BIORETENTION MEDIA BLENDS TO IMPROVE STORMWATER TREATMENT: FINAL PHASE OF STUDY TO DEVELOP NEW SPECIFICATIONS FINAL REPORT

Prepared for
King County

Prepared by
Herrera Environmental Consultants, Inc.

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Stormwater Action Monitoring

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BIORETENTION MEDIA BLENDS TO IMPROVE STORMWATER TREATMENT: FINAL PHASE OF STUDY TO DEVELOP NEW SPECIFICATIONS FINAL REPORT

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CONTENTS

APPENDICES

TABLES

FIGURES

EXECUTIVE SUMMARY

ES1 PROBLEM STATEMENT

Bioretention is the most widely applicable and flexible BMP in the suite of Stormwater Treatment 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 and into local receiving water bodies. The current Washington State Department of Ecology (Ecology) specification for bioretention soil media (BSM) in western Washington is a mixture of 60 percent sand and 40 percent compost (60/40). While the 60/40 BSM can provide reliable water quality treatment for some contaminants (e.g., solids removal, zinc [Zn], and hydrocarbons), regional and national research indicate that nitrogen (N), phosphorus (P), and copper (Cu) are often exported from BSM containing compost.

ES1.1 STUDY GOALS, OBJECTIVES AND APPROACH

The overall goal of this project was to develop new recommendations for a BSM that protects beneficial uses of receiving waters and achieves the following objectives in order of priority: 1) meets basic treatment (Ecology's treatment objectives for total suspended solids); 2) meets enhanced treatment (Ecology's treatment objectives for dissolved Cu and Zn); 3) meets Ecology's treatment objective for phosphorus; 4) is affordable and available; and 5) reduces stormwater toxicity for aquatic organisms.

Overall the study approach was designed to optimize the BSM for total suspended solids (TSS), P, Cu and Zn capture. While achieving Ecology's basic, phosphorus, and enhanced treatment was the focus of this study, other contaminants of concern were also evaluated including dissolved organic carbon (DOC), nitrate+nitrite, cadmium (Cd), lead (Pb), diesel and motor oil fractions of total petroleum hydrocarbons (TPH), polycyclic aromatic hydrocarbons (PAH), and fecal coliform bacteria. These additional parameters were assessed to confirm adequate treatment of other common stormwater contaminants of concern. There were six primary components to the study:

1. Review potential bioretention BSM components based on pollutant capture capability, cost, availability, and sustainability. Select individual BSM components based on survey and project partner input.
2. Conduct laboratory tests (EPA Method 1312) to determine N, P, and Cu leaching potential of the BSM components. Select the components that minimize leaching

potential, provide adequate hydraulic conductivity and support plants. Note that results from the BSM Phase 1 and this study were used to make these determinations.

3. Combine selected components at various ratios, place in columns, flush the BSM blends with deionized water, and measure hydraulic conductivity and pollutant leaching.

4. Dose the BSM blends with stormwater collected from State Route 520 in Seattle and evaluate their pollutant removal efficiency.

5. Conduct toxicological tests to determine how well the BSM blends protect aquatic organisms.

6. Select the best performing BSM blend and determine metrics and numeric ranges for a specification that describes the best performing BSM.

Table ES 1 describes the BSM treatments used in the study.

Table ES-1. Primary Bioretention Soil Media and Polishing Layer Blends.

Treatment Number	BSM Blend Abbreviations	Primary Layer	Polishing Layer
1	60/40	60% ecology sand/40%compost	none
2	60/40/aafep-layer	60% ecology sand/40%compost	90% state sand/7% coarse activated alumina/3% iron aggregate
3	70vs/20cp/10ash/ compmulch	70% volcanic sand/20% coco coir/10% high carbon wood ash/2-inch compost mulch	None
4	70vs/20cp/10ash/ compmulch /aafep-layer	70% volcanic sand/20% coco coir/10% high carbon wood ash/2-inch compost mulch	90% state sand/7% coarse activated alumina/3% iron aggregate
5	70vs/20cp/10ash	70% volcanic sand/20% coco coir/10% high carbon wood ash	None
6	70ss/20cp/10ash	70% state sand/20% coco coir/10% high carbon wood ash	None
7	70ls/20cp/10ash	70% lava sand/20% coco coir/10% high carbon wood ash	None
8	70ls/20cp/10ash/ orifice	70% lava sand/20% coco coir/10% high carbon wood ash (orifice control)	None

All percentages by volume.

Treatment comparisons (rows that share the same color are paired as follows):

- Treatments 1 and 2: Compare 60/40 with and without polishing layer.
- Treatment 3 and 4: Compare different BSM blends placed below compost mulch (compost mulch provides improved plant growth).
- Treatments 5 and 6: Evaluate treatment performance of high Ksat vs higher Ksat media.
- Treatments 7 and 8: Same high Ksat blends with no orifice vs orifice control.

ES2. FINDINGS

The following provides a brief summary of the study findings:

- Treatment 4 was the only media blend that met all TAPE objectives for water quality treatment.
- Treatment 1 (60/40) continued to export TP, ortho-P, nitrate+nitrite, and total and dissolved Cu after flushing for one water year and was dropped from the study after the second dosing experiment.
- Treatment 2 (60/40/aafep-layer) performed better than Treatment 1 due to the polishing layer capturing contaminants flushing from the compost-based media. However, the polishing layer could not fully mitigate the TP, ortho-P and nitrate+nitrite from the 60/40 media above.
- Treatments 7 and 8 performed well for most contaminants; however, the sand exported very high concentrations of aluminum during the initial flushing experiments.
- Treatment 3 included the sand, coir and ash blend with a compost mulch to improve plant growth. Treatment 3 performed reasonably well for many contaminants (TSS, TPH, PAH, and Zn). However, the sand, coir and ash could not fully mitigate the contaminants flushing from the compost mulch.
- Treatments 5 and 6 did meet TAPE criteria for basic treatment (80 percent TSS reduction) and enhanced treatment (30 percent reduction of dissolved Cu and 60 percent reduction dissolved Zn). However, as with all other treatments except Treatment 4, Treatments 5 and 6 did not meet TP reduction objectives for TAPE.
- The experimental bioretention media were similarly able to prevent expected toxic impacts including acute lethality and reproductive impairment in *C. dubia*, and reduced growth and pericardial edema in *D. rerio*. However, collectively, the bioassays showed a reduced ability of bioretention media to prevent toxicity during the final dosing event (Event 5).

ES2.1 COMPARISON OF RESULTS TO TAPE PERFORMANCE OBJECTIVES

The following provides pollutant capture performance in relation to TAPE objectives for all treatments. To provide 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 ES-2). The statistical analyses involved the computation of bootstrapped lower confidence intervals around the mean percent removal for TSS, TP, dissolved Zn, and dissolved Cu. A bootstrapped upper confidence limit was also computed around the mean effluent concentration for TSS. Note that not all sampling events met TAPE influent guidelines.

Table ES-2. Dosing Results in Relation to TAPE Pollutant Reduction Objectives.						
Objective	TSS ≤ 20 mg/L[a]	TSS ≥ 80% removal[b]	Dissolved Cu > 30% removal[b]	Dissolved Zn > 60% removal[b]	TP Treatment ≥ 50% removal[b]	Notes
	Bootstrapped upper 95 percent confidence interval around the mean effluent concentration (mg/L).	Bootstrapped lower 95 percent confidence interval around the mean effluent concentration (mg/L)				
Treatment						
Treatment 1: 60/ 40 mg/L		38.6%	11.7%	83.7%	-382%	treatment dropped after 2nd dosing
Treatment 2: 60/ 40/aafep-layer		84.9%	89.3%	94.4%	15.3%	
Treatment 3: 70vs/20cp/10ash/ compmulch		66.2%	48.5%	86.5%	-37.6%	
Treatment 4: 70vs/20cp/10ash/ compmulch/aafep-layer	All effluent < 20 mg/L including experiment 4 with an influent concentration of 254 mg/L.	88.5%	94.6%	96%	71.3%	
Treatment 5: 70vs/20cp/10ash		80.1%	62.4%	88.5%	-1%	
Treatment 6: 70ss/20cp/10ash		83.9%	70.5%	88.6%	41.3%	
Treatment 7: 70ls/20cp/10ash		82.4%	63.4%	75.8%	-29.7%	
Treatment 8: 70ls/20cp/10ash/ orifice		82.7%	70.6%	86.5%	-52.8%	treatment dropped after 2nd dosing

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.

The percent removals are bootstrapped means typically used for TAPE analyses. However, the influent values vary for the four dosing experiments. Some influent concentrations are only slightly above the TAPE influent thresholds for specific analytes, but others are well above the upper TAPE influent threshold. For example, influent concentrations for dissolved Cu are 120 µg/L for day 1 and 222 µg/L for day 2 for dosing experiment 4. Threshold criteria are the following for TAPE:

TSS: 20-100 mg/L with an effluent objective of ≤ 20 mg/L, 100-200 mg/L with an objective of ≥ 80% removal, and >200mg/L ≥ 80%.

Dissolved Cu: 5-20 µg/L with an effluent objective of > 30% removal.

Dissolved Zn: 20-300 µg/L with an effluent objective of ≥ 60% removal.

Total phosphorus: 0.1-0.5 mg/L with an effluent objective of ≥ 50% removal.

ES3. RECOMMENDATIONS

Treatment 4 consists of a two-inch compost mulch layer, a primary layer, and a polishing layer placed under the primary layer. The primary layer, which is the same as Treatment 5, met basic and enhanced treatment criteria; however, adding the polishing layer under the primary layer was necessary to meet TP criteria. Accordingly, the following options provided in Table ES-3 are recommended for adopting Treatment 4 for a new Washington State bioretention media.

Table ES-3. Components and Application of New Washington Bioretention Media.

	Basic Treatment	Enhanced reatment	Phosphorus Treatment	Expanded Plant Palette and Robust Plant Growth
Primary layer	X	X		
Primary plus polishing layer	X	X	X	
Primary plus polishing layer plus compost mulch[a]	X	X	X	X

[a] Do not use the primary media alone with compost mulch. The primary media and compost mulch without the polishing layer will export phosphorus and nitrogen.

The components of the bioretention media presented above are as follows:

- Primary layer: 70 percent sand/20 percent coir/10 percent high carbon wood ash (biochar).
- Polishing layer: 90 percent sand/7.5 percent activated alumina/2.5 percent iron aggregate.
- Compost mulch: coarse compost meeting Ecology’s compost specifications for bioretention (BMP T7.30).

See the Final Report for recommended specifications describing the media components and blends.

1. INTRODUCTION

The current Washington State, Phase I and Phase 2 municipal National Pollutant Discharge Elimination System stormwater permits (NPDES stormwater permits), effective August 1, 2019, require the use of low impact development (LID) practices where feasible as the first option for managing stormwater. Phase 1 and 2 Permittees must require On-site Stormwater Management (LID) best management practices (BMPs) as outlined in Minimum Requirement#5 of the NPDES stormwater permits.

Bioretention is the most widely applicable and flexible BMP in the suite of Stormwater Treatment 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 and into local receiving water bodies. The current Washington State Department of Ecology (Ecology) specification for bioretention soil media (BSM) in western Washington (Ecology 2014) is a mixture of 60 percent sand and 40 percent compost (60/40). While the 60/40 BSM can provide reliable water quality treatment for some contaminants (e.g., solids removal, zinc [Zn], and hydrocarbons), regional and national research indicate that nitrogen (N), phosphorus (P), and copper (Cu) are often exported from BSM containing compost (Herrera 2015a, 2015b, 2016; Mullane et al. 2015; Hatt, Fletcher and Deletic 2009; Glanville, et al. 2004; Trousdale and Simcock 2011; Classen and Young, 2010; Chahal, Shi and Flury 2016).

The use of bioretention with underdrains will increase dramatically with the NPDES stormwater permit requirement for on-site stormwater management and the widespread distribution of soils with poor infiltration or facilities built near sensitive subsurface infrastructure. As a result, the export of contaminants from bioretention with the current BSM specification will be an increasing concern for: 1) facilities with under-drains; or 2) installations in proximity to phosphorus and nitrogen-sensitive receiving waters.

The Bioretention Media Blends to Improve Stormwater Treatment: Final Phase of Study to Develop New Specifications (BSM Phase 2 Study) described in this report is the final phase of BSM research which began in 2014. King County was the grant recipient and Herrera Environmental Consultants, Inc. (Herrera) the technical lead. Three studies during this period led up to and informed the BSM Phase 2 Study. A 2015 report prepared by Herrera in partnership with Kitsap County entitled *Analysis of Bioretention Soil Media for Improved Nitrogen, Phosphorus, and Copper Retention* focused on the selection and leaching potential of a broad range of BSM components as well as pollutant export and capture characteristics of new BSM blends for high performance water quality treatment (Herrera 2015a). Findings from that research suggest that some of the new BSM blends significantly reduce the export of N, P, and Cu compared to the currently prescribed 60/40 BSM. The Kitsap County sponsored study was limited in scope and did not include the following critical components for recommending new BSM and developing an associated specification:

- Chemical (with the exception of leaching tests) or physical characterization of the BSM components.
- Hydraulic analysis (e.g., manipulation of particle size distribution to control permeability).
- Plant growth tests using plants typical to bioretention systems.
- Selection of appropriate metrics to describe the BSM components and blends in a specification.
- Information on how well these new blends protect targeted aquatic organisms (biological effectiveness).

A second study funded by the City of Seattle (Seattle) focused on developing a polishing layer as part of a bioretention media system. The polishing layer (sand, activated alumina and iron aggregate) was used under the existing compost-based media specified by Seattle (70 percent sand and 30 percent compost) to capture P and Cu from the compost above. For the limited dosing period using typical residential stormwater, the best polishing layer blend reduced total phosphorus and ortho-phosphorus by more than an order of magnitude. (Herrera 2016b).

A third study sponsored by Kitsap County (Bioretention Media Component Analysis to Improve Runoff Treatment or BSM Phase 1 Study) was completed June 2017 to: 1) test and select additional BSM components for inclusion in new BSM blends; and 2) test the plant-growing capability of these new blends (Herrera 2017). Findings from the Phase 1 study demonstrated that all the selected BSMs grow plants; however, compost-based BSMs supported more vigorous plant growth than those without compost. Two other BSM approaches supported vigorous plant growth and could potentially improve water quality treatment. These included a sand and compost BSM with a polishing layer beneath to capture contaminants from the BSM above; and a sand, coconut coir, and high-carbon wood ash (biochar) blend developed in the first Kitsap study (Herrera 2015a) with a 2-inch mulch layer placed on top of the BSM. While the initial BSM study completed in 2015 with Kitsap County focused on water quality treatment of the BSM, no water quality treatment analyses were performed in the Phase 1 study.

This document was prepared by Herrera to summarize the results from the BSM Phase 2 Study and is organized as follows:

- *Study Design and Methodology*: this section provides a summary of procedures identified in the Quality Assurance Project Plan (QAPP) for the study.
- *Results*: this section summarizes data from the study and includes the ranked treatment performance of different media blends for specific contaminants.

- *Conclusions and Recommendations*: major conclusions from the study are summarized in this section with recommendations for the best media to meet the performance objectives.

The BSM Phase 2 Study was funded through Washington State's Stormwater Action Monitoring program (SAM) as part of the Effective Studies Component (S8.C). Ecology administers SAM project funding for the Stormwater Work Group (SWG). King County was the funding recipient and manager. Herrera was the technical lead and designed and conducted the BSM evaluation in cooperation with project partners.

A Technical Advisory Group (TAG) comprised of members of a regional Bioretention Work Group (BWG) including King County, Kitsap County, Thurston County, Cities of Seattle and Tacoma, Herrera, and Ecology provided guidance throughout the study.

Exact Scientific Services, Specialty Analytical, and Western Washington University (WWU) Institute for Watershed Studies provided analytical laboratory services for the water quality analyses. Washington State University (WSU) and the National Oceanic and Atmospheric Association (NOAA) conducted toxicological analyses exposing daphnia and zebrafish to influent and effluent water.

2. STUDY DESIGN AND METHODOLOGY

This section describes the study goals, objectives and design developed in the Quality Assurance Project Plan (QAPP). Changes in the QAPP are outlined below.

2.1. Study Goals and Objectives

The overall goal of this project was to develop new recommendations for a BSM that protects beneficial uses of receiving waters and achieves the following objectives in order of priority: 1) meets basic treatment (Ecology's treatment objectives for total suspended solids); 2) meets enhanced treatment (Ecology's treatment objectives for dissolved Cu and Zn); 3) meets Ecology's treatment objective for phosphorus; 4) is affordable and available; and 5) reduces stormwater toxicity for aquatic organisms.

2.2. Study Approach

Overall the study approach was designed to optimize the BSM for total suspended solids (TSS), P, Cu and Zn capture. Note that achieving Ecology's basic, phosphorus, and enhanced treatment was the focus of this study; however, other contaminants of concern were also evaluated including dissolved organic carbon (DOC), nitrate+nitrite, cadmium (Cd), lead (Pb), diesel and motor oil fractions of total petroleum hydrocarbons (TPH), polycyclic aromatic hydrocarbons (PAH), and fecal coliform bacteria. These additional parameters were assessed to confirm adequate treatment of other common stormwater contaminants of concern. There were six primary components to the study:

1. Review potential bioretention BSM components based on pollutant capture capability, cost, availability, and sustainability. Select individual BSM components from survey and project partner input.

2. Conduct Synthetic Precipitation Leaching Protocol EPA Method 1312 (SPLP) to determine N, P, and Cu leaching potential of the BSM components. Select the components that minimize leaching potential, provide adequate hydraulic conductivity and support plants. Note that results from the BSM Phase 1 and this study were used to make these determinations.

3. Combine components at various ratios, place in columns, flush the BSM blends with deionized water, and assess the effluent for TSS, pH, DOC, nitrate+nitrite, total phosphorus (TP), ortho-phosphorus (ortho-P), Cd, Cu, Pb, Zn, fecal coliform bacteria (bacteria samples will be collected at the first and last flush only), PAH, and TPH. Hydraulic conductivity of the media blends was also assessed during the flushing

experiments. See Table 1 for a complete list of contaminants, target influent concentrations, and actual or measured influent concentrations.

4. Dose the BSM blends with natural stormwater and assess the effluent for TSS, pH, DOC, nitrate+nitrite, TP, ortho-P, Cd, Cu, Pb, Zn, fecal coliform bacteria, PAH, and TPH. See Table 1 for a complete list of contaminants.

5. Conduct toxicological tests to determine how well the BSM blends protect aquatic organisms.

6. Select the best performing BSM blend and determine metrics and numeric ranges for a specification that describes the best performing BSM.

Table 1. Target Analytes and Analyte Concentrations for Influent Stormwater.

Analyte	Target Concentration	Target Range	Actual Median Concentration	Actual Range
Total Suspended Solids (TSS)	75 mg/L	50–200 mg/L	104 mg/L	36.6-310.0 mg/L
pH	no target	no target	No target	No target
Dissolved Organic Carbon (DOC)	no target	no target	No target	No target
Total cadmium (Cd)	0.3 µg/L	0.3–1.0 µg/L	No target	No target
Dissolved Cd	0.2 µg/L	0.2–1.0 µg/L	No target	No target
Total Cu	20.0 µg/L	10.0–50.0 µg/L	80.6 µg/L	21.4-246.0 µg/L
Dissolved Cu	7.0 µg/L	5.0–20.0 µg/L	28.4 µg/L	6.4-120.0 µg/L
Total lead (Pb)	no target	no target	No target	No target
Dissolved Pb	no target	no target	No target	No target
Total Zn	150.0 µg/L	100.0–500.0 µg/L	291.5 µg/L	103.0-743.0 µg/L
Dissolved Zn	50 µg/L	2.0–300.0 µg/L	130.5 µg/L	40.9-386 µg/L
Nitrate+nitrite	0.3 mg/L	0.1–1.0 mg/L	0.543 mg/L	0.203-1.21 mg/L
Total phosphorus (TP)	0.25 mg/L	0.1–0.5 mg/L	0.140 mg/L	0.055-0.757 mg/L
Ortho-phosphorus (ortho-P)	0.035 mg/L	0.02–0.1 mg/L	0.0115 mg/L	0.0086-0.0192 mg/L
Total Petroleum Hydrocarbons (TPH diesel and motor oil)	no target	no target	No target	No target
Polycyclic Hydrocarbons (PAH)	no target	no target	No target	No target
Fecal coliform bacteria	no target	no target	No target	No target

µg/L = micrograms per liter

mg/L = milligrams per liter

The following qualitative criteria were used to guide the selection of BSM components and blends:

- **Leaching:** BSM components that leached the minimum amount of N, P, and Cu were considered first for testing in the BSM blends.

- **Pollutant retention:** BSM blends estimated to meet or exceed Ecology's basic, enhanced, and phosphorus treatment from previous BSM studies were considered optimal.

- **Hydraulic performance:** BSM blends that had a saturated hydraulic conductivity (Ksat) greater than 20 inches/hour (51 cm/hour) were considered optimal. No maximum Ksat was targeted.

- **Sustainability:** includes availability, transportation requirements, manufacturing and/or extraction processes.

- **Cost:** cost, along with the above criteria, to attain the best balance of cost to optimum performance.

2.3. Select Media Components

A survey of the scientific literature, regional studies for bioretention media treatment performance, and project partner input provided the basis for selecting the best component candidates. Additionally, practical considerations including availability, sustainability, and cost were taken into account. Candidate primary media and polishing layer components considered for this study are summarized in Appendix A. Also see Appendix A for manufacturers, suppliers, material composition, and manufacturing processes of the media components.

2.4. Media Component Leaching Tests

The leaching potential for N, P and Cu for selected media components was assessed using SPLP EPA Method 1312. Note that the SPLP method is used to provide a worst-case test for potential leaching and is not used to approximate conditions in bioretention systems. The analysis was performed at Analytical Resources, Inc. (an Ecology certified laboratory) and was conducted for nitrate+nitrite, TP, ortho-P, and dissolved Cu using two procedures:

- **Metals** – weak acid (H2SO4/HNO3) extraction using a pH recommended for the western United States (pH = 5.0 standard units). Note that dissolved copper was filtered using a 0.7 micron filter per Method 1312.

- **Nutrients** – deionized water extraction.

Suppliers were identified for components selected from the survey process described in Section 2.3. Samples of the selected media components were collected from suppliers and, where possible, samples were collected by Herrera staff from multiple locations in material stockpiles and composited for analysis.

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

2.5. COMBINE COMPONENTS AND FLUSH MEDIA IN COLUMNS

Media components meeting criteria in Section 2 from the SPLP analysis were combined into media blends, placed in polyvinyl chloride (PVC) columns, and flushed with deionized water to assess potential contaminant export at the Western Washington University (WWU) Environmental Toxicology Laboratory. The primary media depth was 18 inches (45.7 cm). The primary media was placed on top of a 12-inch (30.5 cm) drainage layer comprised of the same sand used in the primary media or a polishing layer to provide a final filter before discharge through the underdrain pipe. The columns were 8 inches (20.3 cm) diameter and 36 inches (91.4 cm) tall. Eight treatments were selected. Each treatment was replicated three times (24 columns). See Table 2 for primary and polishing layer blends.

Flushing experiment hydraulic load was based on typical bioretention surface area to contributing area ratios (see below) and peristaltic pump capacity. The facility surface area was 20/1 or 5 percent of the contributing area and the contributing area effectiveness was 0.9 (i.e., 90 percent of precipitation depth delivered from contributing area to facility area).

Flushing equivalent precipitation depth was based on the Ecology water quality treatment design storm. The four flushing experiments were conducted using two loading rates to provide a conservative test of effluent quality. The first two flushing tests used the Ecology water quality treatment design storm. The effective precipitation depth was doubled for the second two flushing tests. See Table 3 for the equivalent precipitation depth and flushing volumes applied. The flushing regime was as follows:

- **Target depth for first two flushing experiments:** 1.32 inches (3.35 cm) of equivalent precipitation (the 6-month, 24-hour storm for the Seattle area).

- **Per column flushing volume for the first two experiments:** approximately 17.81 liters per sampling event.

  Flushing volume is determined by the following:

  (Column Area x Contributing to Facility Surface Area Ratio x Contributing Area Effectiveness x Bypass)/61.02

  where: Column Area = 50.264 in^2 (324.28 cm^2)

  Contributing to Facility Surface Area Ratio = 20/1

  Contributing Area Effectiveness = 0.9

  Bypass = 0.91

  61.02 = conversion for cubic inches to liters

Table 2. Primary Bioretention Soil Media and Polishing Layer Blends.				
Treatment Number	**BSM Blend Abbreviations**	**Primary Layer**	**Polishing Layer**	**Justification (see table notes for color codes)**
1	60/40	60% ecology sand/40%compost	none	Current Ecology specification for comparison to other treatments. Sand: Use current BSM sand specification.
2	60/40/aafep-layer	60% ecology sand/40%compost	90% state sand/7% coarse activated alumina (14x28 mesh)/3% iron aggregate (GPM ETI CC-1004)	Current Ecology specification with polishing layer to assess performance compared to 60/40 without polishing layer and other high-performance treatments. Sand: Use current BSM sand specification.
3	70vs/20cp/10ash/compmulch	70% volcanic sand/20% coco coir/10% high carbon wood ash/2-inch compost mulch	None	BSM Phase 1 Study suggests that this blend with compost mulch grows plants as well as the 60/40 BSM; however, no water quality treatment performance was evaluated in that study. Sand: volcanic sand has tested well in previous studies and represents the finer gradation material for this study.
4	70vs/20cp/10ash/compmulch/ aafep-layer	70% volcanic sand/20% coco coir/10% high carbon wood ash/2-inch compost mulch	90% state sand/7% coarse activated alumina (14x28 mesh)/3% iron aggregate (GPM ETI CC-1004)	BSM Phase 1 Study suggests that this blend with compost mulch grows plants as well as the 60/40 media; however, no water quality treatment performance was evaluated in that study. This blend adds the polishing layer to ensure higher treatment performance if primary media does not capture all contaminants from compost mulch. Sand: volcanic sand has tested well in previous studies and represents the finer gradation material for this study.
5	70vs/20cp/10ash	70% volcanic sand/20% coco coir/10% high carbon wood ash	None	Volcanic sand media combined with best performing materials from initial high-performance media study with Kitsap County (Herrera 2015). Sand: volcanic sand has tested well in previous studies and represents the finer, high flow gradation material for this study.
6	70ss/20cp/10ash	70% state sand/20% coco coir/10% high carbon wood ash	None	State sand media combined with best performing materials from initial high-performance media study with Kitsap County (Herrera 2015). Sand: state sand has tested well in previous studies and represents the coarser, high flow gradation material for this study.
7	70ls/20cp/10ash	70% lava sand/20% coco coir/10% high carbon wood ash	None	Lava sand media combined with best performing materials from initial high-performance media study with Kitsap County (Herrera 2015). Sand: Lava sand is more porous with a rougher surface and may provide better TSS capture.
8	70ls/20cp/10ash/orifice	70% lava sand/20% coco coir/10% high carbon wood ash (orifice control)	None	Lava sand media combined with best performing materials from initial high-performance media study with Kitsap County (Herrera 2015). Sand: Lava sand is more porous with a rougher surface and may provide better TSS capture.

All percentages by volume.

Treatment comparisons (rows that share the same color are paired as follows):

- Treatments 1 and 2: Compare 60/40 with and without polishing layer.
- Treatment 3 and 4: Compare different BSM blends placed below compost mulch (compost mulch provides improved plant growth).
- Treatments 5 and 6: Evaluate treatment performance of high Ksat vs higher Ksat media.
- Treatments 7 and 8: Same high Ksat blends with no orifice vs orifice control.

BACK of page 2

Event	Day	Projected Volume Applied from QAPP (liters/column)	Equivalent Storm Size (inches)	Cumulative Rain (in)	Percent Water Year (Seattle)	Median, Max, Min Volume Applied (liters/Column)
Sample 1	1	17.8	1.3	1.3	4	13.9, 18.0, 12.1
Flush 2	3	17.8	1.3	2.6	7	no volume recorded
Flush 3	5	17.8	1.3	3.9	11	no volume recorded
Flush 4	7	17.8	1.3	5.2	15	no volume recorded
Flush 5	9	17.8	1.3	6.6	18	no volume recorded
Flush 6	11	17.8	1.3	7.9	22	no volume recorded
Sample 2	13	17.8	1.3	9.2	26	18.9, 20.2, 17.5
Flush 8	15	17.8	1.3	10.5	29	no volume recorded
Flush 9	17	17.8	1.3	11.8	33	no volume recorded
Flush 10	19	17.8	1.3	13.2	37	no volume recorded
Flush 11	21	17.8	1.3	14.5	40	no volume recorded
Flush 12	23	17.8	1.3	15.8	44	no volume recorded
Sample 3	25	35.6	2.6	18.4	51	21.5, 22.5, 20.5
Flush 14	27	35.6	2.6	21.1	59	no volume recorded
Flush 15	29	35.6	2.6	23.7	66	no volume recorded
Flush 16	31	35.6	2.6	26.4	73	no volume recorded
Flush 17	33	35.6	2.6	29.0	81	no volume recorded
Flush 18	35	35.6	2.6	31.6	88	no volume recorded
Flush 19	37	35.6	2.6	34.3	95	no volume recorded
Sample 4	39	35.6	2.6	36.9	103	20.9, 22.0, 19.4

Table 3. Flushing Schedule, and Projected and Measured Volumes.

Median = median of all sample volumes for each sample event.

Max = maximum of all sample volumes for each sample event.

Min = minimum of all sample volumes for each sample event.

Note that for the last two flushing experiments a total of 35.62 liters was applied to each column; however, to accommodate sample bottle volume a target volume of 22 liters was collected by removing the effluent line from the sample bottle approximately every 20 minutes for approximately 15 minutes discarding approximately 13 liters.

- **Target depth for the last two flushing experiments:** 2.64 inches (6.70 cm) equivalent precipitation
- **Per column flushing volume for the last two flushing experiments:** approximately 35.62 liters per sampling event.
- **Drain down:** columns were allowed to drain down for a minimum of 18 hours between flushing experiments.
- **Sampling event duration:** for the first two lower-rate flushing events, 17.81 liters was delivered with a pump rate set at 6.7 liters per hour for approximately 2.5 hours. For the last two higher-rate flushing events, 35.62 liters was delivered at a pump rate of 11.0 liters per hour for approximately 3.2 hours.

- **Sample event coverage:** the entire storm volume and one sub-sample for each analyte was collected from each column for the first two sampling events. For the last two flushing experiments a 22-liter composite sample was collected by removing the effluent line from the sample bottle every 20 minutes (five times) for 15 minutes and discarding approximately 13 liters.

- **Influent concentrations:** Deionized water was used for the flushing experiments. Median influent concentrations were as follows for the analyzed contaminants: TSS (0.5 mg/L), TP (2.5 µg/L), ortho-P (4.3 µg/L, nitrate+nitrite (0.05 mg/L), dissolved Cu (2.1 µg/L), and dissolved Zn (5.1 µg/L) for deionized water. See Results Section, Tables 8 through 27 for influent concentrations by flushing experiment.

- Table 3 summarizes the flushing regime developed from these metrics.

Calibrated peristaltic pumps were used to deliver water from the distribution tank to the columns over a 45-day period. The peristaltic pumps were calibrated at beginning of the flushing regime for the low flow rate (6.68 liters/hour) and before sample event 3 for high flow delivery rate (11.00 liters/hour). See Appendix C for calibration results.

Samples were collected on four occasions corresponding to the first, thirteenth, twenty-fifth, and thirty-ninth flushing events. Sample collection occurred over a 2-day period (12 of the 24 columns were sampled the first day and the remaining 12 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). Sample volumes were measured at each sample event. See Table 3 for flushing schedule and projected and measured volumes.

2.6. Saturated Hydraulic Conductivity

Saturated hydraulic conductivity was evaluated for each media blend to compare with the current BSM Ksat guideline, evaluate how different sands effect permeability, and, in general, correlate treatment capability with Ksat. At the end of the flushing experiments, falling head tests were conducted using the following procedure:

- At the end of the flushing period (saturate media) 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.

2.7. Dose Media in Columns

Following flushing, the same media treatments were dosed with stormwater five times to evaluate their treatment performance. All dosing experiments were conducted at the WWU Environmental Toxicology Laboratory. The dosing experiment hydraulic load was based on typical bioretention facility surface area to contributing area ratios. The facility surface area was 20/1 or 5 percent of the contributing area and the contributing area effectiveness was 0.9 (i.e., 90 percent of precipitation depth delivered from contributing area to facility area). See Section 2.5 for more detail on hydraulic load calculation. The dosing hydraulic regime was as follows:

- **Target depth for all dosing experiments:** 2.64 inches equivalent precipitation.
- **Dosing volume for all dosing experiments:** Approximately 35.62 liters per sampling event.
- **Column drain down:** minimum of 18 hours between dosing experiments.
- **Sampling event duration:** For all five dosing events 35.62 liters were delivered at a pump rate of 11 liters per hour for approximately 3.2 hours.
- **Sample event coverage:** a 22-liter composite sample was collected by removing the effluent line from the sample bottle every 20 minutes (five times) for 15 minutes and discarding approximately 13 liters.

Stormwater used for the testing was from State Route (SR) 520 collected at the National Oceanic and Atmospheric Association (NOAA) where stormwater drains off the highway and onto NOAA parking areas. Immediately after collection, the stormwater was transported to the WWU lab in a 300-gallon stainless steel container and pumped to a 180-gallon plastic HDPE tank in the lab. Dosing experiments were conducted the following two days to minimize degradation or transformation of contaminants. Twelve of the 24 columns were sampled the first day and the remaining 12 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). Sample volumes were measured at each sample event. See Table 1 for contaminants analyzed in the effluent and the target concentrations for the influent.

2.8. Toxicological Experiments

During the five dosing events described in Section 2.7, composite samples were collected from the influent and effluent water to test the ability of the eight BSM blends to protect aquatic organisms from contaminants that produce acute toxicity. Tests were conducted on two model aquatic organisms to screen BSM blends. First, an early life stage screening test with zebrafish (*Danio rerio*) embryos was used to assess survival and sublethal toxicity to fish. Sublethal toxicity included changes in morphometrics associated with exposure to toxic contaminants such as changes in embryo size and development of cardiovascular abnormalities. Second, Daphnia (*Ceriodaphnia dubia*) neonates were used to test toxicity to aquatic invertebrates.

Stormwater from SR 520 collected at NOAA Fisheries Science Center in Seattle was used for continuity with previous experiments conducted on daphnia and zebrafish with WSU and NOAA. Composite samples were collected for each treatment (subsamples collected from each column into one sample for each treatment). The composite samples were immediately frozen at the WWU lab and then transported to freezers at NOAA and WSU.

2.8.1. Day 1 vs Day 2 Influent Stormwater

For each dosing event, influent water was used on two consecutive days. On Day 1, influent was passed through bioretention treatments T1-4 and on Day 2 the remaining influent water was passed through treatments T5-8. Although changes in the toxicity of the influent water over time was not anticipated to be a major issue in the study, there were ultimately some differences in toxicity observed for the Day 1 compared with Day 2 influent waters for both the fish and invertebrate bioassays. This prevented the direct comparison of the effectiveness of T1-4 with that of T5-8. As a result, samples for the fish bioassays were separated into Day 1 and Day 2 samples and tested as though they received different influent stormwater. Bioassays for Day 1 samples were assessed by NOAA, whereas Day 2 samples were assessed by the Washington State University Puyallup Research and Extension Center (WSU-P), with slightly different but comparable methods. The NOAA method used 0.33 mL/embryo, whereas the WSU method used 0.25 mL/embryo. Note that exposures tend to be limited by the concentration of chemical in the exposure solution, not by the exposure volume, so this small difference in volume/embryo should not be biologically relevant (Braunbeck et al.). For the aquatic invertebrate bioassays at WSU-P, Day 1 and Day 2 influent and effluent waters for a given event were tested together, with each event tested separately.

2.8.2. Aquatic Invertebrate Bioassays (*Ceriodaphnia dubia*)

Assays were performed using the 4th brood offspring of *C. dubia* cultured at WSU-P according to the U.S. Environmental Protection Agency (EPA) protocol for estimating chronic effects of effluents (EPA 2002). *C. dubia* were reared in a 1-L glass aquarium filled with culture water maintained at 24 ± 1°C in a light:dark regimen of 16:8 h. Three times a week, culture water was changed and organisms were fed with a suspension of 1:1 mixture of yeast-cereal leaves-trout chow (YCT) and the algal species *Raphidocelis subcapitata* (formerly known as *Selenastrum capricornutum*) and *Pseudokirchneriella subcapitata* (Aquatic Research Organisms, Hampton, NH).

Tests were conducted in 50-mL glass beakers containing 20 mL of exposure water (influent and effluent stormwater or culture water as a laboratory control) and 0.1 mL of YCT: algae suspension. Exposure was performed on neonates (<24 hours old) at 1 individual per beaker introduced into each beaker at the beginning of the test (10 replicates per treatment). These individuals are designated as 'founders'. The duration of the test was 7 days ± 1 to allow time for at least 3 broods to be produced. Immobile ('dead') adults and neonates when present were counted and removed every day to measure survival and reproduction. Daily, surviving test organisms were transferred to fresh medium and fed with YCT: algae mixture. Neonate production was the sum of neonates produced per female across the duration of the exposure. Valid assays were those with founder survival of at least 80 percent and neonate production of at least 15 per surviving founder (EPA 2002).

2.8.3. Zebrafish Bioassays (*Danio rerio*)

Zebrafish (*D. rerio*) embryos for testing were generated at the NOAA Northwest Fisheries Science Center (Seattle, WA) or the WSU-P by allowing wild-type adult zebrafish (*AB genotype) to spawn overnight 12 to 18 hours before exposure. Eggs collected from the spawn were visually sorted to approximately 3 hours of development (hours post fertilization; hpf). Exposures were for 48 hours at 25°C.

Each Day 1 sample (NOAA) was tested on 4 replicates of 45 embryos in glass petri dishes containing 15 mL of BSM treatment water or fish rearing water as a laboratory control. Up to 15 embryos per replicate were imaged at 48 hours as described below and 25 embryos were flash-frozen in liquid nitrogen for subsequent qPCR analysis.

Each Day 2 sample (WSU-P) was tested on 32 individuals, each randomly placed in a well on a 96-well microplate. Glass-coated microplates were used to reduce the potential of chemical adhesion to the microplate well. Using an auto-pipetter, each well of the microplate was filled with 250 µL of control or BSM treatment water (0.25 mL/embryo). Control water was from the zebrafish rearing system. Embryos at the proper developmental stage were placed into each well using tweezers. Microplates were covered and allowed to incubate at 25°C until 48 hpf.

After 24 hours of development embryos were screened for mortality and dead embryos noted and removed at both WSU and NOAA research stations. A water change was performed by removing and replacing most water from solutions kept in the incubator. At 48 hpf dead embryos were noted and removed. Unhatched embryos were noted and the chorion manually removed using tweezers. Individual zebrafish were immobilized in a 2.5 percent methyl cellulose solution and oriented with their left side up so that the eyes were stacked. Digital images and videos were recorded from a stereomicroscope (Nikon SMZ800). After imaging, zebrafish were euthanized in a solution of tricaine methanesulfonate (MS-222).

During image analysis the length, eye area, and pericardial of each zebrafish was measured using ImageJ 1.52N. These measurements were converted from pixels to millimeters using a micrometer calibration. Valid assays were those with control survival of at least 90 percent.

Zebrafish bioassays for Day 2 experimental waters took place after the Technical Advisory Committee had reviewed the chemical performance of the experimental bioretention media and determined that Treatment T7 and T8 did not meet enhanced treatment requirements. Therefore, effluents from T7 and T8 were not exposed to zebrafish.

2.8.4. qPCR Analysis of Zebrafish

In addition to morphometrics, induction of a xenobiotic oxidizing gene cytochrome P450, family 1, subfamily A (*cyp1a)* was measured in zebrafish embryos exposed to Day 1 waters from dosing events 1-4. This additional bioassay was conducted prior to the final dosing event, so embryos from Event 5 were not include. Two replicates of 25 embryos were processed per treatment. RNA was isolated as previously described (McIntyre et al. 2015) by homogenization with Trizol, followed by phase separation with 1-bromo-3-chloropropane, and dissolution in ethanol. RNA was isolated by column elution vis Direct-zol protocol and eluted with molecular grade water. Complement DNA was created from the isolated RNA according to the SuperScript IV protocol and amplified by real-time polymerase chain reaction using a Viia 7 Real-Time PCR system with Fast SYBER. Results were normalized with 5 reference genes (*ef1a*, *wdtc1*, *mtm1*, *spop1*, & *rxrba*). The quantitation cycle at which amplification of *cyp1a* departed from baseline (δCq) was used to calculate a relative fold-change from controls for each replicate from each storm event assessed.

2.9. Experiment Duration

Four composite samples for flushing experiments and five composite samples for the dosing experiments were collected over a period of approximately 10 months (November 2018 to September 2019). Toxicity testing was completed October 2019 and within 5 months of sample delivery.

2.10. Data Analysis Procedures

2.10.1. Water Quality Treatment Analyses

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 effluent concentration and the other factor was the sampling event sequence (samples were collected at the 1st, 7th, 13th, and 20th flushing events). For the dosing experiments, one factor was the media effluent concentration and the other factor was the sampling event sequence as well.

Because an ANOVA test is 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 equal variance. After visual assessment using boxplot distributions, the effluent concentration and percent removal 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 (instead of the raw values) following guidance provide in Helsel and Hirsh (2002). Each test indicated whether there was a significant difference in effluent concentration or percent removal due to one or both 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 were different 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 from one another.

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

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 51). The statistical analyses involved the computation of bootstrapped lower confidence intervals around the mean percent removal for TSS, TP, dissolved Zn, and dissolved Cu. Note that not all sampling events met TAPE influent guidelines; however, bootstrap analysis was run on all dosing events.

2.10.2. Toxicological Analyses

C. dubia. For each Event, impact of the experimental bioretention treatments on *C. dubia* survival was assessed using a chi-squared test followed by post-hoc testing using adjusted residuals for differences among treatments. Impact on reproduction was assessed with the non-parametric Kruskall-Wallis followed by a Dunn post-hoc test for differences among treatments. Treatment effects were determined using $\alpha = 0.05$. For post-hoc tests, α was corrected for multiple comparisons using a false discovery rate approach to reduce false positives (Narum 2006).

Zebrafish morphometrics. Treatment effects on zebrafish length, eye area, and pericardial area were assessed by multivariate general linear model (GLM) separately for Day 1 and Day 2 treatments. Reduction in treatment of pericardial edema over time was tested statistically by calculating the proportional reduction in toxicity for Treatments T2-T4 on Day 1 [(mean influent – mean treatment)/(mean influent – mean control)] in a univariate GLM with treatment and event as factors. To reduce false positives due to multiple comparisons, α was adjusted using a false discovery rate approach (Narum 2006).

Zebrafish qPCR. Treatment effects on *cyp1a* expression were assessed by univariate general linear model using the baseline-corrected quantitation cycle (δCq) values, with treatment and event as factors. Treatment T1 was excluded from the analysis because it was not present for each Event. Significant differences among treatments were assessed post-hoc by Tukey's HSD. The δCq is related to fold-change of gene expression by $2^{(-\delta\delta Cq)}$, where δCq is normalized to control.

2.11. Changes to QAPP

The following changes were made to the QAPP due to source water requirements for the toxicological experiments and findings as the study progressed.

Source for dosing stormwater: initial plans for the study included collecting stormwater from catch basins located near the WWU lab where flushing and dosing experiments were conducted (see Section 6.1.4 page 24 of QAPP). To provide continuity with previous experiments and obtain stormwater with known toxicity to the target organisms for the toxicological analyses (daphnia and zebrafish) stormwater was instead collected from SR 520 at NOAA Fisheries Science Center. Stormwater was immediately delivered to the WWU lab in Bellingham in a stainless steel tank rather than collected in an HDPE tank as originally planned to prevent PAH adhesion to the tank walls. Stormwater was then pumped to the lab and experiment conducted in accordance with the QAPP.

Treatments for dosing: eight treatments were selected for flushing and dosing. All treatments were included for all flushing experiments; however, Treatments 1 and 8 were eliminated after the second dosing experiment. Treatment 1 (60 percent sand/40 percent compost) was eliminated due to continued export of N, P and Cu and, as a result, could not meet the study objectives for enhanced and phosphorus treatment guidelines. Treatment 8 was a duplicate of

Treatment 7; however, Treatment 8 included an orifice control to reduce the infiltration rate. The orifice control was included to assess whether the lower rate improved TSS capture. No difference was observed between Treatments 7 and 8 accordingly, Treatment 8 was eliminated for most efficiently using sampling resources.

2.12. BSM Specification Development

The ultimate goal for this and previous associated studies is to develop a bioretention BSM specification that meets Ecology's basic, enhanced and phosphorus treatment requirements for stormwater runoff. Results from the flushing, Ksat and dosing experiments were used by Ecology and the TAG to select the media blend that meets the stated objectives.

Draft metrics and numeric ranges for the specification were developed and reviewed by the TAG. Once reviewed, the metrics were narrowed to those considered the most important for adequately describing and ensuring media component quality and a consistent blend to meet treatment objectives. See Table 53 in Results section for the selected metrics. Media components and blends for the selected, best performing media were then sent to Specialty Analytical lab in Gresham, Oregon. for analyses. The same materials used for the column experiments were used for the specification analyses.

3. RESULTS

3.1. Select Media Components

Components selected for the primary and polishing layer blends in the column tests consist of:

- Bulk aggregate
  - Ecology sand
    - Selection criteria: Ecology sand specification developed during development of initial LID manual (Hinman, 2005) to provide adequate permeability and water holding capacity in BSM.
    - Volcanic sand (vs)
    - Selection criteria: volcanic sand leaching potential from previous analyses was low and material is locally available. All volcanic sand used was a Walrath 4120 product which was dredged from the Toutle and Cowlitz rivers after those channels were filled with sand from the Mt Saint Helens eruption.
  - State Sand (ss)
    - Selection criteria: state sand leaching potential from previous analyses was low and material is excavated and available from local quarries.
  - Lava Sand (ls)
    - Selection criteria: lava sand has unique properties that warranted testing including a rough, porous structure that could possibly aid in TSS capture and increased water holding capacity for plant growth. The material is locally available and excavated from a southeastern Washington quarry.

- Bulk organic
  - Coconut coir (cp)
    - Selection criteria: coconut coir leaching potential from previous analyses was low for dissolved Cu and nitrate+nitrite, but high for TP and ortho-P. However, TP and ortho-P concentrations were low for this study. Previous flushing and dosing experiments demonstrated good performance with this material and this is the cleanest bulk organic material found to date. The material is available from west coast suppliers and is a renewable resource harvested in Indonesia and India.

- Compost
  - Selection criteria: compost (following Ecology specification for BMP T7.30) selected during development of initial LID manual (Hinman, 2005) to provide nutrients for plant growth and water holding capacity in BSM.

- Mineral additives
  - Activated alumina (aa)
    - Selection criteria: activated alumina ranked low overall for leaching potential from previous tests (except for nitrate) and has a high phosphorus binding capability. The material is manufactured in eastern U.S. and Canada.
  - Iron aggregate (fe)
    - Selection criteria: research indicates that iron aggregate has a high phosphorus binding capability; however, this material can only be used in small amounts (maximum 3 percent by volume) to prevent cementing of aggregates. To provide adequate phosphorus capture capability, activated alumina is used in combination with iron aggregate. This material is processed in Chicago from waste machine cuttings.

- Organic additives
  - High-carbon wood ash (ash)
    - Selection criteria: high carbon wood ash (PD 100+mesh) ranked low overall from previous research for leaching potential compared to other organic additives. High carbon wood ash is a valuable additive for metals capture and plant growth. This material is manufactured in northern Oregon from waste wood chips.

For a complete list of media components, sources and manufacturing and extraction processes see Appendix A.

3.2. Media Component Leaching Tests

Synthetic Precipitation Leaching Protocol extractions were performed on six media components identified in the previous Section 3.1. These extractions were analyzed for TP, ortho-P, dissolved Cu, and nitrate+nitrite. The SPLP extraction results are provided in Tables 4 through 7, organized by contaminant, and ranked from lowest to highest concentration.

Media components were selected from the SPLP analysis using the following criteria: Cu ≤10 micrograms per liter (µg/L); nitrate+nitrite ≤0.5 milligrams per liter (mg/L); and TP ≤0.5 mg/L. If none of the components initially selected met these criteria, additional components were considered for SPLP analysis. If none of the components initially or subsequently selected met these criteria, then components with the lowest concentrations were selected and polishing layers with chemically active materials (e.g., activated alumina) were considered to reduce effluent concentrations from the BSM blends.

For TP and ortho-P, all selected bulk and additive mineral and organic materials performed very well except the high carbon wood ash (see Tables 4 and 5, respectively). The State Sand, lava sand, activated alumina, and iron aggregate all came in below the 0.5 mg/L threshold. High carbon wood ash had relatively high TP leaching results as in previous research. However, previous research has also indicated that these levels do not promote flushing of phosphorus when this material is used in media blends. Additionally, the low level of phosphorus in the material will aid plant growth. All materials performed well (below 10 µg/L) for dissolved Cu (Table 6). All materials performed well (below 0.5 mg/L) for nitrate+nitrite except activated alumina (Table 7). Flushing of nitrate+nitrite has not been observed in previous research when activated alumina has been placed in blends, so this component was accepted and carried forward in the mixes.

Table 4. SPLP Extraction Results for Total Phosphorus.

Sample Component	Sample Treatment Type	Units	Value
iron aggregate	mineral additive	mg-P/L	ND
activated alumina (Actiguard F 14x28 mesh)	mineral additive	mg-P/L	ND
coco coir (Botanicare Cocogro)	organic bulk	mg-P/L	0.034
State Sand	mineral bulk	mg-P/L	0.084
lava sand	mineral bulk	mg-P/L	0.192
high carbon wood ash (PD 100+mesh)	organic additive	mg-P/L	0.988

mg/L = milligrams per liter. Components are arranged from lowest to highest concentration.

ND = not detected.

Reporting Limit = 0.008 mg-P/L

Table 5. SPLP Extraction Results for Ortho-Phosphorus.

Sample Component	Sample Treatment Type	Units	Value
activated alumina (Actiguard F 14x28 mesh)	mineral additive	mg/L	0.014
iron aggregate	mineral additive	mg/L	0.030
coco coir (Botanicare Cocogro)	organic bulk	mg/L	0.033
State Sand	mineral bulk	mg/L	0.053
lava sand	mineral bulk	mg/L	0.157
high carbon wood ash (PD 100+mesh)	organic additive	mg/L	1.150

mg/L = milligrams per liter. Components are arranged from lowest to highest concentration.

ND = not detected

Reporting Limit = 0.004 mg/L

Table 6. SPLP Extraction Results for Dissolved Copper.			
Sample Component	**Sample Treatment Type**	**Units**	**Value**
iron aggregate	mineral additive	µg/L	ND
high carbon wood ash (PD 100+mesh)	organic additive	µg/L	ND
activated alumina (Actiguard F 14x28 mesh)	mineral additive	µg/L	ND
State Sand	mineral bulk	µg/L	1.69
coco coir (Botanicare Cocogro)	organic bulk	µg/L	2.77
lava sand	mineral bulk	µg/L	4.54

µg/L = micrograms per liter. Components are arranged from lowest to highest concentration.

ND = not detected.

Reporting Limit = 0.5 µg/L

Note that a 0.7 µm filter is used for the Cu SPLP extraction and, therefore, a higher mass per volume will be reported than with the standard 0.45 µm filter used for EPA 200.8.

Table 7. SPLP Extraction Results for Nitrate+Nitrite.			
Sample Component	**Sample Treatment Type**	**Units**	**Value**
iron aggregate	mineral additive	mg/L	0.021
high carbon wood ash (PD 100+mesh)	organic additive	mg/L	0.024
State Sand	mineral bulk	mg/L	0.035
coco coir (Botanicare Cocogro)	organic bulk	mg/L	0.043
lava sand	mineral bulk	mg/L	0.050
activated alumina (Actiguard F 14x28 mesh)	mineral additive	mg/L	1.140

mg/L = milligrams per liter. Components are arranged from lowest to highest concentration.

Reporting Limit = 0.01 mg/L

3.2.1. Combine Media Components

Once individual components were evaluated for leaching potential, media blends were developed to assess the performance of various combinations and ratios of the components. In general, there were three classes of media blends: 1) the current Ecology media specification of sand and compost; 2) primary layers consisting of various sands, coir and biochar; and 3) polishing layers using sand activated alumina and iron aggregate. See Table 2 for media blends, explanations for the blends, and color-coded treatment comparisons.

3.3. Flush Media in Columns

Results from the flushing experiments are presented in this section. For these experiments, each of the eight media treatments identified in Table 2 were replicated three times in the 24-column array.

Results for the treatments are presented in separate subsections below for TSS, DOC, TP, ortho-P, nitrate+nitrite, total and dissolved Cu, Pb and Zn, aluminum, TPH, PAH, and fecal coliform. Summary statistics are presented in Tables 8 through 27. Figures 1 through 20 provide a flushing trend line on the left with dots representing composites of the three replicates of each treatment for each experiment. The figure on the right represent all data displayed as box plots. The horizontal line across the graph represents the reporting limit.

3.3.1. Total Suspended Solids

Total suspended solids influent concentrations were below the reporting limit (1.0 mg/L) for all flushing events (Table 8 and Figure 1). All treatments exported TSS, some at initially high levels. In the first two flushing experiments Treatments 3 and 8 (70vs/20cp/10ash/compmulch and 70ls/20cp/10ash/orifice, respectively) had the highest initial TSS concentrations of 183.0 and 145.0 mg/L respectively. Treatment 4 consistently produced the lowest concentrations starting with a maximum of 73.3 mg/L and declining to 1.4 mg/L by the last flushing experiment. Total suspended solids effluent concentrations for all treatments declined rapidly to concentrations ranging from 1.4 to 14 mg/L. Interestingly, TSS concentrations in all treatments without the polishing layer increased from the first to second flush and then steadily declined. However, TSS concentrations in treatments with the polishing layer declined steadily from the initial flushing experiment. The TSS concentration increase from flushing Experiment 1 to 2 is likely due to the pulse of sediment progressing from the top to the bottom of the media column. The polishing layer, however, appears to provide effective TSS capture and mitigate the sediment pulse within the media.

3.3.2. Dissolved Organic Carbon

Dissolved organic carbon is a strong sorbent and is speculated to protect aquatic organisms from the toxic impacts of dissolved metals. Most interesting is evaluating the difference in concentrations from the treatments containing compost (high organic matter content) and the treatments containing coir and biochar (lower organic matter content). As speculated, DOC concentrations in the treatments containing compost are significantly higher initially (maximum of 130 mg/L for Treatment 1) compared to Treatments 5-8 (2.94-20.60 mg/L). However, as the flushing experiments progressed, DOC concentrations tended to equalize with minimum concentrations ranging from 0.75 to 3.16 mg/L. Note the 0.75 mg/L concentration is half the reporting limit for non-detects. See Table 9 and Figure 2 for results.

3.3.3. Total Phosphorus

Total phosphorus influent concentrations were near or below the reporting limit (5.0 µg/L) for all flushing events (Table 10, Figure 3). All treatments flushed TP; however, Treatment 1 (60/40) concentrations were significantly higher than all other treatments (maximum of 2,030 µg/L). As in previous media experiments (Herrera 2015a and 2015b), TP concentrations initially decline and then begin to increase from the third to fourth flushing experiment for most treatments.

The exceptions are treatments with the polishing layer where TP concentrations begin low and continue to decline throughout the flushing experiments. Treatment 4 (70vs/20cp/10ash/aafep-layer) was the best performer with a median effluent concentration of 61 µg/L compared to 986 µg/L for Treatment 1 and 120 to 272 µg/L for the remaining treatments.

3.3.4. Ortho-Phosphorus

Ortho-Phosphorus influent concentrations ranged from 0.9 to 9.5 µg/L which is at or slightly above the reporting limit (3.0 µg/L). See Table 11, Figure 4. All treatments flushed ortho-P; however, Treatment 1 (60/40) concentrations were significantly higher than all other treatments (maximum of 1,331 µg/L). As in previous media experiments (Herrera 2015a and 2015b), ortho-P concentrations initially increase from the first to second flushing experiment for most treatments. The exceptions are treatments with the polishing layer where ortho-P concentrations begin low and continue to decline throughout the flushing experiments. Treatment 4 (70vs/20cp/10ash/aafep-layer) was the best performer with a median effluent concentration of 14.40 µg/L compared to 913 µg/L for Treatment 1 and 47.80 to 305 µg/L for the remaining treatments.

