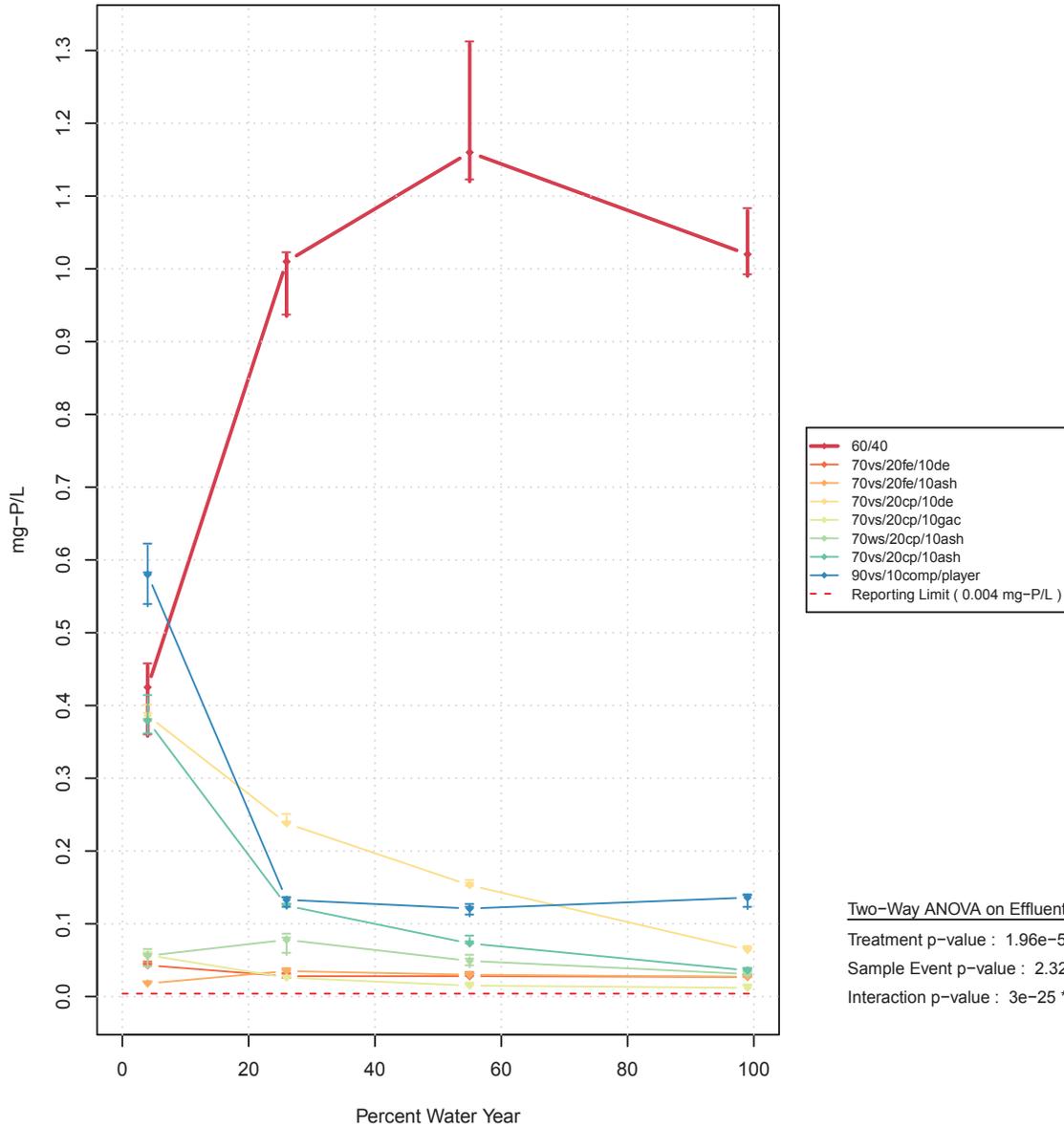


Effluent Concentration by Treatment

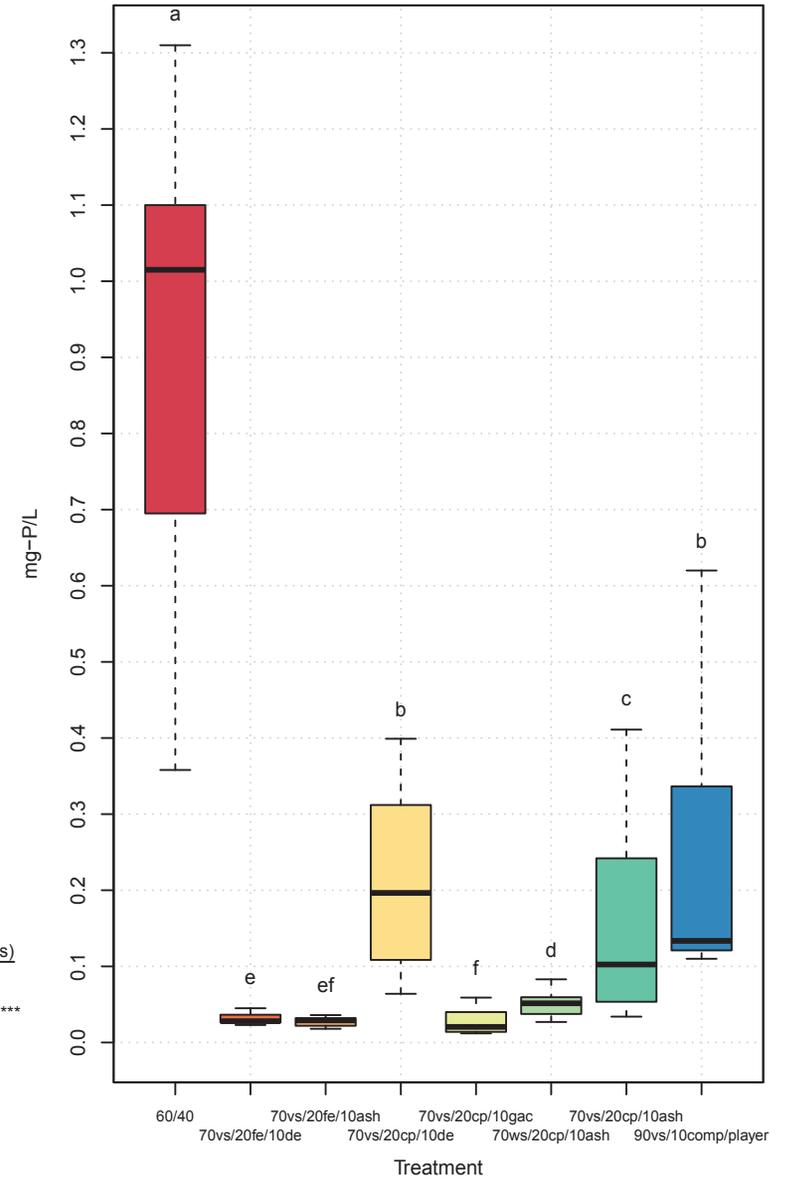


Ortho-Phosphorus

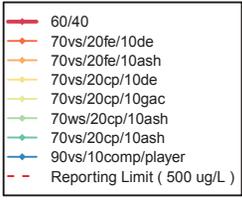
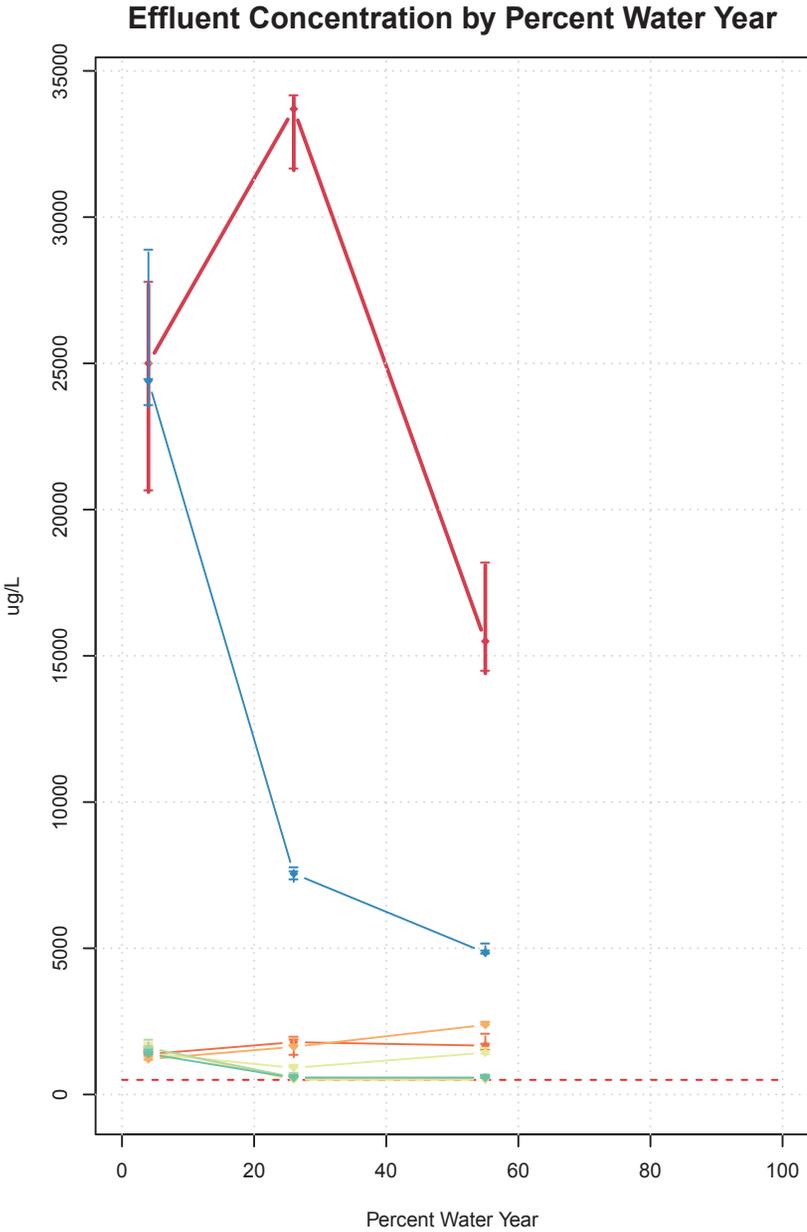
Effluent Concentration by Percent Water Year



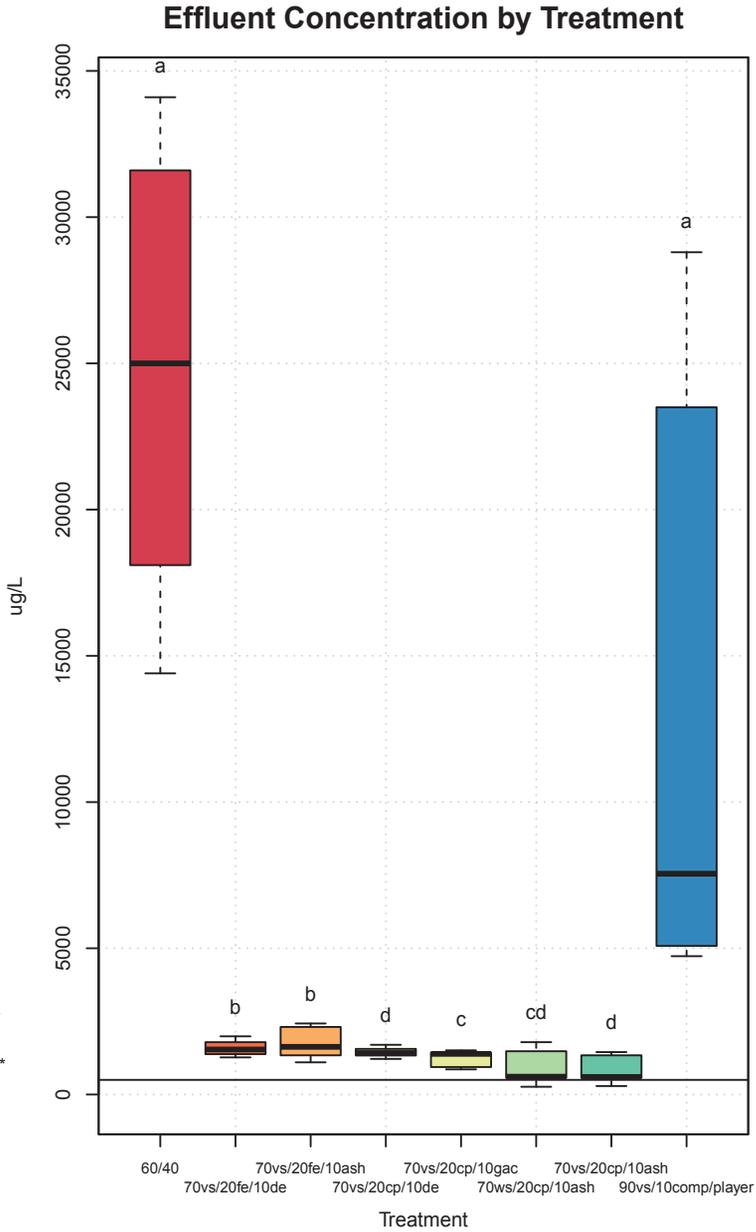
Effluent Concentration by Treatment



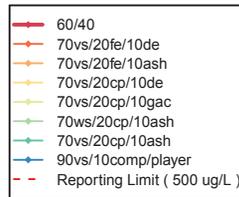
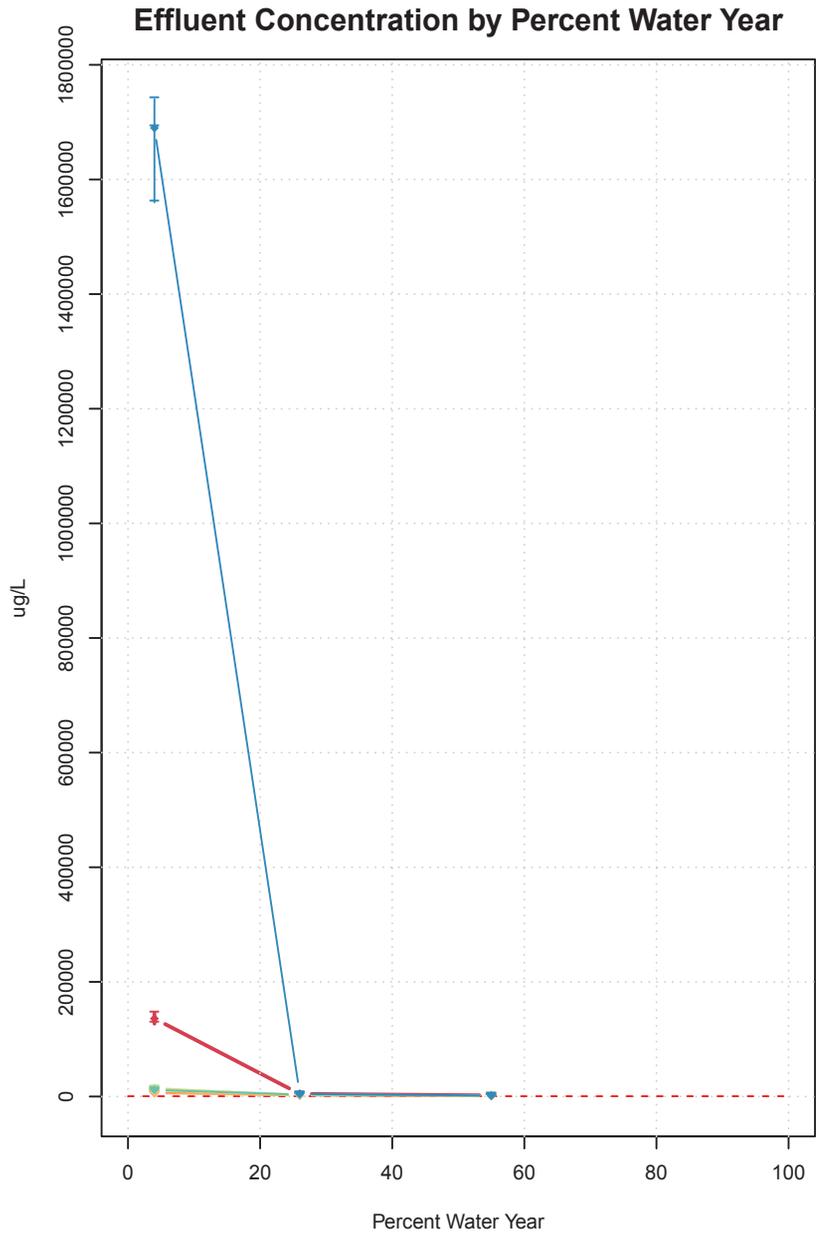
Dissolved Potassium



Two-Way ANOVA on Effluent (ranks)
 Treatment p-value : 5.7e-30 ***
 Sample Event p-value : 4.61e-08 ***
 Interaction p-value : 7.3e-16 ***



Dissolved Sodium

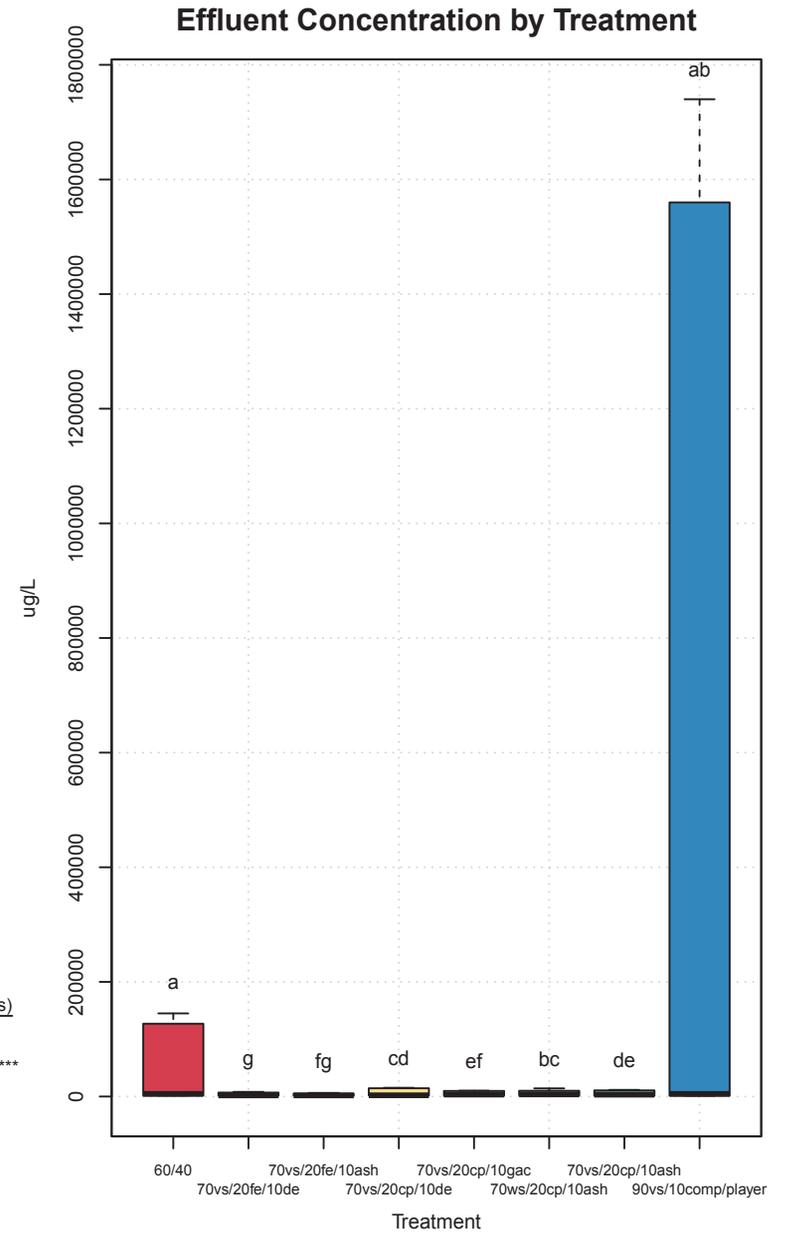


Two-Way ANOVA on Effluent (ranks)

Treatment p-value : 1.95×10^{-20} ***

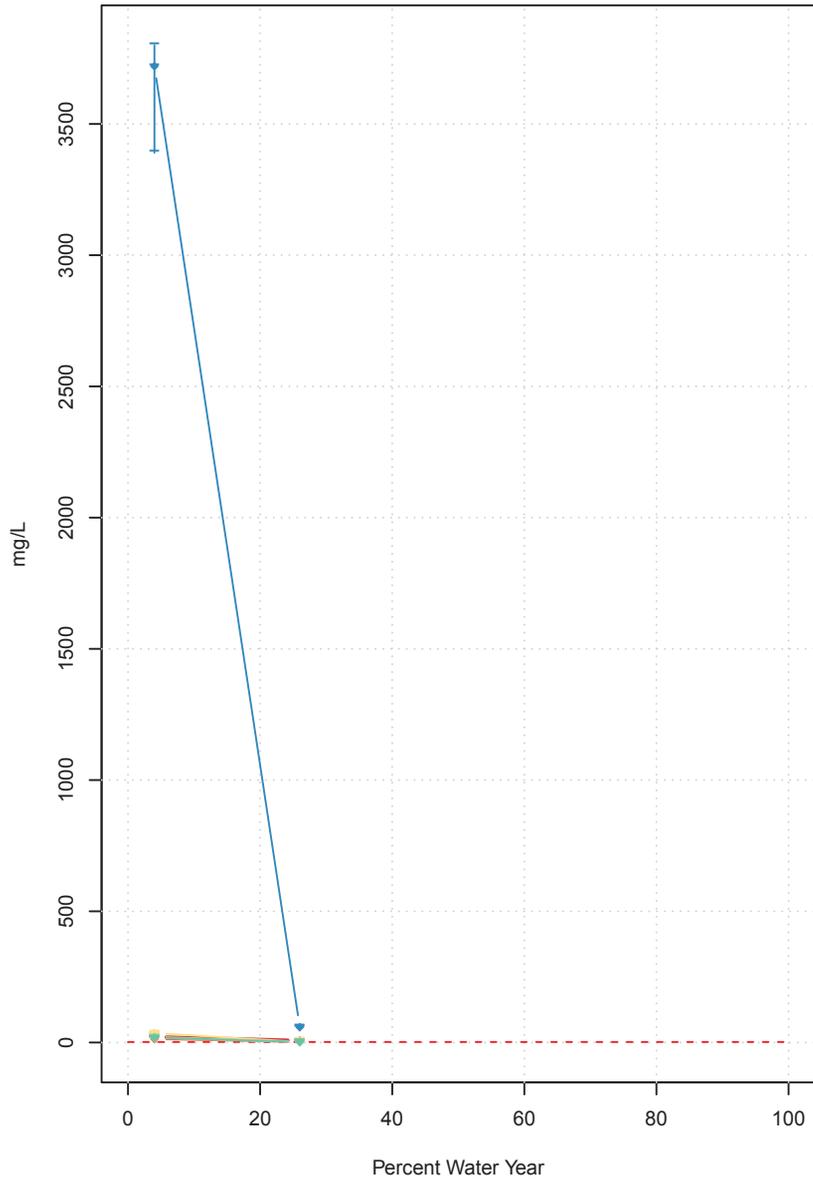
Sample Event p-value : 2.25×10^{-46} ***

Interaction p-value : 5.58×10^{-09} ***



Sulfate

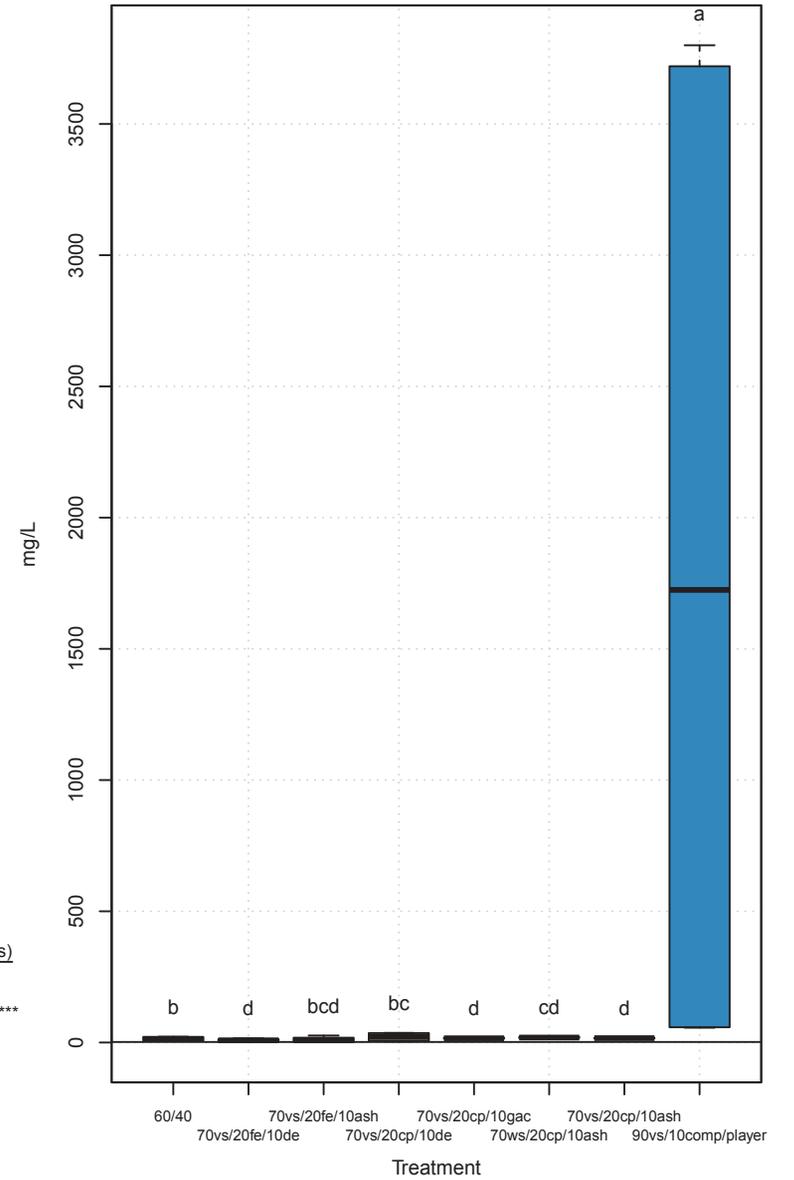
Effluent Concentration by Percent Water Year



- 60/40
- 70vs/20fe/10de
- 70vs/20fe/10ash
- 70vs/20cp/10de
- 70vs/20cp/10gac
- 70vs/20cp/10ash
- 70vs/20cp/10ash
- 90vs/10comp/player
- Reporting Limit (2 mg/L)

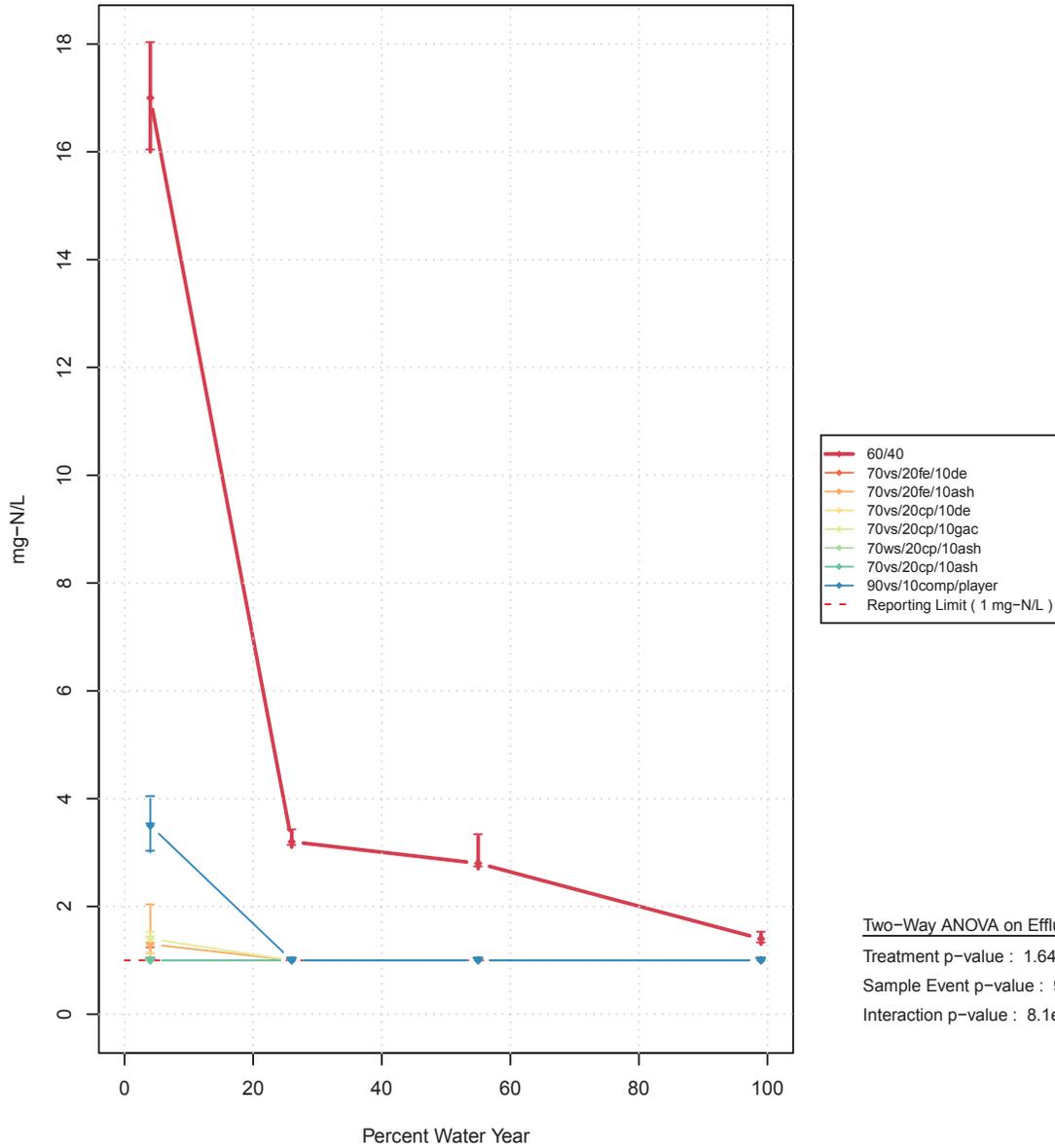
Two-Way ANOVA on Effluent (ranks)
 Treatment p-value : 4.77e-15 ***
 Sample Event p-value : 2.03e-19 ***
 Interaction p-value : 1.66e-07 ***

