ASSESSMENT OF COPPER AND ZINC ADSORPTION TO LIGNOCELLULOSIC FILTRATION MEDIA USING LABORATORY AND FIELD SCALE COLUMN TESTS FOR THE PURPOSE OF URBAN STORMWATER REMEDIATION

By

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To the Faculty of Washington State University:

The members of the Committee appointed to examine the thesis of VINCENT PAUL McINTYRE find it satisfactory and recommend that it be accepted.

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ASSESSMENT OF COPPER AND ZINC ADSORPTION TO LIGNOCELLULOSIC FILTRATION MEDIA

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OF URBAN STORMWATER REMEDIATION

Abstract

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Practical engineering solutions to address growing municipal stormwater issues are needed to maintain a healthy relationship between humans and the environment. In the Pacific Northwest, elevated soluble zinc and copper concentrations originating from urban stormwater runoff provide a significant threat to native salmon and steelhead populations. In response to urbanization, existing stormwater infrastructure needs to be upgraded to treat non-point source pollution, including soluble metals, prior to entering the receiving water. Media filtration BMPs provide the flexibility and small footprint needed for retrofit applications that are space limited, such as ferry terminal staging areas. An effective yet low-cost filtration media needs to be identified to remove soluble metals of concern from urban runoff. Laboratory and field scale continuous flow column studies were performed on torrefied and non-torrefied Douglas-fir wood crumbles, charcoal, and pea gravel to evaluate their effectiveness at sorbing soluble copper and zinc. The Bainbridge Island ferry terminal staging area was selected as the field test site. Laboratory column tests indicated that the most efficient adsorption media in relation to both metals was non-torrefied wood, followed in order by pea gravel, torrefied wood, and charcoal. High stormwater flow tests performed in the laboratory on charcoal and torrefied wood columns resulted in no statistically significant difference in effluent metal concentrations. A deicer flush performed on torrefied wood and charcoal columns following adsorption tests resulted in a significant increase in effluent metal concentration. The field test column containing charcoal averaged respective percent soluble zinc, soluble copper and total suspended solids removal of 41%, -17%, and 54%.

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Dedication

The feasibility of this project is entirely attributed to my wonderful bride, Randi Dawn McIntyre, who has been and forever will be my strength and purpose – and to whom I can never repay. This thesis is dedicated to her and to my beautiful daughters, Madelynn Lahree and Sydnee Keredah. The joy that daughters bring to a father is unparalleled.

1. BACKGROUND AND INTRODUCTION

Two overarching parameters of interest when discussing urban stormwater issues are quality and quantity. Decreased stormwater quality and increased quantity has been directly correlated to population growth, urbanization, and land development that results in an increased percentage of impervious surfaces.[1] Significant nationwide stream, lake, and estuary impairment is directly attributed to this low-quality, high-quantity urban runoff.[1,2] Impairment due to stormwater quantity manifests in the form of changes to established seasonal flow patterns, disruption and degradation of habitat, abnormal stream energy fluctuations, and resulting changes to species populations and communities.[1,3] Water quality impairment is attributed to pollutants that have been identified as having harmful impacts on aquatic ecosystems and human health.[1] Nationally, over 65 % of all impaired waterbodies are attributed to the pollutants listed below.[1] Stormwater runoff was identified as being the primary source of elevated heavy metal concentrations which are the fifth most reported cause of waterbody pollution in the United States.[1,4,5]

- Mercury
- Pathogens
- Sediment
- Heavy Metals (other than mercury)
- Nutrients
- PCBs
- Pesticides
- Salinity/TDS/Chlorides

Dissolved metals naturally exist in surface waters due to mineral dissolution, with normal background concentrations varying from waterbody to waterbody depending on the surrounding soil content and composition.[4] Commonly monitored toxic metals consists of arsenic, cadmium, chromium, copper, lead, mercury, nickel, selenium, and zinc.[4]

In the Pacific Northwest, zinc (Zn) and copper (Cu) are two heavy metals of particular concern. While they present relatively low toxicity to humans, their allowable surface water limits into fresh and saltwater bodies are relatively low (Table 1).[6] Significant adverse health effects manifest in fish and other aquatic invertebrates when exposed to even slightly elevated levels of soluble Zn and Cu.[3,7] Anadromous salmonids, of which five species are currently classified as "threatened" in Washington State, are particularly sensitive.[7–11] Salmonids exposed to acute and/or chronic soluble Zn and Cu during various life stages exhibit reduced reproductive ability, inhibited egg fertilization, low egg survivability, predatory avoidance interference, navigation confusion during migration, altered feeding habits, gill damage, inhibited gill function, stunted growth, sexual morphism, decreased oxygen consumption, increased heart rate, organ deformities and degradation, divergent behavior, changes to blood and serum chemical composition, and increased mortality rate.[7–9,12,13] For adult salmonids, acute copper and zinc toxicity (96 hr, LC_{50}) ranges from 60 – 680 µg/L and 90 – 141 µg/L , respectivly.[7,14,15] Chronic exposure data, testing, and standardization is less prevalent, however, observable adverse effects to salmonids from chronic exposure has been reported in concentrations as low as 5 µg/L Cu and 30 µg/L Zn.[7,15]

Table 1: Soluble zinc and copper USEPA regulatory discharge limits.

Metal	Discharge to Freshwaters (μg/L)		Discharge to Marine Waters (μg/L)	
	Acute (1 hr. ave)	Chronic (4 day ave)	Acute (1 hr. ave)	Chronic (4 day ave)
Zinc	120 [a]	120 [a]	90	81
Copper	13 [a]	9 [a]	4.8	3.1

Sources: National Recommended Water Quality Criteria: 2002. EPA-822-R-02-047. USEPA, 2002.
Water Quality Standards for Surface Waters: Toxic substances. WAC 173-201A-240. Washington State, 2008.
a. The tabulated values correspond to a hardness of 100 mg/L as $CaCO_3$.

Primary anthropogenic sources of total Zn and Cu concentrations in watersheds proximal to urban environments are attributed to vehicle fluid leaks, vehicle component wear (brake pad dust, tire wear, engine wear, ect.), deposition from atmospheric pollution, road surface degradation, roofing, siding, marine antifouling coatings, wood preservatives, copper containing pesticides, galvanized metal surfaces, hydraulic fluid, zinc containing fertilizers and pesticides, and moss controlling agents.[9,12,14–16] Zn and Cu concentrations in urban stormwater vary widely depending on the region, source, and pathway.[16] However, typical values range nationally from 20 – 5,000 μg/L total Zn and 5 – 200 μg/L total Cu.[16] In highly galvanized industrial locations, it's not uncommon to see dissolved Zn concentrations up to 15,000 μg/L in runoff.[17]

Zinc and Copper exist in aquatic environments as divalent free metal ions and as formed complexes with inorganic ligands or natural organic matter (NOM).[7,13,18] Toxicity to marine organisms is attributed to the free metal ion form.[18] Primary removal from the water column occurs via sedimentation and metabolic uptake by organisms.[7]

The 2012 Stormwater Management Manual for Western Washington (SMMWW) details best management practices (BMPs) that are established in the State of Washington for treating stormwater quality and quantity.[19] Sedimentation ponds or "wetpools" can be highly effective at removing metals sorbed onto particulates and grass-lined swales provide filtration and biological uptake of soluble metals through vegetation, however, these BMPs require a significant footprint that many urban retrofit sites cannot accomodate.[19] One option that addresses limited space requirements is filtration.[19]

Filtration BMPs used to treat contaminated runoff are attractive due to their versatility, ease of operation, and controllability.[19] The media can be engineered to treat unique stormwater compositions and space requirements are generally less than for other BMPs.[19] The mechanisms for metal contaminant removal from stormwater using a filtration BMP is through the removal of metal bound particulates and adsorption of soluble metal species.[20]

Adsorption is the process by which dissolved constituents are physically, chemically, or electrostatically bonded to a media surface and removed from the bulk phase solution.[20–22] Physical adsorption is a process achieved by weak molecular bonding such as Van der Waals forces and hydrogen bonding.[21,22] IN addition, physical adsorption is a reversible process that can allow for media regeneration and is the most common adsorption mechanism utilized in water treatment applications.[21] Chemisorption is essentially an irreversible bond facilitated by electron transfer between the sorbate and sorbent.[21,22] Electrostatic attraction and bonding is attributed to differences in charge between the sorbent surface and the sorbate.[22] A greater charge gradient between the two results in a stronger bond.[22] Cation exchange occurs when an electrostatically bound lower-valence cation is replaced by a higher-valence cation.[22] For example, two electrostatically bound sodium (Na^{+}) ions would be replaced by a single zinc (Zn^{2+}) ion because the affinity is stronger due to the larger charge difference.[22] Electrostatic attraction is the most significant mechanism for ionic solute removal – such as free metal ions.[21]

Adsorption capacity of a sorbent relies heavily on available surface area for bonding sites which is why adsorption media is often made out of porous materials.[21] Granular activated carbon (GAC), for example, has a surface area range of 950 - 1250 m^2/g, despite only having a mean particle size of 0.5 - 3 mm.[21] Additionally, the surface must contain adsorption sites that attract the contaminant of interest.[23] Electrostatic adsorption of heavy metals is primarily attributed to the presence of carboxyl (R-COOH) and hydroxyl (R-OH) functional groups.[23]

Common stormwater treatment filtration medias include sand, crushed rock, dolomite, gypsum, and perlite.[19] GAC, a staple for drinking water and wastewater treatment, has also been investigated alongside novel medias such as agricultural wastes, compost, recycled natural fibers, and various biomass derived chars.[24–27] Research has shown GAC to effectively adsorb heavy metals, however, production costs and issues with regeneration have kept it from being widely accepted as a feasible option to treat municipal stormwater.[28] This research project primarily investigated two, low-cost, novel, aqueous filter media for soluble zinc and copper adsorption – fast pyrolyzed charcoal and torrefied wood crumbles.

Charcoal derived from fast pyrolysis is largely a byproduct of the global biofuels initiative.[29] Since the mid-1970's oil shortage in the United States, researchers have been investigating pathways to convert lignocellulosic biomass into liquid fuels.[29] One such pathway is pyrolysis.[29] During pyrolysis, biomass is heated in an anoxic environment allowing volatile gases to escape without combustion.[25] The collected volatilized gasses and excreted tars are then purified and treated to form biofuels, bio-oils, and biochemicals.[28] Charcoal is the carbonized spent biomass residual.[25] Charcoal has been monikered "biochar" when produced for and used in soil amendment applications or other environmental management processes and will be referred to as such continuing forward in this report.[30]

Biochar's parent feedstock (i.e. softwood, hardwood, bark, corn stover, animal manure, rice husks, straw, ect.) can determine its eventual adsorption application and removal efficacy.[25] Additionally, adsorption effectiveness is dependent on pyrolysis temperature, atmosphere, and residence time[25,28,31]. Researchers have been attempting to optimize adsorption performance by adjusting these governing parameters, increasing surface area through activation, and chemically modifying the surface functional groups.[28] Research has shown that standard, modified, and activated biochars are effective to varying degrees at removing soluble metals, dyes, phenols, pesticides, polycyclic aromatic hydrocarbons, solvents, anions, E. coli, endocrine-disrupting compounds, and pharmaceutically active compounds from aqueous solutions.[28,32,33]

Torrefied wood was also investigated in this report as a novel adsorption media. Torrefaction is a mild pyrolysis process intended to preserve the biomass lower heating value while volatilizing off low caloric value gases like CO_2, water, and some organic acids.[34,35] The resulting wood exhibits darkened color, weakened structural integrity, enhanced hydrophobicity, increased energy density, heightened resistance to biodegradation, and significantly reduced weight.[28] Torrefaction is currently used to decrease transportation costs, increase fuel quality, improve storability, and as a preprocessing treatment.[34]

Torrefaction largely maintains the biomass pore structure integrity and therefore lacks the easily accessible surface area needed for adsorption sites.[28] Because of this, torrefied wood is not typically considered for adsorption applications.[28] However, in a recent review of cellulosic biosorption, Hubbe, 2013, indicated that torrefied wood should not be immediately discounted as a sorbent based solely on limited surface area.[36] He highlighted the diverse surface chemistry developed by torrefaction and theorized that torrefied wood's retained structural integrity may be advantageous and worthy of investigation.[36]

The research reported herein was designed to evaluate the effectiveness of torrefied wood crumbles and biochar to sorb soluble metals, specifically Zn and Cu, from stormwater. Non-torrefied Doug-fir crumbles and pea gravel were also investigated to a lesser degree. The focus was directed towards the treatment of stormwater generated on ferry terminal parking lots.

2. EXPERIMENTAL METHODS

Bench scale and field scale tests were performed to determine if biochar and torrefied wood could be used to remove soluble zinc and copper from stormwater. Laboratory column tests were employed to test performance under controlled conditions. A field scale filter column was designed and installed at the Bainbridge Island, WA ferry terminal and data was collected over a seven month period (April-Oct.).

2.1 Media Tested

The two primary materials tested for zinc and copper adsorption were biochar and torrefied wood crumbles. To a lesser extent, adsorption column tests were also performed on non-torrefied wood or "raw wood" crumbles and pea gravel. The pea gravel was used in continuous flow columns to evenly distribute influent flow and stabilize the media and it was necessary to determine its contribution to zinc and copper removal.

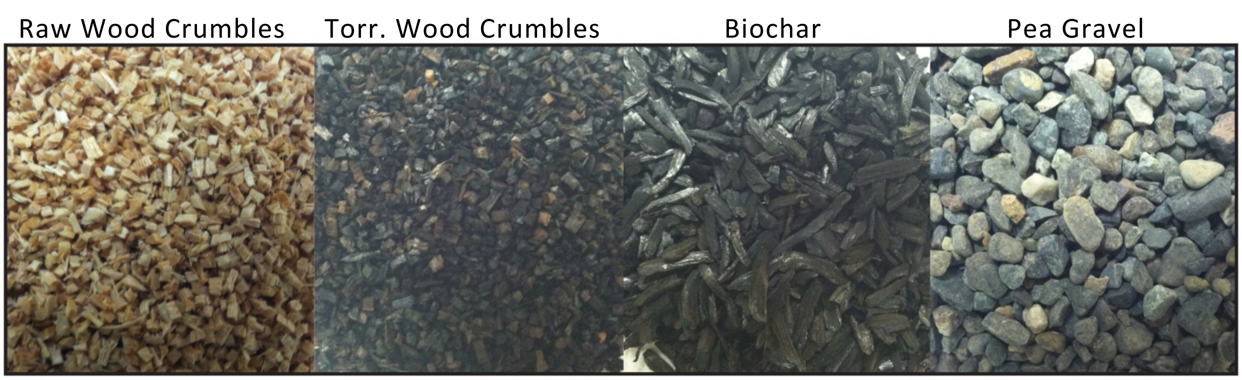


Figure 1. Media evaluated in this project (not to scale).

The biochar used in this project was sourced from Biochar Products, a startup company located in Halfway, Oregon that produces biochar and bio-oil via fast pyrolysis.[37] The char was produced using beetle-killed, lodge pole pine that was fast pyrolyzed using a mobile, pilot scale Abri Tech reactor.[38] Prior to entering into the reactor, the feedstock was dried and pulverized using a gas-fired chain flail dryer.[38] The reactor itself used an externally heated hot shell auger with an inert high density 2 mm steel heat carrier.[38] The mean operating temperature for the main auger and the carrier reservoir was 400 °C and the average total residence time in the system was six minutes.[38] Carbonization and evacuation of gas phase volatiles occurred within 2-4 seconds.[38] No carrier gas was used.[38] The production yields were 15% process gas, 60% bio-oil, and 25% biochar by weight.[38] The observed average biochar production rate was 7.5 kg/hr.[38] Once received, the biochar was roughly sieved (US series, number 6 and 8 mesh) through a large capacity, dual screen shaker table to remove bulk fines. It was then dried at 103 °C for 24 hours and sieved again using a RAINHART Co. 637 Mary Ann® laboratory sifter to further remove fines and achieve a more uniform media. The size fraction passing through the 6 mesh sieve (3.35 mm) and retained on the 8 mesh sieve (2.36 mm) was utilized in the laboratory and field column experiments. In previous work, the media was measured to have a specific surface area of 395 m^2/g.[31]

Two millimeter, Doulas-fir Crumbles™ were sourced from Forest Concepts, LLC, located in Auburn, Washington. The media was produced from an industrial grade, Doug-fir veneer that was passed through a paper-shredder-like rotary shearing machine (cutters set at 1.6 mm) resulting in uniform wood cube particles.[39] It was then screened to a nominal 2mm size and dried to approximately 8% moisture content prior to shipping. When received, the majority of the crumbles were apportioned for torrefaction while a smaller fraction was set aside to be used as a control.

The Doug-fir crumbles were torrefied at Washington State University (WSU) using a bench scale continuous auger pyrolysis reactor. The feed auger passed through a Lindberg/Blue M Tube Furnace set at 270 °C with an approximate residence time of 30 minutes. Torrefaction occurred in the presence of air which was supplied from a compressed air tank at a flow of 4.5 liters per minute. The torrefied wood was then sieved to remove fines using a RAINHART Co. 637 Mary Ann® laboratory sifter. The fraction used in testing was retained on a US Series 10 mesh (2.00 mm) sieve. Raw wood crumbles were also sieved in the same manner prior to utilization.

Pea gravel was used as a top layer in the continuous flow columns to help disperse the influent flow, prevent accelerated media degradation by absorbing flow energy, and stabilize the media by opposing buoyant forces under saturated conditions. It was sourced from Atlas Sand & Rock in Pullman, Washington. Prior to use, the pea gravel was washed in tap water to remove dust, dirt and sand and then allowed to dry overnight at room temperature. Select physical characteristics of all four media investigated are listed in Table 2. The values reported in Table 2 were determined specifically for this project and are applicable to the media used in the laboratory and field column tests. The measurements taken and calculations used to develop Table 2 are included in the Appendix.

Table 2. Physical characteristics of the media.