3.3.5. Nitrate+Nitrite

Nitrate+nitrite influent concentrations were all below the reporting limit (0.1 mg/L). See Table 12, Figure 5 for results. Effluent concentrations were near or below reporting limit for all treatments not containing compost (Treatments 5-8). Treatment 1 (60/40) nitrate+nitrite concentrations were significantly higher than all other treatments with a maximum of 20.50 mg/L). Treatments 2, 3 and 4 contained compost, but performed significantly better than Treatment 1 (p value=0.05) due to the sand, coir and ash primary layer or polishing layer under the compost mulch. Previous experiments (Herrera 2015a) suggest that the coir captures nitrate+nitrite. These experiments suggest that the polishing layer may capture nitrate+nitrite as well. The mechanisms for N capture are not known for these materials.

3.3.6. Total Copper

Total Cu influent concentrations varied among flushing events ranging from 0.4 to 17.6 µg/L (Table 13, Figure 6). Initial Cu concentrations for Treatment 1 were quite high (maximum of 41.1 µg/L). The initial maximum concentrations for all other treatments were approximately half that of Treatment 1 and ranged from 17.4 to 31.3 µg/L. Effluent concentrations declined rapidly for all treatments reaching median values of 5.4 to 11.6 µg/L except for Treatment 1 with a median value of 19.9 µg/L. Treatment 4 was numerically the best performer with a median effluent concentrations of 5.4 µg/L, but performed statistically the same as Treatments 2, 6, 7' and 8 (p-value=0.05).

3.3.7. Dissolved Copper

Dissolved Cu influent concentrations varied among flushing events ranging from 0.5 to 17.5 µg/L (Table 14, Figure 7). Initial Cu concentrations for Treatment 1 were quite high initially (maximum of 39.4 µg/L). The initial concentrations for all other treatments were significantly less than Treatment 1 with maximums ranging from 3.4 to 9.3 µg/L. Effluent concentrations declined rapidly for all treatments reaching median values of 0.1 To 5.2 µg/L except for Treatment 1 with a median value of 13.2 µg/L. Treatment 8 was numerically the best performer with a median effluent concentrations of 0.1 µg/L, but performed statistically the same as Treatments 4, 5, 6' and 7 (p-value=0.05). Activated alumina is a good Cu sorbent and is likely the reason for the superior performance of Treatment 4 which contained compost.

3.3.8. Total Zinc

Total Zn influent concentrations varied among flushing events ranging from 1.0 to 9.0 µg/L (Table 15, Figure 8). Zinc concentrations for Treatments 1, 7 and 8 were initially elevated (maximum of 50.4, 50.8, and 44.7 µg/L for Treatments 1, 7, and 8 respectively). The initial concentrations for all other treatments were significantly less than Treatments 1, 7 and 8, and ranged from a maximum of 7.7 to 28.7 µg/L. Effluent concentrations declined rapidly for all treatments reaching median values of 1.5 To 10.5 µg/L except for Treatments 1, 7 and 8 with median values all approximately 11 µg/L. Treatment 4 was numerically the best performer with a median effluent concentrations of 1.5 µg/L, but performed statistically the same as Treatment 3 (p-value=0.05). Activated alumina is likely a good Zn sorbent and may be the reason for the superior performance of Treatment 4 which included compost mulch.

3.3.9. Dissolved Zinc

Dissolved Zn influent concentrations varied among flushing events ranging from 1.5 to 10.3 µg/L (Table 16, page Figure 9). All treatments performed well with many effluent concentrations near or below the reporting limit (1.0 µg/L). All treatments performed statistically the same and with lower effluent concentrations than the influent except Treatment 1 which showed no significant difference between influent and effluent (p-value=0.05). Rather than the typical steady decline in concentration as experiments progressed, effluent concentrations for many treatments except Treatments 3 (70vs/20cp/10ash/compmulch) and 6 (70ss/20cp/10ash) declined from flushing experiment 1 and then increased from experiment 2 to 3 and then declined again from 3 to 4. The reason for the fluctuation is not known; however, this may be simply the initial pulse of Zn progressing through the column.

3.3.10. Total Lead

Total Pb influent concentrations were low (Table 17, Figure 10) for all experiments. Treatment 1 was the poorest performer with median concentrations statistically higher than all other treatments and the influent. All other treatments performed statistically the same with median effluent slightly above influent concentrations except Treatment 4 which showed no difference from the influent (p-value=0.05).

3.3.11. Dissolved Lead

Dissolved Pb influent concentrations ranged from the reporting limit (0.1 µg/L) to 2.4 µg/L (Table 18, Figure 11). All treatments without compost performed very well with many effluent concentrations near or below the reporting limit. Effluent concentrations were numerically slightly higher for the treatments containing compost (Treatments 1-4). Treatment 1 was numerically the poorest performer with a median effluent concentration of 0.3 µg/L (median influent was 0.13 µg/L). The median effluent concentrations for all treatments were statistically the same as the median influent concentration. Rather than the typical steady decline in concentration as experiments progressed, effluent concentrations for Treatments 1-4 declined from flushing experiments 1 to 2 and then increased from experiment 2 to 3 and then declined again from 3 to 4. Conversely concentrations for Treatments 5-8 increased from experiment 1 to 2 then decreased. The reason for the fluctuation is not known; however, this may be simply the initial pulse of Pb progressing through the column at different time intervals.

3.3.12. Cadmium

Total and dissolved Cd were also analyzed; however, nearly all influent and effluent concentrations were below the reporting limit and are therefore not reported here or in tables or plots.

3.3.13. Aluminum

Because activated alumina is used in the polishing layers for Treatments 2 and 4, aluminum is analyzed for the first, second and fourth flushing experiments for Treatments 2 and 4 and the first and fourth flushing experiments for all other treatments. All aluminum influent concentrations were below the reporting limit (1.0 µg/L). See Table 19, Figure 12 for results. All treatments exported aluminum and all concentrations declined steadily as flushing experiments progressed. Interestingly, median effluent concentrations were similar for Treatments 1-6 ranging from 1,010 µg/L to 3,940 µg/L). Median concentrations for Treatments 2 and 4 with the polishing layer were lower than 1 (60/40), 5 (70vs/20cp/10ash) and 6 (70ss/20cp/10ash). Most interesting is the extremely high concentrations flushing from Treatments 7 (70ls/20cp/10ash) and 8 (70ls/20cp/10ash/orifice). The difference between Treatments 7 and 8 and the remaining treatments is the lava sand which appears to be the source of the high aluminum concentrations.

3.3.14. Total Petroleum Hydrocarbons (motor oil and diesel)

Total petroleum hydrocarbons were analyzed for the first and fourth flushing experiment. For the first flush influent and effluent concentrations (diesel range) were near or below reporting limit for all treatments except Treatment 1 (60/40) with a maximum concentration of 0.59 mg/L). By the fourth flushing experiment effluent concentrations for all treatments were non-detect (<0.25 mg/L). For motor oil range all influent and effluent concentrations non-detect (<0.50 mg/L). See Tables 20 and 21 and Figures 13 and 14.

3.3.15. Polycyclic Aromatic Hydrocarbons

Polycyclic aromatic hydrocarbons are considered toxic to aquatic organisms and were analyzed to correlate with the toxicological analyses presented in Section 3.8. Specific analytes assessed include phenanthrene, fluoranthene, chrysene, benzo[K]fluoranthene, and benzo[a]pyrene, and were measured for the first flushing experiments only. All PAH influent and effluent concentrations were below reporting limits (0.11 µg/L) except for Treatment 1 effluent (chrysene and fluoranthene) and Treatment 2 effluent (fluoranthene). Maximum chrysene and fluoranthene effluent concentrations for Treatment 1 (60/40) was 0.021 and 0.050 µg/L respectively. Maximum fluoranthene concentration for Treatment 2 (60/40/aafep-layer) was 0.016 µg/L. See Tables 22 through 26 and Figures 15 through 19.

3.3.16. Fecal Coliform

Fecal coliform levels were assessed for the first and last flush only to evaluate bacteria levels inherent in the column array (Table 27, Figure 20). Influent concentrations were all below the reporting limit. Effluent concentrations varied widely among treatments. The treatments containing 60 percent compost (1 and 2) hade very high initial effluent concentrations (≥25,000 CFU). By the fourth flush effluent concentrations were very low (most near or below the reporting limit of 2 CFU) for all treatments. Treatment 4 was numerically the best performer with a media effluent concentration of 502 CFU and a median value that was statistically lower (p-value=0.05) than all other treatments except 3 (10vs/20cp/10ash/compmulch) and 6 (70ss/20cp/10ash).

Flushing Experiments Results – Plots

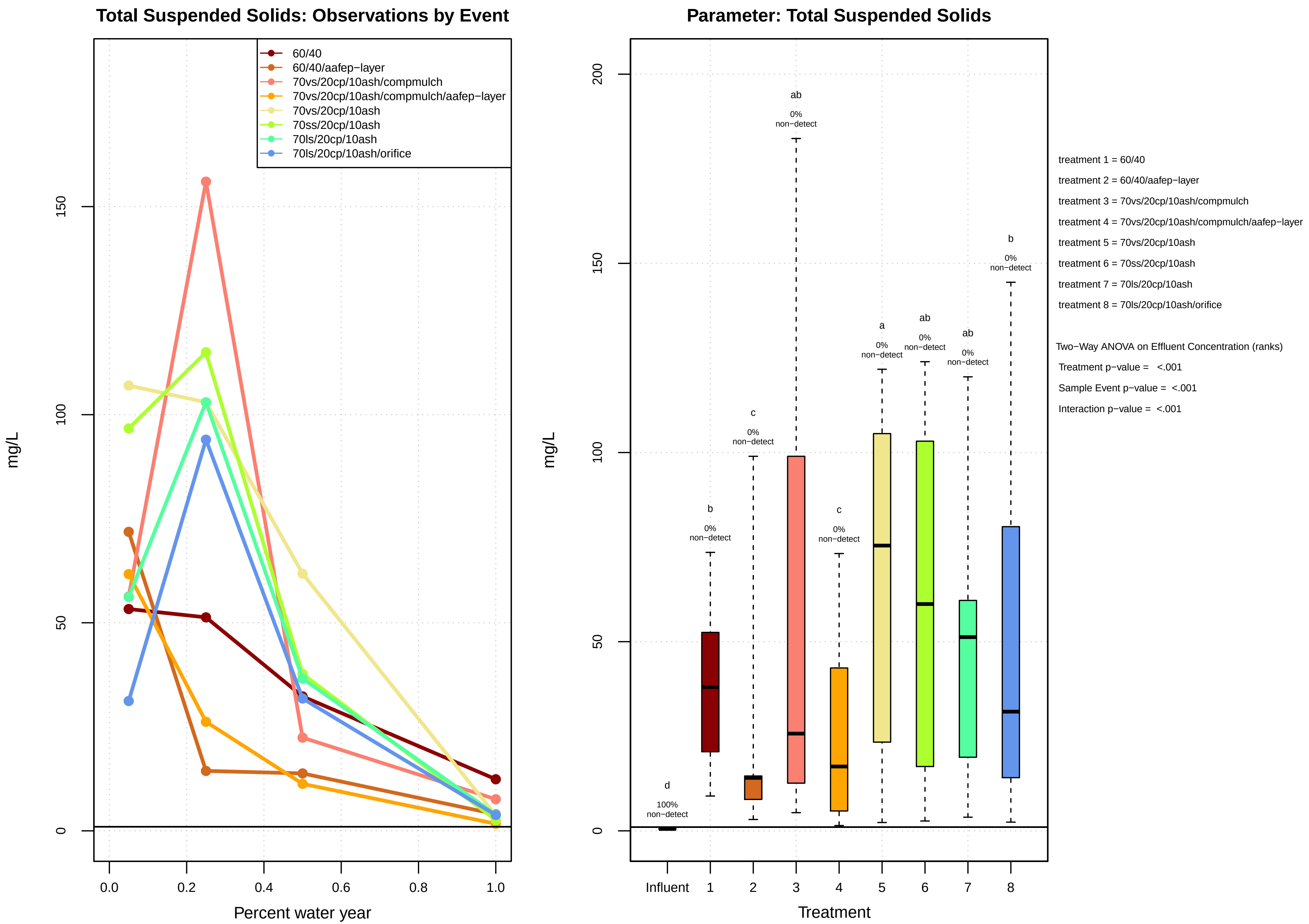


Figure 1. Flushing Boxplots for Total Suspended Solids.

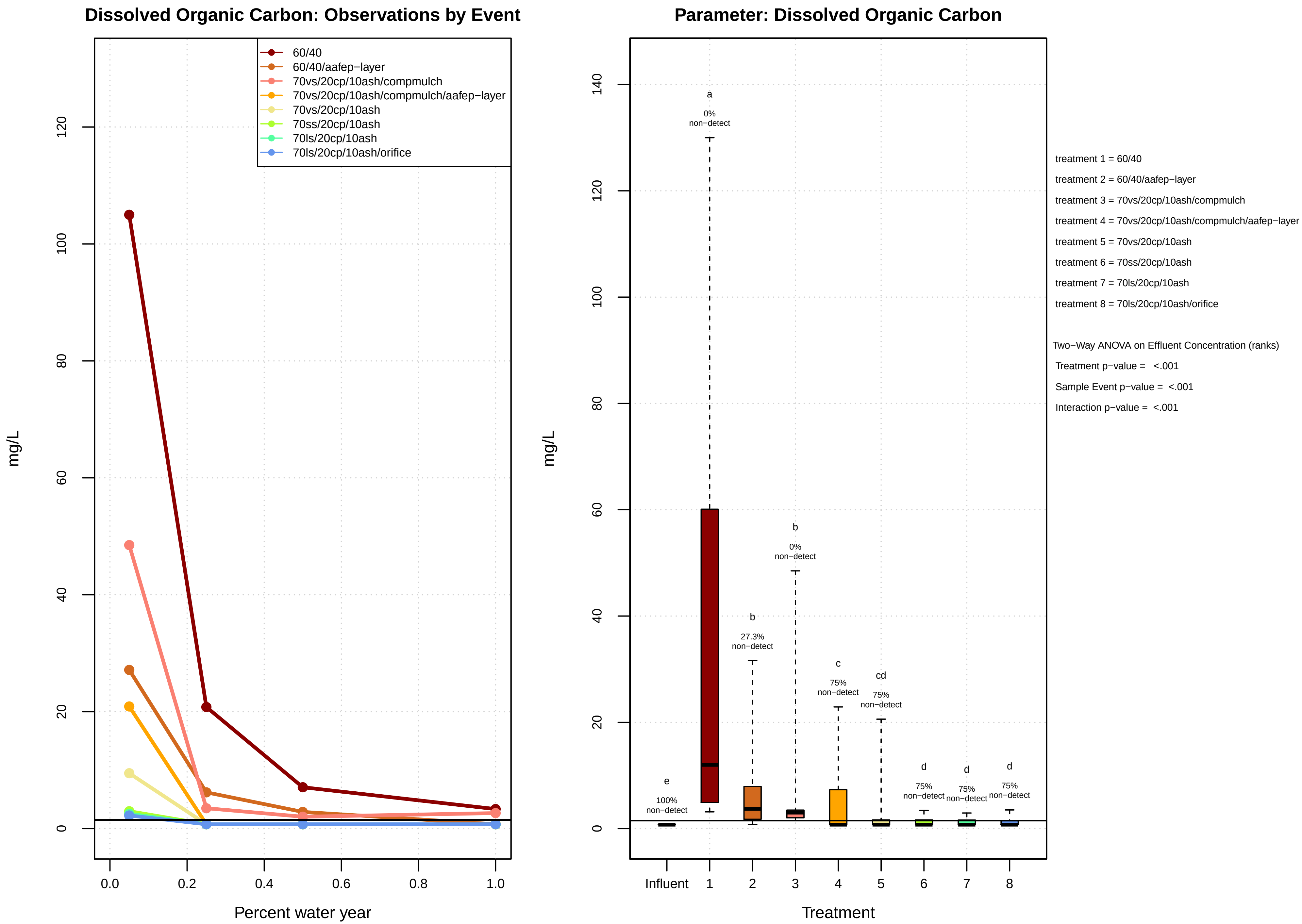


Figure 2. Flushing Boxplots for Dissolved Organic Carbon.

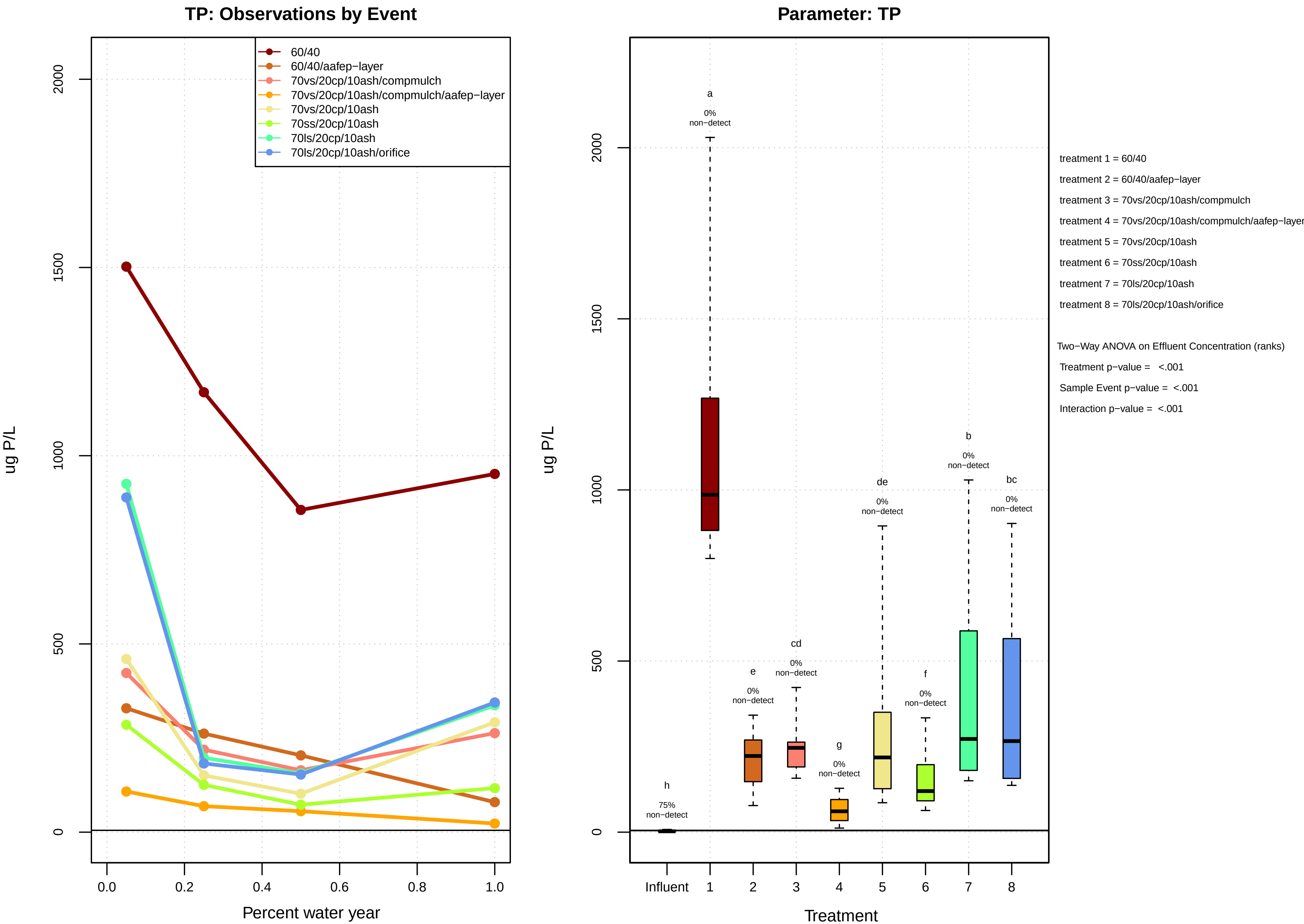


Figure 3. Flushing Boxplots for Total Phosphorus.

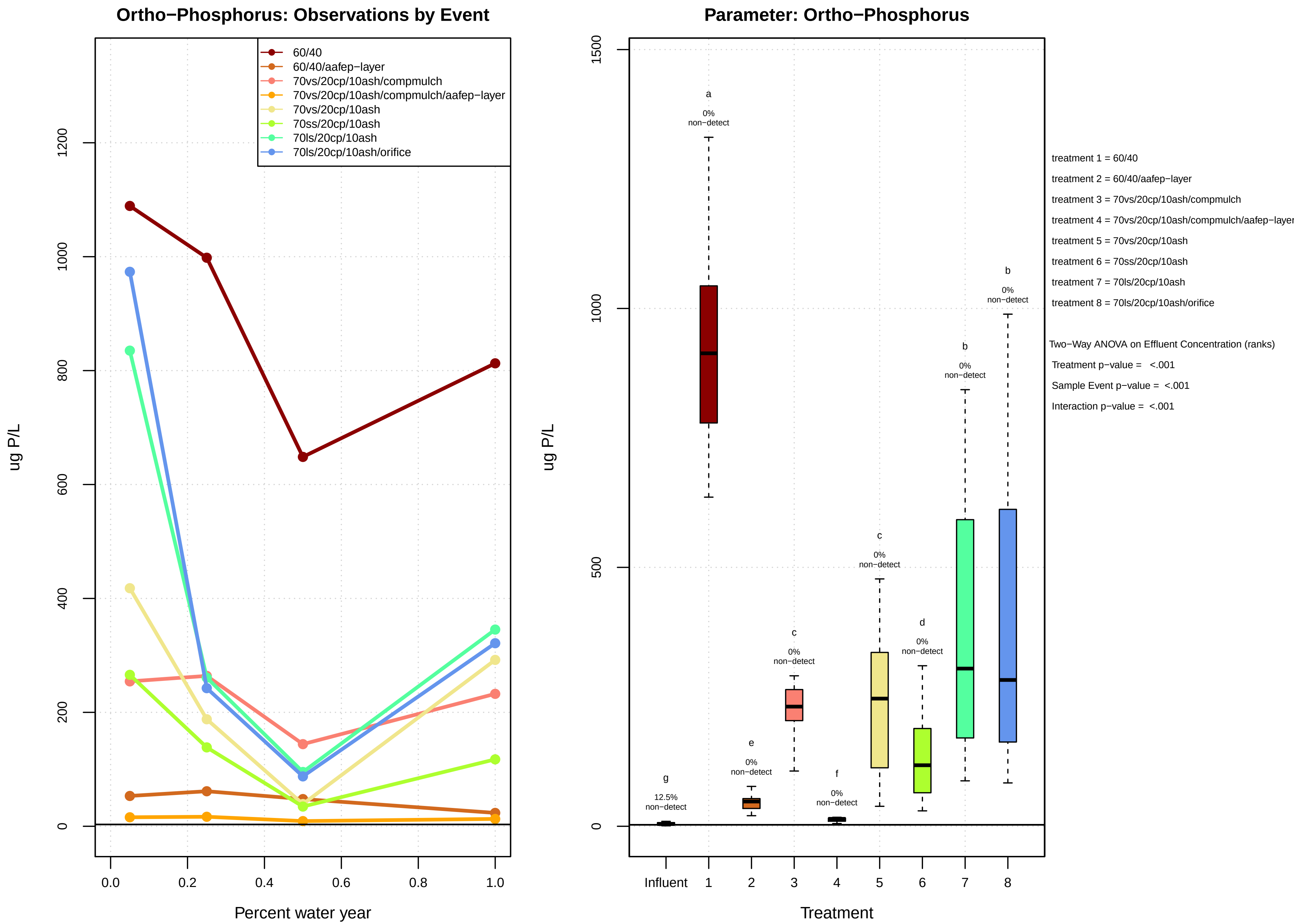
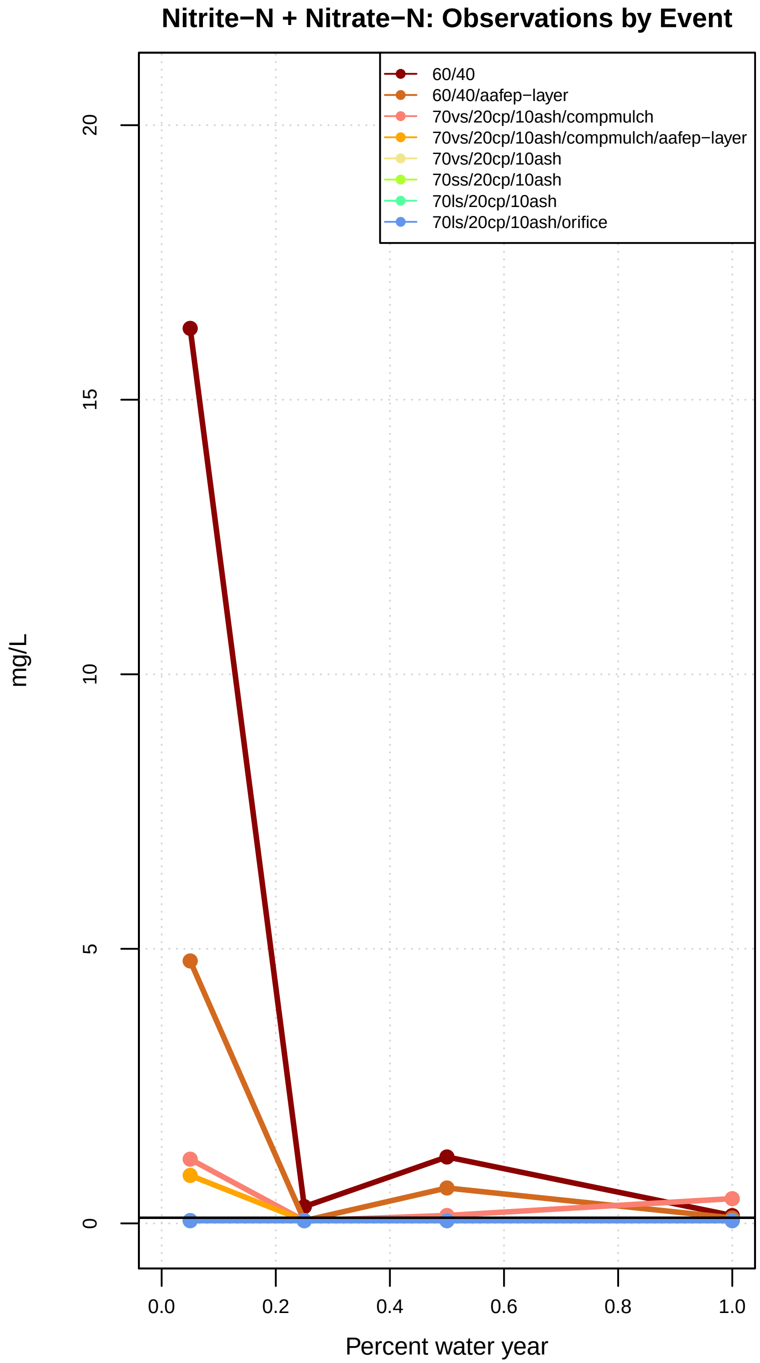


Figure 4. Flushing Boxplots for Ortho-Phosphorus.



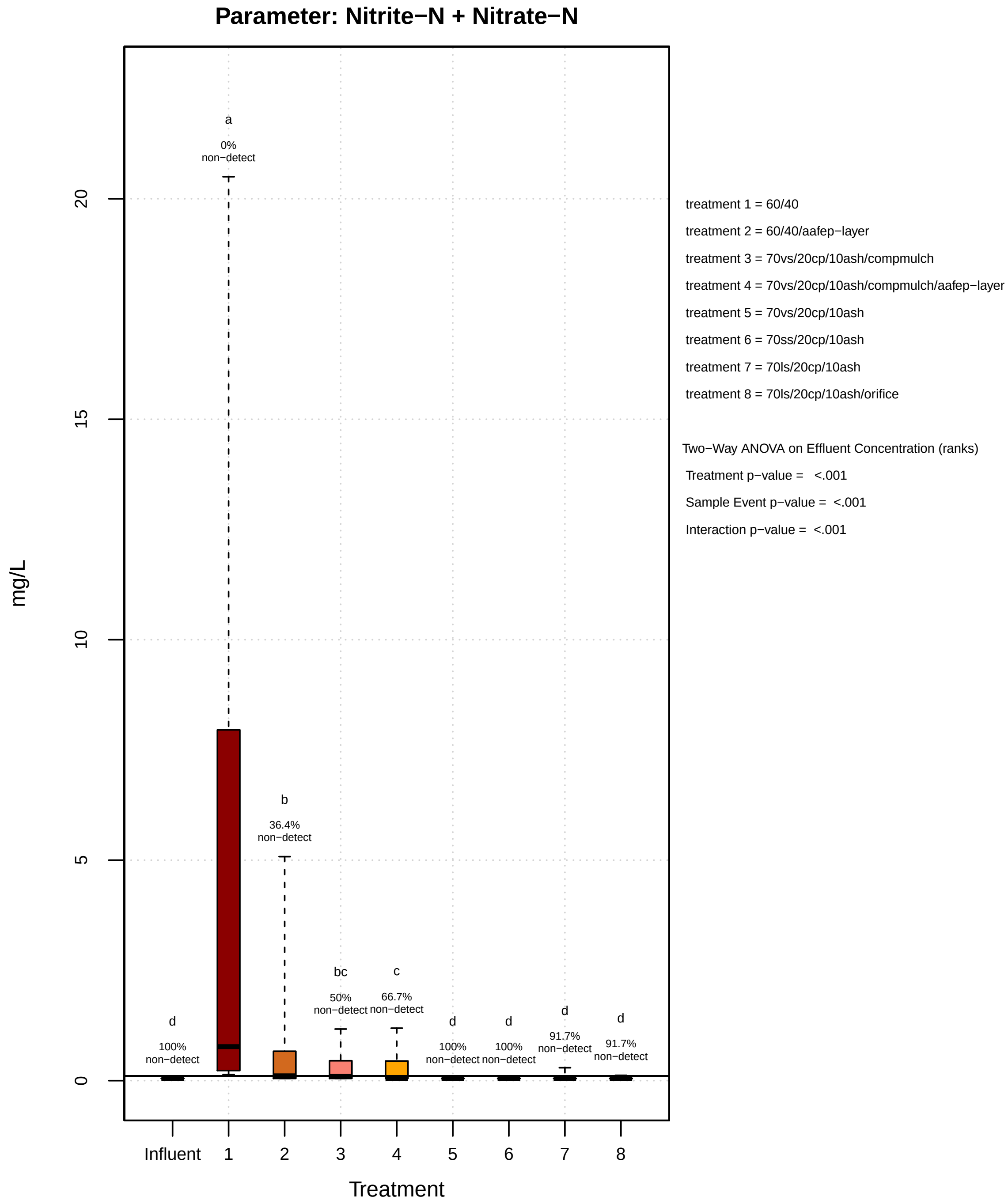


Figure 5. Flushing Boxplots for Nitrate+nitrite.

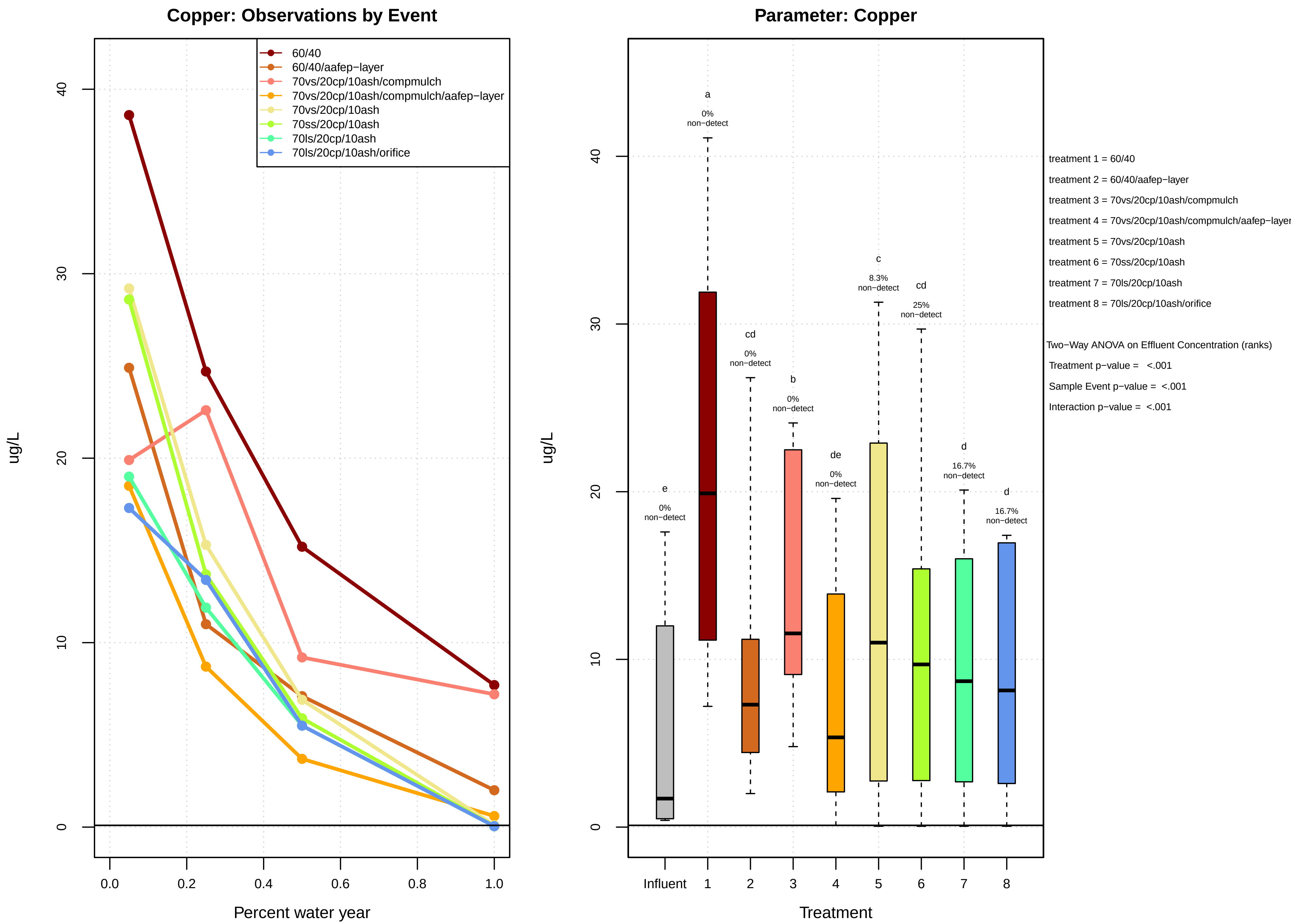


Figure 6. Flushing Boxplots for Copper, Total.

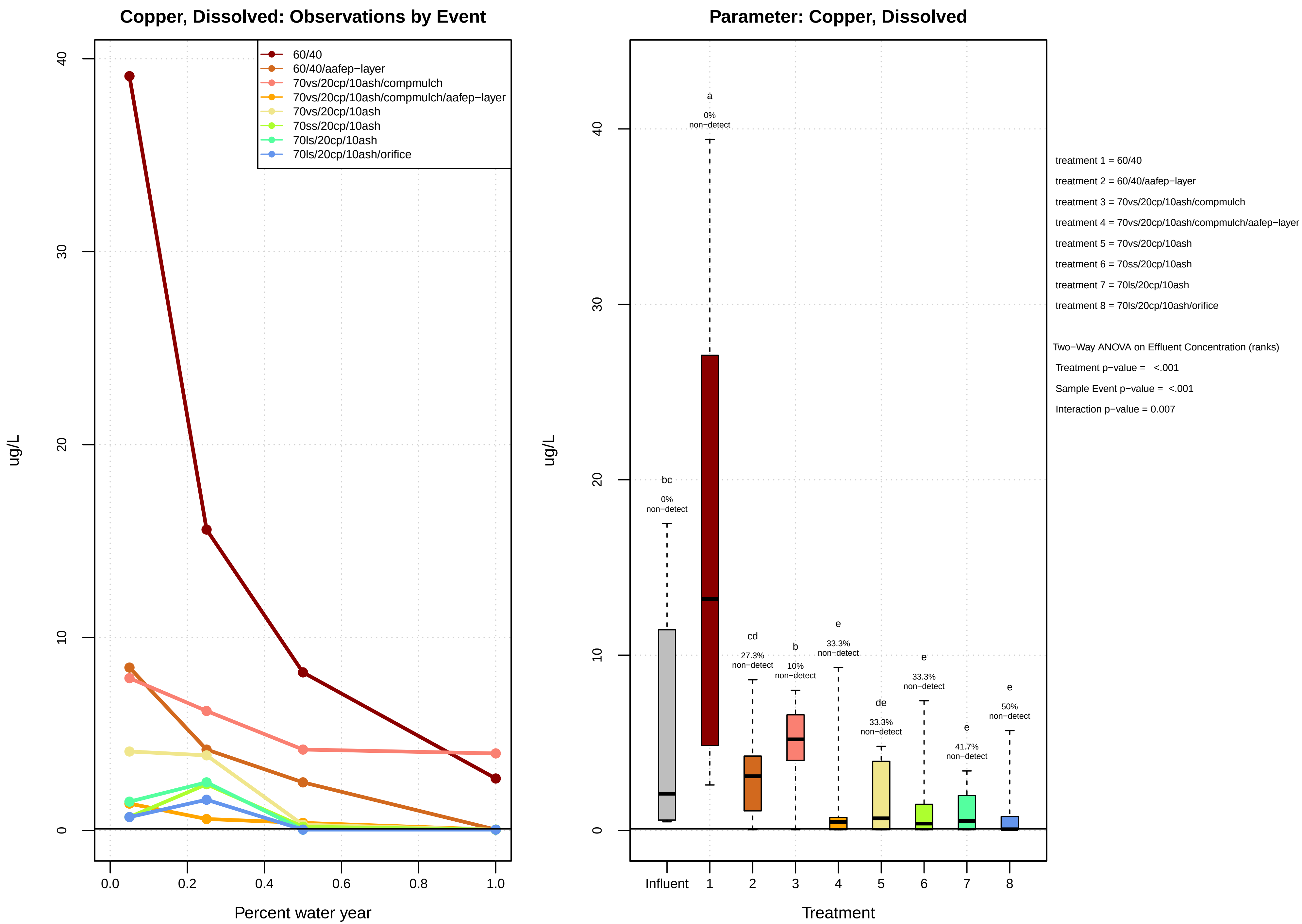


Figure 7. Flushing Boxplots for Copper, Dissolved.

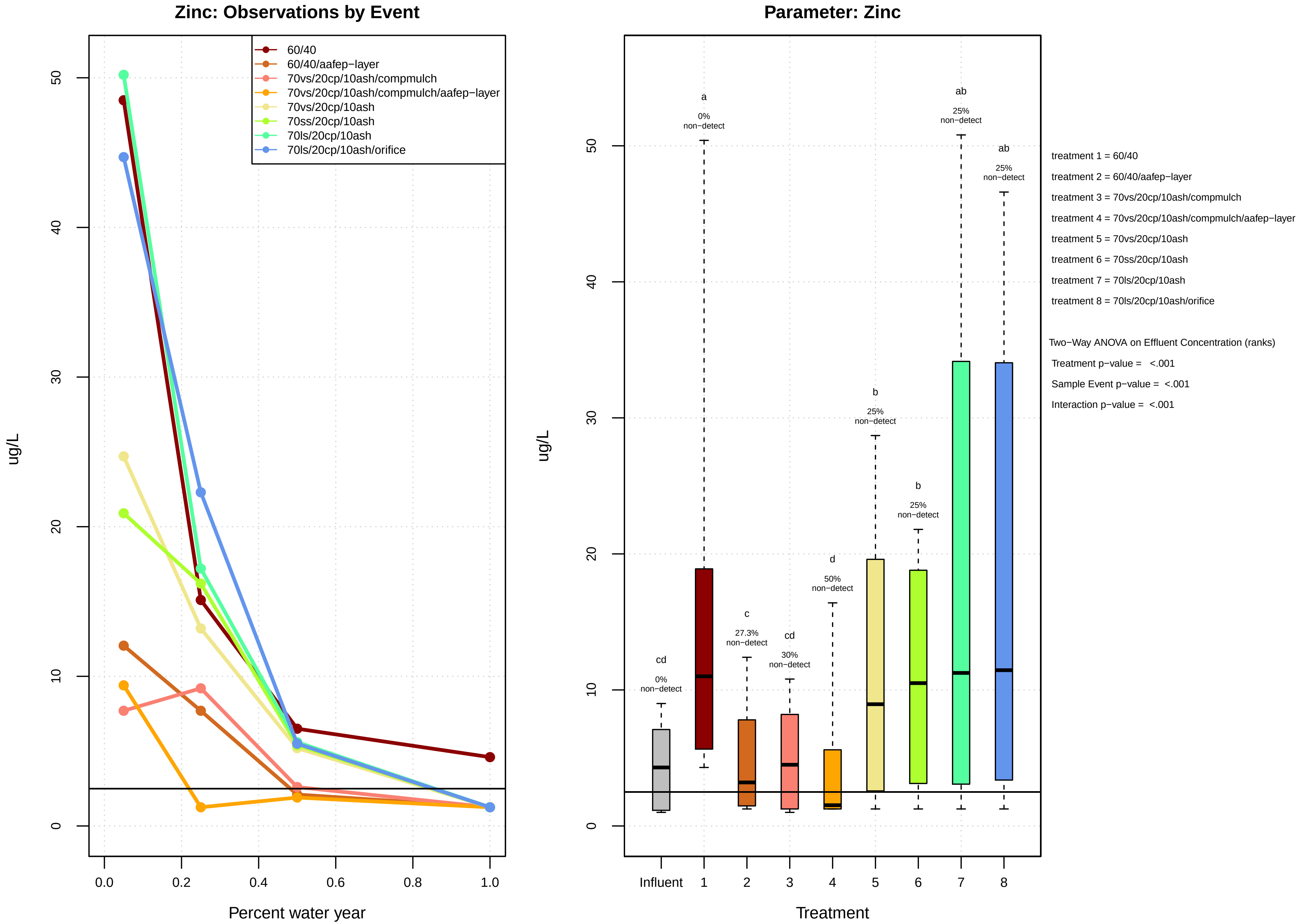


Figure 8. Flushing Boxplots for Zinc, Total.

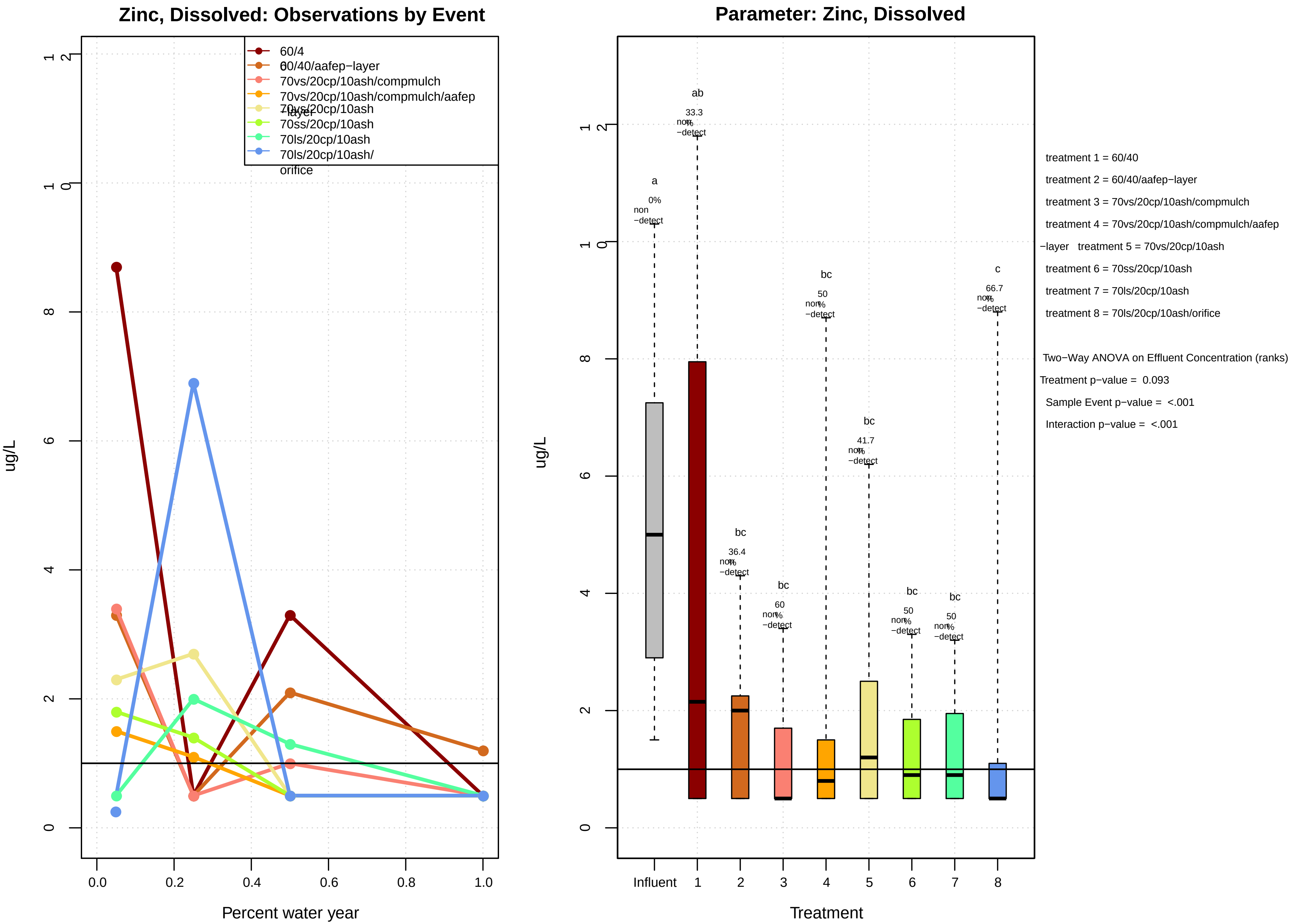


Figure 9. Flushing Boxplots for Zinc, Dissolved.

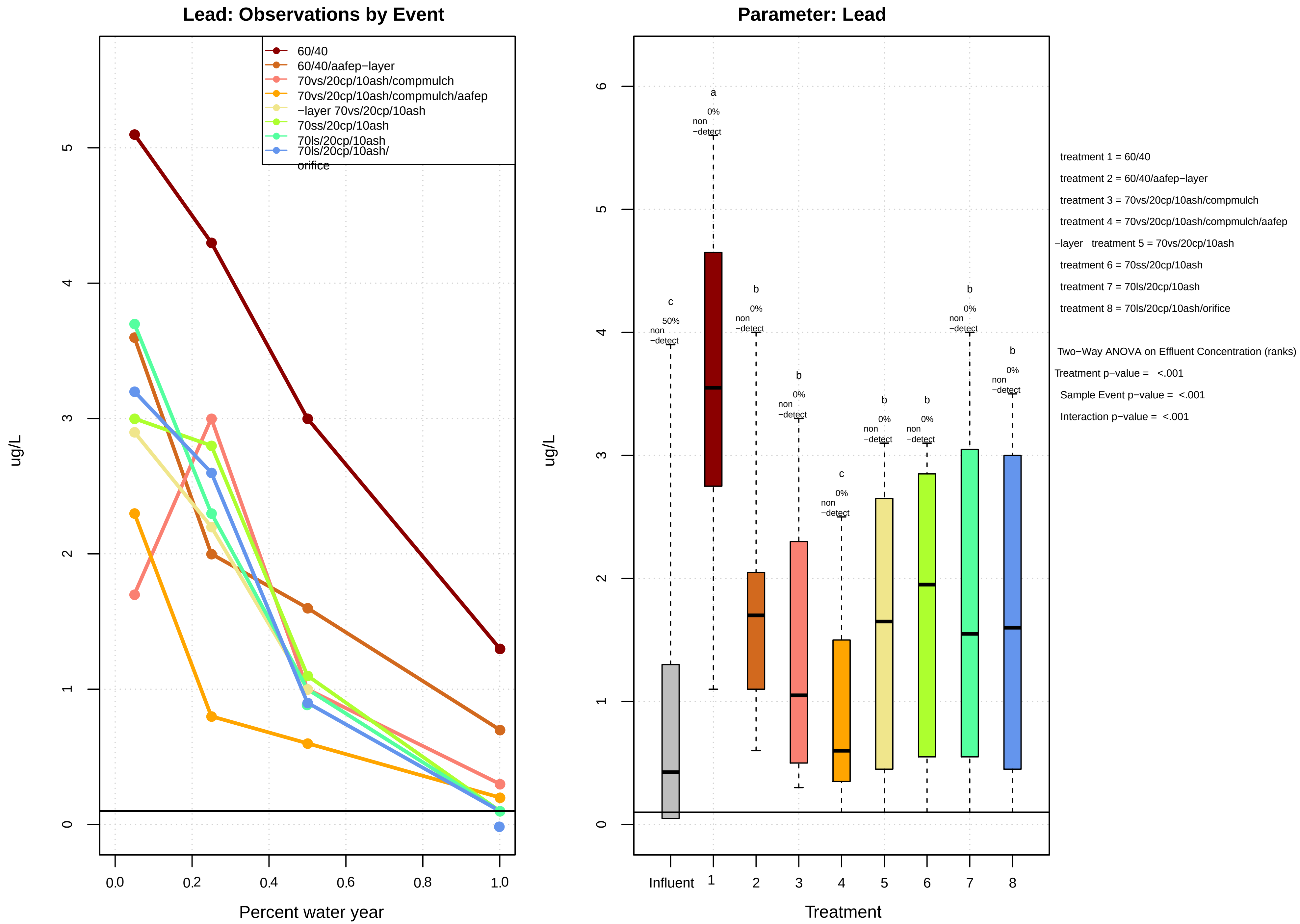


Figure 10. Flushing Boxplots for Lead, Total.

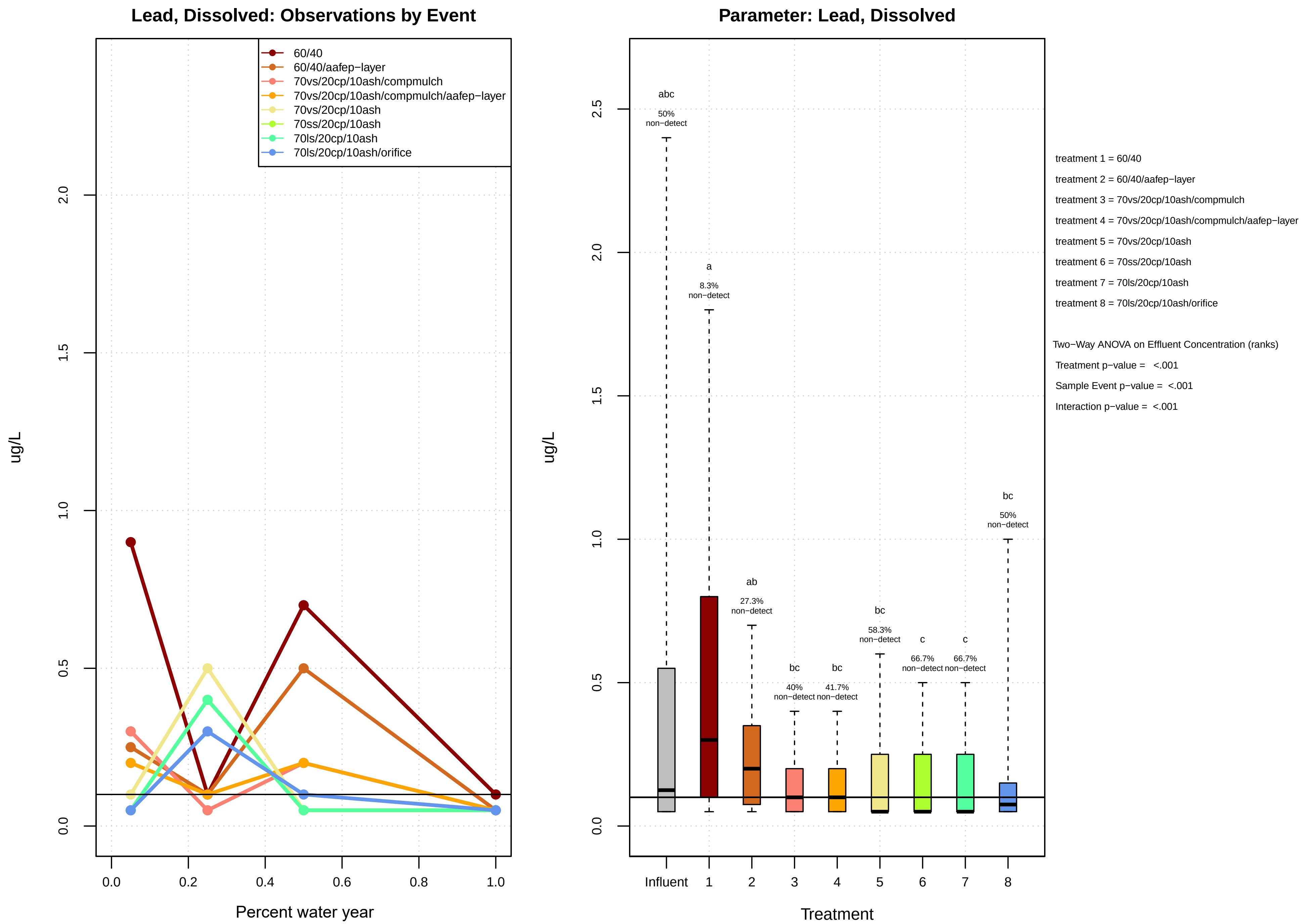


Figure 11. Flushing Boxplots for Lead, Dissolved.

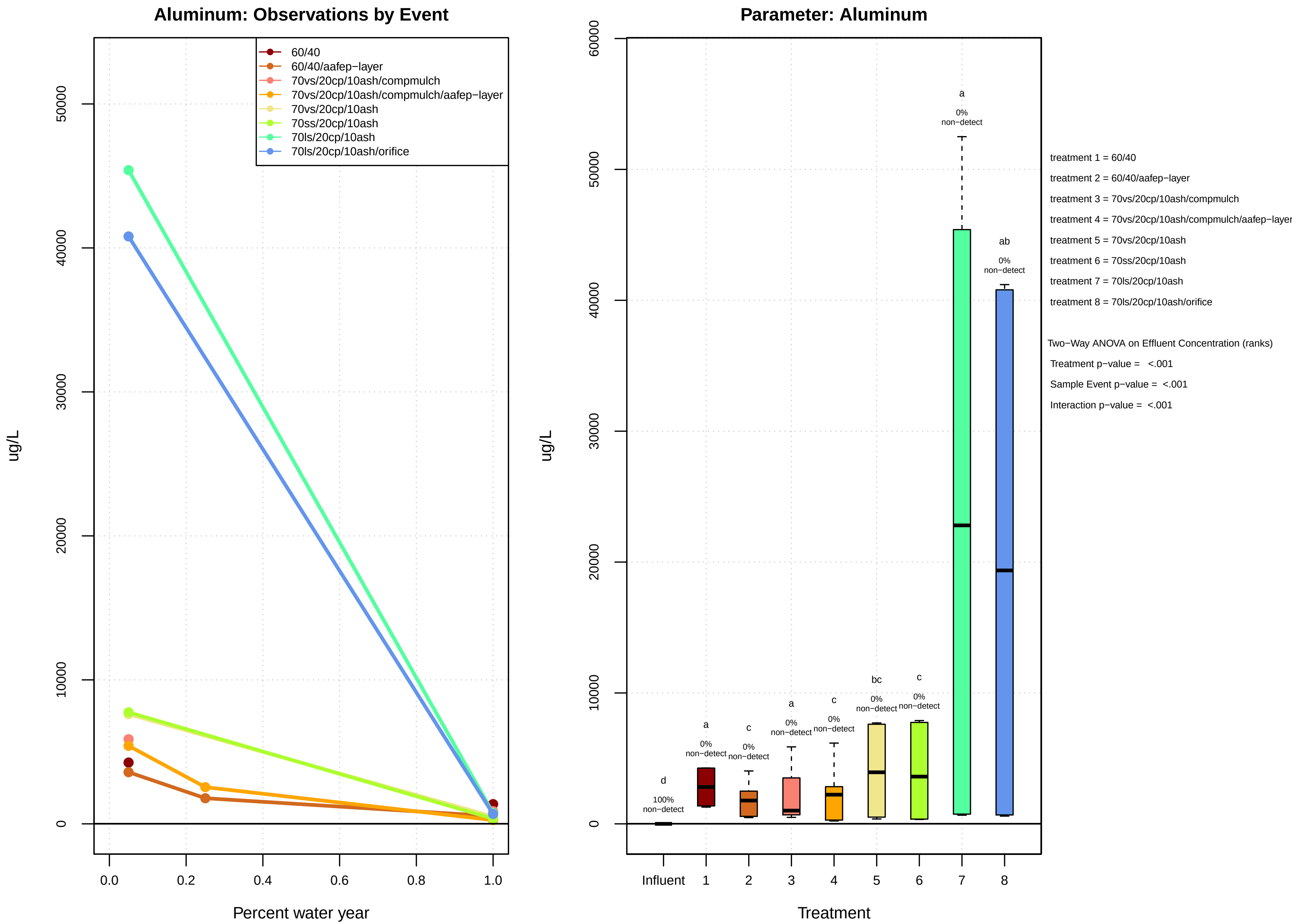


Figure 12. Flushing Boxplots for Aluminum.