Effluent Concentration by Treatment

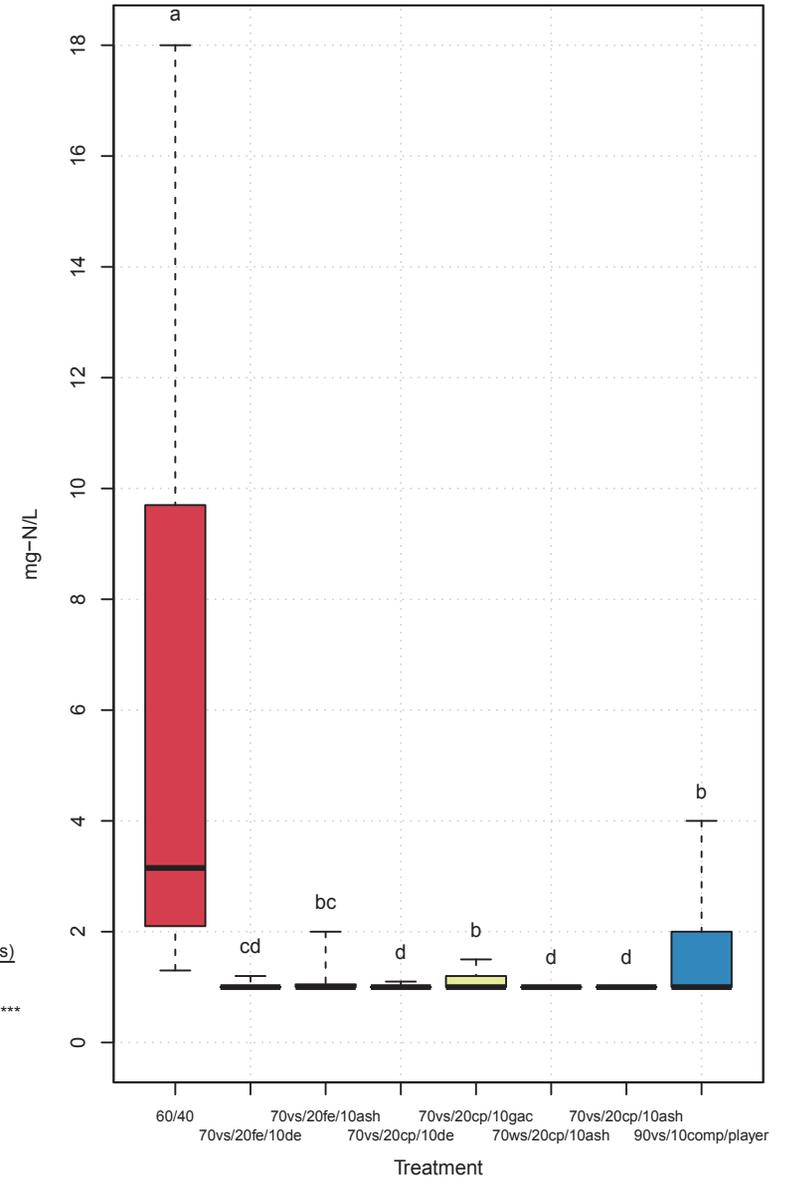


Total Kjeldahl Nitrogen

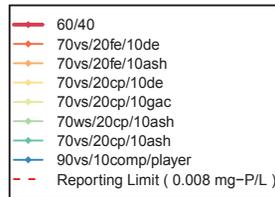
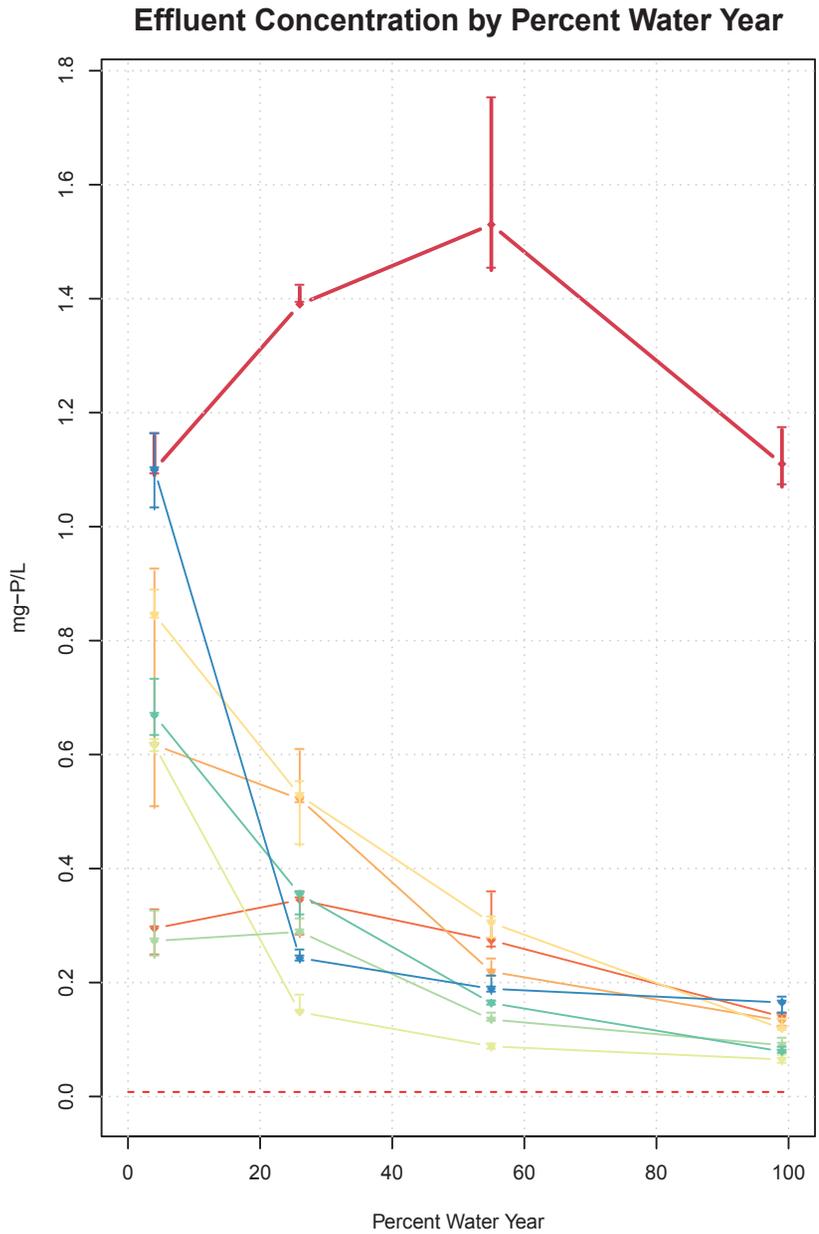
Effluent Concentration by Percent Water Year



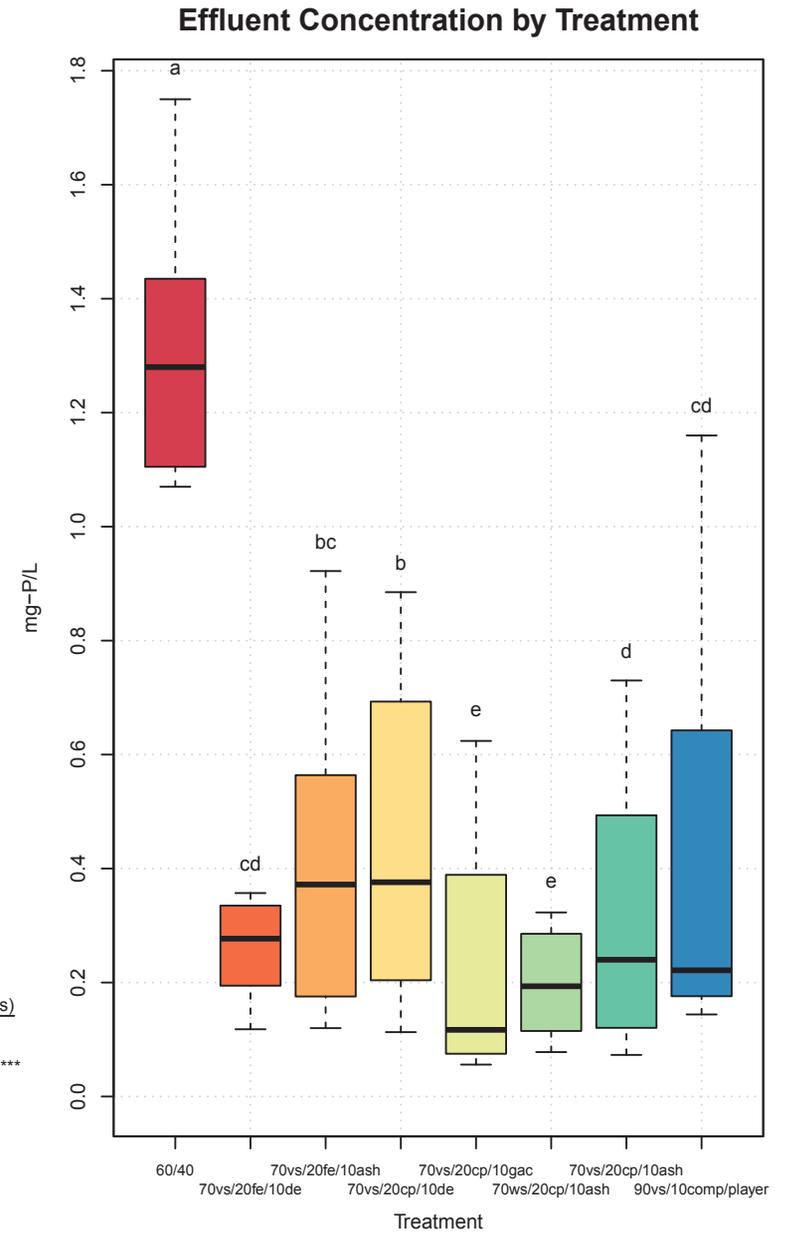
Effluent Concentration by Treatment



Total Phosphorus

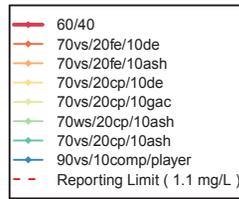
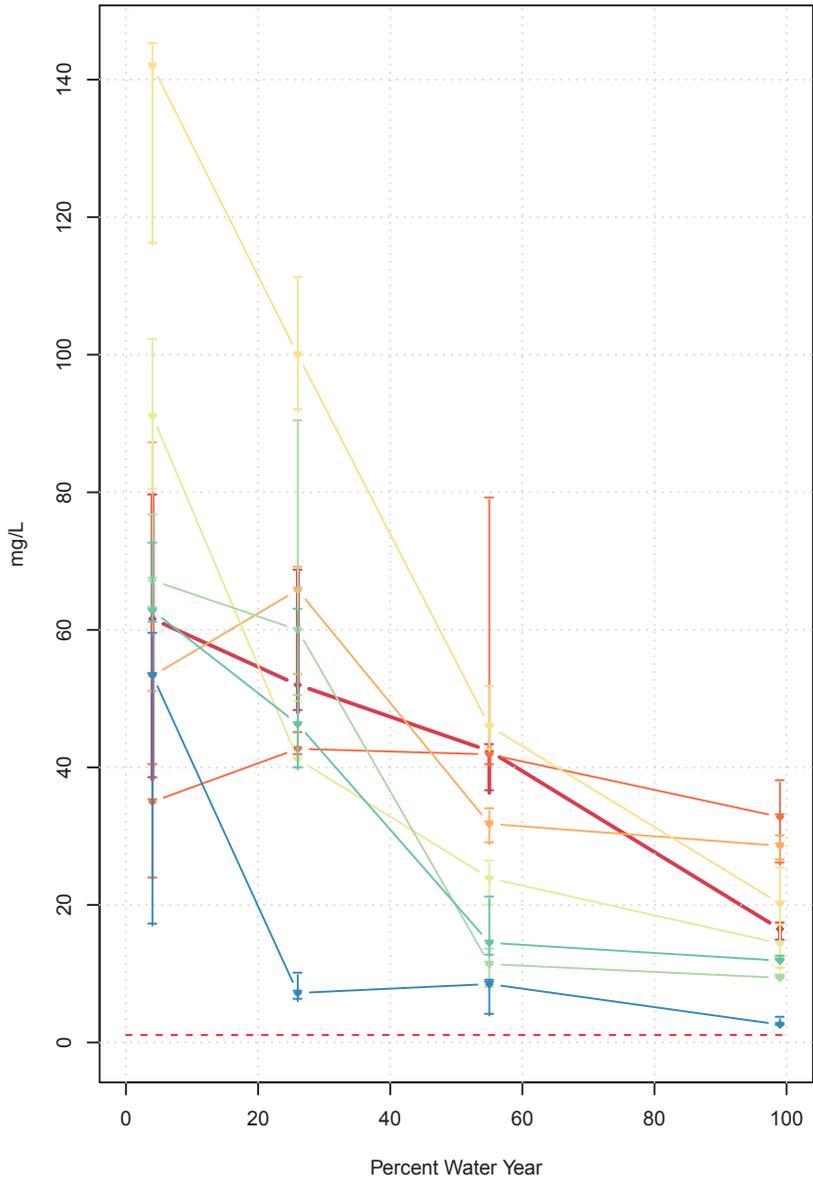


Two-Way ANOVA on Effluent (ranks)
 Treatment p-value : 1.43e-44 ***
 Sample Event p-value : 1.19e-47 ***
 Interaction p-value : 3.48e-27 ***



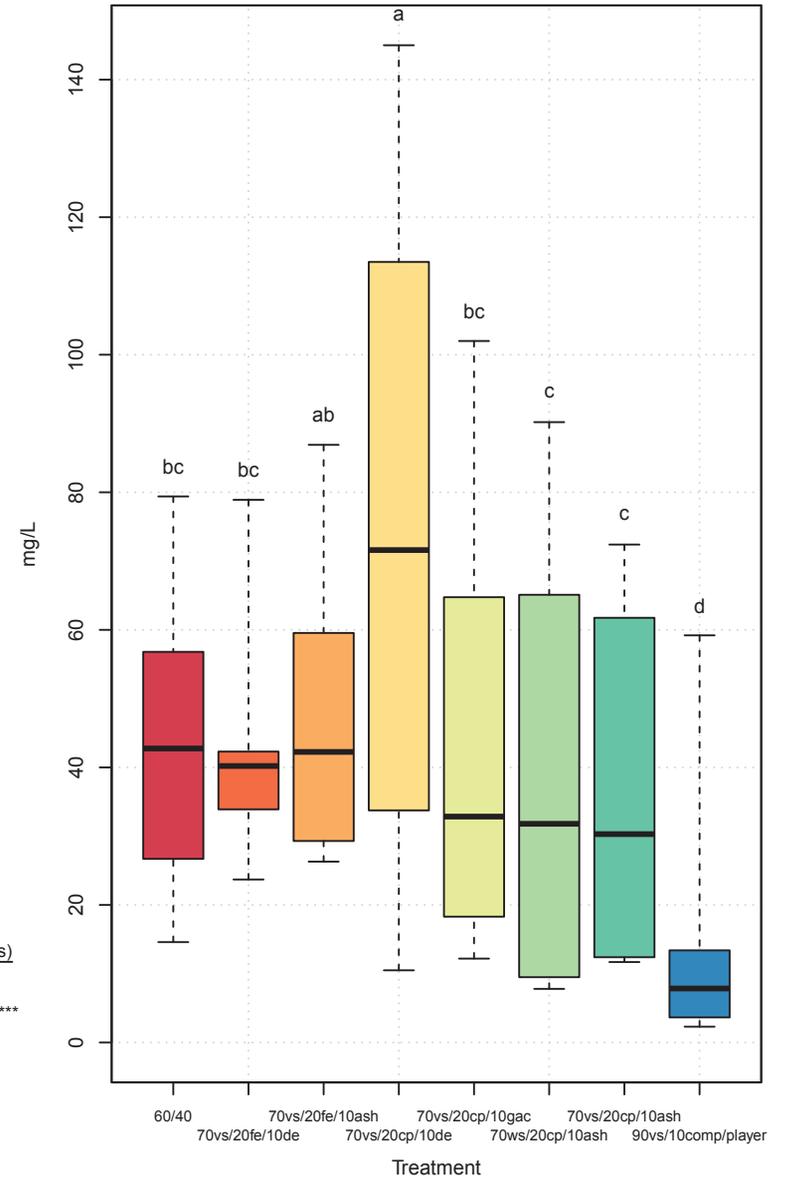
Total Suspended Solids

Effluent Concentration by Percent Water Year



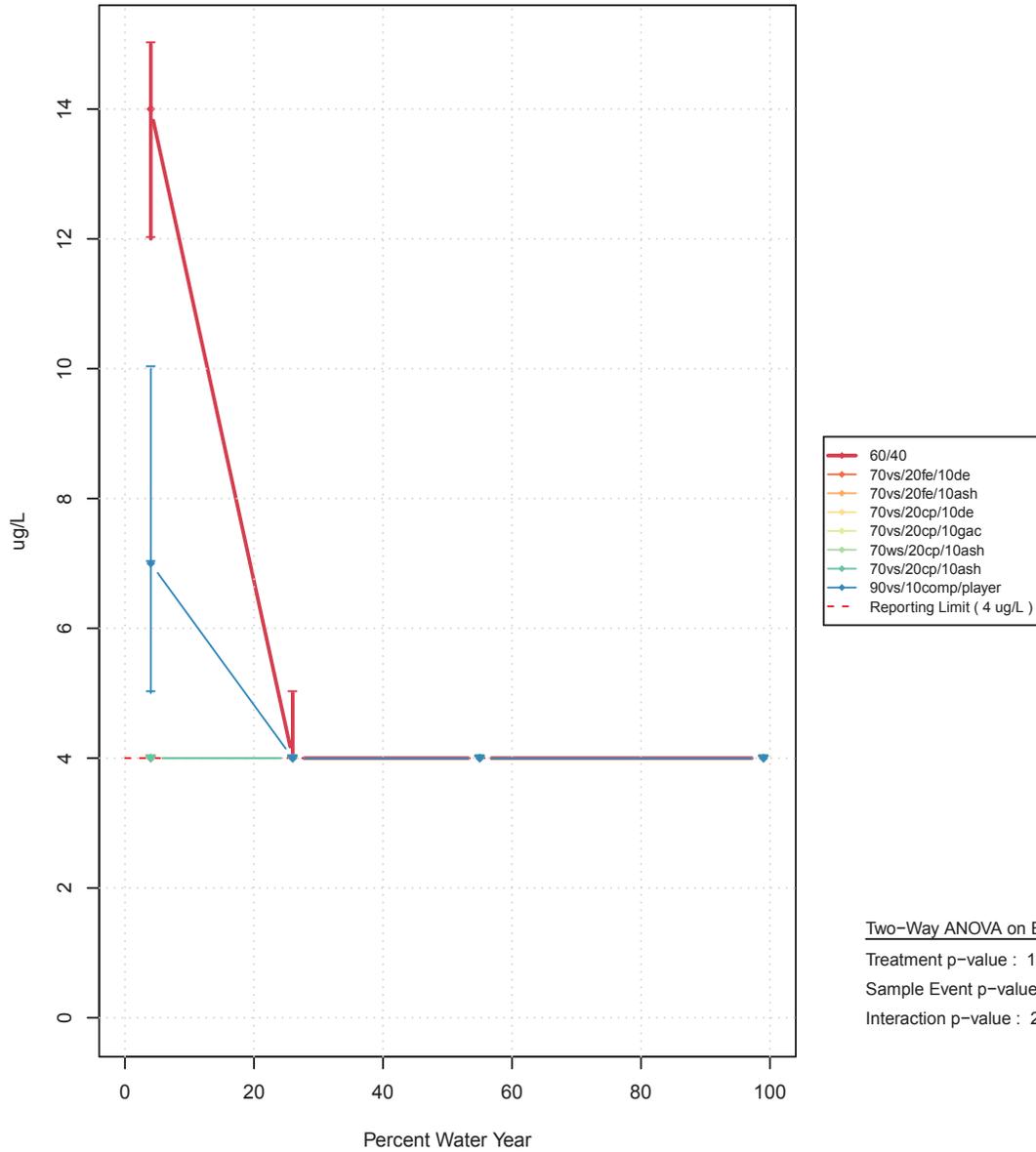
Two-Way ANOVA on Effluent (ranks)
 Treatment p-value : 2.13e-18 ***
 Sample Event p-value : 2.01e-29 ***
 Interaction p-value : 6.44e-12 ***

Effluent Concentration by Treatment



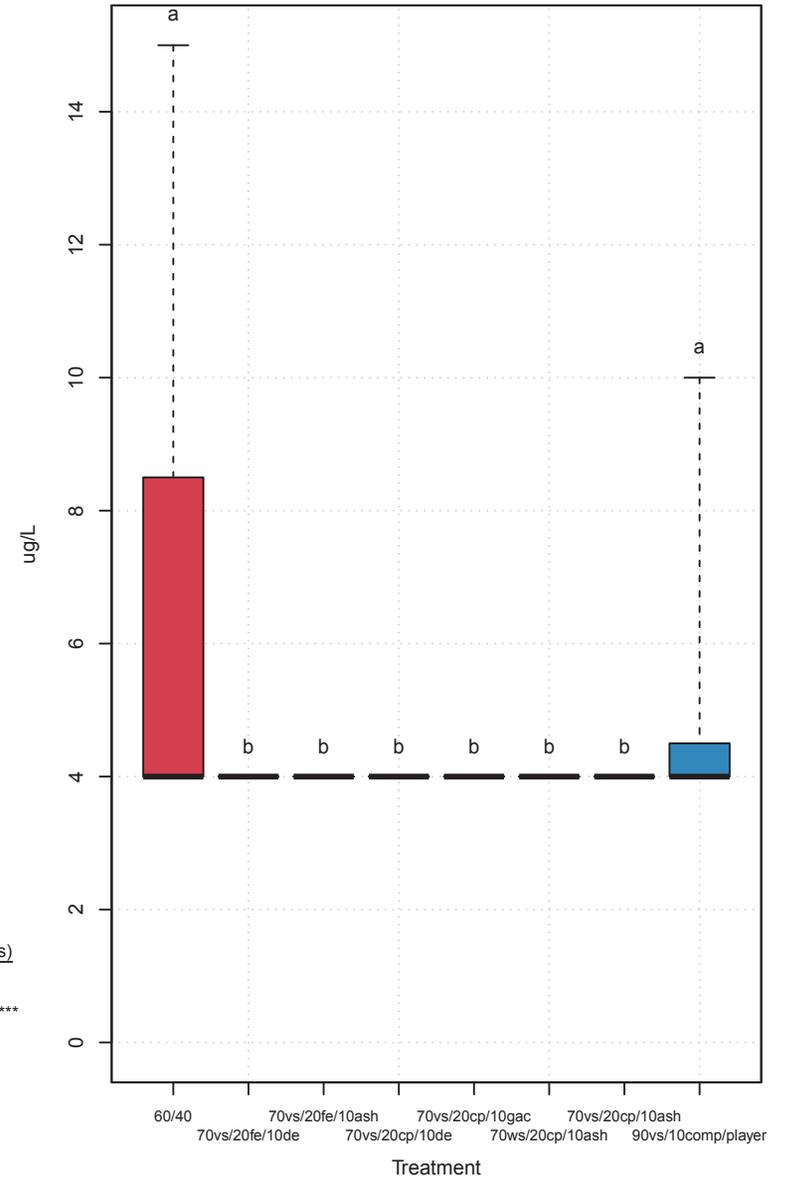
Dissolved Zinc

Effluent Concentration by Percent Water Year



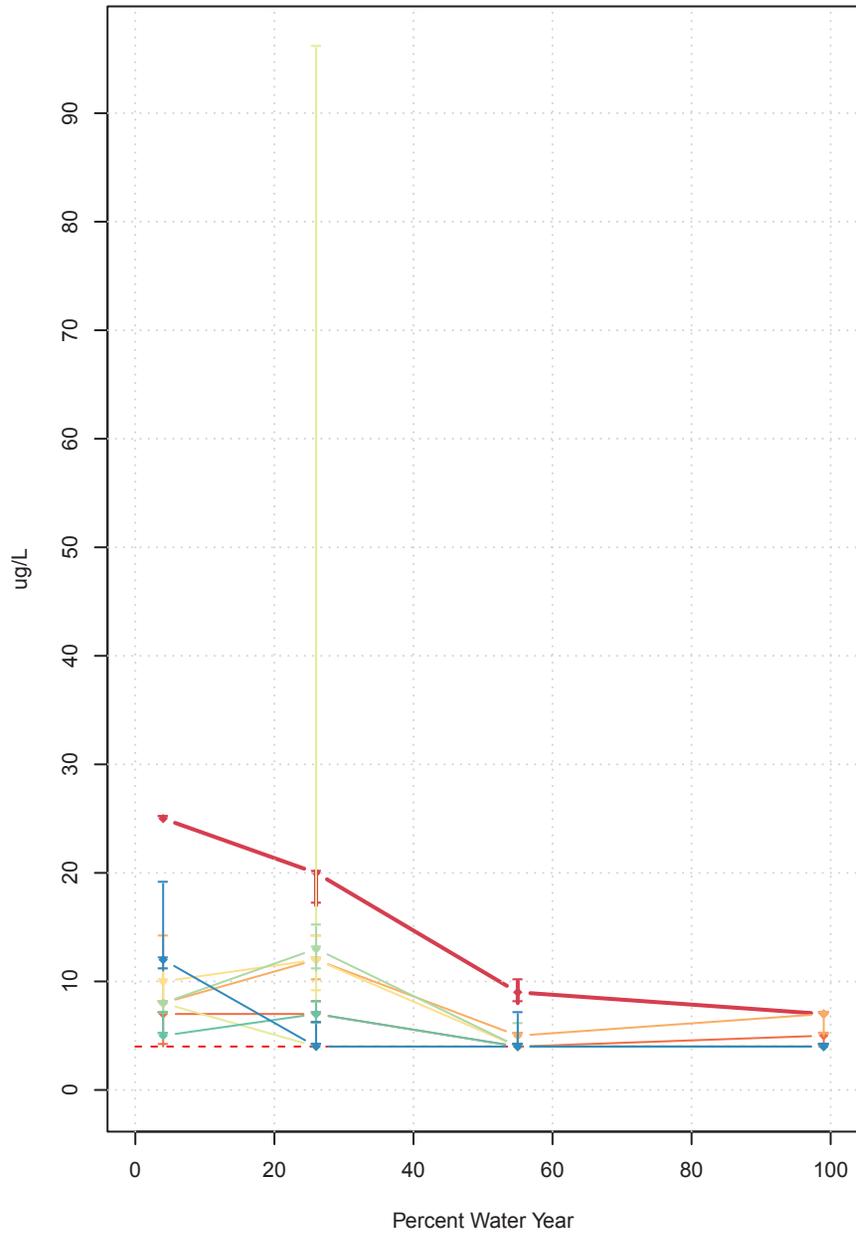
Two-Way ANOVA on Effluent (ranks)
 Treatment p-value : 1.04e-15 ***
 Sample Event p-value : 4.46e-14 ***
 Interaction p-value : 2.17e-18 ***

Effluent Concentration by Treatment

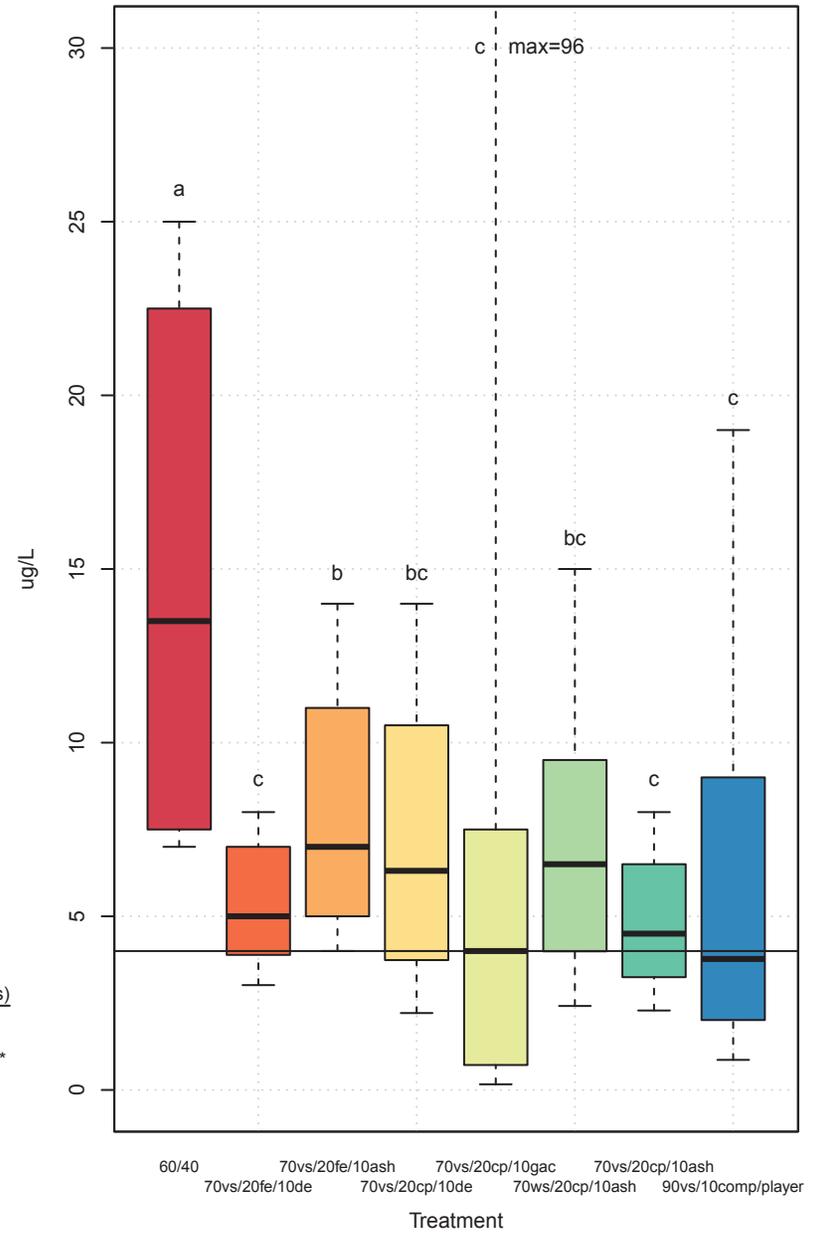


Total Zinc

Effluent Concentration by Percent Water Year



Effluent Concentration by Treatment



APPENDIX G

Tabular Summaries for Flushing Experiment Results

Table G-1. Summary Statistics for Measured Effluent Concentrations During Flushing Experiments.

Parameter/ Treatment	Minimum	25th Percentile	Median	75th Percentile	Maximum
Alkalinity (mg/L as CaCO₃)					
60/40	49.9	52.9	126.0	242.0	271.0
70vs/20fe/10de	6.1	7.2	10.7	11.2	11.6
70vs/20fe/10ash	8.5	9.9	13.0	15.8	21.3
70vs/20cp/10de	4.1	4.7	4.8	5.3	5.4
70vs/20cp/10gac	8.5	9.0	15.0	32.6	34.8
70ws/20cp/10ash	6.8	9.2	11.5	13.9	17.3
70vs/20cp/10ash	5.5	6.7	9.6	12.5	14.2
90vs/10comp/player	28.8	32.8	33.1	174.0	202.0
Cadmium, Dissolved (µg/L)					
60/40	0.1	0.1	0.1	0.1	0.1
70vs/20fe/10de	0.1	0.1	0.1	0.1	0.1
70vs/20fe/10ash	0.1	0.1	0.1	0.1	0.1
70vs/20cp/10de	0.1	0.1	0.1	0.1	0.1
70vs/20cp/10gac	0.1	0.1	0.1	0.1	0.1
70ws/20cp/10ash	0.1	0.1	0.1	0.1	0.1
70vs/20cp/10ash	0.1	0.1	0.1	0.1	0.1
90vs/10comp/player	0.1	0.1	0.1	0.1	0.1
Cadmium, Total (µg/L)					
60/40	0.0	0.0	0.1	0.2	0.4
70vs/20fe/10de	0.1	0.1	0.1	0.1	0.1
70vs/20fe/10ash	0.0	0.1	0.1	0.1	0.2
70vs/20cp/10de	0.0	0.1	0.1	0.1	0.2
70vs/20cp/10gac	0.1	0.1	0.1	0.1	0.1
70ws/20cp/10ash	0.1	0.1	0.1	0.1	0.1
70vs/20cp/10ash	0.1	0.1	0.1	0.1	0.1
90vs/10comp/player	0.1	0.1	0.1	0.1	0.1
Calcium (mg/L)					
60/40	6,980	9,105	16,550	70,300	136,000
70vs/20fe/10de	1,040	1,490	2,915	6,500	10,400
70vs/20fe/10ash	1,320	1,795	3,780	6,015	10,100
70vs/20cp/10de	750	1,070	1,790	9,795	18,000
70vs/20cp/10gac	1,160	1,730	2,735	6,945	11,500
70ws/20cp/10ash	1,200	1,460	2,095	6,755	14,400
70vs/20cp/10ash	1,060	1,415	2,215	7,195	12,000
90vs/10comp/player	8,780	10,550	13,550	14,800	20,300

Table G-1 Continued. Summary Statistics for Measured Effluent Concentrations During Flushing Experiments.

Parameter/ Treatment	Minimum	25th Percentile	Median	75th Percentile	Maximum
Chloride (mg/L)					
60/40	1.3	5.0	149.1	300.0	336.0
70vs/20fe/10de	1.2	1.5	6.7	12.2	14.4
70vs/20fe/10ash	1.9	2.0	3.7	6.3	9.3
70vs/20cp/10de	0.2	0.8	19.8	39.7	42.7
70vs/20cp/10gac	1.2	1.2	5.2	9.4	9.6
70ws/20cp/10ash	0.2	0.9	13.0	29.4	35.7
70vs/20cp/10ash	0.2	0.7	11.8	23.7	24.4
90vs/10comp/player	26.6	32.9	41.0	51.5	62.5
Copper, Dissolved (µg/L)					
60/40	4.4	5.7	9.3	25	39.1
70vs/20fe/10de	1.5	2.1	3.0	5.5	9.9
70vs/20fe/10ash	1.5	2.7	3.8	4.4	6.1
70vs/20cp/10de	0.3	0.8	1.1	1.9	3.6
70vs/20cp/10gac	0.1	0.2	0.5	1.1	2.2
70ws/20cp/10ash	0.3	0.5	0.6	0.7	1.0
70vs/20cp/10ash	0.4	0.8	1.1	1.5	2.2
90vs/10comp/player	0.7	0.9	1.0	3.9	6.8
Copper, Total (µg/L)					
60/40	7.7	8.6	16.4	33.7	44.0
70vs/20fe/10de	5.1	7.5	11.0	12.9	16.3
70vs/20fe/10ash	5.7	8.5	13.0	19.9	27.2
70vs/20cp/10de	2.5	3.8	8.3	14.8	20.5
70vs/20cp/10gac	1.2	2.6	4.4	14.0	19.7
70ws/20cp/10ash	1.7	2.7	6.1	9.3	14.3
70vs/20cp/10ash	1.2	2.9	6.3	10.3	13.9
90vs/10comp/player	1.7	2.9	4.9	14.7	27.4
Dissolved Organic Carbon (mg/L)					
60/40	5.1	7.1	12.4	68.6	138.0
70vs/20fe/10de	2.3	3.5	6.5	22.3	43.5
70vs/20fe/10ash	1.8	3.0	5.7	14.7	26.7
70vs/20cp/10de	0.2	1.3	2.0	5.8	16.6
70vs/20cp/10gac	0.0	0.2	1.1	4.8	17.9
70ws/20cp/10ash	0.0	0.3	1.1	4.0	14.1
70vs/20cp/10ash	0.1	0.4	1.4	4.1	12.0
90vs/10comp/player	0.1	0.4	0.9	3.1	10.7

Table G-1 Continued. Summary Statistics for Measured Effluent Concentrations During Flushing Experiments.