Media	Biochar	Raw Wood	Torrefied Wood	Pea Gravel
Mean Particle Size (mm)	2.55	2.19	1.97	4.40
Moisture Content	8%	4%	4%	1%
Compacted Volumetric Mass Density (oven dried g/L)	98	150	172	1706

2.2 Bench Scale Column Tests

Laboratory scale column tests were performed on each media to evaluate performance under continuous flow conditions. Columns were constructed from clear, extruded acrylic (estreetplastics.com). Each column was 30.5 cm (12 in) long with a 10.2 cm (4 in) outer diameter (OD) and a 9.5 cm (3.75) inner diameter (ID). Two layers of Phifer® fiberglass screen with a 0.16 cm (1/16 in) mesh was affixed to the bottom of the columns, to retain the media, using 10.2 cm (4in) dia. hose clamps.

Triplicate columns were used for each media. Each column was packed incrementally with media using a vibrating table until a stabilized compacted height of 20.3 cm (8 in) was reached. Packed column density values are reported in Table 2. Following compaction, 5.1 cm (2 in) of pea gravel was carefully placed on top of the media.

Synthetic stormwater was made in 379 L (100 gallon) batches and stored in high-density polyethylene (HDPE) containers. De-ionized (DI) water (resistivity of ≥ 2MΩ) was used as the foundation for the batch synthetic stormwater. Individual stock solutions (1 g/L) of copper and zinc were made using reagent grade, granular cupric chloride dihydrate and zinc chloride (Fisher Scientific). DI water was spiked with a known volume of stock solution to achieve target influent concentrations of 300 μg/L Zn and 100 μg/L Cu. The pH of the synthetic stormwater was adjusted to 6.1 ± 0.2 using a 1 M NaOH stock solution made from reagent grade sodium hydroxide pellets (J.T. Baker). A HACH® Benchtop pH meter combined with an IntelliCAL™ Ultra Refillable pH probe, designed for low ionic strength samples, was used to measure pH. The synthetic stormwater solution was mixed for 1 minute with a PVC rod and allowed to equilibration for a minimum of 12 hours prior to use. Following the equilibrium period, pH was checked to assure that it was within the desired range.

A high flow, dual-head, variable speed Cole-Parmer peristaltic pump (model #7549-30) connected to a network of 1.6 cm (5/8 in) ID vinyl tubing was used to convey the synthetic stormwater from the feed barrel to the top of the columns. Norprene® tubing (1.3 cm ID) was used inside the peristaltic pump head. At the top of the columns, the influent flow was distributed and applied across the surface area using HDPE distribution heads. Effluent samples were collected at the base of the columns using acid washed laboratory glassware. A schematic of the setup is displayed in Figure 2.

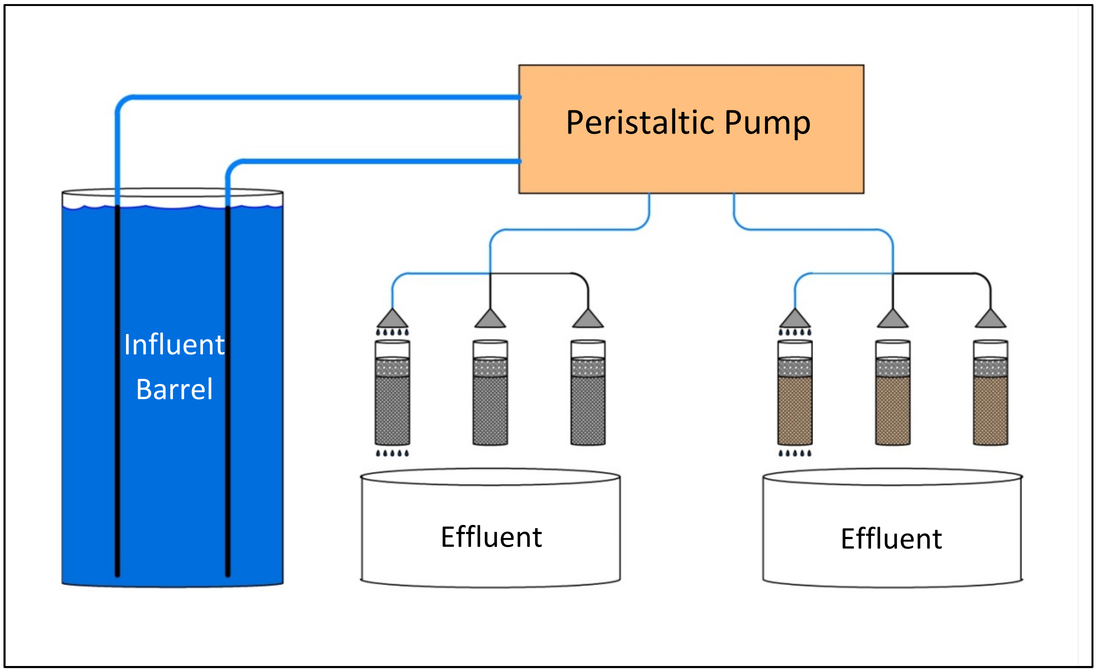


Figure 2. Laboratory scale continuous flow column system.

All materials in contact with stormwater were selected based on their documented inert properties. All stormwater conveyance materials were tested periodically for metals removal to ensure accuracy of the data. No significant metal sorption was detected in the conveyance system.

Each column test event consisted of two sets (e.g. biochar and torrefied wood or raw wood and pea gravel) of triplicate columns being exposed to the same feed water at the same flow rate. The dual-head pump allowed for two out of the six columns to be tested simultaneously (Figure 2). On/off valves were used to change influent flow between columns during operations.

Metals removal testing was divided into two, 40 event phases differentiated by event duration. During Phase I, each event lasted 20 minutes per column. Phase II events that lasted 80 minutes per column. Both phases were conducted at an influent flow rate of 0.76 lpm (0.2 gpm).

During Phase I testing, both discrete and composite effluent samples were collected. Composite samples were developed for each event by collecting 20 mL samples in laboratory glassware at t =1, 5, 10, 15, and 20 minutes. These samples were then combined to produce a composite. In addition, 80 mL discrete samples were collected and tested every 5th event at t = 1, 10, and 20 minutes. A portion of all samples were filtered using Whatman™ 0.45 µm mixed cellulose ester membrane filters and placed in SARSTEDT 15mL sterile screw-cap vials and preserved by adding nitric acid to pH < 2.[40] Another aliquot was similarly preserved without filtration for later comparison against filtered values to check for metal retention by the filters. The remaining sample in the glassware was used to measure pH. An influent sample was extracted from the feed water barrel during each event and prepared for analysis in the same manner. All samples were delivered and tested for zinc and copper concentrations by ICPMS (WSU Peter Hooper GeoAnalytical Lab) within two weeks of sampling.

The same columns used in Phase I were subjected to Phase II testing where event duration was extended from 20 to 80 minutes while flow was maintained at 0.76 lpm (0.2 gpm). Effluent samples were collected for analysis at t = 1, 20, 40, 60, and 80 minutes. Additionally, six influent samples were taken from the feed water barrel at equally distributed intervals throughout each series of events. After 10 events, effluent sample collection intervals were reduced to t = 1, 40, and 80 minutes and influent samples reduced to 3 per event series feed water batch. Processing, preservation, and analysis of the samples followed the methods described previously.

Filtration interference was evaluated by testing filtered and non-filtered samples. The USEPA recommends using mixed cellulose esters (MCE) filter membranes for evaluation of dissolved metals based on their relatively inert performance.[41] However, MCE filters are not completely inert and even a slight metal removal interference can have a significant impact when measuring low concentrations. The 30 influent samples tested showed an average loss through filtration of 18 ± 4 μg/L Zn and 29 ± 4 μg/L Cu. This equates to approximately 6% Zn removal and 30% Cu removal from the filtered influent samples. Ninety effluent samples were tested and showed an average loss through filtration of 5 ± 2 μg/L Zn and 12 ± 3 μg/L Cu. Effluent concentrations are continuously changing, however, initial copper effluent values were less than 5 μg/L which makes a 12.3 μg/L interference unacceptable. This is why the Phase I & II data reported in the results and discussion section are of unfiltered samples. Filtered values are included in the appendix.

Additional tests performed during Phase I & II consisted of measuring effluent total suspended solids and comparing interval sample concentrations to composites. Total suspended solids in the effluent was measured per USEPA method 1684, section 11.[42]

After Phase II was complete, high flow tests and a salt flush were performed on the same torrefied and biochar columns. During the short-term increased flow test events, the Phase I & II flow rate (0.76 lpm, 0.2 gpm) was doubled (1.5 lpm, 0.4 gpm) and quadrupled (3.0 lpm, 0.8 gpm). During these higher flow events, flow duration was maintained at 80 minutes. Influent and effluent sample collection, preparation, and quantification was performed as previously discussed. Next, the columns were subjected to a salt flush test that could occur in the field following an anti-icing agent application to an upstream road surface. For these tests, America West Environmental donated some of their product, Calcium Chloride with BOOST™ (CCB), for evaluation. CCB is listed by WSDOT as a commonly utilized liquid anti-icing agent that is applied during light to moderate snow events.[43] CCB is a low-toxicity salt solution combined with proprietary additives that enhance performance and inhibit corrosion.[44] WSDOT recommends an application rate of approximately 30 gallons CCB per lane mile.[43] The concentration of calcium chloride in CCB is 32 percent and it has a density of 1.345 g/mL.[43] While fully miscible in water, CCB's enhanced viscosity binds the product to the target surface allowing for slower dilution and longer periods between application.[45,46] Design storm (6 mo., 24 hr.) tabulated values for Bainbridge Island were taken from the Stormwater Management Manual for Western Washington (SWMMWW) and parking lot stormwater volume was calculated using the SCS runoff method, (equations 1 – 3).[47]

$$S = \frac{1000}{CN} - 10 \qquad (1)$$

Where: S = weighted curve number (in.)
CN = curve number (98.00 for asphalt)

$$P_e = \frac{(P-0.2S)^2}{(P+0.8S} \tag{2}$$

Where: P_e = runoff (in.)
P = rainfall (1.87 in. for Bremerton, WA. SWMMWW)

$$V = P_e * A \tag{3}$$

Where: V = runoff volume (in^3)
A = catchment area (in^2)

The simulated influent salt flush concentration was calculated assuming the applied CCB, from one application, was contained in one-half of a design storm runoff volume – calculated to be 126,861 Liters (33,513 gal.). The estimated applied volume of CCB to the Bainbridge Island catchment (detailed information in section 2.3) was 117 Liters (31 gal.) This resulted in an influent CCB concentration of 1.24 g CCB/L correlating to an influent calcium concentration of 144 mg Ca^{2+}/L. In the laboratory, the salt flush event duration was 80 minutes at a flow rate of 0.76 lpm (0.2 gpm). No metals were added to the influent during this event. The pH did not require adjustment as it was within the desired target influent range. Discrete effluent samples were taken at t = 1, 20, 40, 60, and 80 minutes. Two influent samples were taken per column set at equally distributed intervals. After the salt flush, a standard stormwater test event was performed on the columns to evaluate the media response after being exposed to the anti-icing agent.

Following completion of all column tests performed on biochar and torrefied wood, metals that were sorbed onto the media during column tests were desorbed and quantified.[40] A representative sample from each column (six columns total) was taken from the top, middle, and bottom of the media along with a portion of the pea gravel. The samples were oven dried at 60 °C and then ground into a powder using a mortar and pestle – pea gravel samples were excluded from the grinding procedure.[40] One gram of each sample was mixed with diluted (1+1) hydrochloric (10 mL) and nitric acids (4 mL) and refluxed at 95 °C for 30 minutes.[40] The samples were cooled, diluted to 100 mL using 18 MΩ water, and allowed to rest for 24 hours.[40] The supernatant was drawn off the top and analyzed for zinc and copper concentrations using ICPMS. Total metals desorbed from the media was then determined from the ICPMS results, using equation 4,[40] and compared to the values calculated using the difference between influent and effluent concentrations, the associated volume of stormwater treated, and the mass of media in the column.

$$\frac{mg\ metal}{g\ media} = \frac{C*V*D}{W} \tag{4}$$

Where: C = metal concentration in the extract (mg/L)
V = Volume of the extract (0.1 L)
D = Dilution Factor (undiluted =1)
W = Weight of the sample (1.0 g)

2.3 Field Scale Column Test

The Bainbridge Island ferry terminal was selected as the field test site. The catchment used in this project was a paved, 1.5 acre, vehicle staging area set aside for traffic waiting to board the ferry to Seattle. The approximate catchment boundary is shown below in Figure 3.

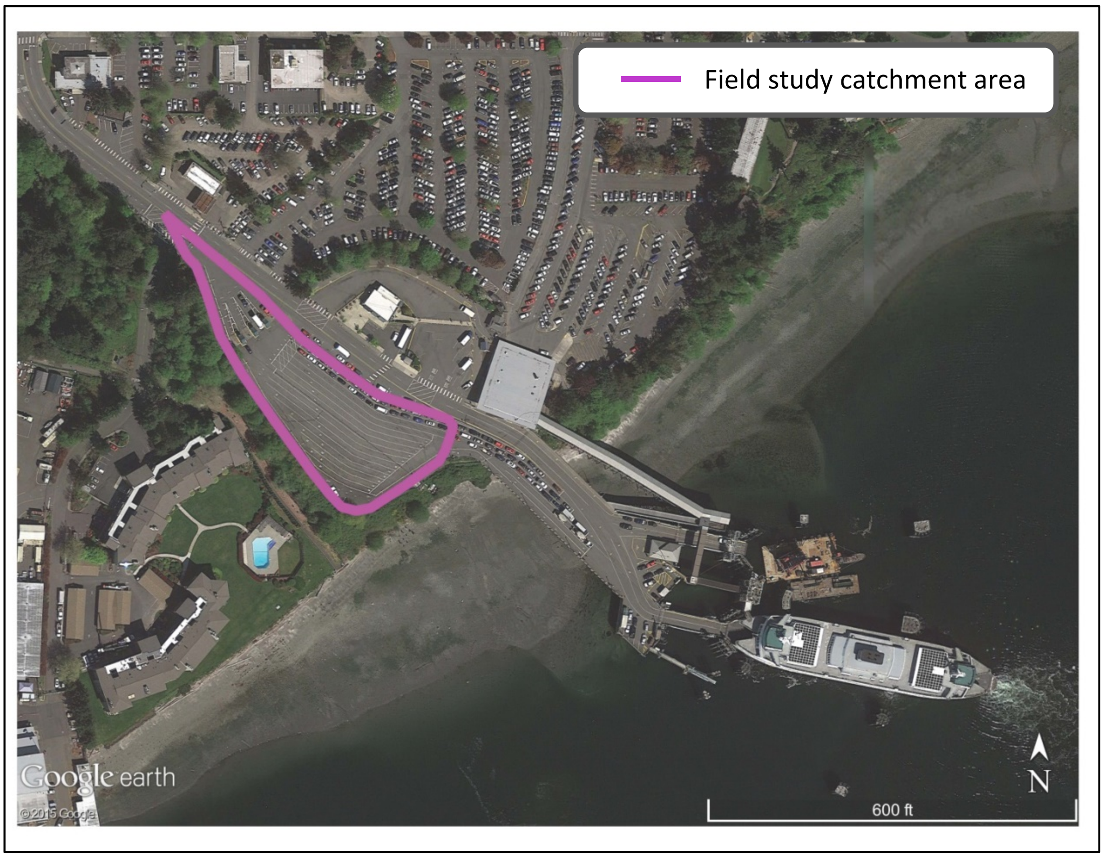


Figure 3. Bainbridge Island, WA ferry terminal with field study catchment area encircled.

A subsurface stormwater network collects the staging area runoff and coveys it to a subsurface, dual chambered, concrete vault that is located on the southern edge of the property (Figure 4). The first chamber of the vault is designed to remove debris and large settleable particulates. Stormwater enters into the fist chamber, passes over a dividing barrier, and fills the second chamber. The dimensions of the entire vault are 1.8 m (6 ft) wide, 3.0 m (10 ft) long, and 1.2 m (4 ft) deep. The two chambers are divided along the length of the vault with the dimensions of the first chamber being 1.8 x 0.6 x 1.2 meters and the second being 1.8 x 2.4 x 1.2 meters.