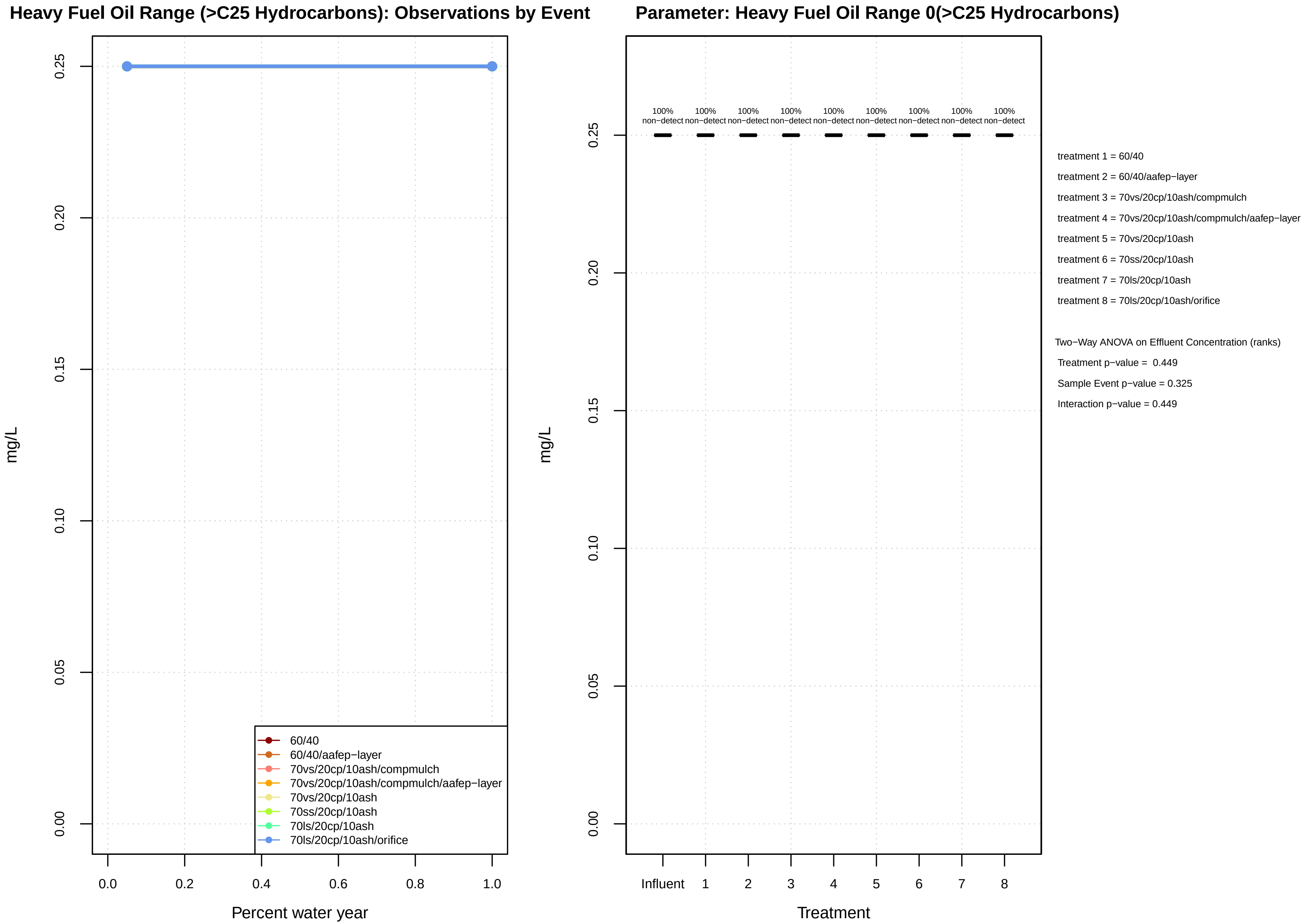


Figure 13. Flushing Boxplots for Total Petroleum Hydrocarbons Motor Oil Range (>C25).

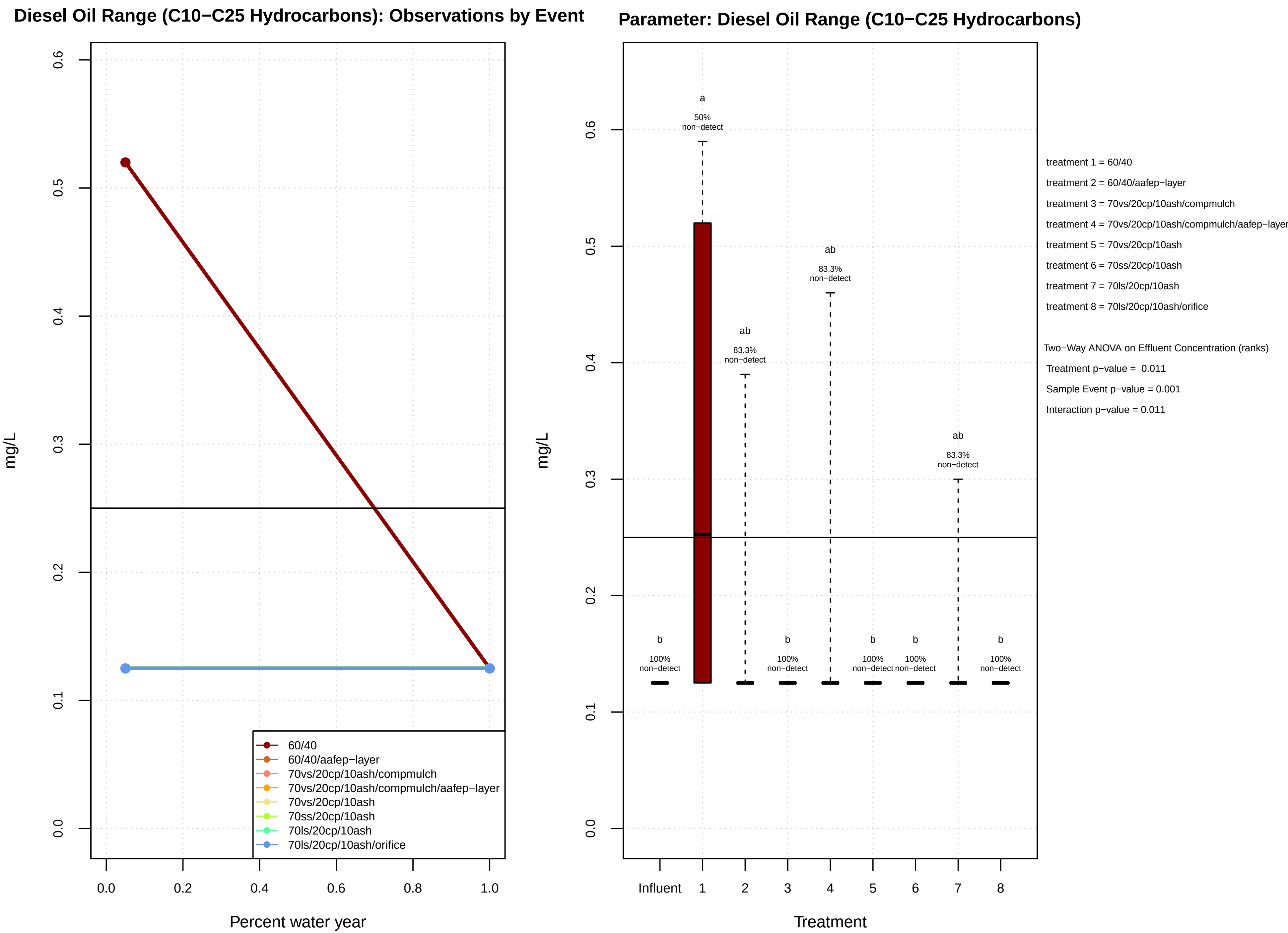


Figure 14. Flushing Boxplots for Total Petroleum Hydrocarbons Diesel Oil Range (C10-C25).

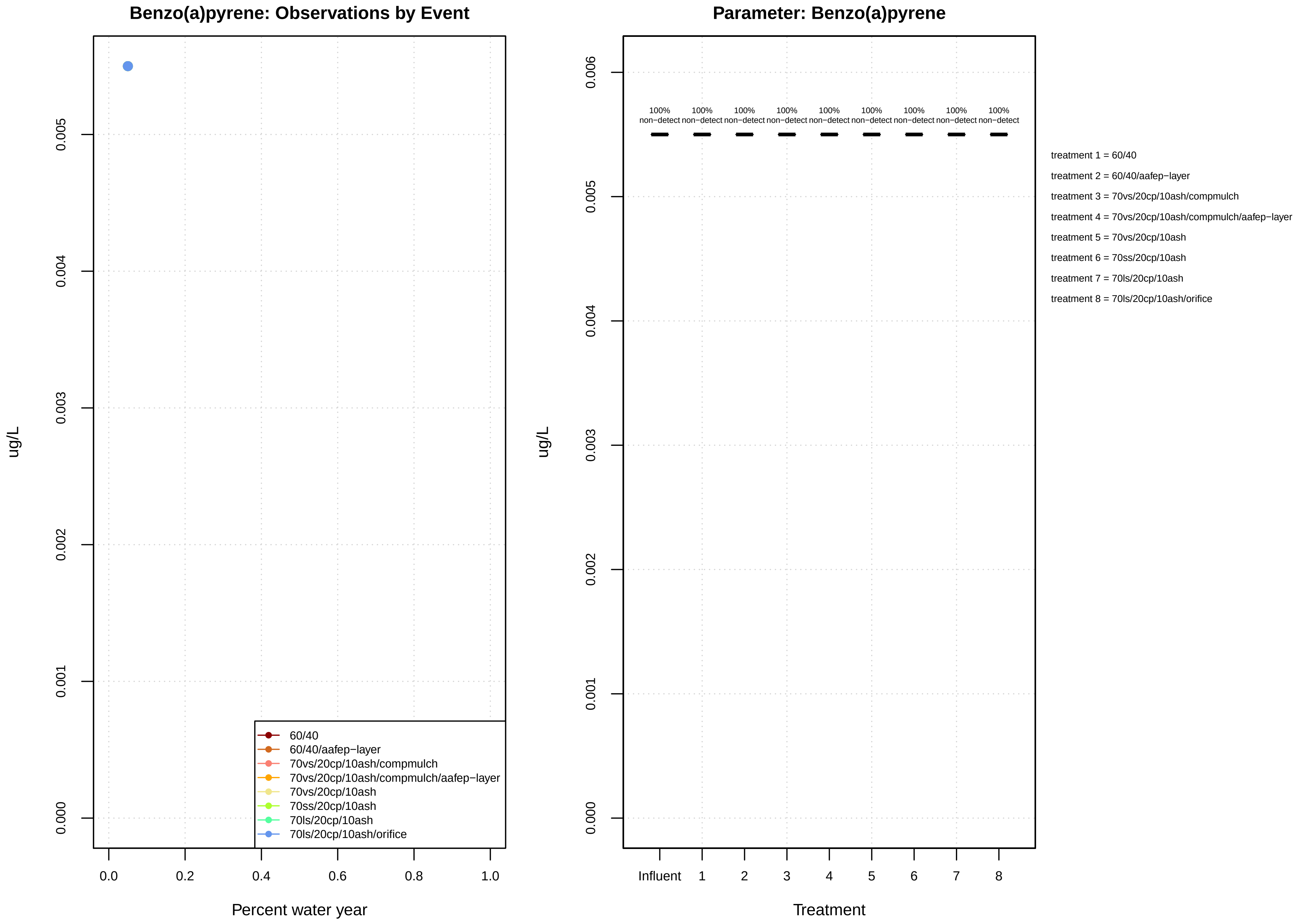
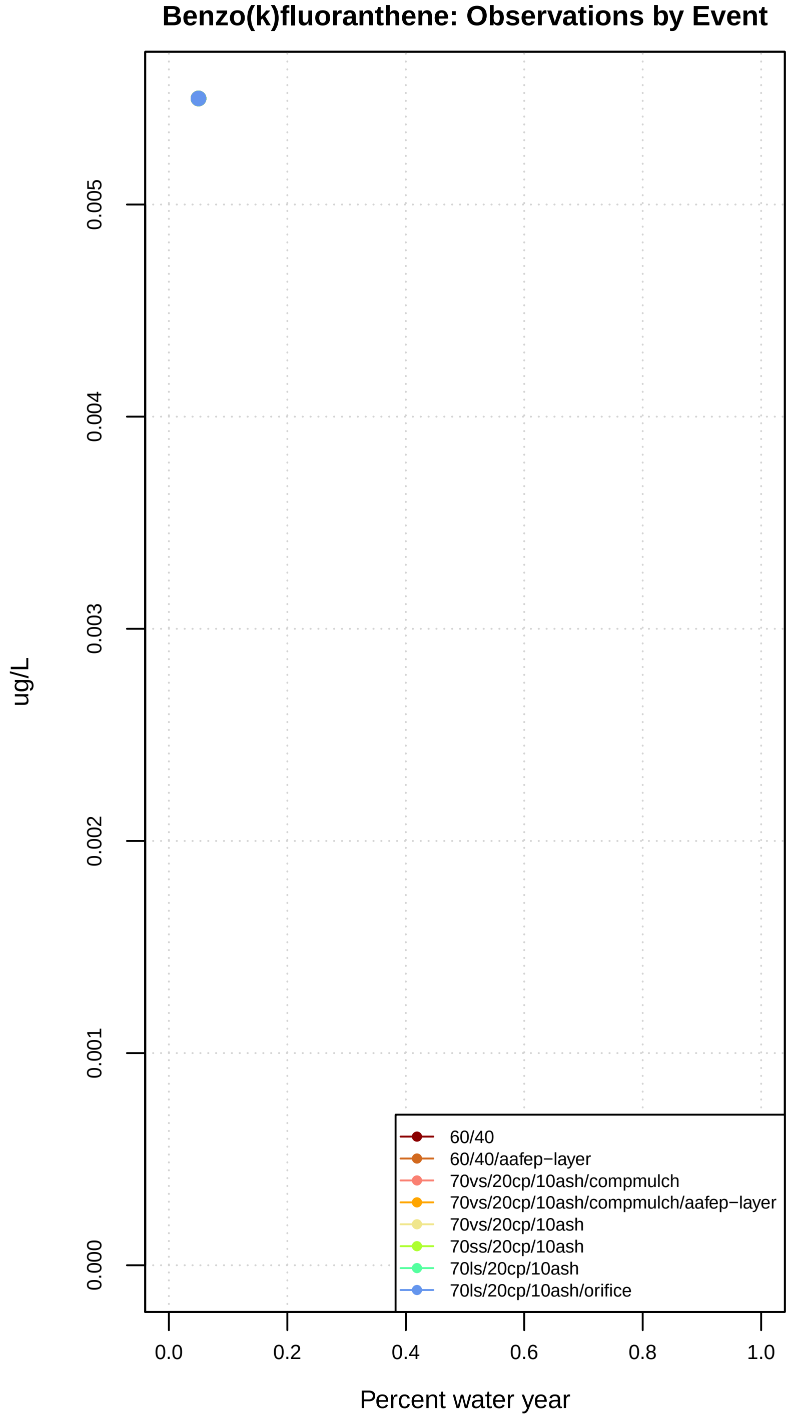


Figure 15. Flushing Boxplots for Benzo(a)pyrene.



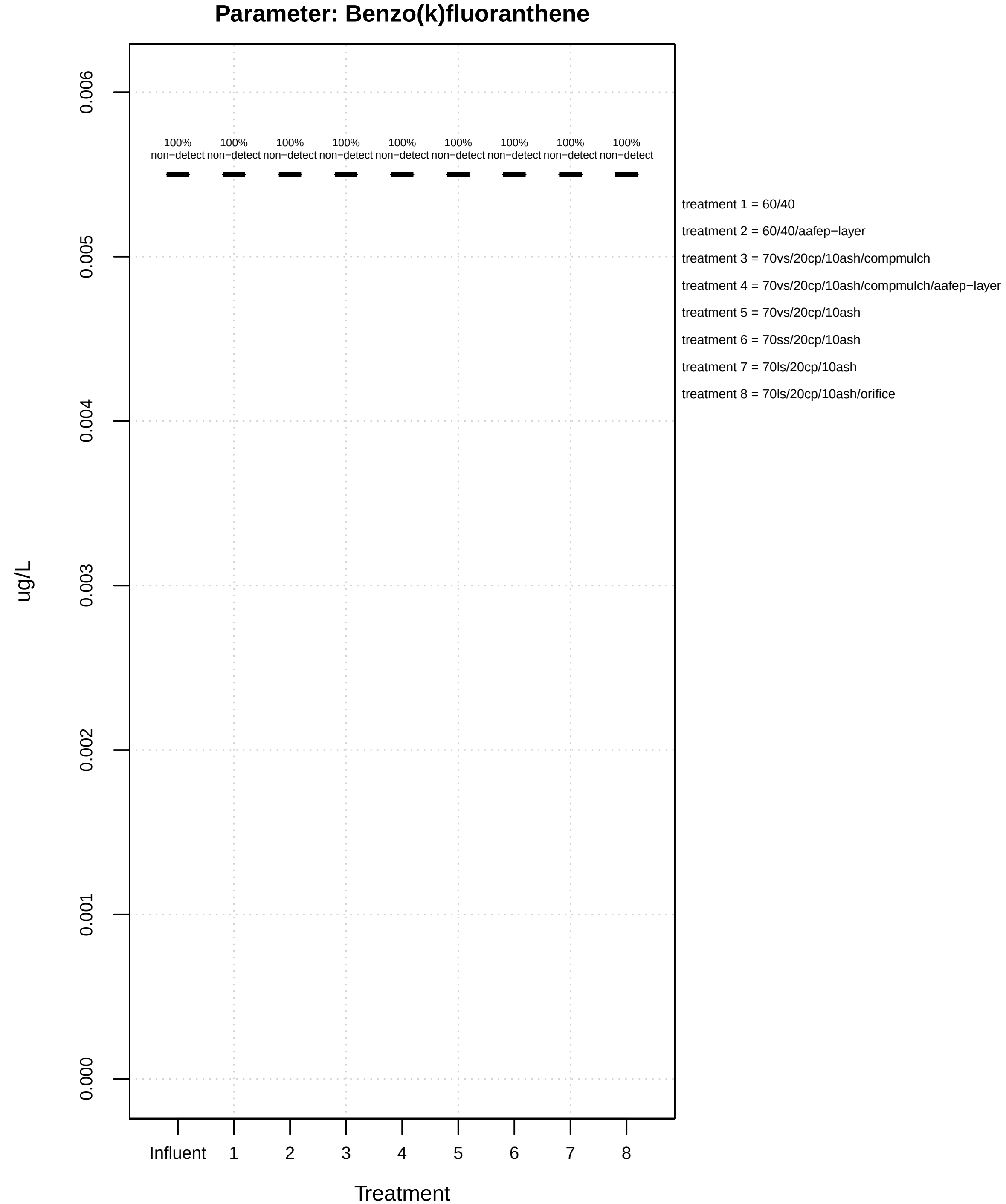
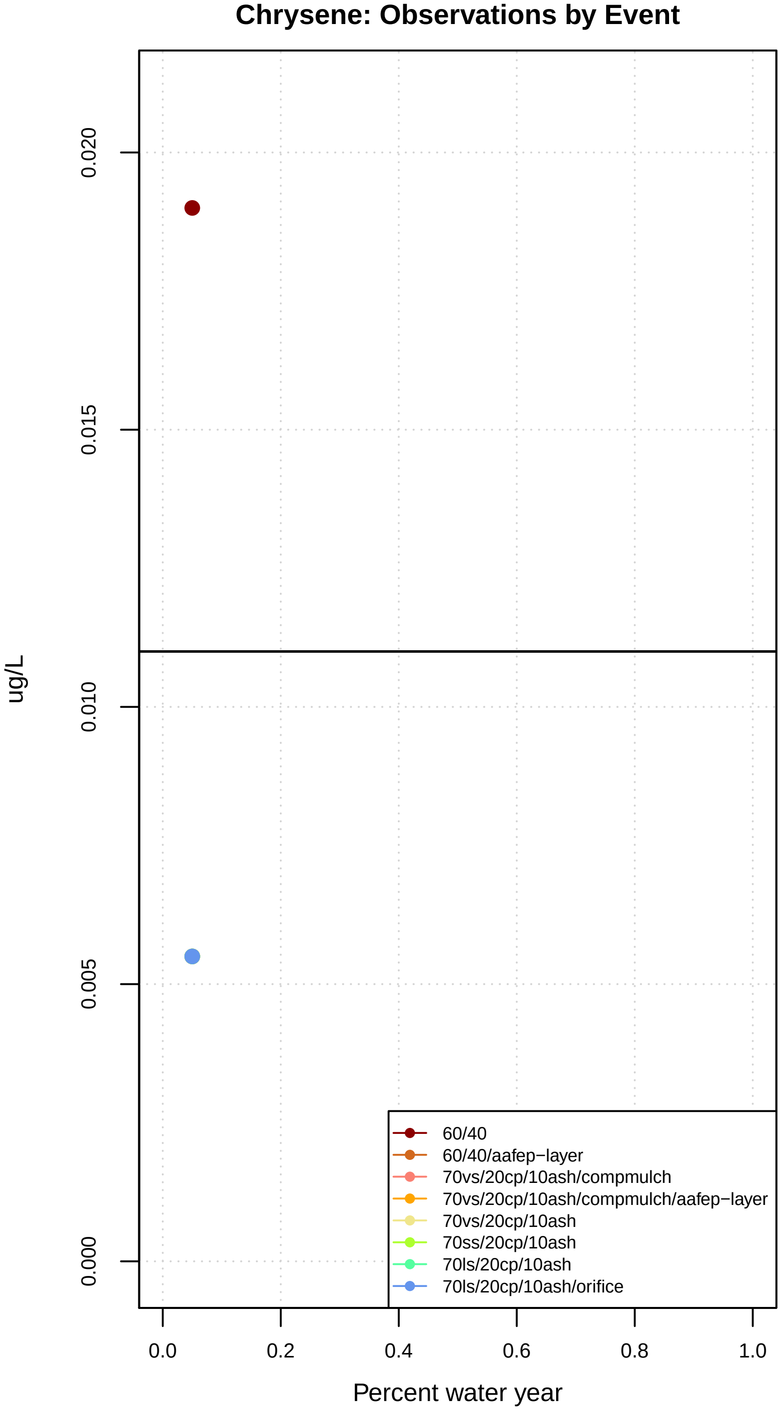


Figure 16. Flushing Boxplots for Benzo(k)fluoranthene.



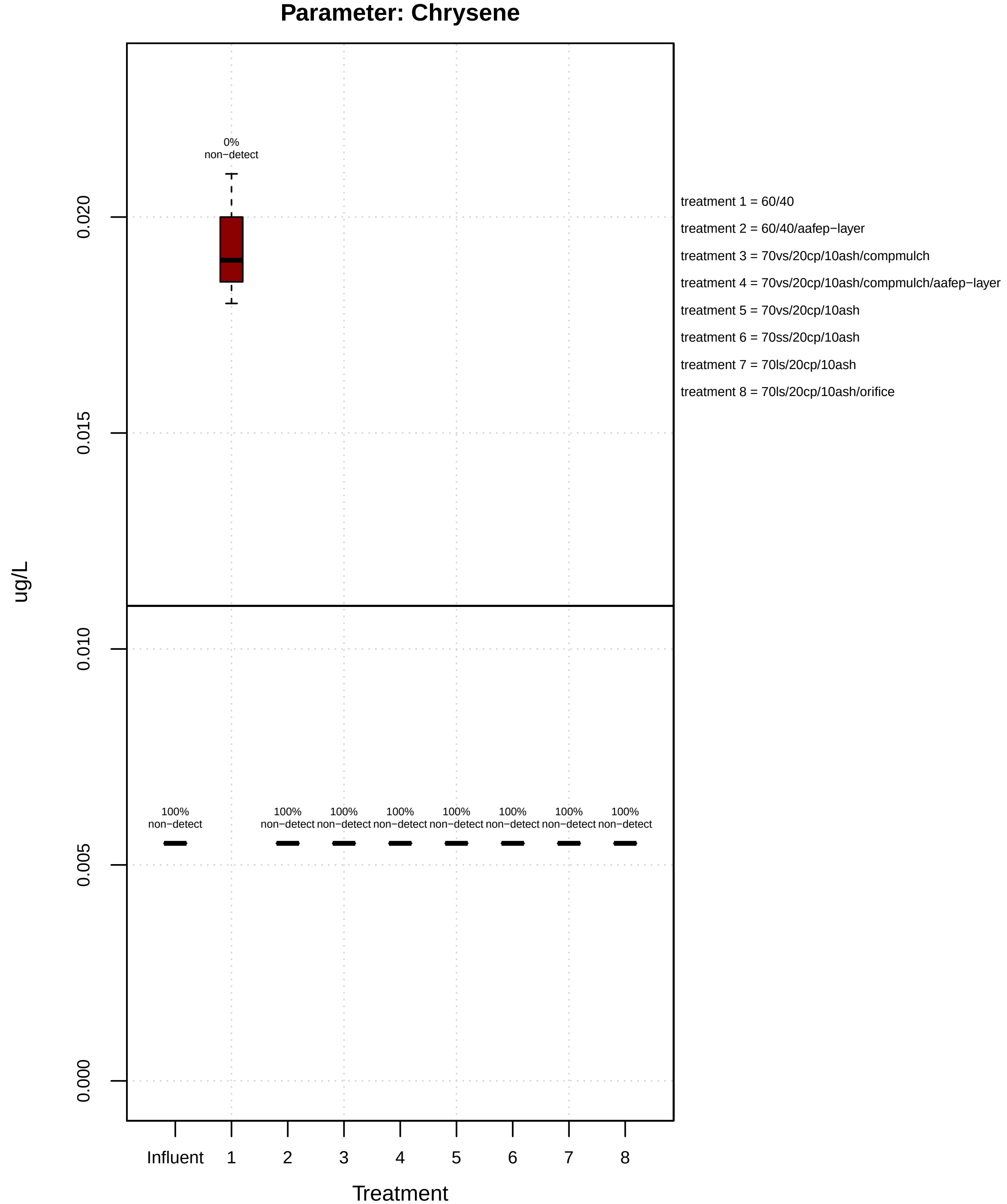


Figure 17. Flushing Boxplots for Chrysene.

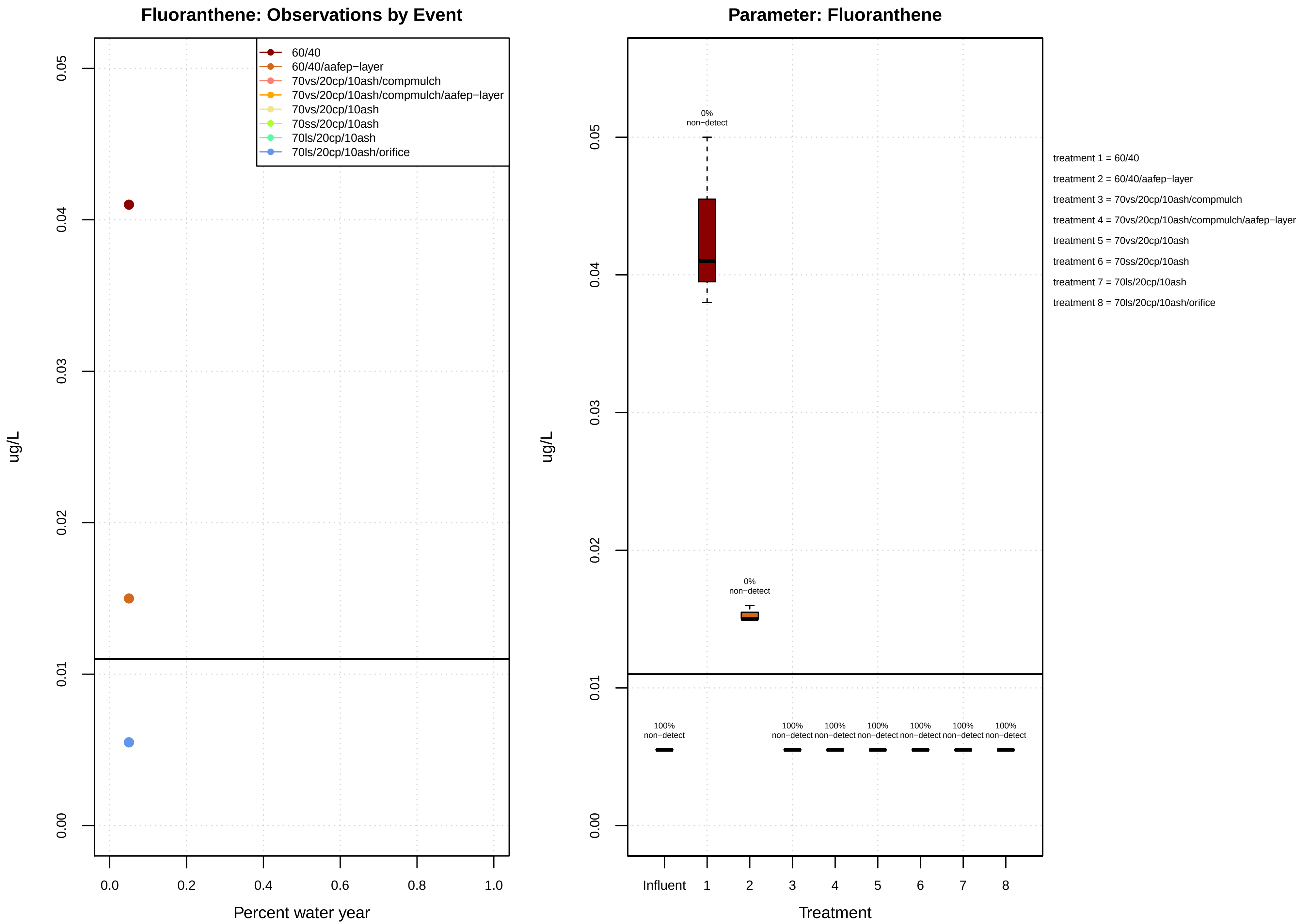


Figure 18. Phenanthrene Flushing Boxplots for Fluoranthene.

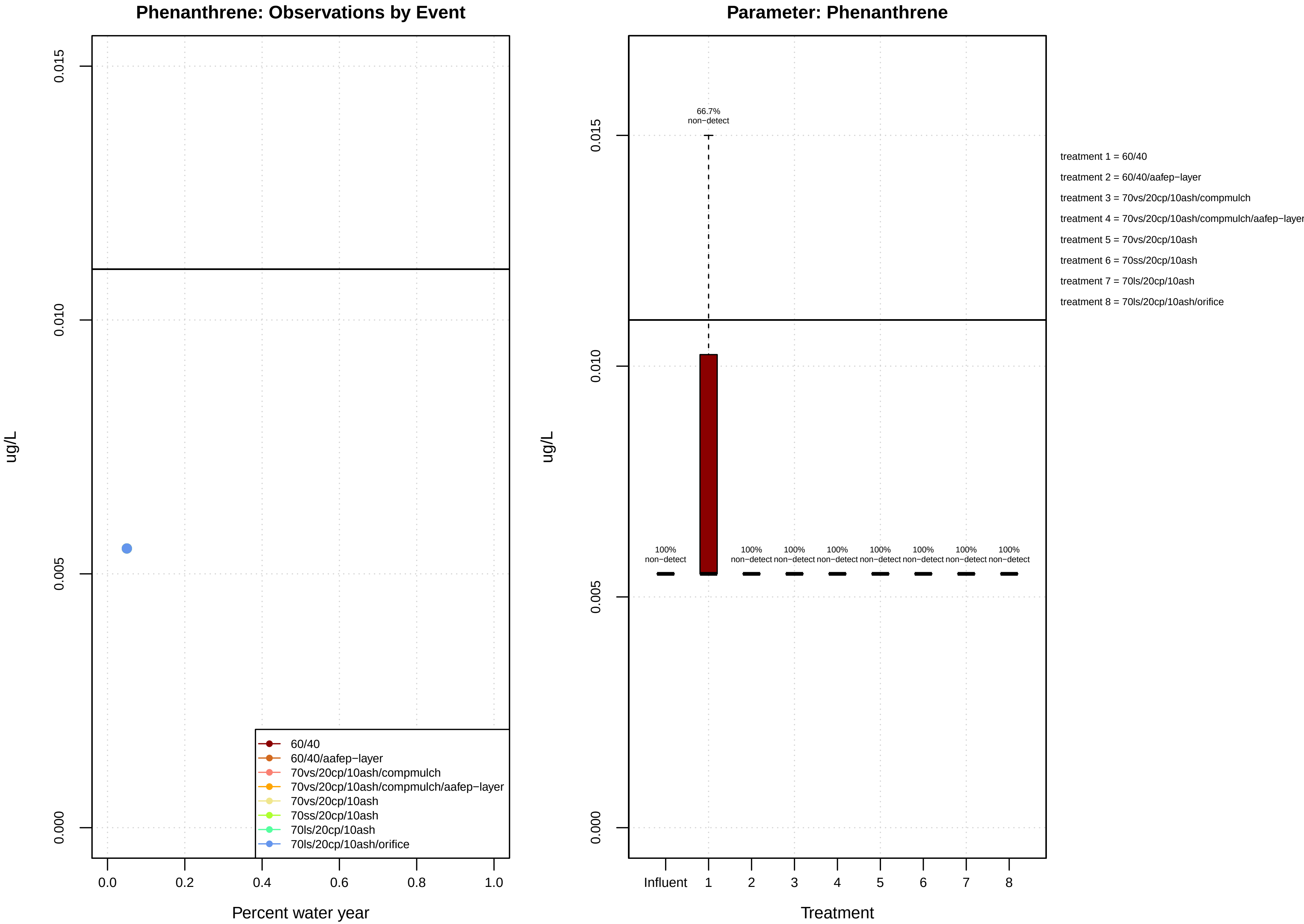


Figure 19. Flushing Boxplots for Phenanthrene.

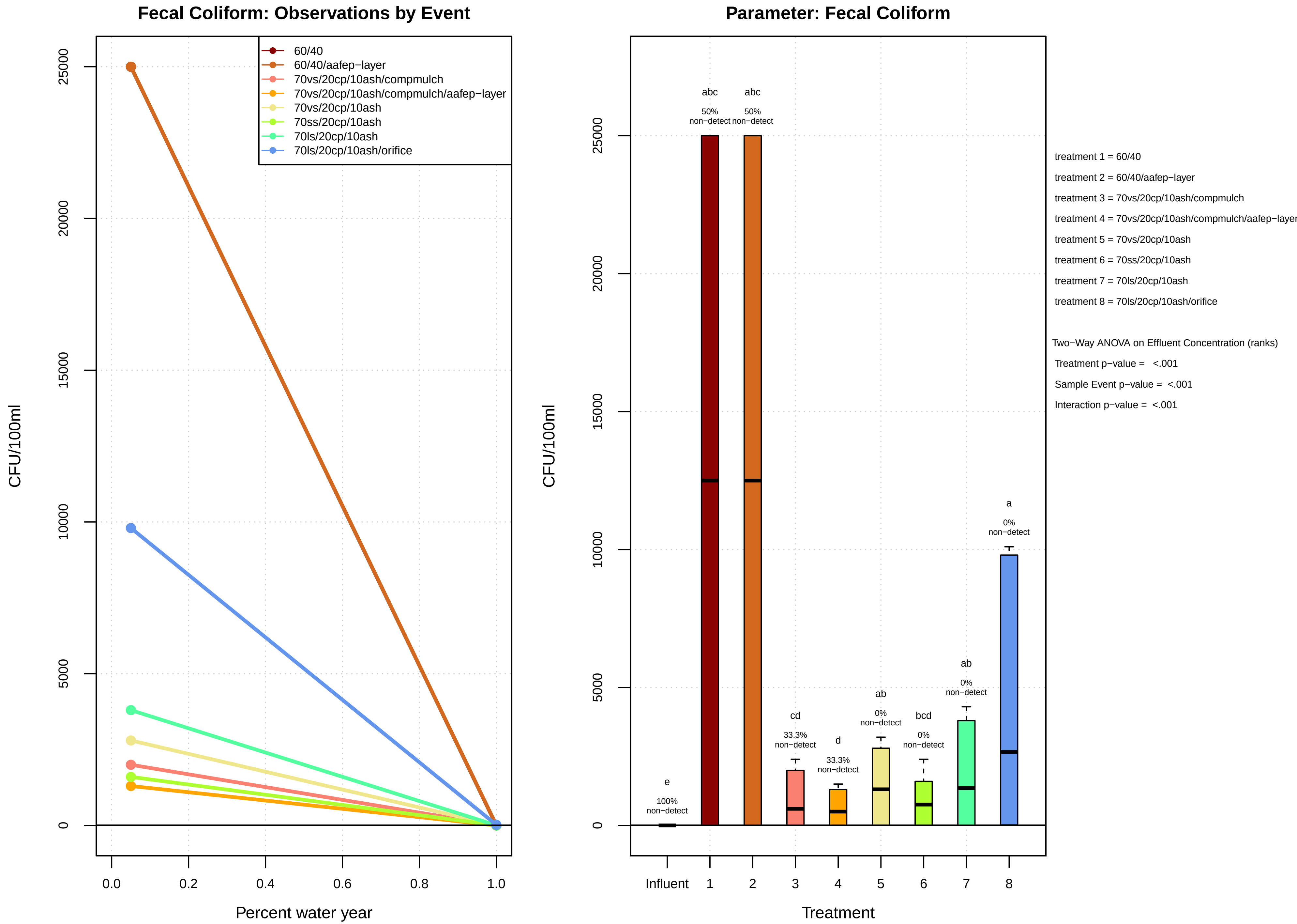


Figure 20. Flushing Boxplots for Fecal Coliform.

Flushing Experiments Results – Tables

Table 8. Flushing Experiment Raw Data and Summary Statistics for Total Suspended Solids.

Flushing Event	Flushing Volume	Percent Water Year	Flow Rate (liters/hr)	Influent Day 1 (mg/L)	Flag	Treatment 1 60/40 (mg/L)	Flag	Treatment 2 60/40/aafep-layer (mg/L)	Flag	Treatment 3 70vs/20cp/10ash/ compmulch (mg/L)	Flag	Treatment 4 70vs/20cp/10ash/ compmulch/ aafep-layer (mg/L)	Flag	Influent Day 2 (mg/L)	Flag	Treatment 5 70vs/20cp/ 10ash (mg/L)	Flag	Treatment 6 70ss/20cp/ 10ash (mg/L)	flag	Treatment 7 70ls/20cp/ 10ash (mg/L)	Flag	Treatment 8 70ls/20cp/10ash/ orifice (mg/L)	Flag
1	17.81	0.05	6.67	1	U	53.3		44.7		56.3		61.7		1	U	107.0		96.7		47.0		31.2	
						51.6		99.0		no sample		73.3				122.0		99.0		63.4		92.8	
						69.0		no sample		no sample		54.3				92.7		74.3		56.2		27.2	
2	17.81	0.25	6.67	1	U	51.3		14.0		156.0		26.2		1	U	115.0		124.0		103.0		145.0	
						73.6		14.4		99.0		20.2				103.0		107.0		58.4		94.0	
						36.3		14.6		183.0		31.8				87.4		115.0		120.0		68.0	
3	35.62	0.5	11	1	U	32.3		13.8		18.6		8.6		1	U	61.8		37.7		55.4		31.8	
						27.8		12.0		22.4		11.3				40.5		31.0		34.2		21.5	
						39.7		14.4		29.0		13.8				63.4		45.6		36.6		59.6	
4	35.62	1	11	1	U	9.2		3.0		12.6		1.9		1	U	2.2		2.6		4.7		6.6	
						12.4		4.6		4.8		1.7				6.4		3.0		3.6		2.3	
						14.0		4.0		7.6		1.4				3.7		2.6		3.9		3.8	
Min				0.5		9.2		3.0		4.8		1.4		0.5		2.2		2.6		3.6		2.3	
Max				0.5		73.6		99.0		183.0		73.3		0.5		122.0		124.0		120.0		145.0	
Mean				0.5		39.2		21.7		58.9		25.5		0.5		67.1		61.5		48.9		48.6	
Median				0.5		38.0		14.0		25.7		17.0		0.5		75.4		60.0		51.2		31.5	

U = undetected at the reporting limit noted. For these results, one-half the reporting limit is used to calculate Minimum, Maximum, Mean, and Median.

mg/L = milligrams per liter.

Table 9. Flushing Experiment Raw Data and Summary Statistics for Dissolved Organic Carbon.

Flushing Event	Flushing Volume	Percent Water Year	Flow Rate (liters/hr)	Influent Day 1 (mg/L)	Flag	Treatment 1 60/40 (mg/L)	Flag	Treatment 2 60/40/aafep-layer (mg/L)	Flag	Treatment 3 70vs/20cp/10ash/ compmulch (mg/L)	Flag	Treatment 4 70vs/20cp/10ash/ compmulch/ aafep-layer (mg/L)	Flag	Influent Day 2 (mg/L)	Flag	Treatment 5 70vs/20cp/ 10ash (mg/L)	Flag	Treatment 6 70ss/20cp/ 10ash (mg/L)	flag	Treatment 7 70ls/20cp/ 10ash (mg/L)	Flag	Treatment 8 70ls/20cp/10ash/ orifice (mg/L)	Flag
1	17.81	0.05	6.67	1.50	U	94.80		22.70		48.50		13.90		1.50	U	2.54		3.44		2.54		2.19	
						130.00		31.60		no sample		20.90				9.48		2.98		2.94		3.52	
						105.00		no sample		no sample		22.90				20.60		2.54		2.49		2.25	
2	17.81	0.25	6.67	1.50	U	16.60		9.65		3.10		1.50	U	1.50	U	1.50	U	1.50	U	1.50	U	1.50	U
						20.80		6.07		3.70		1.50	U			1.50	U	1.50	U	1.50	U	1.50	U
						25.40		6.21		3.49		1.50	U			1.50	U	1.50	U	1.50	U	1.50	U
3	35.62	0.5	11	1.50	U	7.40		2.78		2.04		1.50	U	1.50	U	1.50	U	1.50	U	1.50	U	1.50	U
						7.08		2.86		2.95		1.50	U			1.50	U	1.50	U	1.50	U	1.50	U
						6.32		3.72		1.54		1.50	U			1.50	U	1.50	U	1.50	U	1.50	U
4	35.62	1	11	1.50	U	3.16		1.50	U	3.08		1.50	U	1.50	U	1.50	U	1.50	U	1.50	U	1.50	U
						3.55		1.50	U	1.56		1.50	U			1.50	U	1.50	U	1.50	U	1.50	U
						3.35		1.50	U	2.66		1.50	U			1.50	U	1.50	U	1.50	U	1.50	U
Min				0.75		3.16		0.75		1.54		0.75		0.75		0.75		0.75		0.75		0.75	
Max				0.75		130.00		31.60		48.50		22.90		0.75		20.60		3.44		2.94		3.52	
Mean				0.75		35.30		7.99		7.26		5.37		0.75		3.28		1.31		1.23		1.23	
Median				0.75		12.00		3.72		3.02		0.75		0.75		0.75		0.75		0.75		0.75	

U = undetected at the reporting limit noted. For these results, one-half the reporting limit is used to calculate Minimum, Maximum, Mean, and Median.

mg/L = milligrams per liter.

Table 10. Flushing Experiment Raw Data and Summary Statistics for Total Phosphorus.

Flushing Event	Flushing Volume	Percent Water Year	Flow Rate (liters/hr)	Influent Day 1 (ug/L)	Flag	Treatment 1 60/40 (ug/L)	Flag	Treatment 2 60/40/aafep-layer (ug/L)	Flag	Treatment 3 70vs/20cp/10ash/ compmulch (ug/L)	Flag	Treatment 4 70vs/20cp/10ash/ compmulch/ aafep-layer (ug/L)	Flag	Influent Day 2 (ug/L)	Flag	Treatment 5 70vs/20cp/ 10ash (ug/L)	Flag	Treatment 6 70ss/20cp/ 10ash (ug/L)	flag	Treatment 7 70ls/20cp/ 10ash (mg/L)	Flag	Treatment 8 70ls/20cp/10ash/ orifice (ug/L)	Flag
1	17.81	0.05	6.67	5	U	1502.3		316.4		422.8		128.2		5.0	U	460.1		285.3		836.6		763.7	
						1001.6		341.9		no sample		106.2				894.8		265.3		1029.1		902.1	
						2030.0		no sample		no sample		108.0				393.5		334.1		925.3		889.1	
2	17.81	0.25	6.67	6.1	J	1168.6		276.7		219.1		84.5		7.9		151.0		129.3		189.3		182.5	
						1115.1		255.5		259.3		69.0				152.4		114.2		216.9		203.7	
						1367.6		261.9		190.6		58.9				150.8		125.7		197.8		148.8	
3	35.62	0.5	11	5	U	856.0	J	204.0	J	157.6	J	55.7	J	2.5	U	103.2	J	72.9	J	171.6	J	153.0	J
						799.7	J	222.6	J	250.2	J	62.9	J			86.0	J	63.3	J	156.1	J	136.8	
						859.6	J	203.8	J	164.4	J	42.0	J			102.1	J	78.5	J	150.2	J	161.2	
4	35.62	1	11	5	U	951.6		91.3		295.3		25.7		5.0	U	307.3		117.1		339.8		367.5	
						970.1		79.8		242.5		23.0				284.3		104.8		337.0		328.5	
						903.7		77.7		263.1		11.9				291.9		123.0		327.8		344.5	
Min				2.5		799.7		77.7		157.6		11.9		1.3		86.0		63.3		150.2		136.8	
Max				6.1		2030.0		341.9		422.8		128.2		7.9		894.8		334.1		1029.1		902.1	
Mean				3.4		1130.0		212.0		246.0		64.7		3.5		281.0		151.0		406.0		382.0	
Median				2.5		986.0		223.0		246.0		60.9		2.5		218.0		120.0		272.0		266.0	

U = undetected at the reporting limit noted. For these results, one-half the reporting limit is used to calculate Minimum, Maximum, Mean, Median, and Percent Reduction.

ug/L = micrograms per liter

Table 11. Flushing Experiment Raw Data and Summary Statistics for Ortho-Phosphorus.

Flushing Event	Flushing Volume	Percent Water Year	Flow Rate (liters/hr)	Influent Day 1 (ug/L)	Flag	Treatment 1 60/40 (ug/L)	Flag	Treatment 2 60/40/aafep-layer (ug/L)	Flag	Treatment 3 70vs/20cp/10ash/ compmulch (ug/L)	Flag	Treatment 4 70vs/20cp/10ash/ compmulch/ aafep-layer (ug/L)	Flag	Influent Day 2 (ug/L)	Flag	Treatment 5 70vs/20cp/ 10ash (ug/L)	Flag	Treatment 6 70ss/20cp/ 10ash (ug/L)	flag	Treatment 7 70ls/20cp/ 10ash (mg/L)	Flag	Treatment 8 70ls/20cp/10ash/ orifice (ug/L)	Flag
1	17.81	0.05	6.67	9.5		1233.7		54.9		254.4		15.8		5.2		477.7		265.9		835.1		859.0	
						1089.1		51.6		no sample		12.5	J			418.0		227.4		843.2		973.5	
						997.5		no sample		no sample		16.0				368.8		310.0		833.4		989.0	
2	17.81	0.25	6.67	5.3		991.8		77.0		229.7		16.7		8.9		183.9		138.5		260.9		242.5	
						998.2		46.6		290.6		17.4				208.2		117.2		278.2		259.7	
						1330.6		61.5		264.0		16.0				187.9		150.2		241.3		230.9	
3	35.62	0.5	11	3.4		635.6		47.8		106.7		10.4		2.5	U	38.6		34.6		95.3		94.6	
						648.5		52.0		225.3		9.1				39.0		29.8		99.8		83.7	
						759.6		44.0	J	144.2		5.2				41.9		35.1		87.8		87.6	
4	35.62	1	11	0.9	J	798.2		24.8		267.7		15.9		3.1		284.9		117.5		330.9		365.1	
						812.8		23.5		232.5		12.9				292.1		94.3		350.8		305.4	
						835.0		20.4		204.0		8.7				302.7		118.2		345.4		321.4	
Min				0.9		635.6		20.4		106.7		5.2		1.3		38.6		29.8		87.8		83.7	
Max				9.5		1330.6		77.0		290.6		17.4		8.9		477.7		310.0		843.2		989.0	
Mean				4.78		928.0		45.8		222.0		13.0		4.6		237.0		137.0		384.0		401.0	
Median				4.35		913.0		47.8		231.0		14.4		4.2		247.0		118.0		305.0		283.0	

U = undetected at the reporting limit noted. For these results, one-half the reporting limit is used to calculate Minimum, Maximum, Mean, Median, and Percent Reduction.

ug/L = micrograms per liter

Table 12. Flushing Experiment Raw Data and Summary Statistics for Nitrite N+Nitrate N.																							
Flushing Event	Flushing Volume	Percent Water Year	Flow Rate (liters/hr)	Influent Day 1 (mg/L)	Flag	Treatment 1 60/40 (mg/L)	Flag	Treatment 2 60/40/aafep-layer (mg/L)	Flag	Treatment 3 70vs/20cp/10ash/ compmulch (mg/L)	Flag	Treatment 4 70vs/20cp/10ash/ compmulch/ aafep-layer (mg/L)	Flag	Influent Day 2 (mg/L)	Flag	Treatment 5 70vs/20cp/ 10ash (mg/L)	Flag	Treatment 6 70ss/20cp/ 10ash (mg/L)	flag	Treatment 7 70ls/20cp/ 10ash (mg/L)	Flag	Treatment 8 70ls/20cp/10ash/ orifice (mg/L)	Flag
1	17.81	0.05	6.67	0.1	U	20.50		5.08		1.17		1.19		0.1	U	0.10	U	0.10	U	0.10	U	0.10	U
						16.30		4.48		no sample		0.78				0.10	U	0.10	U	0.29		0.12	
						14.60		no sample		no sample		0.87				0.10	U	0.10	U	0.10	U	0.10	U
2	17.81	0.25	6.67	0.1	U	0.31		0.10	U	0.10	U	0.10	U	0.1	U	0.10	U	0.10	U	0.10	U	0.10	U
						0.34		0.10	U	0.10	U	0.10	U			0.10	U	0.10	U	0.10	U	0.10	U
						0.30		0.10	U	0.10	U	0.10	U			0.10	U	0.10	U	0.10	U	0.10	U
3	35.62	0.5	11	0.1	U	1.20		0.69		0.19		0.10	U	0.1	U	0.10	U	0.10	U	0.10	U	0.10	U
						1.31		0.60		0.14		0.11				0.10	U	0.10	U	0.10	U	0.10	U
						1.21		0.65		0.10	U	0.10	U			0.10	U	0.10	U	0.10	U	0.10	U
4	35.62	1	11	0.1	U	0.14		0.11		0.45		0.10	U	0.1	U	0.10	U	0.10	U	0.10	U	0.10	U
						0.16		0.10	U	0.10	U	0.10	U			0.10	U	0.10	U	0.10	U	0.10	U
						0.14		0.10		0.48		0.10	U			0.10	U	0.10	U	0.10	U	0.10	U
Min				0.05		0.14		0.05		0.05		0.05		0.05		0.05		0.05		0.05		0.05	
Max				0.05		20.50		5.08		1.17		1.19		0.05		0.05		0.05		0.29		0.12	
Mean				0.05		4.71		1.08		0.27		0.28		0.05		0.05		0.05		0.07		0.06	
Median				0.05		0.77		0.11		0.10		0.05		0.05		0.05		0.05		0.05		0.05	

U = undetected at the reporting limit noted. For these results, one-half the reporting limit is used to calculate Minimum, Maximum, Mean, and Median.

mg/L = milligrams per liter.

Table 13. Flushing Experiment Raw Data and Summary Statistics for Copper.																							
Flushing Event	Flushing Volume	Percent Water Year	Flow Rate (liters/hr)	Influent Day 1 (ug/L)	Flag	Treatment 1 60/40 (ug/L)	Flag	Treatment 2 60/40/aafep-layer (ug/L)	Flag	Treatment 3 70vs/20cp/10ash/ compmulch (ug/L)	Flag	Treatment 4 70vs/20cp/10ash/ compmulch/ aafep-layer (ug/L)	Flag	Influent Day 2 (ug/L)	Flag	Treatment 5 70vs/20cp/ 10ash (ug/L)	Flag	Treatment 6 70ss/20cp/ 10ash (ug/L)	flag	Treatment 7 70ls/20cp/ 10ash (mg/L)	Flag	Treatment 8 70ls/20cp/10ash/ orifice (ug/L)	Flag
1	17.81	0.05	6.67	0.5		41.1		23.0		19.9		18.5		0.4		27.9		28.6		20.1		16.9	
						38.6		26.8		no sample		18.3				29.2		29.7		18.8		17.3	
						38.5		no sample		no sample		19.6				31.3		16.3		19.0		17.4	
2	17.81	0.25	6.67	0.5		24.7		10.5		22.6		8.7		0.5		15.3		13.0		13.2		17.0	
						24.3		11.4		22.5		6.6				14.9		13.7		10.0		13.4	
						25.3		11.0		24.1		9.5				17.9		14.5		11.9		9.1	
3	35.62	0.5	11	2.9		15.5		7.3		9.1		3.5		7.1		7.1		5.9		7.4		4.9	
						15.2		7.1		12.9		4.1				5.1		5.5		5.1		5.5	
						14.4		6.7		9.2		3.7				6.9		6.4		5.5		7.2	
4	35.62	1	11	17.6		7.2		2.0		10.2		0.7		16.9		0.1	U	0.1	U	0.3		0.3	
						7.7		2.0		4.8		0.6				0.4		0.1	U	0.1	U	0.1	U
						7.9		2.2		7.2		0.1				0.1		0.1	U	0.1	U	0.1	U
Min				0.5		7.2		2.0		4.8		0.1		0.4		0.1		0.1		0.1		0.1	
Max				17.6		41.1		26.8		24.1		19.6		16.9		31.3		29.7		20.1		17.4	
Mean				5.4		21.7		10.0		14.2		7.8		6.2		13.0		11.1		9.3		9.1	
Median				1.7		19.9		7.3		11.6		5.4		3.8		11.0		9.7		8.7		8.2	

U = undetected at the reporting limit noted. For these results, one-half the reporting limit is used to calculate Minimum, Maximum, Mean, Median, and Percent Reduction.

ug/L = micrograms per liter

Table 14. Flushing Experiment Raw Data and Summary Statistics for Copper, Dissolved.

Flushing Event	Flushing Volume	Percent Water Year	Flow Rate (liters/hr)	Influent Day 1 (ug/L)	Flag	Treatment 1 60/40 (ug/L)	Flag	Treatment 2 60/40/aafep-layer (ug/L)	Flag	Treatment 3 70vs/20cp/10ash/ compmulch (ug/L)	Flag	Treatment 4 70vs/20cp/10ash/ compmulch/ aafep-layer (ug/L)	Flag	Influent Day 2 (ug/L)	Flag	Treatment 5 70vs/20cp/ 10ash (ug/L)	Flag	Treatment 6 70ss/20cp/ 10ash (ug/L)	flag	Treatment 7 70ls/20cp/ 10ash (mg/L)	Flag	Treatment 8 70ls/20cp/10ash/ orifice (ug/L)	Flag
1	17.81	0.05	6.67	0.6		39.1		8.3		7.9		1.4		1.8		3.2	J	0.7	J	1.5	J	0.9	J
						39.4		8.6		no sample		0.5				4.8	J	1.1	J	1.5	J	0.7	J
						38.4		no sample		no sample		9.3				4.1	J	0.6	J	0.9	J	0.7	J
2	17.81	0.25	6.67	0.5		15.6		4.2		4.5		0.9		0.6		4.0		2.4		2.5		0.1	
						14.8		3.1		6.6		0.6				3.9		7.4		2.5		5.7	
						15.8		4.3		6.2		0.6				1.1		1.9		3.4		1.6	
3	35.62	0.5	11	2.4		6.9		2.5		4.2		0.5		6.9		0.1	U	0.2		0.1	U	0.1	U
						8.2		2.2		8.0		0.4				0.3		0.2		0.1	U	0.1	U
						11.6		3.1		2.5		0.1	U			0.3		0.1	U	0.2		0.1	U
4	35.62	1	11	17.5		2.6		0.1	U	5.9		0.1	U	16		0.1	U	0.1	U	0.1	U	0.1	U
						2.7		0.1	U	0.1	U	0.1	U			0.1	U	0.1	U	0.1	U	0.1	U
						2.8		0.1	U	4.0		0.1	U			0.1	U	0.1	U	0.1	U	0.1	U
Min				0.5		2.6		0.1		0.1		0.1		0.6		0.1		0.1		0.1		0.1	
Max				17.5		39.4		8.6		8.0		9.3		16.0		4.8		7.4		3.4		5.7	
Mean				5.3		16.5		3.3		5.0		1.2		6.3		1.8		1.2		1.1		0.8	
Median				1.5		13.2		3.1		5.2		0.5		4.4		0.7		0.4		0.6		0.1	

U = undetected at the reporting limit noted. For these results, one-half the reporting limit is used to calculate Minimum, Maximum, Mean, Median, and Percent Reduction.

ug/L = micrograms per liter

Table 15. Flushing Experiment Raw Data and Summary Statistics for Zinc.