Parameter/ Treatment	Minimum	25th Percentile	Median	75th Percentile	Maximum
Hardness (mg/L)					
60/40	29.0	40.0	65.5	181.8	530.0
70vs/20fe/10de	5.2	7.4	13.0	23.3	43.0
70vs/20fe/10ash	6.9	9.3	17.0	26.3	42.0
70vs/20cp/10de	3.9	6.5	10.2	28.5	73.0
70vs/20cp/10gac	5.5	8.8	12.5	22.3	47.0
70ws/20cp/10ash	6.2	7.1	12.0	25.5	60.0
70vs/20cp/10ash	4.6	7.0	11.3	24.3	48.0
90vs/10comp/player	33.0	46.8	62.0	71.3	87.0
Lead, Dissolved (µg/L)					
60/40	0.1	0.1	0.1	0.2	0.2
70vs/20fe/10de	0.0	0.0	0.1	0.1	0.2
70vs/20fe/10ash	0.0	0.1	0.1	0.1	0.2
70vs/20cp/10de	0.1	0.1	0.1	0.1	0.1
70vs/20cp/10gac	0.1	0.1	0.1	0.1	0.1
70ws/20cp/10ash	0.1	0.1	0.1	0.1	0.1
70vs/20cp/10ash	0.1	0.1	0.1	0.1	0.1
90vs/10comp/player	0.1	0.1	0.1	0.1	0.1
Lead, Total (µg/L)					
60/40	1.1	1.4	1.9	2.8	3.4
70vs/20fe/10de	0.4	0.6	1.0	1.2	1.5
70vs/20fe/10ash	0.5	0.8	1.5	2.6	3.8
70vs/20cp/10de	0.2	0.4	0.8	1.5	1.7
70vs/20cp/10gac	0.1	0.3	0.4	0.9	1.1
70ws/20cp/10ash	0.3	0.4	0.9	1.3	1.9
70vs/20cp/10ash	0.1	0.4	0.7	1.0	1.2
90vs/10comp/player	0.1	0.2	0.4	0.8	1.3
Magnesium (µg/L)					
60/40	2,690	3,455	5,865	23,580	45,400
70vs/20fe/10de	630	820	1,405	2,685	4,170
70vs/20fe/10ash	850	985	1,865	2,910	4,190
70vs/20cp/10de	480	750	1,380	4,250	6,760
70vs/20cp/10gac	620	910	1,395	2,970	4,630
70ws/20cp/10ash	690	850	1,660	4,050	5,840
70vs/20cp/10ash	480	705	1,415	3,400	4,710
90vs/10comp/player	2,600	3,935	6,825	8,365	8,880

Table G-1 Continued. Summary Statistics for Measured Effluent Concentrations During Flushing Experiments.

Parameter/ Treatment	Minimum	25th Percentile	Median	75th Percentile	Maximum
Nitrate + Nitrite (mg-N/L)					
60/40	0.42	0.84	1.28	9.02	19.80
70vs/20fe/10de	0.01	0.01	0.01	0.02	0.02
70vs/20fe/10ash	0.01	0.01	0.01	0.01	0.02
70vs/20cp/10de	0.01	0.01	0.01	0.02	0.02
70vs/20cp/10gac	0.01	0.01	0.02	0.02	0.03
70ws/20cp/10ash	0.00	0.01	0.02	0.02	0.18
70vs/20cp/10ash	0.01	0.01	0.01	0.02	0.02
90vs/10comp/player	0.07	0.10	0.19	0.70	1.30
Ortho-Phosphorus (mg-P/L)					
60/40	0.36	0.70	1.02	1.10	1.31
70vs/20fe/10de	0.02	0.03	0.03	0.04	0.05
70vs/20fe/10ash	0.02	0.02	0.03	0.03	0.04
70vs/20cp/10de	0.06	0.11	0.20	0.31	0.40
70vs/20cp/10gac	0.01	0.01	0.02	0.04	0.06
70ws/20cp/10ash	0.03	0.04	0.05	0.06	0.08
70vs/20cp/10ash	0.03	0.05	0.10	0.24	0.41
90vs/10comp/player	0.11	0.12	0.13	0.34	0.62
Dissolved Potassium (µg/L)					
60/40	14,400	18,100	25,000	31,600	34,100
70vs/20fe/10de	1,270	1,380	1,540	1,790	1,990
70vs/20fe/10ash	1,100	1,340	1,630	2,310	2,430
70vs/20cp/10de	1,218	1,334	1,420	1,560	1,700
70vs/20cp/10gac	860	940	1,390	1,430	1,510
70ws/20cp/10ash	265	570	610	1,480	1,790
70vs/20cp/10ash	290	570	600	1,340	1,450
90vs/10comp/player	4,730	5,080	7,550	23,500	28,800
Dissolved Sodium (µg/L)					
60/40	1810	1,920	4,540	127,000	145,000
70vs/20fe/10de	1180	1,410	1,960	6,880	8,000
70vs/20fe/10ash	1340	1,620	1,970	5,010	6,260
70vs/20cp/10de	1700	1,720	2,140	14,400	15,200
70vs/20cp/10gac	1190	1,230	3,360	9,700	10,100
70ws/20cp/10ash	1750	1,940	3,620	9,990	14,200
70vs/20cp/10ash	1310	1,360	3,190	10,700	11,500
90vs/10comp/player	1610	1,700	4,540	1,560,000	1,740,000

Table G-1 Continued. Summary Statistics for Measured Effluent Concentrations During Flushing Experiments.

Parameter/ Treatment	Minimum	25th Percentile	Median	75th Percentile	Maximum
Sulfate (mg/L)					
60/40	6.6	7.0	13.9	21.0	22.1
70vs/20fe/10de	2.1	2.3	8.3	13.2	15.8
70vs/20fe/10ash	2.5	3.2	8.3	18.3	26.6
70vs/20cp/10de	3.9	6.9	21.2	35.5	36.7
70vs/20cp/10gac	13.5	14.8	16.1	18.3	19.3
70ws/20cp/10ash	16.1	17.4	18.8	20.8	22.1
70vs/20cp/10ash	14.8	15.7	16.7	17.9	18.8
90vs/10comp/player	56.5	58.2	1724.5	3720.0	3800.0
Total Kjeldahl Nitrogen (mg-N/L)					
60/40	1.3	2.1	3.2	9.7	18.0
70vs/20fe/10de	0.5	0.6	0.7	0.9	1.2
70vs/20fe/10ash	0.2	0.4	0.6	1.0	2.0
70vs/20cp/10de	0.7	0.8	0.9	0.9	1.1
70vs/20cp/10gac	1.1	1.2	1.2	1.3	1.5
70ws/20cp/10ash	1.0	1.0	1.0	1.0	1.0
70vs/20cp/10ash	1.0	1.0	1.0	1.0	1.0
90vs/10comp/player	1.1	1.6	2.0	2.6	4.0
Total Phosphorus (mg-P/L)					
60/40	1.07	1.11	1.28	1.44	1.75
70vs/20fe/10de	0.12	0.19	0.28	0.34	0.36
70vs/20fe/10ash	0.12	0.18	0.37	0.56	0.92
70vs/20cp/10de	0.11	0.20	0.38	0.69	0.89
70vs/20cp/10gac	0.06	0.08	0.12	0.39	0.62
70ws/20cp/10ash	0.08	0.12	0.19	0.29	0.32
70vs/20cp/10ash	0.07	0.12	0.24	0.49	0.73
90vs/10comp/player	0.14	0.18	0.22	0.64	1.16
Total Suspended Solids (mg/L)					
60/40	14.6	26.7	42.8	56.8	79.4
70vs/20fe/10de	23.7	33.9	40.2	42.3	44.8
70vs/20fe/10ash	26.3	29.3	42.3	59.6	86.9
70vs/20cp/10de	10.5	33.8	71.6	113.5	145.0
70vs/20cp/10gac	12.2	18.3	32.9	64.8	102.0
70ws/20cp/10ash	7.8	9.5	31.8	65.1	90.2
70vs/20cp/10ash	11.7	12.4	30.3	61.8	72.4
90vs/10comp/player	2.3	3.7	7.9	13.4	17.0

Table G-1 Continued. Summary Statistics for Measured Effluent Concentrations During Flushing Experiments.

Parameter/ Treatment	Minimum	25th Percentile	Median	75th Percentile	Maximum
Zinc, Dissolved (µg/L)					
60/40	0.7	1.8	3.3	6.8	15.0
70vs/20fe/10de	4.0	4.0	4.0	4.0	4.0
70vs/20fe/10ash	4.0	4.0	4.0	4.0	4.0
70vs/20cp/10de	4.0	4.0	4.0	4.0	4.0
70vs/20cp/10gac	4.0	4.0	4.0	4.0	4.0
70ws/20cp/10ash	4.0	4.0	4.0	4.0	4.0
70vs/20cp/10ash	4.0	4.0	4.0	4.0	4.0
90vs/10comp/player	0.4	1.1	1.9	3.7	10.0
Zinc, Total (µg/L)					
60/40	7.0	7.5	13.5	22.5	25.0
70vs/20fe/10de	3.0	3.9	5.0	7.0	8.0
70vs/20fe/10ash	4.0	5.0	7.0	11.0	14.0
70vs/20cp/10de	2.2	3.9	6.3	10.3	14.0
70vs/20cp/10gac	0.2	0.8	4.0	7.3	96.0
70ws/20cp/10ash	2.4	4.1	6.5	8.8	15.0
70vs/20cp/10ash	2.3	3.3	4.5	6.3	8.0
90vs/10comp/player	0.9	2.1	3.8	8.0	19.0

µg/L: micrograms per liter

mg/L: milligrams per liter

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

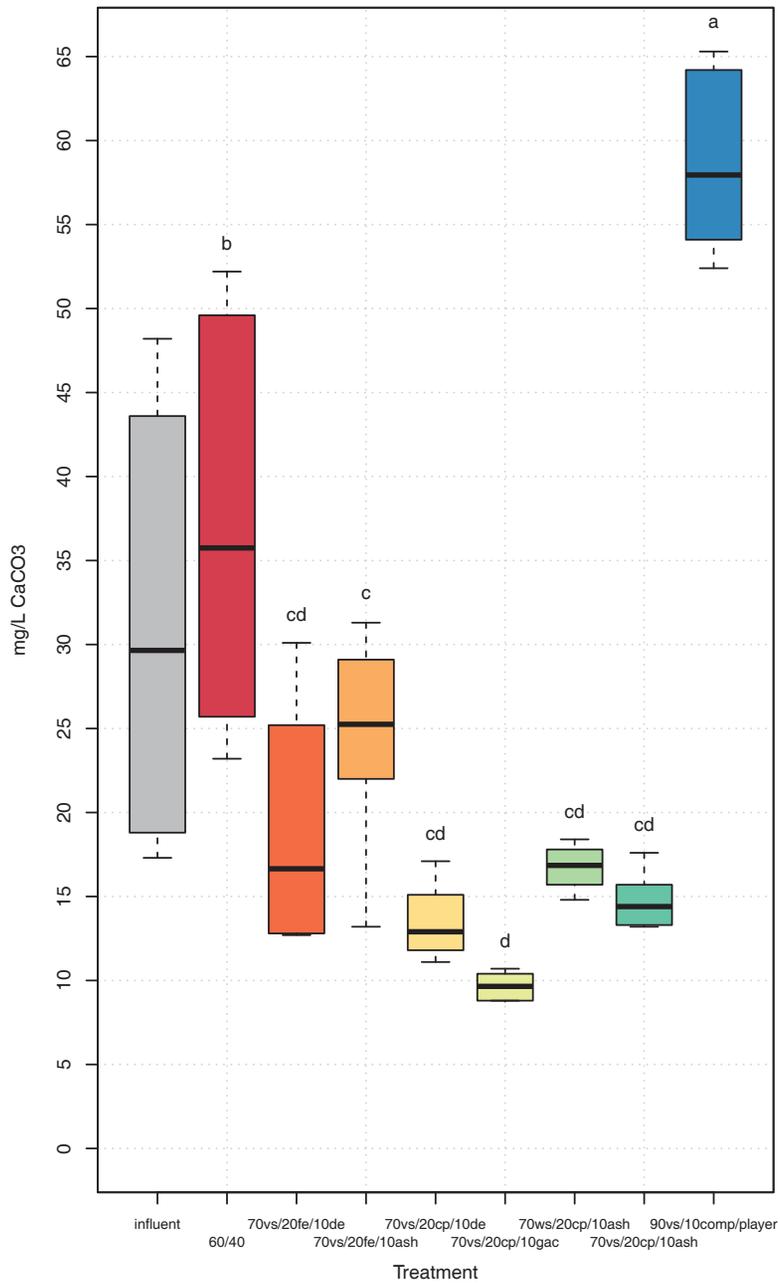
player: polishing layer

APPENDIX H

Graphical Summaries for Dosing Experiment Results

Alkalinity

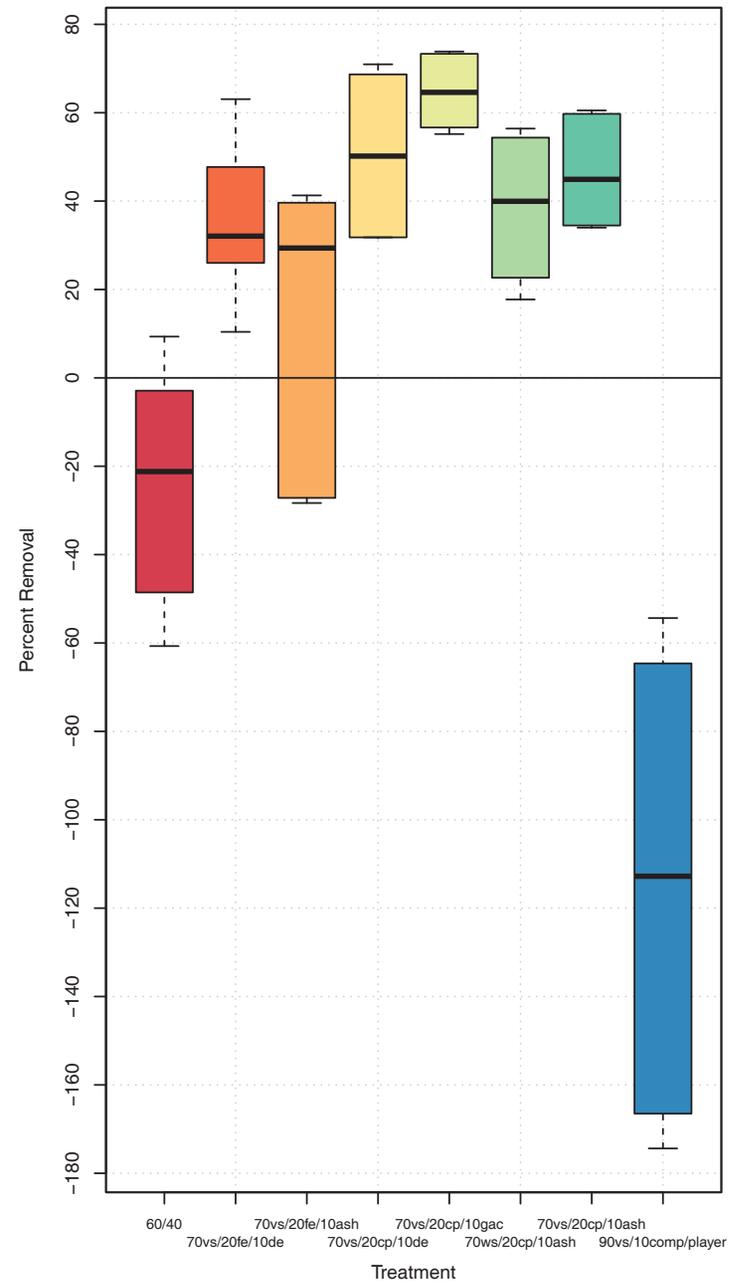
Effluent Concentration by Treatment



Two-Way ANOVA on Removal (ranks)

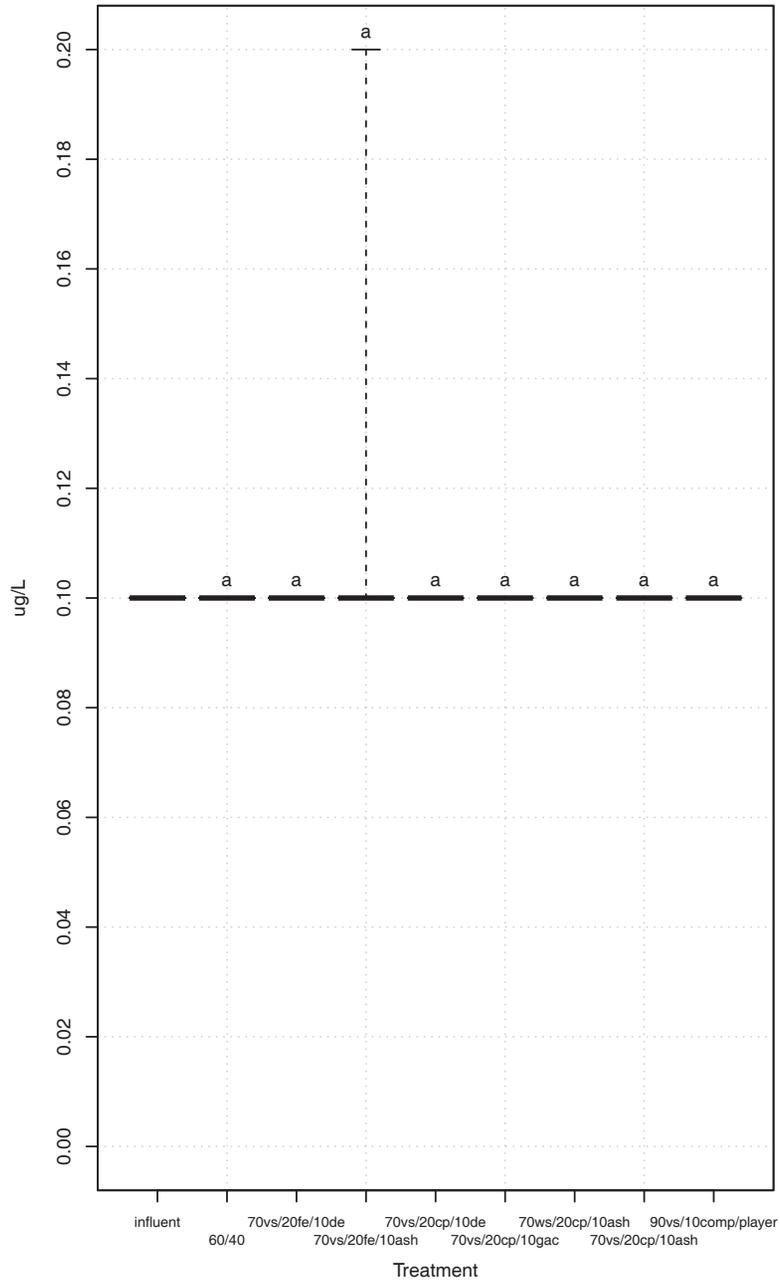
Treatment p-value : 1.57e-09 ***

Percent Removal by Treatment

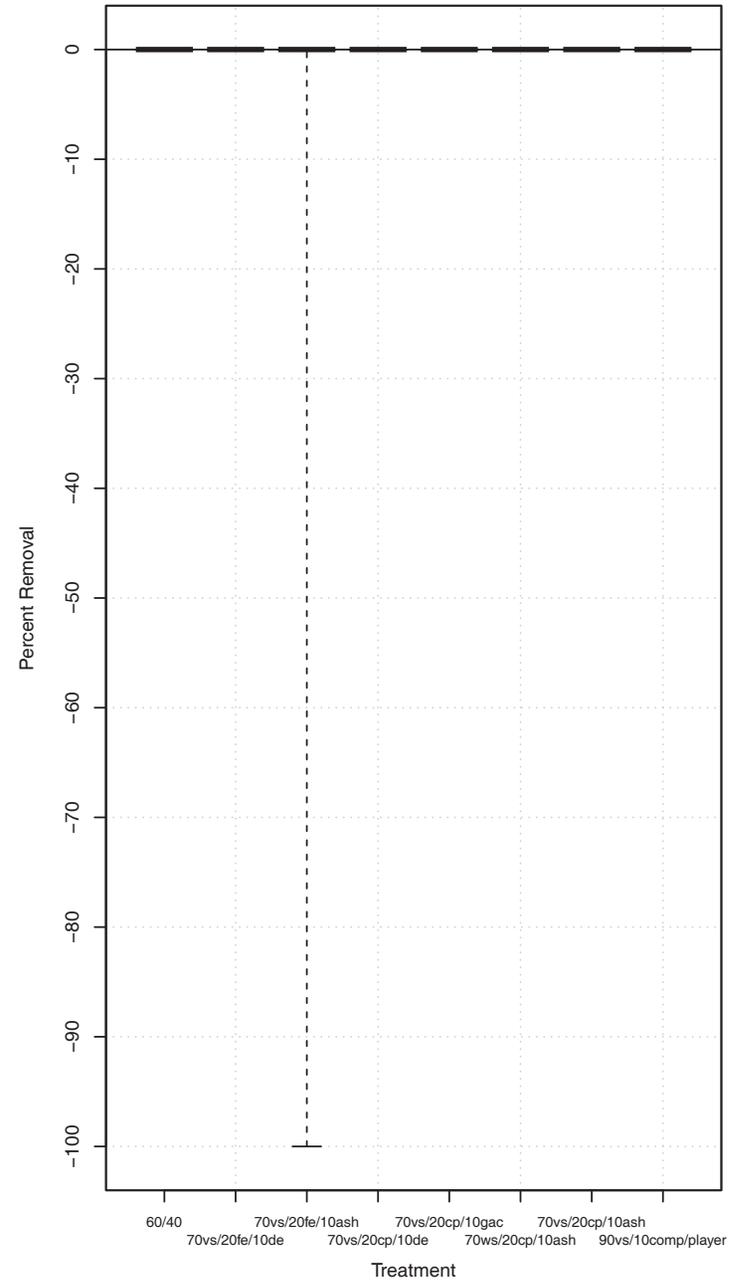


Dissolved Cadmium

Effluent Concentration by Treatment



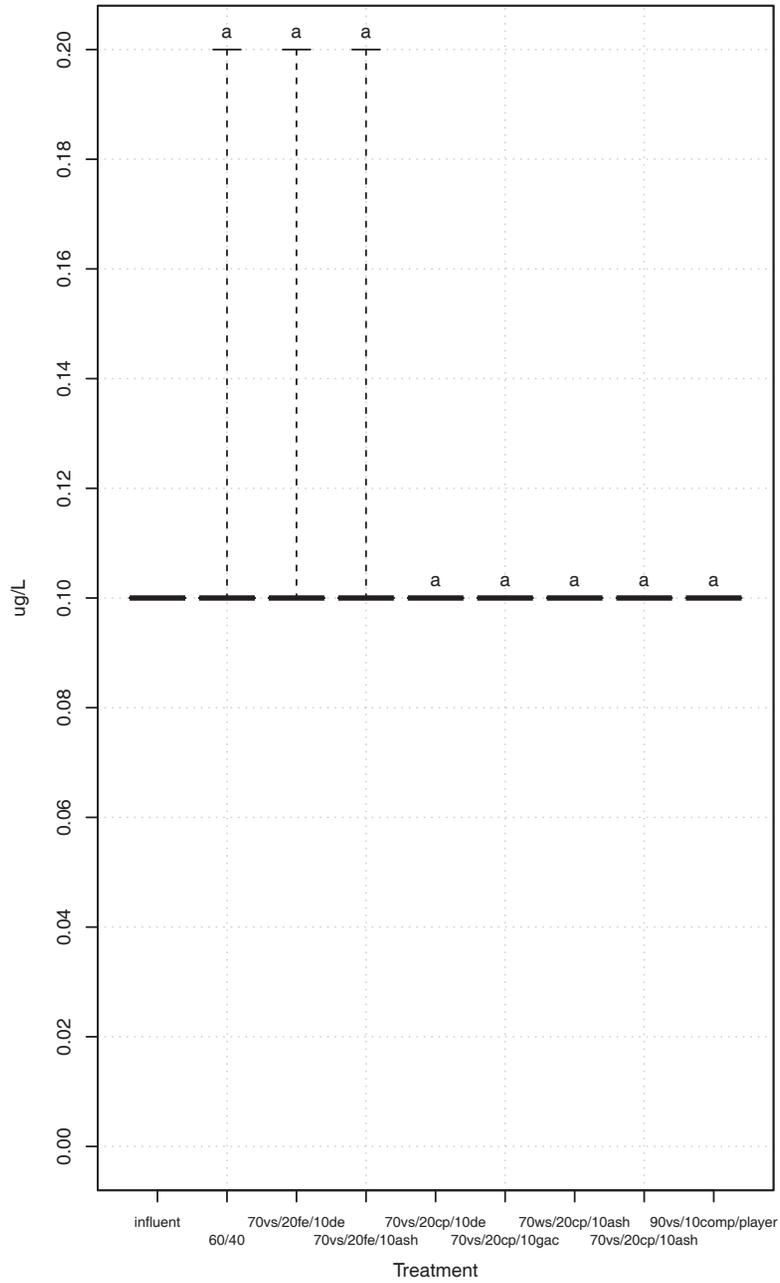
Percent Removal by Treatment



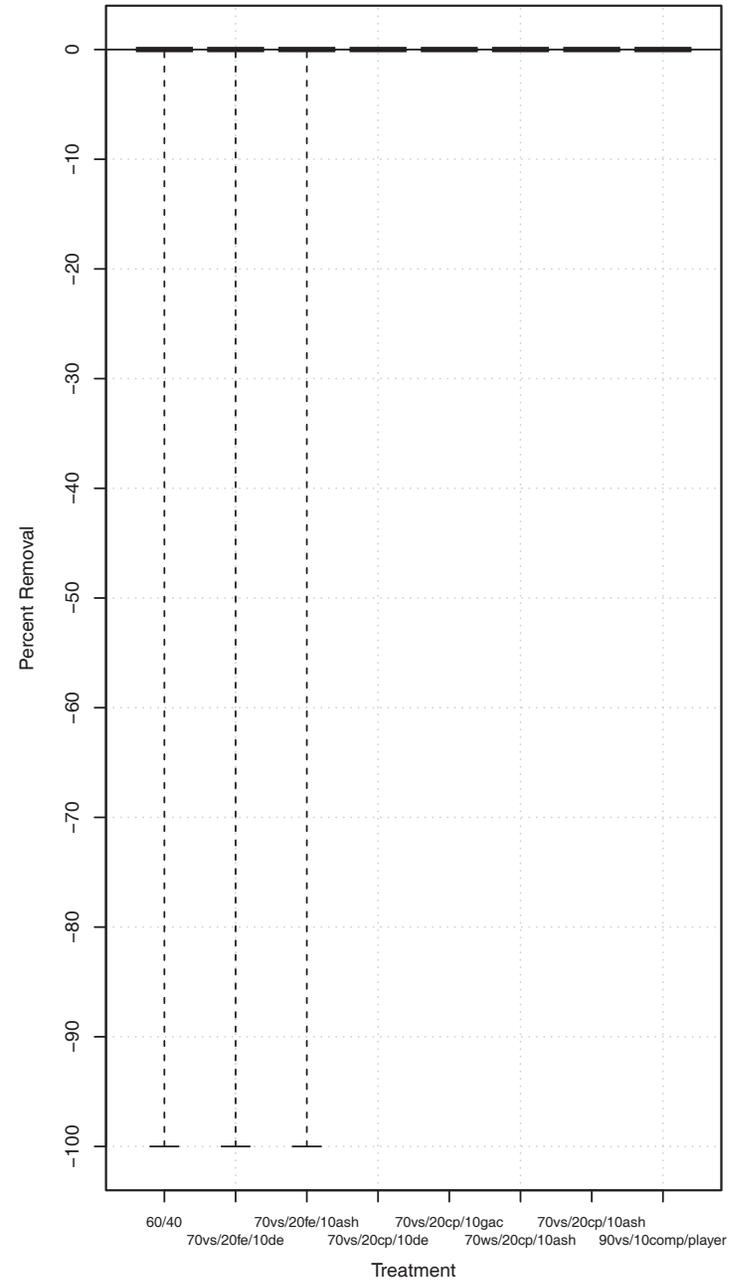
Two-Way ANOVA on Removal (ranks)
 Treatment p-value : 0.483
 Influent Concentration p-value : 0.623
 Interaction p-value : 0.976

Total Cadmium

Effluent Concentration by Treatment



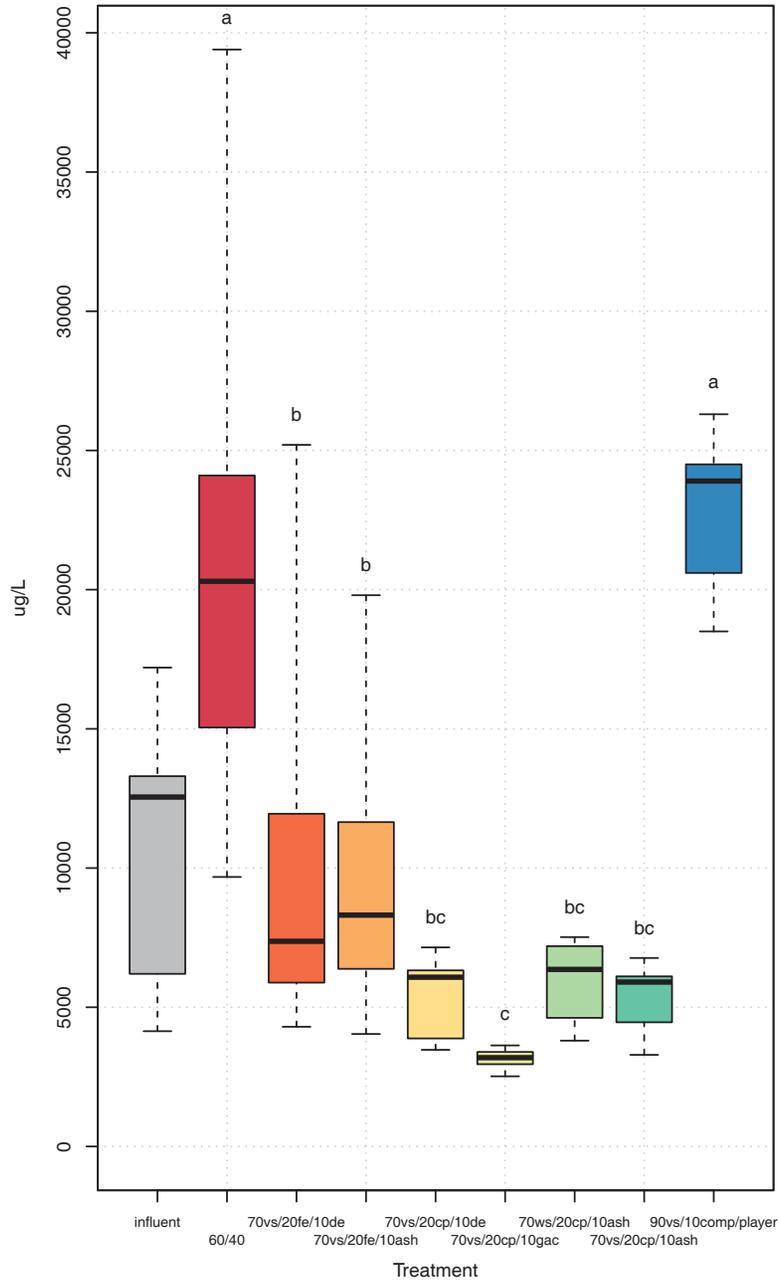
Percent Removal by Treatment



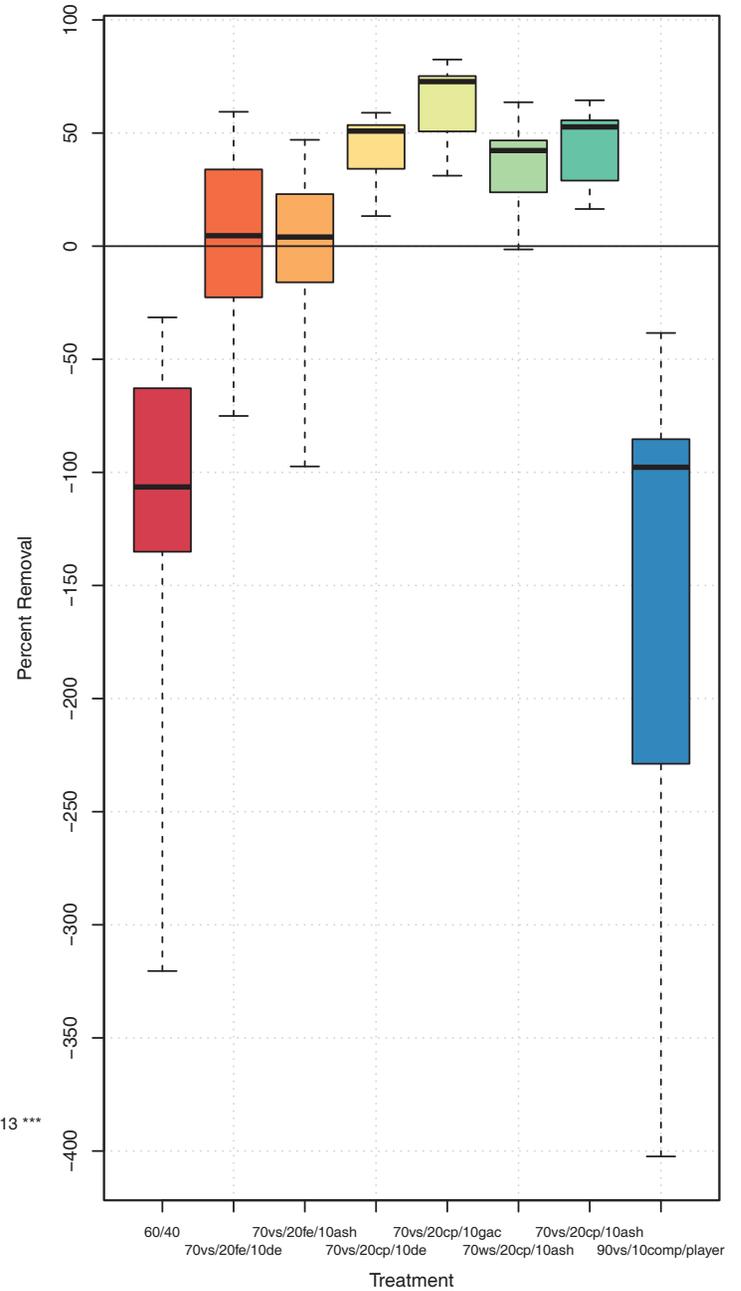
Two-Way ANOVA on Removal (ranks)
 Treatment p-value : 0.701
 Influent Concentration p-value : 0.395
 Interaction p-value : 0.992

Total Calcium

Effluent Concentration by Treatment



Percent Removal by Treatment



Two-Way ANOVA on Removal (ranks)