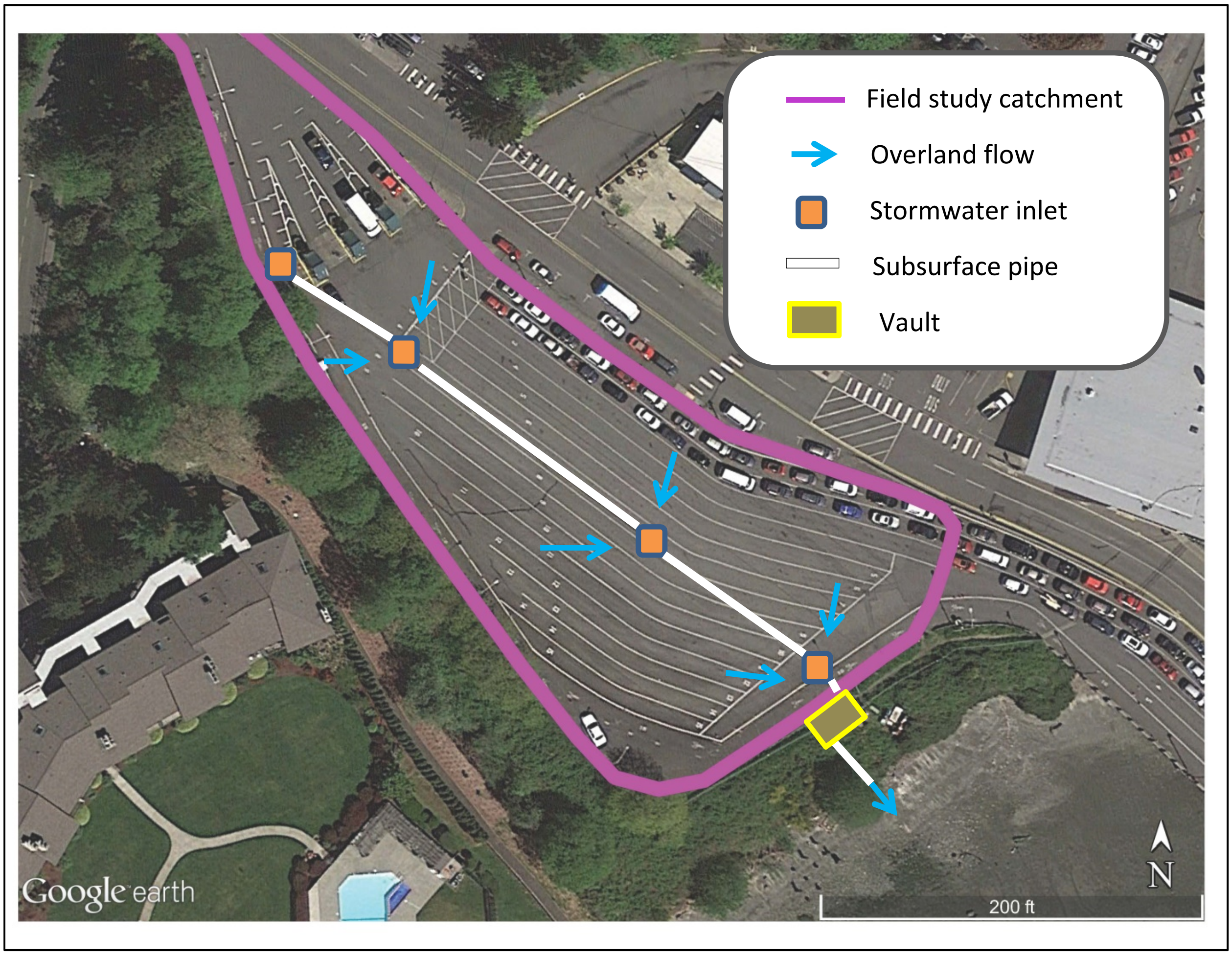


Figure 4. Field study stormwater catchment.**Symbols are not to scale and are exaggerated in size. Map is provided for qualitative purposes only.*

Six existing filters were removed from the second chamber to make room for the installation of our prototype filter and effluent weir box that was used for flow monitoring.

Column influent and effluent samples were collected using two Teledyne ISCO® 6712 full-size portable samplers. Rainfall data was collected using a Sigma® tip bucket rain gauge and logged on one of the samplers. Both samplers were programmed to collect up to 24 discrete samples during a storm event on a preselected time interval of 2 minutes. Sample collection was initiated based on water height inside the column effluent weir box.

The weir box was designed to operate submerged and had interchangeable v-notch weir plates ranging from 10° to 90° that can be installed based upon the expected flow range. For this project, the weir box was equipped with the 20° v-notch weir plate that could measure flows up to 258 lpm (68 gpm). A schematic diagram of the weir box is shown in Figure 5.

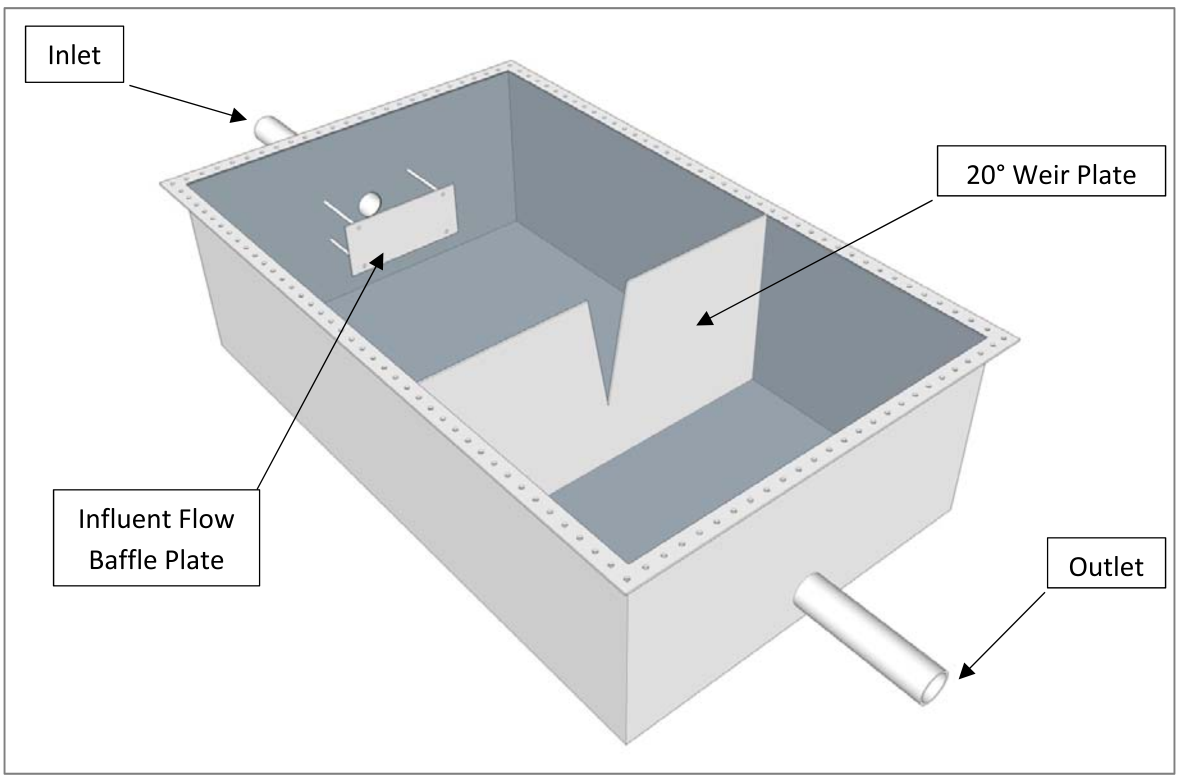


Figure 5. Schematic of the submersible weir box with a sharp-crested, 20° v-notch weir plate inserted and lid removed.

A pressure transducer anchored inside the weir box, on the influent side of the weir plate, was used to measure water height in front of the weir plate. Prior to field installation, the weir was calibrated at WSU's hydraulic laboratory. The resulting empirical equation relating water height to flow is shown along with the Kindsvater-Carter design equation (Eqn. 5) that applies to v-notch weirs other than 90° in Figure 6.[48] Dimensions of the weir box, partial contraction calculations, and calibration data for all interchangeable weir plates are included in the appendix.

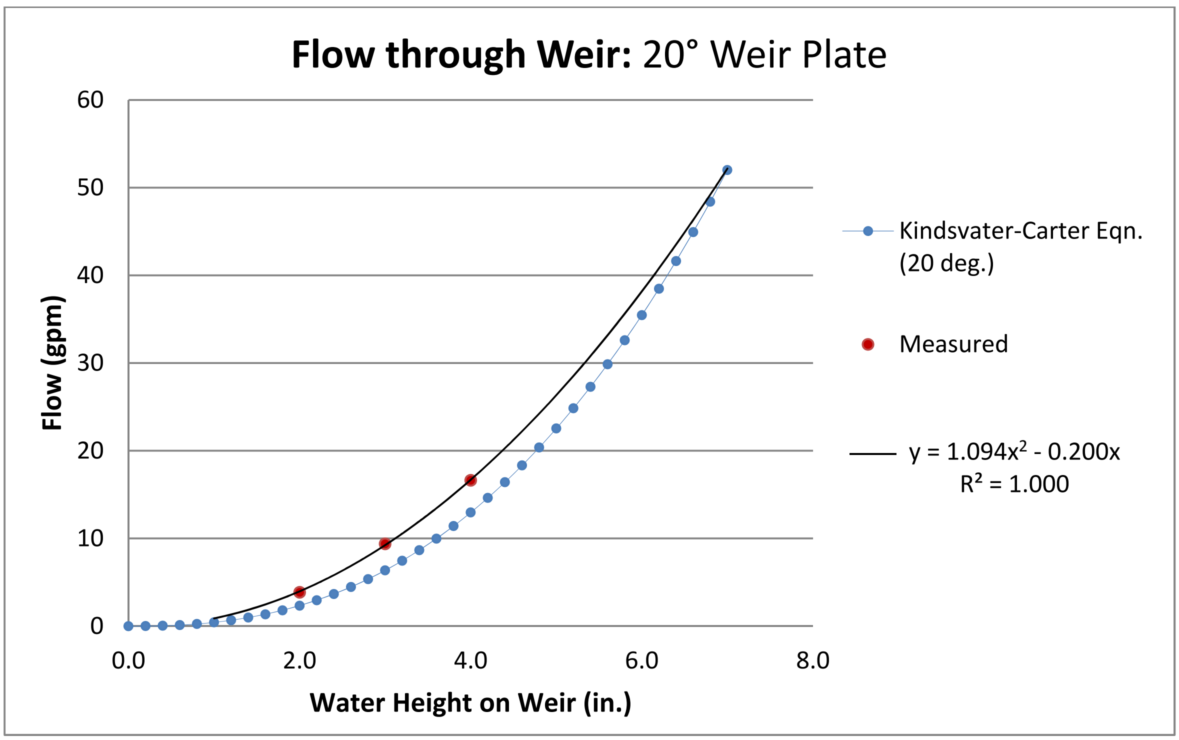


Figure 6. Laboratory and empirical flow calibration data for a 20° partially contracted v-notch weir.

$$Q = 4.28\ C_e\ Tan\left(\frac{\theta}{2}\right)\left(\frac{H+k}{12}\right)^{\frac{5}{2}} \tag{5}$$

Where: Q = flow (cfs)

C_e = effective discharge coefficient, tabulated value (s^{-1})

θ = angle of the v-notch (degree)

H = head over the weir (in.)

k = head correction factor, tabulated value (in.)

The prototype column was constructed out of 1.27 cm (½ in) extruded acrylic. All fasteners, connecting rods, and adjustable feet were made out of stainless steel. Inside the column, 5.1 cm (2 in) of pea gravel were laid on top and bottom of 45.7 cm (18 in) of biochar. A stainless steel wire mesh screen was used to cover the PVC outlet of the column in order to prevent pea gravel or media from exiting. A flow distribution plate was built into the column lid to distribute flow across the media. A schematic of the column is shown in Figure 7.

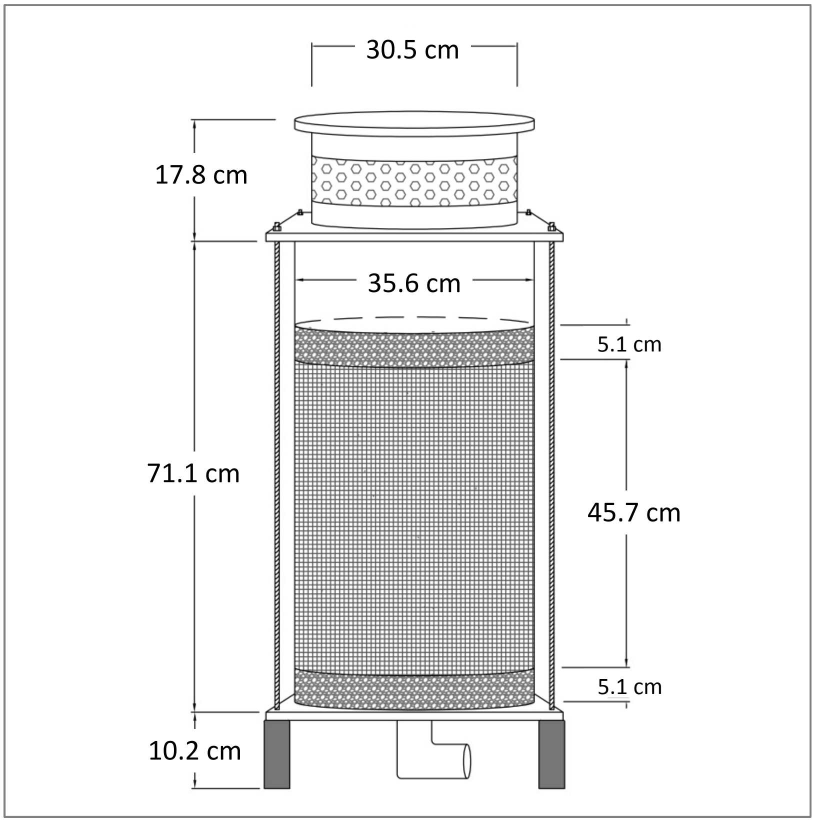


Figure 7. Schematic of the field column with basic dimensions shown.

During each storm event, the column's design allowed stormwater to enter laterally through the top of the column, pass vertically downward through the media, and exit via a 5.1 cm (2 in) PVC pipe at the base of the column (Figure 7 & 8). Treated water passed from the column into the weir box via sealed 5.1 cm (2 in) PVC conduit. Water passed over the v-notch weir and through the sidewall of the vault where it rejoined the untreated storm flow. Sampling was triggered via the pressure transducer (affixed inside the weir box) by the rising water level. The influent sampling line inlet was affixed to the outside of the column near where stormwater entered into the column. The effluent sample line was attached to a sealed port installed in the conduit passing between the column and the weir box (Figure 8). A schematic of the field site stormwater sampling equipment configuration is shown in Figure 8.

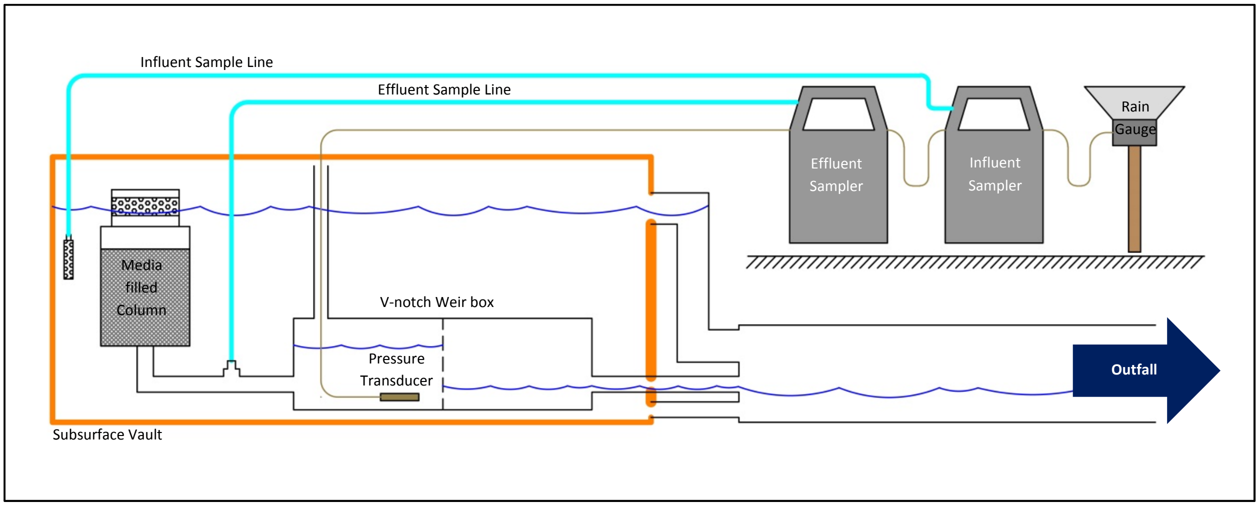


Figure 8. Schematic of the stormwater sampling configuration during a rain event (pump not shown).

Limited rainfall through the summer months prompted the installment of a submersible pump to capture minor rain events as well as significant storms. The pump was placed on the floor inside the vault and the discharge hose was connected to the top of the column. The pump was utilized for the first two captured rain events but was disconnected in September to limit sediment loading on the column.

Following a storm event, samples were collected, put on ice, and transported to our laboratory at Washington State University. Samples 1-12 and 13-24 were composited and the composite samples were prepared for analysis. Triplicate samples were taken from each composite, filtered through 0.45 µm MCE membranes, acidified, and tested for dissolved zinc and copper concentrations by ICPMS. Total recoverable metal concentrations were determined per EPA method 200.7, section 11.2.[40] Total suspended solids (TSS) and volatile suspended solids (VSS) were determined per EPA method 1684, section 11.[42]

A representative sludge sample was taken from inside the vault after the August 29th storm event and tested for Zn and Cu concentrations. Procedural steps for sludge sample preparation and analysis were determined from EPA 200.7 and EPA 1684 respectively.[40,42] A particle size analysis was conducted on the sludge sample using a Malvern Mastersizer 3000.

3. RESULTS AND DISCUSSION

3.1 Phase I & II Bench Scale Testing

3.1.1 General Long-Term Trends

Influent and effluent zinc and copper concentration data are shown in Figures 9 & 10 for biochar and torrefied wood columns. Each effluent data point represents an average from three replicate columns. Each influent data point in Phase I represents an individual sample taken – several of which originated from the same influent batch. Phase II influent data points represent an average of 3 samples taken from the same influent batch. To reiterate, the difference between Phase I & II was duration of each test event. Phase I column loading events lasted 20 minutes while Phase II events were 80 minutes in duration. The detailed behavior exhibited by each effluent concentration profile will be discussed later in section 3.1.2. Here the focus is on general long-term data trends.