Flushing Event	Flushing Volume	Percent Water Year	Flow Rate (liters/hr)	Influent Day 1 (ug/L)	Flag	Treatment 1 60/40 (ug/L)	Flag	Treatment 2 60/40/aafep-layer (ug/L)	Flag	Treatment 3 70vs/20cp/10ash/ compmulch (ug/L)	Flag	Treatment 4 70vs/20cp/10ash/ compmulch/ aafep-layer (ug/L)	Flag	Influent Day 2 (ug/L)	Flag	Treatment 5 70vs/20cp/ 10ash (ug/L)	Flag	Treatment 6 70ss/20cp/ 10ash (ug/L)	flag	Treatment 7 70ls/20cp/ 10ash (mg/L)	Flag	Treatment 8 70ls/20cp/10ash/ orifice (ug/L)	Flag
1	17.81	0.05	6.67	2.3	J	50.4		11.7		7.7		9.4		1.3	J	24.0		20.9		50.8		44.7	
						19.8		12.4		no sample		8.9				24.7		21.8		49.9		46.6	
						48.5		no sample		no sample		16.4				28.7		20.5		50.2		44.4	
2	17.81	0.25	6.67	1	J	18.0		7.9		10.8		2.5	U	1.0	J	12.5		15.1		18.4		22.3	
						15.0		7.7		8.2		2.5	U			13.2		17.1		15.9		23.7	
						15.1		5.7		9.2		2.5	U			15.2		16.2		17.2		14.6	
3	35.62	0.5	11	6.3		7.0		3.2		1.0	J	2.3	J	9.0		5.4		5.0		6.6		5.5	
						6.1		2.1	J	2.6		1.9	J			3.9		5.9		4.9		5.5	
						6.5		1.7	J	6.4		1.8	J			5.2		5.4		5.6		8.3	
4	35.62	1	11	6.6		4.3		2.5	U	2.5	U	2.5	U	7.6		2.5	U	2.5	U	2.5	U	2.5	U
						4.6		2.5	U	2.5	U	2.5	U			2.5	U	2.5	U	2.5	U	2.5	U
						5.2		2.5	U	2.5	U	2.5	U			2.5	U	2.5	U	2.5	U	2.5	U
Min				1		4.3		1.3		1.0		1.3		1.0		1.3		1.3		1.3		1.3	
Max				6.6		50.4		12.4		10.8		16.4		9.0		28.7		21.8		50.8		46.6	
Mean				4.05		16.7		5.1		5.0		4.0		4.7		11.4		11.0		18.6		18.3	
Median				4.3		11.0		3.2		4.5		1.5		4.4		9.0		10.5		11.2		11.4	

U = undetected at the reporting limit noted. For these results, one-half the reporting limit is used to calculate Minimum, Maximum, Mean, Median, and Percent Reduction.

ug/L = micrograms per liter

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

Flushing Event	Flushing Volume	Percent Water Year	Flow Rate (liters/hr)	Influent Day 1 (ug/L)	Flag	Treatment 1 60/40 (ug/L)	Flag	Treatment 2 60/40/aafep-layer (ug/L)	Flag	Treatment 3 70vs/20cp/10ash/ compmulch (ug/L)	Flag	Treatment 4 70vs/20cp/10ash/ compmulch/ aafep-layer (ug/L)	Flag	Influent Day 2 (ug/L)	Flag	Treatment 5 70vs/20cp/ 10ash (ug/L)	Flag	Treatment 6 70ss/20cp/ 10ash (ug/L)	flag	Treatment 7 70ls/20cp/ 10ash (mg/L)	Flag	Treatment 8 70ls/20cp/10ash/ orifice (ug/L)	Flag
1	17.81	0.05	6.67	3.5		7.8		4.3		3.4		1.5		4.9		2.3		1.8		1.0	U	1.0	U
						8.7		2.3		no sample		1.5				2.3		1.0	U	1.0	U	1.0	U
						11.8		no sample		no sample		8.7				6.2		2.6		1.0	U	1.0	U
2	17.81	0.25	6.67	1.5		1.9		1.0	U	1.0	U	5.7		2.3		2.7		1.4		1.8		8.8	
						1.0	U	1.0	U	2.9		1.0	U			2.7		3.3		2.0		6.9	
						1.0	U	1.0	U	1.0	U	1.1				1.0	U	1.3		2.7		1.1	
3	35.62	0.5	11	7.7		2.4		2.0		1.0		1.0	U	10.3		1.0	U	1.0	U	1.0	U	1.0	U
						3.3		2.2		1.7		1.0	U			1.1		1.9		3.2		1.0	U
						8.1		2.1		1.0	U	1.2				1.0	U	1.0	U	1.3		1.1	
4	35.62	1	11	6.8		1.0	U	3.7		1.0	U	1.0	U	5.1		1.0	U	1.0	U	1.0	U	1.0	U
						1.0	U	1.2		1.0	U	1.0	U			1.3		1.0	U	1.0	U	1.0	U
						1.4		1.0	U	1.0	U	1.0	U			1.0	U	1.0	U	1.9		1.0	U
Min				1.5		0.5		0.5		0.5		0.5		2.3		0.5		0.5		0.5		0.5	
Max				7.7		11.8		4.3		3.4		8.7		10.3		6.2		3.3		3.2		8.8	
Mean				4.88		4.0		1.8		1.2		1.9		5.7		1.8		1.3		1.3		1.8	
Median				5.15		2.2		2.0		0.5		0.8		5.0		1.2		0.9		0.9		0.5	

U = undetected at the reporting limit noted. For these results, one-half the reporting limit is used to calculate Minimum, Maximum, Mean, Median, and Percent Reduction.

ug/L = micrograms per liter

Table 17. Flushing Experiment Raw Data and Summary Statistics for Lead.																									
Flushing Event	Flushing Volume	Percent Water Year	Flow Rate (liters/hr)	Influent Day 1 (ug/L)	Flag	Treatment 1 60/40 (ug/L)	Flag	Treatment 2 60/40/aafep-layer (ug/L)	Flag	Treatment 3 70vs/20cp/10ash/ compmulch (ug/L)	Flag	Treatment 4 70vs/20cp/10ash/ compmulch/ aafep-layer (ug/L)	Flag	Influent Day 2 ug/L)	Flag	Treatment 5 70vs/20cp/ 10ash (ug/L)	Flag	Treatment 6 70ss/20cp/ 10ash (ug/L)	flag	Treatment 7 70ls/20cp/ 10ash (mg/L)	Flag	Treatment 8 70ls/20cp/10ash/ orifice (ug/L)	Flag
1	17.81	0.05	6.67	0.1	U	5.6		3.2		1.7		2.3		0.1	U	2.8		3.0		4.0		3.2	
						5.0		4.0		no sample		2.2				2.9		3.1		3.7		3.5	
						5.1		no sample		no sample		2.5				3.1		2.9		3.7		3.1	
2	17.81	0.25	6.67	0.1	U	4.3		2.0		3.0		0.8		0.1	U	2.2		2.7		2.4		2.9	
						4.1		2.1		2.3		0.6				2.2		2.8		2.0		2.6	
						4.3		2.0		3.3		0.8				2.5		2.8		2.3		2.0	
3	35.62	0.5	11	1		3.0		1.5		0.9		0.6		3.9		1.1		1.1		1.1		0.8	
						3.0		1.7		1.1		0.6				0.8		1.0		1.0		0.9	
						3.0		1.6		1.0		0.5				1.0		1.2		1.0		1.2	
4	35.62	1	11	1.6		1.1		0.7		0.5		0.2		0.8		0.1		0.1		0.1		0.1	
						1.3		0.7		0.3		0.2				0.1		0.1		0.1		0.1	
						2.5		0.6		0.3		0.1				0.1		0.1		0.1		0.1	
Min				0.05		1.10		0.60		0.30		0.10		0.05		0.10		0.10		0.10		0.10	
Max				1.60		5.60		4.00		3.30		2.50		3.90		3.10		3.10		4.00		3.50	
Mean				0.68		3.52		1.83		1.44		0.95		1.20		1.58		1.74		1.79		1.71	
Median				0.53		3.55		1.70		1.05		0.60		0.43		1.65		1.95		1.55		1.60	

U = undetected at the reporting limit noted. For these results, one-half the reporting limit is used to calculate Minimum, Maximum, Mean, Median, and Percent Reduction.

ug/L = micrograms per liter

Table 18. Flushing Experiment Raw Data and Summary Statistics for Lead, Dissolved.																							
Flushing Event	Flushing Volume	Percent Water Year	Flow Rate (liters/hr)	Influent Day 1 (ug/L)	Flag	Treatment 1 60/40 (ug/L)	Flag	Treatment 2 60/40/aafep-layer (ug/L)	Flag	Treatment 3 70vs/20cp/10ash/ compmulch (ug/L)	Flag	Treatment 4 70vs/20cp/10ash/ compmulch/ aafep-layer (ug/L)	Flag	Influent Day 2 (ug/L)	Flag	Treatment 5 70vs/20cp/ 10ash (ug/L)	Flag	Treatment 6 70ss/20cp/ 10ash (ug/L)	flag	Treatment 7 70ls/20cp/ 10ash (mg/L)	Flag	Treatment 8 70ls/20cp/10ash/ orifice (ug/L)	Flag
1	17.81	0.05	6.67	0.1	U	0.5		0.3		0.3		0.2		0.1	U	0.1	U	0.1	U	0.1	U	0.1	U
						0.9		0.2		no sample		0.1	U			0.1		0.1	U	0.1	U	0.1	U
						1.1		no sample		no sample		0.4				0.2		0.1	U	0.1	U	0.1	U
2	17.81	0.25	6.67	0.1	U	0.2		0.1		0.1	U	0.1		0.1	U	0.5		0.5		0.4		0.2	
						0.1	U	0.1	U	0.1		0.1				0.6		0.4		0.4		1.0	
						0.1		0.2		0.1	U	0.1	U			0.3		0.4		0.5		0.3	
3	35.62	0.5	11	0.2		0.4		0.4		0.2		0.2		2.4		0.1	U	0.1	U	0.1	U	0.1	
						0.7		0.5		0.4		0.2				0.1	U	0.1	U	0.1		0.1	
						1.8		0.7		0.1		0.1				0.1	U	0.1		0.1	U	0.1	
4	35.62	1	11	0.6		0.1		0.1		0.1		0.1	U	0.5		0.1	U	0.1	U	0.1	U	0.1	U
						0.1		0.1	U	0.1	U	0.1	U			0.1	U	0.1	U	0.1	U	0.1	U
						0.1		0.1	U	0.1	U	0.1	U			0.1	U	0.1	U	0.1	U	0.1	U
Min				0.05		0.05		0.05		0.05		0.05		0.05		0.05		0.05		0.05		0.05	
Max				0.60		1.80		0.70		0.40		0.40		2.40		0.60		0.50		0.50		1.00	
Mean				0.23		0.50		0.24		0.14		0.13		0.75		0.17		0.15		0.15		0.18	
Median				0.13		0.30		0.20		0.10		0.10		0.28		0.05		0.05		0.05		0.08	

U = undetected at the reporting limit noted. For these results, one-half the reporting limit is used to calculate Minimum, Maximum, Mean, Median, and Percent Reduction.

ug/L = micrograms per liter

Table 19. Flushing Experiment Raw Data and Summary Statistics for Aluminum.

Flushing Event	Flushing Volume	Percent Water Year	Flow Rate (liters/hr)	Influent Day 1 (ug/L)	Flag	Treatment 1 60/40 (ug/L)	Flag	Treatment 2 60/40/aafep-layer (ug/L)	Flag	Treatment 3 70vs/20cp/10ash/ compmulch (ug/L)	Flag	Treatment 4 70vs/20cp/10ash/ compmulch/ aafep-layer (ug/L)	Flag	Influent Day 2 (ug/L)	Flag	Treatment 5 70vs/20cp/ 10ash (ug/L)	Flag	Treatment 6 70ss/20cp/ 10ash (ug/L)	flag	Treatment 7 70ls/20cp/ 10ash (mg/L)	Flag	Treatment 8 70ls/20cp/10ash/ orifice (ug/L)	Flag
1	17.81	0.05	6.67	1	U	4260		3140		5880		5420		1	U	7260		7750		52500		41200	
						4220		4040		no sample		6170				7610		7890		44800		40800	
						4270		no sample		no sample		595				7710		6840		45400		37700	
2	17.81	0.25	6.67	1	U			1780				2550											
								1860				2230											
								1780				2840											
3	35.62	0.5	11																				
4	35.62	1	11	1	U	1280		607		1140		287		1	U	371		335		805		1020	
						1410		534		495		260				619		361		743		682	
						1370		477		882		218				514		378		660		593	
Min				0.5		1280		477		495		218		1		371		335		660		593	
Max				0.5		4270		4040		5880		6170		1		7710		7890		52500		41200	
Mean				0.5		2800		1780		2100		2290		1		4010		3930		24200		20300	
Median				0.5		2820		1780		1010		2230		1		3940		3610		22800		19400	

U = undetected at the reporting limit noted. For these results, one-half the reporting limit is used to calculate Minimum, Maximum, Mean, Median, and Percent Reduction.

ug/L = micrograms per liter

Table 20. Flushing Experiment Raw Data and Summary Statistics for Total Petroleum Hydrocarbons Diesel Range (C10-C25).

Flushing Event	Flushing Volume	Percent Water Year	Flow Rate (liters/hr)	Influent Day 1 (mg/L)	Flag	Treatment 1 60/40 (mg/L)	Flag	Treatment 2 60/40/aafep-layer (mg/L)	Flag	Treatment 3 70vs/20cp/10ash/ compmulch (mg/L)	Flag	Treatment 4 70vs/20cp/10ash/ compmulch/ aafep-layer (mg/L)	Flag	Influent Day 2 (mg/L)	Flag	Treatment 5 70vs/20cp/ 10ash (mg/L)	Flag	Treatment 6 70ss/20cp/ 10ash (mg/L)	flag	Treatment 7 70ls/20cp/ 10ash (mg/L)	Flag	Treatment 8 70ls/20cp/10ash/ orifice (mg/L)	Flag
1	17.81	0.05	6.67	0.25	U	0.52		0.39		0.25	U	0.25	U	0.25	U	0.25	U	0.25	U	0.25	U	0.25	U
						0.59		0.25	U	0.25	U	0.25	U			0.25	U	0.25	U	0.25	U	0.25	U
						0.38		0.25	U	0.25	U	0.46				0.25	U	0.25	U	0.30		0.25	U
2	17.81	0.25	6.67																				
3	35.62	0.5	11																				
4	35.62	1	11	0.25	U	0.25	U	0.25	U	0.25	U	0.25	U	0.25	U	0.25	U	0.25	U	0.25	U	0.25	U
						0.25	U	0.25	U	0.25	U	0.25	U			0.25	U	0.25	U	0.25	U	0.25	U
						0.25	U	0.25	U	0.25	U	0.25	U			0.25	U	0.25	U	0.25	U	0.25	U
Min				0.13		0.13		0.13		0.13		0.13		0.125		0.13		0.13		0.13		0.13	
Max				0.13		0.59		0.39		0.13		0.46		0.125		0.13		0.13		0.30		0.13	
Mean				0.13		0.31		0.17		0.13		0.18		0.125		0.13		0.13		0.15		0.13	
Median				0.13		0.25		0.13		0.13		0.13		0.125		0.13		0.13		0.13		0.13	

U = undetected at the reporting limit noted. For these results, one-half the reporting limit is used to calculate Minimum, Maximum, Mean, and Median.

mg/L = milligrams per liter.

Table 21. Flushing Experiment Raw Data and Summary Statistics for Total Petroleum Hydrocarbons Motor Oil Range (>C25).																									
Flushing Event	Flushing Volume	Percent Water Year	Flow Rate (liters/hr)	Influent Day 1 (mg/L)	Flag	Treatment 1 60/40 (mg/L)	Flag	Treatment 2 60/40/aafep-layer (mg/L)	Flag	Treatment 3 70vs/20cp/10ash/ compmulch (mg/L)	Flag	Treatment 4 70vs/20cp/10ash/ compmulch/ aafep-layer (mg/L)	Flag	Influent Day 2 (mg/L)	Flag	Treatment 5 70vs/20cp/ 10ash (mg/L)	Flag	Treatment 6 70ss/20cp/ 10ash (mg/L)	flag	Treatment 7 70ls/20cp/ 10ash (mg/L)	Flag	Treatment 8 70ls/20cp/10ash/ orifice (mg/L)	Flag
1	17.81	0.05	6.67	0.50	U	0.50	U	0.50	U	0.50	U	0.50	U	0.50	U	0.50	U	0.50	U	0.50	U	0.50	U
						0.50	U	0.50	U	0.50	U	0.50	U			0.50	U	0.50	U	0.50	U	0.50	U
						0.50	U	0.50	U	0.50	U	0.50	U			0.50	U	0.50	U	0.50	U	0.50	U
2	17.81	0.25	6.67																				
3	35.62	0.5	11																				
4	35.62	1	11	0.50	U	0.50	U	0.50	U	0.50	U	0.50	U	0.50	U	0.50	U	0.50	U	0.50	U	0.50	U
						0.50	U	0.50	U	0.50	U	0.50	U			0.50	U	0.50	U	0.50	U	0.50	U
						0.50	U	0.50	U	0.50	U	0.50	U			0.50	U	0.50	U	0.50	U	0.50	U
Min				0.25		0.25		0.25		0.25		0.25		0.25		0.25		0.25		0.25		0.25	
Max				0.25		0.25		0.25		0.25		0.25		0.25		0.25		0.25		0.25		0.25	
Mean				0.25		0.25		0.25		0.25		0.25		0.25		0.25		0.25		0.25		0.25	
Median				0.25		0.25		0.25		0.25		0.25		0.25		0.25		0.25		0.25		0.25	

U = undetected at the reporting limit noted. For these results, one-half the reporting limit is used to calculate Minimum, Maximum, Mean, and Median.

mg/L = milligrams per liter.

Table 22. Flushing Experiment Raw Data and Summary Statistics for Benzo(a)pyrene.

Flushing Event	Flushing Volume	Percent Water Year	Flow Rate (liters/hr)	Influent Day 1 (ug/L)	Flag	Treatment 1 60/40 (ug/L)	Flag	Treatment 2 60/40/aafep-layer (ug/L)	Flag	Treatment 3 70vs/20cp/10ash/ compmulch (ug/L)	Flag	Treatment 4 70vs/20cp/10ash/ compmulch/ aafep-layer (ug/L)	Flag	Influent Day 2 (ug/L)	Flag	Treatment 5 70vs/20cp/ 10ash (ug/L)	Flag	Treatment 6 70ss/20cp/ 10ash (ug/L)	flag	Treatment 7 70ls/20cp/ 10ash (mg/L)	Flag	Treatment 8 70ls/20cp/10ash/ orifice (ug/L)	Flag
1	17.81	0.05	6.67	0.011	U	0.011	U	0.011	U	0.011	U	0.011	U	0.011	U	0.011	U	0.011	U	0.011	U	0.011	U
						0.011	U	0.011	U	0.011	U	0.011	U			0.011	U	0.011	U	0.011	U	0.011	U
						0.011	U	0.011	U	0.011	U	0.011	U			0.011	U	0.011	U	0.011	U	0.011	U
2	17.81	0.25	6.67																				
3	35.62	0.5	11																				
4	35.62	1	11																				
Min				0.0055		0.0055		0.0055		0.0055		0.0055		0.0055		0.0055		0.0055		0.0055		0.0055	
Max				0.0055		0.0055		0.0055		0.0055		0.0055		0.0055		0.0055		0.0055		0.0055		0.0055	
Mean				0.0055		0.0055		0.0055		0.0055		0.0055		0.0055		0.0055		0.0055		0.0055		0.0055	
Median				0.0055		0.0055		0.0055		0.0055		0.0055		0.0055		0.0055		0.0055		0.0055		0.0055	

U = undetected at the reporting limit noted. For these results, one-half the reporting limit is used to calculate Minimum, Maximum, Mean, Median, and Percent Reduction.

ug/L = micrograms per liter

Table 23. Flushing Experiment Raw Data and Summary Statistics for Benzo(k)fluoranthene.																									
Flushing Event	Flushing Volume	Percent Water Year	Flow Rate (liters/hr)	Influent Day 1 (ug/L)	Flag	Treatment 1 60/40 (ug/L)	Flag	Treatment 2 60/40/aafep-layer (ug/L)	Flag	Treatment 3 70vs/20cp/10ash/ compmulch (ug/L)	Flag	Treatment 4 70vs/20cp/10ash/ compmulch/ aafep-layer (ug/L)	Flag	Influent Day 2 (ug/L)	Flag	Treatment 5 70vs/20cp/ 10ash (ug/L)	Flag	Treatment 6 70ss/20cp/ 10ash (ug/L)	flag	Treatment 7 70ls/20cp/ 10ash (mg/L)	Flag	Treatment 8 70ls/20cp/10ash/ orifice (ug/L)	Flag
1	17.81	0.05	6.67	0.011	U	0.011	U	0.011	U	0.011	U	0.011	U	0.011	U	0.011	U	0.011	U	0.011	U	0.011	U
						0.011	U	0.011	U	0.011	U	0.011	U			0.011	U	0.011	U	0.011	U	0.011	U
						0.011	U	0.011	U	0.011	U	0.011	U			0.011	U	0.011	U	0.011	U	0.011	U
2	17.81	0.25	6.67																				
3	35.62	0.5	11																				
4	35.62	1	11																				
Min				0.0055		0.0055		0.0055		0.0055		0.0055		0.0055		0.0055		0.0055		0.0055		0.0055	
Max				0.0055		0.0055		0.0055		0.0055		0.0055		0.0055		0.0055		0.0055		0.0055		0.0055	
Mean				0.0055		0.0055		0.0055		0.0055		0.0055		0.0055		0.0055		0.0055		0.0055		0.0055	
Median				0.0055		0.0055		0.0055		0.0055		0.0055		0.0055		0.0055		0.0055		0.0055		0.0055	

U = undetected at the reporting limit noted. For these results, one-half the reporting limit is used to calculate Minimum, Maximum, Mean, Median, and Percent Reduction.
ug/L = micrograms per liter

Table 24. Flushing Experiment Raw Data and Summary Statistics for Chrysene.																										
Flushing Event	Flushing Volume	Percent Water Year	Flow Rate (liters/hr)	Influent Day 1 (ug/L)	Flag	Treatment 1 60/40 (ug/L)	Flag	Treatment 2 60/40/aafep-layer (ug/L)	Flag	Treatment 3 70vs/20cp/10ash/ compmulch (ug/L)	Flag	Treatment 4 70vs/20cp/10ash/ compmulch/ aafep-layer (ug/L)	Flag	Influent Day 2 (ug/L)	Flag	Treatment 5 70vs/20cp/ 10ash (ug/L)	Flag	Treatment 6 70ss/20cp/ 10ash (ug/L)	flag	Treatment 7 70ls/20cp/ 10ash (mg/L)	Flag	Treatment 8 70ls/20cp/10ash/ orifice (ug/L)	Flag
1	17.81	0.05	6.67	0.011	U	0.021		0.011	U	0.011	U	0.011	U	0.011	U	0.011	U	0.011	U	0.011	U	0.011	U
						0.018		0.011	U	0.011	U	0.011	U			0.011	U	0.011	U	0.011	U	0.011	U
						0.019		0.011	U	0.011	U	0.011	U			0.011	U	0.011	U	0.011	U	0.011	U
2	17.81	0.25	6.67																				
3	35.62	0.5	11																				
4	35.62	1	11																				
Min				0.0055		0.0180		0.0055		0.0055		0.0055		0.0055		0.0055		0.0055		0.0055		0.0055	
Max				0.0055		0.0210		0.0055		0.0055		0.0055		0.0055		0.0055		0.0055		0.0055		0.0055	
Mean				0.0055		0.0193		0.0055		0.0055		0.0055		0.0055		0.0055		0.0055		0.0055		0.0055	
Median				0.0055		0.0190		0.0055		0.0055		0.0055		0.0055		0.0055		0.0055		0.0055		0.0055	

U = undetected at the reporting limit noted. For these results, one-half the reporting limit is used to calculate Minimum, Maximum, Mean, Median, and Percent Reduction.
ug/L = micrograms per liter

Table 25. Flushing Experiment Raw Data and Summary Statistics for Fluoranthene.																							
Flushing Event	Flushing Volume	Percent Water Year	Flow Rate (liters/hr)	Influent Day 1 (ug/L)	Flag	Treatment 1 60/40 (ug/L)	Flag	Treatment 2 60/40/aafep-layer (ug/L)	Flag	Treatment 3 70vs/20cp/10ash/ compmulch (ug/L)	Flag	Treatment 4 70vs/20cp/10ash/ compmulch/ aafep-layer (ug/L)	Flag	Influent Day 2 (ug/L)	Flag	Treatment 5 70vs/20cp/ 10ash (ug/L)	Flag	Treatment 6 70ss/20cp/ 10ash (ug/L)	flag	Treatment 7 70ls/20cp/ 10ash (mg/L)	Flag	Treatment 8 70ls/20cp/10ash/ orifice (ug/L)	Flag
1	17.81	0.05	6.67	0.011	U	0.050		0.015		0.011	U	0.011	U	0.011	U	0.011	U	0.011	U	0.011	U	0.011	U
						0.038		0.015		0.011	U	0.011	U			0.011	U	0.011	U	0.011	U	0.011	U
						0.041		0.016		0.011	U	0.011	U			0.011	U	0.011	U	0.011	U	0.011	U
2	17.81	0.25	6.67																				
3	35.62	0.5	11																				
4	35.62	1	11																				
Min				0.0055		0.038		0.015		0.006		0.006		0.0055		0.006		0.006		0.006		0.006	
Max				0.0055		0.050		0.016		0.006		0.006		0.0055		0.006		0.006		0.006		0.006	
Mean				0.0055		0.043		0.015		0.006		0.006		0.0055		0.006		0.006		0.006		0.006	
Median				0.0055		0.041		0.015		0.006		0.006		0.0055		0.006		0.006		0.006		0.006	

U = undetected at the reporting limit noted. For these results, one-half the reporting limit is used to calculate Minimum, Maximum, Mean, Median, and Percent Reduction.

ug/L = micrograms per liter

Table 26. Flushing Experiment Raw Data and Summary Statistics for Phenanthrene																										
Flushing Event	Flushing Volume	Percent Water Year	Flow Rate (liters/hr)	Influent Day 1 (ug/L)	Flag	Treatment 1 60/40 (ug/L)	Flag	Treatment 2 60/40/aafep-layer (ug/L)	Flag	Treatment 3 70vs/20cp/10ash/ compmulch (ug/L)	Flag	Treatment 4 70vs/20cp/10ash/ compmulch/ aafep-layer (ug/L)	Flag	Influent Day 2 (ug/L)	Flag	Treatment 5 70vs/20cp/ 10ash (ug/L)	Flag	Treatment 6 70ss/20cp/ 10ash (ug/L)	flag	Treatment 7 70ls/20cp/ 10ash (mg/L)	Flag	Treatment 8 70ls/20cp/10ash/ orifice (ug/L)	Flag
1	17.81	0.05	6.67	0.011	U	0.011	U	0.011	U	0.011	U	0.011	U	0.011	U	0.011	U	0.011	U	0.011	U	0.011	U
						0.011	U	0.011	U	0.011	U	0.011	U			0.011	U	0.011	U	0.011	U	0.011	U
						0.015		0.011	U	0.011	U	0.011	U			0.011	U	0.011	U	0.011	U	0.011	U
2	17.81	0.25	6.67																				
3	35.62	0.5	11																				
4	35.62	1	11																				
Min				0.0055		0.0055		0.0055		0.0055		0.0055		0.0055		0.0055		0.0055		0.0055		0.0055	
Max				0.0055		0.0150		0.0055		0.0055		0.0055		0.0055		0.0055		0.0055		0.0055		0.0055	
Mean				0.0055		0.0087		0.0055		0.0055		0.0055		0.0055		0.0055		0.0055		0.0055		0.0055	
Median				0.0055		0.0055		0.0055		0.0055		0.0055		0.0055		0.0055		0.0055		0.0055		0.0055	

U = undetected at the reporting limit noted. For these results, one-half the reporting limit is used to calculate Minimum, Maximum, Mean, Median, and Percent Reduction.

ug/L = micrograms per liter

Table 27. Flushing Experiment Raw Data and Summary Statistics for Fecal Coliform.

Flushing Event	Flushing Volume	Percent Water Year	Flow Rate (liters/hr)	Influent Day 1 (CFU)	Flag	Treatment 1 60/40 (CFU)	Flag	Treatment 2 60/40/aafep-layer (CFU)	Flag	Treatment 3 70vs/20cp/10ash/ compmulch (CFU)	Flag	Treatment 4 70vs/20cp/10ash/ compmulch/ aafep-layer (CFU)	Flag	Influent Day 2 (CFU)	Flag	Treatment 5 70vs/20cp/ 10ash (CFU)	Flag	Treatment 6 70ss/20cp/ 10ash (CFU)	flag	Treatment 7 70ls/20cp/ 10ash (CFU)	Flag	Treatment 8 70ls/20cp/10ash/ orifice (CFU)	Flag
1	17.81	0.05	6.67	2	U	25000		25000		2000		1000		2	U	3200		2400		3800		9800	
						25000		25000		2400		1300				2600		1500		2700		10100	
						25000		25000		1200		1500				2800		1600		4300		5300	
2	17.81	0.25	6.67																				
3	35.62	0.5	11																				
4	35.62	1	11	2	U	2	U	2	U	8		2	U	2	U	4		12		2		20	
						2	U	2	U	2	U	2	U			20		4		4		28	
						2	U	2	U	2	U	4				4		2		12		4	
Min				1		1		1		1		1		1		4		2		2		4	
Max				1		25000		25000		2400		1500		1		3200		2400		4300		10100	
Mean				1		12500		12500		935		634		1		1440		920		1800		4210	
Median				1		12500		12500		604		502		1		1310		756		1360		2660	

U = undetected at the reporting limit noted. For these results, one-half the reporting limit is used to calculate Minimum, Maximum, Mean, and Median.

(CFU/100mL) = colony forming units per 100 milliliter

3.4. Saturated Hydraulic Conductivity

As shown in Figure 21, saturated hydraulic conductivities range from approximately 165 to 360 in/hr. Recent field testing of bioretention media indicates that Ksat values measured in columns are significantly higher than actual field rates. The relationship of the lab (column) and field rates is not known; however, the actual field rate is likely well above the maximum rate used to size bioretention (12 in/hr) recommended in the SWMMWW.

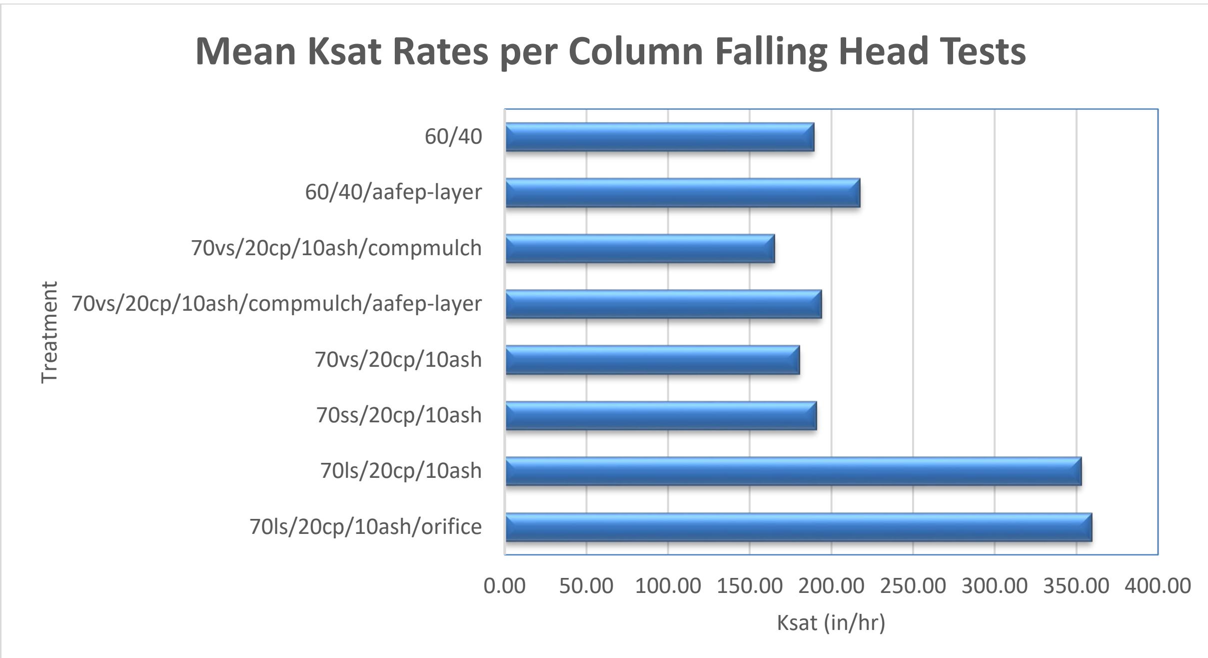


Figure 21. Saturated Hydraulic Conductivity Results for Each Treatment.

3.5. Dose Media in Columns

Results from the dosing experiments performed on different treatments are presented in separate subsections below for pH, TSS, DOC, TP, ortho-P, nitrate+nitrite, total and dissolved Cu, Pb and Zn, aluminum, TPH, PAH, and fecal coliform. Tables 28 through 47 and Figures 22 through 41 summarize results for all five sampling events for these contaminants. Note that only the first two dosing experiments were conducted on Treatments 1 and 8. Treatment 1 continued to export phosphorus and nitrogen after one water year of flushing experiments, was not meeting basic or enhanced water quality treatment criteria and was, therefore, dropped from the dosing experiments. Treatment 8 was the same media as Treatment 7 except Treatment 8 was orifice controlled to potentially improve TSS capture. No significant difference was observed and the treatment dropped after the second dosing experiment.

3.5.1. pH

The pH observed in the collected stormwater from SR 520 was slightly lower than observed nationally. The National Stormwater Quality Database reports a median pH value for freeways of 7.19 standard Units (SU). The median influent pH concentration from 520 was 6.87 SU with a maximum of 7.19 and a minimum of 6.58 SU. The median effluent for all treatments (6.83 SU) was slightly lower than the median pH for bioretention effluent reported nationally (7.20 SU) in the International Stormwater Database. As demonstrated by the above results, the median influent and effluent pH for all dosing experiments were similar. The effluent pH was in range for optimum treatment within media filters that rely to a large degree on sorption processes (weak and specific sorption and complexation) as filter mechanisms.

3.5.2. Total Suspended Solids

Total suspended sediment capture was very good for all treatments except Treatment 1 (60/40) (Table 28 and Figure 22). Treatment 4 was numerically and statistically the best performer for median effluent concentration and percent removal (p-value=0.05). Two of the dosing experiments had TSS influent concentrations below 100 mg/L, one with day one slightly over 100 mg/L and day two slightly below 100 mg/L, one from 100 to 200 mg/L and one over 200 mg/L. Different treatment criteria apply for these different ranges for TAPE testing; however, a bootstrapped lower 95 percent confidence interval was performed on all dosing experiment results. Treatments 2, 4, 5, 6 and 7 all met the 80 percent TAPE reduction criteria used for influent concentrations between 100-200 mg/L. However, Treatment 4 (70vs/20cp/10ash/compmulch/aafep-layer) had the highest percent reduction (90 percent) and was the only treatment with all effluent concentrations below 20 mg/L (overall median effluent concentration of 5 mg/L). A maximum of 20 mg/L is the TAPE criteria used for influent concentrations below 100 mg/L.

3.5.3. Dissolved Organic Carbon

Dissolved organic carbon is a strong sorbent and is speculated to protect aquatic organisms from the toxic impacts of dissolved metals. Most interesting is evaluating the difference in concentrations from the treatments containing compost (higher organic matter content) and the treatments containing coir and biochar (lower organic matter content). As speculated, DOC effluent concentrations for the treatments containing compost were higher (median of 9.20 mg/L for Treatment 2 and 11.60 mg/L for Treatment 3) compared to Treatment 5 at a median of 6.95 mg/L. The polishing layer appears to reduce DOC concentrations. Treatment 4 (70vs/20cp/10ash/compmulch/aafep-layer) had the lowest overall median effluent concentration of 5.01 mg/L. See Table 29 and Figure 23 for DOC results.

3.5.4. Total Phosphorus

Total phosphorus capture was poor for all treatments except Treatment 4 (Table 30 and Figure 24). After one year of flushing Treatment 1 (60/40) continued to export TP (-382 percent reduction, bootstrapped lower 95 percent confidence interval) during the first and second dosing experiments and was dropped from further testing. Influent concentrations for two experiments were below TAPE criteria (0.1 to 0.5 mg/L), two were within range and one above. Treatment 4 (70vs/20cp/10ash/compmulch/aafep-layer) was statistically the best performer and significantly surpassed the TAPE goal of 50 percent TP capture with 73 percent reduction for all experiments (bootstrapped lower 95 percent confidence interval).

3.5.5. Ortho-Phosphorus

Ortho-phosphorus capture was poor for all treatments except Treatment 4 (Table 31 and Figure 25). After one year of flushing Treatment 1 continued to export ortho-P (-3,480 percent reduction) during the first and second dosing experiments and was dropped from further testing. Treatments 3, 5, 6, and 7 also exported ortho-P, but at much lower concentrations than Treatment 1. The treatments including the polishing layer did not export ortho-P. Treatment 4 (70vs/20cp/10ash/ compmulch/aafep-layer) was statistically (p-value=0.05) the best performer with 45.7 percent reduction for all experiments and very low overall median effluent concentration of 6.1 µg/L.

3.5.6. Nitrate+Nitrite

Treatments 1-3 containing compost exported nitrate+nitrite. After one year of flushing Treatment 1 continued to export (-1,310 percent reduction) during the first and second dosing experiments and was dropped from further testing. Treatment 2 (60/40/aafep-layer) also exported significant nitrate+nitrite with a median effluent concentration almost an order of magnitude above influent concentrations (-939 percent reduction). Nitrate+nitrite capture for the treatments without compost was reasonably good considering this contaminant is a very difficult to filter. Biological transformation using a saturated zone is typically used for nitrate reduction in bioretention; however, no treatments included a saturated zone for this study. The best performers were Treatments 5-8 which did not contain compost, but rather coir and biochar for organic materials. Good nitrate capture was also observed in previous research with coir and biochar blends suggesting that one or both of these two organic materials sorb nitrate+nitrite. See Table 32 and Figure 26 for nitrate+nitrite results.

3.5.7. Total Copper

Total Cu reductions were excellent for all treatments (Table 33 and Figure 27) except Treatment 1. Treatments 2 and 4 containing polishing layers were statistically the best performers with percent reductions of 91 and 93 percent, respectively (p-value=0.05). Influent concentrations were reasonably similar for experiments 1, 2, 3 and 5 on day one (21.4, 92.0, 36.2, and 95.2 µg/L respectively) and (24.8, 87.4, 31.6, and 73.9 µg/L respectively) for day two; however, experiment 4 influent water was exceptionally dirty with an influent concentration of 246.0 µg/L. Given the relatively high influent concentrations median effluent concentration for all experiments were very low for Treatments 2 and 4 at 5.4 and 4.0 µg/L respectively.

3.5.8. Dissolved Copper

Dissolved Cu reductions were good for all treatments (Table 34 and Figure 28) except Treatment 1 (60/40). Treatments 2 and 4 containing polishing layers were statistically the best performers both with percent reductions of 91 percent (bootstrapped lower 95 percent confidence interval). While targeting P (anion), the polishing layer also provides excellent dissolved Cu (cation) capture. Influent concentrations varied widely across experiments; however, the majority of effluent concentrations were below 10 µg/L for Treatments 2 and 4. The overall median effluent concentrations for Treatments 2 and 4 were 1.9 and 1.7 µg/L, respectively.

3.5.9. Total Zinc

Total Zn influent concentrations were high ranging from 103 to 743 µg/L (Table 35 and Figure 29). Given these high influent concentrations, Total Zn capture was impressive with percent reductions ranging from 79 to 96 percent. Treatment 4 was statistically the best performer with 96 percent reduction and a median effluent of 8.9 µg/L for all experiments (p-value=0.05). Effluent concentrations were mostly all below 10 µg/L for Treatment 4 except experiment 4 where the influent concentration was extremely high (743 µg/L). Median effluent concentration was 50.1 µg/L for experiment 4, which indicates that additional treatment steps are necessary using bioretention to bring very high stormwater concentrations found on highways after longer antecedent dry periods and industrial areas to acceptable levels.

3.5.10. Dissolved Zinc

Dissolved Zn reductions were good for all treatments (Table 36 and Figure 30). Treatment 4 was statistically the best performer with percent reductions of 96 percent (bootstrapped lower 95 percent confidence interval). Influent concentrations varied widely across experiments (40.9 to 386.0 µg/L); however, the majority of effluent concentrations for Treatment 4 were below 10 µg/L and the overall median effluent concentration was 3.5 µg/L.

3.5.11. Total Lead

Total Pb influent concentrations ranged from low to fairly high (5.6 to 27.3 µg/L). See Table 37 and Figure 31 for results. All treatment performed well for Pb capture with percent removals ranging from 81 (Treatment 1, 60/40) to 93 percent (Treatment 4, 70vs/20cp/10ash/aafep-layer). Treatment 4 was statistically the best performer with the lowest median effluent concentration of 0.7 µg/L for all experiments (p-value=0.05).

3.5.12. Dissolved Lead

Dissolved Pb influent concentrations were very low ranging from 0.2 to 1.2 µg/L (Table 38 and Figure 32). Given these low influent concentrations, dissolved Pb percent removal was lower than total Pb, but capture was impressive with most effluent concentrations near or below the reporting limit (0.1 µg/L). Treatment 4 (70vs/20cp/10ash/aafep-layer) was the best performer with a median effluent concentration of 0.1 µg/L and percent reduction of 75 percent.

3.5.13. Cadmium

Nearly all influent and effluent concentrations were near or below the reporting limit for total and dissolved Cd. Accordingly, total and dissolved Cd were not analyzed after the first two dosing experiments and not reported here.

3.5.14. Aluminum

Activated alumina was used in the polishing layers to capture P and Cu. However, aluminum can be toxic to aquatic organisms and was evaluated for the fifth and last dosing experiment to determine if aluminum is flushing from the media (Table 39 and Figure 33). Surprisingly, the effluent concentrations for the treatments containing activated alumina in the polishing layer were lower than the treatments without a polishing layer. Median effluent concentrations for Treatments 2 and 4 (the best performers) were 88.5 and 178.0 µg/L, and percent removal 98 and 95 percent respectively. Treatment 3 (70vs/20cp/10ash/compmulch) was the poorest performer with a median effluent concentration of 1,000 µg/L and percent removal of 77 percent. The increased effluent concentration may be due to aluminum binding to the DOC in the compost mulch layer which readily moves through the media column and into effluent water.

3.5.15. Total Petroleum Hydrocarbons (motor oil and diesel)

All treatments performed well for TPH capture. Diesel fraction influent concentrations ranged from 0.217 to 6.85 mg/L and motor oil influent concentrations from 0.622 to 9.71 mg/L. Percent reduction was very good for diesel (71 to 85 percent) and median effluent concentrations below the reporting limit (0.100 mg/L) for treatments 3(70vs/20cp/10ash/ compmulch), 4 (70vs/20cp/10ash/aafep-layer) and 5 (70vs/20cp/10ash). Percent reduction was also very good for the motor oil fraction (85 to 90 percent) and median effluent below the reporting limit (0.200 mg/L) for Treatments 3 (70vs/20cp/10ash/compmulch), 4 (70vs/20cp/10ash/aafep-layer) and 5 (70vs/20cp/10ash). See Tables 40 and 41 and Figures 34 and 35 for results.

3.5.16. Polycyclic Aromatic Hydrocarbons

Polycyclic aromatic hydrocarbons are considered toxic to aquatic organisms and were analyzed to correlate with the toxicological analyses presented in Section 3.8. Specific analytes assessed include phenanthrene, fluoranthene, chrysene, benzo[K]fluoranthene, and benzo[a]pyrene.

Influent concentrations for individual PAHs ranged from 0.010 (non-detect) to 0.135 µg/L for experiments 1, 2, 3, and 5. Dosing experiment 4 influent water was particularly dirty with a maximum influent concentration of 0.211 µg/L (Chrysene). Most all effluent concentrations were below the reporting limit (0.010 µg/L). See Tables 42 through 46 and Figures 36 through 40 for results.

3.5.17. Fecal Coliform

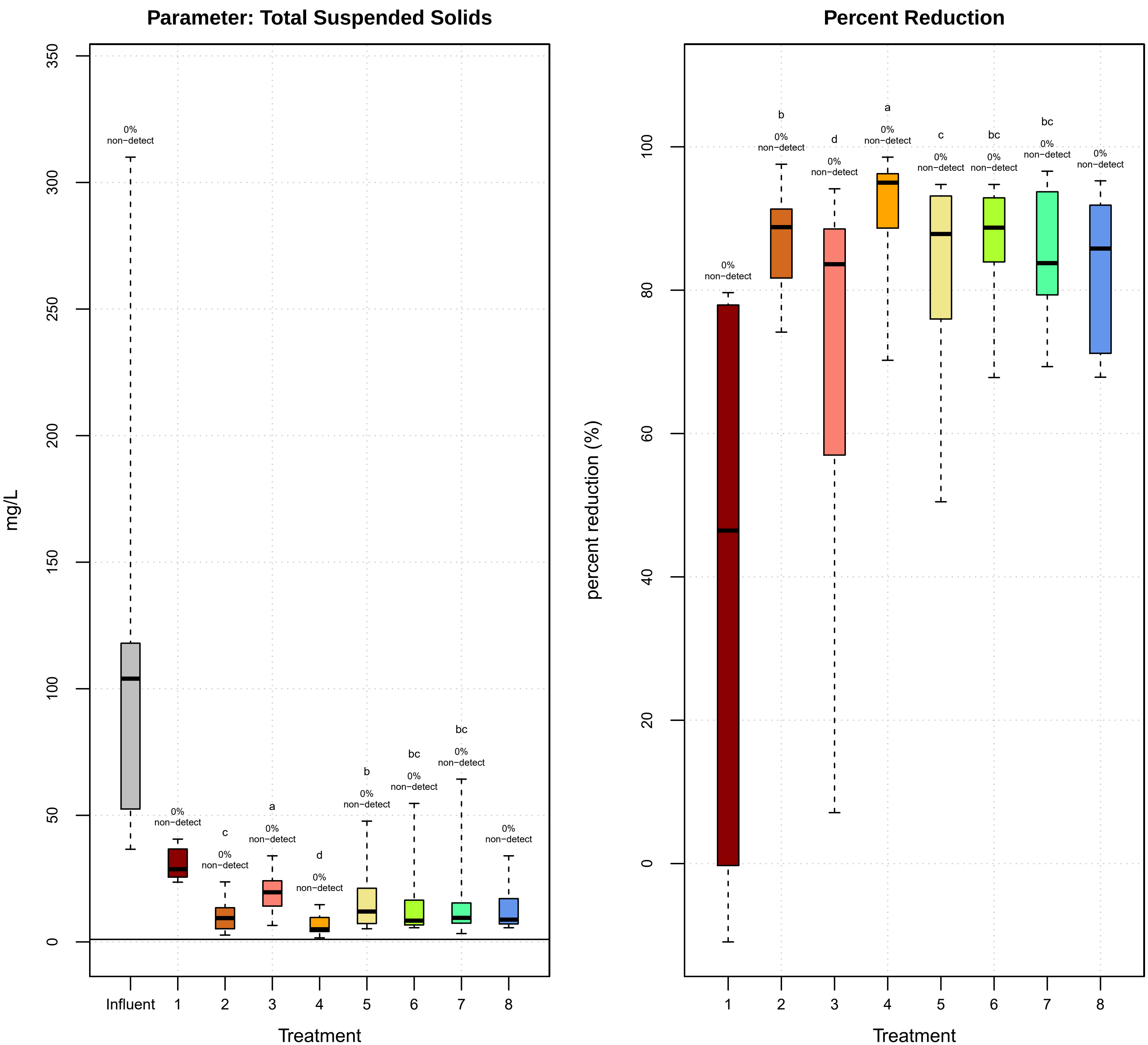
Influent concentrations varied widely for fecal coliform (13 to 7,500 CFU/100mL). Bacteria capture was good for all treatments with median effluent concentrations from 127 to 300 CFU/100mL and percent removal from 27 percent (Treatment 5, 70vs/20cp/10ash) to 60 percent (Treatment 4, 70vs/20cp/10ash/aafep-layer). For the lower influent concentrations (e.g., 20 CFU/100mL) Treatment 4 performed very well with a median effluent concentration near or below the reporting limit (2 CFU/10mL). All treatments performed statistically similar for median effluent concentrations and percent removal (p-value=0.05). To provide context, WAC 173-201A requires "Water contact recreation bacteria criteria" of 14 CFU/100 mL geometric mean for freshwater. See Table 47, Figure 41 for results.

3.5.18. Additional Observations

Stormwater from SR 520 in Seattle has been used for several studies to test the ability of bioretention media to protect aquatic organisms. Accordingly, stormwater from 520 was transported to the lab in Bellingham to provide consistency with past toxicological studies. Measured contaminant concentrations were typical for roads in four of the five experiments. However, water delivered for the fourth experiment was collected after a long antecedent dry period and many of the contaminant concentrations were exceptionally high (e.g. Total Zn 743 µg/L and TSS at 310 mg/L). Due to the high TSS concentrations, clogging (ponding water) was observed in the treatments with finer sands (Treatments 2-6).

For experiment 5, influent concentrations were more typical for roadway stormwater. No ponding was observed during the fifth experiment and the top performing treatment (Treatment 4, 70vs/20cp/10ash/aafep-layer) performed well for all other contaminant capture. Exposing the media to very high contaminant concentrations and then subsequent exposures with lower concentrations suggests that contaminants are captured in relatively strong bonds (e.g., stable complexes or specific/inner sphere sorption) rather than weaker outer sphere complexes.

Dosing Experiments Results – Plots



treatment 2 = 60/40/aafep−layer

treatment 3 = 70vs/20cp/10ash/compmulch

treatment 4 = 70vs/20cp/10ash/compmulch/aafep−layer

treatment 5 = 70vs/20cp/10ash

treatment 6 = 70ss/20cp/10ash

treatment 7 = 70ls/20cp/10ash

Two−Way ANOVA on Effluent Concentration (ranks)

Treatment p−value = <.001

Sample Event p−value = <.001

Interaction p−value = <.001

Two−Way ANOVA on Percent Removal (ranks)

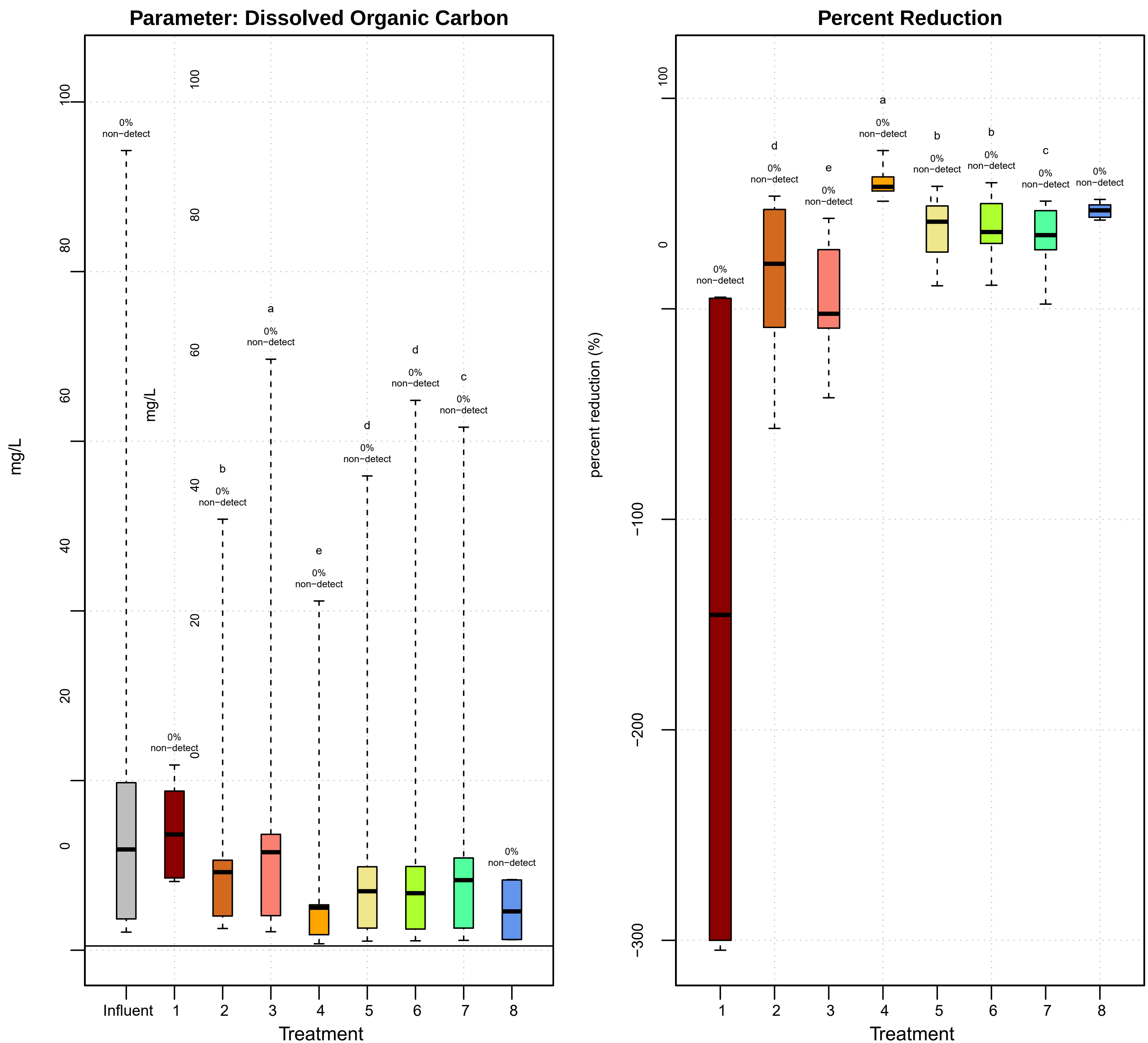
Treatment p−value = <.001

Sample Event p−value = <.001

Interaction p−value = <.001

Note that Treatment 1 and Treatment 8 do not include letters above the boxplots indicating which treatments are statistically different or not different (p-value 0.05). Treatment 1 was eliminated after the first dosing experiment due to continued export of N, P and Cu. Treatment 8 was dropped since no difference was observed between Treatment 7 (70ls/20cp/10ash) and Treatment 8 which was the same media blend but with orifice control.