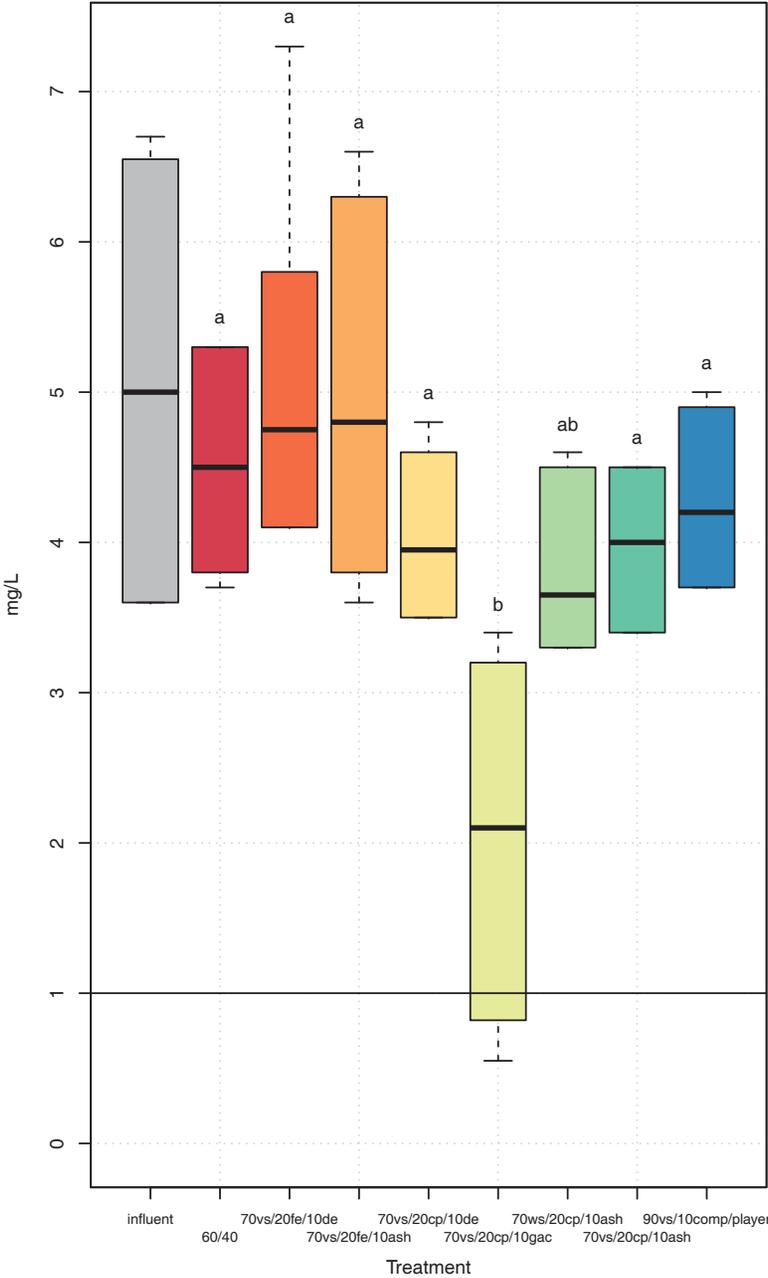
Treatment p-value : 1.67e-36 ***

Influent Concentration p-value : 9.32e-13 ***

Interaction p-value : 0.451

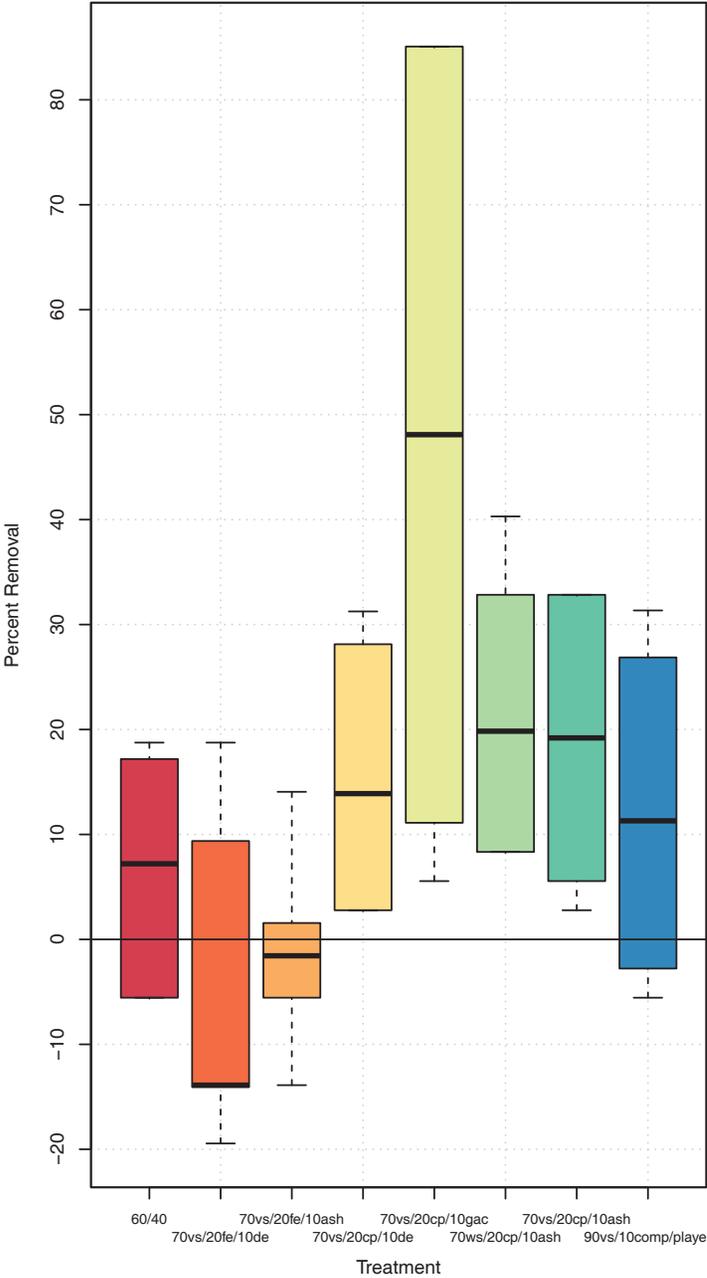
Chloride

Effluent Concentration by Treatment



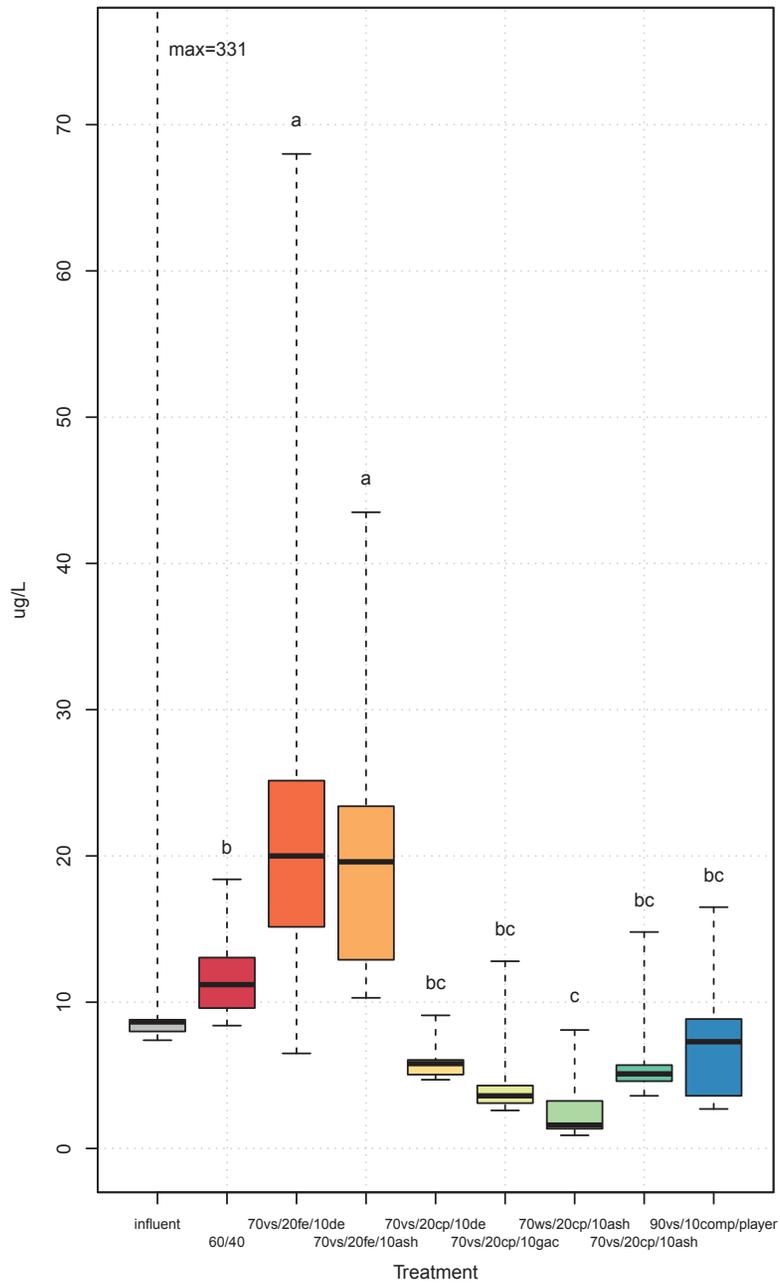
Two-Way ANOVA on Removal (ranks)
 Treatment p-value : 0.00567 **

Percent Removal by Treatment

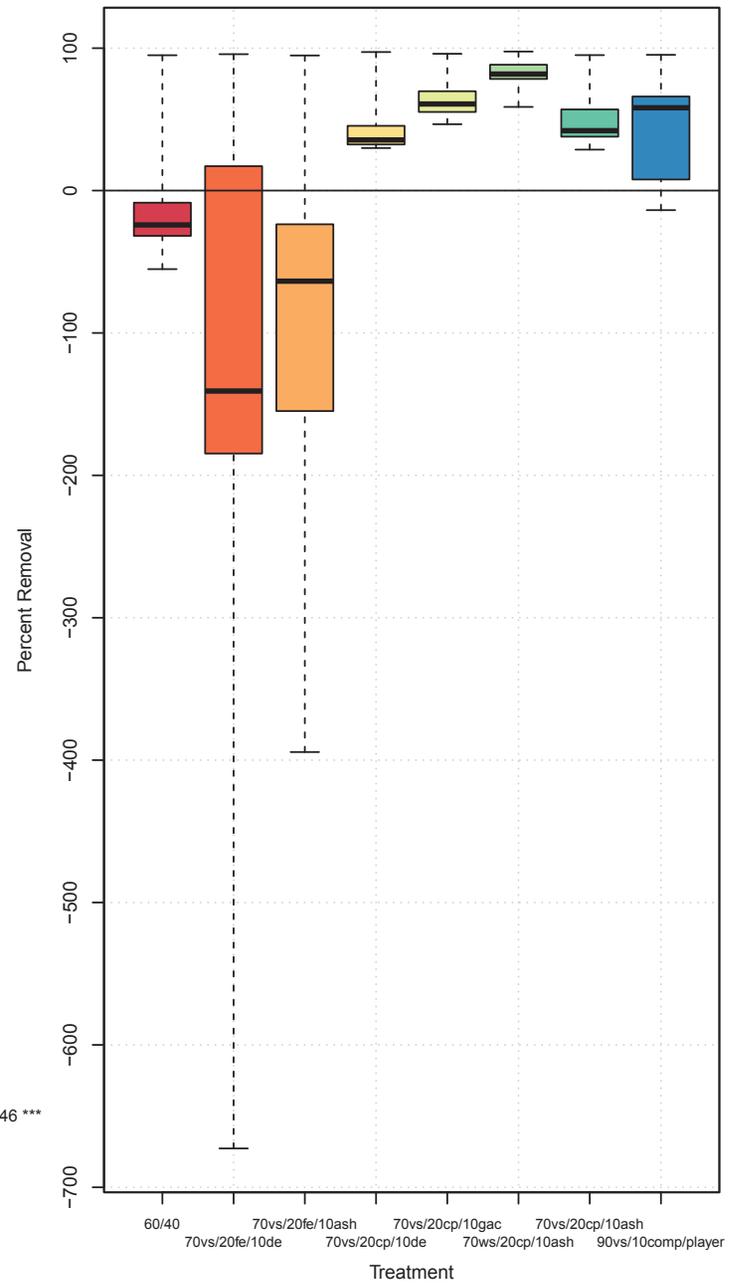


Dissolved Copper

Effluent Concentration by Treatment



Percent Removal by Treatment



Two-Way ANOVA on Removal (ranks)

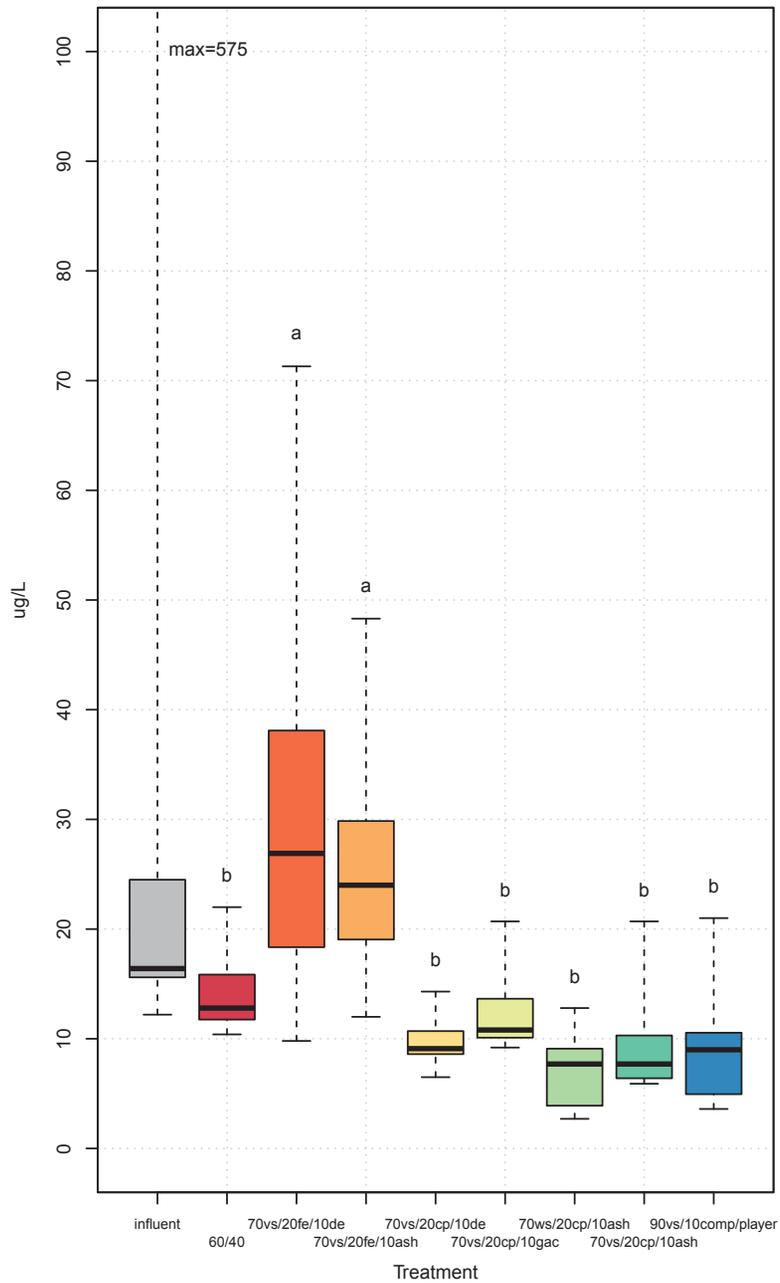
Treatment p-value : 4.95e-38 ***

Influent Concentration p-value : 3.09e-46 ***

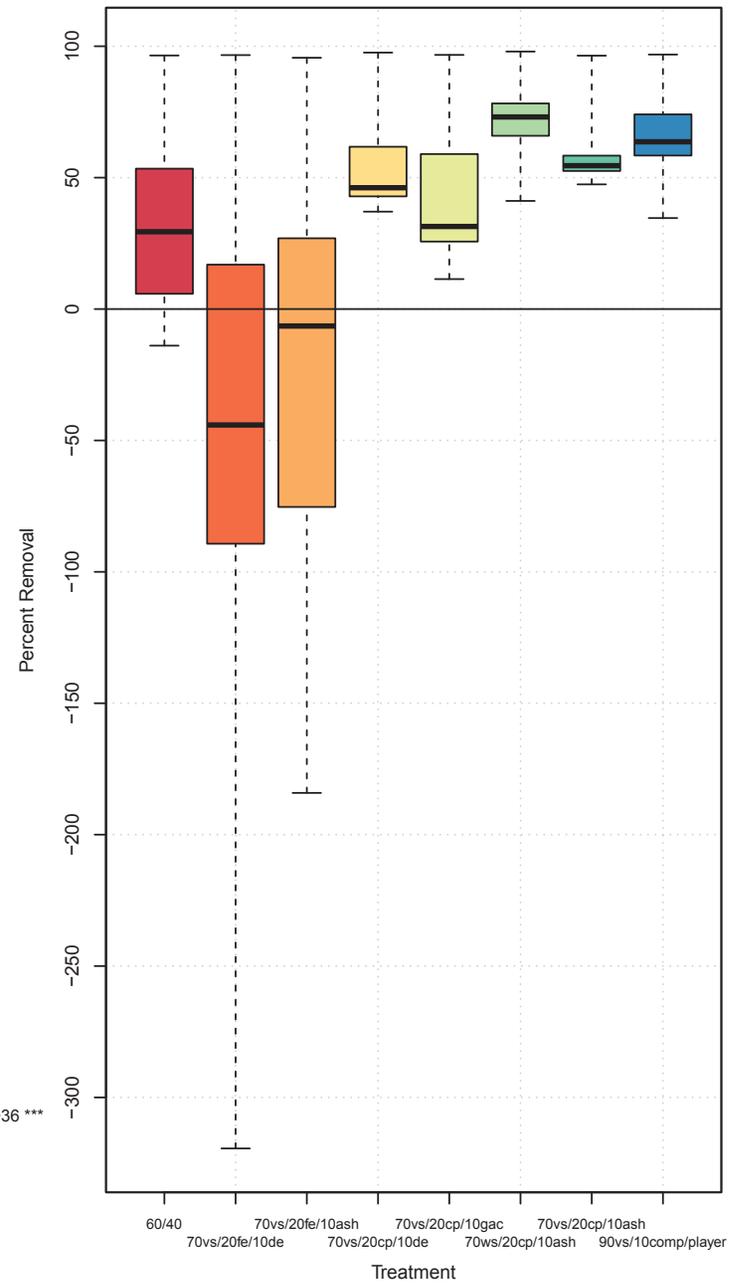
Interaction p-value : 3.98e-11 ***

Total Copper

Effluent Concentration by Treatment



Percent Removal by Treatment



Two-Way ANOVA on Removal (ranks)

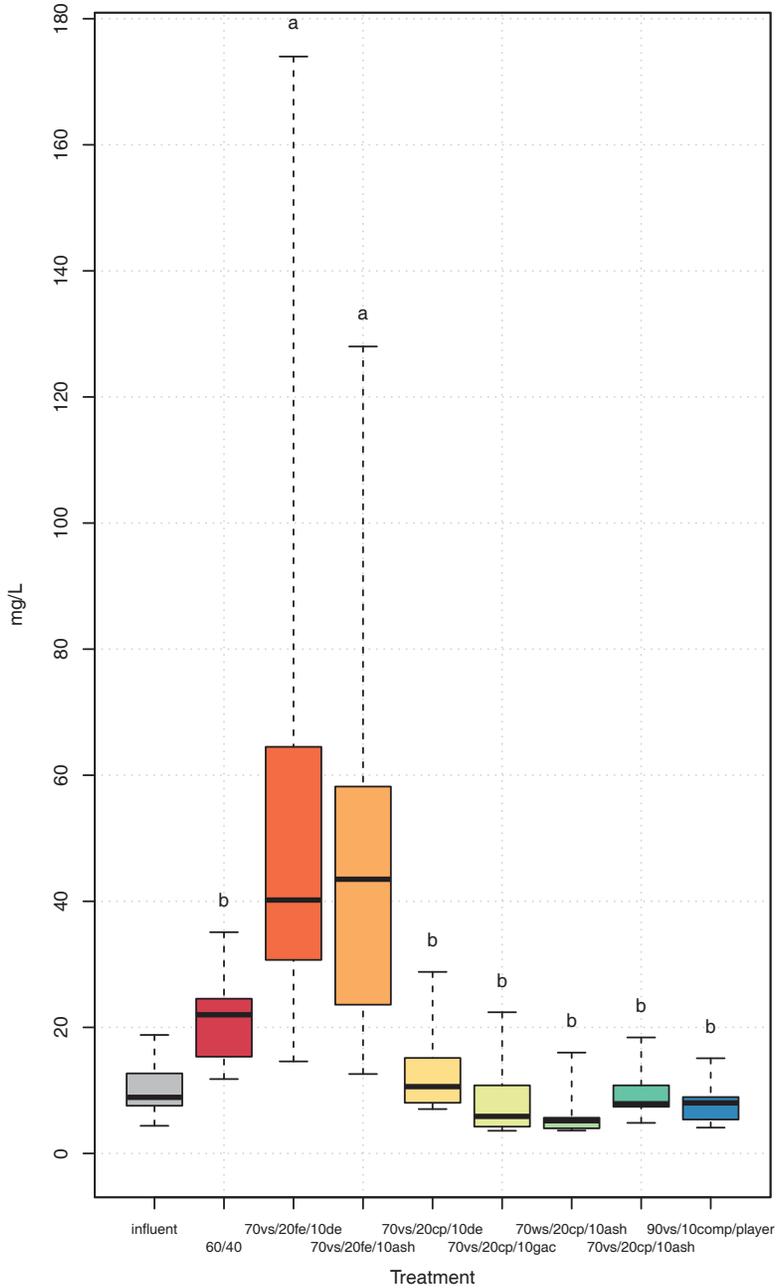
Treatment p-value : 6.47e-26 ***

Influent Concentration p-value : 4.96e-36 ***

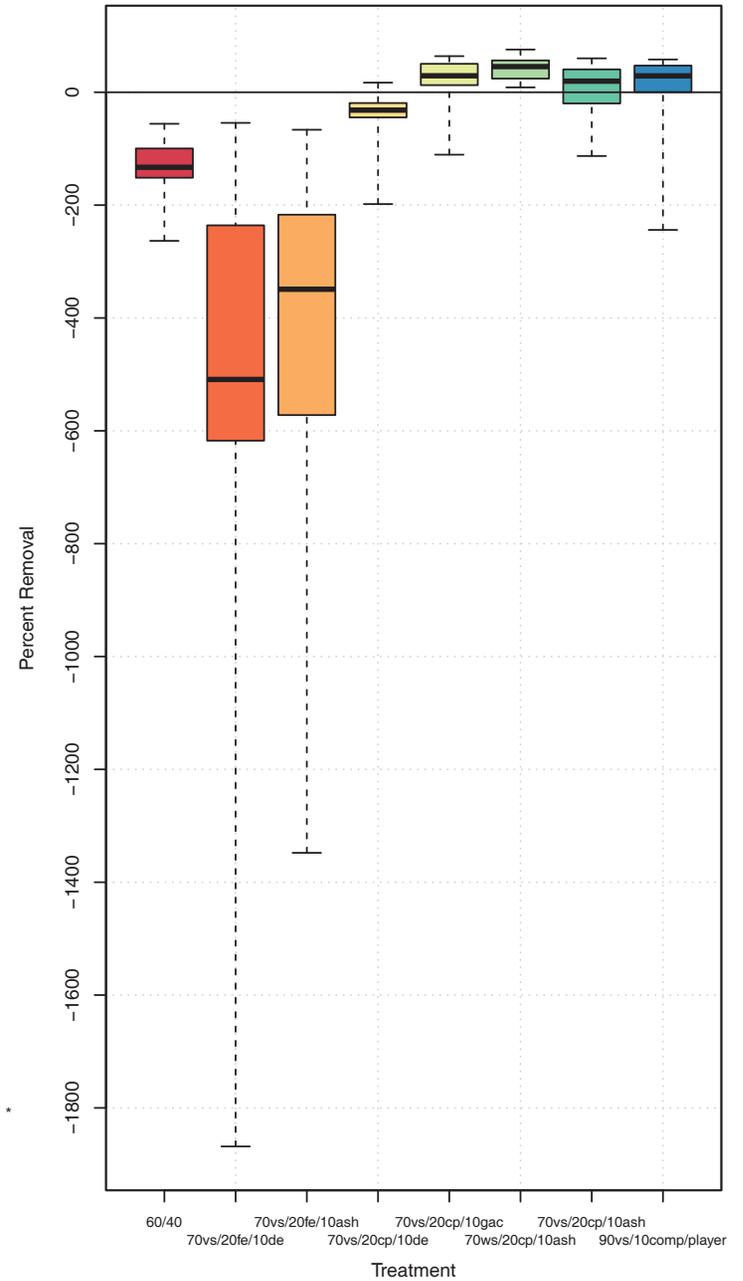
Interaction p-value : 1.31e-05 ***

Dissolved Organic Carbon

Effluent Concentration by Treatment



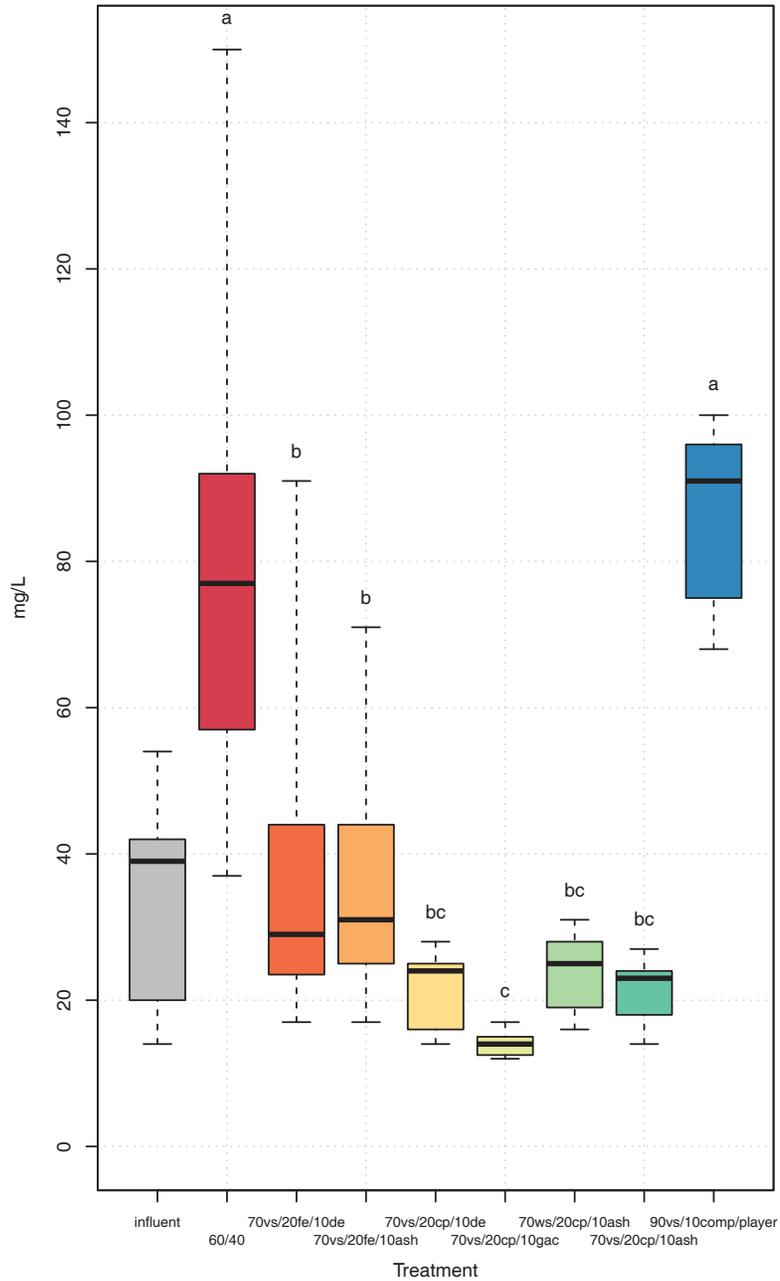
Percent Removal by Treatment



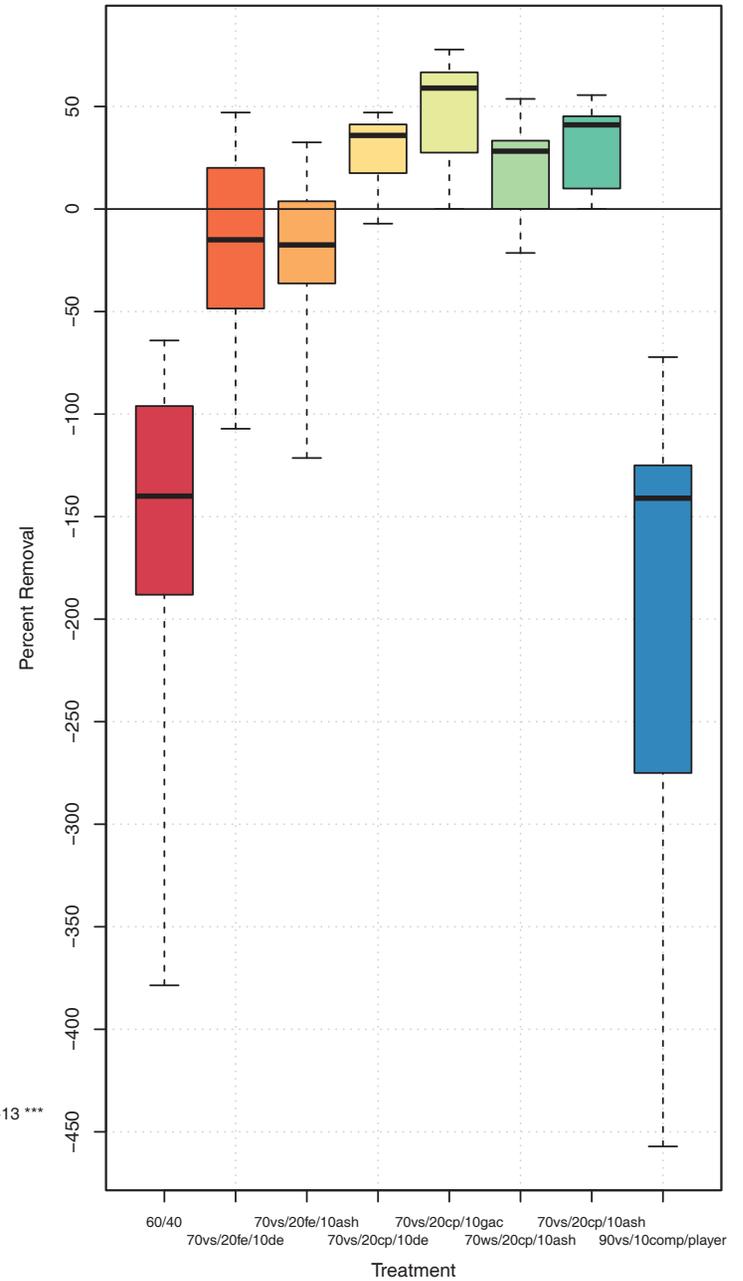
Two-Way ANOVA on Removal (ranks)
 Treatment p-value : 2.82e-31 ***
 Influent Concentration p-value : 0.0198 *
 Interaction p-value : 0.00185 **

Hardness

Effluent Concentration by Treatment



Percent Removal by Treatment



Two-Way ANOVA on Removal (ranks)