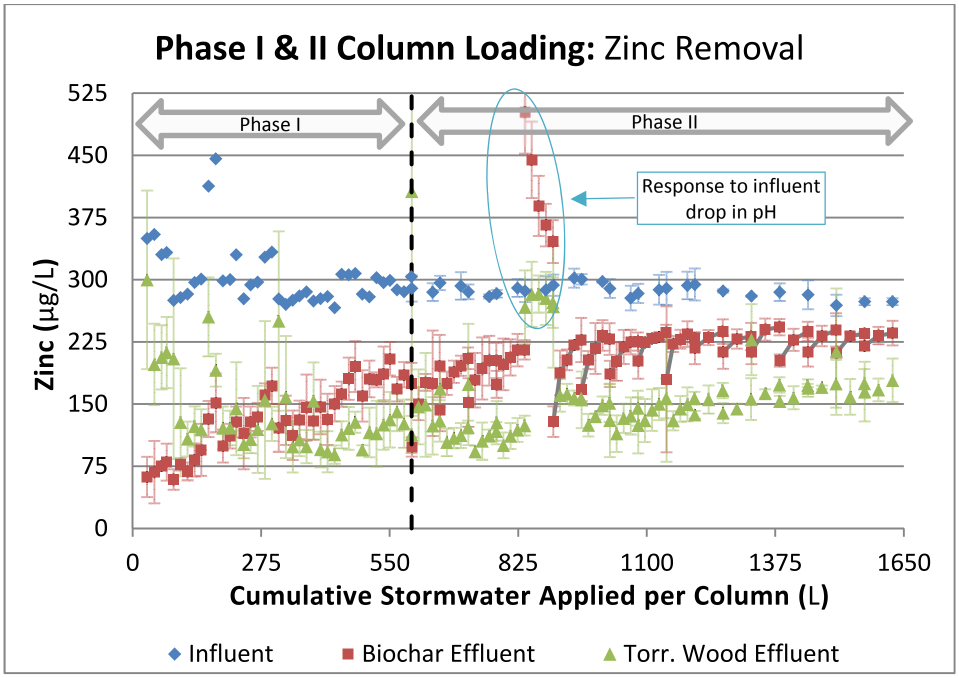


Figure 9. Zinc concentrations for the influent and effluent during Phase I & II column loading experiments. Error bars represent the 95% confidence interval.

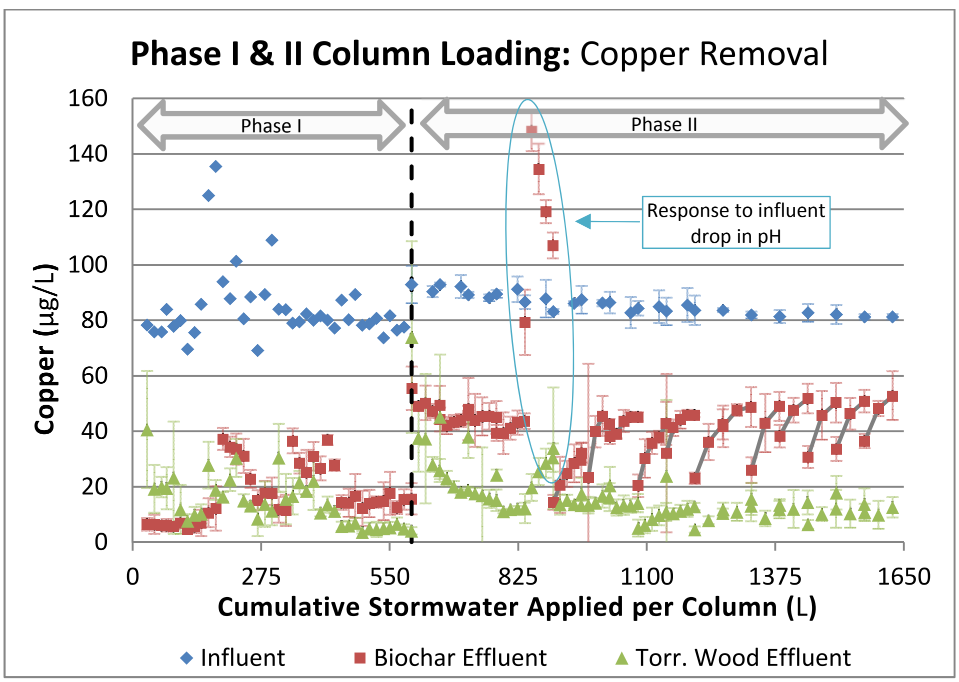


Figure 10. Copper concentrations for the influent and effluent during Phase I & II column loading experiments. Error bars represent the 95% confidence interval.

The influent and effluent data for Phase I testing exhibits more scatter than the Phase II data (Figure 9 and 10). This is due to greater experimental error experienced during start-up of the column tests. The only effluent concentration profile that shows a discernable long term trend is that for zinc on biochar columns (Figure 9). The concentration continually increases from about 75 µg/L to 175 µg/L at the end of Phase I. This is typical behavior for most sorbents in adsorption systems; as available sorption sites become occupied, the contaminant removal efficiency decreases and effluent concentration increases. This reflects the lower equilibrium zinc sorption capacity for biochar compared to copper that was defined in previous work.[31]

An interesting trend can be observed in the torrefied wood column effluent data, at the early stage of operation (up to about 100 L). The effluent zinc data in Figure 9 clearly shows a decreasing concentration during this period of operation. This behavior is related to the changing moisture content of the media as testing progresses. At Phase I testing initiation, the moisture content of torrefied wood (4%) was well below the fiber saturation point (fsp) which is 25 – 30% for most wood species.[49] As column testing progressed the torrefied wood crumbles swelled with hydration, opening capillary structure and allowing metals to access additional sites of adsorption through molecular diffusion.[21] Once inside the cell structure, the metals are removed from solution by electrostatic bonding with hydroxyl groups associated with wood polymers.[50]

In Phase II the overall effluent zinc concentration continues to increase for both media as cumulative stormwater throughput increases (Figure 9). For biochar, zinc concentration appears to stabilize at an average value of approximately 230 µg/L at stormwater throughput greater than 1325 L (350 gal.). However, the stabilization is offset by a decreasing influent zinc concentration that results in an actual 7% decrease in percent zinc removal between 1211-1628 Liters (320-430 gal.) Torrefied wood columns showed a continued gradual increase in zinc concentration. At the end of phase II testing (1628 L total stormwater throughput), effluent zinc concentration for torrefied wood was approximately 160 µg/L. Overall, both media decreased in percent zinc removal with increased cumulative stormwater throughput across Phase II, which is attributed to the decreasing number of available sorption sites.

The data shown in Figure 10 indicates that the long-term Phase II effluent copper concentration for biochar is stable at approximately 45 µg/L. Again, this biochar effluent stabilization is actually a continued period of decreasing percent metal removal when the influent concentration is also taken into consideration. Across Phase II, the influent copper concentration steadily decreases 11 µg/L from start to finish resulting in an overall 7% decrease in biochar copper removal. The torrefied wood effluent data shows an initial decrease in copper concentration from the initiation of Phase II to a throughput of approximately 870 Liters (230 gal.). This is likely attributed to a significant column rest period that occurred between phases, resulting in decreased moisture content of the media. At the initiation of Phase II, rehydration was required to restore full sorption capacity, as previously discussed. As throughput volume increased across Phase II, torrefied wood effluent copper concentration leveled out and remained stable at an average concentration of 12 µg/L, for the remainder of the period.

At the completion of phase II, the biochar columns were yielding respective zinc and copper removals of about 14 and 35 % while the torrefied wood columns were operating at zinc and copper removals of 35 and 84%. The overall removal for both Phase I and II was determined by calculating total mass of zinc and copper adsorbed using influent and effluent concentration and flow data. After 1628 Liters (430 gal.) of synthetic stormwater passed through the columns, the respective total mass of zinc and copper removed from solution by biochar was 163 and 78 mg and by torrefied wood was 231 and 114 mg. This equates to an overall percent removal of 34% Zn, 57% Cu for biochar and 48% Zn, 83% Cu for torrefied wood. It is clear that, for the conditions studied, torrefied wood outperforms biochar with regard to lower effluent metal concentration and higher percent removals.

The pH data shown in Figure 11 indicates that the biochar column increased the simulated stormwater pH during Phase I while torrefied wood lowered the pH, which – is expected behavior relative to each media. Most woods originating from temperate zones are inherently acidic, including Douglas-fir and members of the *Pinus* genus[51] When wood, including torrefied wood, is in contact with water, free acids and acidic groups (primarily acetic acid, formic acid, and acetyl groups) are released into solution lowering the pH.[29,51] During complete pyrolysis, acidic chemical compounds are released from the wood along with the desired sugar polymers, leaving behind a char that is typically alkaline.[29] Additionally, the ash content of the biochar, which is known to be basic, could be contributing to the effluent pH increase.[52]

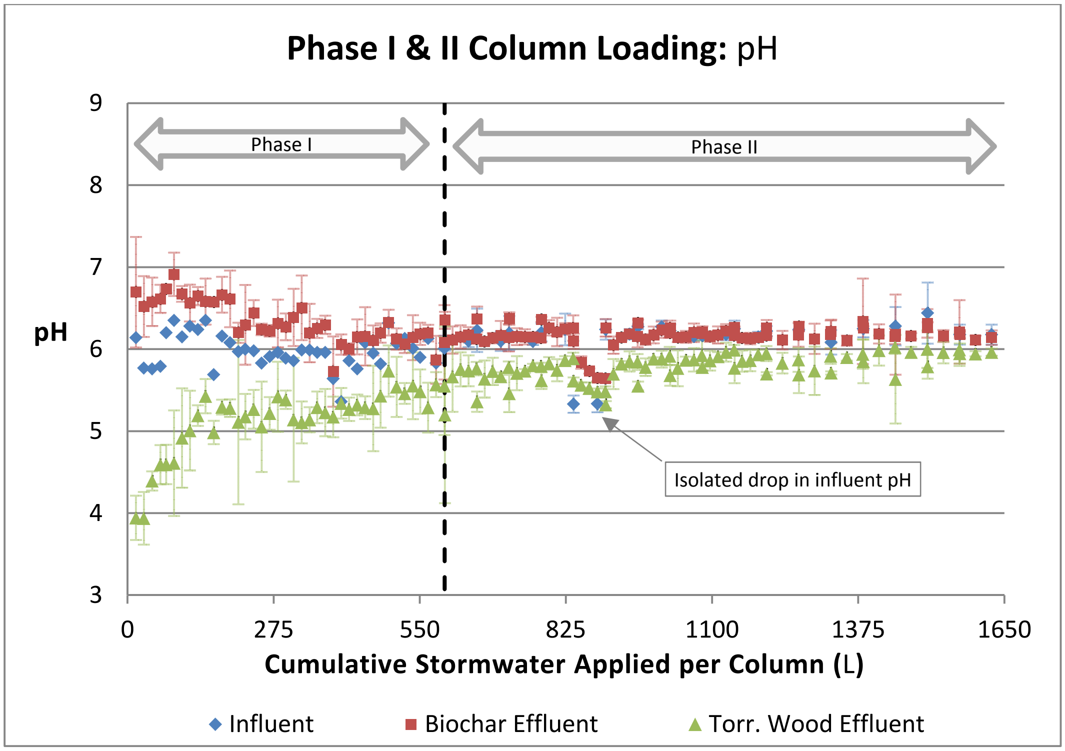


Figure 11. Influent and effluent pH values are shown during Phase I & II column loading. Error bars represent the 95% confidence interval.

At the end of Phase I and continued through Phase II, influent and effluent pH were the same for biochar. Torrefied wood effluent pH continued to be lower through Phase II, but is seen to be gradually approaching the influent pH as testing progressed.

3.1.2 Short-Term Trends

Short term trends refer to effluent concentration profiles (Figure 9 and 10) within and between single storm events. One of the most interesting single event concentration profiles occurs in phase II at a cumulative application volume of 230 gal. These profiles are the result of an unexpected low influent pH caused by a failure in the house deionized water system. The data in Figure 11 show that the pH decreased from a desired value of 6.1 to 5.2. The decrease in pH resulted in a significant increase in column effluent metal concentration. In fact, as can be seen in Figures 9 and 10, the effluent zinc and copper concentrations during this event were greater than the influent for the biochar columns. Effluent concentrations from the torrefied wood columns also increased, but not as dramatically as for biochar. These concentration increases indicate the importance of pH on adsorption, particularly with regard to the adsorption of metals.

Excluding the isolated pH anomaly, most of the single event effluent concentration data show an interesting profile for both zinc and copper, regardless of media. These profiles are most evident in phase II where it can be seen that at the beginning of each event the effluent concentration is relatively low and as the event proceeds, the effluent concentration increases. For example, consider the event that begins at a cumulative stormwater volume of 900 L (Figure 9). The initial effluent zinc concentration is 129 µg/L and as the event progresses the concentration increases to 225 µg/L. This pattern is repeated for each event, that is, lower initial effluent concentration following a 12-24 hour no-flow period, with concentration increasing throughout the event. These “r-shaped” profiles are the result of intraparticle metal concentration decreasing between storm events (no flow period) as metal accesses harder to reach sites of adsorption and adsorbs to the media surface. Consequently, at the initiation of a run following a no-flow period, the concentration gradient between the interparticle and intraparticle water is relatively high resulting in a higher metal diffusion into the media and lower concentrations in the column effluent.

Influent metal concentration fluctuations shown in Phase I are likely responsible for corresponding effluent data perturbations. This is most visible on Figure 10 because the graph is shown on a smaller scale. At first glance, zinc effluent concentrations appear to be more consistent than copper across Phase I & II suggesting that zinc may be more stable than copper. Upon closer inspection, the copper effluent trend line break, occurring at the point of phase change, is in response to a 16 µg/L Cu influent increase whereas zinc influent concentrations were stable from Phase I to Phase II. As experimental techniques were refined during Phase I which resulted in more stable influent concentrations, effluent concentration trends also stabilized. From this data set alone, it is unclear whether or not copper adsorption is more sensitive than zinc, however, it is clear that both media showed increased effluent concentrations corresponding with increased influent concentrations indicating that the lowest achievable discharge limit is a function of influent concentration.

3.1.3 Supplementary Tests

Parallel to the Phase I & II primary investigation, supplementary testing was performed to evaluate effluent total suspended solids concentrations and interval vs. composite sampling results. Relatively low total suspended solids (TSS) concentrations (< 3 mg/L) were measured in the effluent for a short duration at the initiation of Phase I testing. The effluent TSS were likely a result of loose fines flushed off the media surface. After 7 percent of the total stormwater volume applied to the columns, solids concentrations fell to less than 0.5 mg/L and remained there for the remainder of testing for both biochar and torrefied wood.

For selected events in Phase I, discrete effluent samples (80 mL) were taken simultaneously with and in addition to standard composite samples. The resulting discrete metal concentrations were then compared against the composite sample concentrations as a means of checking analytical techniques. Discrete sample concentrations supported the macro trends described by the composite samples. This extra step confirmed laboratory techniques and assisted in validating metal quantification.

Following the end of Phase II, biochar and torrefied wood columns were subjected to increased flow testing. Column effluent metal concentrations and pH values during the increased flow tests are shown graphically in Figures 12-14. Averages are provided in Table 3 for comparison.

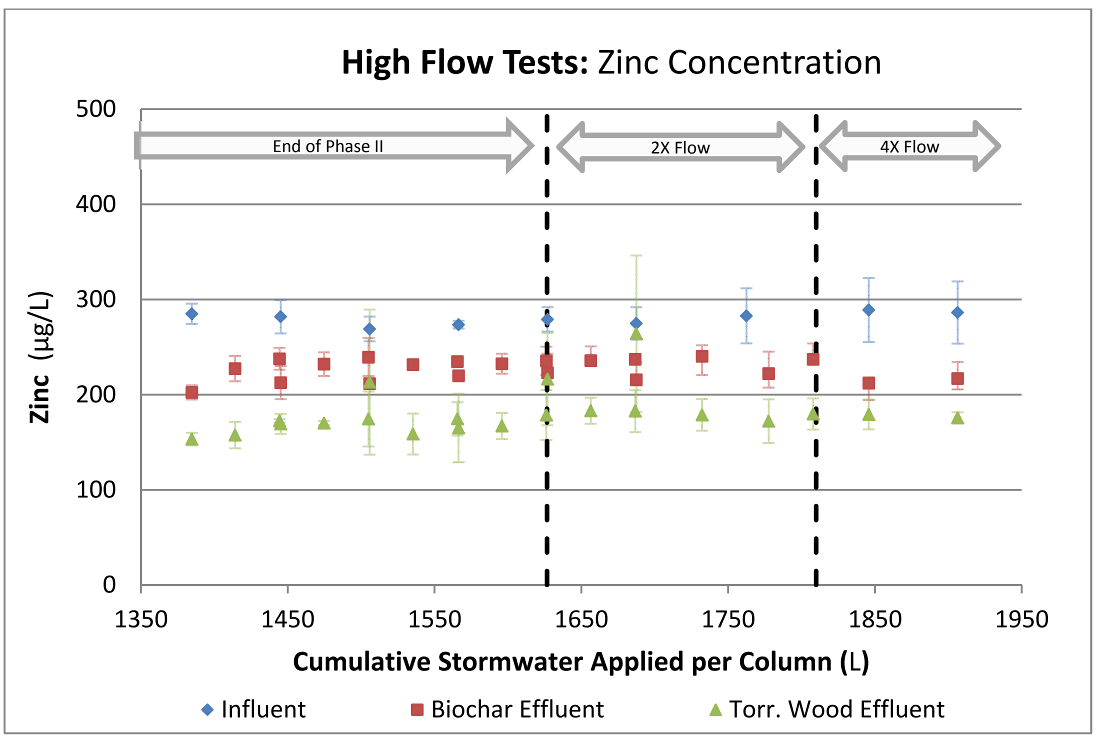


Figure 12. Zinc influent and effluent concentrations during high flow tests.