Figure 22. Dosing Boxplots for Total Suspended Solids.



treatment 2 = 60/40/aafep−layer

treatment 3 = 70vs/20cp/10ash/compmulch

treatment 4 = 70vs/20cp/10ash/compmulch/aafep−layer

treatment 5 = 70vs/20cp/10ash

treatment 6 = 70ss/20cp/10ash

treatment 7 = 70ls/20cp/10ash

Two−Way ANOVA on Effluent Concentration (ranks)

Treatment p−value = <.001

Sample Event p−value = <.001

Interaction p−value = <.001

Two−Way ANOVA on Percent Removal (ranks)

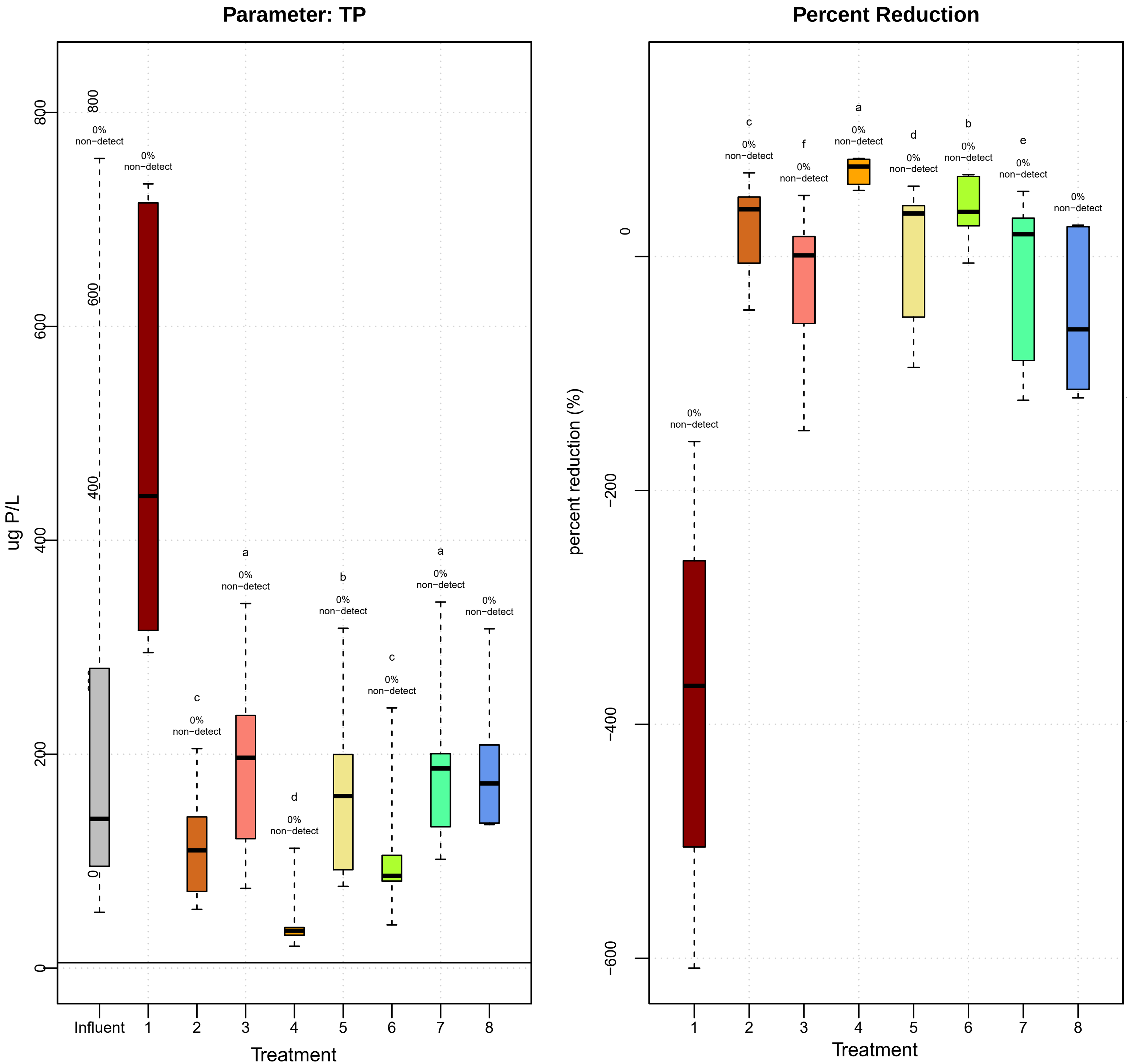
Treatment p−value = <.001

Sample Event p−value = <.001

Interaction p−value = <.001

Note that Treatment 1 and Treatment 8 do not include letters above the boxplots indicating which treatments are statistically different or not different (p-value 0.05). Treatment 1 was eliminated after the first dosing experiment due to continued export of N, P and Cu. Treatment 8 was dropped since no difference was observed between Treatment 7 (70ls/20cp/10ash) and Treatment 8 which was the same media blend but with orifice control.

Figure 23. Dosing Boxplots for Dissolved Organic Carbon.



treatment 2 = 60/40/aafep−layer

treatment 3 = 70vs/20cp/10ash/compmulch

treatment 4 = 70vs/20cp/10ash/compmulch/aafep−layer

treatment 5 = 70vs/20cp/10ash

treatment 6 = 70ss/20cp/10ash

treatment 7 = 70ls/20cp/10ash

Two−Way ANOVA on Effluent Concentration (ranks)

Treatment p−value = <.001

Sample Event p−value = <.001

Interaction p−value = <.001

Two−Way ANOVA on Percent Removal (ranks)

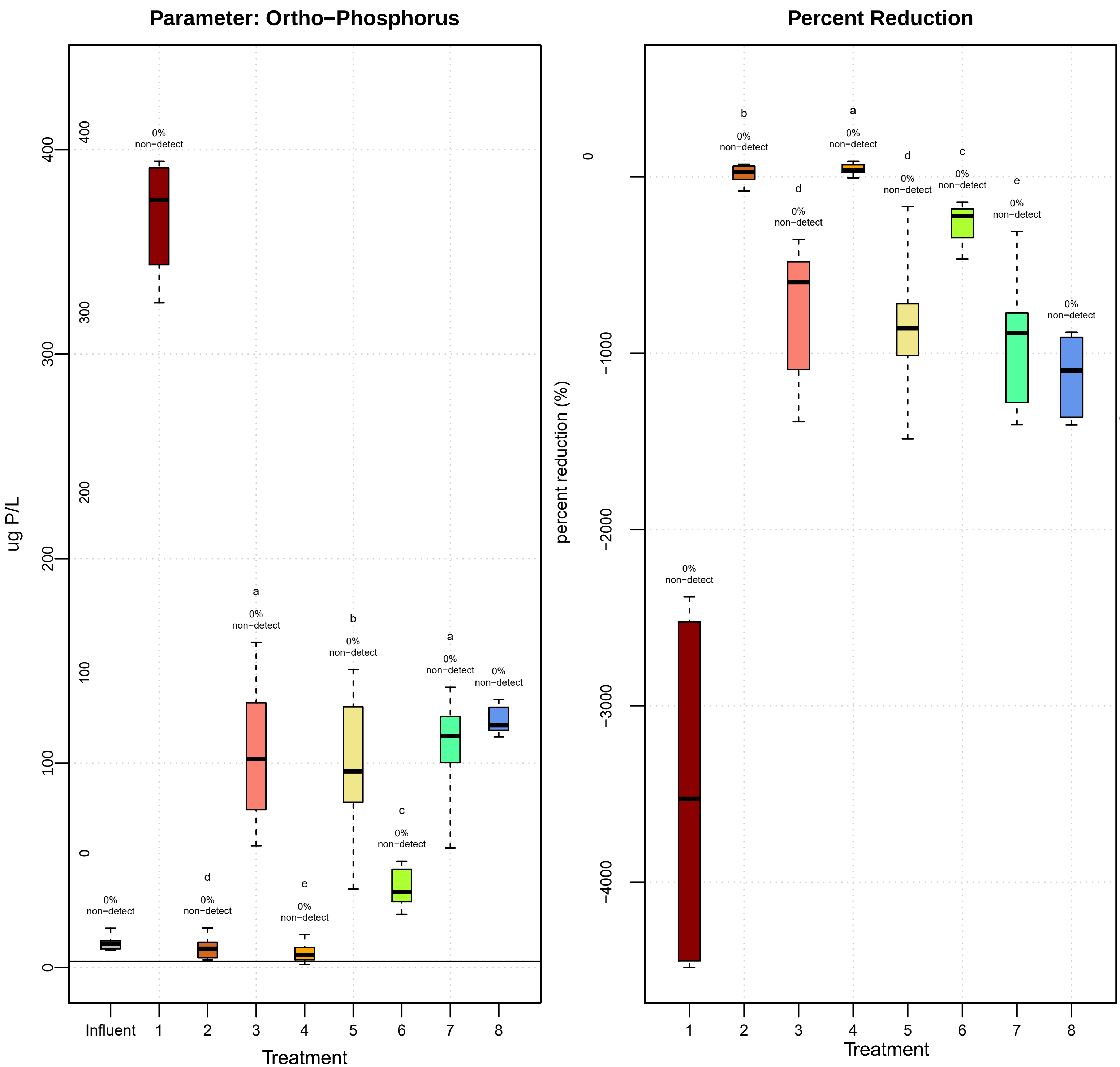
Treatment p−value = <.001

Sample Event p−value = <.001

Interaction p−value = <.001

Note that Treatment 1 and Treatment 8 do not include letters above the boxplots indicating which treatments are statistically different or not different (p-value 0.05). Treatment 1 was eliminated after the first dosing experiment due to continued export of N, P and Cu. Treatment 8 was dropped since no difference was observed between Treatment 7 (70ls/20cp/10ash) and Treatment 8 which was the same media blend but with orifice control.

Figure 24. Dosing Boxplots for Total Phosphorus.



treatment 2 = 60/40/aafep−layer

treatment 3 = 70vs/20cp/10ash/compmulch

treatment 4 = 70vs/20cp/10ash/compmulch/aafep−layer

treatment 5 = 70vs/20cp/10ash

treatment 6 = 70ss/20cp/10ash

treatment 7 = 70ls/20cp/10ash

Two−Way ANOVA on Effluent Concentration (ranks)

Treatment p−value = <.001

Sample Event p−value = <.001

Interaction p−value = <.001

Two−Way ANOVA on Percent Removal (ranks)

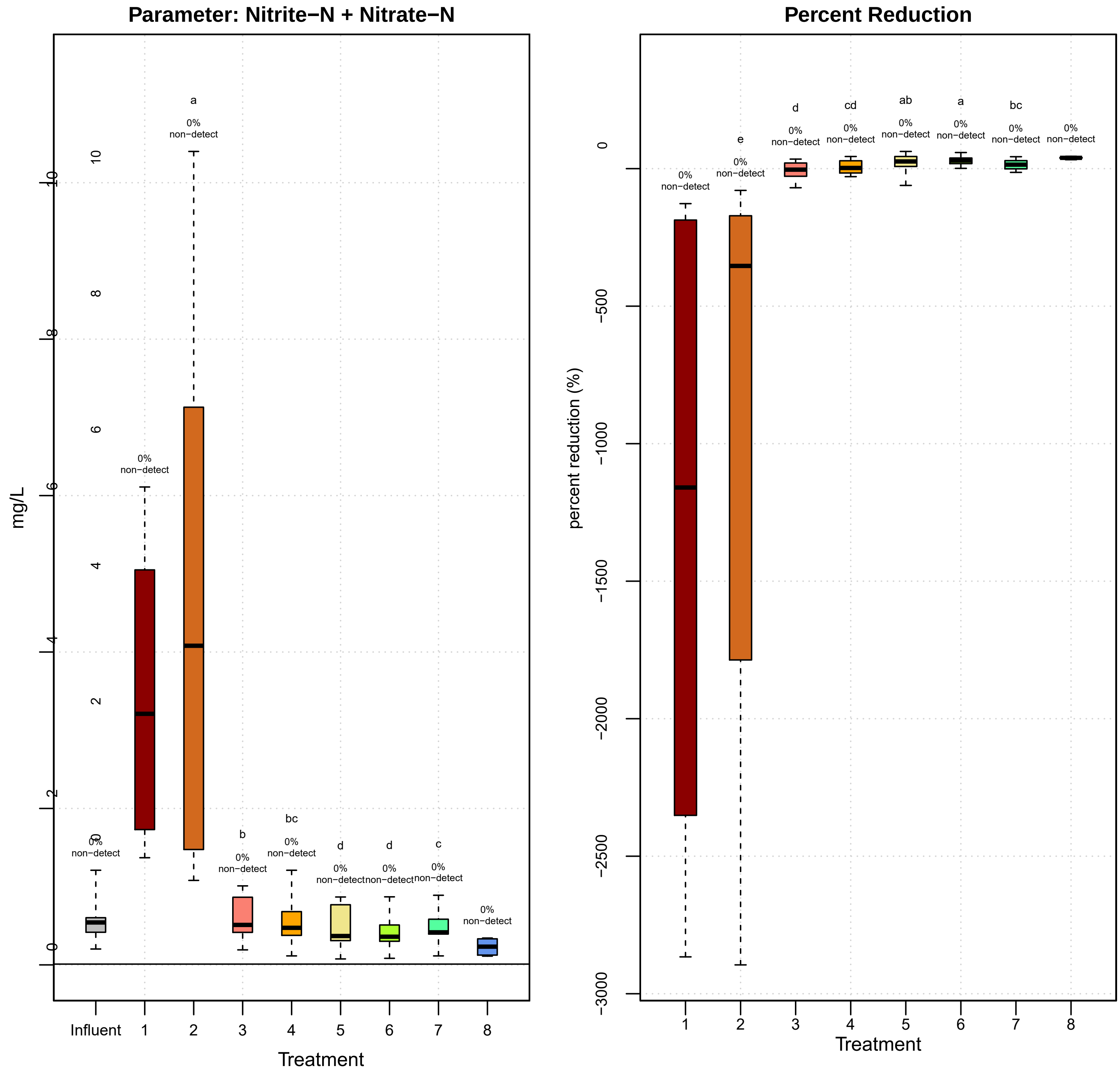
Treatment p−value = <.001

Sample Event p−value = <.001

Interaction p−value = <.001

Note that Treatment 1 and Treatment 8 do not include letters above the boxplots indicating which treatments are statistically different or not different (p-value 0.05). Treatment 1 was eliminated after the first dosing experiment due to continued export of N, P and Cu. Treatment 8 was dropped since no difference was observed between Treatment 7 (70ls/20cp/10ash) and Treatment 8 which was the same media blend but with orifice control.

Figure 25. Dosing Boxplots for Ortho-Phosphorus.



treatment 2 = 60/40/aafep−layer

treatment 3 = 70vs/20cp/10ash/compmulch

treatment 4 = 70vs/20cp/10ash/compmulch/aafep−layer

treatment 5 = 70vs/20cp/10ash

treatment 6 = 70ss/20cp/10ash

treatment 7 = 70ls/20cp/10ash

Two−Way ANOVA on Effluent Concentration (ranks)

Treatment p−value = <.001

Sample Event p−value = <.001

Interaction p−value = <.001

Two−Way ANOVA on Percent Removal (ranks)

Treatment p−value = <.001

Sample Event p−value = <.001

Interaction p−value = <.001

Note that Treatment 1 and Treatment 8 do not include letters above the boxplots indicating which treatments are statistically different or not different (p-value 0.05). Treatment 1 was eliminated after the first dosing experiment due to continued export of N, P and Cu. Treatment 8 was dropped since no difference was observed between Treatment 7 (70ls/20cp/10ash) and Treatment 8 which was the same media blend but with orifice control.

Figure 26. Dosing Boxplots for Nitrate+nitrite.

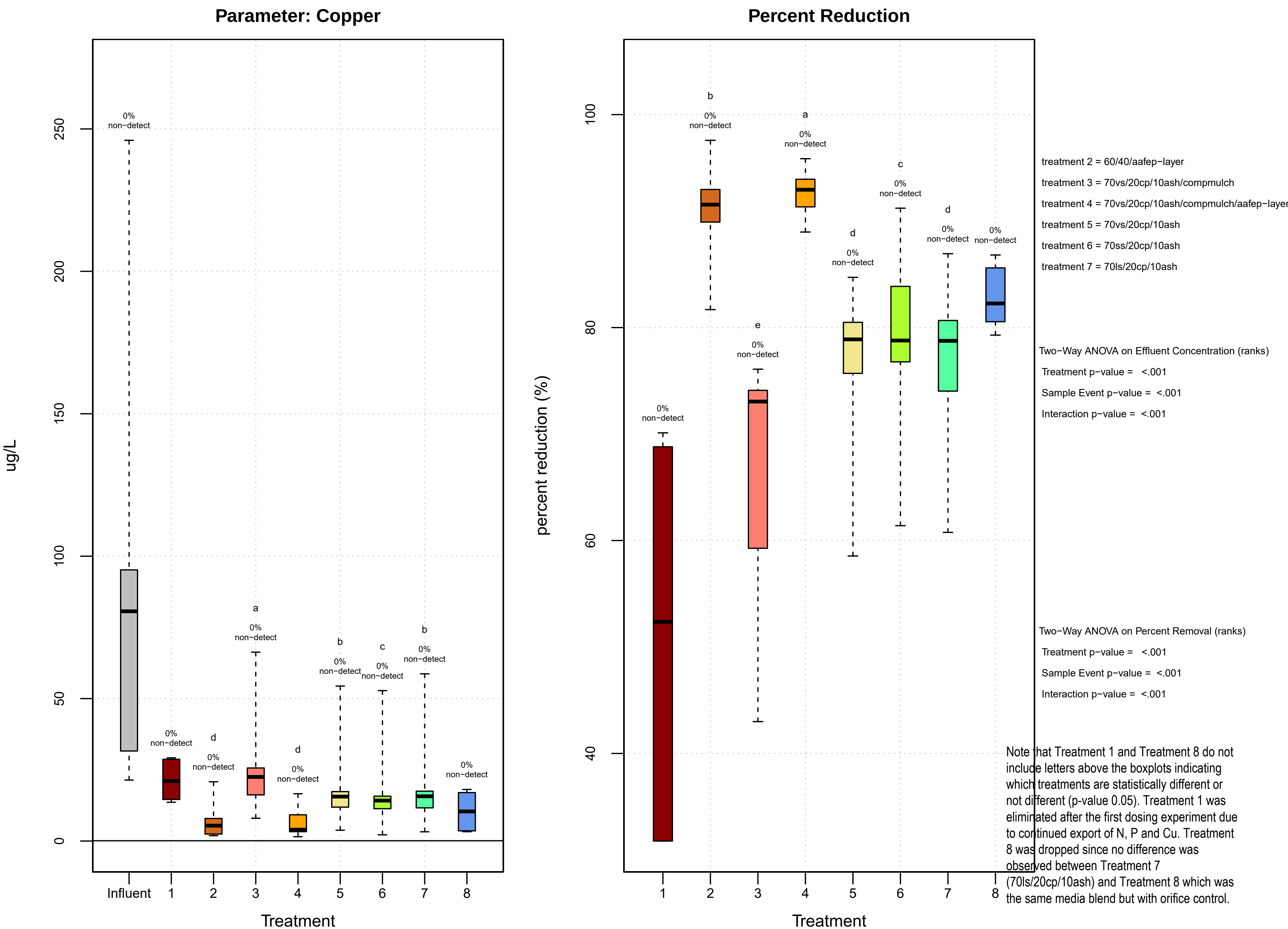
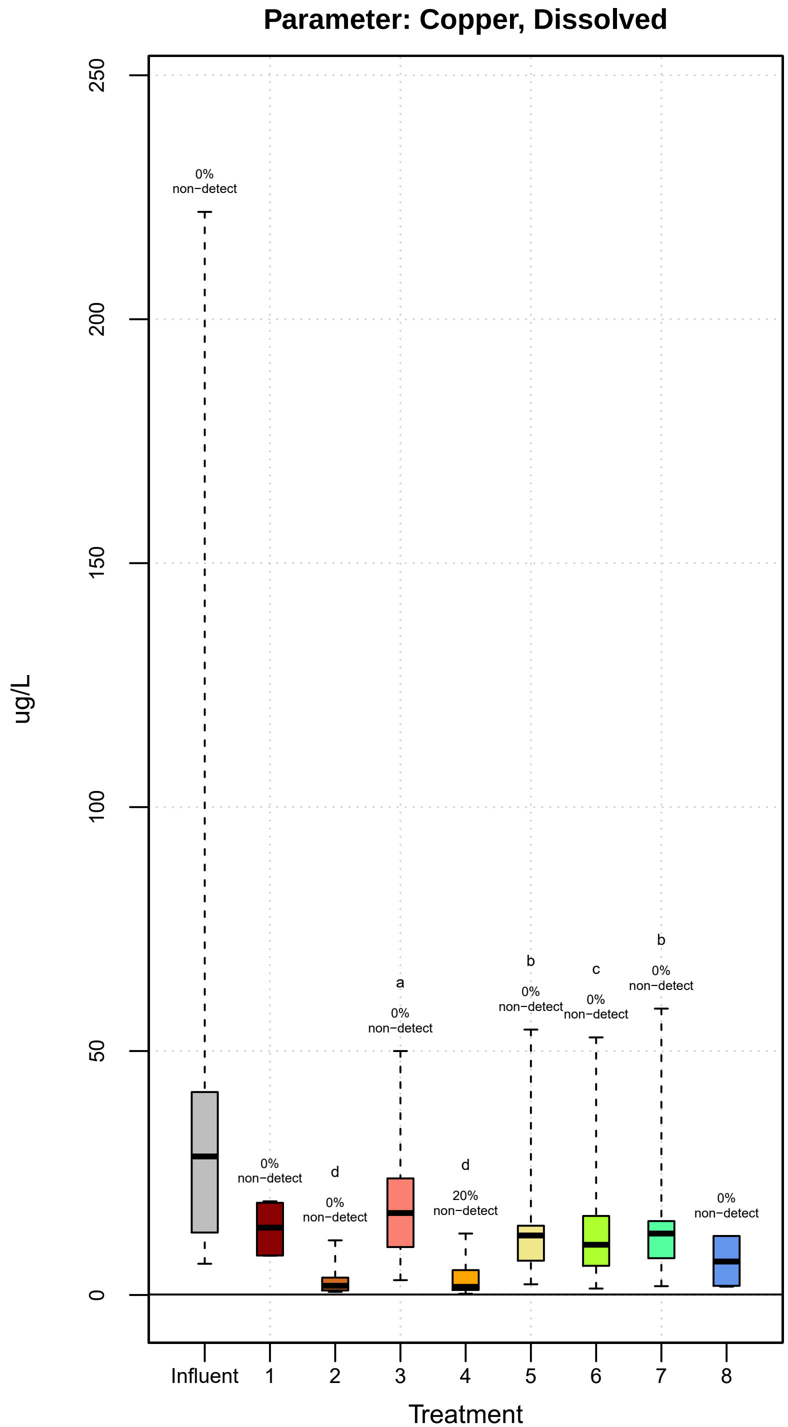
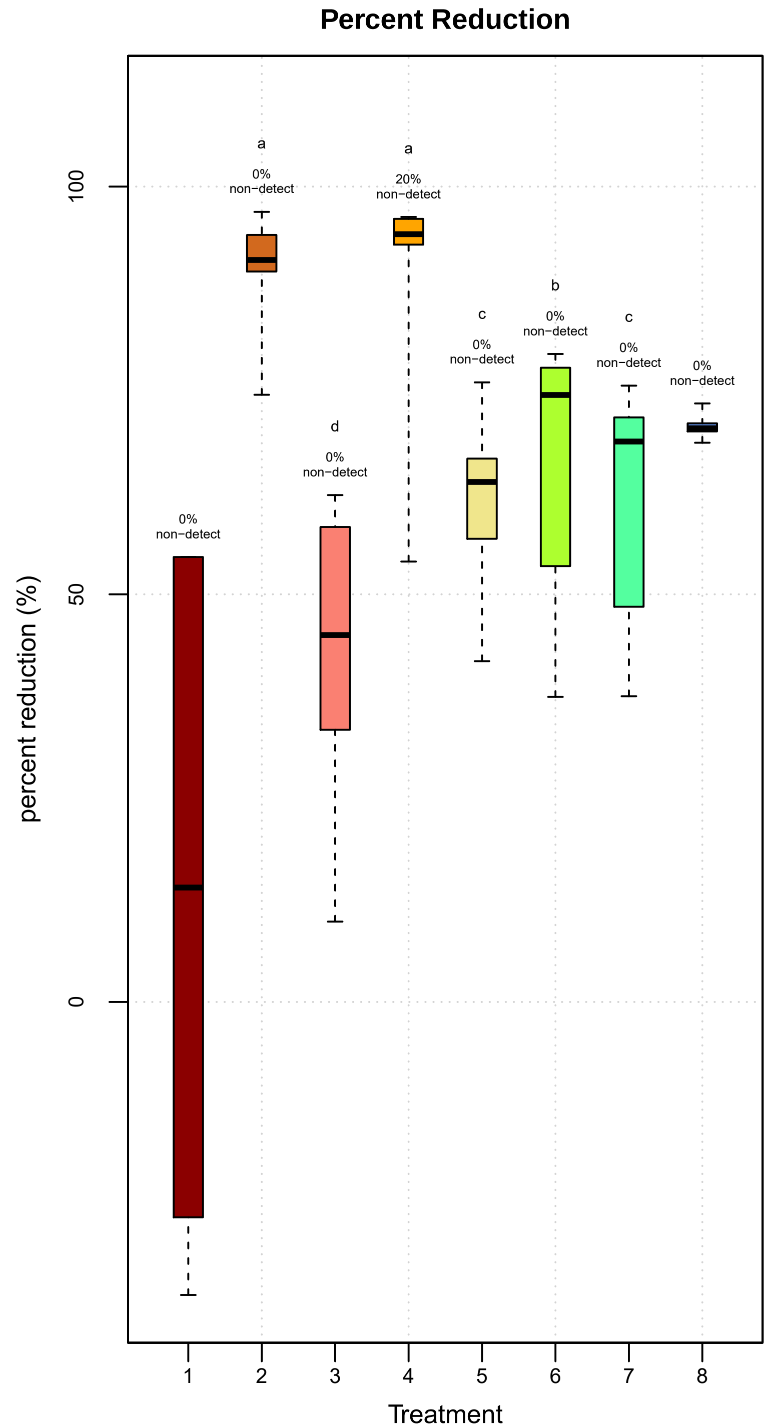


Figure 27. Dosing Boxplots for Copper, Total.





treatment 2 = 60/40/aafep−layer

treatment 3 = 70vs/20cp/10ash/compmulch

treatment 4 = 70vs/20cp/10ash/compmulch/aafep−layer

treatment 5 = 70vs/20cp/10ash

treatment 6 = 70ss/20cp/10ash

treatment 7 = 70ls/20cp/10ash

Two−Way ANOVA on Effluent Concentration (ranks)

Treatment p−value = <.001

Sample Event p−value = <.001

Interaction p−value = <.001

Two−Way ANOVA on Percent Removal (ranks)

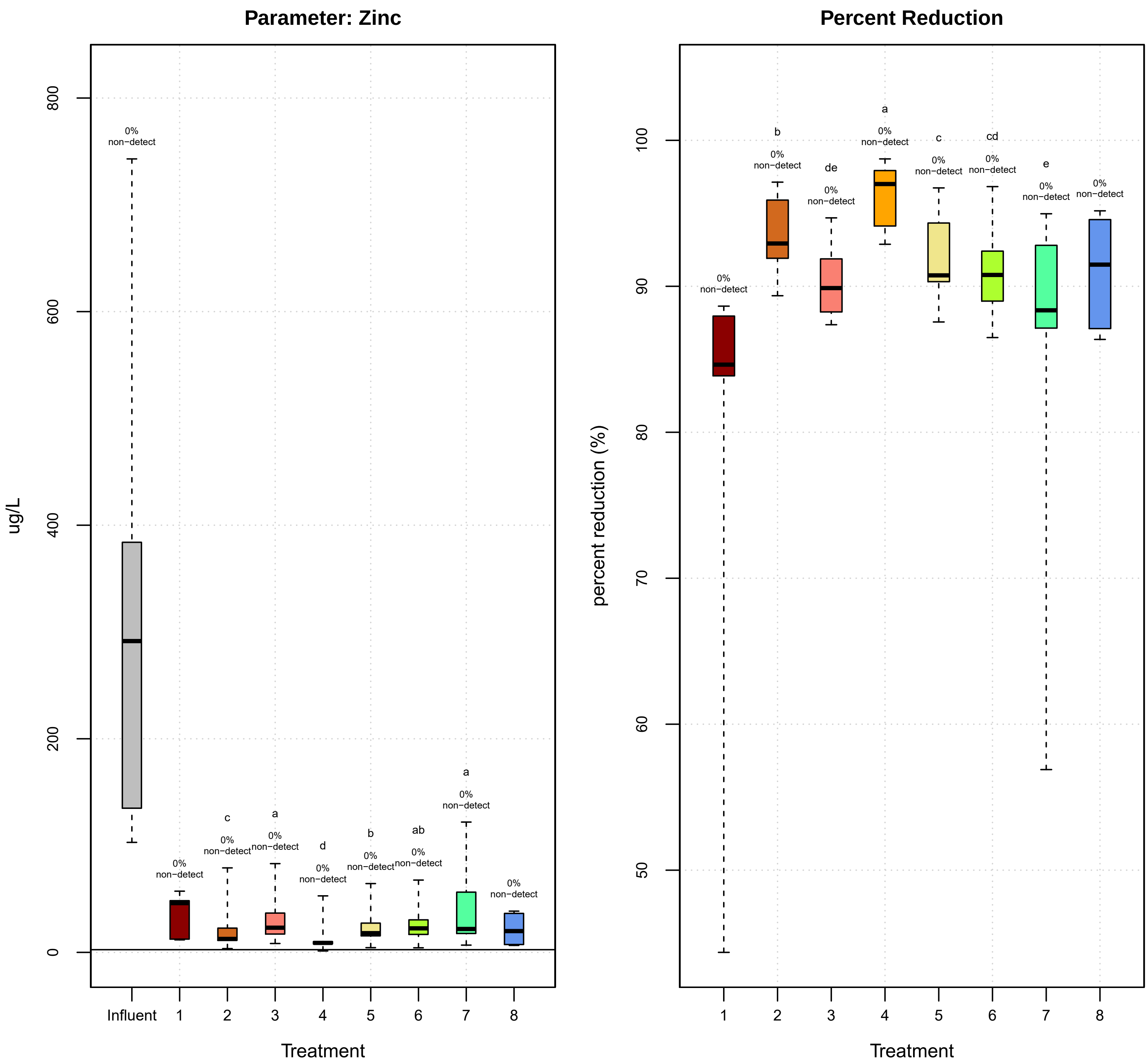
Treatment p−value = <.001

Sample Event p−value = <.001

Interaction p−value = <.001

Note that Treatment 1 and Treatment 8 do not include letters above the boxplots indicating which treatments are statistically different or not different (p-value 0.05). Treatment 1 was eliminated after the first dosing experiment due to continued export of N, P and Cu. Treatment 8 was dropped since no difference was observed between Treatment 7 (70ls/20cp/10ash) and Treatment 8 which was the same media blend but with orifice control.

Figure 28. Dosing Boxplots for Copper, Dissolved.



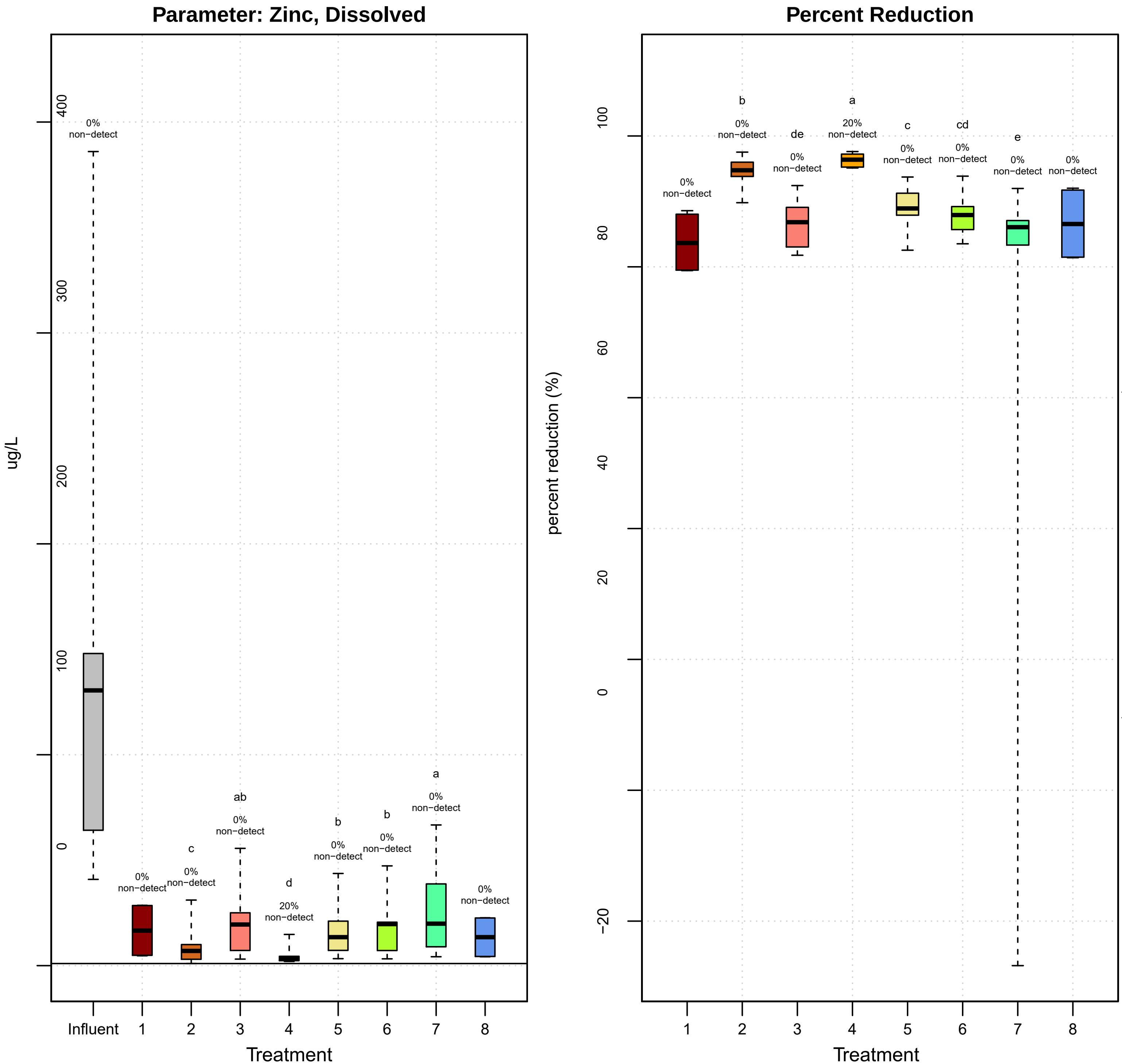
treatment 2 = 60/40/aafep−layer
treatment 3 = 70vs/20cp/10ash/compmulch
treatment 4 = 70vs/20cp/10ash/compmulch/aafep−layer
treatment 5 = 70vs/20cp/10ash
treatment 6 = 70ss/20cp/10ash
treatment 7 = 70ls/20cp/10ash

Two−Way ANOVA on Effluent Concentration (ranks)
Treatment p−value = <.001
Sample Event p−value = <.001
Interaction p−value = <.001

Two−Way ANOVA on Percent Removal (ranks)
Treatment p−value = <.001
Sample Event p−value = <.001
Interaction p−value = <.001

Note that Treatment 1 and Treatment 8 do not include letters above the boxplots indicating which treatments are statistically different or not different (p-value 0.05). Treatment 1 was eliminated after the first dosing experiment due to continued export of N, P and Cu. Treatment 8 was dropped since no difference was observed between Treatment 7 (70ls/20cp/10ash) and Treatment 8 which was the same media blend but with orifice control.

Figure 29. Dosing Boxplots for Zinc, Total.



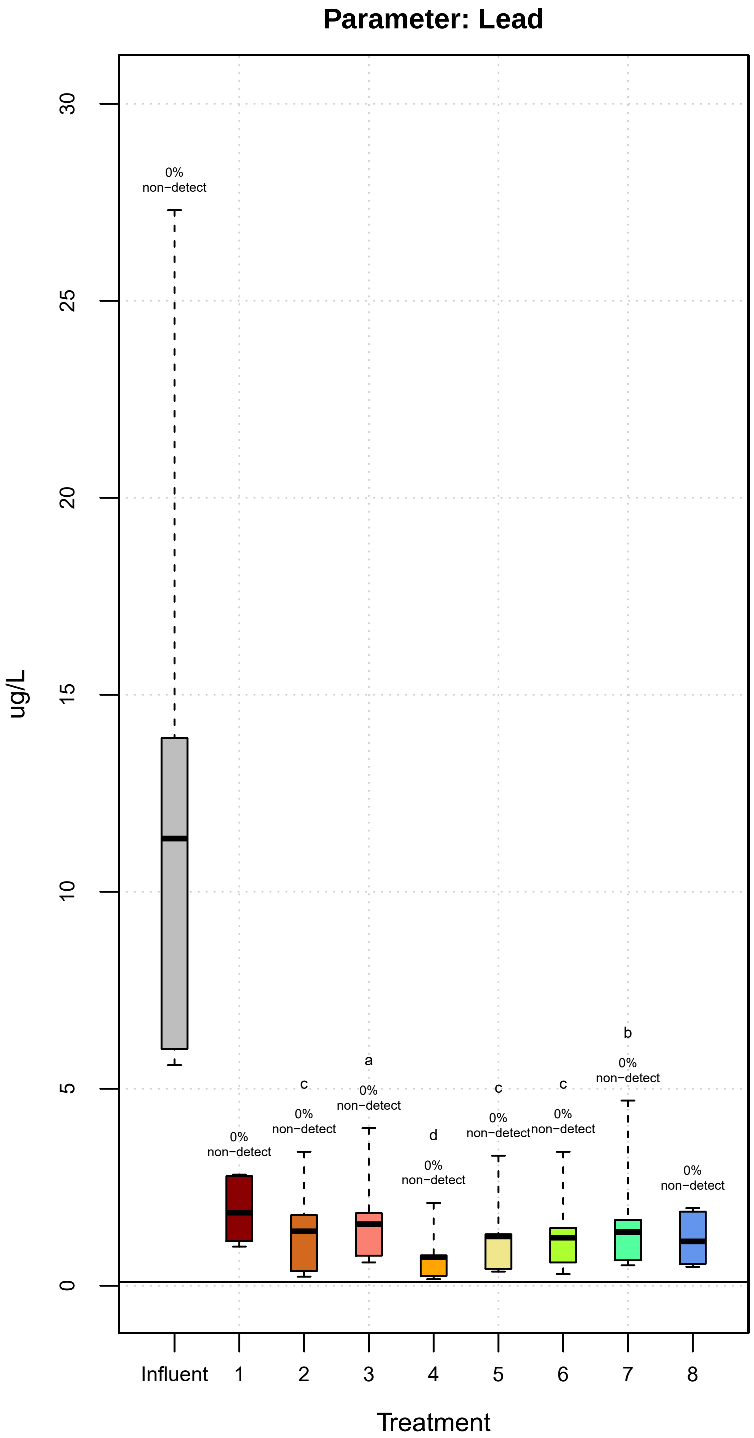
treatment 2 = 60/40/aafep−layer
treatment 3 = 70vs/20cp/10ash/compmulch
treatment 4 = 70vs/20cp/10ash/compmulch/aafep−layer
treatment 5 = 70vs/20cp/10ash
treatment 6 = 70ss/20cp/10ash
treatment 7 = 70ls/20cp/10ash

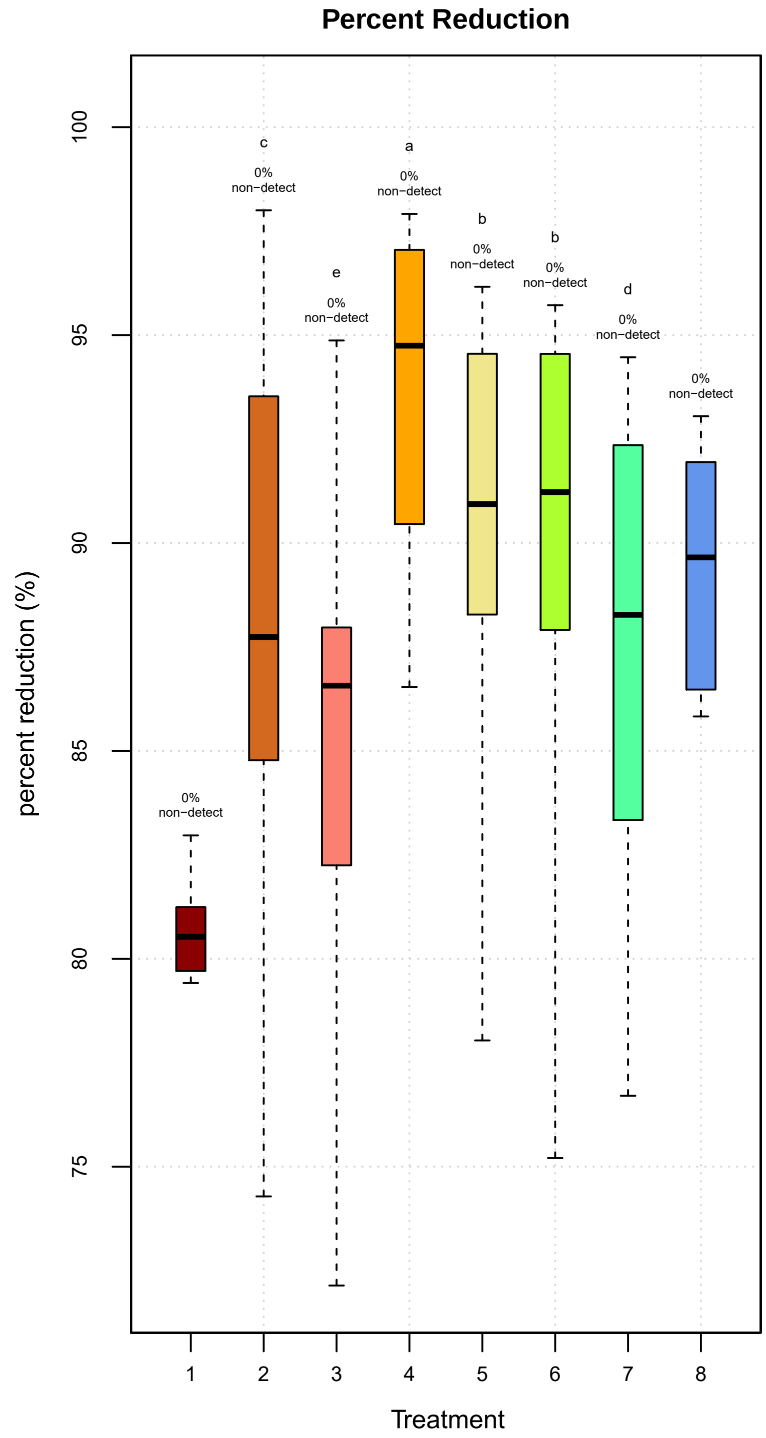
Two−Way ANOVA on Effluent Concentration (ranks)
Treatment p−value = <.001
Sample Event p−value = <.001
Interaction p−value = 0.013

Two−Way ANOVA on Percent Removal (ranks)
Treatment p−value = <.001
Sample Event p−value = <.001
Interaction p−value = <.001

Note that Treatment 1 and Treatment 8 do not include letters above the boxplots indicating which treatments are statistically different or not different (p-value 0.05). Treatment 1 was eliminated after the first dosing experiment due to continued export of N, P and Cu. Treatment 8 was dropped since no difference was observed between Treatment 7 (70ls/20cp/10ash) and Treatment 8 which was the same media blend but with orifice control.

Figure 30. Dosing Boxplots for Zinc, Dissolved.





treatment 2 = 60/40/aafep−layer

treatment 3 = 70vs/20cp/10ash/compmulch

treatment 4 = 70vs/20cp/10ash/compmulch/aafep−layer

treatment 5 = 70vs/20cp/10ash

treatment 6 = 70ss/20cp/10ash

treatment 7 = 70ls/20cp/10ash

Two−Way ANOVA on Effluent Concentration (ranks)

Treatment p−value = <.001

Sample Event p−value = <.001

Interaction p−value = <.001

Two−Way ANOVA on Percent Removal (ranks)

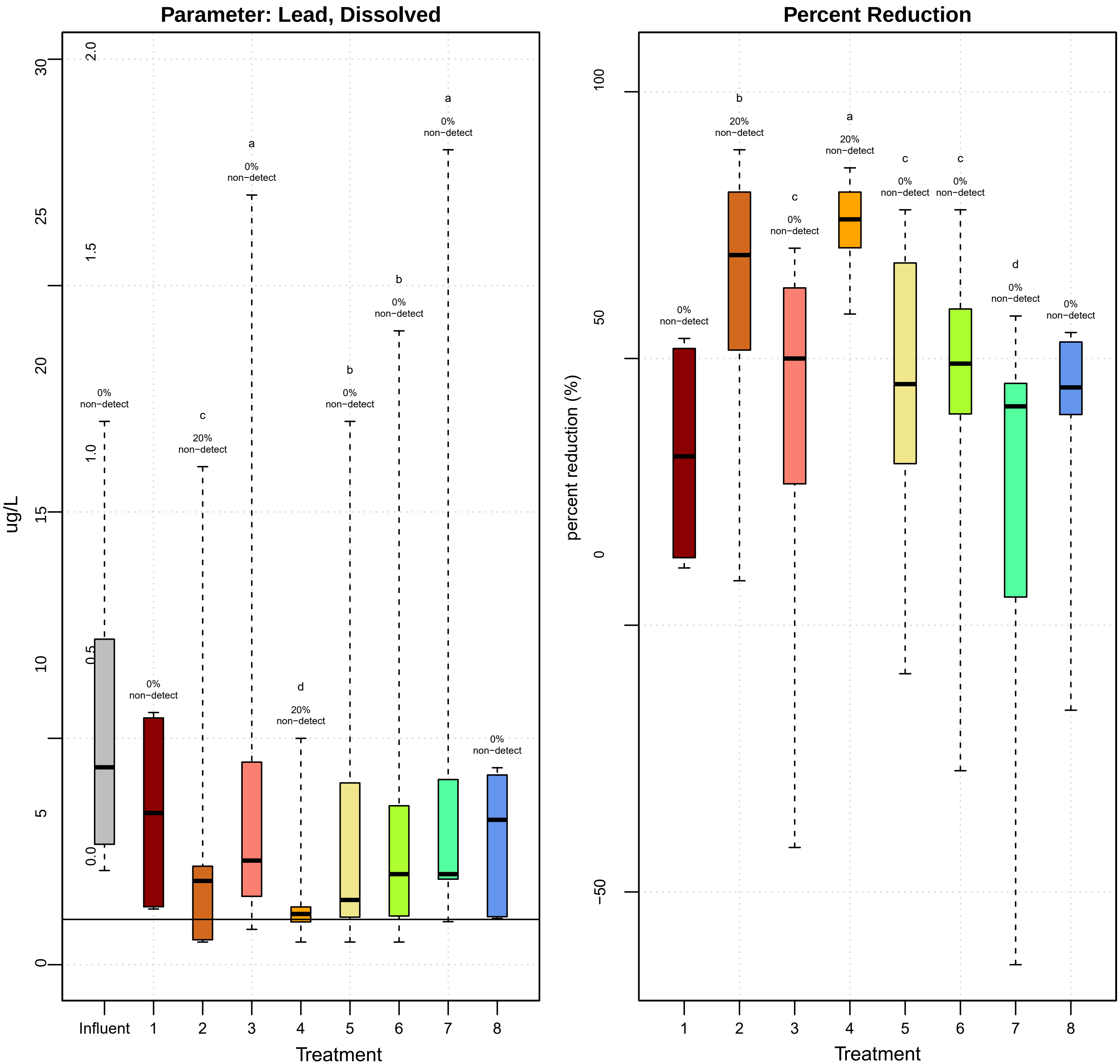
Treatment p−value = <.001

Sample Event p−value = <.001

Interaction p−value = <.001

Note that Treatment 1 and Treatment 8 do not include letters above the boxplots indicating which treatments are statistically different or not different (p-value 0.05). Treatment 1 was eliminated after the first dosing experiment due to continued export of N, P and Cu. Treatment 8 was dropped since no difference was observed between Treatment 7 (70ls/20cp/10ash) and Treatment 8 which was the same media blend but with orifice control.

Figure 31. Dosing Boxplots for Lead, Total.



treatment 2 = 60/40/aafep−layer

treatment 3 = 70vs/20cp/10ash/compmulch

treatment 4 = 70vs/20cp/10ash/compmulch/aafep−layer

treatment 5 = 70vs/20cp/10ash

treatment 6 = 70ss/20cp/10ash

treatment 7 = 70ls/20cp/10ash

Two−Way ANOVA on Effluent Concentration (ranks)

Treatment p−value = <.001

Sample Event p−value = <.001

Interaction p−value = <.001

Two−Way ANOVA on Percent Removal (ranks)

Treatment p−value = <.001

Sample Event p−value = <.001

Interaction p−value = <.001

Note that Treatment 1 and Treatment 8 do not include letters above the boxplots indicating which treatments are statistically different or not different (p-value 0.05). Treatment 1 was eliminated after the first dosing experiment due to continued export of N, P and Cu. Treatment 8 was dropped since no difference was observed between Treatment 7 (70ls/20cp/10ash) and Treatment 8 which was the same media blend but with orifice control.

Figure 32. Dosing Boxplots for Lead, Dissolved.

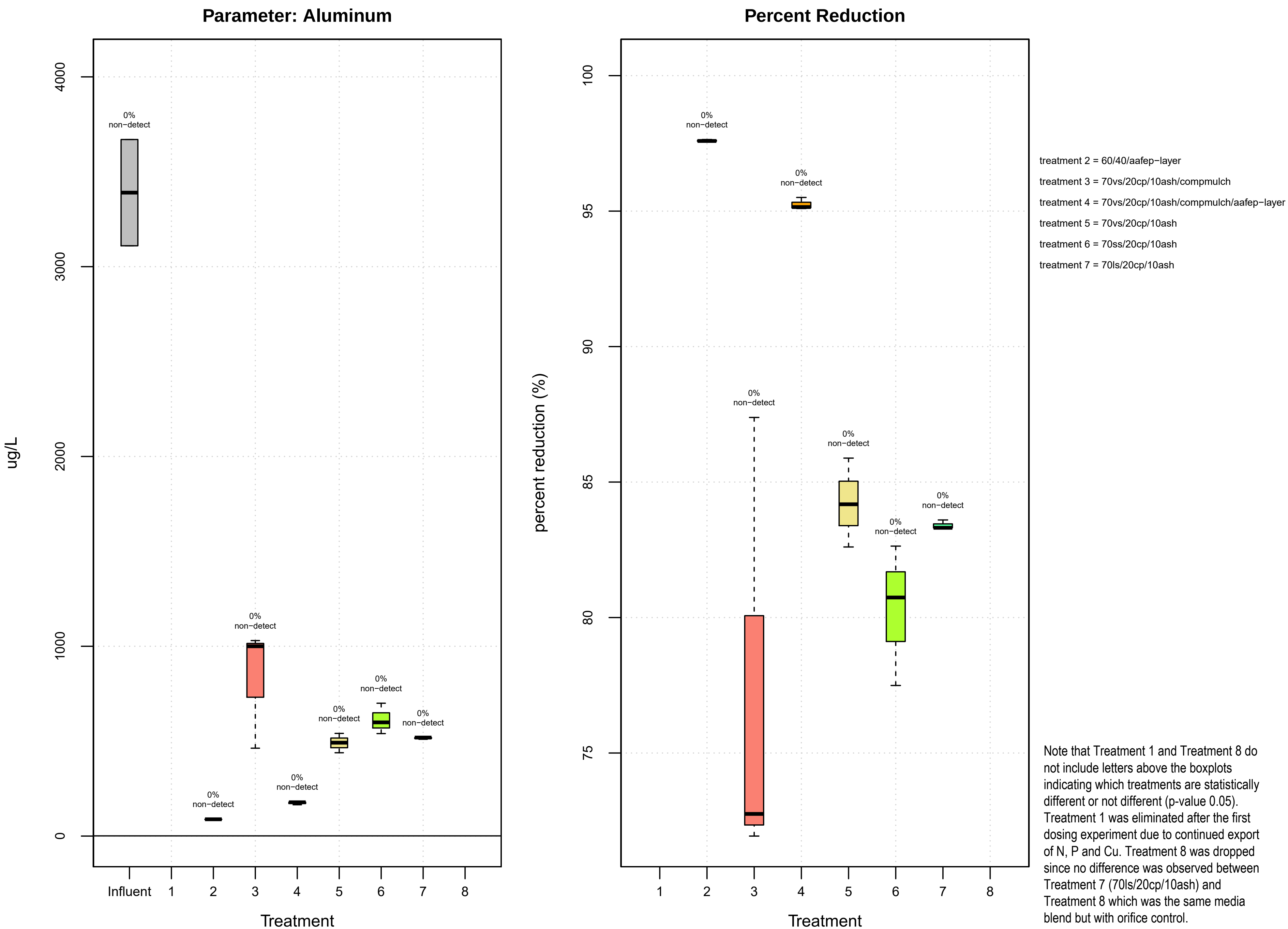


Figure 33. Dosing Boxplots for Aluminum.

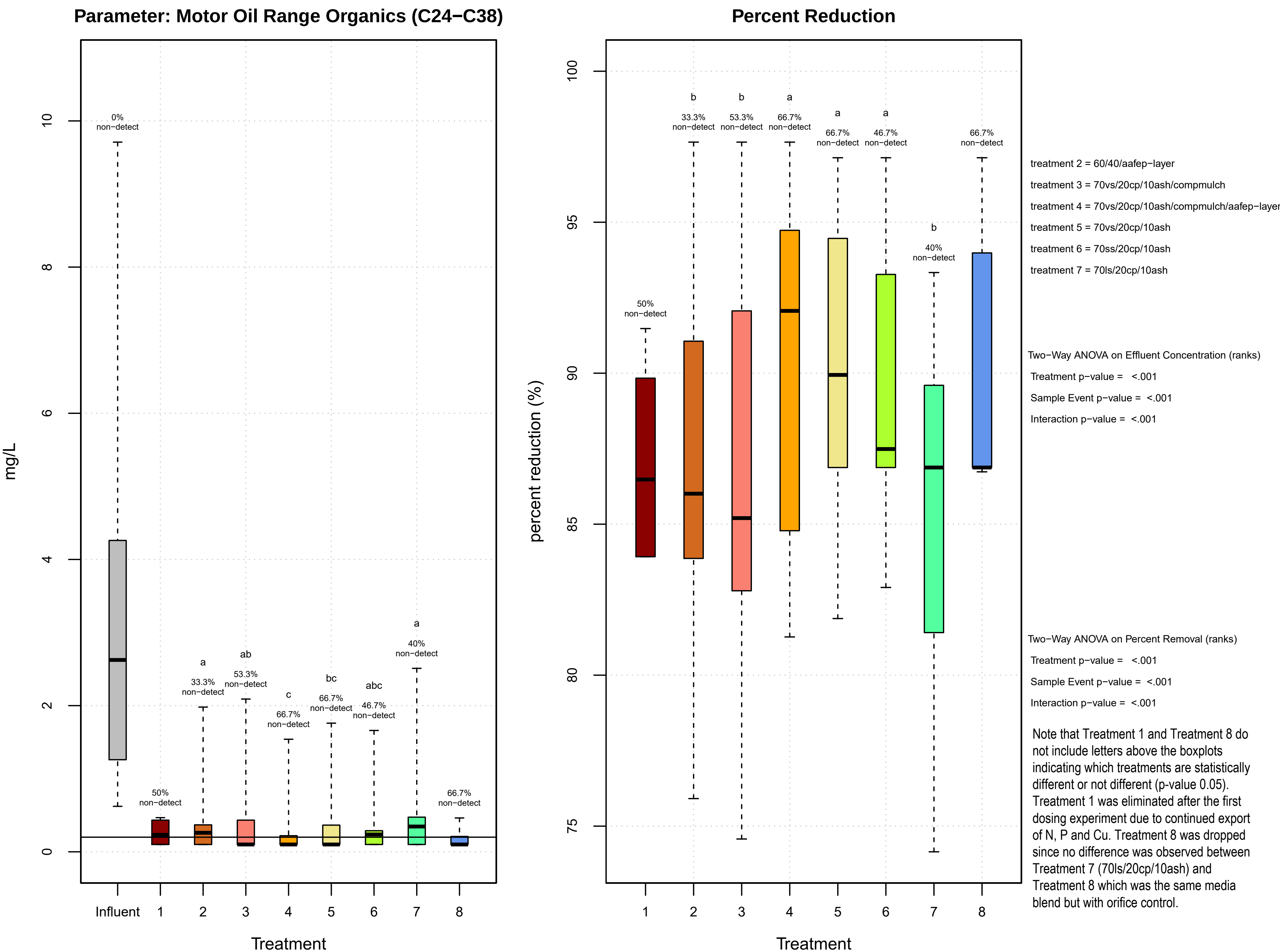
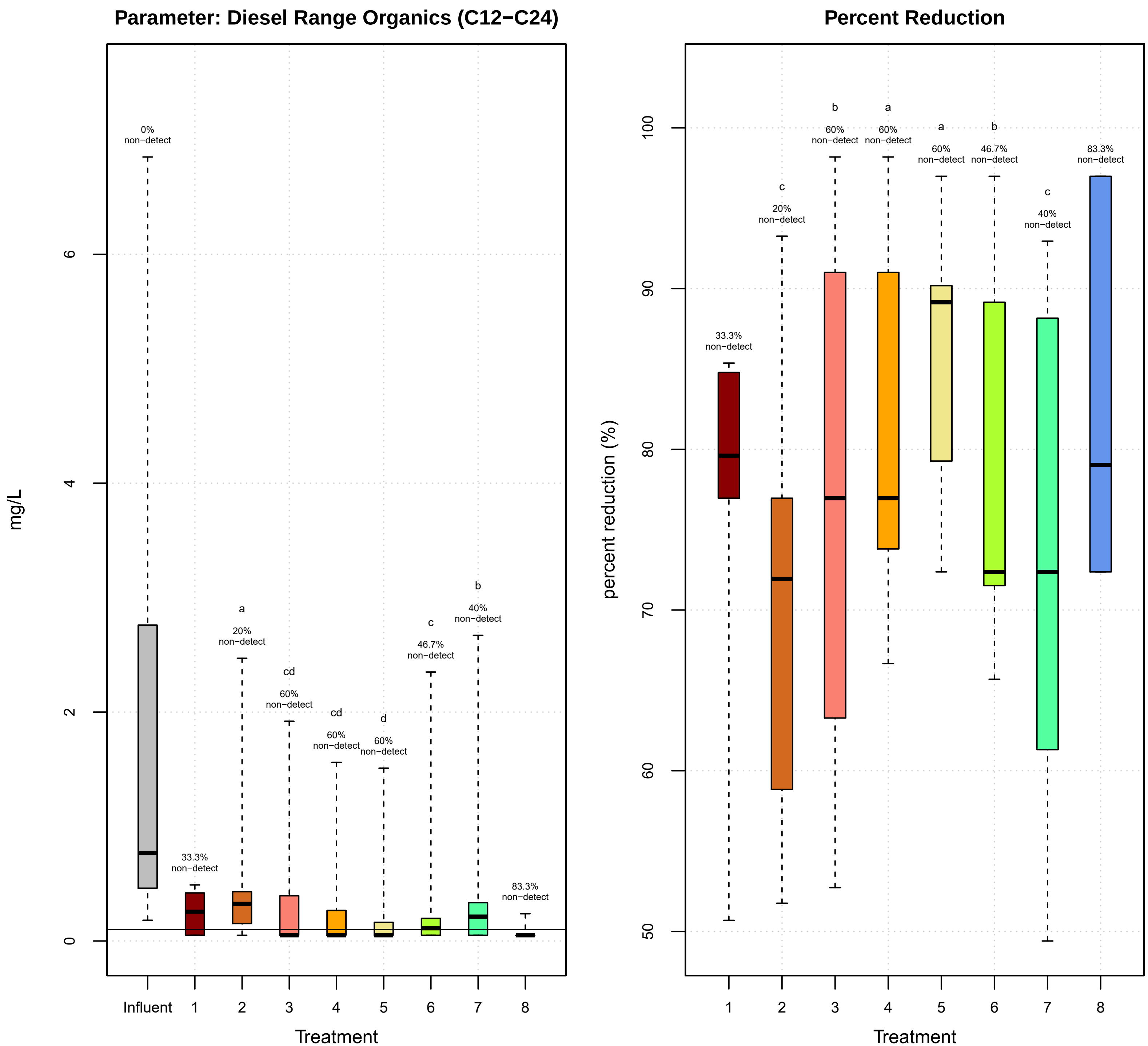


Figure 34. Dosing Boxplots for Total Petroleum Hydrocarbons Motor Oil Range (C24-C38).



treatment 2 = 60/40/aafep−layer

treatment 3 = 70vs/20cp/10ash/compmulch

treatment 4 = 70vs/20cp/10ash/compmulch/aafep−layer

treatment 5 = 70vs/20cp/10ash

treatment 6 = 70ss/20cp/10ash

treatment 7 = 70ls/20cp/10ash

Two−Way ANOVA on Effluent Concentration (ranks)

Treatment p−value = <.001

Sample Event p−value = <.001

Interaction p−value = <.001

Two−Way ANOVA on Percent Removal (ranks)

Treatment p−value = <.001

Sample Event p−value = <.001

Interaction p−value = <.001

Note that Treatment 1 and Treatment 8 do not include letters above the boxplots indicating which treatments are statistically different or not different (p-value 0.05). Treatment 1 was eliminated after the first dosing experiment due to continued export of N, P and Cu. Treatment 8 was dropped since no difference was observed between Treatment 7 (70ls/20cp/10ash) and Treatment 8 which was the same media blend but with orifice control.