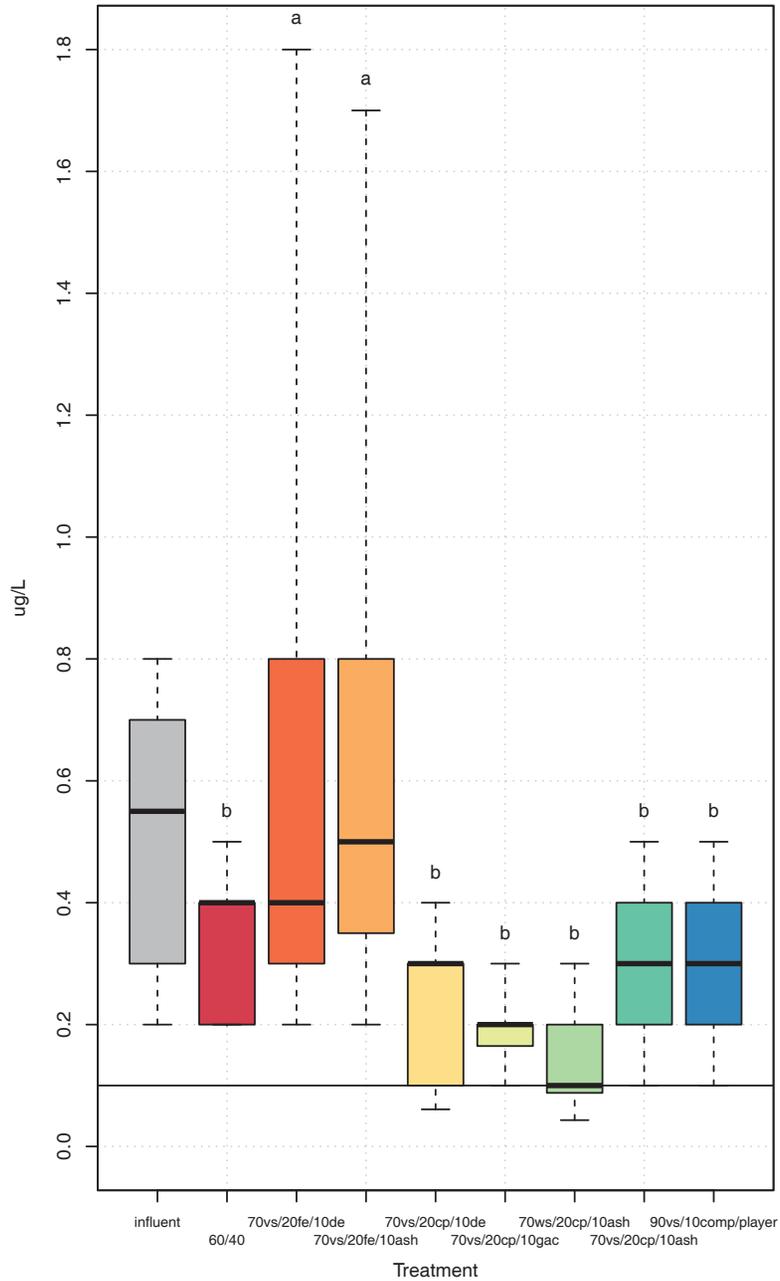
Treatment p-value : 2.5e-35 ***

Influent Concentration p-value : 7.91e-13 ***

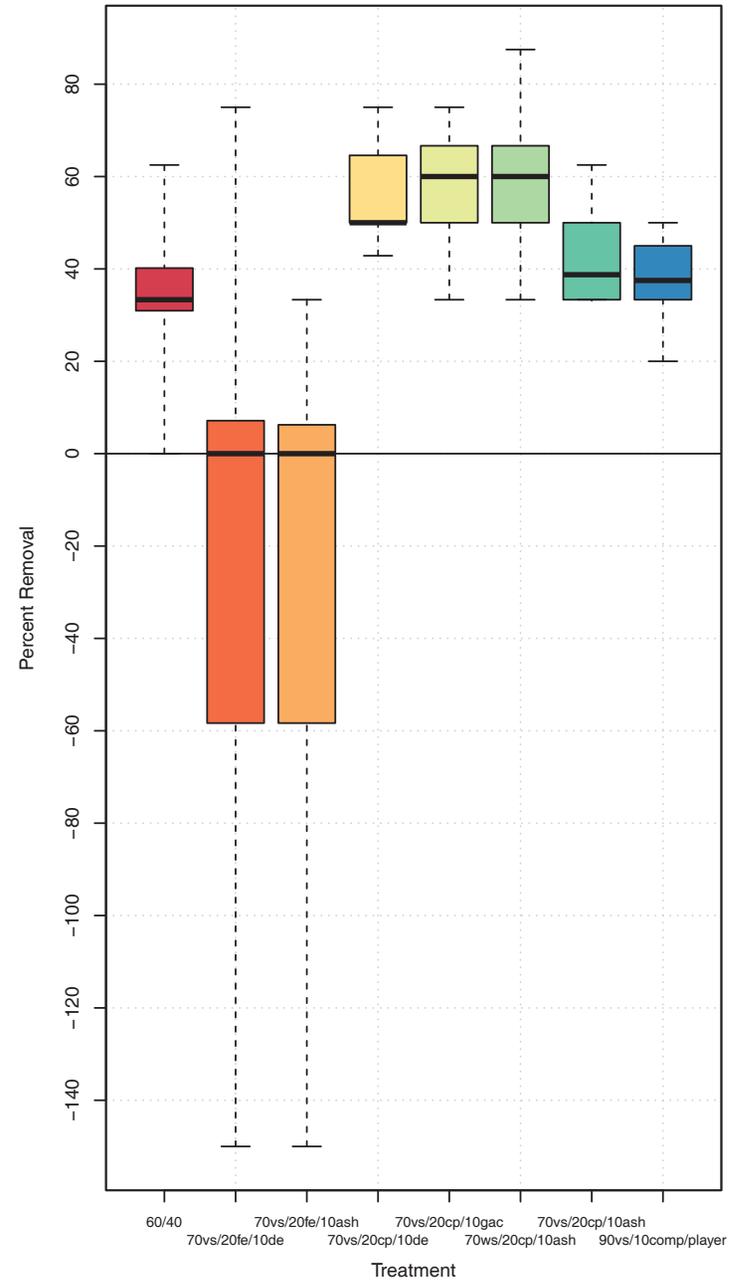
Interaction p-value : 0.296

Dissolved Lead

Effluent Concentration by Treatment



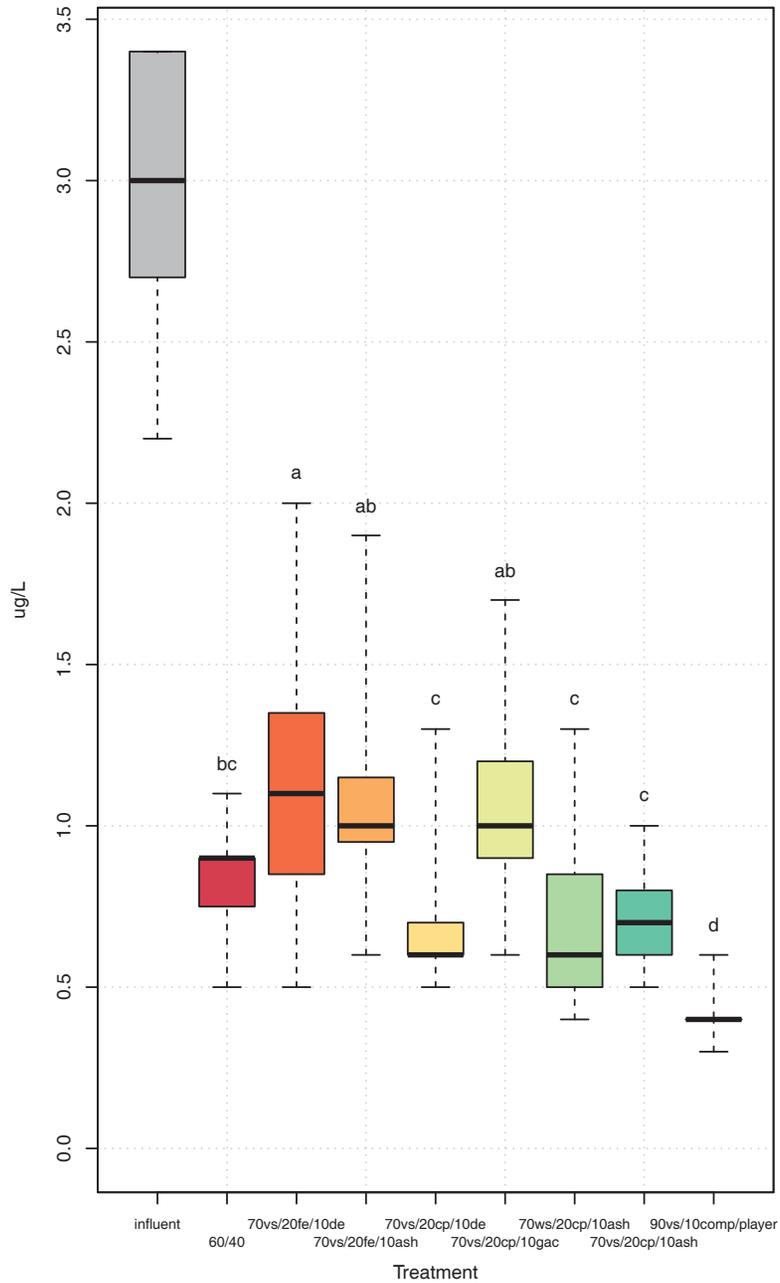
Percent Removal by Treatment



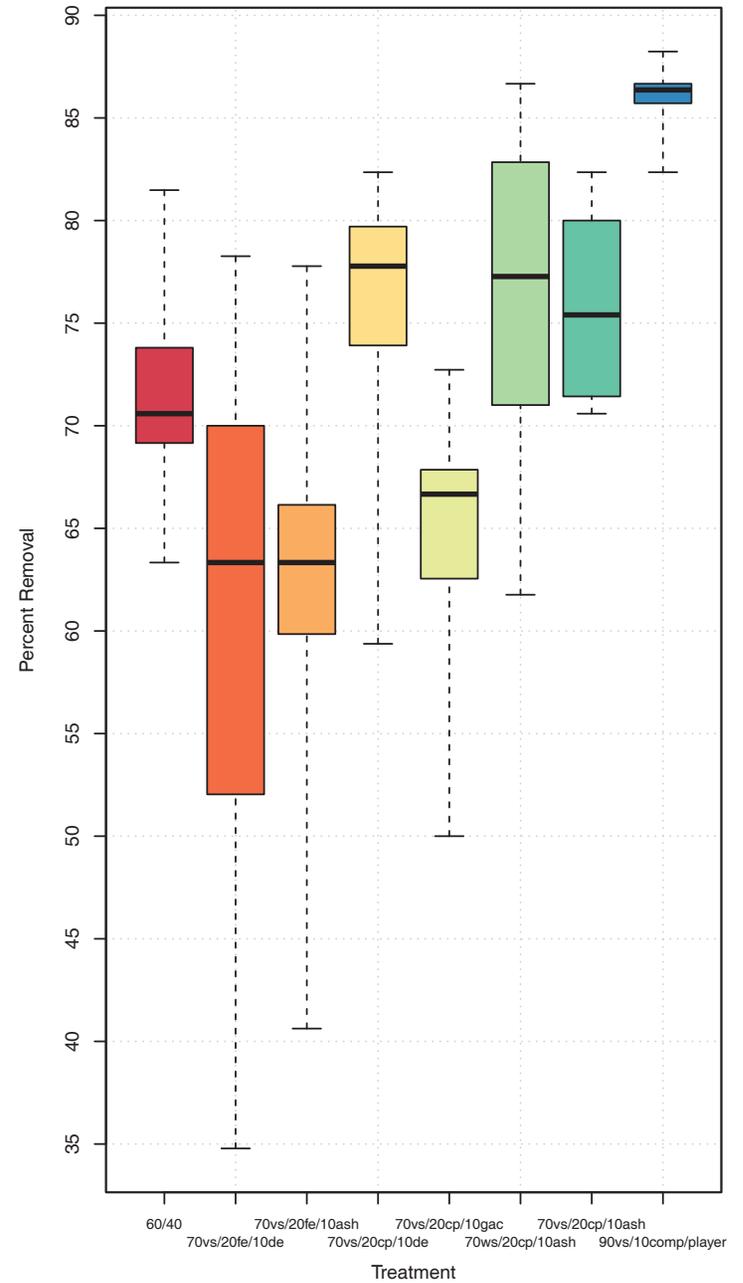
Two-Way ANOVA on Removal (ranks)
 Treatment p-value : 2.17e-21 ***
 Influent Concentration p-value : 0.227
 Interaction p-value : 0.0174 *

Total Lead

Effluent Concentration by Treatment

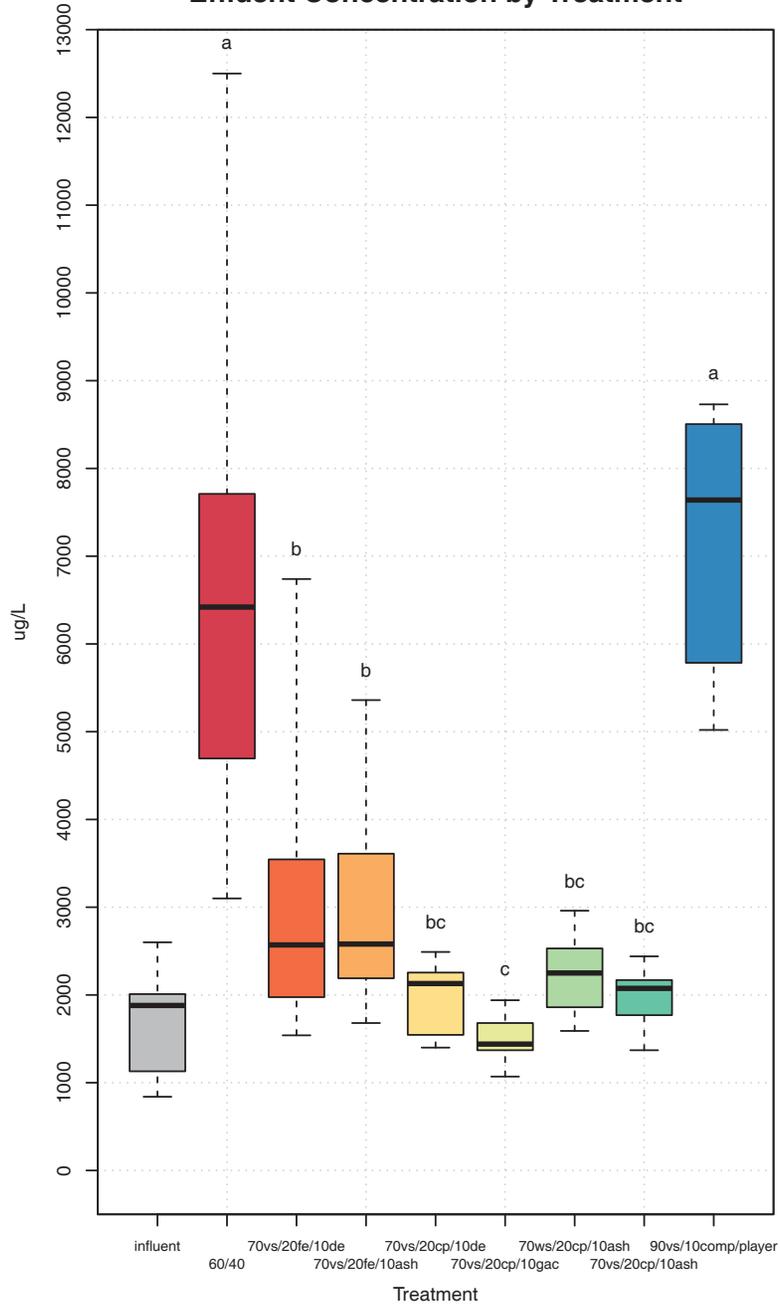


Percent Removal by Treatment

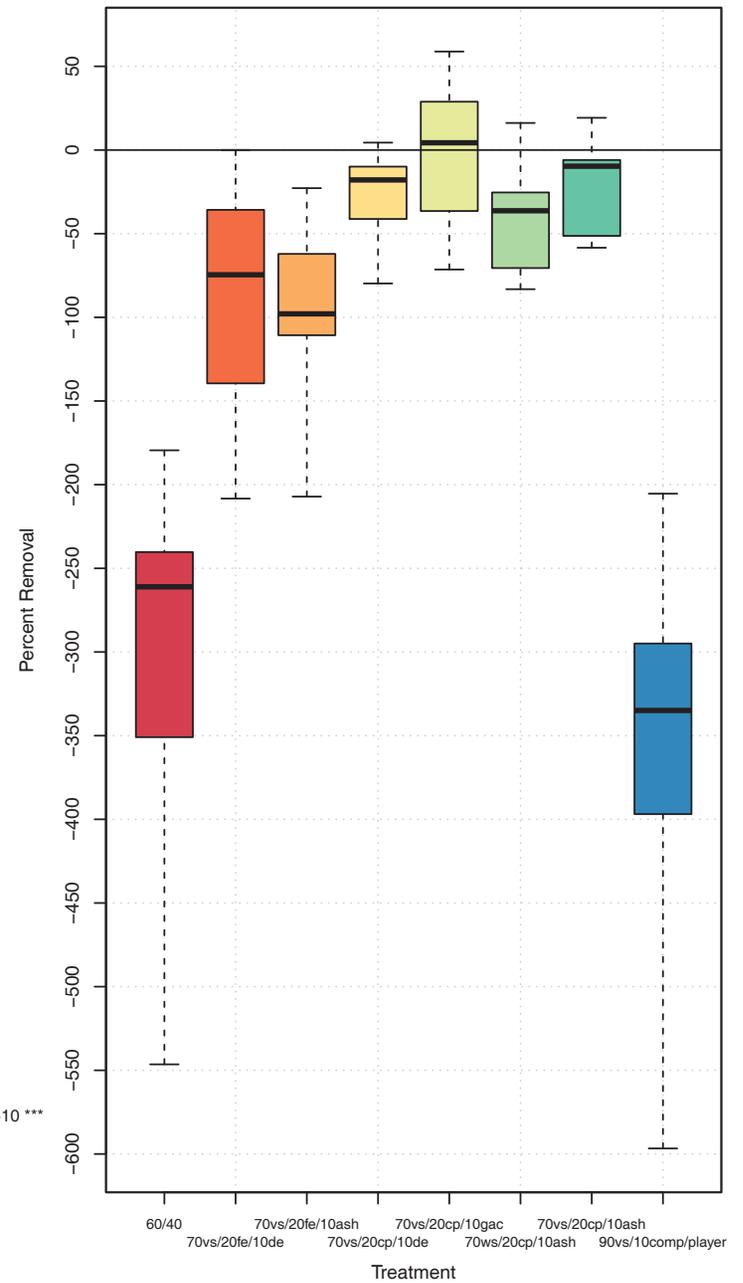


Total Magnesium

Effluent Concentration by Treatment



Percent Removal by Treatment



Two-Way ANOVA on Removal (ranks)

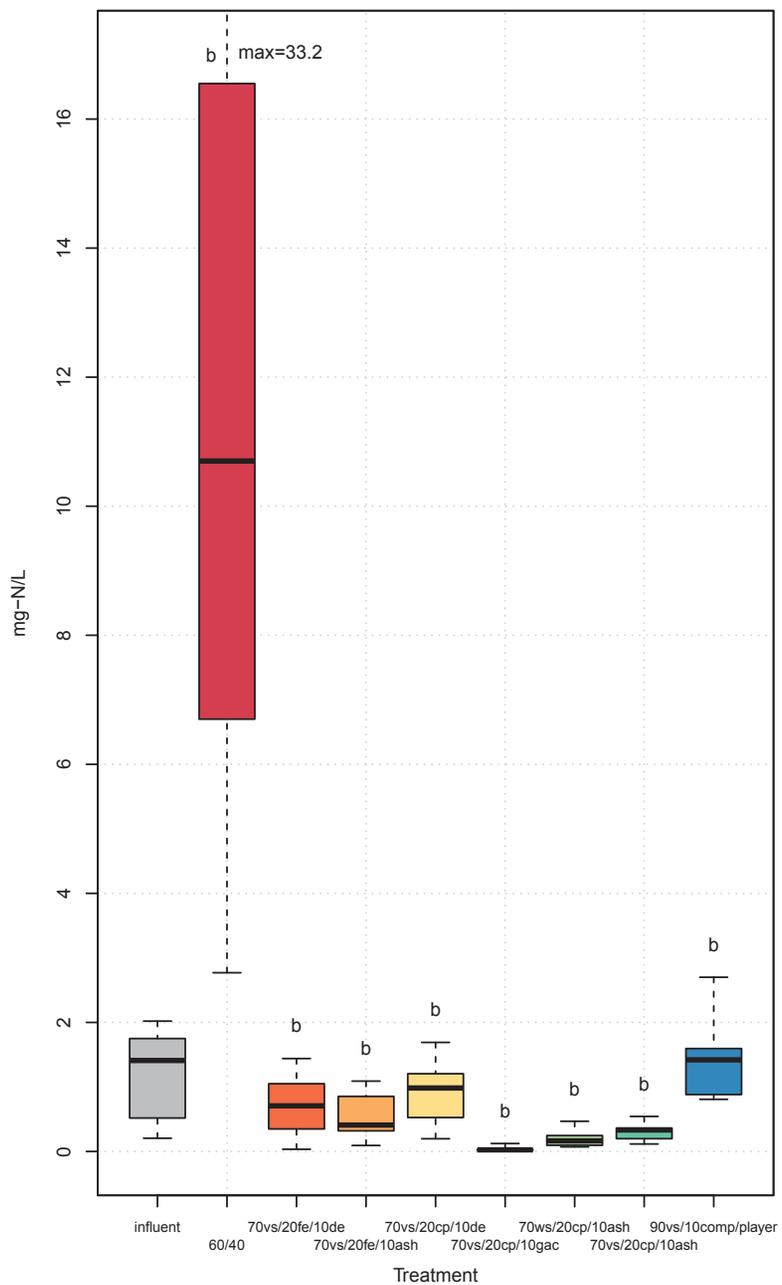
Treatment p-value : 3.5e-33 ***

Influent Concentration p-value : 1.92e-10 ****

Interaction p-value : 0.305

Nitrate + Nitrite

Effluent Concentration by Treatment



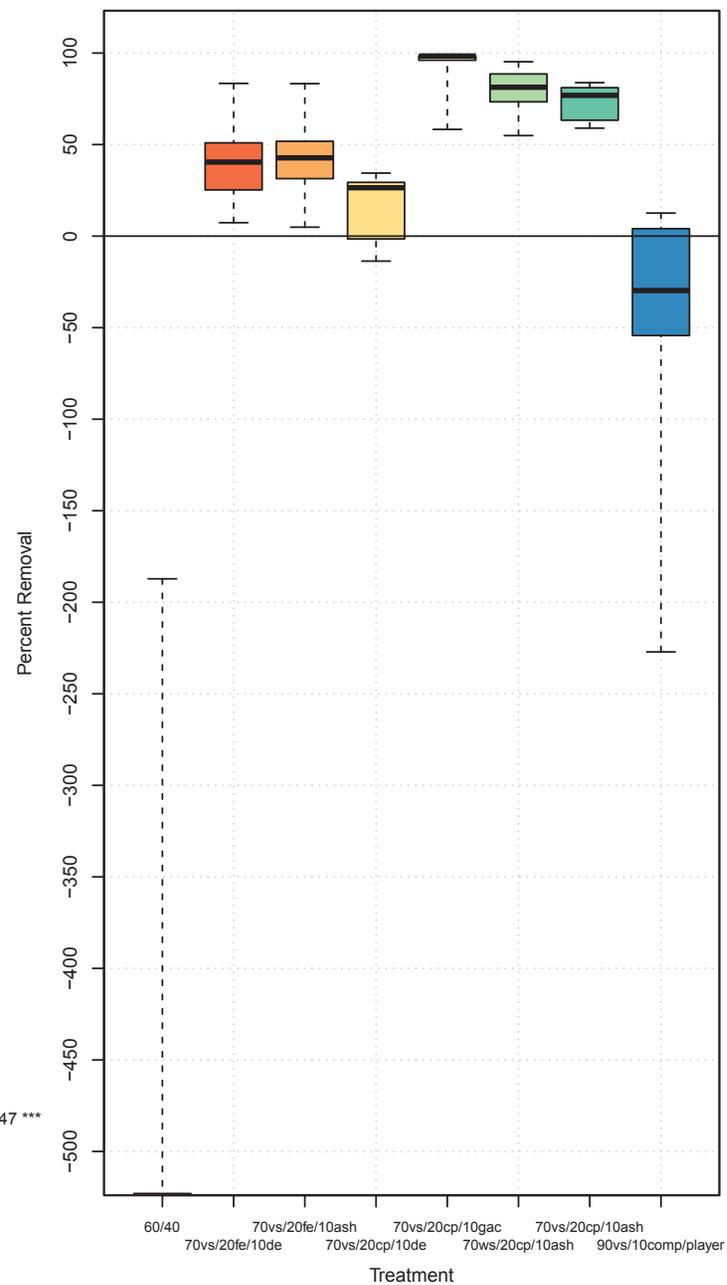
Two-Way ANOVA on Removal (ranks)

Treatment p-value : 1.16e-48 ***

Influent Concentration p-value : 0.000547 ***

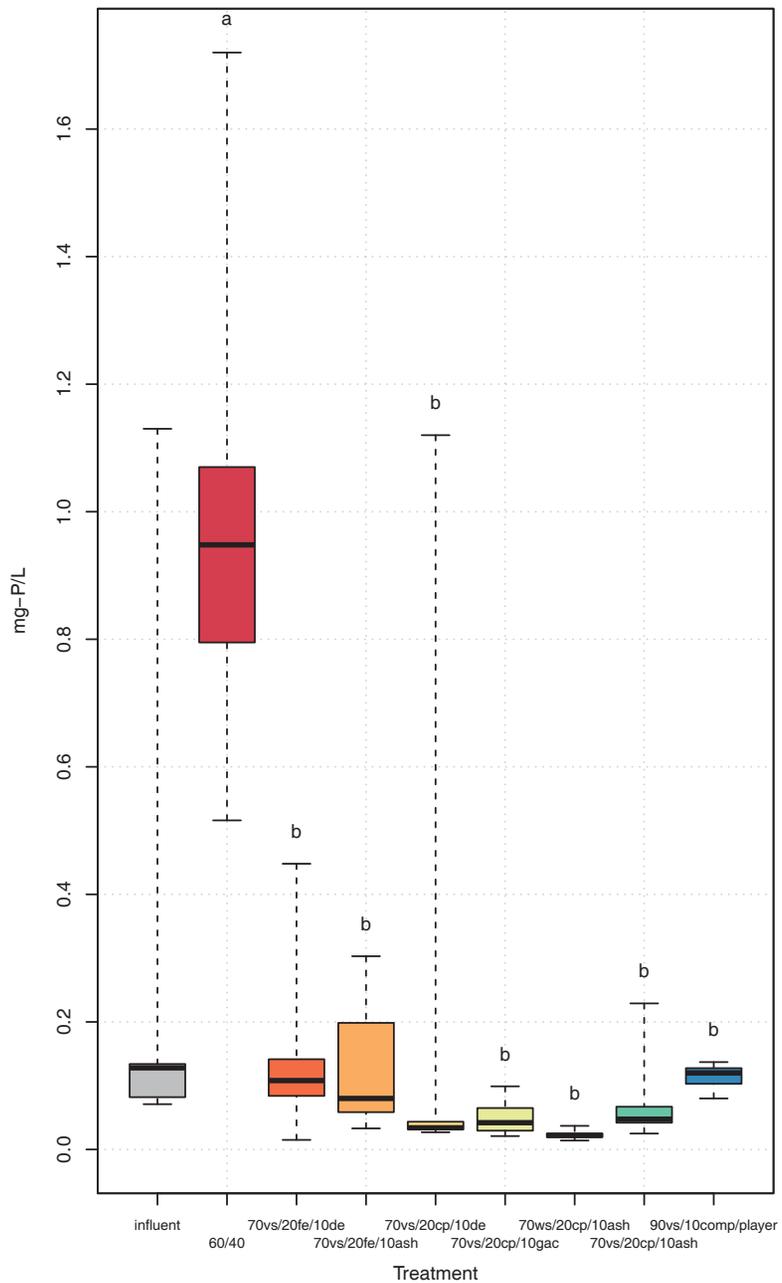
Interaction p-value : 0.45

Percent Removal by Treatment

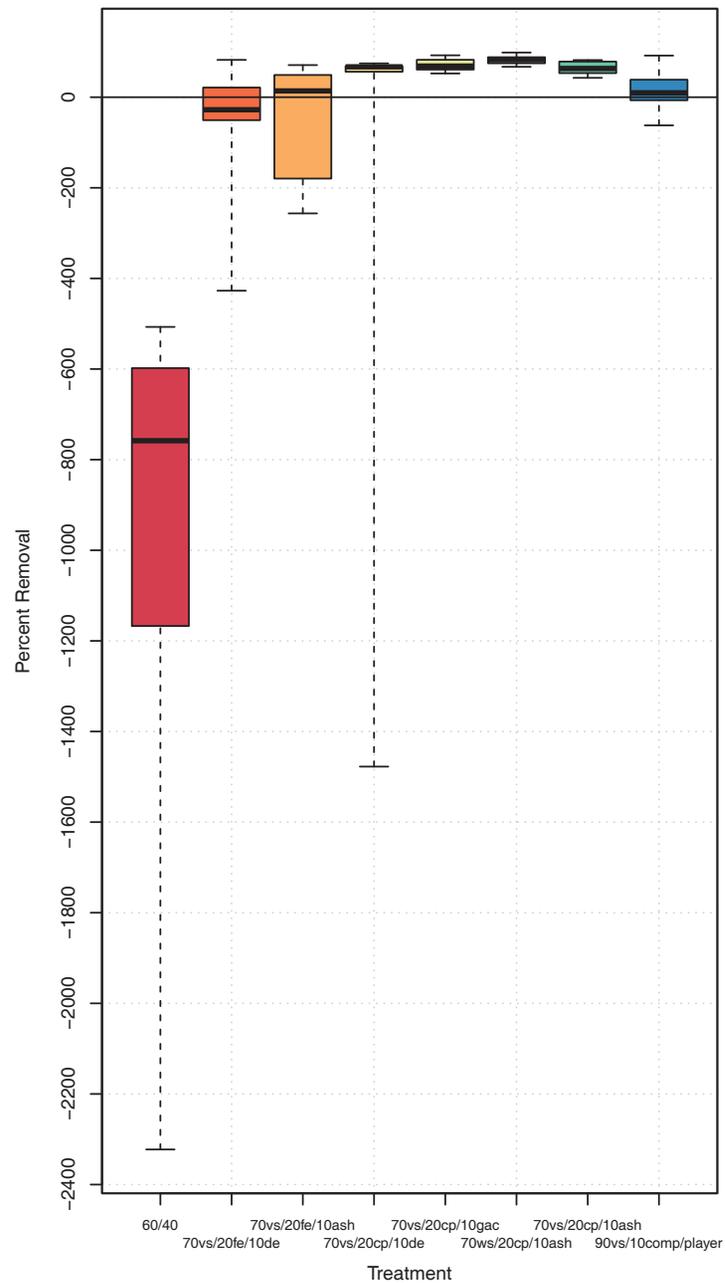


Ortho-Phosphorus

Effluent Concentration by Treatment



Percent Removal by Treatment



Two-Way ANOVA on Removal (ranks)

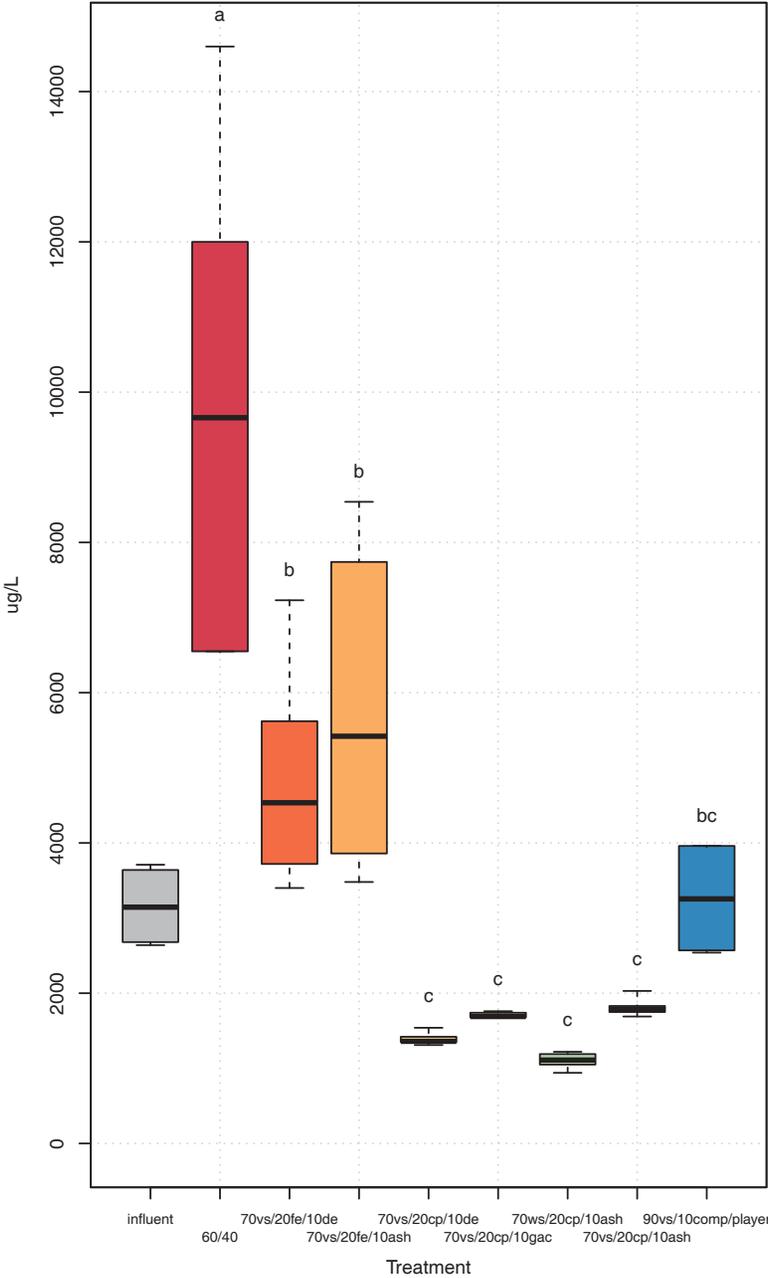
Treatment p-value : 4.4e-32 ***

Influent Concentration p-value : 0.075 .