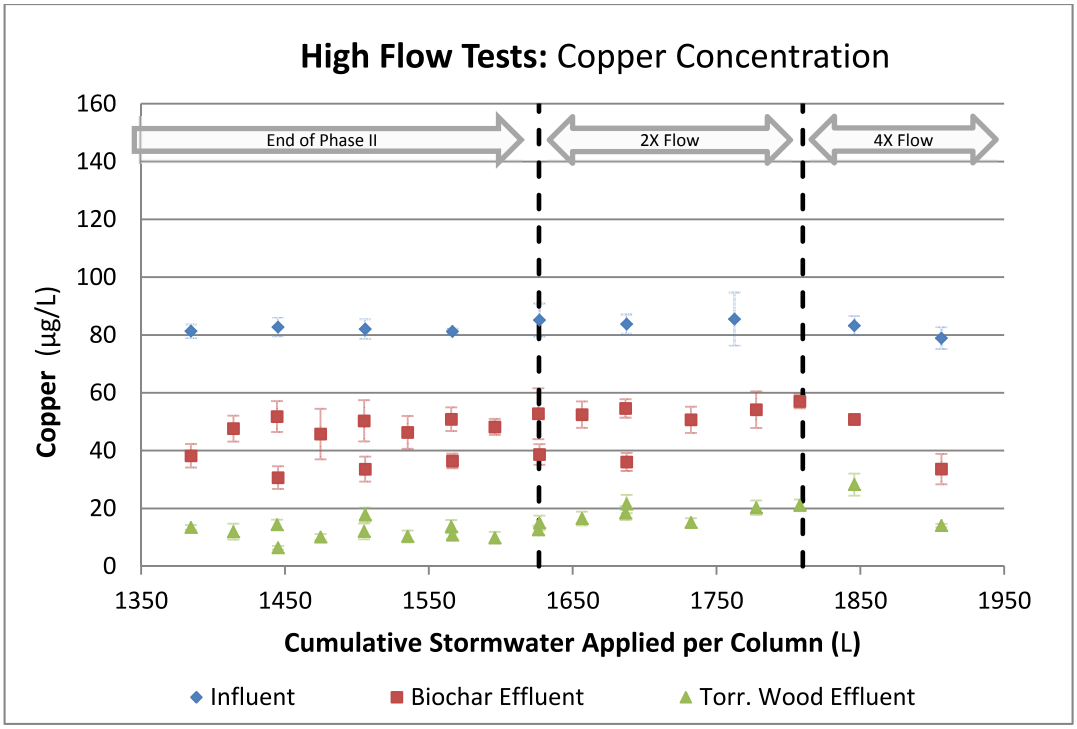


Figure 13. Copper influent and effluent concentrations during high flow tests.

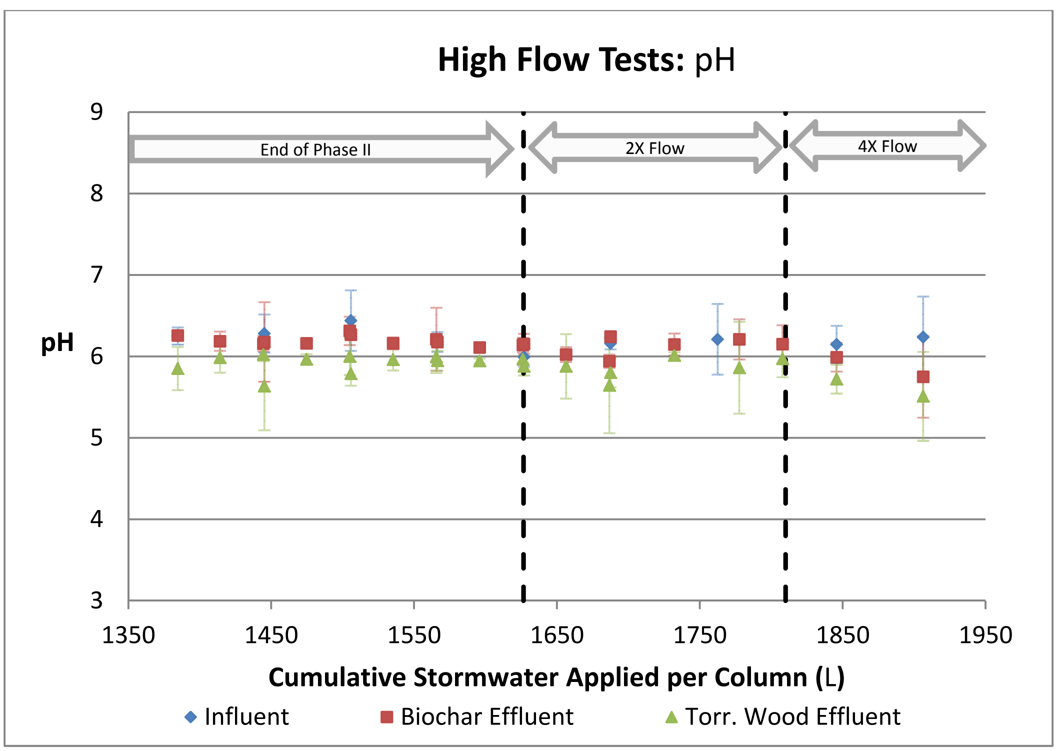


Figure 14. Influent and effluent pH values during high flow tests.

Table 3. Average effluent metal concentrations from torrefied wood and biochar columns when exposed to increasing influent flow rates of 0.76, 1.51, and 3.03 liters per minute.

Media / Metal		End of Phase II (µg/L)	2x Flow (µg/L)	4x Flow (µg/L)
Biochar	Zn	227 ± 7	230 ± 8	215 ± 6
	Cu	44 ± 5	49 ± 7	42 ± 21
Torrefied Wood	Zn	171 ± 9	197 ± 28	177 ± 4
	Cu	12 ± 2	18 ± 2	21 ± 18

It can be seen that increasing the flow rate resulted in no significant increase in effluent metal concentrations or change in pH over the range of flow studied for both media tested. Theoretically, a higher flow rate could open up new pathways through the media and allow access to new sorption sites. This is neither rejected nor confirmed by the data. The data does suggest that metal adsorption is stable with regard to flow rate for both media. The influence of flow on removal is important with regard to stormwater treatment applications because of the highly variable flows expected during rain events. Flow through the media may not need to be regulated prior to entering a filtration device based on performance limitations.

After increased flow testing was complete, the same biochar and torrefied wood columns were subjected to a deicer flush. The column influent contained Calcium Chloride with Boost™ (CCB) (0.40 g $CaCl_2$/L) and no added metals. Flow through the columns was maintained at 0.76 lpm (0.2 gpm). Low concentrations of zinc and copper were detected in the influent and attributed to residual metals on the barrel. The 61 liter per column deicer flush was followed by an equal volume standard stormwater influent batch with influent metal concentrations adjusted to 300 µg/L Zn and 100 µg/L Cu and the pH adjusted to 6.1 ± 0.1. The stormwater application rate remained at 0.76 lpm. Influent and effluent metal concentrations and pH values for the deicer tests are shown in Figures 15-17. In Figures 15 & 16, the y-axis metal concentrations are displayed in log scale.

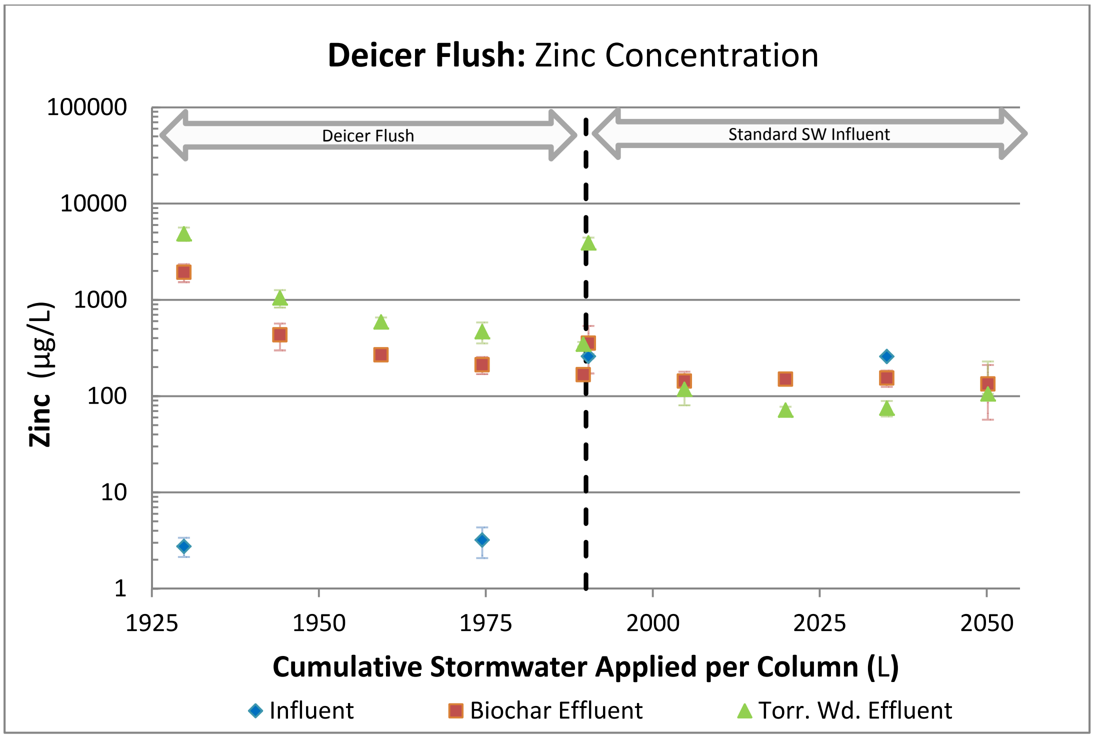


Figure 15. Influent and effluent zinc concentrations (log scale) during and following a deicer flush. Calcium Chloride with Boost™ was used as the anti-icing agent.

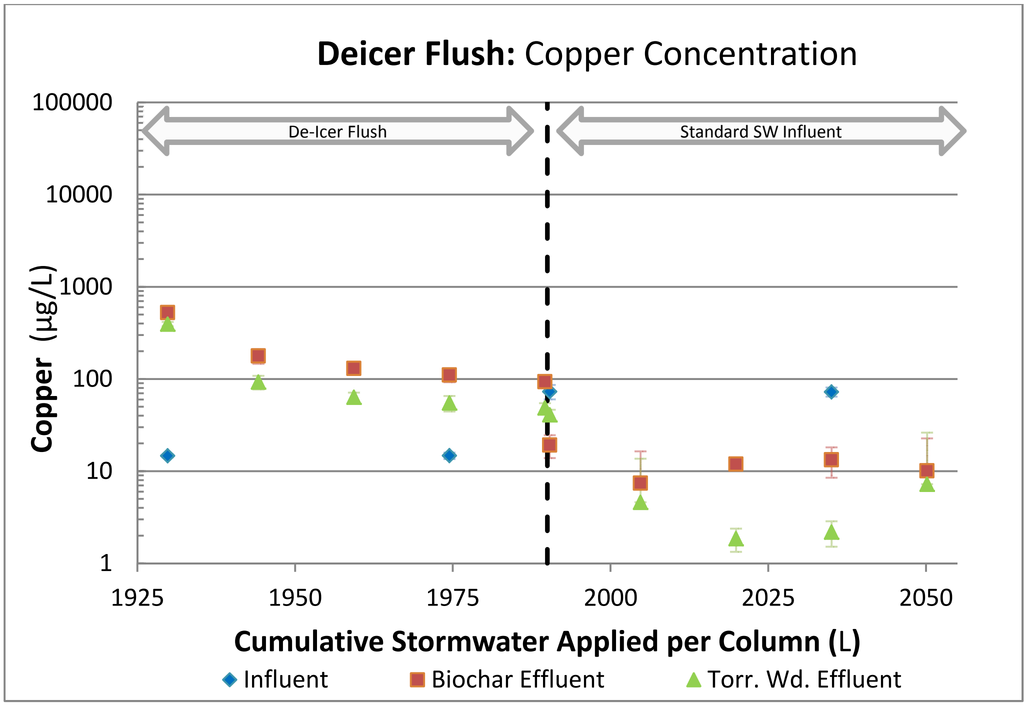


Figure 16. Influent and effluent copper concentrations (log scale) during and following a deicer flush. Calcium Chloride with Boost™ was used as the anti-icing agent.

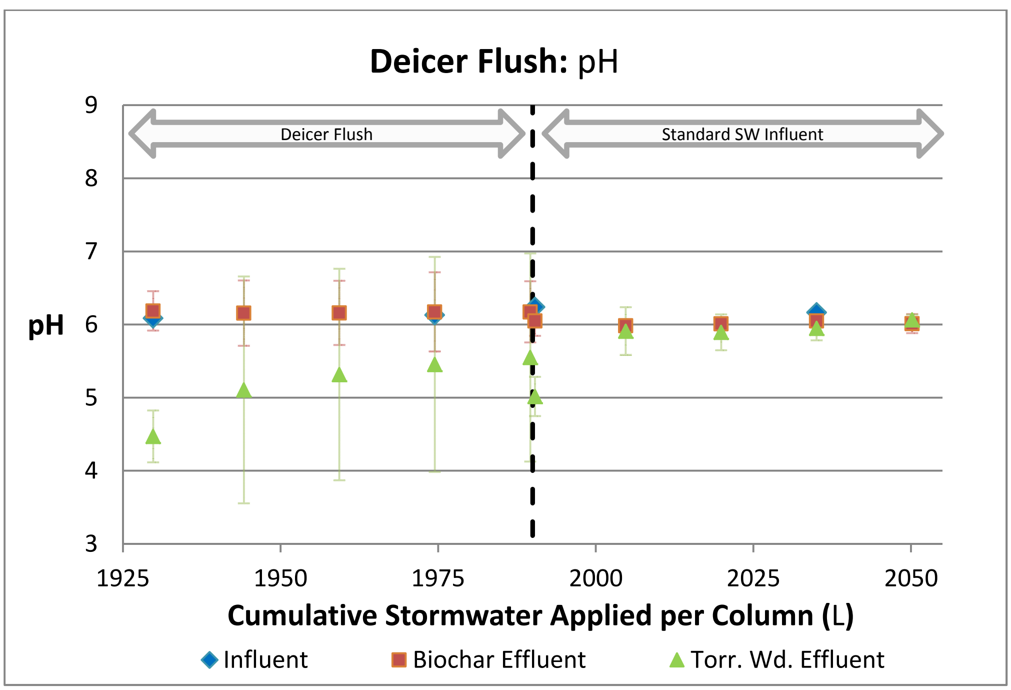


Figure 17. Influent and effluent pH values during and following a deicer flush. Calcium Chloride with Boost™ was used as the anti-icing agent.

Both media released metals when exposed to the deicer solution, resulting in significant effluent concentrations. Biochar's peak effluent metal concentrations were 1936 μg/L Zn and 526 μg/L Cu. Torrefied wood's peak effluent metal concentrations were 4873 μg/L Zn and 395 μg/L Cu. The calcium chloride concentration in the simulated deicer runoff was three orders of magnitude greater than previous influent zinc and copper concentrations. While copper, zinc, and calcium ions are equally charged, the sheer number of calcium ions in solution forces a cation exchange with zinc and copper.

At the beginning of the deicer flush, the most accessible and exchangeable copper and zinc were replaced by calcium, resulting in the highest effluent concentrations (Figure 15 & 16). As the deicer testing progressed biochar and torrefied wood columns exhibited a decrease in metal effluent concentration. This is likely because the easily accessible metals have been displaced and the exchange rate is controlled by intraparticle molecular diffusion.

When standard stormwater influent (300 μg/L Zn, 100 μg/L Cu, pH = 6.1, and Q = 0.76 lpm) was resumed through the columns following a 24 hour rest, the initial effluent zinc concentrations in both media columns increased when compared to the last samples collected at the end of the deicer flush (Figure 15). The last sample collected during the deicer flush for biochar and torrefied wood had a respective zinc concentration of 167 ± 22 μg/L and 347 ± 18 μg/L and the first sample collected after resuming a standard stormwater run yielded a concentration of 355 ± 182 μg/L and 3915 ± 518 μg/L. This behavior is due to continued cation exchange occurring in the intraparticle water during the rest period. Diffusion of high concentration calcium into harder to reach sorption sites forced zinc back into solution. When testing resumed after the rest period the zinc concentration gradient was initially reversed and zinc moved from the intraparticle water into the interparticle water. The zinc concentration spike at standard influent initiation was more pronounced in torrefied wood compared to biochar, likely because torrefied wood has more difficult to reach adsorption sites. This behavior was not observed for copper (Figure 16).

Torrefied wood columns exhibited a more acidic pH effluent during the salt flush (Figure 17). It's likely the calcium ions were replacing hydrogen ions from hydroxyl groups along with previously adsorbed metals. Biochar did not show an effluent pH change from the influent primarily because the media was already close to metal adsorption capacity and available carboxyl sites, either in their basic or acid form, were not prevalent enough to affect the pH.

The total mass of metals released during the salt flush for biochar and torrefied wood columns were 17.5 mg Zn, 8.0 mg Cu and 40.0 mg Zn, 4.2 mg Cu, respectively. When compared to the total mass of metals sorbed onto the media, the percentage of sorbed metals released by biochar and torrefied wood were 11% Zn, 10% Cu and 17% Zn, 4% Cu, respectively. The deicer tests indicate that steps may need to be taken to temporarily divert runoff from entering field columns if an anti-icing solution was applied prior to a runoff event. The tests also show that both biochar and torrefied wood potentially can be regenerated with a high concentration salt solution. Future tests should be conducted to determine true regeneration potential and the long-term effects on the media.

3.1.4 Raw wood and Pea Gravel

Based on the significant level of metal removal exhibited by torrefied wood, it was decided to also test raw wood crumbles. A small volume of pea gravel was used in the media columns and therefore was also subjected to full column tests. Influent and effluent zinc and copper concentrations and pH values are shown in Figures 18-20 for raw wood and pea gravel columns. Phase I & II biochar and torrefied wood 7-point moving average trend lines are also displayed on the graphs for a visual comparison between all four media.