Figure 35. Dosing Boxplots for Total Petroleum Hydrocarbons Diesel Oil Range (C12-C24).

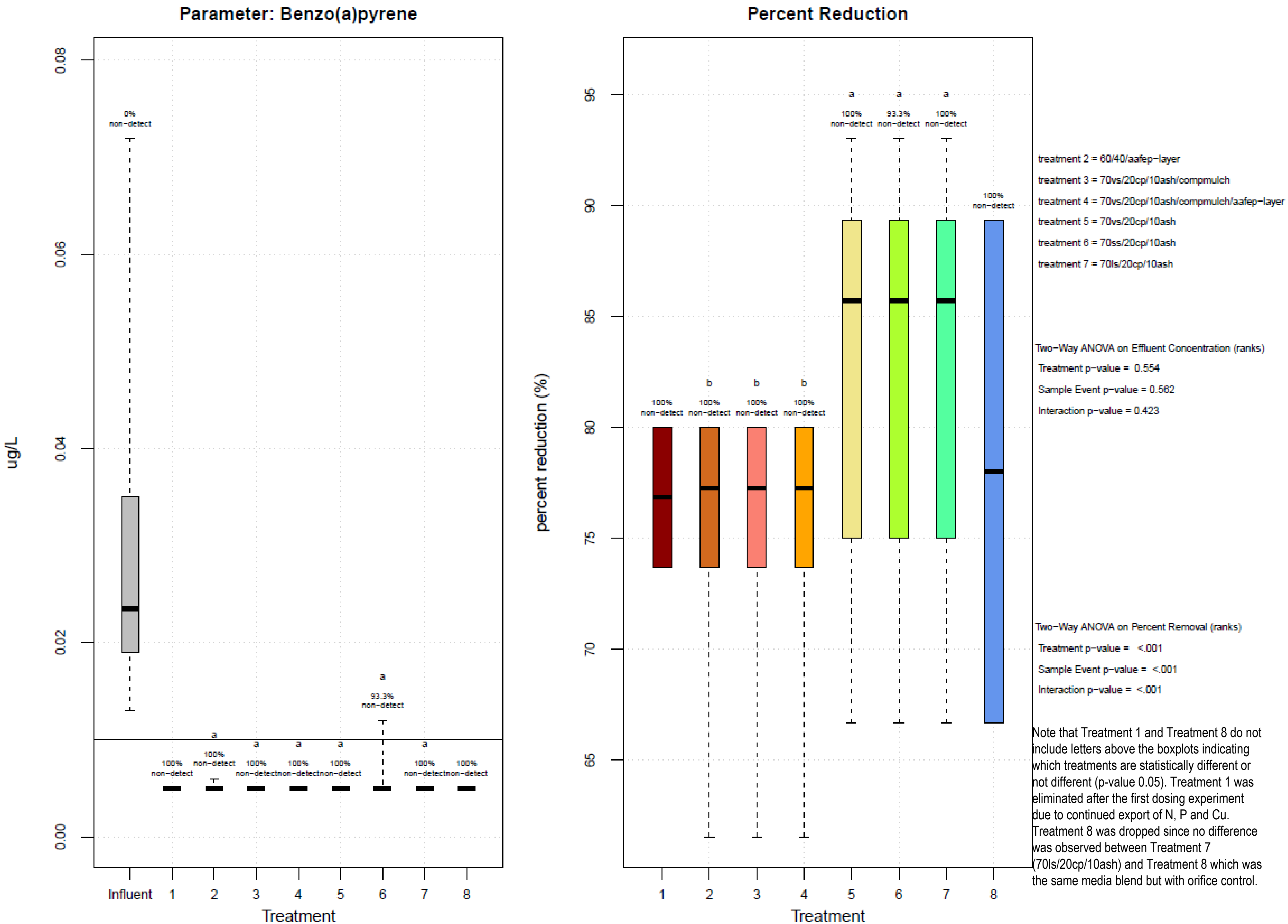
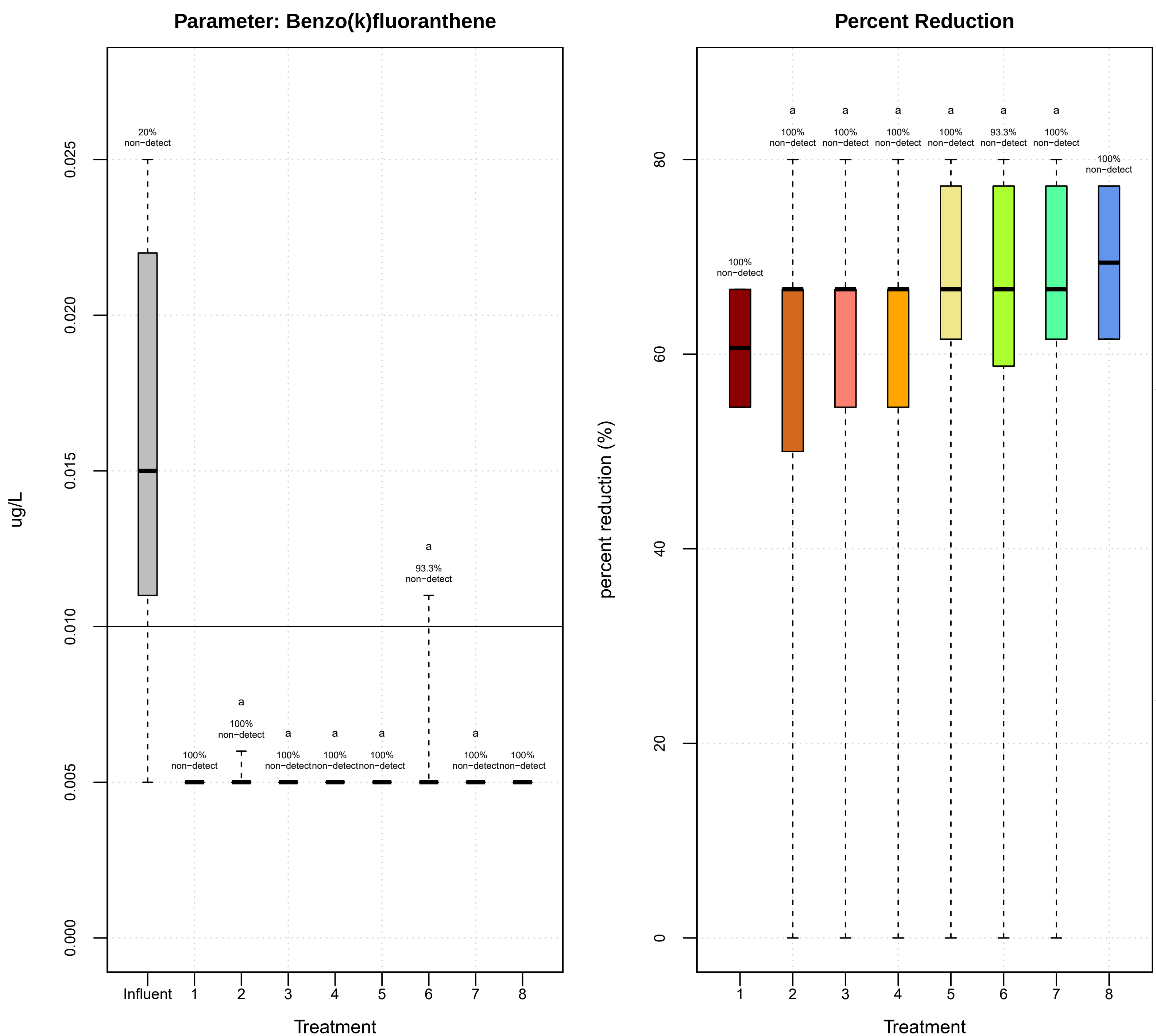


Figure 36. Box Plots for Benzo(a)pyrene.



treatment 2 = 60/40/aafep−layer

treatment 3 = 70vs/20cp/10ash/compmulch

treatment 4 = 70vs/20cp/10ash/compmulch/aafep−layer

treatment 5 = 70vs/20cp/10ash

treatment 6 = 70ss/20cp/10ash

treatment 7 = 70ls/20cp/10ash

Two−Way ANOVA on Effluent Concentration (ranks)

Treatment p−value = 0.554

Sample Event p−value = 0.562

Interaction p−value = 0.423

Two−Way ANOVA on Percent Removal (ranks)

Treatment p−value = 0.008

Sample Event p−value = <.001

Interaction p−value = <.001

Note that Treatment 1 and Treatment 8 do not include letters above the boxplots indicating which treatments are statistically different or not different (p-value 0.05). Treatment 1 was eliminated after the first dosing experiment due to continued export of N, P and Cu. Treatment 8 was dropped since no difference was observed between Treatment 7 (70ls/20cp/10ash) and Treatment 8 which was the same media blend but with orifice control.

Figure 37. Dozing Boxplots for Benzo(k)fluoranthene.

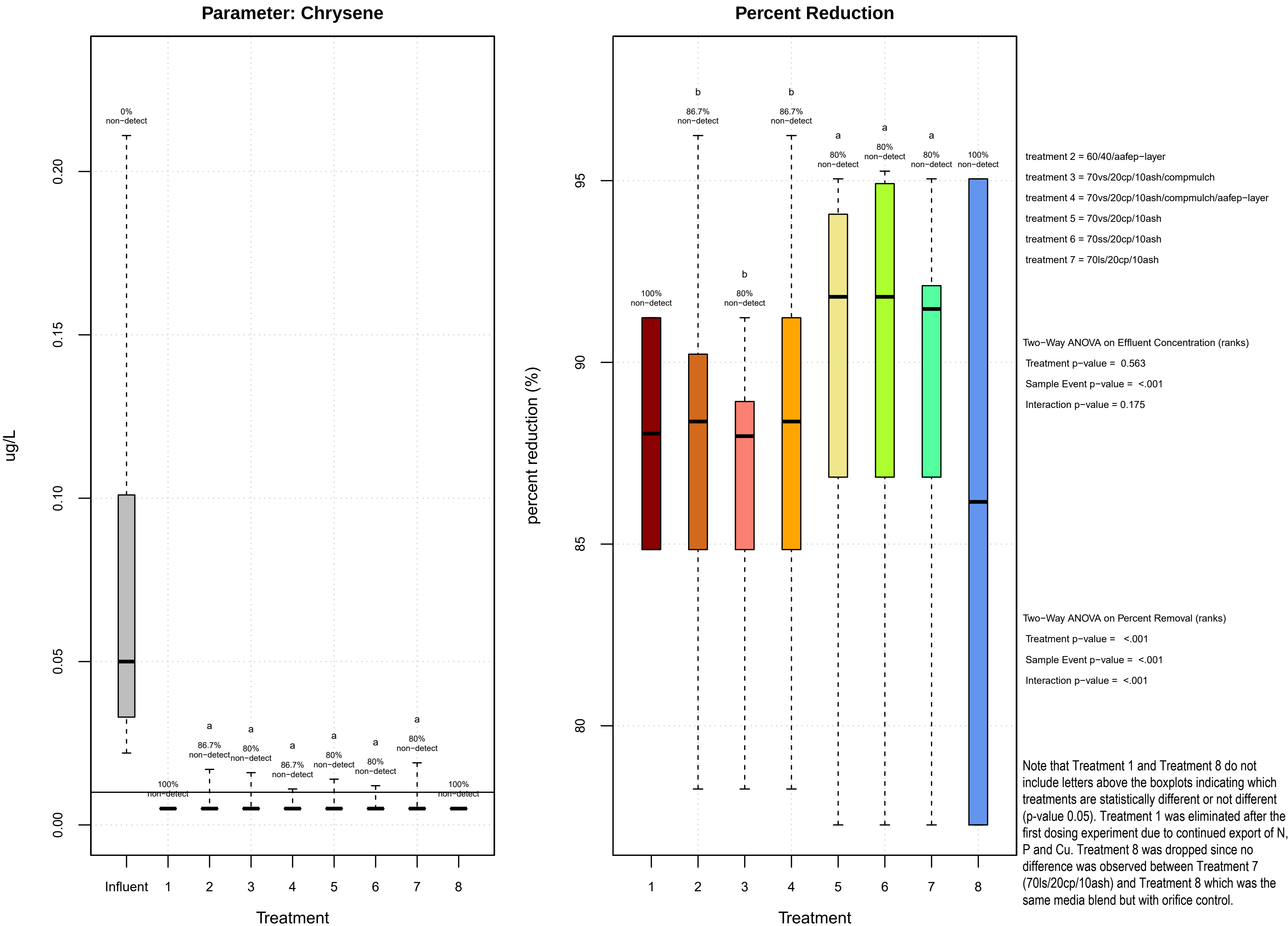
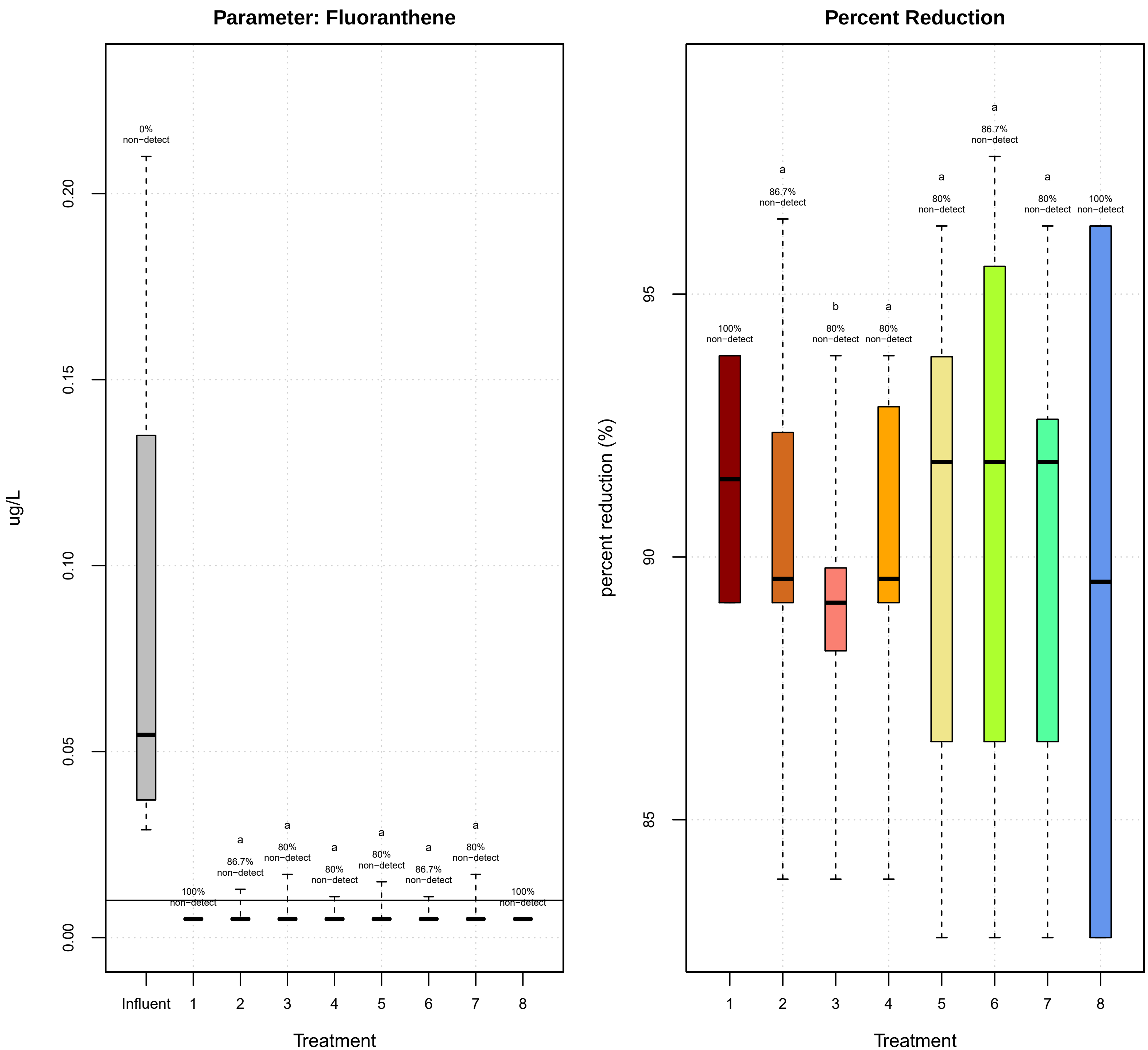


Figure 38. Dozing Boxplots for Chrysene.



treatment 2 = 60/40/aafep−layer

treatment 3 = 70vs/20cp/10ash/compmulch

treatment 4 = 70vs/20cp/10ash/compmulch/aafep−layer

treatment 5 = 70vs/20cp/10ash

treatment 6 = 70ss/20cp/10ash

treatment 7 = 70ls/20cp/10ash

Two−Way ANOVA on Effluent Concentration (ranks)

Treatment p−value = 0.568

Sample Event p−value = <.001

Interaction p−value = 0.098

Two−Way ANOVA on Percent Removal (ranks)

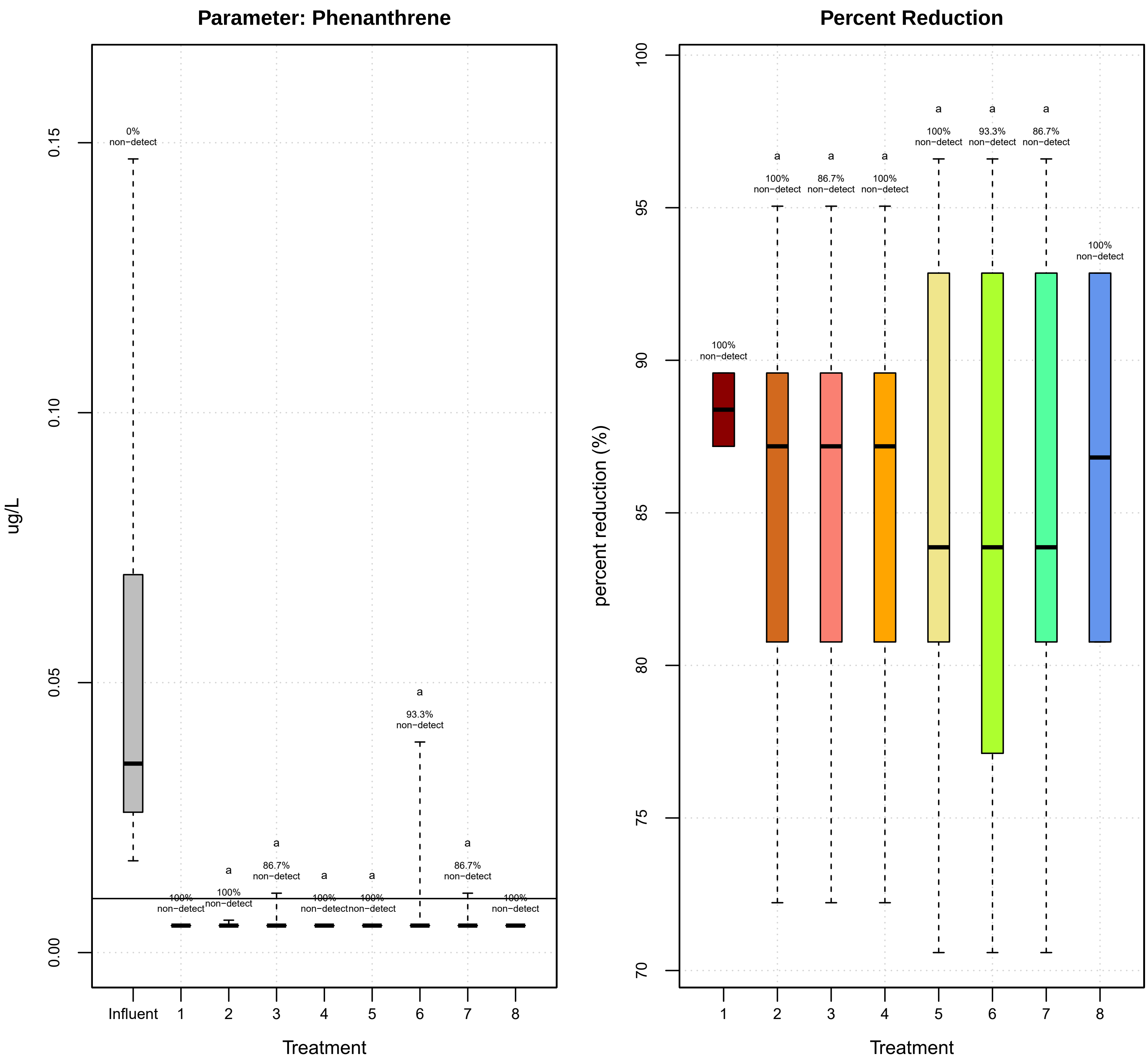
Treatment p−value = <.001

Sample Event p−value = <.001

Interaction p−value = <.001

Note that Treatment 1 and Treatment 8 do not include letters above the boxplots indicating which treatments are statistically different or not different (p-value 0.05). Treatment 1 was eliminated after the first dosing experiment due to continued export of N, P and Cu. Treatment 8 was dropped since no difference was observed between Treatment 7 (70ls/20cp/10ash) and Treatment 8 which was the same media blend but with orifice control.

Figure 39. Dozing Boxplots for Fluoranthene.



treatment 2 = 60/40/aafep−layer

treatment 3 = 70vs/20cp/10ash/compmulch

treatment 4 = 70vs/20cp/10ash/compmulch/aafep−layer

treatment 5 = 70vs/20cp/10ash

treatment 6 = 70ss/20cp/10ash

treatment 7 = 70ls/20cp/10ash

Two−Way ANOVA on Effluent Concentration (ranks)

Treatment p−value = 0.321

Sample Event p−value = <.001

Interaction p−value = 0.043

Two−Way ANOVA on Percent Removal (ranks)

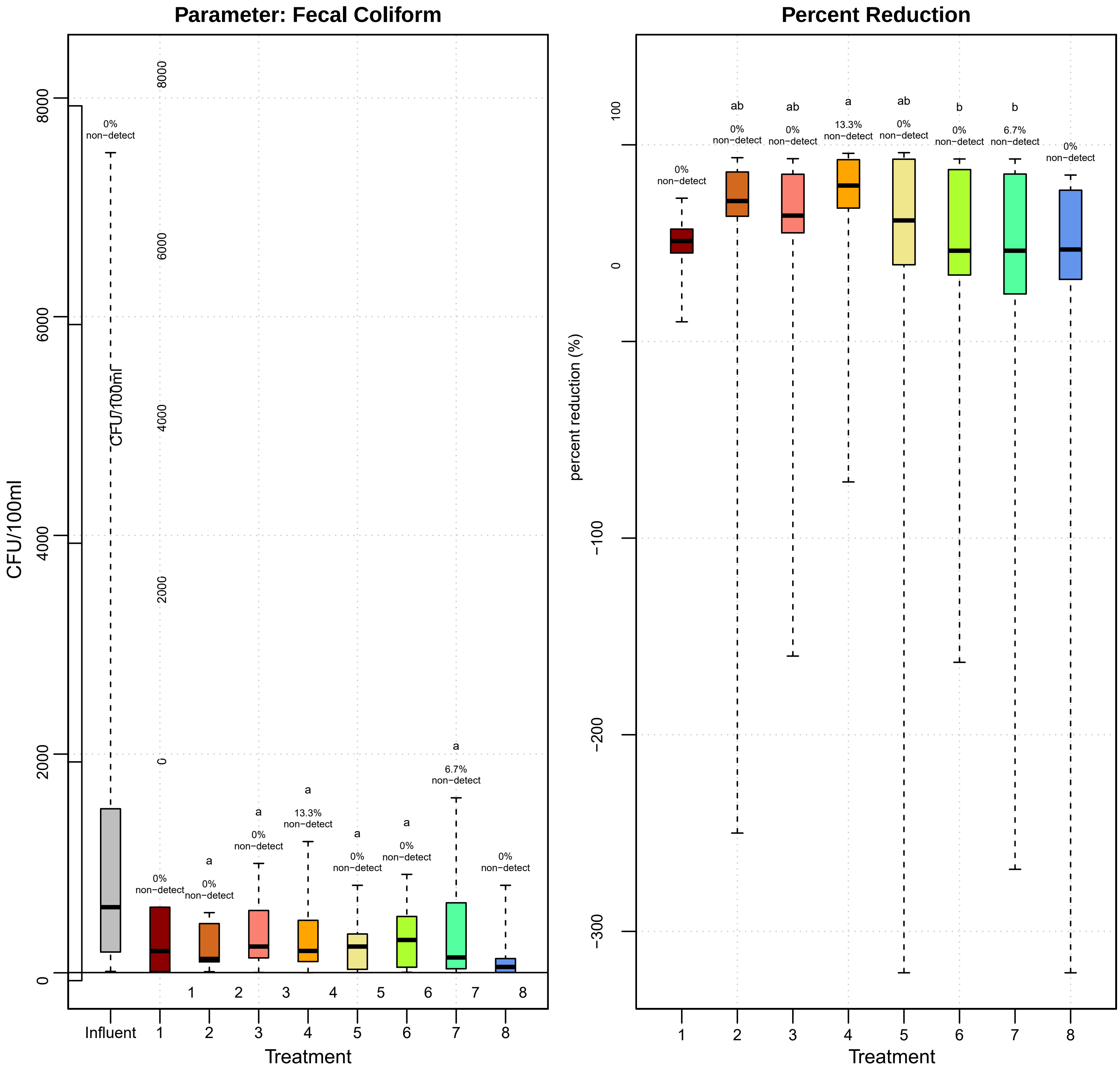
Treatment p−value = 0.513

Sample Event p−value = <.001

Interaction p−value = <.001

Note that Treatment 1 and Treatment 8 do not include letters above the boxplots indicating which treatments are statistically different or not different (p-value 0.05). Treatment 1 was eliminated after the first dosing experiment due to continued export of N, P and Cu. Treatment 8 was dropped since no difference was observed between Treatment 7 (70ls/20cp/10ash) and Treatment 8 which was the same media blend but with orifice control.

Figure 40. Dosing Boxplots for Phenanthrene.



treatment 2 = 60/40/aafep−layer

treatment 3 = 70vs/20cp/10ash/compmulch

treatment 4 = 70vs/20cp/10ash/compmulch/aafep−layer

treatment 5 = 70vs/20cp/10ash

treatment 6 = 70ss/20cp/10ash

treatment 7 = 70ls/20cp/10ash

Two−Way ANOVA on Effluent Concentration (ranks)

Treatment p−value = 0.177

Sample Event p−value = <.001

Interaction p−value = <.001

Two−Way ANOVA on Percent Removal (ranks)

Treatment p−value = 0.003

Sample Event p−value = <.001

Interaction p−value = <.001

Note that Treatment 1 and Treatment 8 do not include letters above the boxplots indicating which treatments are statistically different or not different (p-value 0.05). Treatment 1 was eliminated after the first dosing experiment due to continued export of N, P and Cu. Treatment 8 was dropped since no difference was observed between Treatment 7 (70ls/20cp/10ash) and Treatment 8 which was the same media blend but with orifice control.

Figure 41. Dosing Boxplots for Fecal Coliform.

Dosing Experiments Results – Tables

Table 28. Dosing Experiment Raw Data and Summary Statistics for Total Suspended Solids.

Dosing Event	Flushing Volume (liters)	Percent Water Year	Flow Rate (liters/hr)	Influent Day 1 (mg/L)	flag	Treatment 1 60/40 (mg/L)	flag	Treatment 2 60/40/aafep-layer (mg/L)	flag	Treatment 3 70vs/20cp/10ash/ compmulch (mg/L)	flag	Treatment 4 70vs/20cp/10ash/ compmulch/ aafep-layer (mg/L)	flag	Influent Day 2 (mg/L)	flag	Treatment 5 70vs/20cp/ 10ash (mg/L)	flag	Treatment 6 70ss/20cp/ 10ash (mg/L)	flag	Treatment 7 70ls/20cp/ 10ash (mg/L)	flag	Treatment 8 70ls/20cp/ 10ash/orifice (mg/L)	flag
1	35.62	4	11	36.6		30.8		7.6		34.0		8.1		53.2		10.6		6.0		11.8		7.1	
						40.6		4.6		19.6		8.4				16.4		5.6		8.3		8.0	
						36.7		5.8		12.2		10.9				13.4		7.7		9.5		17.1	
2	35.62	11	11	116.0		23.6		14.0		22.4		4.7		118.0		6.2		7.2		9.5		5.6	
						25.6		11.8		19.0		4.0				7.6		6.2		7.3		34.0	
						26.6		13		15.5		5.3				8.5		8.4		7.5		9.6	
3	35.62	18	11	41.0				10.6		23.0		5.0		52.5		12.0		16.1		14.7			
								9.4		12.8		4.2				15.3		15.6		10.8			
								8.8		21.6		4.3				26.0		16.9		16.1			
4	35.62	26	11	254.0				22.4		31.2		12.3		310.0		36.3		54.7		55.3			
								21.7		25.3		14.7				37.7		35.0		50.3			
								23.7		27.0		12.7				47.7		44.3		64.3			
5	35.62	33	11	111.0				3.4		10.7		1.6		97.0		5.2		10.8		4.3			
								2.7		6.5		2.1				6.9		6.5		3.3			
								3.2		17.9		2.8				6.4		6.9		4.5			
Min				36.6		23.6		2.7		6.5		1.6		52.5		5.2		5.6		3.3		5.6	
Max				254		40.6		23.7		34.0		14.7		310		47.7		54.7		64.3		34	
Mean				112		30.6		10.8		19.9		6.74		126		17.1		16.5		18.5		13.6	
Median				111		28.7		9.4		19.6		5		97		12		8.4		9.5		8.8	
Percent Reduction (bootstrapped lower 95% CI)				0		39		87		71		90		0		83		86		85		83	

U = undetected at the reporting limit noted. For these results, one-half the reporting limit is used to calculate Minimum, Maximum, Mean, and Median.

mg/L = milligrams per liter.

Table 29. Dosing Experiment Raw Data and Summary Statistics for Dissolved Organic Carbon																							
Dosing Event	Flushing Volume (liters)	Percent Water Year	Flow Rate (liters/hr)	Influent Day 1 (mg/L)	flag	Treatment 1 60/40 (mg/L)	flag	Treatment 2 60/40/aafep-layer (mg/L)	flag	Treatment 3 70vs/20cp/10ash/ compmulch (mg/L)	flag	Treatment 4 70vs/20cp/10ash/ compmulch/ aafep-layer (mg/L)	flag	Influent Day 2 (mg/L)	flag	Treatment 5 70vs/20cp/ 10ash (mg/L)	flag	Treatment 6 70ss/20cp/ 10ash (mg/L)	flag	Treatment 7 70ls/20cp/ 10ash (mg/L)	flag	Treatment 8 70ls/20cp/ 10ash/orifice (mg/L)	flag
1	35.62	4	11	2.13		8.52		3.34		3.03		0.85		2.23		1.21		1.11		1.27		1.29	
						8.62		2.56		2.18		0.76				1.07		1.12		1.19		1.24	
						8.10		2.83		2.33		0.83				1.28		1.25		1.16		1.26	
2	35.62	11	11	19.75		21.83		9.62		11.55		5.01		16.36	D	6.84		6.72		8.73		7.86	
						18.76		9.18		11.26		4.90				6.95		7.11	J	7.99		8.32	D
						18.66		10.14		11.59		5.03				7.24		6.56		8.26		8.28	D
3	35.62	18	11	4.03	J			4.62	J	4.40	J	1.97	J	3.69	J	2.67	J	2.55	J	2.68	J		
								3.91	J	4.40	J	1.81	J			2.54	J	2.49	J	2.58	J		
								4.15	J	3.75	J	1.85	J			2.72	J	2.49	J	2.63	J		
4	35.62	26	11	93.37	D			50.81	D	68.70	D	41.05		94.27	D	54.03	D	59.88	D	61.28	D		
								48.07	D	65.53	D	41.17				55.25	D	64.82	D	59.73	D		
								50.52	D	69.67	D	40.77	D			55.91	D	58.46	D	61.66	D		
5	35.62	33	11	12.61	D			11.08		13.45		5.40		11.15	B	9.49	B	9.62	B	10.85	B		
								9.20		13.40		5.20				9.93	B	9.90	B	10.53	B		
								9.91		13.87		5.30				9.74	B	9.84	B	10.90	B		
Min				2.13		8.10		2.56		2.18		0.76		2.23		1.07		1.11		1.16		1.24	
Max				93.37		21.83		50.81		69.67		41.17		94.27		55.91		64.82		61.66		8.32	
Mean				26.40		14.10		15.30		19.90		10.80		25.50		15.10		16.30		16.80		4.71	
Median				12.60		13.60		9.20		11.60		5.01		11.20		6.95		6.72		8.26		4.58	
Percent Reduction				0		-147		15		8		61		0		37		37		33		47	

U = undetected at the reporting limit noted. For these results, one-half the reporting limit is used to calculate Minimum, Maximum, Mean, and Median.

mg/L = milligrams per liter.

Table 30. Dosing Experiment Raw Data and Summary Statistics for Total Phosphorus.																							
Dosing Event	Flushing Volume (liters)	Percent Water Year	Flow Rate (liters/hr)	Influent Day 1 (ug/L)	flag	Treatment 1 60/40 (ug/L)	flag	Treatment 2 60/40/aafep-layer (ug/L)	flag	Treatment 3 70vs/20cp/10ash/ compmulch (ug/L)	flag	Treatment 4 70vs/20cp/10ash/ compmulch/ aafep-layer (ug/L)	flag	Influent Day 2 (ug/L)	flag	Treatment 5 70vs/20cp/ 10ash (ug/L)	flag	Treatment 6 70ss/20cp/ 10ash (ug/L)	flag	Treatment 7 70ls/20cp/ 10ash (ug/L)	flag	Treatment 8 70ls/20cp/ 10ash/orifice (ug/L)	flag
1	35.62	4	11	52.2		295.0		69.9		74.6		22.7		63.5		103.2		45.5		141.5		134.2	
						315.7		55.0		79.7		22.2				87.1		40.4		139.8		140.2	
						369.8		55.3		84.4		20.5				89.5		48.1		124.5		135.6	
2	35.62	11	11	198.7		715.5		144.1		209.9		37.4		280.3		165.4		86.3		192.5		205.1	
						513.0		118.4		190.1		33.4				155.5		84.2		202.7		317.2	
						733.2		110.1		196.7		32.8				160.8		92.1		184.1		208.7	
3	35.62	18	11	95.2				138.7		235.6		38.7		102.9		199.2		99.1		190.5			
								129.5		224.6		35.0				185.9		102.4		198.2			
								100.1		236.9		35.4				200.4		108.6		186.7			
4	35.62	26	11	667.1				205.2		340.9		112.1		757.0		317.8		243.3		334.9			
								195.3		318.7		109.5				301.3		232.3		342.3			
								189.8		336.7		107.6				311.2		231.3		337.8			
5	35.62	33	11	146.0				72.8		132.0		28.7		133.2		84.1		83.8		107.8			
								77.7		112.0		33.6				94.5		82.3		112.2			
								70.5		130.0		35.4				76.4		80.4		101.8			
Min				52.2		295.0		55.0		74.6		20.5		63.5		76.4		40.4		101.8		134.2	
Max				667.1		733.2		205.2		340.9		112.1		757.0		317.8		243.3		342.3		317.2	
Mean				232.0		490.0		115.0		194.0		47.0		267.0		169.0		111.0		193.0		190.0	
Median				146.0		441.0		110.0		197.0		35.0		133.0		161.0		86.3		187.0		173.0	
Percent Reduction (bootstrapped lower 95% CI)				0		-382		22		-28		73		0		-1		41		-21		-53	

U = undetected at the reporting limit noted. For these results, one-half the reporting limit is used to calculate Minimum, Maximum, Mean, Median, and Percent Reduction.

ug/L = micrograms per liter

Table 31. Dosing Experiment Raw Data and Summary Statistics for Ortho-Phosphorus.

Dosing Event	Flushing Volume (liters)	Percent Water Year	Flow Rate (liters/hr)	Influent Day 1 (ug/L)	flag	Treatment 1 60/40 (ug/L)	flag	Treatment 2 60/40/aafep-layer (ug/L)	flag	Treatment 3 70vs/20cp/10ash/ compmulch (ug/L)	flag	Treatment 4 70vs/20cp/10ash/ compmulch/ aafep-layer (ug/L)	flag	Influent Day 2 (ug/L)	flag	Treatment 5 70vs/20cp/ 10ash (ug/L)	flag	Treatment 6 70ss/20cp/ 10ash (ug/L)	flag	Treatment 7 70ls/20cp/ 10ash (ug/L)	flag	Treatment 8 70ls/20cp/ 10ash/orifice (ug/L)	flag
1	35.62	4	11	13.1		325.2		4.8		60.4		3.0	U	8.7		86.5		28.0		124.3		131.1	
						370.2		3.9		59.6		3.0	U			78.3		26.0		131.0		119.2	
						343.8		3.7		59.6		3.0	U			83.4		30.1		116.9		127.3	
2	35.62	11	11	8.6		380.8		11.9		103.1		7.4		11.5		98.8		33.1		108.9		117.9	
						391.1		10.2		101.2		6.1				92.3		31.5		118.1		112.8	
						394.3		9.2		102.1		5.5				96.0		33.9		100.6		116.0	
3	35.62	18	11	10.7				19.3		156.3		11.2		9.2		145.8		48.9		130.0			
								10.0		159.1		8.5				132.2		47.3		137.1			
								12.9		157.0		6.8				138.3		52.0		121.3			
4	35.62	26	11	19.2				13.7		130.6		16.1		11.5		133.1		46.0		101.2			
								7.2		128.3		11.1				120.5		51.1		113.2			
								15.1		123.9		12.5				122.8		50.9		99.8			
5	35.62	33	11	12.7				4.9		88.6		4.3		14.3		41.8		38.0		63.3			
								7.7		65.8		5.9				54.3		37.0		65.3			
								4.0		90.0		3.2				38.4		34.7		58.5			
Min				8.6		325.2		3.7		59.6		1.5		8.7		38.4		26.0		58.5		112.8	
Max				19.2		394.3		19.3		159.1		16.1		14.3		145.8		52.0		137.1		131.1	
Mean				12.9		368.0		9.2		106.0		6.9		11.0		97.5		39.2		106.0		121.0	
Median				12.7		376.0		9.2		102.0		6.1		11.5		96.0		37.0		113.0		119.0	
Percent Reduction				0		-3480		21.9		-784		45.7		0		-839		-266		-926		-1130	

U = undetected at the reporting limit noted. For these results, one-half the reporting limit is used to calculate Minimum, Maximum, Mean, Median, and Percent Reduction.

ug/L = micrograms per liter

Table 32. Dosing Experiment Raw Data and Summary Statistics for Nitrite-N+Nitrate-N.																							
Dosing Event	Flushing Volume (liters)	Percent Water Year	Flow Rate (liters/hr)	Influent Day 1 (mg/L)	flag	Treatment 1 60/40 (mg/L)	flag	Treatment 2 60/40/aafep-layer (mg/L)	flag	Treatment 3 70vs/20cp/10ash/ compmulch (mg/L)	flag	Treatment 4 70vs/20cp/10ash/ compmulch/ aafep-layer (mg/L)	flag	Influent Day 2 (mg/L)	flag	Treatment 5 70vs/20cp/ 10ash (mg/L)	flag	Treatment 6 70ss/20cp/ 10ash (mg/L)	flag	Treatment 7 70ls/20cp/ 10ash (mg/L)	flag	Treatment 8 70ls/20cp/ 10ash/orifice (mg/L)	flag
1	35.62	4	11	0.206		5.050		6.170		0.260		0.246		0.203		0.079		0.104		0.129		0.137	
						4.550		4.080		0.266		0.132				0.084		0.106		0.115		0.125	
						6.110		4.200		0.192		0.115				0.076		0.084		0.126		0.112	
2	35.62	11	11	0.603		1.730		1.540		0.437		0.377		0.556		0.304		0.350		0.394		0.343	
						1.370		1.410		0.459		0.378				0.316		0.392		0.411		0.333	
						1.870		1.080		0.394		0.474				0.332		0.332		0.394		0.329	
3	35.62	18	11	0.420				1.140	D	0.511		0.456		0.417		0.364		0.316		0.416			
								1.640	D	0.627		0.388				0.369		0.360		0.411			
								1.150	D	0.456		0.507				0.399		0.288		0.424			
4	35.62	26	11	1.210	D			3.280	D	1.010		1.180	D	1.030	D	0.777		0.779		0.890			
								5.490	D	0.940		1.210	D			0.761		0.870		0.875			
								8.090	D	0.983		1.160	D			0.748		0.706		0.881			
5	35.62	33	11	0.546				10.200	D	0.805		0.705		0.539		0.868		0.487		0.556			
								9.800	D	0.566		0.657				0.792		0.533		0.553			
								10.400	D	0.925		0.613				0.835		0.426		0.612			
Min				0.206		1.370		1.080		0.192		0.115		0.203		0.076		0.084		0.115		0.112	
Max				1.210		6.110		10.400		1.010		1.210		1.030		0.868		0.870		0.890		0.343	
Mean				0.597		3.450		4.640		0.589		0.573		0.549		0.474		0.409		0.479		0.230	
Median				0.546		3.210		4.080		0.511		0.474		0.539		0.369		0.360		0.416		0.233	
Percent Reduction				0		-1310		-939		-7		5		0		17		29		15		39	

U = undetected at the reporting limit noted. For these results, one-half the reporting limit is used to calculate Minimum, Maximum, Mean, and Median.
mg/L = milligrams per liter.

Table 33. Dosing Experiment Raw Data and Summary Statistics for Copper.

Dosing Event	Flushing Volume (liters)	Percent Water Year	Flow Rate (liters/hr)	Influent Day 1 (ug/L)	flag	Treatment 1 60/40 (ug/L)	flag	Treatment 2 60/40/aafep-layer (ug/L)	flag	Treatment 3 70vs/20cp/10ash/ compmulch (ug/L)	flag	Treatment 4 70vs/20cp/10ash/ compmulch/ aafep-layer (ug/L)	flag	Influent Day 2 (ug/L)	flag	Treatment 5 70vs/20cp/ 10ash (ug/L)	flag	Treatment 6 70ss/20cp/ 10ash (ug/L)	flag	Treatment 7 70ls/20cp/ 10ash (ug/L)	flag	Treatment 8 70ls/20cp/ 10ash/orifice (ug/L)	flag
1	35.62	4	11	21.4		13.6		2.3		12.2		1.6		24.8	D	3.8		2.7		3.5		3.6	
						14.6		1.9		8.0		1.5				3.8		2.2		3.2		3.3	
						14.6		2.0		8.2		1.7				3.9		2.6		3.7		4.1	
2	35.62	11	11	92.0		27.5		7.4		23.6		4.0		87.4	D	17.3		14.0		18.1		16.7	
						28.7		7.6		22.0		4.1				16.8		14.5		16.9		18.1	D
						29.2		8.3		22.5		3.8				17.4		14.2		16.9		17.0	D
3	35.62	18	11	36.2	D			6.6		17.5		3.5		31.6		11.7		11.6		12.4			
								5.4		16.7		3.3				12.1		12.2		11.6			
								5.2		15.7		3.3				13.1		11.1		11.7			
4	35.62	26	11	246.0				20.8		66.3		15.4		222.0		53.3		50.3		56.6			
								14.9		59.1		15.4				54.4		52.8		54.2			
								19.8		64.3		16.6				53.5		47.1		58.7			
5	35.62	33	11	95.2				2.6		25.3		10.5		73.9		15.6		15.8		15.8			
								2.9		25.1		7.9				17.3		15.7		15.4			
								2.3		26.0		5.6				15.2		15.2		15.7			
Min				21.4		13.6		1.9		8.0		1.5		24.8		3.8		2.2		3.2		3.3	
Max				246.0		29.2		20.8		66.3		16.6		222.0		54.4		52.8		58.7		18.1	
Mean				98.2		21.4		7.3		27.5		6.5		87.9		20.6		18.8		21.0		10.4	
Median				92.0		21.0		5.4		22.5		4.0		73.9		15.6		14.2		15.7		10.4	
Percent Reduction				0.0		51		91		67		93		0		76		79		76		83	

U = undetected at the reporting limit noted. For these results, one-half the reporting limit is used to calculate Minimum, Maximum, Mean, Median, and Percent Reduction.

ug/L = micrograms per liter

Table 34. Dosing Experiment Raw Data and Summary Statistics for Copper, Dissolved.																							
Dosing Event	Flushing Volume (liters)	Percent Water Year	Flow Rate (liters/hr)	Influent Day 1 (ug/L)	flag	Treatment 1 60/40 (ug/L)	flag	Treatment 2 60/40/aafep-layer (ug/L)	flag	Treatment 3 70vs/20cp/10ash/ compmulch (ug/L)	flag	Treatment 4 70vs/20cp/10ash/ compmulch/ aafep-layer (ug/L)	flag	Influent Day 2 (ug/L)	flag	Treatment 5 70vs/20cp/ 10ash (ug/L)	flag	Treatment 6 70ss/20cp/ 10ash (ug/L)	flag	Treatment 7 70ls/20cp/ 10ash (ug/L)	flag	Treatment 8 70ls/20cp/ 10ash/orifice (ug/L)	flag
1	35.62	4	11	6.4		8.1		0.9		4.1		0.5	U	6.4	J	2.2	J	1.3	J	1.8	J	2.0	J
						8.7		0.6		3.0		0.5	U			2.2	J	1.4	J	1.8	J	1.7	J
						8.1		0.7		3.5		0.5	U			2.3	J	1.4	J	1.9	J	1.9	J
2	35.62	11	11	41.6	J	19.2	J	2.8	J	17.4	J	1.7	J	40.3		13.1		10.3		12.6		12.1	
						18.9	J	2.6	J	16.8	J	1.6	J			13.8		10.8		12.3		12.1	
						18.9	J	3.3	J	17.6	J	1.7	J			14.6		9.9		13.3		11.7	
3	35.62	18	11	15.0	J			3.8	J	10.4	J	1.2	J	12.8	J	7.5	J	5.8	J	8.0	J		
								1.5	J	11.2	J	1.0	J			7.0	J	6.5	J	7.6	J		
								1.9	J	9.3	J	1.0	J			7.1	J	6.2	J	7.5	J		
4	35.62	26	11	120.0				10.8		47.1		7.0		222.0		53.3		50.3		56.6			
								6.7		45.4		6.9				54.4		52.8		54.2			
								11.2		50.0		8.1				53.5		47.1		58.7			
5	35.62	33	11	27.4				1.1		16.7		3.3		29.4		12.2		11.9		15.2			
								1.0		24.7		2.0				13.2		18.4		15.1			
								0.9		23.1		12.6				12.0		14.0		14.0			
Min				6.4		8.1		0.6		3.0		0.3		6.4		2.2		1.3		1.8		1.7	
Max				120		19.2		11.2		50.0		12.6		222.0		54.4		52.8		58.7		12.1	
Mean				42.1		13.6		3.3		20.0		3.3		62.2		17.9		16.5		18.7		6.9	
Median				27.4		13.8		1.9		16.8		1.7		29.4		12.2		10.3		12.6		6.9	
Percent Reduction (bootstrapped lower 95% CI)				0		12		91		43		91		0		62		66		61		71	

U = undetected at the reporting limit noted. For these results, one-half the reporting limit is used to calculate Minimum, Maximum, Mean, Median, and Percent Reduction.

ug/L = micrograms per liter

Table 35. Dosing Experiment Raw Data and Summary Statistics for Zinc.																							
Dosing Event	Flushing Volume (liters)	Percent Water Year	Flow Rate (liters/hr)	Influent Day 1 (ug/L)	flag	Treatment 1 60/40 (ug/L)	flag	Treatment 2 60/40/aafep-layer (ug/L)	flag	Treatment 3 70vs/20cp/10ash/ compmulch (ug/L)	flag	Treatment 4 70vs/20cp/10ash/ compmulch/ aafep-layer (ug/L)	flag	Influent Day 2 (ug/L)	flag	Treatment 5 70vs/20cp/ 10ash (ug/L)	flag	Treatment 6 70ss/20cp/ 10ash (ug/L)	flag	Treatment 7 70ls/20cp/ 10ash (ug/L)	flag	Treatment 8 70ls/20cp/ 10ash/orifice (ug/L)	flag
1	35.62	4	11	103.0		57.3		4.2		10.2		1.5	J	135.0	D	5.0		4.3		7.3		7.3	
						11.7		3.5	J	8.4		1.3	J			4.5		4.4		6.8		6.5	
						12.4		4.2		8.3		1.4	J			4.4		10.4		7.5		7.6	
2	35.62	11	11	300.0		45.5		20.2		36.1		10.7		283.0	D	27.9		26.7		122.0		32.2	
						48.4		21.2		35.4		9.0				26.9		26.1		33.5		38.6	D
						46.7		24.2		37.5		8.6				26.9		34.2		31.7		36.5	D
3	35.62	18	11	152.0	D			12.6		17.8		8.9		131.0		14.9		17.7		19.0			
								11.5		16.5		8.1				16.0		17.3		17.8			
								12.3		19.2		9.0				16.3		16.3		17.6			
4	35.62	26	11	743.0				73.2		75.2		46.5		681.0		63.0		62.7		83.7			
								54.6		72.7		52.9				64.4		67.7		79.3			
								79.1		83.1		50.1				61.1		63.9		83.4			
5	35.62	33	11	384.0				16.7		23.1		7.9		301.0		19.0		25.6		21.4			
								11.0		20.4		8.0				18.0		22.5		21.9			
								11.9		23.6		9.4				16.1		21.1		24.7			
Min				103.0		11.7		3.5		8.3		1.3		131.0		4.4		4.3		6.8		6.5	
Max				743.0		57.3		79.1		83.1		52.9		681.0		64.4		67.7		122.0		38.6	
Mean				336.0		37.0		24.0		32.5		15.5		306.0		25.6		28.1		38.5		21.5	
Median				300.0		46.1		12.6		23.1		8.9		283.0		18.0		22.5		21.9		19.9	
Percent Reduction				0		79		94		90		96		0		92		91		88		91	

U = undetected at the reporting limit noted. For these results, one-half the reporting limit is used to calculate Minimum, Maximum, Mean, Median, and Percent Reduction.

ug/L = micrograms per liter

Table 36. Dosing Experiment Raw Data and Summary Statistics for Zinc, Dissolved.