Interaction p-value : 8.81e-14 ***

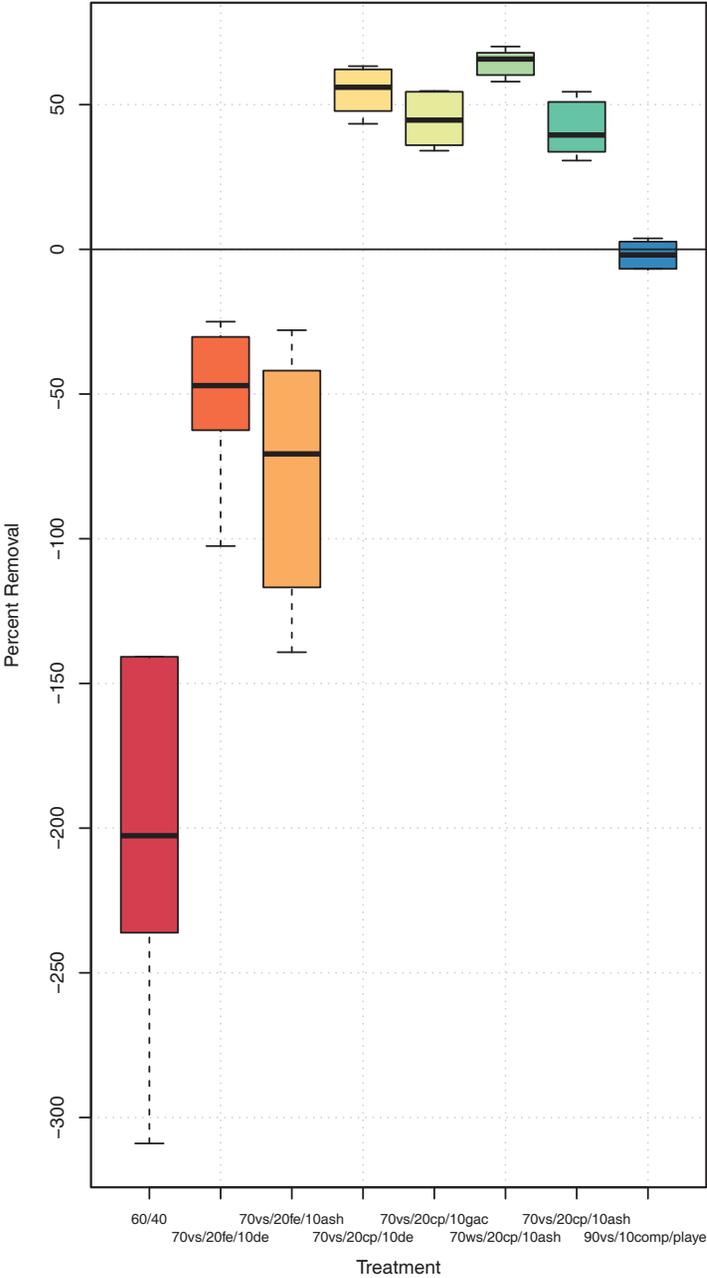
Dissolved Potassium

Effluent Concentration by Treatment



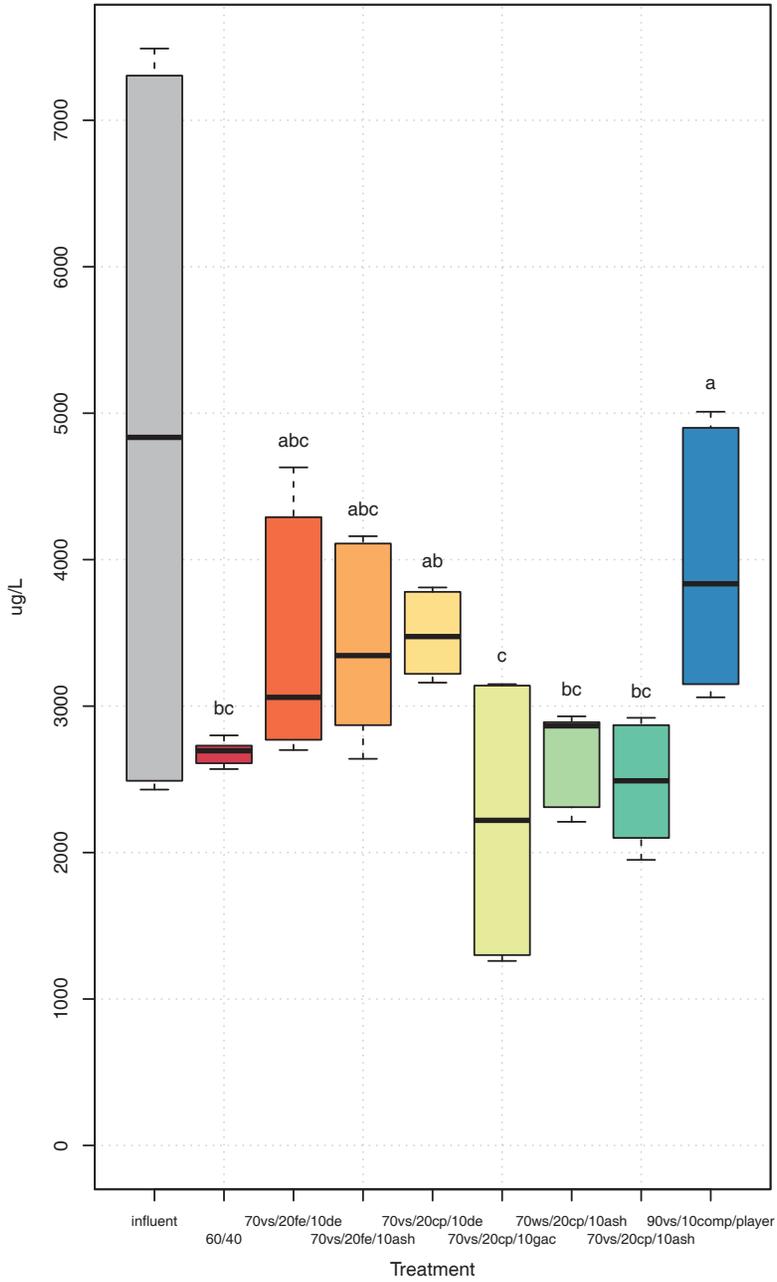
Percent Removal by Treatment

Two-Way ANOVA on Removal (ranks)
 Treatment p-value : 2.74e-21 ***



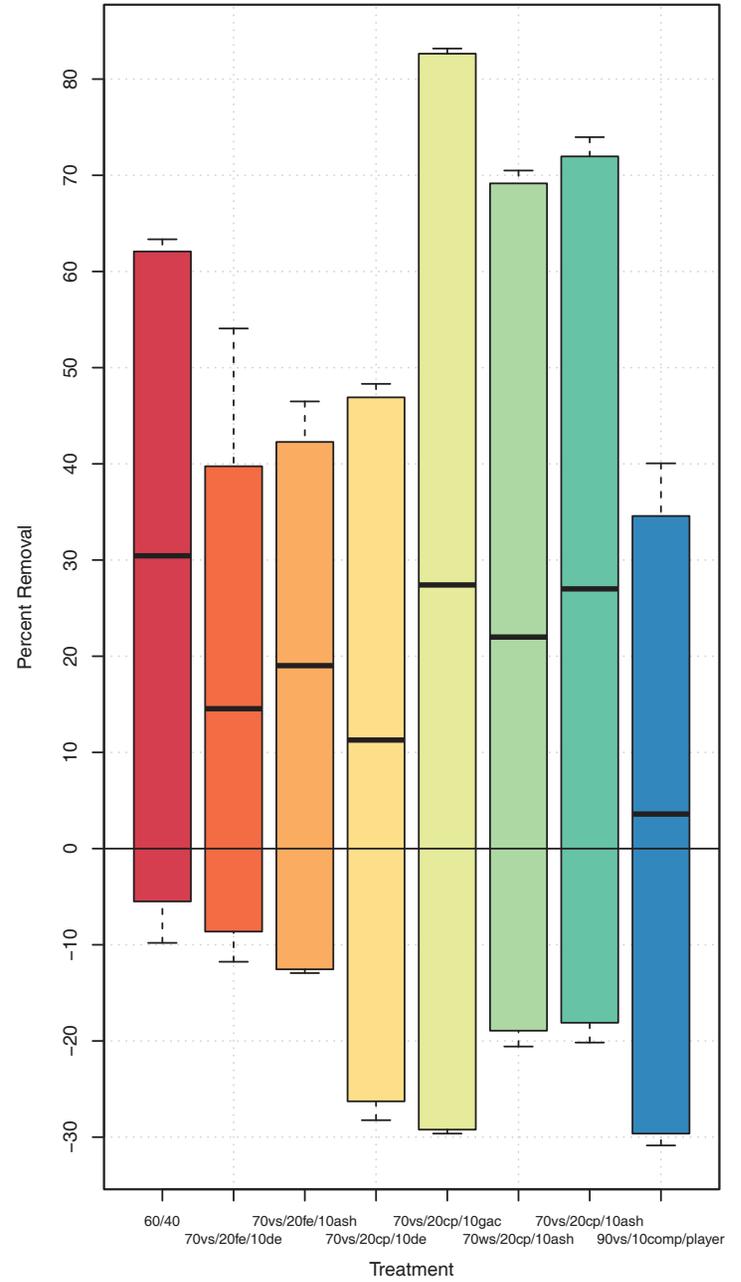
Dissolved Sodium

Effluent Concentration by Treatment



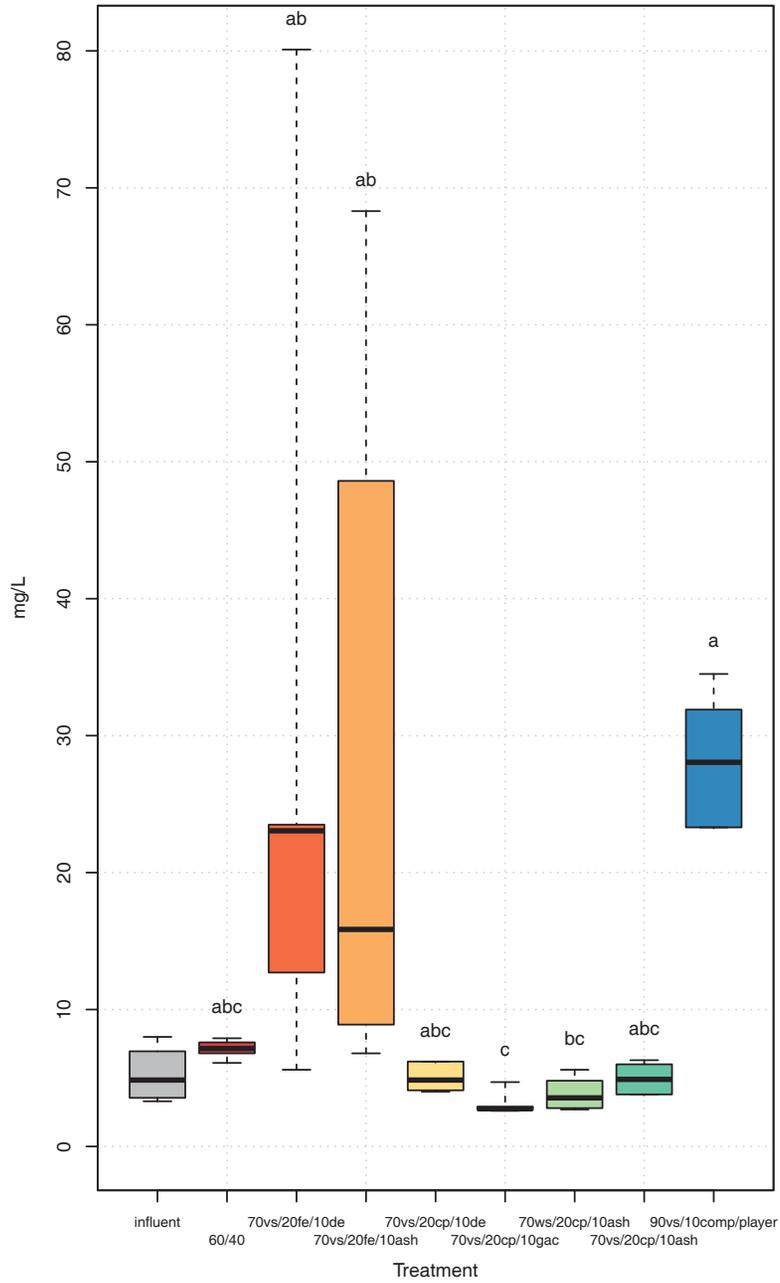
Two-Way ANOVA on Removal (ranks)
Treatment p-value : 0.721

Percent Removal by Treatment

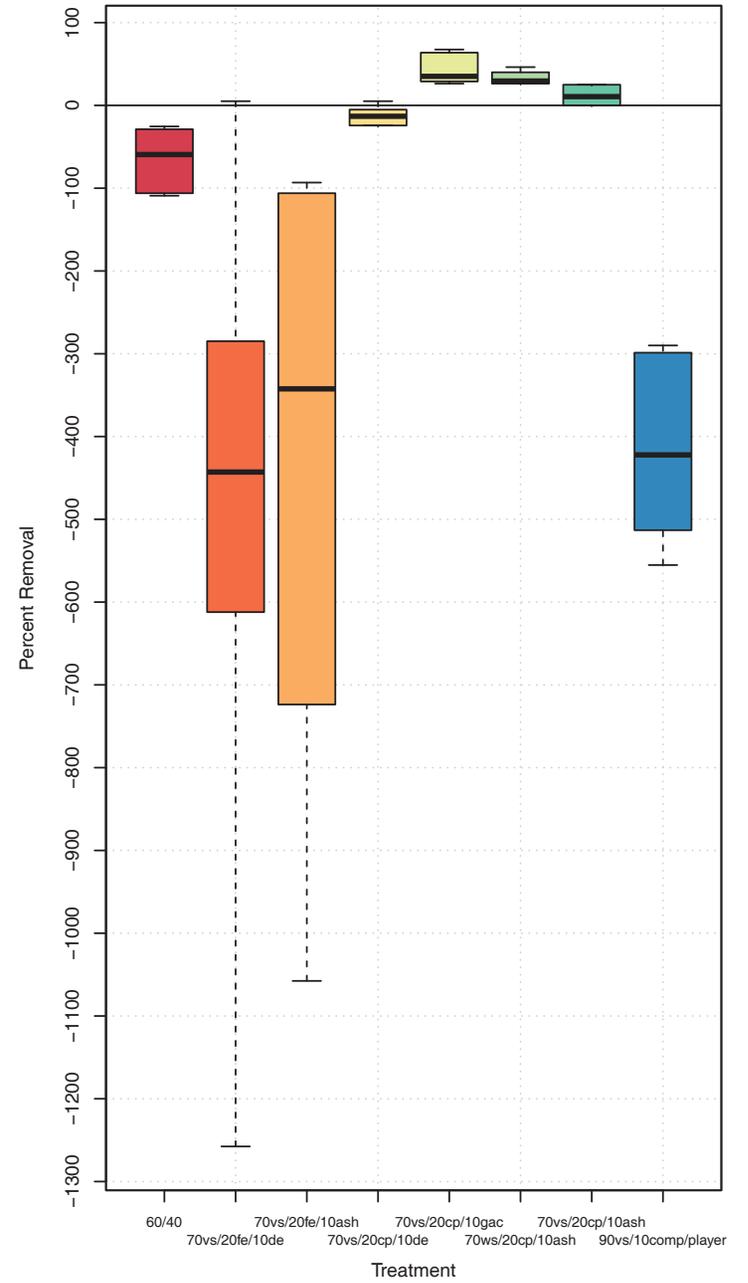


Sulfate

Effluent Concentration by Treatment



Percent Removal by Treatment

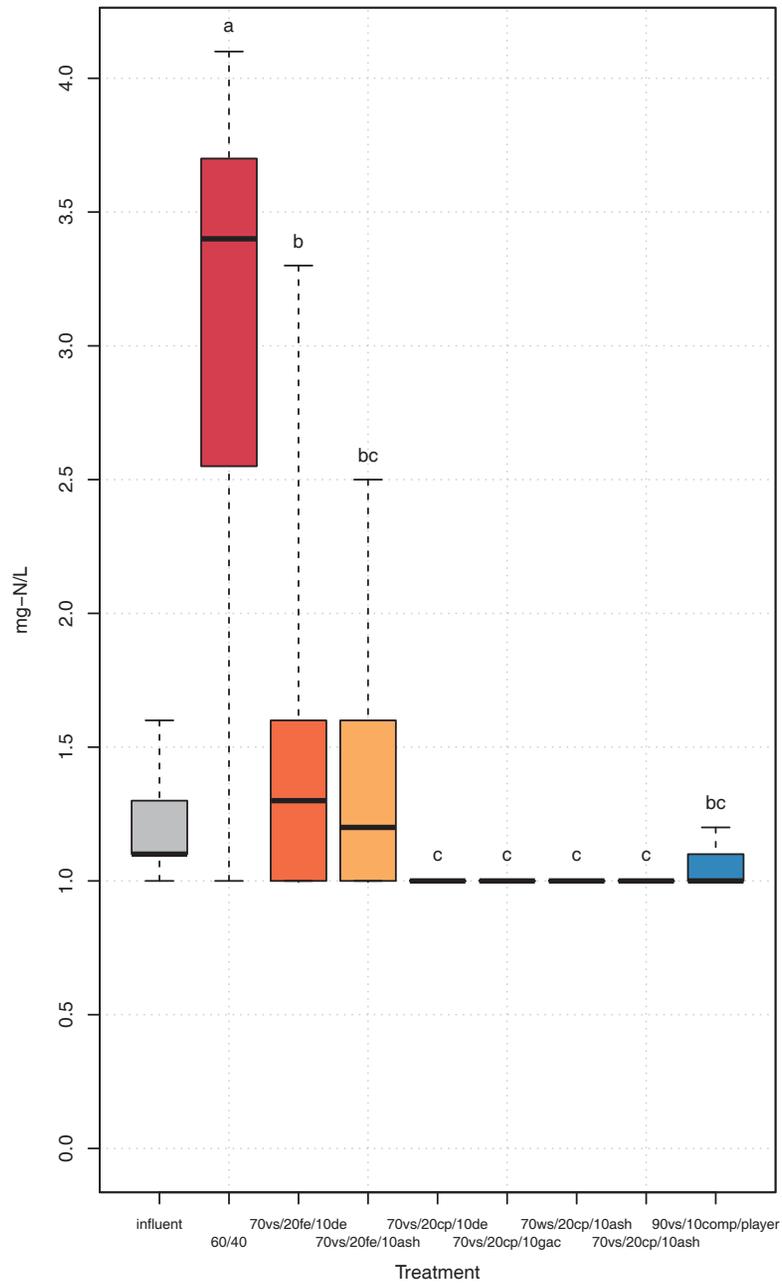


Two-Way ANOVA on Removal (ranks)

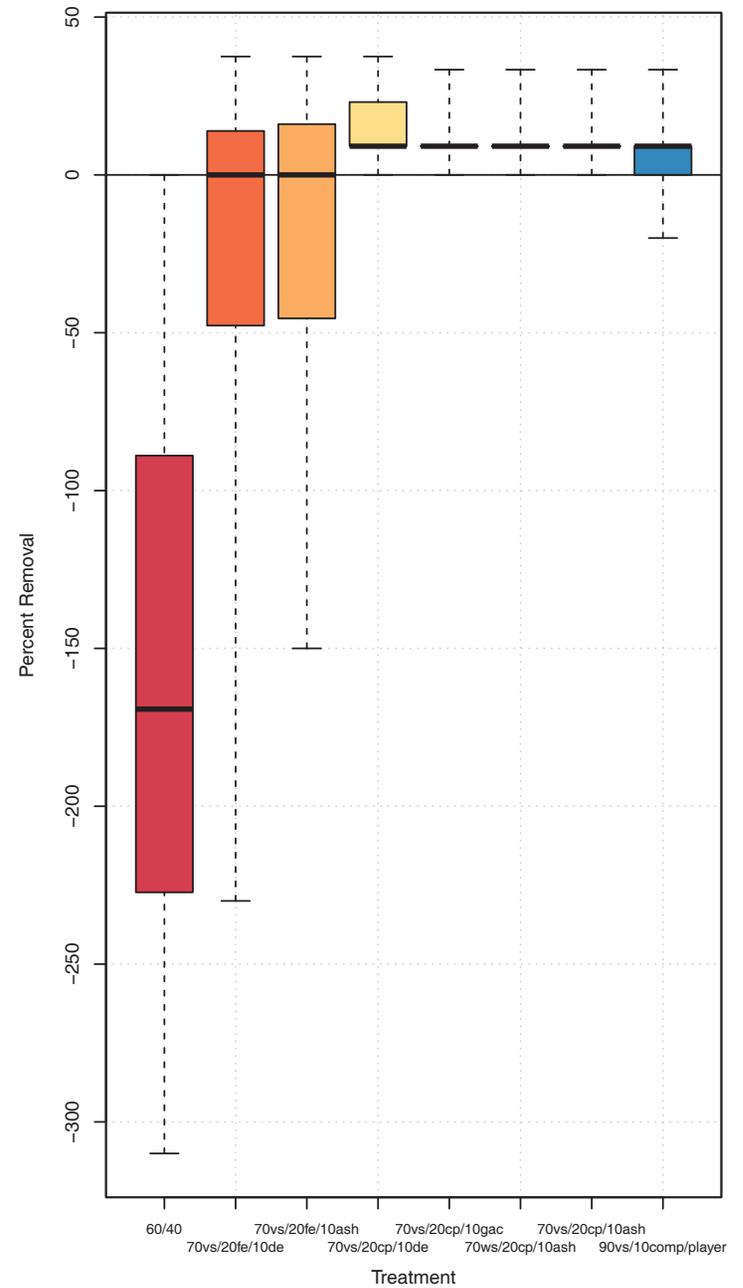
Treatment p-value : 1.28e-15 ***

Total Kjeldahl Nitrogen

Effluent Concentration by Treatment



Percent Removal by Treatment



Two-Way ANOVA on Removal (ranks)

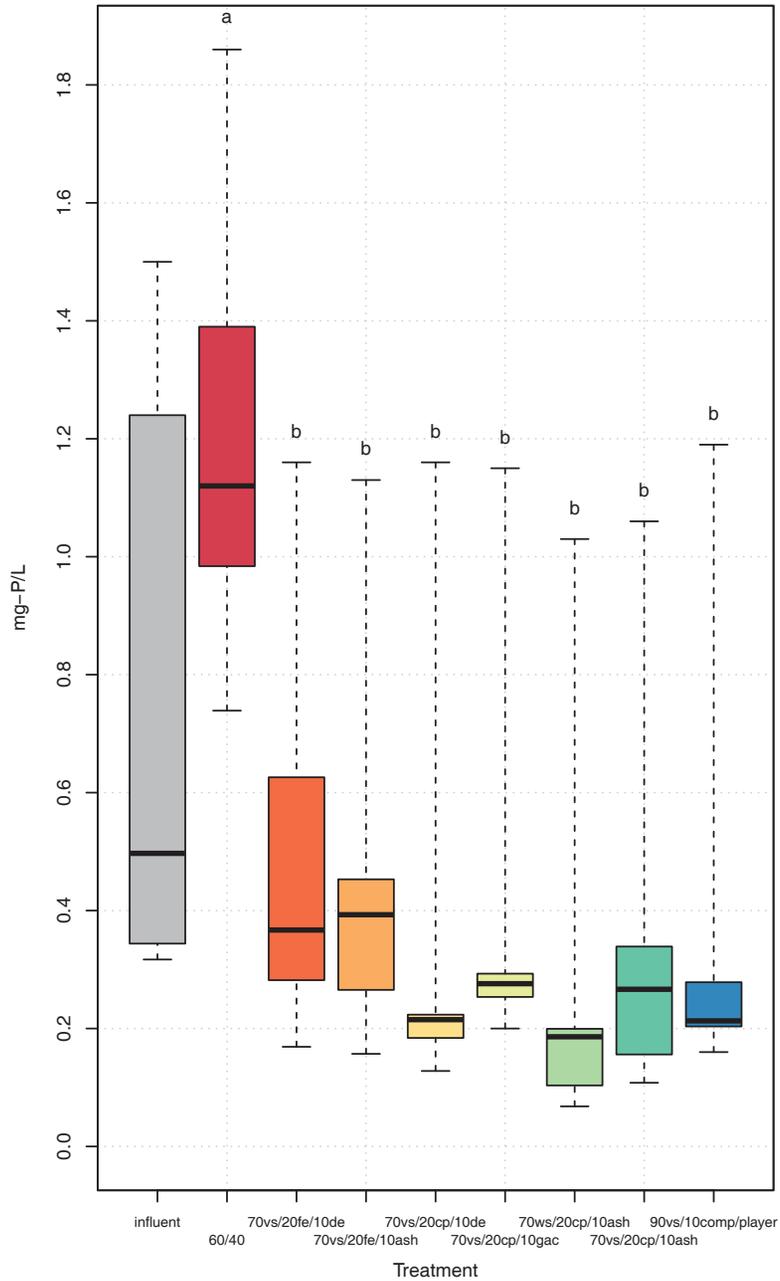
Treatment p-value : 1.33e-08 ***

Influent Concentration p-value : 0.721

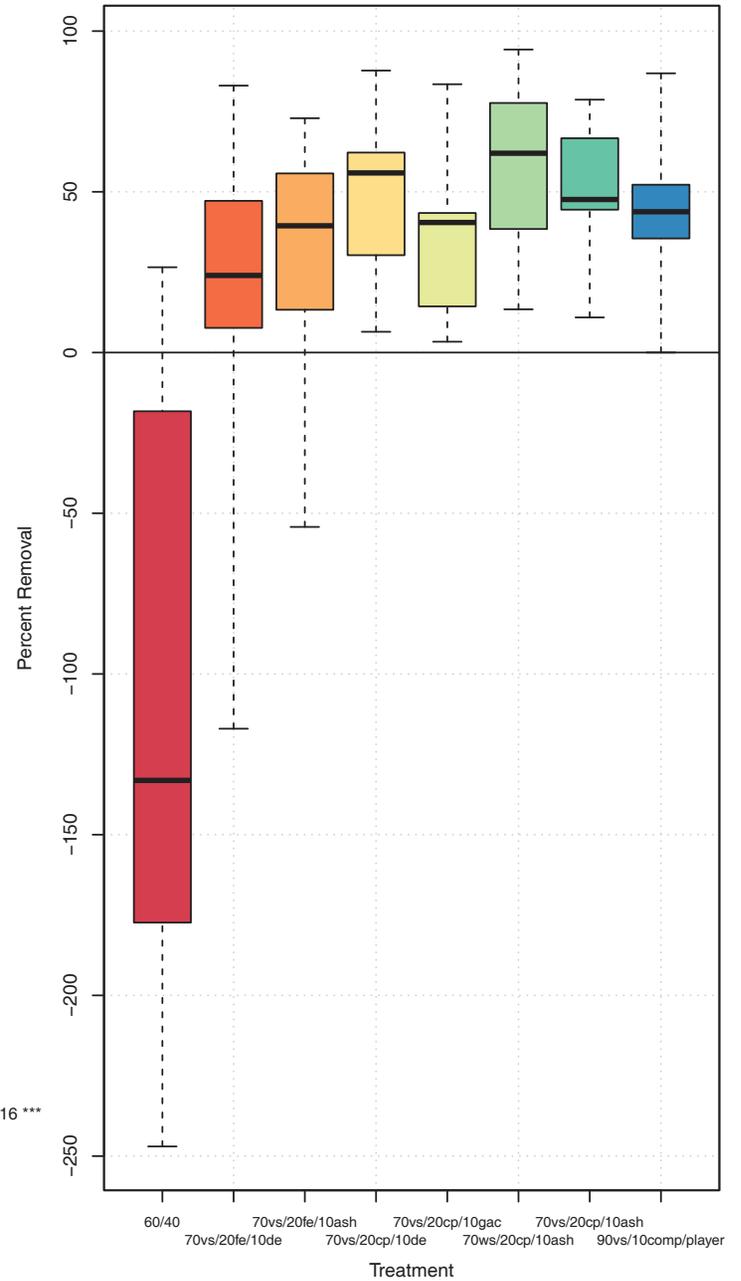
Interaction p-value : 0.995

Total Phosphorus

Effluent Concentration by Treatment



Percent Removal by Treatment



Two-Way ANOVA on Removal (ranks)

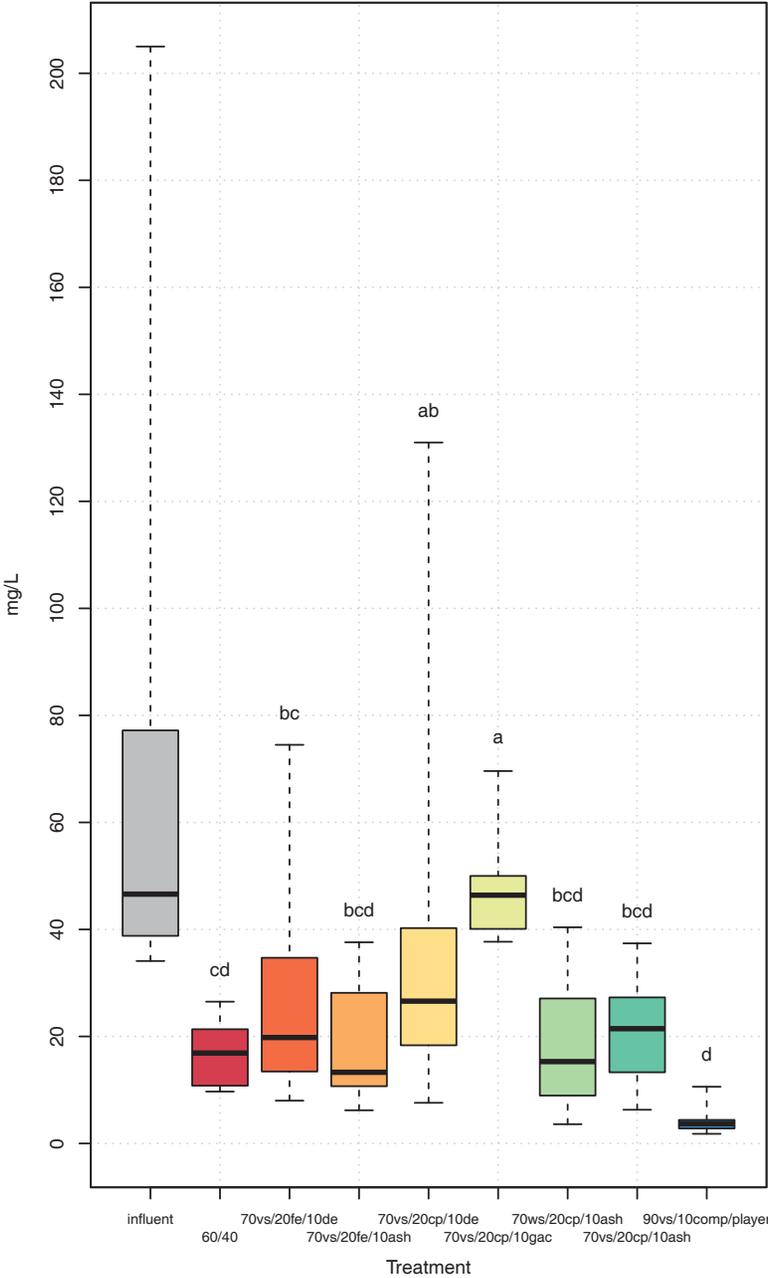
Treatment p-value : 3.14e-14 ***

Influent Concentration p-value : 9.96e-16 ***

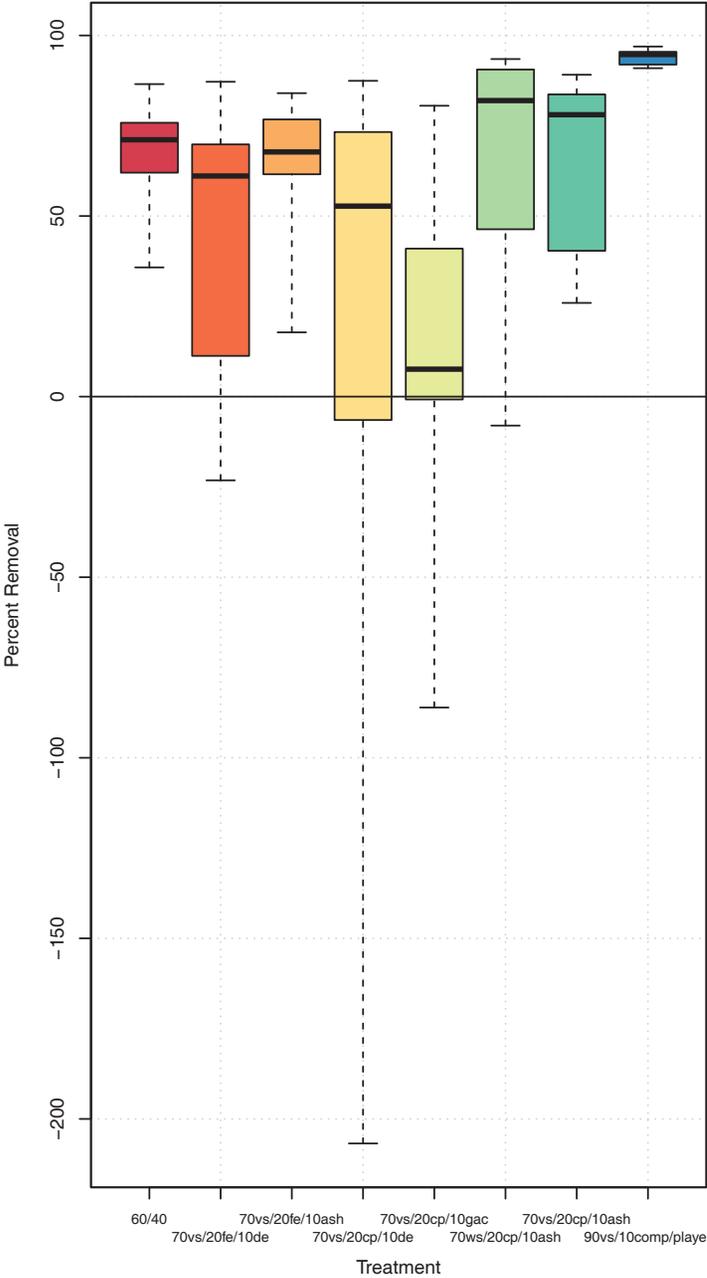
Interaction p-value : 0.0648 .