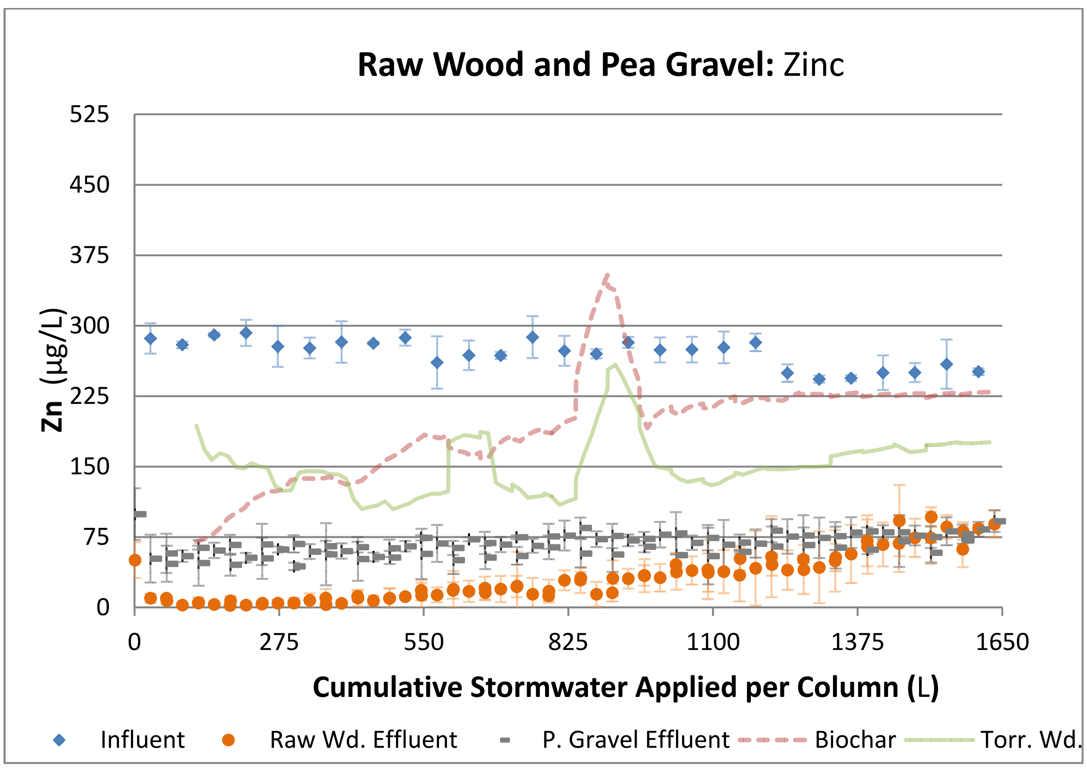


Figure 18. Influent and effluent zinc concentrations for raw wood and pea gravel columns. Phase I & II biochar and torrefied wood moving average trend lines are displayed for graphical comparison.

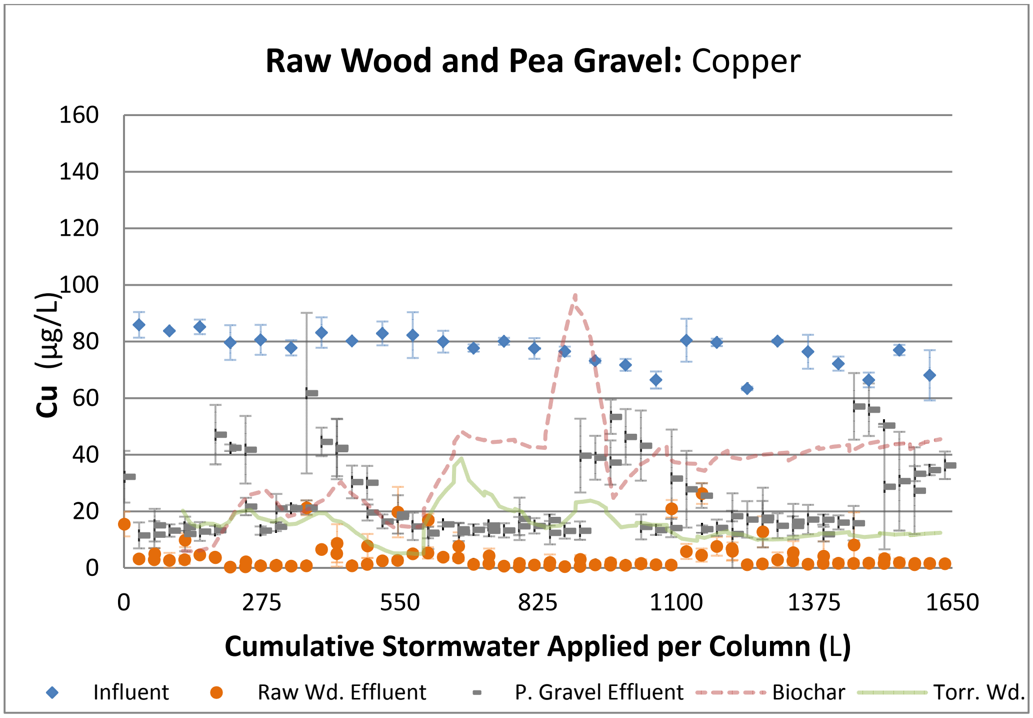


Figure 19. Influent and effluent copper concentrations for raw wood and pea gravel columns. Phase I & II biochar and torrefied wood moving average trend lines are displayed for graphical comparison.

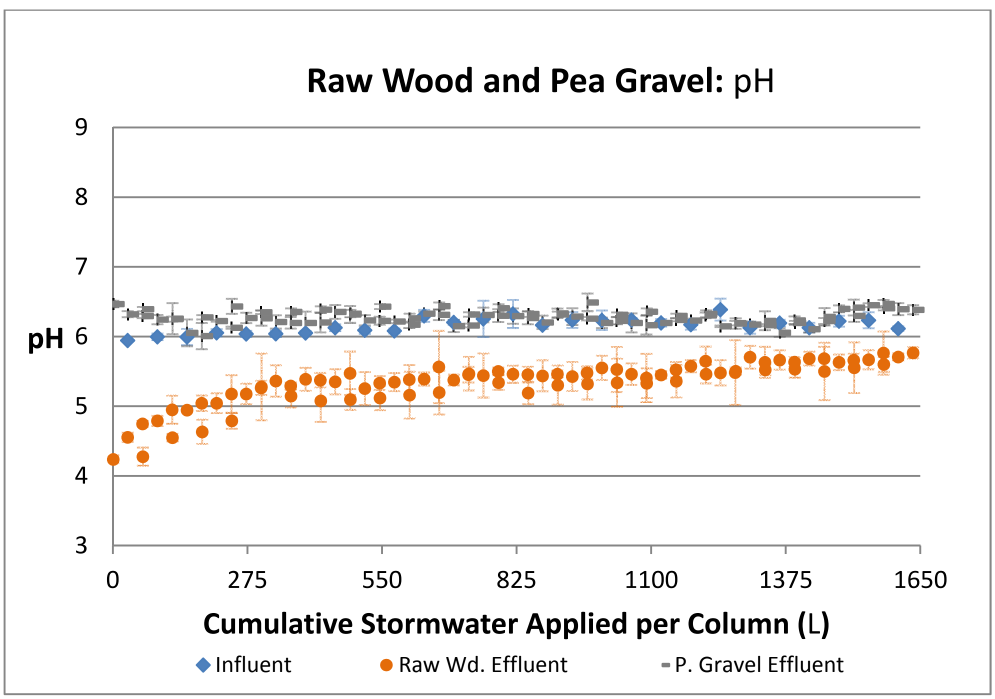


Figure 20. Influent and effluent pH values for raw wood and pea gravel columns.

Both raw wood crumbles and pea gravel exhibited significant metal removal ability when compared to biochar and torrefied wood tests. Torrefied wood's primary metal removal performance hinges on the inherent properties of the intact wood structure and therefore it is not surprising that raw wood proved to be an effective metal adsorbent. It is also well documented that sand and gravel filtration systems are highly effective at removing particulate contaminants and can be moderately effective at removing soluble contaminants.[52]

While torrefied wood outperformed biochar, raw wood and pea gravel proved to be even more effective. Raw wood significantly outperformed all other investigated media in relation to copper by adsorbing 97% of the total exposed dissolved copper from the influent. At the end of 1630 Liters, the effluent exiting raw wood columns contained 2 µg/L Cu which is below the Washington State maximum chronic discharge to marine waters limit of 3.1 µg/L (Figure 19). In relation to zinc, Raw wood again outperformed all other investigated media by adsorbing 89% of the total exposed dissolved zinc from solution. The zinc effluent exiting raw wood and rock columns were just reaching the maximum chronic discharge limit of 81 µg/L over 4 days at the end of testing (Figure 18).

Raw wood and pea gravel adsorbed 393 mg Zn , 123 mg Cu and 328 mg Zn, 89 mg Cu , respectively, during the 1630 Liter (430 gallon) testing period. Values reported in Table 4 are associated with 1630 Liters (430 gallons) of stormwater treated at target influent concentrations of 300 µg/L Zn and 100 µg/L Cu. The biochar and torrefied wood values reported in Table 4 were calculated at the end Phase II and before supplementary tests (high flow and deicer flush) were performed. The percent metals adsorbed data indicate that for all media, copper outcompeted zinc for sites of adsorption, even though the copper feed concentration was 73% less than zinc (Table 4).

Table 4. Summary table highlighting total metals sorbed onto filter media following the cumulative application of 1630 liters of synthetic stormwater.

Media /Metal	Biochar		Torrefied Wd.		Raw Wood		Pea Gravel	
	Zn	Cu	Zn	Cu	Zn	Cu	Zn	Cu
Total mass of metals applied (mg)	477	138	477	138	443	127	443	127
Mass of metal removed by the media column (mg)	163	78	231	114	393	123	328	89
Percentage of total metal removed from influent	34%	57%	48%	83%	89%	97%	74%	70%
Mass of metal sorbed per mass of media (mg/g)	1.15	0.55	0.93	0.46	1.81	0.57	0.13	0.04
Removal efficiency at the end of 1630 Liters	14%	35%	35%	84%	65%	97%	63%	49%

3.1.5 Solid Phase Acid Extraction

Acid extraction tests (EPA Method 200.7) were performed on biochar and torrefied wood column media after testing was complete to quantify the mass of metals sorbed onto the media and compare it against the mass of metals removed based on mass balance calculations using flow and influent and effluent concentrations. The total mass of metals recovered in the acid extraction tests are reported for the entire column which includes metals from of the media and the upper layer of pea gravel. Through acid extraction, the respective mass of zinc and copper recovered from biochar columns was 121 ± 72 mg and 55 ± 12 mg and recovered from the torrefied wood columns was 211 ± 32 mg and 153 ± 24 mg. At the completion of all testing, mass balance calculations using influent and effluent concentrations and flow showed that biochar columns retained 169 mg zinc and 85 mg copper and torrefied wood columns retained 228 mg zinc and 135 mg copper. The percent difference of acid extraction values from mass balance values for biochar are 28% Zn, 35% Cu and for torrefied wood -8% Zn, 12% Cu. A positive percent difference indicates the acid extraction result was less than the mass balance calculation, with the opposite being true for a negative value.

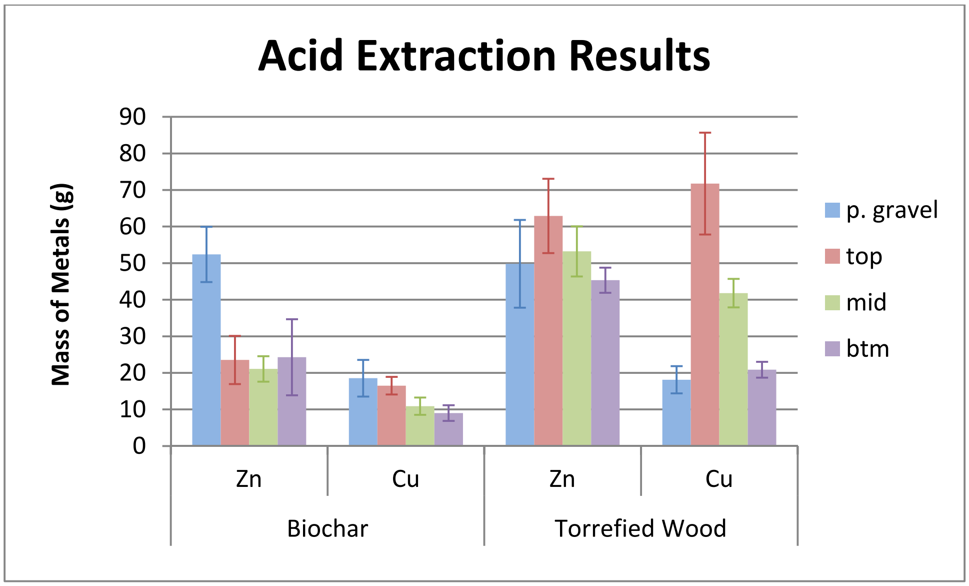


Figure 21. Column graph displaying stratified metal concentrations determined using the acid extraction method.

The data in Figure 21 represents the metal concentration profile through the media. With the exception of zinc on biochar, higher concentrations of metals are found in ascending layers of media because they are first to be exposed to the influent. As adsorption sites at the top become exhausted, the concentration profile moves down gradient until the entire column is exhausted. This behavior is commonly seen in gravity-flow columns used for sorption applications.[22] The zinc profile for biochar shown in Figure 21 exhibits column exhaustion or near exhaustion which is consistent with the 14% zinc removal by biochar columns at the end of testing (Table 4).

When compared to the total mass of metals removed by the columns, the fraction retained by pea gravel, determined from acid extraction results, was considerable. While only occupying 20% of the total column media volume, pea gravel respectively adsorbed 43% and 34% of zinc and copper in biochar columns. Still significant, although to a lesser degree, 24% zinc and 12% copper adsorption was attributed to the pea gravel overlying the torrefied wood crumbles.

3.2 Field Test

3.2.1 Field Column Results

Three stormwater runoff events were captured by the sampling equipment on August 14th, August 29th, and October 10th (Figure 22). A submersible pump was used inside the subsurface vault to supply stormwater influent to the field column during the August 14th and 29th events. Clogging of the column occurred as a result of fine particulates being introduced by the pump which prompted its removal after the Aug. 29th storm event. The top layer of pea gravel was rinsed clean and permeability through the column was regained.

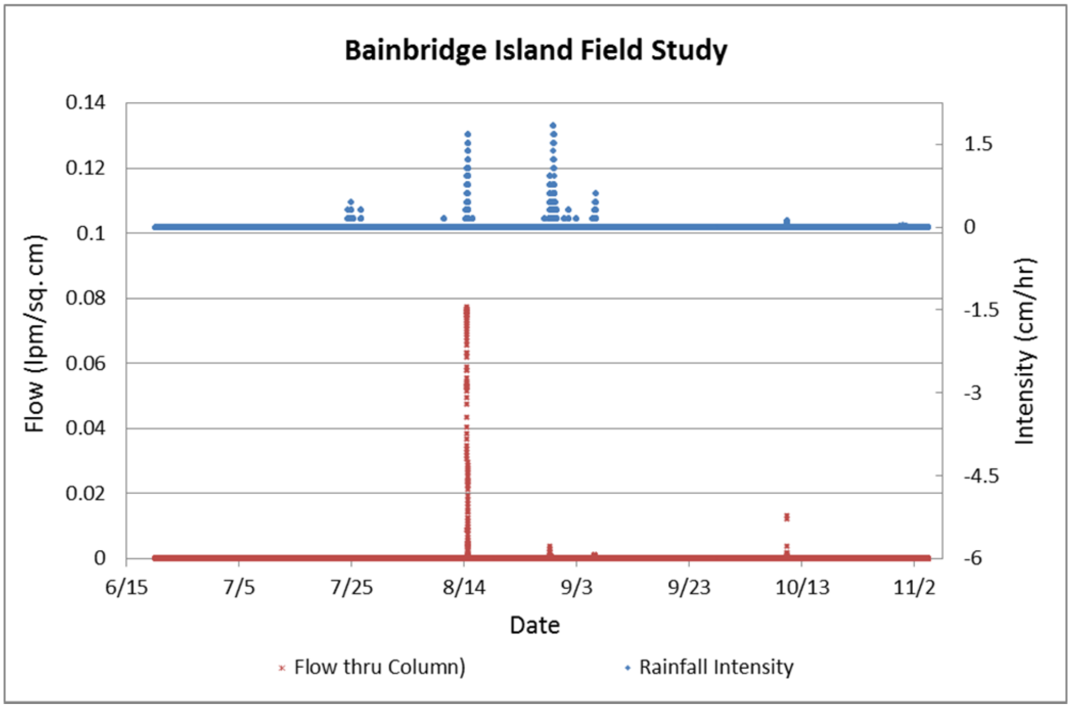


Figure 22. Storm events captured at the Bainbridge Island, WA field site.

The hydrograph, defined as the field column effluent flow, for each event is recorded in Figures 23-25. The region of the hydrograph where influent and effluent samples were collected is indicated in each figure. Normalized flow (flow per column surface area) used in laboratory tests are shown on the graphs for visual comparison. Summarized event values like the total volume of stormwater treated by the field column and the peak flow are reported on the respective figures.