Dosing Event	Flushing Volume (liters)	Percent Water Year	Flow Rate (liters/hr)	Influent Day 1 (ug/L)	flag	Treatment 1 60/40 (ug/L)	flag	Treatment 2 60/40/aafep-layer (ug/L)	flag	Treatment 3 70vs/20cp/10ash/ compmulch (ug/L)	flag	Treatment 4 70vs/20cp/10ash/ compmulch/ aafep-layer (ug/L)	flag	Influent Day 2 (ug/L)	flag	Treatment 5 70vs/20cp/ 10ash (ug/L)	flag	Treatment 6 70ss/20cp/ 10ash (ug/L)	flag	Treatment 7 70ls/20cp/ 10ash (ug/L)	flag	Treatment 8 70ls/20cp/ 10ash/orifice (ug/L)	flag
1	35.62	4	11	40.9		4.7		1.0	J	3.1	J	4.0	U	52.6	J	3.3	J	3.6	J	66.7	J	4.4	J
						4.9		1.0	J	3.3	J	4.0	U			3.3	J	3.4	J	4.4	J	4.4	J
						5.1		1.0	J	4.1		4.0	U			3.4	J	3.2	J	4.2	J	4.2	J
2	35.62	11	11	139.0	J	28.6	J	7.9	J	23.5	J	4.5	J	122.0		20.6		20.1		22.6		22.6	
						28.5	J	7.0	J	24.8	J	3.3	J			21.3		20.0		23.1		22.7	
						28.1	J	11.4	J	25.3	J	3.5	J			20.9		19.7		23.7		22.6	
3	35.62	18	11	66.0	J			4.3	J	7.0	J	2.4	J	64.2	J	7.7	J	7.2	J	8.9	J		
								2.6	J	7.4	J	2.3	J			7.4	J	7.8	J	9.0	J		
								3.5	J	7.4	J	2.8	J			7.1	J	7.2	J	8.3	J		
4	35.62	26	11	305.0				27.1		45.0		14.8		386.0		43.7		42.0		55.1			
								17.8		55.6		14.2				41.2		41.3		57.2			
								31.1		51.9		12.7				37.8		47.3		53.8			
5	35.62	33	11	148.0				8.6		17.9		3.8		144.0		17.5		17.4		18.3			
								6.1		19.5		3.7				13.5		20.7		18.7			
								7.5		19.6		4.4				11.7		20.5		19.9			
Min				40.9		4.7		1.0		3.1		2.0		52.6		3.3		3.2		4.2		4.2	
Max				305.0		28.6		31.1		55.6		14.8		386.0		43.7		47.3		66.7		22.7	
Mean				140.0		16.6		9.2		21.0		5.2		154.0		17.4		18.8		26.3		13.5	
Median				139.0		16.6		7.0		19.5		3.5		122.0		13.5		19.7		19.9		13.5	
Percent Reduction (bootstrapped lower 95% CI)				0		84		95		87		96		0		89		88		78		87	

U = undetected at the reporting limit noted. For these results, one-half the reporting limit is used to calculate Minimum, Maximum, Mean, Median, and Percent Reduction.
ug/L = micrograms per liter

Table 37. Dosing Experiment Raw Data and Summary Statistics for Lead.																							
Dosing Event	Flushing Volume (liters)	Percent Water Year	Flow Rate (liters/hr)	Influent Day 1 (ug/L)	flag	Treatment 1 60/40 (ug/L)	flag	Treatment 2 60/40/aafep-layer (ug/L)	flag	Treatment 3 70vs/20cp/10ash/ compmulch (ug/L)	flag	Treatment 4 70vs/20cp/10ash/ compmulch/ aafep-layer (ug/L)	flag	Influent Day 2 (ug/L)	flag	Treatment 5 70vs/20cp/ 10ash (ug/L)	flag	Treatment 6 70ss/20cp/ 10ash (ug/L)	flag	Treatment 7 70ls/20cp/ 10ash (ug/L)	flag	Treatment 8 70ls/20cp/ 10ash/orifice (ug/L)	flag
1	35.62	4	11	5.8		1.0		0.4		1.0		0.2		6.9		0.4		0.4		0.6		0.6	
						1.1		0.4		0.7		0.2				0.4		0.3		0.5		0.5	
						1.1		0.4		0.7		0.2				0.4		0.3		0.5		0.6	
2	35.62	11	11	13.7		2.6		1.7		1.8		0.8		13.9	D	1.3		1.2		1.7		1.6	
						2.8		1.7		1.7		0.7				1.3		1.2		1.6		2.0	D
						2.8		1.9		1.8		0.7				1.3		1.3		1.6		1.9	D
3	35.62	18	11	5.6	D			1.4		1.6		0.8		6.0		1.3		1.4		1.4			
								1.4		1.3		0.7				1.3		1.5		1.3			
								1.3		1.6		0.8				1.3		1.4		1.4			
4	35.62	26	11	22.0				3.4		3.7		2.0		27.3		3.0		3.4		4.7			
								2.7		3.7		2.1				3.1		3.2		3.9			
								3.3		4.0		2.1				3.3		3.1		4.4			
5	35.62	33	11	11.5				0.2		0.6		0.2		11.2		0.4		0.7		0.7			
								0.2		0.6		0.3				0.5		0.6		0.7			
								0.2		0.8		0.3				0.4		0.6		0.6			
Min				5.6		1.0		0.2		0.6		0.2		6.0		0.4		0.3		0.5		0.5	
Max				22.0		2.8		3.4		4.0		2.1		27.3		3.3		3.4		4.7		2.0	
Mean				11.7		1.9		1.4		1.7		0.8		13.1		1.3		1.4		1.7		1.2	
Median				11.5		1.9		1.4		1.6		0.7		11.2		1.3		1.2		1.4		1.1	
Percent Reduction				0		81		88		85		93		0		90		89		87		89	

U = undetected at the reporting limit noted. For these results, one-half the reporting limit is used to calculate Minimum, Maximum, Mean, Median, and Percent Reduction.

ug/L = micrograms per liter

Table 38. Experiment Raw Data and Summary Statistics for Lead, Dissolved.

Dosing Event	Flushing Volume (liters)	Percent Water Year	Flow Rate (liters/hr)	Influent Day 1 (ug/L)	flag	Treatment 1 60/40 (ug/L)	flag	Treatment 2 60/40/aafep-layer (ug/L)	flag	Treatment 3 70vs/20cp/10ash/ compmulch (ug/L)	flag	Treatment 4 70vs/20cp/10ash/ compmulch/ aafep-layer (ug/L)	flag	Influent Day 2 (ug/L)	flag	Treatment 5 70vs/20cp/ 10ash (ug/L)	flag	Treatment 6 70ss/20cp/ 10ash (ug/L)	flag	Treatment 7 70ls/20cp/ 10ash (ug/L)	flag	Treatment 8 70ls/20cp/ 10ash/orifice (ug/L)	flag
1	35.62	4	11	0.3		0.1		0.1	U	0.1	J	0.1	U	0.2	J	0.1	J	0.1	U,J	0.1	J	0.1	J
						0.1		0.1	U	0.1	J	0.1	U			0.1	U,J	0.1	U,J	0.1	J	0.3	J
						0.1		0.1	U	0.1	J	0.1	U			0.1	J	0.1	U,J	0.1	J	0.1	J
2	35.62	11	11	0.6	J	0.6	J	0.2	J	0.4	J	0.1	J	0.7		0.4		0.3		0.4		0.4	
						0.5	J	0.2	J	0.4	J	0.1	J			0.4		0.4		0.4		0.4	
						0.5	J	0.2	J	0.5	J	0.1	J			0.4		0.4		0.4		0.4	
3	35.62	18	11	0.4	J			0.2	J	0.2	J	0.1	J	0.2	J	0.1	J	0.1	J	0.2	J		
								0.2	J	0.2	J	0.1	J			0.1	J	0.1	J	0.2	J		
								0.2	J	0.2	J	0.1	J			0.1	J	0.1	J	0.2	J		
4	35.62	26	11	1.2				0.8		1.7		0.5		1.1		1.2		0.9		1.7			
								0.6		1.6		0.4				1.1		0.7		1.8			
								1.1		1.7		0.4				0.9		1.4		1.6			
5	35.62	33	11	0.5				0.1	J	0.1		0.1		0.4		0.1		0.1		0.2			
								0.1	J	0.3		0.1				0.1		0.3		0.2			
								0.1	J	0.2		0.1				0.1		0.2		0.3			
Min				0.3		0.1		0.1		0.1		0.1		0.2		0.1		0.1		0.1		0.1	
Max				1.2		0.6		1.1		1.7		0.5		1.1		1.2		1.4		1.8		0.4	
Mean				0.6		0.3		0.3		0.5		0.2		0.5		0.4		0.3		0.5		0.3	
Median				0.5		0.3		0.2		0.2		0.1		0.4		0.1		0.2		0.2		0.3	
Percent Reduction				0		32		64		33		75		0		44		46		18		37	

U = undetected at the reporting limit noted. For these results, one-half the reporting limit is used to calculate Minimum, Maximum, Mean, Median, and Percent Reduction.
ug/L = micrograms per liter

Table 39. Dosing Experiment Raw Data and Summary Statistics for Aluminum.																							
Dosing Event	Flushing Volume (liters)	Percent Water Year	Flow Rate (liters/hr)	Influent Day 1 (ug/L)	flag	Treatment 1 60/40 (ug/L)	flag	Treatment 2 60/40/aafep-layer (ug/L)	flag	Treatment 3 70vs/20cp/10ash/ compmulch (ug/L)	flag	Treatment 4 70vs/20cp/10ash/ compmulch/ aafep-layer (ug/L)	flag	Influent Day 2 (ug/L)	flag	Treatment 5 70vs/20cp/ 10ash (ug/L)	flag	Treatment 6 70ss/20cp/ 10ash (ug/L)	flag	Treatment 7 70ls/20cp/ 10ash (ug/L)	flag	Treatment 8 70ls/20cp/ 10ash/orifice (ug/L)	flag
1	35.62	4	11																				
2	35.62	11	11																				
3	35.62	18	11																				
4	35.62	26	11																				
5	35.62	33	11	3670				88.5		1000		165.0		3110		492.0		700.0		519.0			
								86.5		463.0		178.0				541.0		540.0		519.0			
								89.2		1030		180.0				439.0		599.0		510.0			
Min				3670				86.5		463.0		165.0		3110		439.0		540.0		510.0			
Max				3670				89.2		1030		180.0		3110		541.0		700.0		519.0			
Mean				3670				88.1		831.0		174.3		3110		490.7		613.0		516.0			
Median				3670				88.5		1000		178.0		3110		541.0		700.0		519.0			
Percent Reduction				0				98		77		95		0		84		80		83			

U = undetected at the reporting limit noted. For these results, one-half the reporting limit is used to calculate Minimum, Maximum, Mean, Median, and Percent Reduction.

ug/L = micrograms per liter

Table 40. Dosing Experiment Raw Data and Summary Statistics for Total Petroleum Hydrocarbons Diesel Oil Range (C12-C24).																							
Dosing Event	Flushing Volume (liters)	Percent Water Year	Flow Rate (liters/hr)	Influent Day 1 (mg/L)	flag	Treatment 1 60/40 (mg/L)	flag	Treatment 2 60/40/aafep-layer (mg/L)	flag	Treatment 3 70vs/20cp/10ash/ compmulch (mg/L)	flag	Treatment 4 70vs/20cp/10ash/ compmulch/ aafep-layer (mg/L)	flag	Influent Day 2 (mg/L)	flag	Treatment 5 70vs/20cp/ 10ash (mg/L)	flag	Treatment 6 70ss/20cp/ 10ash (mg/L)	flag	Treatment 7 70ls/20cp/ 10ash (mg/L)	flag	Treatment 8 70ls/20cp/ 10ash/orifice (mg/L)	flag
1	35.62	4	11	0.217		0.100	U	0.100	U	0.100	U	0.100	U	0.181		0.100	U	0.100	U	0.100	U	0.100	U
						0.100	U	0.100	U	0.100	U	0.100	U			0.100	U	0.100	U	0.100	U	0.100	U
						0.107		0.100	U	0.100	U	0.100	U			0.100	U	0.100	U	0.100	U	0.100	U
2	35.62	11	11	2.760		0.490		0.186		0.100	U	0.100	U	1.660		0.100	U	0.111		0.308		0.100	U
						0.420		0.480		0.100	U	0.100	U			0.146		0.100	U	0.213		0.100	U
						0.404		0.324		0.100	U	0.100	U			0.180		0.116		0.117		0.238	
3	35.62	18	11	0.556				0.149		0.100	U	0.100	U	0.461		0.100	U	0.100	U	0.100	U		
								0.156		0.100	U	0.100	U			0.100	U	0.100	U	0.100	U		
								0.166		0.100	U	0.100	U			0.100	U	0.100	U	0.100	U		
4	35.62	26	11	5.120	D			2.470		1.830		1.090		6.85	E	1.330		2.290		2.630			
								1.690		1.840		1.560				1.290		2.350		2.160			
								2.080		1.920		1.220				1.510		1.720		2.670			
5	35.62	33	11	0.861	D			0.374		0.369		0.246		0.676	D	0.100	U	0.197		0.273			
								0.359		0.407		0.247				0.125		0.198		0.342			
								0.382		0.383		0.287				0.100	U	0.188		0.327			
Min				0.217		0.050		0.050		0.050		0.05		0.181		0.050		0.050		0.050		0.050	
Max				5.120		0.490		2.470		1.920		1.560		6.850		1.510		2.350		2.670		0.238	
Mean				1.9		0.254		0.598		0.48		0.34		1.97		0.335		0.501		0.623		0.081	
Median				0.861		0.256		0.324		0.05		0.05		0.676		0.05		0.111		0.213		0.05	
Percent Reduction				0		76		71		77		82		0		85		79		73		83	

U = undetected at the reporting limit noted. For these results, one-half the reporting limit is used to calculate Minimum, Maximum, Mean, and Median.
mg/L = milligrams per liter.

Table 41. Dosing Experiment Raw Data and Summary Statistics for Total Petroleum Hydrocarbons Motor Oil Range (C24-C38).																							
Dosing Event	Flushing Volume (liters)	Percent Water Year	Flow Rate (liters/hr)	Influent Day 1 (mg/L)	flag	Treatment 1 60/40 (mg/L)	flag	Treatment 2 60/40/aafep-layer (mg/L)	flag	Treatment 3 70vs/20cp/10ash/ compmulch (mg/L)	flag	Treatment 4 70vs/20cp/10ash/ compmulch/ aafep-layer (mg/L)	flag	Influent Day 2 (mg/L)	flag	Treatment 5 70vs/20cp/ 10ash (mg/L)	flag	Treatment 6 70ss/20cp/ 10ash (mg/L)	flag	Treatment 7 70ls/20cp/ 10ash (mg/L)	flag	Treatment 8 70ls/20cp/ 10ash/orifice (mg/L)	flag
1	35.62	4	11	0.622		0.238	U	0.238	U	0.238	U	0.238	U	0.762		0.238	U	0.238	U	0.238	U	0.238	U
						0.238	U	0.238	U	0.238	U	0.238	U			0.238	U	0.238	U	0.238	U	0.238	U
						0.238	U	0.238	U	0.238	U	0.238	U			0.238	U	0.238	U	0.238	U	0.238	U
2	35.62	11	11	4.260		0.467		0.238	U	0.238	U	0.238	U	3.490		0.238	U	0.255		0.508		0.210	
						0.433		0.390		0.238	U	0.238	U			0.351		0.238	U	0.440		0.238	U
						0.363		0.292		0.238	U	0.238	U			0.379		0.237		0.286		0.463	
3	35.62	18	11	1.260				0.228		0.238	U	0.238	U	1.500		0.238	U	0.238	U	0.238	U		
								0.238	U	0.238	U	0.238	U			0.238	U	0.238	U	0.238	U		
								0.204		0.231		0.238	U			0.238	U	0.238	U	0.238	U		
4	35.62	26	11	8.220	D			1.980		1.850		1.180		9.710		1.760		1.600		2.510			
								1.150		1.820		1.540				1.540		1.660		2.160			
								1.600		2.090		1.150				1.710		1.410		2.330			
5	35.62	33	11	2.980				0.260		0.425		0.200	U	2.270	D	0.200	U	0.257		0.346			
								0.347		0.410		0.214				0.200	U	0.284		0.407			
								0.283		0.441		0.226				0.200	U	0.293		0.437			
Min				0.622		0.119		0.100		0.100		0.100		0.762		0.100		0.100		0.100		0.119	
Max				8.220		0.467		1.980		2.090		1.540		9.710		1.760		1.660		2.510		0.463	
Mean				3.470		0.260		0.482		0.538		0.354		3.550		0.449		0.446		0.668		0.179	
Median				2.980		0.231		0.260		0.100		0.100		2.270		0.100		0.237		0.346		0.100	
Percent Reduction				0		87		87		87		90		0		90		89		85		90	

U = undetected at the reporting limit noted. For these results, one-half the reporting limit is used to calculate Minimum, Maximum, Mean, and Median.
mg/L = milligrams per liter.

Table 42. Dosing Experiment Raw Data and Summary Statistics for Benzo(a)pyrene.																							
Dosing Event	Flushing Volume (liters)	Percent Water Year	Flow Rate (liters/hr)	Influent Day 1 (ug/L)	flag	Treatment 1 60/40 (ug/L)	flag	Treatment 2 60/40/aafep-layer (ug/L)	flag	Treatment 3 70vs/20cp/10ash/ compmulch (ug/L)	flag	Treatment 4 70vs/20cp/10ash/ compmulch/ aafep-layer (ug/L)	flag	Influent Day 2 (ug/L)	flag	Treatment 5 70vs/20cp/ 10ash (ug/L)	flag	Treatment 6 70ss/20cp/ 10ash (ug/L)	flag	Treatment 7 70ls/20cp/ 10ash (ug/L)	flag	Treatment 8 70ls/20cp/ 10ash/orifice (ug/L)	flag
1	35.62	4	11	0.019		0.010	U	0.010	U	0.010	U	0.010	U	0.015		0.010	U	0.010	U	0.010	U	0.010	U
						0.010	U	0.010	U	0.010	U	0.010	U			0.010	U	0.010	U	0.010	U	0.010	U
						0.010	U	0.010	U	0.010	U	0.010	U			0.010	U	0.010	U	0.010	U	0.010	U
2	35.62	11	11	0.025		0.010	U	0.010	U	0.010	U	0.010	U	0.047		0.010	U	0.010	U	0.010	U	0.010	U
						0.010	U	0.012	U	0.010	U	0.010	U			0.010	U	0.010	U	0.010	U	0.010	U
						0.010	U	0.010	U	0.010	U	0.010	U			0.010	U	0.010	U	0.010	U	0.010	U
3	35.62	18	11	0.013				0.010	U	0.010	U	0.010	U	0.020		0.010	U	0.010	U	0.010	U		
								0.010	U	0.010	U	0.010	U			0.010	U	0.010	U	0.010	U		
								0.010	U	0.010	U	0.010	U			0.010	U	0.010	U	0.010	U		
4	35.62	26	11	0.025	U,D			0.010	U	0.010	U	0.010	U	0.072	D	0.010	U	0.010	U	0.010	U		
								0.010	U	0.010	U	0.010	U			0.010	U	0.012		0.010	U		
								0.010	U	0.010	U	0.010	U			0.010	U	0.010	U	0.010	U		
5	35.62	33	11	0.022				0.010	U	0.010	U	0.010	U	0.035		0.010	U	0.010	U	0.010	U		
								0.010	U	0.010	U	0.010	U			0.010	U	0.010	U	0.010	U		
								0.010	U	0.010	U	0.010	U			0.010	U	0.010	U	0.010	U		
Min				0.013		0.005		0.005		0.005		0.005		0.015		0.005		0.005		0.005		0.005	
Max				0.025		0.005		0.006		0.005		0.005		0.072		0.005		0.012		0.005		0.005	
Mean				0.021		0.005		0.005		0.005		0.005		0.038		0.005		0.005		0.005		0.005	
Median				0.022		0.005		0.005		0.005		0.005		0.035		0.005		0.005		0.005		0.005	
Percent Reduction				0		77		74		75		75		0		82		81		82		78	

U = undetected at the reporting limit noted. For these results, one-half the reporting limit is used to calculate Minimum, Maximum, Mean, Median, and Percent Reduction.

ug/L = micrograms per liter

Table 43. Dosing Experiment Raw Data and Summary Statistics for Benzo(k)fluoranthene.																							
Dosing Event	Flushing Volume (liters)	Percent Water Year	Flow Rate (liters/hr)	Influent Day 1 (ug/L)	flag	Treatment 1 60/40 (ug/L)	flag	Treatment 2 60/40/aafep-layer (ug/L)	flag	Treatment 3 70vs/20cp/10ash/ compmulch (ug/L)	flag	Treatment 4 70vs/20cp/10ash/ compmulch/ aafep-layer (ug/L)	flag	Influent Day 2 (ug/L)	flag	Treatment 5 70vs/20cp/ 10ash (ug/L)	flag	Treatment 6 70ss/20cp/ 10ash (ug/L)	flag	Treatment 7 70ls/20cp/ 10ash (ug/L)	flag	Treatment 8 70ls/20cp/ 10ash/orifice (ug/L)	flag
1	35.62	4	11	0.015		0.010	U	0.010	U	0.010	U	0.010	U	0.013		0.010	U	0.010	U	0.010	U	0.010	U
						0.010	U	0.010	U	0.010	U	0.010	U			0.010	U	0.010	U	0.010	U	0.010	U
						0.010	U	0.010	U	0.010	U	0.010	U			0.010	U	0.010	U	0.010	U	0.010	U
2	35.62	11	11	0.011		0.010	U	0.010	U	0.010	U	0.010	U	0.022		0.010	U	0.010	U	0.010	U	0.010	U
						0.010	U	0.012	U	0.010	U	0.010	U			0.010	U	0.010	U	0.010	U	0.010	U
						0.010	U	0.010	U	0.010	U	0.010	U			0.010	U	0.010	U	0.010	U	0.010	U
3	35.62	18	11	0.010	U			0.010	U	0.010	U	0.010	U	0.01	U	0.010	U	0.010	U	0.010	U		
								0.010	U	0.010	U	0.010	U			0.010	U	0.010	U	0.010	U		
								0.010	U	0.010	U	0.010	U			0.010	U	0.010	U	0.010	U		
4	35.62	26	11	0.025	U,D			0.010	U	0.010	U	0.010	U	0.025	U,D	0.010	U	0.010	U	0.010	U		
								0.010	U	0.010	U	0.010	U			0.010	U	0.011		0.010	U		
								0.010	U	0.010	U	0.010	U			0.010	U	0.010	U	0.010	U		
5	35.62	33	11	0.015				0.010	U	0.010	U	0.010	U	0.015		0.010	U	0.010	U	0.010	U		
								0.010	U	0.010	U	0.010	U			0.010	U	0.010	U	0.010	U		
								0.010	U	0.010	U	0.010	U			0.010	U	0.010	U	0.010	U		
Min				0.005		0.005		0.005		0.005		0.005		0.005		0.005		0.005		0.005		0.005	
Max				0.025		0.005		0.006		0.005		0.005		0.025		0.005		0.011		0.005		0.005	
Mean				0.014		0.005		0.005		0.005		0.005		0.016		0.005		0.005		0.005		0.005	
Median				0.015		0.005		0.005		0.005		0.005		0.015		0.005		0.005		0.005		0.005	
Percent Reduction				0		61		53		54		54		0		57		56		57		69	

U = undetected at the reporting limit noted. For these results, one-half the reporting limit is used to calculate Minimum, Maximum, Mean, Median, and Percent Reduction.

ug/L = micrograms per liter

Table 44. Dosing Experiment Raw Data and Summary Statistics for Chrysene.																							
Dosing Event	Flushing Volume (liters)	Percent Water Year	Flow Rate (liters/hr)	Influent Day 1 (ug/L)	flag	Treatment 1 60/40 (ug/L)	flag	Treatment 2 60/40/aafep-layer (ug/L)	flag	Treatment 3 70vs/20cp/10ash/ compmulch (ug/L)	flag	Treatment 4 70vs/20cp/10ash/ compmulch/ aafep-layer (ug/L)	flag	Influent Day 2 (ug/L)	flag	Treatment 5 70vs/20cp/ 10ash (ug/L)	flag	Treatment 6 70ss/20cp/ 10ash (ug/L)	flag	Treatment 7 70ls/20cp/ 10ash (ug/L)	flag	Treatment 8 70ls/20cp/ 10ash/orifice (ug/L)	flag
1	35.62	4	11	0.033		0.010	U	0.010	U	0.010	U	0.010	U	0.022		0.010	U	0.010	U	0.010	U	0.010	U
						0.010	U	0.010	U	0.010	U	0.010	U			0.010	U	0.010	U	0.010	U	0.010	U
						0.010	U	0.010	U	0.010	U	0.010	U			0.010	U	0.010	U	0.010	U	0.010	U
2	35.62	11	11	0.057		0.010	U	0.010	U	0.010	U	0.010	U	0.101		0.010	U	0.010	U	0.010	U	0.010	U
						0.010	U	0.012	U	0.010	U	0.010	U			0.010	U	0.010	U	0.010	U	0.010	U
						0.010	U	0.010	U	0.010	U	0.010	U			0.010	U	0.010	U	0.010	U	0.010	U
3	35.62	18	11	0.023				0.010	U	0.010	U	0.010	U	0.038		0.010	U	0.010	U	0.010	U		
								0.010	U	0.010	U	0.010	U			0.010	U	0.010	U	0.010	U		
								0.010	U	0.010	U	0.010	U			0.010	U	0.010	U	0.010	U		
4	35.62	26	11	0.133	D			0.017		0.016		0.010		0.211	D	0.014		0.011		0.016			
								0.010	U	0.014		0.011				0.013		0.012		0.018			
								0.012		0.016		0.010	U			0.012		0.010		0.019			
5	35.62	33	11	0.043				0.010	U	0.010	U	0.010	U	0.061		0.010	U	0.010	U	0.010	U		
								0.010	U	0.010	U	0.010	U			0.010	U	0.010	U	0.010	U		
								0.010	U	0.010	U	0.010	U			0.010	U	0.010	U	0.010	U		
Min				0.023		0.005		0.005		0.005		0.005		0.022		0.005		0.005		0.005		0.005	
Max				0.133		0.005		0.017		0.016		0.011		0.211		0.014		0.012		0.019		0.005	
Mean				0.058		0.005		0.006		0.007		0.006		0.087		0.007		0.006		0.008		0.005	
Median				0.043		0.005		0.005		0.005		0.005		0.061		0.005		0.005		0.005		0.005	
Percent Reduction				0		88		87		86		87		0		89		89		89		86	

U = undetected at the reporting limit noted. For these results, one-half the reporting limit is used to calculate Minimum, Maximum, Mean, Median, and Percent Reduction.
ug/L = micrograms per liter

Table 45. Dosing Experiment Raw Data and Summary Statistics for Fluoranthene.																							
Dosing Event	Flushing Volume (liters)	Percent Water Year	Flow Rate (liters/hr)	Influent Day 1 (ug/L)	flag	Treatment 1 60/40 (ug/L)	flag	Treatment 2 60/40/aafep-layer (ug/L)	flag	Treatment 3 70vs/20cp/10ash/ compmulch (ug/L)	flag	Treatment 4 70vs/20cp/10ash/ compmulch/ aafep-layer (ug/L)	flag	Influent Day 2 (ug/L)	flag	Treatment 5 70vs/20cp/ 10ash (ug/L)	flag	Treatment 6 70ss/20cp/ 10ash (ug/L)	flag	Treatment 7 70ls/20cp/ 10ash (ug/L)	flag	Treatment 8 70ls/20cp/ 10ash/orifice (ug/L)	flag
1	35.62	4	11	0.046		0.010	U	0.010	U	0.010	U	0.010	U	0.029		0.010	U	0.010	U	0.010	U	0.010	U
						0.010	U	0.010	U	0.010	U	0.010	U			0.010	U	0.010	U	0.010	U	0.010	U
						0.010	U	0.010	U	0.010	U	0.010	U			0.010	U	0.010	U	0.010	U	0.010	U
2	35.62	11	11	0.081		0.010	U	0.010	U	0.010	U	0.010	U	0.135		0.010	U	0.010	U	0.010	U	0.010	U
						0.010	U	0.012	U	0.010	U	0.010	U			0.010	U	0.010	U	0.010	U	0.010	U
						0.010	U	0.010	U	0.010	U	0.010	U			0.010	U	0.010	U	0.010	U	0.010	U
3	35.62	18	11	0.031				0.010	U	0.010	U	0.010	U	0.037		0.010	U	0.010	U	0.010	U		
								0.010	U	0.010	U	0.010	U			0.010	U	0.010	U	0.010	U		
								0.010	U	0.010	U	0.010	U			0.010	U	0.010	U	0.010	U		
4	35.62	26	11	0.14	D			0.013		0.016		0.010		0.210	D	0.015		0.011		0.014			
								0.010	U	0.014		0.011				0.013		0.011		0.017			
								0.011		0.017		0.010				0.013		0.010	U	0.017			
5	35.62	33	11	0.048				0.010	U	0.010	U	0.010	U	0.061		0.010	U	0.010	U	0.010	U		
								0.010	U	0.010	U	0.010	U			0.010	U	0.010	U	0.010	U		
								0.010	U	0.010	U	0.010	U			0.010	U	0.010	U	0.010	U		
Min				0.031		0.005		0.005		0.005		0.005		0.029		0.005		0.005		0.005		0.005	
Max				0.140		0.005		0.013		0.017		0.011		0.210		0.015		0.011		0.017		0.005	
Mean				0.069		0.005		0.006		0.007		0.006		0.094		0.007		0.006		0.007		0.005	
Median				0.048		0.005		0.005		0.005		0.005		0.061		0.005		0.005		0.005		0.005	
Percent Reduction				0.000		92		90		89		90		0		90		91		90		90	

U = undetected at the reporting limit noted. For these results, one-half the reporting limit is used to calculate Minimum, Maximum, Mean, Median, and Percent Reduction.

ug/L = micrograms per liter

Table 46. Dosing Experiment Raw Data and Summary Statistics for Phenanthrene.																							
Dosing Event	Flushing Volume (liters)	Percent Water Year	Flow Rate (liters/hr)	Influent Day 1 (ug/L)	flag	Treatment 1 60/40 (ug/L)	flag	Treatment 2 60/40/aafep-layer (ug/L)	flag	Treatment 3 70vs/20cp/10ash/ compmulch (ug/L)	flag	Treatment 4 70vs/20cp/10ash/ compmulch/ aafep-layer (ug/L)	flag	Influent Day 2 (ug/L)	flag	Treatment 5 70vs/20cp/ 10ash (ug/L)	flag	Treatment 6 70ss/20cp/ 10ash (ug/L)	flag	Treatment 7 70ls/20cp/ 10ash (ug/L)	flag	Treatment 8 70ls/20cp/ 10ash/orifice (ug/L)	flag
1	35.62	4	11	0.039		0.010	U	0.010	U	0.010	U	0.010	U	0.026		0.010	U	0.010	U	0.010	U	0.010	U
						0.010	U	0.010	U	0.010	U	0.010	U			0.010	U	0.010	U	0.010	U	0.010	U
						0.010	U	0.010	U	0.010	U	0.010	U			0.010	U	0.010	U	0.010	U	0.010	U
2	35.62	11	11	0.048		0.010	U	0.010	U	0.010	U	0.010	U	0.07		0.010	U	0.010	U	0.010	U	0.010	U
						0.010	U	0.012	U	0.010	U	0.010	U			0.010	U	0.010	U	0.010	U	0.010	U
						0.010	U	0.010	U	0.010	U	0.010	U			0.010	U	0.010	U	0.010	U	0.010	U
3	35.62	18	11	0.018				0.010	U	0.010	U	0.010	U	0.017		0.010	U	0.010	U	0.010	U		
								0.010	U	0.010	U	0.010	U			0.010	U	0.010	U	0.010	U		
								0.010	U	0.010	U	0.010	U			0.010	U	0.010	U	0.010	U		
4	35.62	26	11	0.101	D			0.010	U	0.010		0.010	U	0.147	D	0.010	U	0.010	U	0.010	U		
								0.010	U	0.010	U	0.010	U			0.010	U	0.039		0.010			
								0.010	U	0.011		0.010	U			0.010	U	0.010	U	0.011			
5	35.62	33	11	0.026				0.010	U	0.010	U	0.010	U	0.031		0.010	U	0.010	U	0.010	U		
								0.010	U	0.010	U	0.010	U			0.010	U	0.010	U	0.010	U		
								0.010	U	0.010	U	0.010	U			0.010	U	0.010	U	0.010	U		
Min				0.018		0.005		0.005		0.005		0.005		0.017		0.005		0.005		0.005		0.005	
Max				0.101		0.005		0.006		0.011		0.005		0.147		0.005		0.039		0.011		0.005	
Mean				0.046		0.005		0.005		0.006		0.005		0.058		0.005		0.007		0.006		0.005	
Median				0.039		0.005		0.005		0.005		0.005		0.031		0.005		0.005		0.005		0.005	
Percent Reduction				0		88		85		84		85		0		85		83		84		87	

U = undetected at the reporting limit noted. For these results, one-half the reporting limit is used to calculate Minimum, Maximum, Mean, Median, and Percent Reduction.

ug/L = micrograms per liter

Table 47. Dosing Experiment Raw Data and Summary Statistics for Fecal Coliform.

Dosing Event	Flushing Volume (liters)	Percent Water Year	Flow Rate (liters/hr)	Influent Day 1 (CFU)	flag	Treatment 1 60/40 (CFU)	flag	Treatment 2 60/40/aafep-layer (CFU)	flag	Treatment 3 70vs/20cp/10ash/ compmulch (CFU)	flag	Treatment 4 70vs/20cp/10ash/ compmulch/ aafep-layer (CFU)	flag	Influent Day 2 (CFU)	flag	Treatment 5 70vs/20cp/ 10ash (CFU)	flag	Treatment 6 70ss/20cp/ 10ash (CFU)	flag	Treatment 7 70ls/20cp/ 10ash (CFU)	flag	Treatment 8 70ls/20cp/ 10ash/orifice (CFU)	flag
1	35.62	4	11	20		11		10		52		5		13		7		8		2	U	7	
						11		10		3		2	U			5		7		7		2	
						18		70		5		2	U			2		5		7		3	
2	35.62	11	11	1400		380		500		209		200		190		540		130		700		100	
						600		500		240		290				800		500		140		130	
						600		400		600		145				130		300		130		800	
3	35.62	18	11	1500				540		700		320		500		300		320		580			
								200		540		590				310		530		390			
								550		1000		370				240		320		420			
4	35.62	26	11	700				100		600		800		7500		300		900		1600			
								100		300		1200				600		700		1500			
								100		300		900				400		900		1000			
5	35.62	33	11	1800				118		127		145		500		30		66		36			
								127		145		78				62		36		82			
								164		182		127				33		86		38			
Min				20		11		10		3		1		13		2		5		1		2	
Max				1800		600		550		1000		1200		7500		800		900		1600		800	
Mean				1080		270		233		334		345		1740		251		321		442		174	
Median				1400		199		127		240		200		500		240		300		140		53.5	
Percent Reduction				0		48		53		52		60		0		27		37		34		-6	

U = undetected at the reporting limit noted. For these results, one-half the reporting limit is used to calculate Minimum, Maximum, Mean, and Median.
(CFU/100mL) = colony forming units per 100 milliliter

3.6. Comparison of Study Results to TAPE Performance Objectives

The following provides pollutant capture performance in relation to TAPE objectives for all treatments. To provide 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 48). The statistical analyses involved the computation of bootstrapped lower confidence intervals around the mean percent removal for TSS, TP, dissolved Zn, and dissolved Cu. A bootstrapped upper confidence limit was also computed around the mean effluent concentration for TSS. Note that not all sampling events met TAPE influent guidelines. For example, influent concentrations for dissolved Cu are 120 µg/L for day 1 and 222 µg/L for day 2 for dosing experiment 4; however, dissolved Cu influent objectives for TAPE are 5-20 µg/L. Accordingly, the following provides only a general estimate of treatment performance within the context of the TAPE guidelines. See Section 4.1.5 for conclusions and recommendations associated with Table 48 and each media treatment.

3.7. BSM Specification

The draft specification metric and numeric ranges were selected in attempts to describe the new BSM, ensure consistent quality of components and blends, and meet water quality treatment criteria. Appendix B includes the list of all possible metrics, methods and numeric ranges considered by the TAG. Note that many of these tests are routinely provided by the manufacturer or vendor. For example, gradation and iron content are reported by iron suppliers and alumina content, bulk density, gradation and surface area are metrics reported by activated alumina manufacturers.

Many of the metrics and numeric ranges have been use for the previous BSM studies outlined in the Introduction section. For example, SPLP extractions have been performed on the media components multiple times and numeric ranges established (see Tables 3 through 6 in Results section). However, not all metrics and numeric ranges potentially important to properly describe components or blends were known from previous experiments. Accordingly, metrics for media components or blends with no previous data were selected from the table in Appendix B for lab analyses to determine values. That subset of metrics by media component or blend consist of:

- Coir
  - Cation exchange capacity
  - Electrical conductivity
- High carbon wood ash
  - Cation exchange capacity
  - Polycyclic aromatic hydrocarbons
- Iron aggregate
  - Cation exchange capacity
- Activated alumina
  - Cation exchange capacity
- Primary media blend
  - Water holding capacity
  - Organic matter
- Polishing layer
  - Cation exchange capacity

Table 48. Dosing Results in Relation to TAPE Pollutant Reduction Objectives.						
	TSS	**TSS**	**Dissolved Cu**	**Dissolved Zn**	**TP Treatment**	
Objective	**≤ 20 mg/L[a]**	**≥ 80% removal[b]**	**> 30% removal[b]**	**> 60% removal[b]**	**≥ 50% removal[b]**	**Notes**
	Bootstrapped upper 95 percent confidence interval around the mean effluent concentration (mg/L).	Bootstrapped lower 95 percent confidence interval around the mean effluent concentration (mg/L)				
Treatment						
Treatment 1: 60/ 40 mg/L		38.6%	11.7%	83.7%	-382%	treatment dropped after 2nd dosing
Treatment 2: 60/ 40/aafep-layer		84.9%	89.3%	94.4%	15.3%	
Treatment 3: 70vs/20cp/10ash/ compmulch		66.2%	48.5%	86.5%	-37.6%	
Treatment 4: 70vs/20cp/10ash/ compmulch/aafep-layer	All effluent < 20 mg/L including experiment 4 with an influent concentration of 254 mg/L	88.5%	94.6%	96%	71.3%	
Treatment 5: 70vs/20cp/10ash		80.1%	62.4%	88.5%	-1%	
Treatment 6: 70ss/20cp/10ash		83.9%	70.5%	88.6%	41.3%	
Treatment 7: 70ls/20cp/10ash		82.4%	63.4%	75.8%	-29.7%	
Treatment 8: 70ls/20cp/10ash/ orifice		82.7%	70.6%	86.5%	-52.8%	treatment dropped after 2nd dosing

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.

The percent removals are bootstrapped means typically used for TAPE analyses. However, the influent values vary for the four dosing experiments. Some influent concentrations are only slightly above the TAPE influent thresholds for specific analytes, but others are well above the upper TAPE influent threshold. For example, influent concentrations for dissolved Cu are 120 µg/L for day 1 and 222 µg/L for day 2 for dosing experiment 4. Threshold criteria are the following for TAPE:

TSS: 20-100 mg/L with an effluent objective of ≤ 20 mg/L, 100-200 mg/L with an objective of ≥ 80% removal, and >200mg/L ≥ 80%.

Dissolved Cu: 5-20 µg/L with an effluent objective of > 30% removal.

Dissolved Zn: 20-300 µg/L with an effluent objective of ≥ 60% removal.

Total phosphorus: 0.1-0.5 mg/L with an effluent objective of ≥ 50% removal.

Table 49 provides results for the subset of metrics selected. Electrical conductivity was selected for coir because coir processing includes soaking coconuts in sea water for extended periods. The results demonstrate that the coir used for the BSM trial is far below levels considered harmful to plants (4mmhos/cm).

Table 49. Results for Subset of BSM Specification Metrics.

Media Component or Blend	Cation Exchange Capacity (meq/100g)	Anion Exchange Capacity (meq/100g)	Polycyclic Aromatic Hydrocarbons (µg/L)	Water Holding Capacity (% moisture)	Electric Conductivity (mmhos/cm)	Organic Matter (% by weight)
Criteria	≥4	no criteria	no criteria	no criteria	<4mmhos/cm	4-6%
Coir	1510	102	na	na	0.3	na
High carbon wood ash (biochar)	451	na	Non-detect	na	na	na
Iron aggregate	62.6	15.0	na	na	na	na
Activated alumina	603	85.7	na	na	na	na
Primary layer (Treatment 5)	na	na	na	0.33 bars = 6.2% 15 bars = 5.3%	na	4.5
Polishing layer	130	27.3	na	na	na	na

Cation exchange capacity: EPA 9081. Anion exchange capacity: EPA 9081 modified (nitrate as the target ion). Meq = milliequivalent.

Water holding capacity: saturated sample in closed chamber, apply 0.33 bars atmosphere (5 psi), and then 15 bars atmospheres (220 psi) to ceramic plate.

Electric conductivity: TMECC 04.10-A (mmhos/cm = milli mho/cm, Mho = reciprocal of ohm).

PAH: EPA 8270D.

Organic matter: ASTM D2974 or TMECC 05.07A.

High carbon wood ash is a burned material; accordingly, PAH content was analyzed. Results demonstrate the material used for the BSM study is below detection limits and would not contribute PAHs to effluent.

Cation and anion exchange capacities for all measured materials was very high and, surprisingly, extremely high for coir. These results explain why Cu, Zn and P capture is excellent with these media, and, while speculative, perhaps the nitrate+nitrite capture mechanism (sorption) for the primary media containing coir.

Finally, the water holding capacity and plant available water of the primary layer (70 percent sand/20 percent coir/10 percent high carbon wood ash) was analyzed. Note that Treatment 5 with volcanic and was used to determine water holding capacity (WHC) and plant available water for the primary layer and is the same media blend used for the primary layer in Treatment 4.

Plant available water is determined by the difference between percent water held at 15 and 0.33 bars. From Table 49 plant available water is 6.2 percent minus 5.3 percent or 0.9 percent. A sandy soil has a plant available water of approximately 3 percent (personal communication, Markus Flury, 2019). A plant available water of 0.9 percent is then quite low. Coir has a very high water holding capacity and is included in the media blends to provide plant water during drier periods as well as other benefits. However, the addition 20 percent coir by volume does not appear to increase water holding capacity of the predominantly sand media blend. See Section 4.2.4 for plant recommendations.

3.8. Toxicological Analyses

During the five dosing events described in Section 2.7, sub-samples were collected from the single influent sample and composite samples from the three effluent samples per treatment to test the ability of the eight BSM blends to protect aquatic organisms from contaminants that produce acute toxicity. Tests were conducted on two model aquatic organisms: zebrafish (*Danio rerio*) embryos and Daphnia (*Ceriodaphnia dubia*) neonates.

Stormwater from SR 520 collected at NOAA Fisheries Science Center in Seattle was used for continuity with previous experiments conducted on daphnia and zebrafish at WSU and NOAA. Composite samples were collected for each treatment (subsamples collected from each column into one sample for each treatment). The composite samples were immediately frozen at the WWU lab and then transported to freezers at NOAA and WSU.

3.8.1. Aquatic Invertebrate Bioassays

3.8.1.1. Effects gon C. dubia Survival

For three of the five storm events, the influent stormwater did not affect survival of the *C. dubia* founders (Event 2, 3, 4; Figure 1). For Event 1, Day 1 influent caused 100 percent mortality, however no mortality was observed with Day 2 influent (Figure 42). For Event 5, all influents and effluents caused significant mortality compared to the laboratory control (Figure 42).

3.8.1.2. Reproduction

Influent stormwater affected reproduction for three of the five events (Event 1, 2, 4). Influent stormwater affected reproduction on Day 1 but not on Day 2 for Event 1 ($p < 0.001$) and Event 2 ($p = 0.003$). For Event 4, influent stormwater was toxic on both test days, but more toxic on Day 2 ($p = 0.002$). At least some of the treatment effluents from Event 1 and Event 2 had a stimulating effect on the reproduction of *C.* dubia; effluents from T1, T2 and T3 for Event 1, all the effluents except for T4 for Event 2, and effluent from T4 for Event 4 (Figure 43). When influent stormwater reduced reproduction, toxicity was prevented in some but not all cases (Table 50).

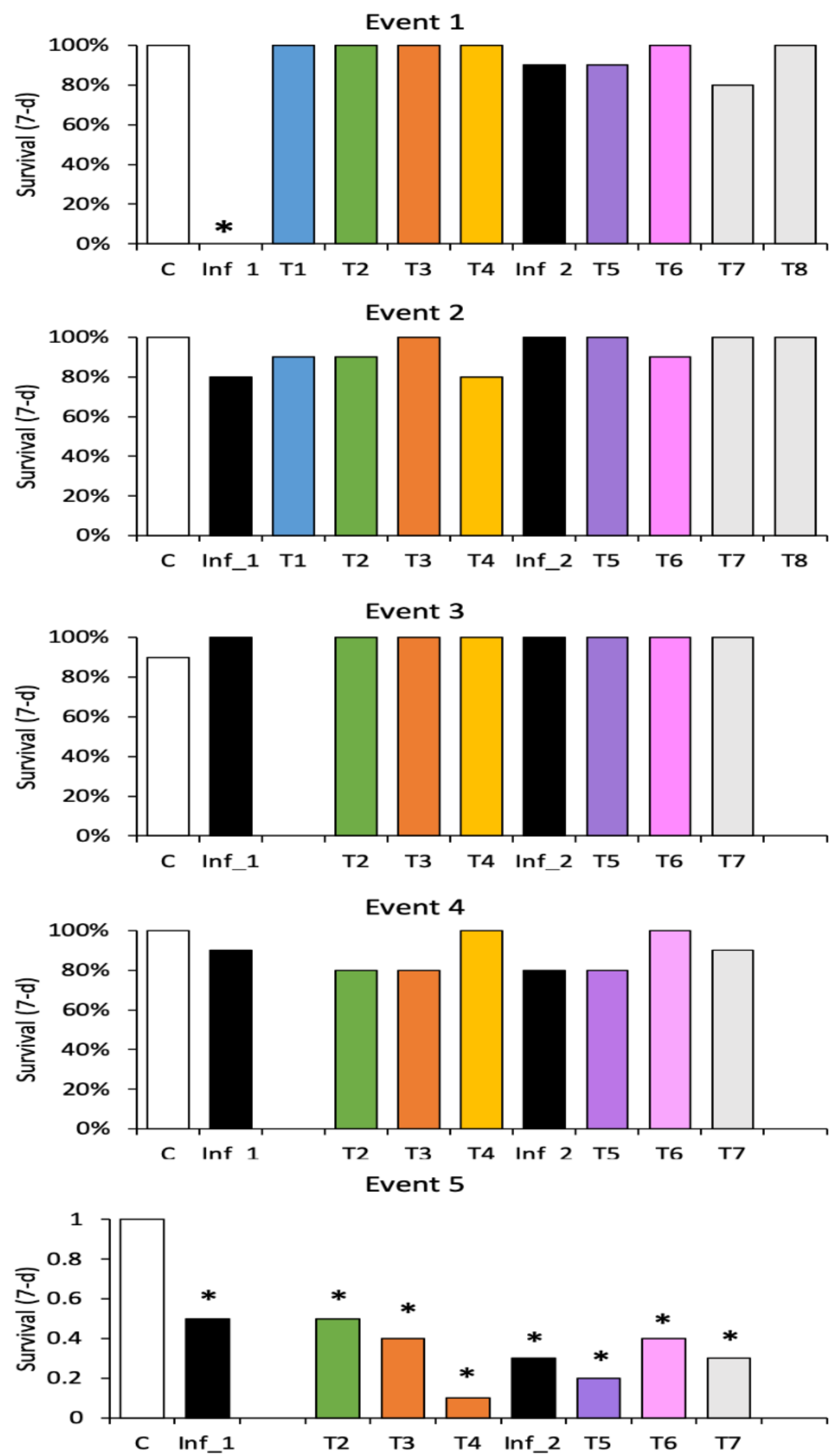


Figure 42. Survival of Neonate Founders (n=10) During 7-Day Exposures to Clean Water Laboratory Control, Influent Stormwater, and Effluent from Each Bioretention Media Treatment.

Influent 1 was treated on Day 1 in T1-4 whereas Influent 2 was treated on Day 2 in T5-8. Asterisks indicate treatments for which survival was significantly reduced from the laboratory control.

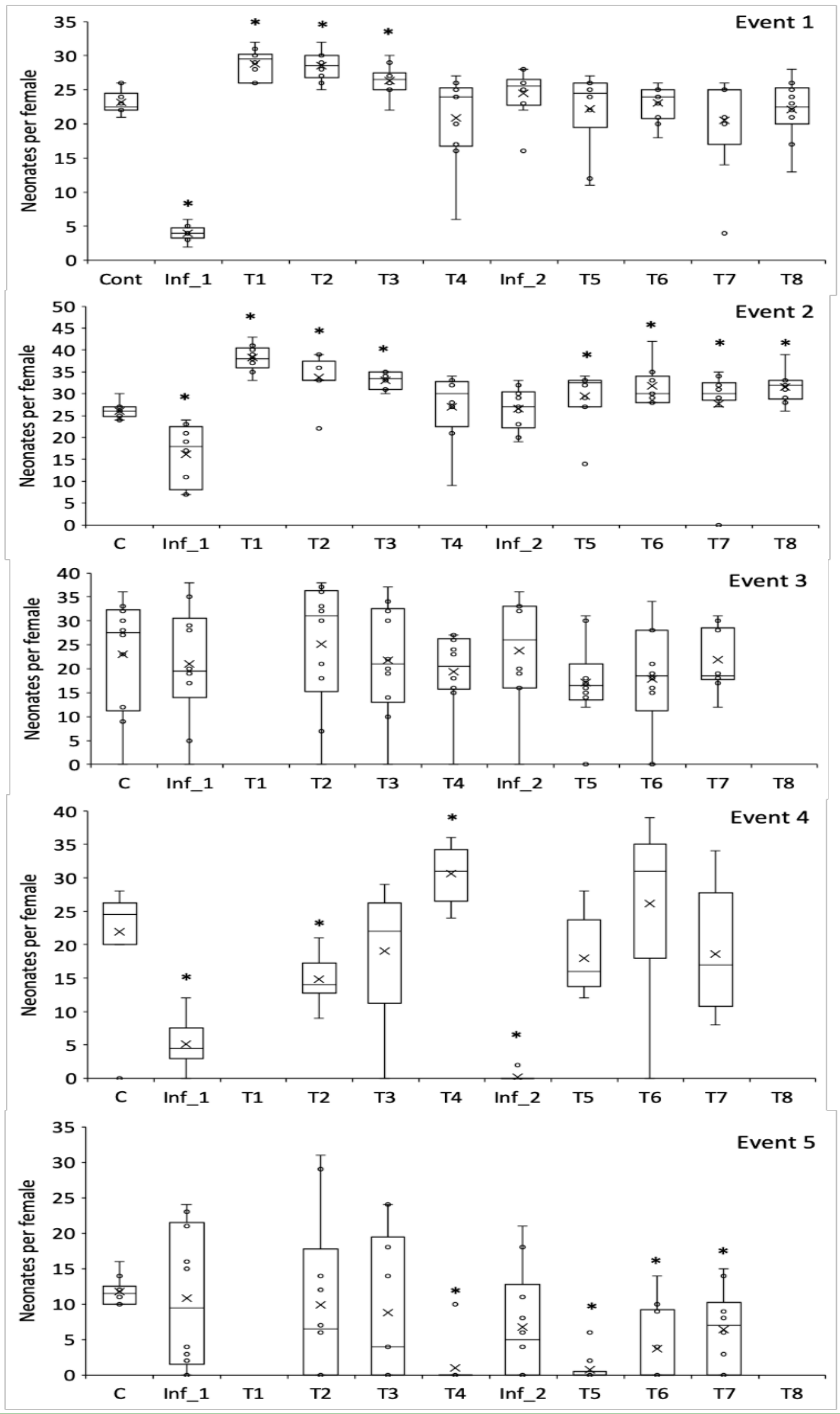


Figure 43. The Average Sum of Reproduction by Neonate Founders (n=10) during 7-Day Exposures to Laboratory Control Water, Influent Stormwater, and Effluent from each Bioretention Media Treatment.

Influent 1 was treated on Day 1 in T1-4 whereas Influent 2 was treated on Day 2 in T5-8. Asterisks indicate treatments for which reproduction was significantly different from the laboratory control.

Table 50. Toxicity to *C. dubia* Associated with Influent and Effluent Waters for Experimental Bioretention Media (T2-T7) Tested for All Five Storm Events.							
Influent	**Effluent**	**Influent Decreased Survival**	**Treatments Prevented Mortality**	**Influent Decreased Reproduction**	**Treatments Prevented Toxicity**	**Reproduction Not Affected by Influent**	**Treatments Impaired Reproduction**
Day 1	T2	2/5	1/2	3/5	2/3	2/5	0/2
	T3		1/2		3/3		0/2
	T4		1/2		3/3		1/2
Day 2	T5	1/5	0/1	1/5	0/1	4/5	1/4
	T6		0/1		0/1		1/4
	T7		0/1		0/1		1/4
TOTAL		3/10 cases	3/9 cases	4/10 cases	8/12 cases	6/10 cases	4/18 cases

One way to consider treatment effectiveness is in terms of the sum of cases of toxic influent water × number of treatments tested. Given differences in the toxicity of Day 1 and Day 2 influent water, and excluding treatments that were dropped after Event 2 (T1, T8), there were 9 cases of testing the ability of different treatments to prevent mortality, 12 cases of testing the ability of different treatments to prevent reproductive toxicity, and 18 cases of testing whether toxicity was associated with effluents when the influent water was not toxic. Treatments prevented mortality of founders in 33 percent of cases, prevented reproductive impairment in 67 percent of cases, and produced toxicity where none was present in 22 percent of cases (Table 50).

3.8.2. Zebrafish Bioassays

3.8.2.1. Morphometrics

There were significant differences in toxicity produced by Day 1 and Day 2 influent waters for Event 2, 3, and 4 ($p \leqq 0.008$), supporting the decision to analyze the two days separately as though they had received different influent stormwater (see IN1 vs IN2 in Figure 44).

The effect of the BSM treatments on the three morphometric endpoints (length, eye area, pericardial area) depended on the dosing event. There were very few instances where influent or BSM-treated waters affected embryo length (Figure 44A). Length was affected only for Event 2 (Day 1 only) and Event 4 (Day 2 only). Influent from Event 2 produced an increase in embryo length relative to laboratory controls that was also present for treated effluent (T1-4). Influent water from Event 4 caused a significant decrease in embryo length that was partially mitigated by the treatments.

The growth stimulation that impacted Day 1 waters for Event 2 also increased eye area (Figure 44B). As with the impact on embryo length, the increase in eye size was also present for all of the Day 1 treatments (T1-4). The expected impact of stormwater on eye size is a reduction

(McIntyre et al. 2014). This toxic effect was not observed for Day 1 influent waters, but was evident for Day 2 influent waters for most Events (1-4). Bioretention treatments on Day 2 (T5, T6) prevented the reduction in eye size for Events 1 and 2 but did not prevent reduced eye size for Event 3 and did not completely recovery eye size for Event 4.

Pericardial area was increased from exposure to Day 1 influent waters for all Events and Day 2 influent for Events 1-3 (Figure 44C). BSM treatment prevented this toxic response for all except Event 5. Performance appeared to decrease after the first Event (Figure 45) but was only statistically significant for Event 5. There were no significant differences among treatments in their ability to prevent pericardial edema.

3.8.2.2. qPCR

In zebrafish embryos exposed to influent stormwater from Events 1-4, *cyp1a* was elevated 85-fold to 123-fold above controls. This effect was significant across events ($F(4,18)=12.670$, $p<0.001$). Bioretention treatment tended to decrease the amount of *cyp1a* induction; *cyp1a* was elevated only 2-fold to 50-fold above controls in treatment waters across events. There was no significant difference among treatments in their ability to prevent *cyp1a* induction from influent stormwater (Figure 46). Bioretention treatment appeared to be less effective at preventing *cyp1a* induction after Event 1, with values statistically indistinguishable from influent for Events 2 and 4 and significantly different from controls for Event 3 (Figure 46).

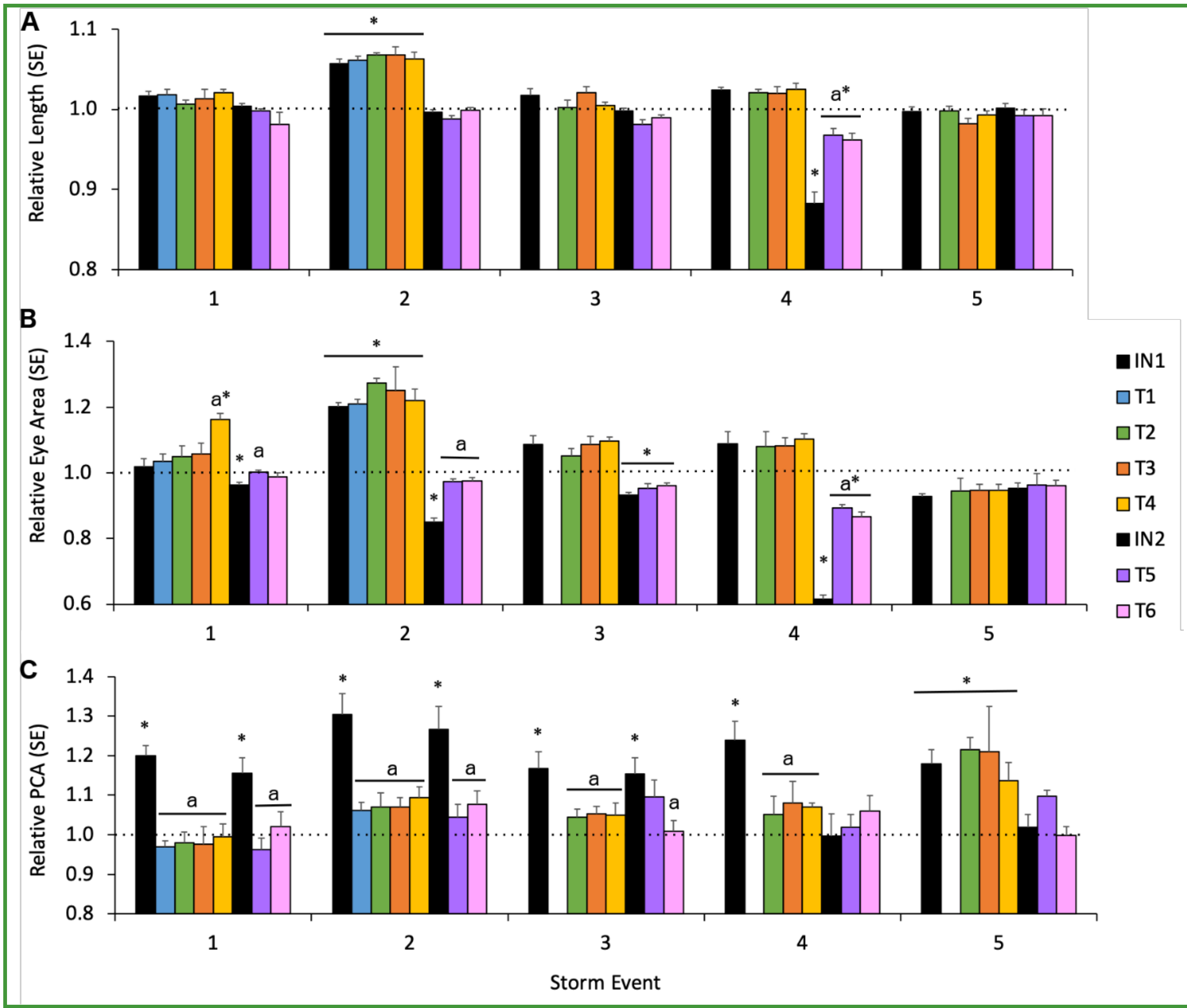


Figure 44. Morphometrics of Zebrafish Embryos Exposed 48 hours to Influent Stormwater from Day 1 or Day 2, or Effluent from BSM Blends T1-T4 (Day 1) and T5-6 (Day 2) for A) Embryo Length, B) Eye Area, and C) Pericardial Area Relative to the Average of the Control Replicates.