Total Suspended Solids

Effluent Concentration by Treatment



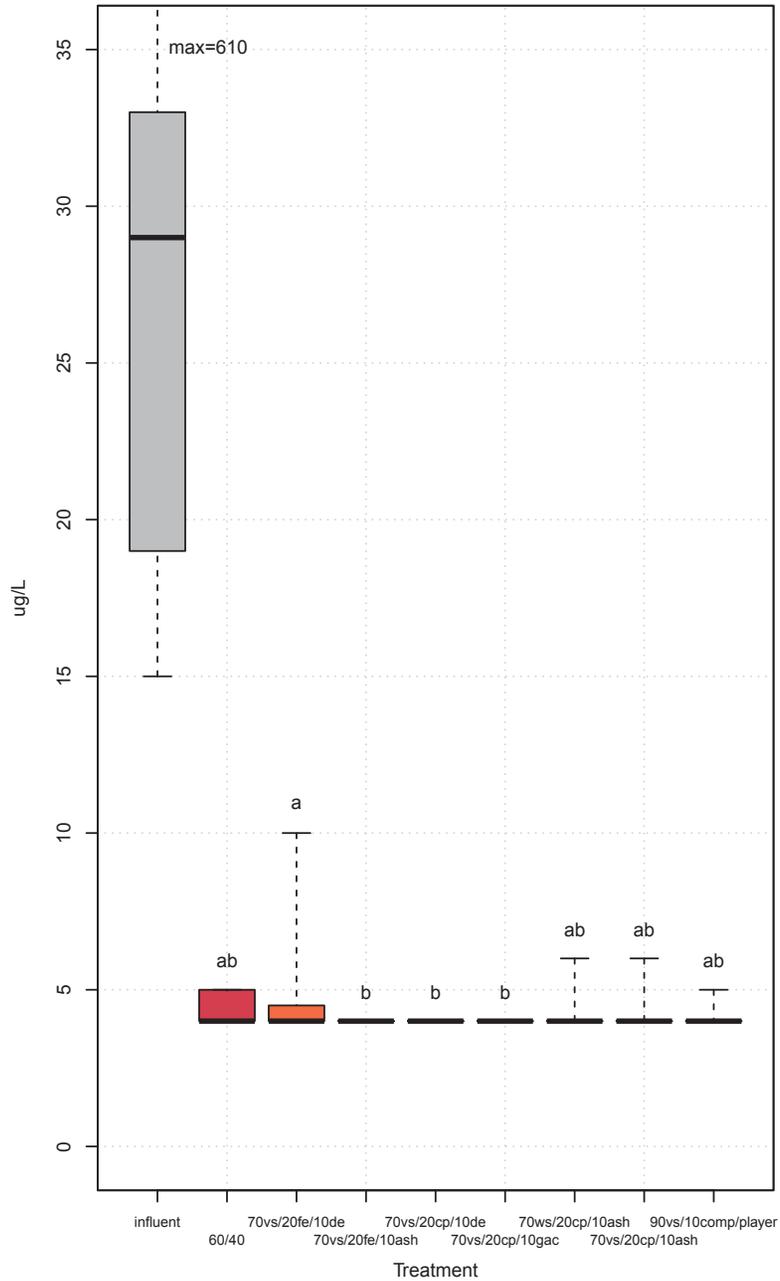
Percent Removal by Treatment



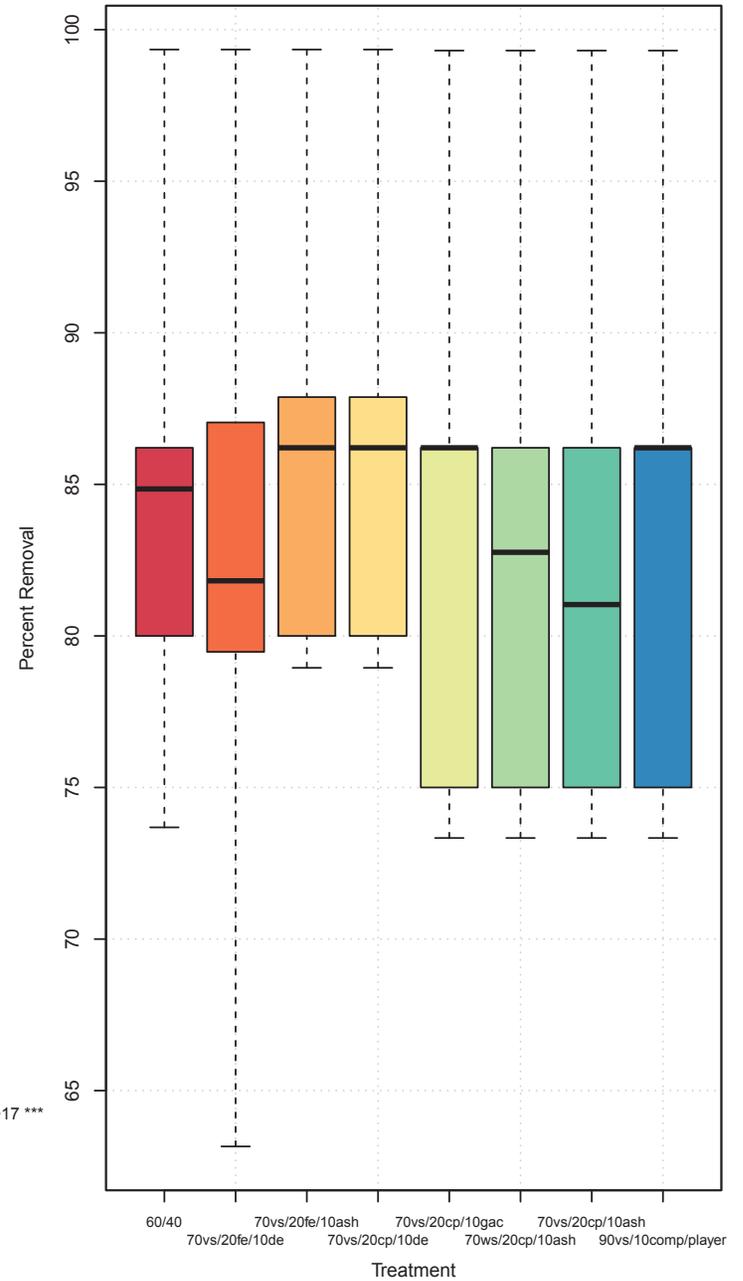
Two-Way ANOVA on Removal (ranks)
 Treatment p-value : 2.1e-14 ***
 Influent Concentration p-value : 0.0115 *
 Interaction p-value : 0.000356 ***

Dissolved Zinc

Effluent Concentration by Treatment



Percent Removal by Treatment



Two-Way ANOVA on Removal (ranks)

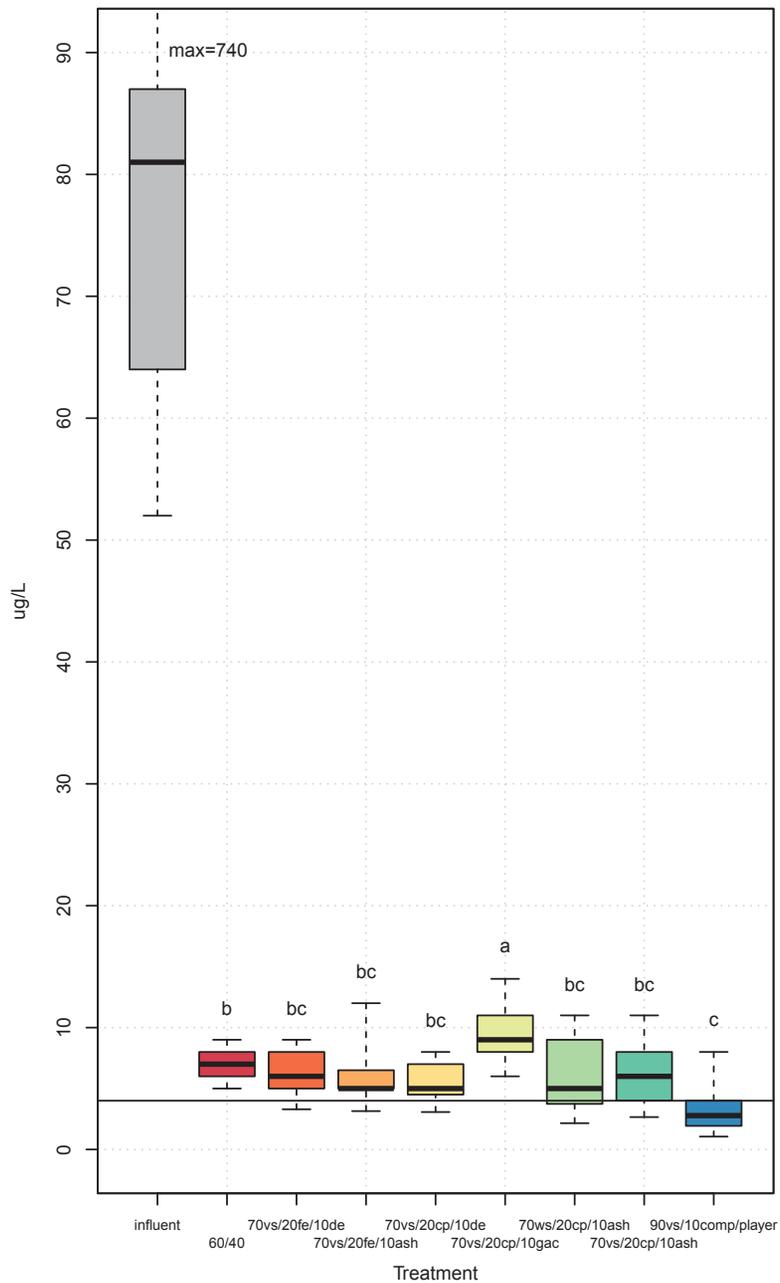
Treatment p-value : 0.123

Influent Concentration p-value : 3.62e-17 ***

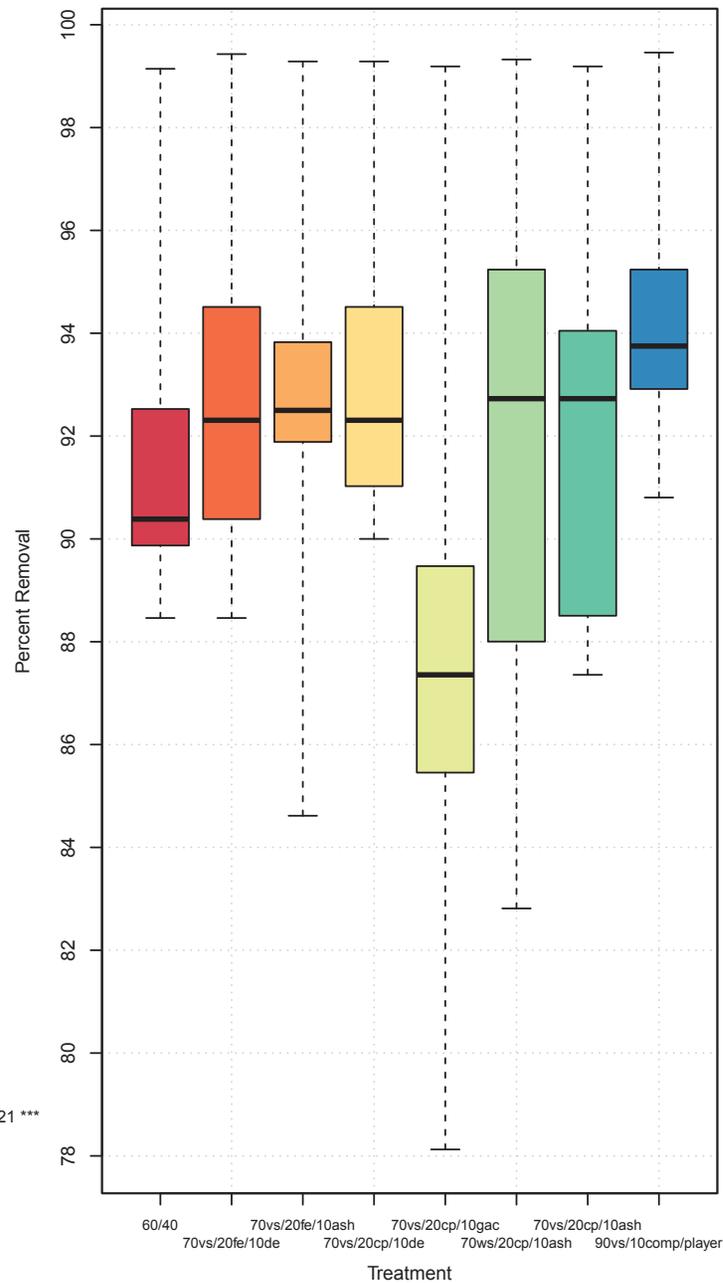
Interaction p-value : 0.998

Total Zinc

Effluent Concentration by Treatment



Percent Removal by Treatment



Two-Way ANOVA on Removal (ranks)
 Treatment p-value : 1.42e-07 ***
 Influent Concentration p-value : 1.94e-21 ***
 Interaction p-value : 0.367

APPENDIX I

Tabular Summaries for Dosing Experiment Results

Table I-1. Summary Statistics for Measured Effluent Concentrations During Dosing Experiments.

Parameter/ Treatment	Minimum	25th Percentile	Median	75th Percentile	Maximum
Alkalinity (mg/L as CaCO₃)					
60/40	23.2	25.7	35.8	49.6	52.2
70vs/20fe/10de	12.7	12.8	16.7	25.2	30.1
70vs/20fe/10ash	13.2	22.0	25.3	29.1	31.3
70vs/20cp/10de	11.1	11.8	12.9	15.1	17.1
70vs/20cp/10gac	8.8	8.8	9.7	10.4	10.7
70ws/20cp/10ash	14.8	15.7	16.9	17.8	18.4
70vs/20cp/10ash	13.2	13.3	14.4	15.7	17.6
90vs/10comp/player	52.4	54.1	58.0	64.2	65.3
Cadmium, Dissolved (µg/L)					
60/40	0.1	0.1	0.1	0.1	0.1
70vs/20fe/10de	0.1	0.1	0.1	0.1	0.1
70vs/20fe/10ash	0.0	0.0	0.0	0.0	0.2
70vs/20cp/10de	0.1	0.1	0.1	0.1	0.1
70vs/20cp/10gac	0.1	0.1	0.1	0.1	0.1
70ws/20cp/10ash	0.1	0.1	0.1	0.1	0.1
70vs/20cp/10ash	0.1	0.1	0.1	0.1	0.1
90vs/10comp/player	0.1	0.1	0.1	0.1	0.1
Cadmium, Total (µg/L)					
60/40	0.0	0.0	0.1	0.1	0.2
70vs/20fe/10de	0.0	0.0	0.1	0.1	0.2
70vs/20fe/10ash	0.0	0.0	0.0	0.0	0.2
70vs/20cp/10de	0.1	0.1	0.1	0.1	0.1
70vs/20cp/10gac	0.1	0.1	0.1	0.1	0.1
70ws/20cp/10ash	0.1	0.1	0.1	0.1	0.1
70vs/20cp/10ash	0.1	0.1	0.1	0.1	0.1
90vs/10comp/player	0.1	0.1	0.1	0.1	0.1
Calcium (mg/L)					
60/40	9,680	15,050	20,300	24,100	29,100
70vs/20fe/10de	4,300	5,885	7,370	11,950	20,000
70vs/20fe/10ash	4,040	6,380	8,310	11,650	18,600
70vs/20cp/10de	3,470	3,880	6,080	6,325	7,150
70vs/20cp/10gac	2,520	2,955	3,190	3,395	3,630
70ws/20cp/10ash	3,800	4,620	6,360	7,195	7,520
70vs/20cp/10ash	3,290	4,460	5,905	6,110	6,770
90vs/10comp/player	18,500	20,600	23,900	24,500	26,300

Table I-1 Continued. Summary Statistics for Measured Effluent Concentrations During Dosing Experiments.

Parameter/ Treatment	Minimum	25th Percentile	Median	75th Percentile	Maximum
Chloride (mg/L)					
60/40	3.7	3.8	4.5	5.3	5.3
70vs/20fe/10de	4.1	4.1	4.8	5.8	7.3
70vs/20fe/10ash	3.6	3.8	4.8	6.3	6.6
70vs/20cp/10de	3.5	3.5	4.0	4.6	4.8
70vs/20cp/10gac	0.6	0.9	2.1	3.2	3.4
70ws/20cp/10ash	3.3	3.3	3.7	4.5	4.6
70vs/20cp/10ash	3.4	3.4	4.0	4.5	4.5
90vs/10comp/player	3.7	3.7	4.2	4.9	5.0
Copper, Dissolved (µg/L)					
60/40	8.4	9.6	11.2	13.1	18.4
70vs/20fe/10de	6.5	15.2	20.0	25.2	68.0
70vs/20fe/10ash	10.3	12.9	19.6	23.4	43.5
70vs/20cp/10de	4.7	5.1	5.8	6.1	9.1
70vs/20cp/10gac	2.6	3.1	3.6	4.3	12.8
70ws/20cp/10ash	0.9	1.4	1.6	3.3	8.1
70vs/20cp/10ash	3.6	4.6	5.1	5.6	14.8
90vs/10comp/player	2.7	3.6	7.3	8.9	16.5
Copper, Total (µg/L)					
60/40	10.4	11.8	12.8	15.9	22.0
70vs/20fe/10de	9.8	18.4	26.9	38.1	64.9
70vs/20fe/10ash	12.0	19.1	24.0	29.9	43.1
70vs/20cp/10de	6.5	8.6	9.1	10.7	13.6
70vs/20cp/10gac	9.2	10.1	10.8	13.7	14.0
70ws/20cp/10ash	2.7	3.9	7.7	9.1	12.8
70vs/20cp/10ash	5.9	6.4	7.7	10.3	10.7
90vs/10comp/player	3.6	5.0	9.0	10.6	18.2
Dissolved Organic Carbon (mg/L)					
60/40	11.8	15.4	22.0	24.6	35.1
70vs/20fe/10de	14.6	30.7	40.2	64.5	85.2
70vs/20fe/10ash	12.6	23.6	43.5	58.2	72.4
70vs/20cp/10de	7.0	8.0	10.6	15.2	23.2
70vs/20cp/10gac	3.6	4.3	5.9	10.8	18.2
70ws/20cp/10ash	3.6	4.0	5.2	5.7	6.6
70vs/20cp/10ash	4.9	7.4	7.9	10.8	11.3
90vs/10comp/player	4.1	5.4	8.0	8.9	13.3

Table I-1 Continued. Summary Statistics for Measured Effluent Concentrations During Dosing Experiments.

Parameter/ Treatment	Minimum	25th Percentile	Median	75th Percentile	Maximum
Hardness (mg/L)					
60/40	37.0	57.0	77.0	92.0	110.0
70vs/20fe/10de	17.0	23.5	29.0	44.0	72.0
70vs/20fe/10ash	17.0	25.0	31.0	44.0	71.0
70vs/20cp/10de	14.0	16.0	24.0	25.0	28.0
70vs/20cp/10gac	12.0	12.5	14.0	15.0	17.0
70ws/20cp/10ash	16.0	19.0	25.0	28.0	31.0
70vs/20cp/10ash	14.0	18.0	23.0	24.0	27.0
90vs/10comp/player	68.0	75.0	91.0	96.0	100.0
Lead, Dissolved (µg/L)					
60/40	0.2	0.2	0.4	0.4	0.5
70vs/20fe/10de	0.2	0.3	0.4	0.8	1.5
70vs/20fe/10ash	0.2	0.4	0.5	0.8	1.4
70vs/20cp/10de	0.1	0.1	0.3	0.3	0.4
70vs/20cp/10gac	0.1	0.2	0.2	0.2	0.3
70ws/20cp/10ash	0.0	0.1	0.1	0.2	0.3
70vs/20cp/10ash	0.1	0.2	0.3	0.4	0.5
90vs/10comp/player	0.1	0.2	0.3	0.4	0.5
Lead, Total (µg/L)					
60/40	0.6	0.8	0.9	0.9	1.1
70vs/20fe/10de	0.5	0.9	1.1	1.4	2.0
70vs/20fe/10ash	0.8	1.0	1.0	1.2	1.4
70vs/20cp/10de	0.5	0.6	0.6	0.7	0.7
70vs/20cp/10gac	0.6	0.9	1.0	1.2	1.6
70ws/20cp/10ash	0.4	0.5	0.6	0.9	1.3
70vs/20cp/10ash	0.5	0.6	0.7	0.8	1.0
90vs/10comp/player	0.4	0.4	0.4	0.4	0.4
Magnesium (µg/L)					
60/40	3,100	4,695	6,420	7,710	9,060
70vs/20fe/10de	1,540	1,975	2,570	3,545	5,400
70vs/20fe/10ash	1,680	2,190	2,580	3,610	5,360
70vs/20cp/10de	1,400	1,545	2,130	2,255	2,490
70vs/20cp/10gac	1,070	1,370	1,440	1,680	1,940
70ws/20cp/10ash	1,590	1,860	2,250	2,530	2,960
70vs/20cp/10ash	1,370	1,770	2,075	2,170	2,440
90vs/10comp/player	5,020	5,785	7,640	8,505	8,730

Table I-1 Continued. Summary Statistics for Measured Effluent Concentrations During Dosing Experiments.

Parameter/ Treatment	Minimum	25th Percentile	Median	75th Percentile	Maximum
Nitrate + Nitrite (mg-N/L)					
60/40	2.77	6.70	10.70	16.55	25.00
70vs/20fe/10de	0.03	0.35	0.71	1.05	1.44
70vs/20fe/10ash	0.09	0.32	0.41	0.85	1.09
70vs/20cp/10de	0.20	0.53	0.98	1.21	1.69
70vs/20cp/10gac	0.01	0.02	0.03	0.03	0.04
70ws/20cp/10ash	0.07	0.10	0.16	0.25	0.47
70vs/20cp/10ash	0.12	0.20	0.33	0.36	0.54
90vs/10comp/player	0.81	0.88	1.42	1.60	2.62
Ortho-Phosphorus (mg-P/L)					
60/40	0.52	0.80	0.95	1.07	1.38
70vs/20fe/10de	0.02	0.08	0.11	0.14	0.17
70vs/20fe/10ash	0.03	0.06	0.08	0.20	0.30
70vs/20cp/10de	0.03	0.03	0.03	0.04	0.05
70vs/20cp/10gac	0.02	0.03	0.04	0.07	0.10
70ws/20cp/10ash	0.01	0.02	0.02	0.03	0.03
70vs/20cp/10ash	0.03	0.04	0.05	0.07	0.07
90vs/10comp/player	0.08	0.10	0.12	0.13	0.14
Dissolved Potassium (µg/L)					
60/40	6,550	6,550	9,660	12,000	14,600
70vs/20fe/10de	3,400	3,720	4,535	5,620	7,230
70vs/20fe/10ash	3,480	3,860	5,420	7,740	8,540
70vs/20cp/10de	1,310	1,350	1,360	1,420	1,420
70vs/20cp/10gac	1,670	1,680	1,690	1,740	1,760
70ws/20cp/10ash	940	1,050	1,110	1,190	1,220
70vs/20cp/10ash	1,690	1,750	1,785	1,830	1,830
90vs/10comp/player	2,540	2,570	3,255	3,960	3,960
Dissolved Sodium (µg/L)					
60/40	2,570	2,610	2,695	2,730	2,800
70vs/20fe/10de	2,700	2,770	3,060	4,290	4,630
70vs/20fe/10ash	2,640	2,870	3,345	4,110	4,160
70vs/20cp/10de	3,160	3,220	3,475	3,780	3,810
70vs/20cp/10gac	1,260	1,300	2,220	3,140	3,150
70ws/20cp/10ash	2,210	2,310	2,865	2,890	2,930
70vs/20cp/10ash	1,950	2,100	2,490	2,870	2,920
90vs/10comp/player	3,060	3,150	3,835	4,900	5,010

Table I-1 Continued. Summary Statistics for Measured Effluent Concentrations During Dosing Experiments.

Parameter/ Treatment	Minimum	25th Percentile	Median	75th Percentile	Maximum
Sulfate (mg/L)					
60/40	6.1	6.8	7.2	7.6	7.9
70vs/20fe/10de	5.6	12.7	23.1	23.5	23.5
70vs/20fe/10ash	6.8	8.9	15.9	48.6	68.3
70vs/20cp/10de	4.0	4.1	4.9	6.2	6.2
70vs/20cp/10gac	2.6	2.7	2.8	2.9	2.9
70ws/20cp/10ash	2.7	2.8	3.6	4.8	5.6
70vs/20cp/10ash	3.8	3.8	4.9	6.0	6.3
90vs/10comp/player	23.3	23.3	28.1	31.9	34.5
Total Kjeldahl Nitrogen (mg-N/L)					
60/40	2.0	2.6	3.4	3.7	4.1
70vs/20fe/10de	0.5	0.8	1.3	1.6	3.3
70vs/20fe/10ash	0.6	0.9	1.2	1.6	2.5
70vs/20cp/10de	1.0	1.0	1.0	1.0	1.0
70vs/20cp/10gac	1.0	1.0	1.0	1.0	1.0
70ws/20cp/10ash	1.0	1.0	1.0	1.0	1.0
70vs/20cp/10ash	1.0	1.0	1.0	1.0	1.0
90vs/10comp/player	0.8	0.9	1.0	1.1	1.2
Total Phosphorus (mg-P/L)					
60/40	0.74	0.98	1.12	1.39	1.86
70vs/20fe/10de	0.17	0.28	0.37	0.63	1.13
70vs/20fe/10ash	0.16	0.27	0.39	0.45	0.49
70vs/20cp/10de	0.13	0.18	0.22	0.22	0.22
70vs/20cp/10gac	0.20	0.25	0.28	0.29	0.30
70ws/20cp/10ash	0.07	0.10	0.19	0.20	0.20
70vs/20cp/10ash	0.11	0.16	0.27	0.34	0.34
90vs/10comp/player	0.16	0.20	0.21	0.28	0.28
Total Suspended Solids (mg/L)					
60/40	9.7	10.8	16.9	21.4	26.5
70vs/20fe/10de	8.0	13.5	19.8	34.7	52.6
70vs/20fe/10ash	6.2	10.7	13.3	28.2	37.6
70vs/20cp/10de	7.6	18.4	26.6	40.3	49.0
70vs/20cp/10gac	37.7	40.1	46.4	50.0	56.5
70ws/20cp/10ash	3.6	9.0	15.3	27.1	40.4
70vs/20cp/10ash	6.3	13.3	21.5	27.3	37.4
90vs/10comp/player	1.8	2.8	3.7	4.4	4.5

Table I-1 Continued. Summary Statistics for Measured Effluent Concentrations During Dosing Experiments.

Parameter/ Treatment	Minimum	25th Percentile	Median	75th Percentile	Maximum
Zinc, Dissolved (µg/L)					
60/40	3.6	4.0	4.2	5.0	5.0
70vs/20fe/10de	0.8	1.7	2.6	4.5	10.0
70vs/20fe/10ash	4.0	4.0	4.0	4.0	4.0
70vs/20cp/10de	4.0	4.0	4.0	4.0	4.0
70vs/20cp/10gac	4.0	4.0	4.0	4.0	4.0
70ws/20cp/10ash	1.1	1.8	2.5	3.3	6.0
70vs/20cp/10ash	1.2	1.9	2.6	3.4	6.0
90vs/10comp/player	5.0	5.0	5.0	5.0	5.0
Zinc, Total (µg/L)					
60/40	5.0	6.0	7.0	8.0	9.0
70vs/20fe/10de	3.3	5.0	6.0	8.0	9.0
70vs/20fe/10ash	3.1	5.0	5.0	6.5	12.0
70vs/20cp/10de	3.1	4.5	5.0	7.0	8.0
70vs/20cp/10gac	6.0	8.0	9.0	11.0	14.0
70ws/20cp/10ash	2.2	3.7	5.0	9.0	11.0
70vs/20cp/10ash	2.7	4.3	6.0	7.8	11.0
90vs/10comp/player	1.1	1.9	2.8	4.0	8.0

µg/L: micrograms per liter

mg/L: milligrams per liter

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

player: polishing layer

**Table I-2. Summary Statistics for
Pollutant Percent Removal During Dosing Experiments.**

Parameter/ Treatment	Minimum	25th Percentile	Median	75th Percentile	Maximum
Alkalinity (percent removal)					
60/40	-60.7	-48.6	-21.2	-2.9	9.3
70vs/20fe/10de	10.4	26.0	32.1	47.7	63.1
70vs/20fe/10ash	-28.3	-27.2	29.4	39.6	41.3
70vs/20cp/10de	31.8	31.8	50.2	68.7	71.0
70vs/20cp/10gac	55.2	56.7	64.6	73.3	73.8
70ws/20cp/10ash	17.7	22.7	40.0	54.4	56.4
70vs/20cp/10ash	34.0	34.5	44.9	59.7	60.5
90vs/10comp/player	-174.4	-166.5	-112.8	-64.6	-54.4
Cadmium, Dissolved (percent removal)					
60/40	0.0	0.0	0.0	0.0	0.0
70vs/20fe/10de	0.0	0.0	0.0	0.0	0.0
70vs/20fe/10ash	0.0	0.0	0.0	0.0	0.0
70vs/20cp/10de	0.0	0.0	0.0	0.0	0.0
70vs/20cp/10gac	0.0	0.0	0.0	0.0	0.0
70ws/20cp/10ash	0.0	0.0	0.0	0.0	0.0
70vs/20cp/10ash	0.0	0.0	0.0	0.0	0.0
90vs/10comp/player	0.0	0.0	0.0	0.0	0.0
Cadmium, Total (percent removal)					
60/40	0.0	0.0	0.0	0.0	0.0
70vs/20fe/10de	0.0	0.0	0.0	0.0	0.0
70vs/20fe/10ash	0.0	0.0	0.0	0.0	0.0
70vs/20cp/10de	0.0	0.0	0.0	0.0	0.0
70vs/20cp/10gac	0.0	0.0	0.0	0.0	0.0
70ws/20cp/10ash	0.0	0.0	0.0	0.0	0.0
70vs/20cp/10ash	0.0	0.0	0.0	0.0	0.0
90vs/10comp/player	0.0	0.0	0.0	0.0	0.0
Calcium (percent removal)					
60/40	-182.7	-135.1	-106.5	-62.8	-31.5
70vs/20fe/10de	-75.1	-22.6	4.6	33.9	59.4
70vs/20fe/10ash	-38.7	-16.0	4.0	23.0	47.0
70vs/20cp/10de	13.3	34.2	50.9	53.5	59.0
70vs/20cp/10gac	31.2	50.7	72.7	75.2	82.5
70ws/20cp/10ash	-1.4	23.8	42.3	46.7	63.6
70vs/20cp/10ash	16.4	29.0	52.7	55.6	64.5
90vs/10comp/player	-402.4	-228.8	-97.7	-85.3	-38.4

**Table I-2 Continued. Summary Statistics for
Pollutant Percent Removal During Dosing Experiments.**

Parameter/ Treatment	Minimum	25th Percentile	Median	75th Percentile	Maximum
Chloride (percent removal)					
60/40	-5.6	-5.6	7.2	17.2	18.8
70vs/20fe/10de	-19.4	-14.1	-13.9	9.4	18.8
70vs/20fe/10ash	-13.9	-5.6	-1.6	1.6	1.6
70vs/20cp/10de	2.8	2.8	13.9	28.1	31.3
70vs/20cp/10gac	5.6	11.1	48.1	85.1	85.1
70ws/20cp/10ash	8.3	8.3	19.8	32.8	40.3
70vs/20cp/10ash	2.8	5.6	19.2	32.8	32.8
90vs/10comp/player	-5.6	-2.8	11.3	26.9	31.3
Copper, Dissolved (percent removal)					
60/40	-55.2	-31.8	-24.1	-8.5	-8.0
70vs/20fe/10de	-296.6	-184.7	-140.8	17.1	95.8
70vs/20fe/10ash	-337.5	-154.9	-63.6	-23.7	94.9
70vs/20cp/10de	29.9	32.4	35.5	45.5	46.6
70vs/20cp/10gac	46.6	55.2	60.8	69.8	69.8
70ws/20cp/10ash	65.0	78.4	81.8	88.4	97.6
70vs/20cp/10ash	28.8	37.8	42.0	57.0	58.1
90vs/10comp/player	-13.8	7.8	58.1	66.1	95.3
Copper, Total (percent removal)					
60/40	-13.9	5.8	29.4	53.4	96.5
70vs/20fe/10de	-151.3	-89.3	-44.1	16.9	96.6
70vs/20fe/10ash	-184.1	-75.3	-6.5	26.9	95.6
70vs/20cp/10de	37.1	42.9	46.2	61.8	62.4
70vs/20cp/10gac	11.4	25.7	31.4	59.0	96.7
70ws/20cp/10ash	58.2	65.9	73.1	78.2	79.5
70vs/20cp/10ash	47.4	52.5	54.6	58.4	59.5
90vs/10comp/player	42.3	58.4	63.6	74.1	96.8
Dissolved Organic Carbon (percent removal)					
60/40	-263.4	-151.5	-132.9	-99.6	-55.9
70vs/20fe/10de	-1,868.3	-617.5	-509.0	-235.8	-54.2
70vs/20fe/10ash	-1,348.0	-572.1	-349.1	-217.0	-66.4
70vs/20cp/10de	-198.1	-44.6	-31.7	-19.1	17.1
70vs/20cp/10gac	-110.6	12.6	29.2	50.4	64.0
70ws/20cp/10ash	8.7	24.2	45.5	56.4	75.7
70vs/20cp/10ash	-113.0	-17.5	19.7	40.4	60.1
90vs/10comp/player	-244.0	0.3	29.1	47.3	58.1