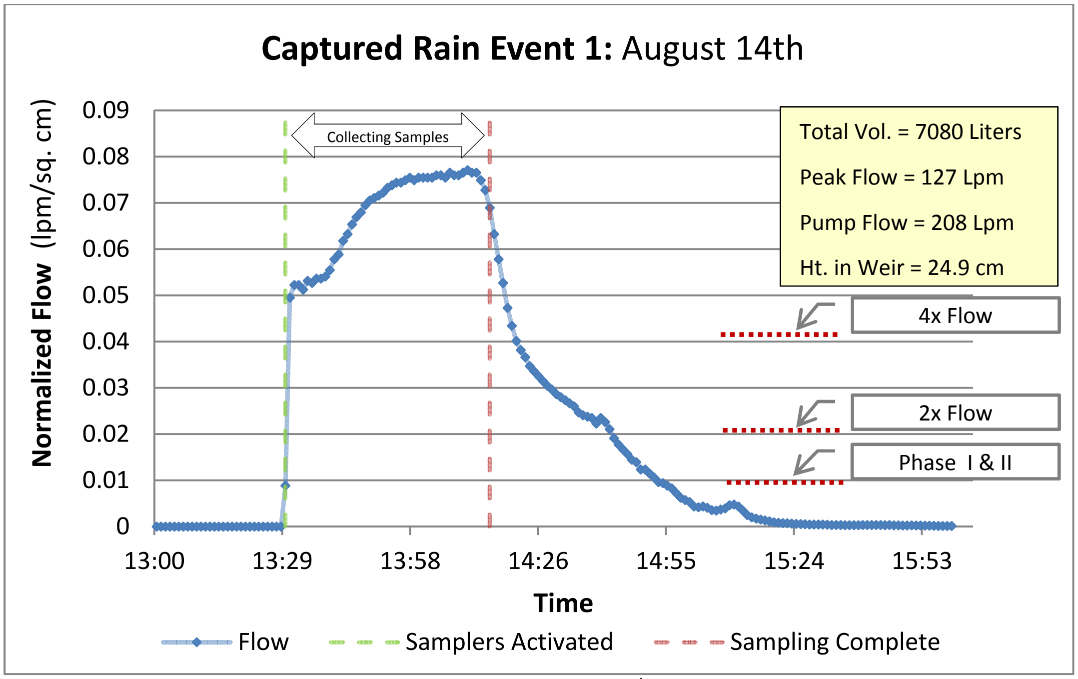


Figure 23. Normalized column flow for the August 14th, 2015 rain event.

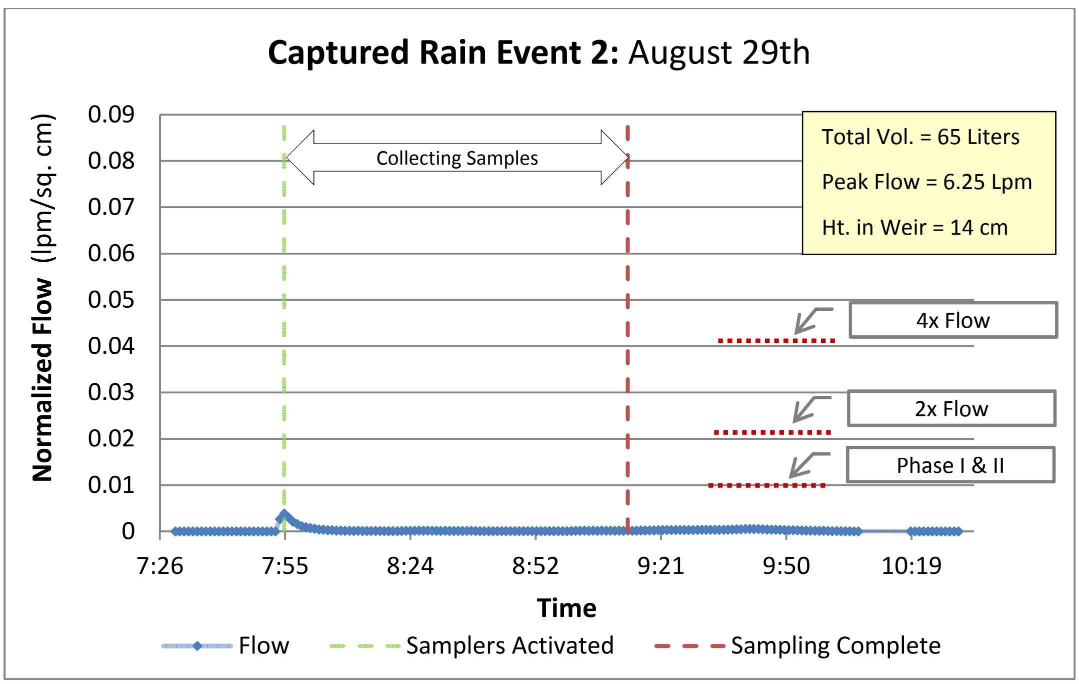


Figure 24. Normalized column flow for the August 29th, 2015 rain event.

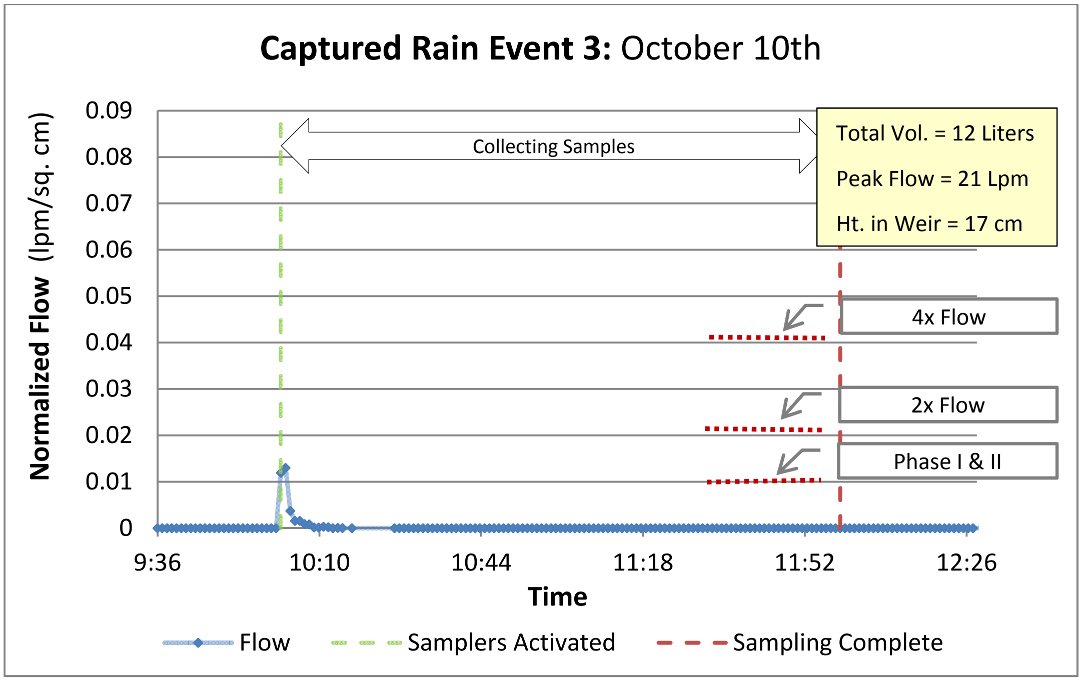


Figure 25. Normalized column flow for the October 10th, 2015 rain event.

During each monitored storm event, discrete samples were programed to be collected every 2 minutes. Up to 24 samples could be collected for each event, if the duration of the event was sufficient. The first half and the second half of the discrete samples for each event were mixed to make two composite samples. These composite samples were then analyzed for total and soluble metals (zinc and copper), TSS, TVSS, and pH. The data shown in Table 5 summarize the results of three storm events at the Bainbridge Island ferry terminal.

Table 5. Summarized influent and effluent field column data for three rain events collected at the Bainbridge Island ferry terminal.

Bainbridge Is. Field Data		Event 1 (August 14th)						Event 2 (August 29th)						Event 3 (October 10th)		
		Comp 1 (samples 1-12)			Comp 2 (samples 13-24)			Comp 1 (samples 1-12)			Comp 2 (samples 13-24)			Comp 1 (samples 1-6)		
		Influent	Effluent	% Rmv.	Influent	Effluent	% Rmv.	Influent	Effluent	% Rmv.	Influent	Effluent	% Rmv.	Influent	Effluent	% Rmv.
TSS (mg/L)		110	97	12%	172	79	54%	164	34	79%	36	11	69%	312.5	130	58%
% VSS of TSS (%)		45%	62%	NA	59%	67%	NA	52%	44%	NA	76%	56%	NA	84%	64%	NA
pH		-	6.21	NA	6.43	6.34	NA	6.79	7.31	NA	6.79	7.33	NA	6.66	6.65	NA
Dissolved Metals (µg/L)	Zn	123	110	10%	108	88	19%	59	19	69%	32	11	67%	45	28	38%
	Cu	22.0	21.6	2%	12	15	-25%	8.0	10.1	-26%	4	6	-48%	3.0	2.6	12%
Total Metals (µg/L)	Zn	245	218	11%	295	149	49%	196	48	76%	67	24	64%	143	78	45%
	Cu	44	74	-66%	46	27	42%	31	17	45%	12	8	27%	38	15	59%

The data from the August 14 event indicate a relative low level of percent removal for the first half of the event (composite 1) but percent removal did increase for the last half of the event for TSS and total metals. This poor performance relative to the laboratory testing may be a result of a field column flow during sample collection that was 73% greater than the highest laboratory flow event or due to higher comparative influent concentrations.

Field events 2 and 3 exhibited overall greater percent removal for the constituents analyzed, with the exception of dissolved copper. The overall greater removal was a result of much lower stormwater flows through the column. The minimal or, in some cases, negative soluble copper removal is a result of very low influent soluble copper concentrations and possible interference from MCE filter membranes used to remove particulates from the sample prior to ICPMS testing.

Total suspended solids (TSS) was not a primary parameter of interest in this project however it is one of the most common reported causes of waterbody impairment in the United

States.[4] The average influent TSS collected during the three events was 159 mg/L TSS. Washington State has a stormwater quality treatment goal of 80% TSS removal for facilities that produce TSS within the 100-200 mg/L range.[19] On average, the field column removed 54% of the total suspended solids that passed through the column. While less than 80%, this indicates that the biochar column can remove both soluble and particulate bound metals as well as sediments. It's important to note that biochar fines were visible in the effluent samples for all three rain events. The filtration media was not flushed prior to installment and biochar fines are expected to flush out from the column for an initial break-in period. However, this could mean that the TSS percent removal calculation could be biased lower than actual due to the introduction of biochar fines in the effluent.

Every media filtration device that capitalizes on bed depth to remove contaminants must prevent surface clogging prior to media exhaustion in order to optimize the usefulness of the device and limit maintenance costs.[52] The difference in flow through the column between the first and second rain event emphasizes how much impact solids can have on a filtration device. In general, filtration devices that receive stormwater from catchments more than 75% impervious will be less prone to clogging and can use a smaller media.[52] This general design principle does not seem to apply to the Bainbridge Island site. While the catchment investigated was closer to 100% impervious, TSS values were over 50% volatile indicating high concentrations of natural organic matter (NOM). It is more likely that an extra effort may be needed to mitigate suspended solids in runoff at Bainbridge Island prior to soluble metal removal by media adsorption.

3.2.2 Sludge Characterization

As discussed previously, significant solids were observed in the stormwater vault. A sample of these solids was collected from inside the main chamber of the vault and characterized for dry weight metal concentrations and particle size distribution. The sludge particle size distribution is shown in Figure 26. The mean particle size of the sludge sample was 53.1 µm which falls within the silt classification range.

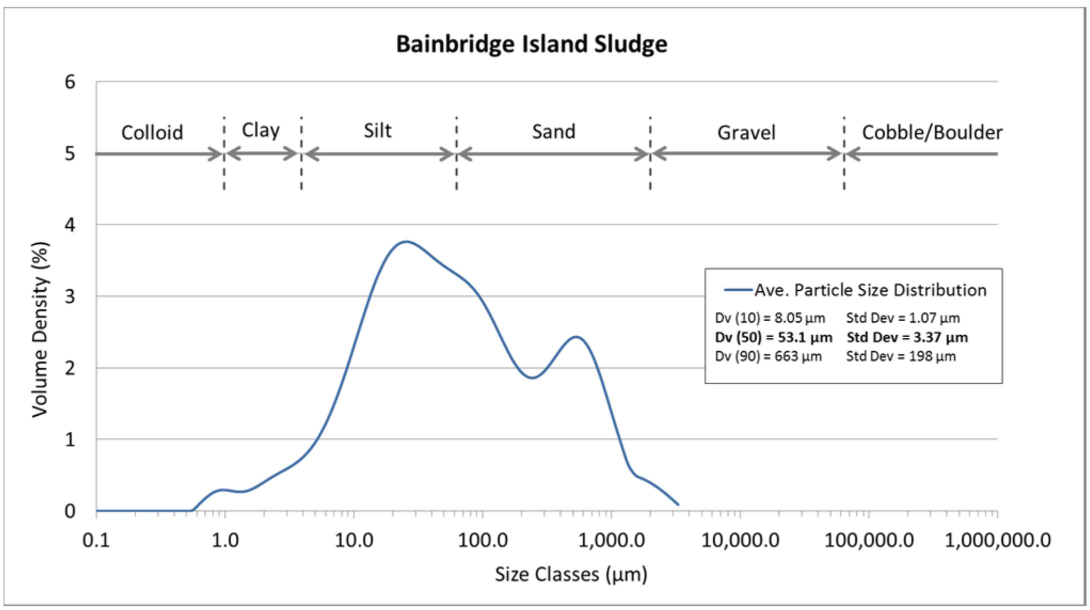


Figure 26. Stormwater vault sludge particle size distribution.

The solids contained an average concentration of 731 ± 132 mg/kg Zn and 107 ± 35 mg/kg Cu and was comprised of 33% volatiles. Washington State marine sediment quality standards limit zinc and copper concentrations to 410 mg/kg Zn and 390 mg/kg Cu.[53] While the sludge sample taken contained almost 80% more zinc than allowed, it was a single sample and several more tests should be performed to determine a more seasonally or annually representative mean.

4. CONCLUSIONS

The purpose of this project was to determine the applicability of biochar and torrefied wood serving as gravity fed column filter media to adsorb soluble zinc and copper from urban stormwater. Torrefied wood out performed biochar by adsorbing 26% more copper and 14% more zinc in laboratory column tests. However, non-torrefied wood (raw wood) columns outperformed all other media evaluated by adsorbing 97% of total exposed dissolved copper and 89% of total exposed dissolved zinc. Peak sorption performance for torrefied wood and raw wood was not realized until the media was hydrated past the fiber saturation point allowing metals to diffuse more readily into the wood cellular structure. Even though torrefaction was shown to increase metal bonding surface functional groups from hemicellulose degradation, it proved to be insignificant when compared to preserved intercellular adsorption sites attributed to the intact hemicellulose fraction of raw wood.

As in previous studies, pH proved to be a significant factor for metal adsorption and retention onto the sorbents. Torrefied wood showed greater resilience to pH fluctuation than biochar. Raw wood and pea gravel were not tested for pH sensitivity, however, it is likely that raw wood will exhibit the same resilience to pH based on similar characteristics with torrefied wood.

Flow rate had no effect on metal effluent concentration in laboratory tests. This is promising for stormwater applications where flow rates can vary widely. The deicer flush through the media resulted in a significant increase in effluent metal concentrations due to the displacement of zinc and copper by calcium. While only a relatively small percentage of the total metals sorbed were released, both media resumed zinc and copper adsorption after the salt flush, indicating media regeneration may be possible.

Moving forward, laboratory tests revealed raw wood to be the most effective metal adsorbent. However, leachate from wood can result in increased stormwater biochemical oxygen demand (BOD_5) and acidity.[54] BOD_5 and pH are both regulated parameters for stormwater discharge.[1] A decrease in raw wood effluent pH was observed during column tests and the degree of pH impact relative to metal removal should be evaluated. Effluent BOD_5 from laboratory columns should be measured to ensure lower effluent metal concentrations are not simply being traded for higher than regulation BOD_5. Likely, these parameters will not disqualify raw wood from application rather they will determine where a raw wood media filter would be applicable. Additionally, high flow tests should be performed on virgin material and a deicer salt flush should be conducted on raw wood to complete the investigation. The possibility of media regeneration was presented during testing and should be further investigated for economic and practical feasibility.

Biochar was used as the filter media in the Bainbridge Island field column. Averaging across the three rain events captured, the field column removed 41% soluble zinc, -17% soluble copper, and 54% TSS. Soluble copper concentrations in the runoff were very low and it is suspected that interference from sample filtering (prior to ICPMS analysis) had a significant influence on the readings. Sludge taken from inside the stormwater vault contained higher than allowable concentrations of zinc. Additional sludge tests should be conducted over time to better define an average sediment metal concentration.

Biochar in the field column should be replaced with raw wood and more field tests should be conducted to evaluate field performance of the media. The field design proved to be successful as a whole, however, the pump caused the column to clog and should not be used again.

5. WORKS CITED

(1) National Research Council. *Urban Stormwater Management in the United States*; The National Academies Press: Washington DC, 2009.

(2) *National Water Quality Inventory: Report to Congress. 2004 Reporting Cycle.*; EPA 841-R-08-001; United States Environmental Protection Agency: Washington, DC, 2009.

(3) Burton, G. Allen Jr.; Pitt, Robert E. *Stormwater effects handbook: a toolbox for watershed managers, scientists, and engineers*; CRC Press, 2001.

(4) *Summaries of Water Pollution Reporting Categories*; EPA841-R-12-104; United States Environmental Protection Agency, 2012.

(5) Barbosa, A. E.; Fernandes, J. N.; David, L. M. Key issues for sustainable urban stormwater management. *Water Research* **2012**, *46* (20), 6787–6798 DOI: 10.1016/j.watres.2012.05.029.

(6) *National Recommended Water Quality Criteria: 2002*; EPA-822-R-02-047; United States Environmental Protection Agency, 2002.

(7) Brooks, K. M.; Mahnken, C. V. W. Interactions of Atlantic salmon in the Pacific Northwest environment: III. Accumulation of zinc and copper. *Fisheries Research* **2003**, *62* (3), 295–305 DOI: 10.1016/S0165-7836(03)00065-1.

(8) *Reducing copper in industrial stormwater*; Fact sheet; State of Oregon Department of Environmental Quality, 2014.

(9) *Reducing Zinc in industrial stormwater*; Fact sheet; Department of Environmental Quality: The State of Oregon, 2014.

(10) Endangered and threatened marine species under NMFS' jurisdiction http://www.nmfs.noaa.gov/pr/species/esa/listed.htm#fish (accessed Oct 4, 2015).

(11) Wilson, M. F.; Halupka, K. C. Anadromous fish as keystone species in vertebrate communities. *Conservation Biology* **1995**, *9* (3), 489–497.