T1 is shown for comparison but was not include in the statistical analysis. Error bars are ± one standard error of the mean. Asterisks indicate significantly different from control, letters indicate significantly different from influent. The control value is shown for reference as a dotted line.

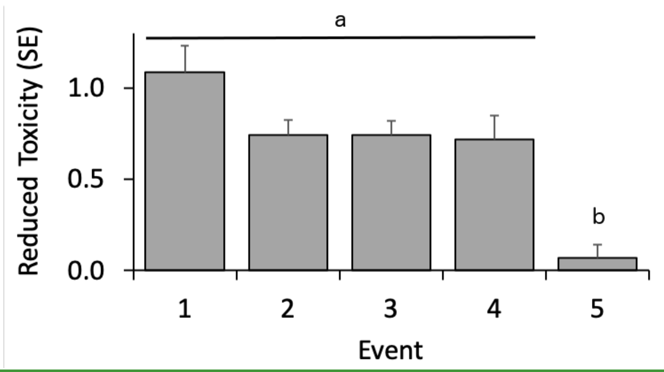


Figure 45. Proportional Reduction in Pericardial Area Compared to Control Values Across Treatments for Each Event.

Error Bars are ± one standard error of the mean. Event 1 had the greatest average reduction in toxicity whereas Event 5 did not prevent pericardial edema (Figure 44). Treatments sharing a letter are not statistically different.

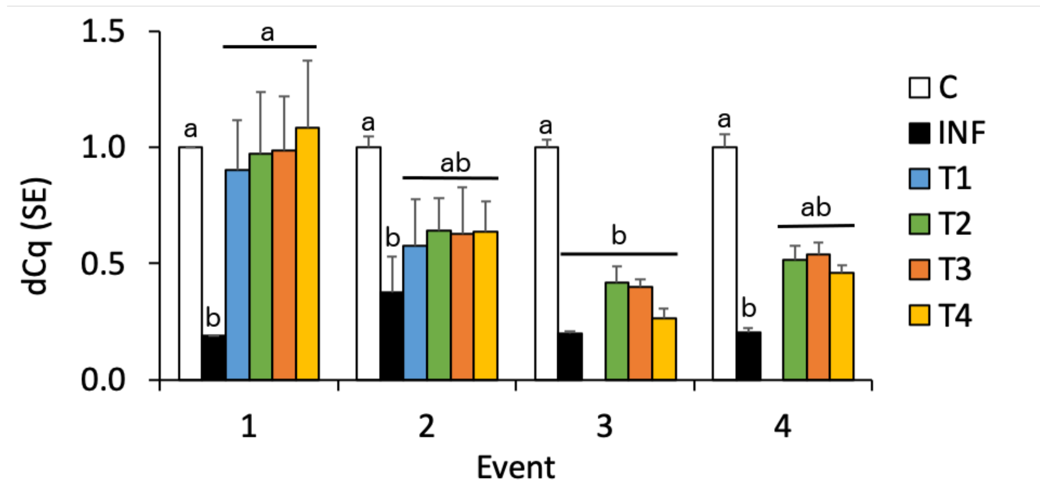


Figure 46. Baseline-Corrected Quantitation Cycles for Cyp1a in Zebrafish Embryos Exposed 48 hours to Control Water, Influent Stormwater, or Effluent from Treatments 1-4 for Events 1-4.

Smaller dCq values indicate more cyp1a expression. Treatment types that share a letter are not statistically different. Error bars are one standard error of the mean. Values for T1 are shown for comparison but were not included in the statistical analysis because the treatment was discontinued after Event 2.

3.8.3. Cost

Three media blends are considered below to compare media costs: 1) the current State BSM specification (60/40); 2) the primary and polishing layer blends for this study; and 3) high-performance proprietary media. Each of these have substantial differences that limit direct comparison. The 60/40 media cost is not appropriate for direct comparison because 60/40 does not perform at the same level as the high-performance media in this study and cannot be used for the same applications (direct release of effluent to sensitive receiving waters). The 60/40 cost is provided only for context of the range of BSM specifications applied in the region. High-performance proprietary media have similar water quality treatment capabilities to the better performing media in this study; however, proprietary media operated at higher infiltration rates. Nevertheless, Treatment 4 (70/vs/20cp/10ash/aafep-layer), 60/40 and high-performance proprietary media are compared again only for context that represents a range of BSM specifications applied in the region. The 60/40 cost per cubic yard provided by City of Seattle, high performance media estimate from Herrera and Treatment 4 cost estimate from Walrath. All costs are approximate estimates developed during fall 2019 and per cubic yard.

1. Treatment 4:
    - Primary media.......$176
    - Polishing layer.......$477
    - Compost mulch.......$25
    - **Total.......$678**
2. High-performance proprietary media
    - Media.......$878
    - Underdrain aggregate.......$60
    - Mulch.......$350
    - **Total.......$1288**
3. 60/40
    - **Total.......$100**

4. CONCLUSIONS AND RECOMMENDATIONS

4.1. CONCLUSIONS

The BSM Phase 2 Study was implemented to build on previous BSM studies and develop new recommendations for a BSM that protects beneficial uses of receiving waters and achieves the following objectives in order of priority: 1) meets basic treatment (Ecology's treatment objectives for total suspended solids); 2) meets enhanced treatment (Ecology's treatment objectives for dissolved Cu and Zn); 3) meets Ecology's treatment objective for phosphorus; 4) is affordable and available; and 5) reduces stormwater toxicity for aquatic organisms.

To meet this goal, the study involved four phases: 1) identify media components and test those components for leaching potential; 2) combine components into media blends, flush with clean water to evaluate contaminant flushing potential, and dose the same media with stormwater to evaluate the pollutant capture capability of the blends; 3) conduct toxicological tests to determine how well the BSM blends protect aquatic organisms; and 4) develop specification metrics and numeric ranges for the best performing BSM selected by the TAG. Based on the results from these experiments, the following major study conclusions were identified.

4.1.1. Selecting Media Components

Criteria for selecting media components included a balance of performance metrics (leaching potential, ability to capture pollutants, and hydraulics), cost and sustainability. Where possible, waste materials with minimal pollutant generating processes and short transportation distances were selected. Table 51 provides a summary of media component selection criteria.

Not all media components meet all sustainability criteria; however, all materials meet the criteria for a balance of required performance and sustainability. Activated alumina only meets sustainability criteria for availability, but this component is the only material that is stable, has the appropriate gradation for required hydraulic conductivity, and is a strong phosphorus sorbent.

Table 51. Media Component Selection Summary.				
Media Component	**Availability/ Supply**	**Transportation**	**Manufacturing**	**Primary or Waste Product/Renewable**
Volcanic Sand	Readily available/ decades	Local (southwestern WA)	Minimal (dredging Mt St Helens debris to reduce flooding)	Primary/non-renewable
State Sand	Readily available/ decades	Local (central Puget Sound)	Minimal (excavation in local quarry)	Primary/non-renewable
Lava Sand	Readily available/ decades	Local (southeastern WA)	Minimal (excavation in local quarry)	Primary/non-renewable
Ecology sand	Readily available/ decades	Local (central Puget Sound)	Minimal (excavation in local quarry)	Primary/non-renewable
Coconut Coir	Readily available/ decades	Distant (Indonesia and India)	Minimal (soaking and shredding coconuts)	Primary/renewable
High-Carbon Wood Ash (biochar)	Readily available/ decades	Local (northern OR)	Minimal (burning hog fuel in high efficiency furnace for co-generation at site)	Waste/renewable
Activated Alumina	Readily available/ decades	Distant (eastern U.S. and Canada)	Intense (high heat applied to aluminum hydroxide)	Primary/non-renewable
Iron Aggregate	Readily available/ decades	Distant (Chicago)	Minimal (sieving waste iron cuttings)	Waste/renewable

4.1.2. Leaching Tests

Total and ortho-phosphorus

The State Sand, lava sand, coir, activated alumina, and iron aggregate all came in below the TP threshold used for this study (0.5 mg/L). No ortho-P threshold was set for the study; however, the same components came in below 0.2 mg/L for ortho-P. However, high carbon wood ash exceeded the TP threshold with an SPLP extraction of 0.988 mg/L for TP and 1.150 mg/L for ortho-P. Similar results were observed with previous research. Previous research has also indicated that high carbon wood ash does not contribute to TP or ortho-P flushing from blends while providing good metals capture and a valuable organic material for plant growth.

Nitrate+nitrite

All components had nitrate+nitrite extractions below 0.5 mg/L (the threshold used for this study) except activated alumina which had an extraction value 1.140 mg/L. Flushing of nitrate+nitrite has not been observed in previous research when activated alumina has been placed in blends. Accordingly, all components were found suitable for further testing including the activated alumina which provides excellent pollutant capture for P and Cu in the media blends.

Dissolved Copper

Dissolved Cu extractions ranged from non-detect (iron, high carbon wood ash and activated alumina) to 4.54 µg/L (lava sand). All results were well below the threshold used for this study (10 µg/L); accordingly, all of the media components were found suitable for the media blends.

4.1.3. Media Flushing Tests

Treatment 1 (60/40) consistently flushed more contaminants (TSS, TP, ortho-P, nitrate+nitrite, dissolved Cu, and fecal coliform) than all other treatments. Some contaminant concentrations were initially alarmingly high (e.g. fecal coliform >25,000 CFU and dissolved Cu 39 µg/L) for the compost-based media. The addition of a polishing layer to the 60/40 blend reduced contaminant flushing for TSS, TP, ortho-P, nitrate+nitrite, and dissolved Cu, but not fecal coliform.

The sand, coir and high carbon wood ash treatments consistently flushed lower concentrations than the compost-based media for all contaminants except aluminum. Aluminum flushing concentrations were very high for Treatments 7 and 8 containing lava sand (overall median of 22,800 and 19,400 µg/L respectively). Treatment 4 containing activated alumina in the polishing layer had the lowest median flushing concentration for aluminum (1010 µg/L). Overall, Treatment 4 (70vs/20cp/10ash/aafep-layer) had the lowest median concentrations for all contaminants in the flushing experiments and was particularly effective for preventing export of TP and ortho-P.

4.1.4. Hydraulic Conductivity

All media Ksat measurements were well above the maximum design rate for sizing bioretention stated in the SWMMWW (12 in/hr. initial/measured rate). This along with the very good pollutant capture demonstrated in the dosing experiments suggest that the media filter mechanisms (primarily physical filtration and sorption) operate well at the Ksat rates typical for these media and bioretention in general. Additionally, no migration of components was observed during experiments. Accordingly, the range of particles sizes for each component is appropriate to prevent migration of components that could result in clogging and provide a stable media. A note of caution: recent field measurements taken for a TAPE pilot project using similar media suggest that column Ksat tests likely overstate Ksat rates by two to three times. Actual field rates will likely be closer to 40-50 in/hr., which is still well above the 12 in/hr. maximum allowed for sizing bioretention in the SWMMWW. The additional Ksat capacity is desirable to provide adequate infiltration capacity over time as sediment is introduced to the media and degrades permeability.

4.1.5. Dosing Experiments and Pollutant Capture

None of the media blends provided adequate pollutant capture for all contaminants when dosed with State Highway 520 stormwater except Treatment 4. Treatment 1 (60/40) continued to export TP, ortho-P, nitrate+nitrite, and total and dissolved Cu after flushing for one water year and was dropped from the study after the second dosing experiment. Treatment 2 (60/40/aafep-layer) performed better than Treatment 1 due to the polishing layer capturing contaminants flushing from the compost-based media. However, the polishing layer could not fully mitigate the TP, ortho-P and nitrate+nitrite from the 60/40 media above. Treatment 1 percent reductions (negative numbers indicate export) were -382 for TP, -3480 for ortho-P, and -1310 for nitrate+nitrite. Percent reductions for Treatment 2 were 22 for TP, 21.9 for ortho-P, and -7 for nitrate+nitrite. TAPE requires 50 percent removal for TP (bootstrapped lower 95 percent confidence interval). Treatment 1, of course, falls far below that requirement, and while performance improved, Treatment 2 also does not meet the TP requirement.

Treatments 7 and 8 performed well for most contaminants; however, the sand exported very high concentrations of aluminum during the initial flushing experiments. Treatments 7 and 8 used a lava sand from eastern Washington cinder cones which was selected for its porous, rough texture to potentially improve TSS capture. The alumina flushed from the treatments and by the last dosing experiment, Treatments 7 and 8 were providing similar percent reductions to other treatments. Nevertheless, the initial flushing was well above acute toxicity criteria and is concerning.

Treatment 3 included the sand, coir and ash blend with a compost mulch to improve plant growth. Treatment 3 performed reasonably well for many contaminants (TSS, TPH, PAH, and Zn). However, the sand, coir and ash could not fully mitigate the contaminants flushing from the compost mulch. Total phosphorus percent reduction was -28 percent (bootstrapped lower 95 percent confidence interval) and ortho-phosphorus reduction was -784 percent.

Treatments 5 and 6 did meet TAPE criteria for basic treatment (80 percent TSS reduction) or enhanced treatment (30 percent reduction of dissolved Cu and 60 percent reduction dissolved Zn). However, as with all other treatments except Treatment 4, Treatments 5 and 6 did not meet TP reduction objectives for TAPE. Percent reductions were -1 for Treatment 5 and 41 percent for Treatment 6. Ortho-P was consistently exported for Treatments 5 and 6 with -839 and -266 percent reduction respectively (negative numbers indicate export).

4.1.6. Toxicology Assessment of Bioretention Treatment Effectiveness

4.1.6.1. C. dubia.

Due in part to the inconsistency between the toxicity of Day 1 and Day 2 influent stormwater, it is difficult to assess which treatments were better or worse performers overall for preventing toxicity from influent stormwater to the model aquatic invertebrate. Relatively low incidence of toxic influent waters meant that few cases of treatment effectiveness were available through the course of this study; there were only one or two cases per treatment for testing prevention of mortality and one to three cases per treatment for testing prevention of reproductive impairment. What we can conclude is that none of the experimental media produced a consistent toxic effect in *C. dubia*, indicating that they tended not to leach chemicals into effluent waters that were toxic to *C. dubia.* Furthermore, all treatments did prevent toxicity for some, but not all dosing events, and no one treatment more consistently prevented toxicity in effluent water than another.

4.1.6.2. Zebrafish.

Pericardial edema was the most common toxic effect of influent stormwater to *D. rerio*, reinforcing that developing fish are sensitive to cardiotoxic contaminants such as aromatic hydrocarbons in stormwater runoff (McIntyre et al. 2014; 2016). Treatment by the bioretention media blends tended to be effective at preventing pericardial edema. Treatments 2-4 prevented edema in four out of five cases where influent waters caused edema, whereas T5 prevented edema in two out of three cases and T6 in three out of three cases. Effectiveness of treatments T2-4 for preventing edema appeared reduced for later events as evidenced by the higher induction of *cyp1a* following Event 1 and the presence of pericardial edema for effluent waters from Event 5. No conclusions can be drawn for T5-6 in terms of the effect of time on treatment ability due to the lack of edema produced by influent water on Day 2 for Events 4 and 5 and the lack of *cyp1a* testing on Day 2 samples. There were no consistent differences in treatment effectiveness among the experimental bioretention blends.

4.1.6.3. Overall.

There were not many similarities between which influent waters were toxic to *C. dubia* versus *D. rerio*. Influent waters that were acutely lethal to *C. dubia* (Event 1 Day 1, Event 5) did not necessarily produce stronger sublethal toxicity in *D. rerio* and *vice versa*. Although many chemical pollutants can produce toxic effects to any organism depending on the concentration, aquatic invertebrates and fish tend to have different relative sensitivities. For example, in previous studies with stormwater, acute lethality in *C. dubia* correlated with concentrations of dissolved zinc whereas mortality of *D. rerio* correlated instead with concentrations of DOC and dissolved copper (McIntyre et al. 2014), and cardiotoxicity correlated with concentrations of total PAHs (McIntyre et al. 2016). That these two species would show differential sensitivities should additionally not be surprising when considering that even closely related species can have very different sensitivities to toxic contaminants in stormwater runoff (e.g., *Oncorhynchus kisutch* and *O. keta*; McIntyre et al. 2018). Pairing bioassays using different species can therefore be useful for assessing treatment effectiveness in order to reduce the possibility of overestimating effectiveness if toxicity were prevented in one species but not another. For the current experiment, experimental bioretention media were similarly able to prevent expected toxic impacts including acute lethality and reproductive impairment in *C. dubia*, and reduced growth and pericardial edema in *D. rerio*. Collectively, the bioassays showed a reduced ability of bioretention media to prevent toxicity during the final dosing event (Event 5). There was approximately three months between dosing Event 4 and 5, which was much longer than the time between the other dosing experiments. Chemical transformations within the columns may have occurred during that time, which may have contributed to the decline in the ability of the media to prevent toxicity. Additional dosing is planned to test whether this lack of effectiveness continues with additional dosing. An additional finding was the drastic difference in toxicity of influent stormwater used on two consecutive days, i.e. 24 hours of holding time between testing treatment ability of T1-4 and T5-8. Since the start of this project, new research shows that holding time can sometimes strongly affect the toxicity associated with roadway particles on the scale of days (Khanal et al. 2019).

4.2. Recommendations

Based on the analyses conducted, the above conclusions and best professional judgement the following recommendations are provided:

4.2.1. Chemical and Physical Capture of Contaminants

Treatment 4 (70vs/20cp/10ash/compmulch/aafep-layer) was the only treatment to meet all water quality treatment criteria established for this study. Table 52 provides a summary of lab results with TAPE guidelines. Again, note that not all influent concentrations met TAPE guidelines. Treatment 4 was the top performer for reducing the TAPE contaminants of concern and provided very good treatment for other contaminants including petroleum oil treatment (exceeded TAPE requirement), PAH (all effluent concentrations near or below detection levels), Pb (dissolved Pb percent reduction of 75 percent), and aluminum capture (95 percent reduction).

Table 52. Bootstrapped Lower 95 Percent Confidence Interval Around the Mean Removal Efficiency (%) for Treatment 4.

Parameter	Treatment 4 Primary Layer	Treatment 4 Primary Layer plus Polishing Layer	TAPE Guideline
Total Suspended Solids	83	90	≥80
Total Phosphorus	- 1	73	≥50
Dissolved Copper	62	91	≥30
Dissolved Zinc	89	96	≥60

Bootstrapped confidence limits were calculated using n=15 for each treatment and 10,000 bootstrap iterations.

Negative numbers indicate export.

Primary layer: 70% sand/20% coir/10% high carbon wood ash.

Polishing layer: 90% sand/7.5% activated alumina/2.5 % iron aggregate.

4.2.2. Toxicology Assessment of Bioretention Treatment Effectiveness

The experimental bioretention media were similarly able to prevent expected toxic impacts including acute lethality and reproductive impairment in *C. dubia*, and reduced growth and pericardial edema in *D. rerio*. However, collectively, the bioassays showed a reduced ability of bioretention media to prevent toxicity during the final dosing event (Event 5). Therefore, additional dosing is planned to test whether this decline in effectiveness continues with additional experiments.

4.2.3. Application of Recommendation

Treatment 4 consists of a two-inch compost mulch layer, a primary layer, and a polishing layer placed under the primary layer. The primary layer, which is the same as Treatment 5, met basic and enhanced treatment criteria; however, adding the polishing layer under the primary layer was necessary to meet TP criteria. Accordingly, the following options provided in Table 53 are recommended for adopting Treatment 4 for a new Washington State bioretention media.

Table 53. Components and Application of New Washington Bioretention Media.

	Basic Treatment	Enhanced Treatment	Phosphorus Treatment	Expanded Plant Palette and Robust Plant Growth
Primary layer	X	X		
Primary plus polishing layer	X	X	X	
Primary plus polishing layer plus compost mulch[a]	X	X	X	X

[a] Do not use the primary media alone with compost mulch. The primary media and compost mulch without the polishing layer will export phosphorus and nitrogen.

The components of the bioretention media presented above are as follows:

1. Primary layer: 70% sand/20% coir/10% high carbon wood ash (biochar).

2. Polishing layer: 90% sand/7.5% activated alumina/2.5% iron aggregate.

3. Compost mulch: coarse compost meeting Ecology's compost specifications in BMP T7.30.

See Section 4.2.5 below for recommended specifications describing the recommended media.

Note that Treatment 4 consisted of compost mulch and a primary and polishing layer. The recommendation above for basic, enhanced and phosphorus treatment consists of a primary and polishing layer without the compost mulch which was not tested directly. However, we conclude that the primary and polishing layer alone will meet or exceed Treatment 4 basic, enhanced and phosphorus treatment results from Treatment 4 which includes compost mulch for the following: elimination of the compost mulch will reduce TP and ortho-P input to the primary and polishing layers; and result for Treatments 5 and 6 (primary layers alone using different sands) significantly reduce (-1 percent reduction for Treatment 5) or eliminate (41.3 percent reduction for Treatment 6) TP export.

4.2.4. Plant Selection

The plant growth study conducted by Herrera (Herrera 2017), demonstrated that the primary layer (state and volcanic sand, coir and high carbon wood ash) can support plants and support robust plant growth equal to the 60/40 media with a two-inch compost mulch layer. However, if the primary layer is used alone to meet basic and enhanced treatment, plants must be selected carefully and adequate water provided during establishment due to the lower nutrient content and low plant available water (see Section 3.7 for plant available water determination). The compost mulch should not be applied over the primary layer without the polishing layer to prevent export of N and P in bioretention areas with underdrains or installations in proximity to phosphorus sensitive receiving waters.

4.2.5. BSM Specification Recommendations

The lab results for the potential BSM specification metrics suggest that the chemically active materials do in fact have high cation and ion exchange capacities, that organic matter content can be met with coir and high carbon wood ash, and the primary media blend will have lower plant available water in drier conditions. These characteristics will likely be inherent in the media components; accordingly, including cation and anion exchange capacity and organic matter is not necessary. While the electrical conductivity results indicate and coir with low salt content can be obtained, this metric should be retained given that coir is processed in sea water and high salt content can degrade plant and soil biota health.

Given the results for the media metrics found in Table 49, a smaller, refined list of recommended specification metrics and numeric ranges from Appendix B is provided in Table 54. Table 55 provides the recommended sand gradation, and Table 56 contains the recommended iron aggregate gradation. Note that Table 54 provides a list of potential metrics and that this list may become shorter as the new media is applied and adopted to this region. Again, note that many of the metrics are routinely performed by manufacturers or vendors, including: sand gradation; maximum passing 100 sieve for high carbon wood ash; iron content and gradation for iron aggregates; and aluminum oxide, bulk density, gradation and surface area for activated alumina. The quality and applicability of the analyses performed by manufacturers or vendors of media components will need to be determined by the media suppliers and end users.

4.2.6. Next Steps

The following are suggested next steps for Ecology to consider in the process for adopting a new Washington State bioretention media specification.

1. The selected BSM media has not been tested in full-scale pilot installations; accordingly, pilot installations should be identified and monitored using TAPE guidelines.

2. The next steps in the development of a construction project specification will be to provide more detail about the specification metrics and procurement process. Some specific recommendations include:
   - Determine which tests are taken from manufacturers published data, which are performed by the vendor as part of a submittal, and which tests are performed by the owner as a verification.
   - Determine when are these tests conducted. (i.e. prior to procurement of the materials, prior to blending, or upon delivery but prior to placement).
   - Determine if permeability is the only test performed on the fully mixed product or should there be other optional or required tests performed by the owner as a verification step prior to placement.

Table 54. Potential BSM Specification Metrics, Methods and Numeric Ranges.

Media Component	Specification Metric	Analytical Method	Numeric Range
Sand	Gradation and Coefficient of Uniformity (Cu)	ASTM D422 (may change to AASHTO T27) or vendor sieve analysis	See Table 55
	Synthetic Precipitation Leaching Protocol	EPA Method 1312	TP: max 0.1 mg/L. Ortho-P: max 0.1 mg/L. Diss Cu: max 8 µg/L. NO3+NO2: max 0.1 mg/L
Coir	Electrical conductivity	TMECC 04.10-A	<4 mmhos/cm
	Synthetic Precipitation Leaching Protocol	EPA Method 1312	TP: max 0.1 mg/L. Ortho-P: max 0.1 mg/L. Diss Cu: max 8 µg/L. NO3-NO2: max 0.1 mg/L
High carbon wood ash (biochar)	Maximum passing 100 sieve	Sieve analysis	10 percent
	Polycyclic aromatic hydrocarbons	EPA 8270D	Not known
	Synthetic Precipitation Leaching Protocol	EPA Method 1312	TP: max 1.2 mg/L. Ortho-P: max 1.2 mg/L. Diss Cu: max 5 µg/L. NO3+NO2: max 0.1 mg/L
Iron aggregate	Gradation	ASTM D422 (may change to AASHTO T27) or vendor sieve analysis	See Table 56
	Iron content	Not available	80-97 percent by weight
	Synthetic Precipitation Leaching Protocol	EPA Method 1312	TP: max 0.05 mg/L. Ortho-P: max 0.05 mg/L. Diss Cu: max 0.01 µg/L. NO3+NO2: max 0.05 mg/L
Activated Alumina	Alumina (Al_3O_2) content	Vendor analysis	Minimum 92 percent
	Bulk density	Vendor analysis	Minimum 760 Kg/m3
	Gradation	ASTM D422 (may change to AASHTO T27) and vendor sieve analysis	0.5-1.5 mm
	Surface area	Vendor analysis	Minimum 300 m^2/g
	Synthetic Precipitation Leaching Protocol	EPA Method 1312	TP: max 0.05 mg/L. Ortho-P: max 0.05 mg/L. Diss Cu: max 0.01 µg/L. Diss Al: not known. NO3+NO2: max 1.5 mg/L
Primary Media: 70% sand/ 20% coir/10% high carbon wood ash (biochar)	Permeability (Ksat)	ASTM D1557 and ASTM D2434 (modified method)	50 to 175 inches/hr. (see Table note)
Polishing Layer: 90% and/ 7% activated alumina/3% iron aggregate	None required	None required	None required

Note: 50 to 175 in/hr is the Ksat range for the BSM specification that reflects the actual Ksat of BSM using ASTM 2434. This range is significantly higher than the 12 in/hr maximum used for BSM under BMP T7.30 in Volume 7 of the SWMMWW. The 12 in/hr guideline (measured or initial rate before correction factors) is a maximum Ksat for sizing bioretention to prevent under-sizing bioretention facilities, excessive maintenance and premature failure.

Table 55. BSM Sand Gradation.			
Particle Size (µm)	US Standard Sieve	Minimum (percent passing)	Maximum (percent passing)
9,510	3/8	100	100
6,350	1/4		
4,760	4	95	100
2,380	8	68	86
2,000	10		
1,680	12		
1,410	14		
1,190	16	47	65
1,000	18		
841	20		
707	25		
595	30	27	42
500	35		
425	40		
354	45		
297	50	9	20
250	60		
177	80		
149	100	0	7
105	140		
88	170		
74	200	0	2.5

Follows WSDOT spec 9-03.1(2)B.

Coefficient of Uniformity (Cu) = 4 (minimum).

Gradation is slightly coarser and more permeable than the existing 60/40 sand specification.

Table 56. Iron Aggregate Gradation.			
Particle Size (µm)	US Standard Sieve	Minimum (percent passing)	Maximum (percent passing)
9,510	3/8		
6,350	1/4		
4,760	4	100	100
2,380	8	95	100
2,000	10		
1,680	12		
1,410	14		
1,190	16	75	90
1,000	18		
841	20		
707	25		
595	30	25	45
500	35		
425	40		
354	45		
297	50	0	10
250	60		
177	80		
149	100	0	5
105	140		
88	170		
74	200		

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APPENDIX A

Candidate Components for Media Blends

Table A-1. Potential Bioretention Media Components for the BSM Phase 2 Study.

Common Name	Component	Material Composition	Source/Process	Vendor	Source Location	Cost/Unit (CY Delivered)	Quantity for Cost Estimate	Estimated % Use in BSM (low)	Estimated % Use in BSM (high)	Target Pollutants	Treatment Mechanism	Project	Tests Completed or in Progress: Leaching or Flushing	Hydraulic Conductivity	Stormwater Dosing	Polishing	Pilot Testing	Performance Notes	Recommended 2014 KC BSM Study	Recommended 2015 KC BSM-Plant (Phase 1) Study	Recommended BSM Phase 2 Study
Activated alumina	Mineral additive	Aluminum hydroxide (1)	Dehydroxylating aluminum hydroxide. Process results in a highly porous material (1) that is 98 to 99% alumina and 1 to 2% sod`a.	Axens, Inc. (eastern U.S.) Contact: Bill Reidbreid@axensna.com	Eastern US and Canada.	$1,750.00	<100 CY	5	10	Fluoride, arsenic, selenium, beryllium, and natural organic matter (10). Phosphorus (11).	sorption, filtration	Port of Olympia and Seattle Polishing Layer Study	X	X	X	X		Best performance for P capture (17, 23). Some have reported possibility to raise pH to 8 to 10 (16). No increase in pH in local trails (22).	Yes	Yes	Yes
Bauxite	Mineral additive	Hydrous aluminum oxides and aluminum hydroxides (13).	Strip-mined.	Not targeted for testing	Australia, Brazil, China, India, etc.	Not targeted for testing	Not targeted for testing	5	20	Phosphorus	sorption and/or precipitation (pH dependent…neutral to lower pH favors Al and Fe adsorption)							Principle source of aluminum.	No	No	No
Bayoxide E33	Mineral additive			AdEdge	Atlanta, Georgia	Not targeted for testing	Not targeted for testing	5	10	Phosphorus									No	No	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 analyzed Environmental Ultra.	Biochar Supreme (Everson, WA), Walrath.	Western WA, Canada or.	$300.00	>300 CY	5	20	Varies by feedstock and burn process.	Filtration, Sorption, complexation and promotes biological activity thus uptake.	Port of Olympia. SPLP extraction for 2014 Kitsap BSM study	X	X	X	X		High variability among sources for P export, pollutant capture and hydraulic conductivity (17). Specifically analyzed Environmental Ultra.	Yes	No	No
Blast furnace slag	Mineral additive	Typically 33 to 43% calcium oxide and 9 to 16% aluminum oxide (13).	By-product of iron ore processing.	Not targeted for testing`	Steel manufacturers.	Not targeted for testing	Not targeted for testing	5	20	Phosphorus	Sorption 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 (14). Potential for metal leaching (13).	No	No	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.	Port of Olympia		X	X				No	No	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	Sorption and/or precipitation (pH dependent…higher pH favors calcium precipitation).								No	No	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).	No source identified	No source identified	5	20	Metals.	Not known.	Port of Olympia						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 (19).	No	No	No
Coco coir fiber (may or may not include pith)	Bulk organic	Coconut husk and coconut husk pith.	Fibrous layer of the fruit is separated from the hard shell manually (~2,000 husk/day) or by machine (~2,000 coconuts/hour) (1).	Sunlight Supply (Vancouver, WA). Using CocoGro from Botanicare for testing.	India, southeast Asia and south Pacific (1).	$130-$150.00	>200 CY	20	40	Not known (primarily applied for soil structure).	Not known.	Kitsap BSM and Redmond Study 2014–15. Kitsap BSM-Plant Study Phase 1 2015.	X	X	X		X	Best performing organic material with very low leaching and high water holding capacity.	Yes	Yes	Yes

Table A-1 (continued). Potential Bioretention Media Components for the BSM Phase 2 Study.

Common Name	Component	Material Composition	Source/Process	Vendor	Source Location	Cost/Unit (CY Delivered)	Quantity for Cost Estimate	Estimated % Use in BSM (low)	Estimated % Use in BSM (high)	Target Pollutants	Treatment Mechanism	Project	Tests Completed or in Progress					Performance Notes	Recommended 2014 KC BSM Study	Recommended 2015 KC BSM-Plant (Phase 1) Study	Recommended BSM Phase 2 Study
													Leaching or Flushing	Hydraulic Conductivity	Stormwater Dosing	Polishing	Pilot Testing				
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, hydrocarbons, bacteria.	Filtration, sorption, complexation and promotes biological activity thus uptake.	Kitsap BSM and Redmond Study 2014–15. Kitsap BSM-Plant Study Phase 1 2015.	X	X	X	X	X	Flushing and leaching of Cu, P and N observed (21).	Yes (selected for comparative performance)	Yes (selected for comparative performance)	Yes (for comparison to existing spec only)
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, sorption.	Kitsap BSM Study 2014. Kitsap BSM-Plant Study Phase 1 2015.	X					Initial SPLP screening indicates N, P and Cu at detection limits.	Yes	No	No
Corliss utility sand	Bulk aggregate	Not known	Various mining processes (dredging, excavation).	Corliss (Puyallup)	Puyallup	$26.65	>100 CY	50	80	Particulates, metals	Filtration, sorption.	Kitsap BSM Study 2014.	X					Initial SPLP screening indicates N, P and Cu at detection limits.	Yes	No	No
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.	Sorption, filtration	Kitsap BSM Study 2014.	X					Initial SPLP screening indicates high N leaching potential (22).	Yes	No	No
Dakota peat	Bulk organic	Decomposed reeds and sedges from ancient swamp lands.	Harvested from old ditched and drained farmland (now shrublands). Field is tilled dried and vacuum harvested (generally to 24" depth).	Dakota Peat (Grand Forks, ND)	c	$300.00	<100 CY	5	20	Metals.	Filtration, sorption, complexation and promotes biological activity thus uptake.	Kitsap BSM Study 2014.	X					Harvested area is returned to habitat (e.g., water fowl) in cooperation with MN DNR. Excellent metals capture at high flow rates (19). May lower pH significantly (19). May export P and Ortho-P (19). Initial SPLP extraction indicates very high N export potential (22).	Yes	No	No
Diatomaceous earth (Diatomite)	Mineral additive	Approximately 80 to 90% silica, 2 to 4% alumina and 0.5 to 2% iron oxide (1).	Skeletal remains of diatoms	Walrath (Puyallup). Envirotech Soil Solutions George Serril 503-723-9790 http://www.axisplayball.com/more_about_axis.htm#AXIS:32Specifications	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.	Kitsap BSM Study 2014. Kitsap BSM-Plant Study Phase 1 2015.	X	X	X			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. High water holding capacity and improved plant growth.	Yes	Yes	No
Eastern OR basalt sand (see lava sands below)	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			Kitsap BSM Study 2014.	X						No	No	No

Table A-1 (continued). Potential Bioretention Media Components for the BSM Phase 2 Study.

Common Name	Component	Material Composition	Source/Process	Vendor	Source Location	Cost/Unit (CY Delivered)	Quantity for Cost Estimate	Estimated % Use in BSM (low)	Estimated % Use in BSM (high)	Target Pollutants	Treatment Mechanism	Project	Tests Completed or in Progress					Performance Notes	Recommended 2014 KC BSM Study	Recommended 2015 KC BSM-Plant (Phase 1) Study	Recommended BSM Phase 2 Study
													Leaching or Flushing	Hydraulic Conductivity	Stormwater Dosing	Polishing	Pilot Testing				
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. Miles Canyon for Kitsap BSM Study 2014–15).	Western Washington.	$40.00	>300 CY	50	80	Phosphorus (sand filters including biological activity).	Filtration and biological uptake.	Kitsap BSM Study 2014. Kitsap BSM-Plant Study Phase 1 2015.	X					Flushing and leaching of Cu, P and N observed (21).	Yes (selected for comparative performance)	Yes (selected for comparative performance)	Yes (for comparison to existing spec only)
Expanded shale	Mineral additive	Depending on parent materials: Hydous 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			Port of Olympia			X			Elevates pH (17).	No	No	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 (13).	No	No	No
G2 Media	Mineral additive	Diatomaceious earth and ferric hydroxide.	Ferric hydroxide is chemically bonded to DE.	ADI International	New Brunswick, Canada	$2700 (not delivered)	Not targeted for testing	5	10	Phosphorus	Sorption								No	No	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 from Charcoal House for analysis. 8x16 mesh http://www.buyactivatedcharcoal.com/product/granular_activated_charcoal/coconut/8x16_mesh	Unknown	$718.20	<100 CY	5	20	Organic compounds, natural organic matter, mercury and Cd (1, 9).	Sorption, filtration	Port of Olympia and Kitsap BSM Study 2014–15. BSM Study Phase 1 2016–17.	X	X	X	X		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 (19). May release (19) or export P (17).	Yes	Yes	No
Gypsum	Mineral additive	Soft sulfate mineral. Calcium sulfate dihydrate (1) (23)	Mined (1) recycled casting gypsum from various manufacturing processes, recycled wallboard gypsum, and flue gas desulfurization (FGD) (23)	The Dirty Gardner, Pro-Pell-It!	Wyoming	$77.71	<1 CY	10	30	Phosphorus	Primarily filtration, sorption and precipitation (24)	Park Place Media Study	X					Gypsum amendments result in flocculation of soil particles, which reduces erosion and crust development allowing for seedling establishment and improving surface infiltration rates (23). The calcium in gypsum can bind with phosphorus to form a calcium phosphate precipitate (23).	No	No	No
Hi-clay alumina	Mineral additive	Minimum 20 to 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	Sorption and/or precipitation (pH dependent…neutral to lower pH favors Al and Fe adsorption)								No	No	No
High carbon wood ash (this is a type of biochar)	Organic additive	Coarse wood chips from log yard waste.	Wood chips are burned at high heat in an oxygen environment then screened and washed for desired gradation.	Biological Carbon LLC. Use PD and AS 100+ mesh for analysis.	Philomath, OR	$400.00	1 CY	5	20	Varies by feedstock and burn process.	Filtration, sorption, complexation and promotes biological activity thus uptake.	Kitsap BSM Study 2014. Kitsap BSM-Plant Study Phase 1 2015.	X	X	X			Initial leaching trials indicate some potential for ortho-P leaching (higher than GAC 1230AW, but lower than biochar) (22).	Yes	Yes	Yes

Table A-1 (continued). Potential Bioretention Media Components for the BSM Phase 2 Study.																					
													Tests Completed or in Progress								
Common Name	Component	Material Composition	Source/Process	Vendor	Source Location	Cost/Unit (CY Delivered)	Quantity for Cost Estimate	Estimated % Use in BSM (low)	Estimated % Use in BSM (high)	Target Pollutants	Treatment Mechanism	Project	Leaching or Flushing	Hydraulic Conductivity	Stormwater Dosing	Polishing	Pilot Testing	Performance Notes	Recommended 2014 KC BSM Study	Recommended 2015 KC BSM-Plant (Phase 1) Study	Recommended BSM Phase 2 Study
Imbrium/ Contech Sorptive media	Mineral additive			Not targeted for testing	Contec.	Not targeted for testing		5	10		Sorption and precipitation.								No (Contech will not release material for testing).	No (Contech will not release material for testing).	No (Contech will not release material for testing).
Iron aggregate	Mineral additive	Iron particles (97% Fe)	Waste from machine and mill operations. Material is then cleaned and sieved.	Connelly-GPM, Inc.	Chicago, IL	$1,992.00	1 CY	5	10	Phosphorus, copper.	Sorption, precipitation.	Seattle Polishing Layer Study 2015. Kitsap Phase 1 BSM-Plant Study 2015	X	X	X	X			No	Yes	Yes
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).	Sorption, filtration							Coating process determines Fe density and performance.	No source identified	No source identified	No source identified
Iron-coated wood chips	Bulk organic	Horse manure and ferrous gluconate	Ferrous gluconate incorporated onto wood pellets. Process facilitated by bacteria.	Experimental stage (no vendor)	Eastern Washington	$70.00	1 CY	5	20	Phosphorus, lead.	Sorption	Kitsap BSM Study 2014.	X	X	X			Exported Cu during dosing trials (22).	Yes	No	No
Lava sand (see lava sand below)	Bulk aggregate		Crushed product from lava rock. Lava rock from volcanic cinder pit exposed to steam.	Palmer Coking Coal and Walrath	Goldendale, WA	$78.30	>5 CY	50	80	Possibly Phosphorus	Sorption	Kitsap BSM Study 2014.	X	X	X			Treatments with this material exported copper during dosing experiments.	Yes	Yes	see below
Lava sand (scoria surplus sand)			Crushed product from lava rock. Lava rock from volcanic cinder pit exposed to steam.	Stein Hauge, Martin's Feed, PO Box 206 Lynden, WA 98264	Goldendale, WA			50	80	Possibly Phosphorus	Sorption	BSM Study Phase 1 (2016–17)	X	X				Porous structure may improve TSS capture.	NA	Yes	Yes
Lava sand (scoria earthtone sand)			Crushed product from lava rock. Lava rock from volcanic cinder pit exposed to steam.	Stein Hauge, Martin's Feed, PO Box 206 Lynden, WA 98264	Goldendale, WA			50	80	Possibly Phosphorus	Sorption	BSM Study Phase 1 (2016–17)	X	X				Porous structure may improve TSS capture.	NA	Yes	No
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 depending on parent materials and OM content.	All stormwater treatment mechanisms if media is biologically active.							Flushing and leaching of Cu, P and N observed. Quality and composition of material varies significantly.	No	No	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 (13).	EP Minerals (Reno, NV)	Nevada	$8,370.00	small	5	20	Arsenic and phosphorus (13).								Does not alter pH and reaction is less pH dependent (13).	No	No	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, metals.	Sorption and precipitation.	Kitsap BSM Study 2014.	X					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 (20). Initial leaching indicates nitrate export potential (22).	Yes	No	No
Perlite	Mineral additive	Silcon 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.		Port of Olympia						Helps prevent soil compaction. Low water holding capacity.	No	No	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	Sorption and precipitation.								No	No	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.	Sorption and precipitation.								No (Contech will not release material for testing).	No (Contech will not release material for testing).	No (Contech will not release material for testing).

Table A-1 (continued). Potential Bioretention Media Components for the BSM Phase 2 Study.																					
													Tests Completed or in Progress								
Common Name	Component	Material Composition	Source/Process	Vendor	Source Location	Cost/Unit (CY Delivered)	Quantity for Cost Estimate	Estimated % Use in BSM (low)	Estimated % Use in BSM (high)	Target Pollutants	Treatment Mechanism	Project	Leaching or Flushing	Hydraulic Conductivity	Stormwater Dosing	Polishing	Pilot Testing	Performance Notes	Recommended 2014 KC BSM Study	Recommended 2015 KC BSM-Plant (Phase 1) Study	Recommended BSM Phase 2 Study
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, sorption.	Port of Olympia			X				No	No	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) (18).	Filtration, sorption.	Port of Olympia			X			Highly porous. May export metals and TP (17). Environmental concerns due to high demand and mining in environmentally sensitive areas (1).	No	No	No
Red mud	Mineral additive	Primarily iron, calcium and titanium oxides (13).	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	Sorption 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 to 13).	No	No	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 (19).	Likely sorption.	Kitsap BSM Study 2014.	X					May provide better pollutant capture than silica sands (19). Did not export P or Ortho-P (19). Initial leaching trials indicate some nitrate export potential (22).	Yes	No	No
Shredded cedar bark	Organic additive	Finely shredded bark	Shredded (often multiple times) timber harvest waste	Swansons (Longview, WA)	Southwest Washington.			5	10	Not known (primarily applied for soil structure).	Not known.	Kitsap BSM-Plant Study Phase 1 2015.	X					While primarily a soil structure and water holding capacity amendment the material should be assessed for leaching if commonly applied. Fairly high ortho-P concentration for SPLP extraction.	No	No	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	Filtration.	Port of Olympia		X	X			Can export metals and TP (17).	No	No	No
State Sand	Bulk aggregate	Native pit sand	Washed several times; well-graded with 2% passing through the 100 sieve	ICON Materials (Auburn, WA)	Auburn mine	$28.60	300 CY	50	80	Particulates	Filtration.	Kitsap BSM-Plant Study Phase 1 2015.	X	X	X	X		Initial leaching trials indicate low flushing potential. Coarser PSD provides higher Ksat.	No	Yes	Yes
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)	$30.00	>200 CY	50	80	Possibly bacteria (5).	Filtration.	Kitsap BSM Study 2014. Kitsap BSMPlant Study Phase 1 2015. Seattle Polishing layer study.	X	X	X	X	X	May provide better pollutant capture than silica sands (19). Initial trials indicate low export potential for N, P and Cu (22).	Yes	Yes	Yes
Washed sand (no longer available through Palmer Coker Coal)	Bulk aggregate		Excavation	Palmer Coking Coal	Black Diamond, WA	$44.50	>3 CY	50	80	Phosphorus (sand filters including biological activity).	Filtration.	Kitsap BSM Study 2014–15	X	X	X	X		No longer available.	Yes	No (no longer available)	No (no longer available)

Table A-1 (continued). Potential Bioretention Media Components for the BSM Phase 2 Study.

Common Name	Component	Material Composition	Source/Process	Vendor	Source Location	Cost/Unit (CY Delivered)	Quantity for Cost Estimate	Estimated % Use in BSM (low)	Estimated % Use in BSM (high)	Target Pollutants	Treatment Mechanism	Project	Tests Completed or in Progress: Leaching or Flushing	Hydraulic Conductivity	Stormwater Dosing	Polishing	Pilot Testing	Performance Notes	Recommended 2014 KC BSM Study	Recommended 2015 KC BSM-Plant (Phase 1) Study	Recommended BSM Phase 2 Study
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	Sorption and/or precipitation (pH dependent…neu tral to lower pH favors Al and Fe adsorption)	Port of Olympia		X	X			Good P capture performance. Exports Cu (17).	No	No	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 (14), 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).	Kitsap BSM Study 2014.	X					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 (19). Initial trials indicate potential to export nitrate (22).	Yes	No	No

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APPENDIX B

All Potential BSM Specification Metrics, Methods and Numeric Ranges

Table B-1. All Potential BSM Specification Metrics, Methods, and Numeric Ranges.			
Media Component	**Specification Metric**	**Analytical Method**	**Numeric Range**
Sand	Gradation and Coefficient of Uniformity	ASTM D422 (may change to AASHTO T27) or vendor sieve analysis	See Table 53 in Results section
	Synthetic Precipitation Leaching Protocol	EPA Method 1312	TP: max 0.1 mg/L. Ortho-P: max 0.1 mg/L. Diss Cu: max 8 µg/L. NO3-NO2: max 0.1 mg/L
Coir	Electrical conductivity	TMECC 04.10-A	<4 mmhos/cm
	Cation exchange capacity	EPA 9081 (sodium)	Not known
	Anion exchange capacity	EPA 9081-Modified (nitrate)	Not known
	Synthetic Precipitation Leaching Protocol	EPA Method 1312	TP: max 0.1 mg/L. Ortho-P: max 0.1 mg/L. Diss Cu: max 8 µg/L. NO3-NO2: max 0.1 mg/L
High carbon wood ash (biochar)	Cation exchange capacity	EPA 9081 (sodium)	Not known
	Maximum passing 100 sieve	Sieve analysis	10 percent
	Polycyclic aromatic hydrocarbons	EPA 8270D	Not known
	Synthetic Precipitation Leaching Protocol	EPA Method 1312	TP: max 1.2 mg/L. Ortho-P: max 1.2 mg/L. Diss Cu: max 5 µg/L. NO3-NO2: max 0.1 mg/L
Iron aggregate	Gradation	ASTM D422 (may change to AASHTO T27) or vendor sieve analysis	See Table 53 in Results section
	Iron content	Not available	80-97 percent by weight
	Cation exchange capacity	EPA 9081 (sodium)	Not known
	Anion exchange capacity	EPA 9081-Modified (nitrate)	Not known
	Synthetic Precipitation Leaching Protocol	EPA Method 1312	TP: max 0.05 mg/L. Ortho-P: max 0.05 mg/L. Diss Cu: max 0.01 µg/L. NO3-NO2: max 0.05 mg/L
Activated Alumina	Alumina (Al_3O_2) content	Vendor analysis	Minimum 92 percent
	Bulk density	Vendor analysis	Minimum 760 Kg/m3
	Gradation	ASTM D422 (may change to AASHTO T27) and vendor sieve analysis	0.5-1.5 mm
	Surface area	Vendor analysis	Minimum 300 m2/g
	Cation exchange capacity	EPA 9081 (sodium)	Not known
	Anion exchange capacity	EPA 9081-Modified (nitrate)	Not known

Table B-1 (continued). All Potential BSM Specification Metrics, Methods, and Numeric Ranges.

Media Component	Specification Metric	Analytical Method	Numeric Range
Activated Alumina (continued)	Synthetic Precipitation Leaching Protocol	EPA Method 1312	TP: max 0.05 mg/L. Ortho-P: max 0.05 mg/L. Diss Cu: max 0.01 µg/L. Diss Al: not known. NO3-NO2: max 1.5 mg/L
Primary Media: 70%sand/20%coir/10%high carbon wood ash (biochar)	Permeability	ASTM D1557 and ASTM D2434 (modified method)	1 to 12 inches/hr.
	Organic Matter	ASTM D2974 or TMECC 05.07A	Not known
	Water holding capacity	Saturated sample in closed chamber. Apply 0.33 atmosphere (5 psi) and then 15 atmospheres (220 psi) to ceramic plate	Not known
Polishing Layer: 90% sand/ 7% activated alumina/ 3% iron aggregate	Cation exchange capacity	EPA 9081 (sodium)	Not known
	Anion exchange capacity	EPA 9081-Modified (nitrate)	Not known

Table B-2. BSM Sand Gradation.			
Particle Size (µm)	Sieve	Minimum (percent passing)	Maximum (percent passing)
9,510	3/8	100	100
6,350	1/4		
4,760	4	95	100
2,380	8	68	86
2,000	10		
1,680	12		
1,410	14		
1,190	16	47	65
1,000	18		
841	20		
707	25		
595	30	27	42
500	35		
425	40		
354	45		
297	50	9	20
250	60		
177	80		
149	100	0	7
105	140		
88	170		
74	200	0	2.5

Follows WSDOT spec 9-03.1(2)B.

Cu = 4 (minimum).

Gradation is slightly coarser and more permeable than the existing 60/40 sand spec.

Table B-3. Iron Aggregate Gradation.			
Particle Size (µm)	**Sieve**	**Minimum (percent passing)**	**Maximum (percent passing)**
9,510	3/8		
6,350	1/4		
4,760	4	100	100
2,380	8	95	100
2,000	10		
1,680	12		
1,410	14		
1,190	16	75	90
1,000	18		
841	20		
707	25		
595	30	25	45
500	35		
425	40		
354	45		
297	50	0	10
250	60		
177	80		
149	100	0	5
105	140		
88	170		
74	200		

APPENDIX C

Peristaltic Pump Calibration

Table C-1. Peristaltic Pump Calibration Pre-Experiment
30 minutes at 53% (stated value = 3340 ml).

Application: Determine accuracy of peristaltic pumps compared to stated value at 53% cycle time (Phase 1 delivery rate) and 30 minute run time. **Analysis performed by**: Curtis Hinman

Method: determine difference between stated value and measured value by determining initial error, adjust pumps and run calibrations to assure pump delivery rate is within stated error (10%) **Date:** 10-26-18 **Sample ID:** none

Pump	Error (%)	Pump Adjustment (%)	Run 1 (mL)	Run 2 (mL)	Run3 (mL)	Run4 (mL)	Stated Value (mL)	Percent Error Run 1	Percent Error Run 2	Percent Error Run 3	Percent Error Run 4	Minutes to Attain 13.4 L	Minutes to Attain 13.4 L	Minutes to Attain 13.4 L	Minutes to Attain 13.4 L
1	0.07	3.80	3310.4	3368.5	3242.6	3418.3	3340.0	-0.89	0.85	-2.92	2.34	161.31	158.53	164.68	156.22
2	-0.02	-1.06	3268.8	3484.7	3077.7	3459.1	3340.0	-2.13	4.33	-7.85	3.57	163.36	153.24	173.51	154.38
3	0.08	4.19	3397.7	3252.2	3322.2	3441.3	3340.0	1.73	-2.63	-0.53	3.03	157.17	164.20	160.74	155.17
4	0.00	0.02	3434.7	3344.8	3290.3	3445.8	3340.0	2.84	0.14	-1.49	3.17	155.47	159.65	162.30	154.97
5	-0.02	-1.02	3434.6	3452.4	3100.5	3819.6	3340.0	2.83	3.37	-7.17	14.36	155.48	154.68	172.23	139.81
6	0.12	6.20	3323.4	3409.6	3134.4	3599.1	3340.0	-0.50	2.08	-6.16	7.76	160.68	156.62	170.37	148.37
7	0.08	4.26	3372.4	3289.1	3262.6	3436.6	3340.0	0.97	-1.52	-2.32	2.89	158.34	162.35	163.67	155.39
8	0.01	0.46	3419.9	3303.7	3266.5	3422.6	3340.0	2.39	-1.09	-2.20	2.47	156.14	161.64	163.48	156.02
9	0.12	6.18	3282.2	3404.1	3219.7	3473.9	3340.0	-1.73	1.92	-3.60	4.01	162.70	156.87	165.85	153.72
10	0.23	12.31	2998.5	3849.1	3084.1	3743.0	3340.0	-10.22	15.24	-7.66	12.07	178.09	138.73	173.15	142.67
11	0.10	5.10	3187.5	3369.0	3174.9	3506.9	3340.0	-4.57	0.87	-4.94	5.00	167.53	158.50	168.19	152.27
12	0.25	13.00	3145.2	3502.5	3216.9	3464.8	3340.0	-5.83	4.87	-3.69	3.74	169.78	152.46	166.00	154.12
13	0.14	7.68	3288.6	3397.9	3112.8	3510.5	3340.0	-1.54	1.73	-6.80	5.10	162.38	157.16	171.55	152.12
Mean			3297.2	3417.5	3192.7	3518.6		-1.28	2.32	-4.41	5.35	162.19	156.51	167.36	151.94

Table C-2. Peristaltic Pump Calibration Initial Dosing Experiment
30 minutes at 87% (stated value = 5500 ml), use 5500 ml because some pumps max delivery rate is below 100% or 6300 ml)
***run 1: can only adjust pumps 1 and 13 up 8% or about 1/2 amount needed to attain target ml; accordingly, adjust pumps 1 and 13 to max (100%) and remaining pumps by ~1/2 of column C.**

Application: Determine accuracy of peristaltic pumps compared to stated value at 87% cycle time (Phase 2 delivery rate) and 30 minute run time.
Method: determine difference between stated value and measured value by determining initial error, adjust pumps and run calibrations to assure pump delivery rate is within stated error (10%)

Analysis performed by: Curtis Hinman
Date: 11-19-18 **Sample ID:** none

Pump	Error (%)	Pump Adjustment (%)	Run 1 (mL)*	Run 2 (mL)	Stated Value (mL)	Percent Error Run 1	Percent Error Run 2	Time to Attain 26.8 L (minutes)	Time to Attain 35.6 L (minutes)
1	0.10	10.35	5092.7	5590.1	5500.00	-7.41	1.64	209.71	191.05
2	0.08	7.63	5331.7	5592.6	5500.00	-3.06	1.68	200.31	190.97
3	0.06	5.79	5348.4	5501.6	5500.00	-2.76	0.03	199.69	194.13
4	0.06	5.96	5422.3	5525.1	5500.00	-1.41	0.46	196.96	193.30
5	0.01	0.65	5453.8	5527.7	5500.00	-0.84	0.50	195.83	193.21
6	0.10	9.65	5464.0	5572.0	5500.00	-0.65	1.31	195.46	191.67
7	0.06	5.68	5453.8	5574.3	5500.00	-0.84	1.35	195.83	191.59
8	0.04	4.21	5437.8	5609.1	5500.00	-1.13	1.98	196.40	190.40
9	0.07	7.36	5422.7	5542.0	5500.00	-1.41	0.76	196.95	192.71
10	0.22	22.08	5876.5	5695.0	5500.00	6.85	3.55	181.74	187.53
11	0.05	5.01	5394.6	5565.0	5500.00	-1.92	1.18	197.98	191.91
12	0.20	20.41	5698.9	5571.0	5500.00	3.62	1.29	187.40	191.71
13	0.14	14.17	5193.4	5621.9	5500.00	-5.57	2.22	205.65	189.97
Minimum			5092.7	5501.6					
Maximum			5348.4	5592.6					
Mean			5430.0	5576.0				196.92	191.55