**Table I-2 Continued. Summary Statistics for
Pollutant Percent Removal During Dosing Experiments.**

Parameter/ Treatment	Minimum	25th Percentile	Median	75th Percentile	Maximum
Hardness (percent removal)					
60/40	-225.0	-188.1	-140.0	-96.1	-64.1
70vs/20fe/10de	-107.1	-48.5	-15.0	20.1	47.1
70vs/20fe/10ash	-64.3	-36.3	-17.5	3.8	32.5
70vs/20cp/10de	-7.1	17.5	35.9	41.3	47.1
70vs/20cp/10gac	0.0	27.5	59.0	66.7	77.8
70ws/20cp/10ash	-21.4	0.0	28.2	33.3	53.7
70vs/20cp/10ash	0.0	10.0	41.0	45.2	55.6
90vs/10comp/player	-457.1	-275.0	-141.0	-125.0	-72.2
Lead, Dissolved (percent removal)					
60/40	28.6	31.0	33.3	40.2	50.0
70vs/20fe/10de	-150.0	-58.3	0.0	7.1	75.0
70vs/20fe/10ash	-150.0	-58.3	0.0	6.3	33.3
70vs/20cp/10de	42.9	50.0	50.0	64.6	75.0
70vs/20cp/10gac	33.3	50.0	60.0	66.7	75.0
70ws/20cp/10ash	33.3	50.0	60.0	66.7	87.5
70vs/20cp/10ash	33.3	33.3	38.8	50.0	62.5
90vs/10comp/player	20.0	33.3	37.5	45.0	50.0
Lead, Total (percent removal)					
60/40	63.3	69.2	70.6	73.8	77.8
70vs/20fe/10de	34.8	52.0	63.3	70.0	78.3
70vs/20fe/10ash	53.1	59.8	63.3	66.1	70.6
70vs/20cp/10de	65.6	73.9	77.8	79.7	82.4
70vs/20cp/10gac	58.8	62.5	66.7	67.9	72.7
70ws/20cp/10ash	61.8	71.0	77.3	82.8	86.7
70vs/20cp/10ash	70.6	71.4	75.4	80.0	82.4
90vs/10comp/player	85.3	85.7	86.4	86.7	86.7
Magnesium (percent removal)					
60/40	-400.0	-350.9	-261.1	-240.3	-179.5
70vs/20fe/10de	-208.3	-139.5	-74.6	-35.8	0.0
70vs/20fe/10ash	-146.4	-110.7	-97.9	-62.1	-22.8
70vs/20cp/10de	-79.8	-41.2	-17.9	-9.9	4.4
70vs/20cp/10gac	-71.4	-36.5	4.3	28.9	58.8
70ws/20cp/10ash	-83.2	-70.5	-36.3	-25.4	16.2
70vs/20cp/10ash	-58.4	-51.3	-9.7	-6.0	19.2
90vs/10comp/player	-540.7	-396.9	-334.9	-294.9	-205.4

**Table I-2 Continued. Summary Statistics for
Pollutant Percent Removal During Dosing Experiments.**

Parameter/ Treatment	Minimum	25th Percentile	Median	75th Percentile	Maximum
Nitrate + Nitrite (percent removal)					
60/40	-3,461.0	-1,975.1	-812.6	-523.0	-187.2
70vs/20fe/10de	7.3	25.2	40.4	50.9	83.4
70vs/20fe/10ash	4.9	31.4	42.7	51.8	80.7
70vs/20cp/10de	-13.7	-1.5	26.4	29.4	34.4
70vs/20cp/10gac	95.5	96.1	98.4	98.5	99.2
70ws/20cp/10ash	54.9	73.3	81.3	88.6	95.3
70vs/20cp/10ash	59.0	63.3	76.9	81.1	83.8
90vs/10comp/player	-56.9	-54.3	-29.7	4.1	12.6
Ortho-Phosphorus (percent removal)					
60/40	-1,843.7	-1,167.1	-758.2	-598.0	-507.1
70vs/20fe/10de	-124.6	-50.7	-27.7	21.3	82.4
70vs/20fe/10ash	-256.5	-179.6	13.8	49.0	70.9
70vs/20cp/10de	56.2	56.2	67.1	68.4	74.6
70vs/20cp/10gac	52.4	61.0	68.7	82.5	92.5
70ws/20cp/10ash	67.1	74.9	82.8	88.2	98.6
70vs/20cp/10ash	42.7	53.1	63.4	78.6	81.9
90vs/10comp/player	-62.2	-6.7	9.7	38.6	91.9
Dissolved Potassium (percent removal)					
60/40	-309.0	-236.1	-202.6	-140.8	-140.8
70vs/20fe/10de	-102.5	-62.5	-47.1	-30.3	-25.0
70vs/20fe/10ash	-139.2	-116.8	-70.7	-41.9	-27.9
70vs/20cp/10de	43.4	47.8	56.0	62.2	63.3
70vs/20cp/10gac	34.1	36.0	44.7	54.4	54.7
70ws/20cp/10ash	58.0	60.2	65.8	67.9	70.1
70vs/20cp/10ash	30.7	33.7	39.5	50.9	54.4
90vs/10comp/player	-6.7	-6.7	-1.9	2.7	3.8
Dissolved Sodium (percent removal)					
60/40	-9.8	-5.5	30.4	62.1	63.3
70vs/20fe/10de	-11.8	-8.6	14.5	39.7	54.1
70vs/20fe/10ash	-12.9	-12.5	19.0	42.3	46.5
70vs/20cp/10de	-28.2	-26.3	11.3	46.9	48.3
70vs/20cp/10gac	-29.6	-29.2	27.4	82.6	83.2
70ws/20cp/10ash	-20.6	-18.9	22.0	69.2	70.5
70vs/20cp/10ash	-20.2	-18.1	27.0	72.0	74.0
90vs/10comp/player	-30.9	-29.6	3.6	34.6	40.1

**Table I-2 Continued. Summary Statistics for
Pollutant Percent Removal During Dosing Experiments.**

Parameter/ Treatment	Minimum	25th Percentile	Median	75th Percentile	Maximum
Sulfate (percent removal)					
60/40	-109.1	-100.8	-59.4	-30.1	-25.4
70vs/20fe/10de	-1257.6	-606.8	-442.9	-287.4	5.1
70vs/20fe/10ash	-1057.6	-671.6	-342.4	-122.0	-93.2
70vs/20cp/10de	-24.2	-23.5	-13.1	-5.1	5.1
70vs/20cp/10gac	26.3	28.9	35.1	58.1	67.5
70ws/20cp/10ash	26.3	27.0	29.5	37.5	46.3
70vs/20cp/10ash	0.0	0.0	10.6	24.1	25.0
90vs/10comp/player	-555.3	-513.2	-422.2	-306.9	-290.0
Total Kjeldahl Nitrogen (percent removal)					
60/40	-310.0	-227.3	-169.2	-88.9	0.0
70vs/20fe/10de	-81.8	-47.7	0.0	13.9	37.5
70vs/20fe/10ash	-100.0	-45.5	0.0	16.1	37.5
70vs/20cp/10de	0.0	9.1	9.1	23.1	37.5
70vs/20cp/10gac	9.1	9.1	9.1	9.1	9.1
70ws/20cp/10ash	9.1	9.1	9.1	9.1	9.1
70vs/20cp/10ash	9.1	9.1	9.1	9.1	9.1
90vs/10comp/player	-9.1	0.0	9.1	9.1	9.1
Total Phosphorus (percent removal)					
60/40	-247.0	-177.3	-133.1	-18.3	26.5
70vs/20fe/10de	-6.7	7.7	24.0	47.2	83.0
70vs/20fe/10ash	-31.5	13.3	39.4	55.7	72.9
70vs/20cp/10de	6.5	30.3	55.9	62.2	87.7
70vs/20cp/10gac	3.4	14.4	40.5	43.4	83.5
70ws/20cp/10ash	13.4	38.4	62.0	77.6	94.3
70vs/20cp/10ash	14.3	44.4	47.6	66.7	78.7
90vs/10comp/player	17.6	35.5	43.8	52.2	54.4
Total Suspended Solids (percent removal)					
60/40	43.8	62.0	71.1	75.8	86.5
70vs/20fe/10de	-23.2	11.3	61.1	69.8	87.2
70vs/20fe/10ash	48.4	61.6	67.7	76.7	84.0
70vs/20cp/10de	-43.7	-6.5	52.7	73.3	87.4
70vs/20cp/10gac	-51.1	-0.8	7.6	41.0	80.5
70ws/20cp/10ash	-8.0	46.3	82.0	90.6	93.5
70vs/20cp/10ash	25.9	40.4	78.0	83.7	89.1
90vs/10comp/player	90.9	91.9	94.7	95.5	96.9

**Table I-2 Continued. Summary Statistics for
Pollutant Percent Removal During Dosing Experiments.**

Parameter/ Treatment	Minimum	25th Percentile	Median	75th Percentile	Maximum
Zinc, Dissolved (percent removal)					
60/40	73.7	80.0	84.8	86.2	86.2
70vs/20fe/10de	78.9	79.5	81.8	87.0	87.9
70vs/20fe/10ash	78.9	80.0	86.2	87.9	99.3
70vs/20cp/10de	78.9	80.0	86.2	87.9	99.3
70vs/20cp/10gac	73.3	75.0	86.2	86.2	99.3
70ws/20cp/10ash	73.3	75.0	82.8	86.2	99.3
70vs/20cp/10ash	73.3	75.0	81.0	86.2	99.3
90vs/10comp/player	73.3	75.0	86.2	86.2	99.3
Zinc, Total (percent removal)					
60/40	88.5	89.9	90.4	92.5	93.6
70vs/20fe/10de	88.5	90.4	92.3	94.5	99.4
70vs/20fe/10ash	89.7	91.9	92.5	93.8	93.9
70vs/20cp/10de	90.0	91.0	92.3	94.5	99.3
70vs/20cp/10gac	81.3	85.5	87.4	89.5	89.7
70ws/20cp/10ash	82.8	88.0	92.7	95.2	99.3
70vs/20cp/10ash	87.4	88.5	92.7	94.0	99.2
90vs/10comp/player	90.8	92.9	93.8	95.2	95.2

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
 player: polishing layer

APPENDIX J

Description of Media Components Used for Study

Media Component/Image	Description
<p>Volcanic sand</p> 	<p>Material Composition: varies, olivine, pyroxene and magnetite, usually Fe rich</p> <p>Origin: Southwest Washington (dredged from Chehalis River after Mt Saint Helens eruption)</p> <p>Supplier: Walrath</p> <p>Availability: abundant local source</p> <p>Cost: \$40.50/cubic yard</p>
<p>Washed sand</p> 	<p>Material Composition: silica sand</p> <p>Origin: Black Diamond, WA</p> <p>Supplier: Palmer Coking Coal</p> <p>Availability: Moderate (questionable if Palmer can supply large quantities for region-wide application)</p> <p>Cost: \$44.50/cubic yard</p>
<p>Iron-coated wood chips</p> 	<p>Material Composition: Ferrous gluconate incorporated onto fine wood chips during composting process. Process facilitated by bacteria.</p> <p>Origin: eastern Washington</p> <p>Supplier: experimental stage (no vendor)</p> <p>Availability: currently very limited</p> <p>Cost: \$70.00/cubic yard</p>

<p>Coco coir pith</p> 	<p>Material Composition: Coconut husk and coconut husk pith (layer between outer husk and inner nut)</p> <p>Origin: India, southeast Asia and south Pacific</p> <p>Supplier: Sunlight Supply (Vancouver, WA) for CocoGro.</p> <p>Availability: abundant</p> <p>Cost: \$176.70/cubic yard</p>
<p>Cedar Grove compost</p> <p>No image</p>	<p>Material Composition: yard debris and food waste</p> <p>Origin: western Washington</p> <p>Supplier: Cedar Grove</p> <p>Availability: abundant</p> <p>Cost: \$22.00/cubic yard</p>
<p>Land Recovery Inc compost</p> 	<p>Material Composition: all yard debris</p> <p>Origin: western Washington</p> <p>Supplier: Land Recovery Inc</p> <p>Availability: abundant</p> <p>Cost: \$22.00/cubic yard</p>
<p>Diatomaceous earth</p> 	<p>Material Composition: Approximately 80-90% silica, 2-4% alumina and 0.5-2% iron oxide</p> <p>Origin: Several sites in western U.S.</p> <p>Supplier: Walrath, Puyallup</p> <p>Availability: abundant</p> <p>Cost: \$300.00/cubic yard</p>

Activated alumina



Material Composition: Aluminum hydroxide

Origin: Eastern U.S.

Supplier: Axens, Inc.

Availability: abundant

Cost: \$1750.00/cubic yard

High carbon wood ash



Material Composition: Ligno-cellulosic product that may be created from multiple types of raw material (e.g., tree slash, etc)

Origin: Philomath, OR

Supplier: Biological Carbon LLC.

Availability: Moderate; however Biological Carbon is increasing manufacturing capability to large-scale production

Cost: \$400.00/cubic yard

GAC 1230AW



Material Composition: Carbonaceous (e.g. nutshells, coconut husk or wood)

Origin: Crawford, NE

Supplier: Charcoal House

Availability: abundant

Cost: \$718.20/cubic yard

CAG 824BC



Material Composition: bones

Origin: Crawford, NE

Supplier: Charcoal House

Availability: abundant

Cost: \$3,097.60/cubic yard

APPENDIX K

Candidate Media Components for Study

Table K-1. Candidate Media Components for the Study

Common Name	Component	Material Composition	Source or Manufacturing Process	Vendor	Source Location	Unit Cost (CY Delivered)	Quantity for Cost Estimate	Estimated % Use in BSM		Target Pollutants	Treatment Mechanism	Performance Notes	Recommend
								(low)	(high)				
Activated alumina	Mineral additive	Aluminum hydroxide (1)	Dehydroxylating aluminum hydroxide. Process results in a highly porous material (1).	Axens, Inc. (eastern U.S.)	Eastern US and Canada.	\$1,750.00	<100 CY	5	20	Fluoride, arsenic, selenium, beryllium, and natural organic matter (10). Phosphorus (11).	Adsorption, filtration	Best performance for P capture (15). May raise pH to 8-10 (14).	Yes
Bauxite	Mineral additive	Hydrous aluminum oxides and aluminum hydroxides (12).	Strip-mined.	Not targeted for testing	Australia, Brazil, China, India, etc.	Not targeted for testing	Not targeted for testing	5	20	Phosphorus	Adsorption and/or precipitation (pH dependent...neutral to lower pH favors Al and Fe adsorption)	Principle source of aluminum.	No
Biochar	Organic additive	Ligno-cellulosic product that may be created from multiple types of raw material (e.g., bamboo, douglas fir, reeds, etc.)	Any ligno-cellulosic material burned at specific temperature and in a low- or no-oxygen environment. Specifically will analyze Environmental Ultra.	Biochar Supreme (Everson, WA), Walrath.	Western WA, Canada or Oregon.	\$300.00	>300 CY	5	20	Varies by feedstock and burn process.	Filtration, adsorption, complexation and promotes biological activity thus uptake.	High variability among sources for P export, pollutant capture and hydraulic conductivity (15). Specifically will analyze Environmental Ultra that has high surface area.	Yes
Blast furnace slag	Mineral additive	Typically 33-43% calcium oxide and 9-16% aluminum oxide (12).	By-product of iron ore processing.	Not targeted for testing	Steel manufacturers.	Not targeted for testing	Not targeted for testing	5	20	Phosphorus	Adsorption and/or precipitation (pH dependent...lower pH favors Al and Fe adsorption, higher pH favors calcium precipitation).	Some studies have found significant reduction in infiltration capability using slag (13). Potential for metal leaching (12).	No
C-33 sand	Bulk aggregate	Usually common silica sand.	Various mining processes (dredging, excavation). C-33 is an ASTM specification for concrete aggregates generally with no more than 4% passing the 100 sieve and a uniformity coefficient that is ≤ 4 .	Cadmin (Redmond plant)	Likely western Washington pits.	Not targeted for testing	Not targeted for testing	50	80	Particulates, metals	Filtration, adsorption.		No
Carbonate sands	Bulk aggregate	Calcium carbonate (1).	Skeletal remains of plants or animals or weathered rock with a high calcium carbonate content (1).	No source identified	No source identified	No source identified	No source identified	50	80	Phosphorus	Adsorption and/or precipitation (pH dependent, higher pH favors calcium precipitation).		No
Coco peat	Primary additive	Coconut husks and sphagnum peat.	Coir waste from coir fiber industries is washed, heat-treated, screened, graded, and processed into coco peat products of various granularity and denseness.	No source identified	India, southeast Asia and south Pacific, New Zealand (1).			5	20	Metals.		High water holding capacity. Low nutrient content. May have naturally occurring beneficial fungi (Trichoderma) that protects plants from pathogens (e.g. pythium) (1). May lower pH significantly (17).	Yes

Table K-1 Continued). Candidate Media Components for the Study

Common Name	Component	Material Composition	Source or Manufacturing Process	Vendor	Source Location	Unit Cost (CY Delivered)	Quantity for Cost Estimate	Estimated % Use in BSM		Target Pollutants	Treatment Mechanism	Performance Notes	Recommend
								(low)	(high)				
Coco coir fiber	Bulk organic	Coconut husk and coconut husk pith.	Fibrous layer of the fruit is separated from the hard shell by manually (~2,000 husk/day) or by machine (~2,000 coconuts/hour) (1).	Sunlight Supply (Vancouver, WA). Using CocoGro for testing.	India, southeast Asia and south Pacific (1).	\$176.70		5	20	Not known (primarily applied for soil structure).	Not known.	While primarily a soil structure and water holding capacity amendment the material should be assessed for leaching if commonly applied.	No
Compost	Bulk organic	Usually yard trimmings or yard trimmings with food waste. Will not include manure- or biosolids-based composts.	Biologic decomposition.	Several local vendors and producers, Walrath.	Several local vendors and producers.	\$24.00	>300 CY	5	20	Metals, hydrocarbon, bacteria.	Filtration, adsorption, complexation and promotes biological activity thus uptake.	Flushing and leaching of Cu, P and N observed (19).	Yes
Corliss pipe bedding sand	Bulk aggregate	Not known	Various mining processes (dredging, excavation).	Corliss (Puyallup)	Puyallup	\$25.00	>100 CY	50	80	Particulates, metals	Filtration, adsorption.	Initial SPLP screening indicates N, P and Cu at detection limits.	Yes
Corliss utility sand	Bulk aggregate	Not known	Various mining processes (dredging, excavation).	Corliss (Puyallup)	Puyallup	\$26.65	>100 CY	50	80	Particulates, metals	Filtration, adsorption.	Initial SPLP screening indicates N, P and Cu at detection limits.	Yes
Crushed brick	Mineral additive	Clay-bearing soil, sand and lime, or concrete material that is fire hardened or air dried (1).	Recycled or new brick crushed to specific gradation.	RealGoods Company (Daniel Wheeler, 814-676-0700)	Oil City, PA	not known		5	20	Phosphorus.	Adsorption, filtration		Yes
Dakota peat	Bulk organic	Decomposed reeds and sedges from ancient swamp lands.	Harvested from old ditched and drained farmland (now shrub lands). Field is tilled dried and vacuum harvested (generally to 24" depth).	Dakota Peat (Grand Forks, ND)	Red River Valley in NW MN.	\$300.00	<100 CY	5	20	Metals.	Filtration, adsorption, complexation and promotes biological activity thus uptake.	Harvested area is returned to habitat (e.g. water fowl) in cooperation with MN DNR. Excellent metals capture at high flow rates (17). May lower pH significantly (17). May export P and Ortho-P (17).	Yes
Diatomaceous earth (Diatomite)	Mineral additive	Approximately 80-90% silica, 2-4% alumina and 0.5-2% iron oxide (1).	Skeletal remains of diatoms	Walrath (Puyallup).	Several sites in western US.	\$300.00	>300 CY	5	20	Bacteria, fine particulates, phosphorus.	Adsorption and/or precipitation (pH dependent, higher pH favors calcium precipitation). Filtration.	For wastewater treatment DE is mixed in a slurry and fed onto a fine screen (septum). The DE coats the septum and creates a microscopic filter (3). Discharge of DE from filters controlled by DOE in current SWMMWW. Air borne particle and lung disease guidelines necessary for handling.	Yes
Eastern OR basalt sand	Bulk aggregate	Basalt is an aphanitic igneous rock with less than 20% quartz and less than 10% feldspathoid by volume, and where at least 65% of the feldspar is in the form of plagioclase. Rapidly weathers to brown or rust-red due to oxidation of its mafic (iron-rich) minerals into rust (1).	Common extrusive igneous (volcanic) rock formed from the rapid cooling of basaltic lava exposed at or very near the earth's surface (1).	not known	not known	not known		50	80				Yes

Table K-1 Continued). Candidate Media Components for the Study

Common Name	Component	Material Composition	Source or Manufacturing Process	Vendor	Source Location	Unit Cost (CY Delivered)	Quantity for Cost Estimate	Estimated % Use in BSM		Target Pollutants	Treatment Mechanism	Performance Notes	Recommend
Ecology bioretention sand specification /gradation	Bulk aggregate	Silicate minerals (most commonly quartz and smaller percentages of other minerals such as feldspars) (4).	Various mining processes (dredging, excavation).	Several local suppliers (primary supplier currently Miles Sand and Gravel and Walrath).	Western Washington.	\$40.00	>300 CY	50	80	Phosphorus (sand filters including biological activity).	Filtration and biological uptake.	Flushing and leaching of Cu, P and N observed (19).	Yes
Expanded shale	Mineral additive	Depending on parent materials: Hydrous aluminum silicates, feldspar, quartz, carbonates and/or micas.	Crushed clay, shale or slate exposed to high heat (3,600 F).	Walrath (Puyallup)	Utelite, Inc. UT.	\$78.00	Not targeted for testing	10	20			Elevates pH (15).	No
Fly ash	Mineral additive		Residual of combustion from coal power plants.	Not targeted for testing	Not targeted for testing	Not targeted for testing	Not targeted for testing	5	20	Phosphorus		Potential for metal leaching (12).	No
Granular activated carbon	Organic additive	Carbonaceous (e.g. nutshells, coconut husk or wood) (1).	Physical (e.g. hot gasses) or chemical (e.g. acid, base or salt) activation to increase porosity and surface functional groups.	Charcoal House, (Crawford, NE). Use 1230AW GAC form Charcoal House for analysis.	Unknown	\$718.20	<100 CY	5	20	Organic compounds, natural organic matter, mercury and Cd (1, 9).	Adsorption, filtration	Powdered and granulated forms available (granulated likely best material for bioretention application) (1). Performance determined by surface area and chemical characteristics (e.g. surface functional groups). Improved N03-N02 capture in media mixtures and Cu capture when tested individually (17). May release (17) or export P (15).	Yes
Hi-clay alumina	Mineral additive	Minimum 20-40% Al2O3.	By-product of commercial alum production (1).	Not targeted for testing	CA, MT, UT, CO, Argentina.	Not targeted for testing	Not targeted for testing	5	20	Phosphorus	Adsorption and/or precipitation (pH dependent, neutral to lower pH favors Al and Fe adsorption)		No
High carbon wood ash	Organic additive	Ligno-cellulosic product that may be created from multiple types of raw material (e.g., tree slash, etc.)	Any ligno-cellulosic material burned at specific temperature and in an oxygen environment. Specifically will analyze products from Biological Carbon	Biological Carbon LLC. Use PD and AS 100+ mesh for analysis.	Philomath, OR	\$400.00		5	20	Varies by feedstock and burn process.	Filtration, adsorption, complexation and promotes biological activity thus uptake.		Yes
Imbrium/ Contech Sorptive media	Mineral additive			Not targeted for testing	Contec.	Not targeted for testing					Adsorption and precipitation.		No
Iron shavings	Mineral additive	Iron particles (97% Fe)	Likely machine and mill operations.	No source identified	No source identified	No source identified	No source identified	5	10				No
Iron-coated sand	Mineral additive	Usually common silica sand coated with hydrated iron oxide.	Mixing iron oxides with sand and acids or bases and applying heat.	No source identified	No source identified	No source identified	No source identified	5	10	Metals (Cu) (6), humic acids (7), phosphorus (8).	Adsorption, filtration	Coating process determines Fe density and performance.	No source identified

Table K-1 Continued). Candidate Media Components for the Study

Common Name	Component	Material Composition	Source or Manufacturing Process	Vendor	Source Location	Unit Cost (CY Delivered)	Quantity for Cost Estimate	Estimated % Use in BSM		Target Pollutants	Treatment Mechanism	Performance Notes	Recommend
Iron-fused wood chips	Bulk organic	Horse manure and ferrous gluconate	Ferrous gluconate incorporated onto composted manure. Process facilitated by bacteria.	Experimental stage (no vendor)	Eastern Washington	\$70.00		5	20	Phosphorus, lead.	Adsorption	Material in experimental stages	Yes
Lava sand	Bulk aggregate		Crushed product from lava rock. Lava rock from volcanic cinder pit exposed to steam.	Palmer Coking Coal	Goldendale, WA	\$78.30	>5 CY	50	80	Possibly Phosphorus	adsorption		Yes
Loamy sand topsoil	Bulk aggregate	Varies with source. See soil classification	Varies, often removed during land clearing.	Various western WA locations	Various western WA locations.	\$20.00	>300 CY	10	50	Treatment capabilities for various pollutants.	All stormwater treatment mechanisms if media is biologically active.	Flushing and leaching of Cu, P and N observed.	No
NXT-2 (lanthunum coated DE)	Mineral additive	Lanthunum (metallic element #57)-iron oxyhydroxide and diatomaceous earth (calcium carbonate).	Manufactured metallic element from monazite and bastnasite...atomic #57 (12).	EP Minerals (Reno, NV)	Nevada	\$8,370.00	small	5	20	Arsenic and phosphorus (12).		Does not alter pH and reaction is less pH dependent (12).	No
Oyster shells	Mineral additive	Primarily CaCo3.	By-product of local oyster growers.	Several in Western WA. Used Gold Coast Oyster LLC	Western Washington.	\$75.00	>300 CY	5	20	Phosphorus	Adsorption and precipitation.	Good performance from oyster shells heated in an air atmosphere and very good performance from shells conditioned by pyrolysis in a nitrogen environment (converted CaCo3 to Ca oxide at surface (18).	Yes
Perlite	Mineral additive	Silicon dioxide, aluminum oxide, sodium oxide and iron oxide.	Expanded amorphous volcanic glass.	Walrath (Puyallup), Great Western Supply (Olympia).	Lakeview, OR (south-central OR)	\$45.00	Not targeted for testing	10	20	TSS, oil and grease.		Helps prevent soil compaction. Low water holding capacity.	No
Phoslock	Mineral additive	Modified bentonite clay containing lanthanum.	Proprietary phosphorus capture media.	Not targeted for testing	SePRO, CSIRO Land and Water.	Not targeted for testing				Phosphorus	Adsorption and precipitation.		No
Phosphosorb	Mineral additive	Heat expanded volcanic rock (Perlite) and activated alumina.	Proprietary phosphorus capture media.	Not targeted for testing	Contec.	Not targeted for testing				Phosphorus, TSS.	Adsorption and precipitation.		No
Play sand	Bulk aggregate	Usually common silica sand.	Various mining processes (dredging, excavation). Specific process unknown.	Home Depot	Unknown.	Not targeted for testing	Not targeted for testing	50	80	Particulates, metals	Filtration, adsorption.		No
Pumice	Mineral additive	Silicic (igneous rock with ≥ 65% silica) or felsic (igneous rock with ≥75 % felsic minerals...quartz, orthoclase and plagioclase), but basaltic and other compositions are known. (1).	Super-heated, highly pressurized rock violently ejected from volcanoes (1).	Hess Pumice (ID)	Mined in ID, CA, OR, Canada.	\$41.24	Not targeted for testing	10	20	Particulates, metals (with Fe additive) (16).	Filtration, adsorption.	Highly porous. May export metals and TP (15). Environmental concerns due to high demand and mining in environmentally sensitive areas (1).	No

Table K-1 Continued). Candidate Media Components for the Study

Common Name	Component	Material Composition	Source or Manufacturing Process	Vendor	Source Location	Unit Cost (CY Delivered)	Quantity for Cost Estimate	Estimated % Use in BSM		Target Pollutants	Treatment Mechanism	Performance Notes	Recommend
Red mud	Mineral additive	Primarily iron, calcium and titanium oxides (12).	By-product of bauxite refining.	Not targeted for testing	Australia, Brazil, China, India, etc.	Not targeted for testing	Not targeted for testing	5	20	Phosphorus	Adsorption and/or precipitation (pH dependent...lower pH favors Al and Fe adsorption, higher pH favors calcium precipitation).	Toxic waste product with difficult disposal issues. May have high concentrations of arsenic and chromium. Can have high pH (10-12).	No
Rhyolite sand	Bulk aggregate	Quartz, alkali feldspar and plagioclase	High viscous lava. Volcanic plugs, dikes and breccias.	Walrath (Puyallup)	Nevada	\$200.00	<100 CY	50	80	Possibly nutrients and metals (17).	Likely adsorption.	May provide better pollutant capture than silica sands (17). Did not export P or Ortho-P (17).	Yes
Shredded cedar bark	Organic additive	Finely shredded bark	Shredded (often multiple times) timber harvest waste	Swansons (Longview, WA)	Southwest Washington.	Not targeted for testing		5	10	Not known (primarily applied for soil structure).	Not known.	While primarily a soil structure and water holding capacity amendment the material should be assessed for leaching if commonly applied.	No
Snohomish Co filter sand	Bulk aggregate	Usually common silica sand.	Various mining processes (dredging, excavation). Snoho Co filter sand is used for stormwater filter media and is a moderately well-graded sand with 4% or less passing the 100 sieve.	CADMAN, Inc. (western WA)	Western Washington.	\$38.48	Not targeted for testing	50	80	Particulates, metals	Filtration, adsorption.	Can export metals and TP (15).	No
Volcanic sand	Bulk aggregate	Varies: olivine, pyroxene and magnetite. Usually Fe rich (4).	Eroded from volcanic terrain or product of eruption.	Walrath (Puyallup)	Southwest Washington (Mt Saint Helens origin)	\$40.50	>300 CY	50	80	Possibly bacteria (5).	Filtration and adsorption	May provide better pollutant capture than silica sands (17).	Yes
Washed sand	Bulk aggregate		Excavation	Palmer Coking Coal	Black Diamond, WA	\$44.50	>3 CY	50	80	Phosphorus (sand filters including biological activity).	adsorption		Yes
Water treatment residuals	Mineral additive	Aluminum or iron hydroxides coagulated with various particulates suspended in natural waters (silt, clay, organic matter).	Drinking water treatment plant intakes to settle suspended material.	Drinking water treatment plants (western WA).	Drinking water treatment plants throughout WA.	Material usually free. Transportation costs unknown.	Not targeted for testing	5	20	Phosphorus	Adsorption and/or precipitation (pH dependent, neutral to lower pH favors Al and Fe adsorption)	Good P capture performance. Exports Cu (15).	No
Zeolite	Mineral additive	Aluminosilicate	Industrial crystallization of silica-alumina or volcanic rock reacting with alkaline water (1).	Walrath (Puyallup)	Mined in CA, ID, WY, NV, AZ, OR.	\$449.00	<100 CY	5	20	Nitrogen compounds (1), humic acids (2), metals (2), phosphorus (13), some organics.	Molecular sieving, ion exchange (1), sorption, cation exchange (2). Possible to modify zeolite (e.g. acid treatment) for OM and anion capture (2).	Has regular pore structure that can selectively sort molecules based primarily on size (1). High water holding capacity (1). May be modified to be "aluminum-loaded" (2). There are many different types of Zeolite with different performance characteristics. May be issue with ion exchange, release of Na and leaching of metals. Did not export Cu, P or Ortho-P (17).	Yes

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APPENDIX L

Raw Study Data and Laboratory Reports

The contents of this appendix will be provided separately as an electronic file.

APPENDIX M

Cost of Media Blends per Cubic Yard

Cost of Media Blends per Cubic Yard			
Component	Cost/CY	Component Percentage	Cost/CY Blend
60% Ecology bioretention sand/40% CG compost (control)			
Ecology bioretention sand	\$40.00	0.6	\$24.00
CG Compost	\$24.00	0.4	\$9.60
		Total/CY	\$33.60
70% volcanic sand/20% iron-coated wood chips/10% diatomaceous earth			
Volcanic sand	\$40.50	0.7	\$28.35
Iron-fused wood chips	\$70.00	0.2	\$14.00
Diatomaceous earth	\$300.00	0.1	\$30.00
		Total/CY	\$72.35
70% volcanic sand/20% iron-coated wood chips/10% high carbon wood ash			
Volcanic sand	\$40.50	0.7	\$28.35
Iron-fused wood chips	\$70.00	0.2	\$14.00
High carbon wood ash	\$400.00	0.1	\$40.00
		Total/CY	\$82.35
70% volcanic sand/20% coco coir pith/10% diatomaceous earth			
Volcanic sand	\$40.50	0.7	\$28.35
Coco coir	\$176.70	0.2	\$35.34
Diatomaceous earth	\$300.00	0.1	\$30.00
		Total/CY	\$93.69
70% volcanic sand/20% coco coir pith/10% granulated activated charcoal			
Volcanic sand	\$40.50	0.7	\$28.35
Coco coir	\$176.70	0.2	\$35.34
GAC	\$718.20	0.1	\$71.82
		Total/CY	\$135.51
70% washed sand/30% coco coir pith/10% high carbon wood ash			
Washed sand	\$44.50	0.7	\$31.15
Coco coir peat	\$176.70	0.2	\$35.34
High carbon wood ash	\$400.00	0.1	\$40.00
		Total/CY	\$106.49
70% volcanic sand/20% coco coir pith/10% high carbon wood ash			
Volcanic sand	\$40.50	0.7	\$28.35
Coco coir peat	\$176.70	0.2	\$35.34
High carbon wood ash	\$400.00	0.1	\$40.00
		Total/CY	\$103.69
90% volcanic sand/10% compost/polishing drainage layer (volcanic sand, activated alumina and bone char)			
Volcanic sand	\$40.50	0.9	\$36.45
Compost	\$24.00	0.1	\$2.40
Activated alumina *	\$1,750.00	0.067	\$77.39
Bone char *	\$3,097.60	0.067	\$136.98
		Total/CY	\$253.21

* p-layer percentages: 12 in/18 in = 0.67 (percentage of polishing layer in relation to total media column) x 0.1 (percentage of bone char and activate alumina in polishing layer)

Bulk mineral and organic price for 100 CY delivered to central Seattle area and mineral and organic additive price per cubic yard.