(12) Mahrosh, U.; Kleiven, M.; Meland, S.; Rosseland, B. O.; Salbu, B.; Teien, H.-C. Toxicity of road deicing salt (NaCl) and copper (Cu) to fertilization and early developmental stages of Atlantic salmon (Salmo salar). *Journal of Hazardous Materials* **2014**, *280*, 331–339 DOI: 10.1016/j.jhazmat.2014.07.076.

(13) Skidmore, J. F. Toxicity of zinc compounds to aquatic animals, with special reference to fish. *The Quaterly Review of Biology* **1964**, *39* (3), 227–248.

(14) *The dictionary of substances and their effects: t-z and index*, Second.; Gangolli, S., Ed.; Royal Society of Chemistry, 1999.

(15) United States Environmental Protection Agency. Environmental toxicity data for tri-listed chemicals http://www2.epa.gov/toxics-release-inventory-tri-program/environmental-toxicity-data-tri-listed-chemicals (accessed Oct 18, 2015).

(16) Davis, A. P.; Shokouhian, M.; Ni, S. Loading estimates of lead, copper, cadmium, and zinc in urban runoff from specific sources. *Chemosphere* **2001**, *44* (5), 997–1009 DOI: 10.1016/S0045-6535(00)00561-0.

(17) Golding, S. *Suggested practices to reduce zinc concentrations in industrial stormwater discharges*; Water Quality Program 08-10-025; Department of Ecology: The State of Washington, 2008.

(18) Harrison, F. L.; Knezovich, J. P.; Rice Jr., D. W.; Lam, J. R. *Distribution, fate and effects of energy-related residuals in marine environments.*; DOE/ER-0317; USDOE Office of Energy Research, Washington, DC. Ecological Research Div., 1987; pp 251–258.

(19) *Stormwater management manual for Western Washington: Amended December 2014.*; WADOE 14-10-055; Department of Ecology: The State of Washington, 2014.

(20) Reynolds, T. D.; Richards, P. *Unit Operations and Processes in Environmental engineering*, 2nd ed.; CL Engineering, 1995.

(21) Crittenden, J. C.; Hand, D. W.; Howe, K. J.; Trussell, R. R.; Tchobanoglous, G. *MWH's water treatment: Principles and design*, 3rd ed.; John Wiley & Sons, 2012.

(22) Watts, R. J. *Hazardous wastes: Sources, pathways, receptors*, 1st ed.; John Wiley & Sons, 1998.

(23) Nartey, O. D.; Zhao, B.; Nartey, O. D.; Zhao, B. Biochar preparation, characterization, and adsorptive capacity and its effect on bioavailability of contaminants: an overview, biochar preparation, characterization, and adsorptive capacity and its effect on bioavailability of contaminants: An overview. *Advances in Materials Science and Engineering* **2014**, *2014*, 12 DOI: 10.1155/2014/715398.

(24) Chen, J. P.; Wang, X. Removing copper, zinc, and lead ion by granular activated carbon in pretreated fixed-bed columns. *Separation and Purification Technology* **2000**, *19* (3), 157–167 DOI: 10.1016/S1383-5866(99)00069-6.

(25) Chen, X.; Chen, G.; Chen, L.; Chen, Y.; Lehmann, J.; McBride, M. B.; Hay, A. G. Adsorption of copper and zinc by biochars produced from pyrolysis of hardwood and corn straw in aqueous solution. *Bioresource Technology* **2011**, *102* (19), 8877–8884 DOI: 10.1016/j.biortech.2011.06.078.

(26) Demirbas, A. Heavy metal adsorption onto agro-based waste materials: A review. *Journal of Hazardous Materials* **2008**, *157* (2–3), 220–229 DOI: 10.1016/j.jhazmat.2008.01.024.

(27) Yonge, D.; Roelen, P. *An evaluation of stormwater permeable rapid infiltration barriers for use in class V stormwater injection wells*; Research Report WA-RD 559.1; Washington State Department of Transportation: Washington State University, Pullman, WA, 2003.

(28) Mohan, D.; Sarswat, A.; Ok, Y. S.; Pittman Jr., C. U. Organic and inorganic contaminants removal from water with biochar, a renewable, low cost and sustainable adsorbent – A critical review. *Bioresource Technology* **2014**, *160*, 191–202 DOI: 10.1016/j.biortech.2014.01.120.

(29) Mohan, D.; Pittman, Charles U.; Steele, P. H. Pyrolysis of Wood/Biomass for Bio-oil: A Critical Review. *Energy Fuels* **2006**, *20* (3), 848–889 DOI: 10.1021/ef0502397.

(30) Thea Whitman. What is Biochar? *Soil Science, Microbiology, and Biogeochemistry*.

(31) Smith, J. Assessing copper and zinc adsorption to thermally treated lignocellulosic biomass. M.S., Washington State University: Pullman, WA, 2015.

(32) Jung, C.; Park, J.; Lim, K. H.; Park, S.; Heo, J.; Her, N.; Oh, J.; Yun, S.; Yoon, Y. Adsorption of selected endocrine disrupting compounds and pharmaceuticals on activated biochars. *Journal of Hazardous Materials* **2013**, *263, Part 2*, 702–710 DOI: 10.1016/j.jhazmat.2013.10.033.

(33) Mohanty, S. K.; Cantrell, K. B.; Nelson, K. L.; Boehm, A. B. Efficacy of biochar to remove Escherichia coli from stormwater under steady and intermittent flow. *Water Research* **2014**, *61*, 288–296 DOI: 10.1016/j.watres.2014.05.026.

(34) Sarvaramini, A.; Assima, G. P.; Larachi, F. Dry torrefaction of biomass – Torrefied products and torrefaction kinetics using the distributed activation energy model. *Chemical Engineering Journal* **2013**, *229*, 498–507 DOI: 10.1016/j.cej.2013.06.056.

(35) Prins, M. J.; Ptasinski, K. J.; Janssen, F. J. J. G. Torrefaction of wood: Part 2. Analysis of products. *Journal of Analytical and Applied Pyrolysis* **2006**, *77* (1), 35–40 DOI: 10.1016/j.jaap.2006.01.001.

(36) Hubbe, M. A. New Horizons for Use of Cellulose-Based Materials to Adsorb Pollutants from Aqueous Solutions. *Lignocellulose Journal* **2013**, *2* (2), 386–411.

(37) H7 Solutions. About Biochar Products http://www.biocharproducts.com/about-biochar-products.html (accessed Sep 16, 2015).

(38) Dumroese, D.; Englund, K.; Smith, J. Biochar Origins, 2015.

(39) Lanning, D. N.; Dooley, J. H.; Lanning, C. J. Low-energy comminution of woody biomass to create precision feedstock particles; 12-1337409; ASABE: Dallas, Texas, 2012.

(40) Martin, T. D.; Brockhoff, C. A.; Creed, J. T.; EMMC Methods Work Group. *Determination of metals and trace elements in water and wastes by inductively coupled plasma-atomic emission spectrometry*; Standard Method 200.7; Environmental Monitoring Systems Laboratory, Office of Research and Development, U.S. Environmental Protection Agency: Cincinnati, OH, 1994.

(41) Lytle, D.; Kelty, K.; Pham, M.; Schaub, M. *A systematic evaluation of dissolved metals loss during water sample filtration*; Science in Action; Research Report EPA 600/F-11/029b; USEPA: Office of Research and Development: EPA Region 6, 2014; p 2.

(42) U.S. Environmental Protection Agency. *Total, fixed, and volatile solids in water, solids, and biosolids*; Method 1684; USEPA: Washington, DC, 2001.

(43) Washington State Department of Transportation. *Statewide snow and ice plan. 2014-2015*.

(44) Boost with Calcium Chloride http://www.caclwithboost.com/home.html (accessed Oct 18, 2015).

(45) Hand, J. Calcium Chloride with Boost, 2015.

(46) America West. Material safety data sheet: Calcium chloride with boost. July 25, 2006.

(47) Mays, L. W. *Water resources engineering*; John Wiley & Sons, 2010.

(48) *Water measurement manual*; Technical Publication; U.S. Department of the Interior Bureau of Reclamation: Washington, DC, 2001.

(49) Reeb, J. E. *Wood and moisture relationships*; Catalog EM 8600; Oregon State University, 1995; p 7.

(50) Engelund, E. T.; Thygesen, L. G.; Svensson, S.; Hill, C. A. S. A critical discussion of the physics of wood–water interactions. *Wood Science Technology* **2013**, No. 47, 141–161 DOI: 10.1007/s00226-012-0514-7.

(51) Fengel, D. *Wood: chemistry, ultrastructure, reactions*; Walter de Gruyter, 2011.

(52) Claytor, R. A.; Schueler, T. R. *Design of stormwater filtering systems*; Design Manual; The Center for Watershed Protection: Ellicott City, MD, 1996.

(53) *Sediment management standards*; WAC 173-204-320; Department of Ecology: Washington State, 2013.

(54) Washington State Department of Ecology. *Industrial stormwater general permit implementation manual for log yards*; Water Quality Program; Manual 04-10-031; Olympia, WA, 2004.

(55) Lambe, T. W.; Whitman, R. V. *Soil mechanics*; Series in soil engineering; John Wiley & Sons: New York, 1969.

(56) Bear, J. *Dynamics of Fluids in Porous Media*; Courier Corporation, 2013.

(57) Herrera Environmental Consultants Inc. *Untreated highway runoff in Western Washington*; White Paper wp4 /06-03427-004; Washington State Department of Transportation: Seattle, Washington, 2007; p 66.

6. APPENDIX

6.1: Media Permeability Discussion and Data

Hydraulic conductivity coefficient (k) was determined using a constant head permeability apparatus. The design and construction of the apparatus was based on information in Soil Mechanics (Lambe & Whitman, 1969).[55] Flow through the packed column was measured and recorded corresponding to a range of fixed head potentials. The hydraulic conductivity was determined using Equation 6, a derivation of Darcy's Law, and normalized by temperature using Equation 7.[55]

$$k = \frac{Q}{A}\frac{L}{h} \tag{6}$$

Where: Q = flow through the column (cm^3/s)
L = length of media in the column (cm)
A = surface area of the column (cm^2)
h = hydraulic head (cm)
k = hydraulic conductivity (cm/s)

$$k_{20°C} = \frac{\mu_T}{\mu_{20°C}} k_T \tag{7}$$

Where: $k_{20°C}$ = normalized hydraulic conductivity, (cm/s)
k_T = conductivity at temperature T, (cm/s)
$\mu_{20°C}$ = dynamic viscosity of water at 20 °C, ($g/m \cdot s$)
μ_T = dynamic viscosity of water at temp. T, ($g/m \cdot s$)

Laboratory determined and normalized hydraulic conductivity values (k) are reported below in Table 6 for raw wood, torrefied wood, and biochar. As expected, biochar exhibited a higher conductivity attributed to its larger mean particle size.

Table 6. Hydraulic conductivity data.

Media	k_T	T	μ_T	$\mu_{20\,°C}$	$k_{20\,°C}$
	(cm/s)	(°C)	(g/m·s)	(g/m·s)	(cm/s)
2mm Raw Wood	0.337	16.5	1.098	1.002	0.369
2mm Torrefied Wood	0.308	14.0	1.166		0.358
Biochar (8 < x < 6)	0.547	12.5	1.223		0.668

Sources: Dynamic viscosity: 21 All other values: This study

The hydraulic conductivity values for all filter medias tested fall within the pervious medium range (10^{-1} to 10^{2} cm/s).[56] It should be noted that biochar and torrefied wood both out performed their expected maximum flow capacity, calculated using the empirically determined hydraulic conductivity values and Darcy's law, by greater than 60 percent. Therefore, the reported values should be considered conservative when used for design purposes. It's possible a more representative conductivity value could be determined using the effective cross-sectional area rather than the entire column cross-sectional area. During 4x flow events, torrefied wood visually exhibited a changing hydraulic conductivity attributed to wood particle swelling that decreased pore openings within the medium. A visual change in hydraulic conductivity is evidence of a change in bound water storage between runs.[49] Once the fiber saturation point (fsp) of the wood media is reached, swelling will cease and hydraulic conductivity will stabilize.[49]

Table 7. Hydraulic conductivity data table with associated graph for 2mm Douglas-fir crumbles.

2 mm Douglas Fir

Temp (°C)	Length (in.)	Dia. (in)	Area (in^2)	k ave tot (in/s)	k ave tot (cm/s)	k graph (in/s)	k graph (cm/s)
16.5	7.94	3.94	12.18	0.1325	0.3365	0.1330	0.3379

Trial		Vol. (mL)	Vol. (in^3)	Δh (in.)	Δt (sec.)	k (in/s)	k ave (in/s)	Q (cis)	Q ave (cis)	i (in/in)
	A	1120	68.3		5.1	0.135		13.38		
1	B	1145	69.9	64.38	5.2	0.137	0.135	13.54	13.29	8.11
	C	1215	74.1		5.7	0.131		12.94		
	A	1300	79.3		6.2	0.136		12.75		
2	B	1520	92.8	61.31	7.3	0.136	0.135	12.78	12.71	7.72
	C	1400	85.4		6.8	0.134		12.60		
	A	1565	95.5		8.1	0.132		11.78		
3	B	1360	83.0	58.31	7.1	0.131	0.131	11.76	11.68	7.35
	C	1825	111.4		9.7	0.129		11.52		
	A	1530	93.4		8.2	0.135		11.43		
4	B	1530	93.4	55.25	8.2	0.135	0.132	11.44	11.21	6.96
	C	1555	94.9		8.8	0.127		10.77		
	A	1770	108.0		9.9	0.137		10.95		
5	B	1260	76.9	52.25	7.3	0.128	0.130	10.48	10.56	6.58
	C	1530	93.4		9.1	0.125		10.26		

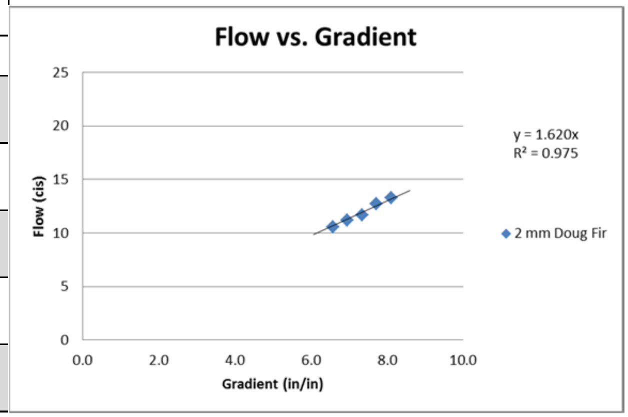


Table 8. Hydraulic conductivity data table with associated graph for 2mm torrefied wood.

2mm Torrefied Wood

Temp (°C)	Length (in.)	Dia. (in)	Area (in^2)	k ave tot (in/s)	k ave tot (cm/s)	k graph (in/s)	k graph (cm/s)
14	7.91	3.94	12.18	0.1209	0.3071	0.1214	0.3083

Trial		Vol. (mL)	Vol. (in^3)	Δh (in.)	Δt (sec.)	k (in/s)	k ave (in/s)	Q (cis)	Q ave (cis)	i (in/in)
	A	895	54.6		4.4	0.1265		12.47		
1	B	910	55.5	64.00	4.5	0.1241	0.125	12.23	12.30	8.09
	C	1000	61.0		5.0	0.1238		12.20		
	A	1160	70.8		6.1	0.1245		11.70		
2	B	1000	61.0	61.00	5.2	0.1256	0.125	11.80	11.70	7.72
	C	1350	82.4		7.1	0.1235		11.60		
	A	1460	89.1		8.3	0.1209		10.80		
3	B	1800	109.8	58.00	10.3	0.1194	0.121	10.66	10.77	7.34
	C	1440	87.9		8.1	0.1213		10.84		
	A	1480	90.3		8.8	0.1216		10.30		
4	B	1630	99.5	55.00	10.0	0.1174	0.119	9.95	10.07	6.96
	C	1700	103.7		10.4	0.1176		9.97		
	A	1330	81.2		8.6	0.1173		9.39		
5	B	1680	102.5	52.00	10.9	0.1170	0.116	9.37	9.27	6.58
	C	1440	87.9		9.7	0.1129		9.04		

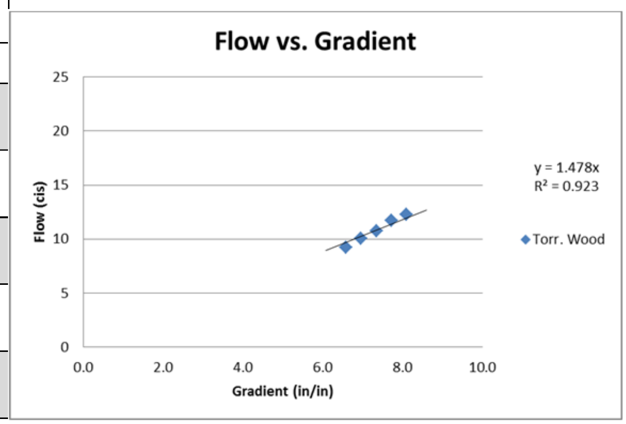
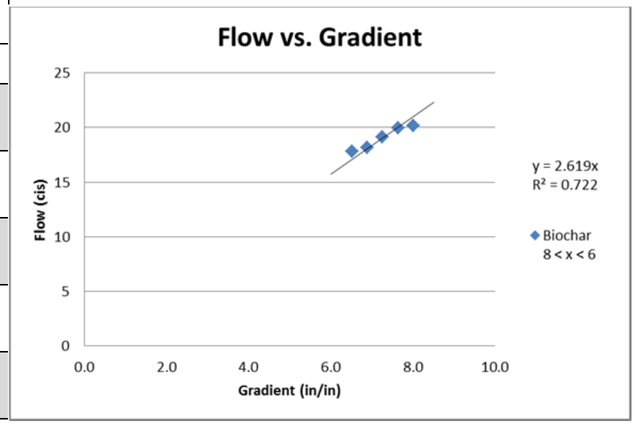
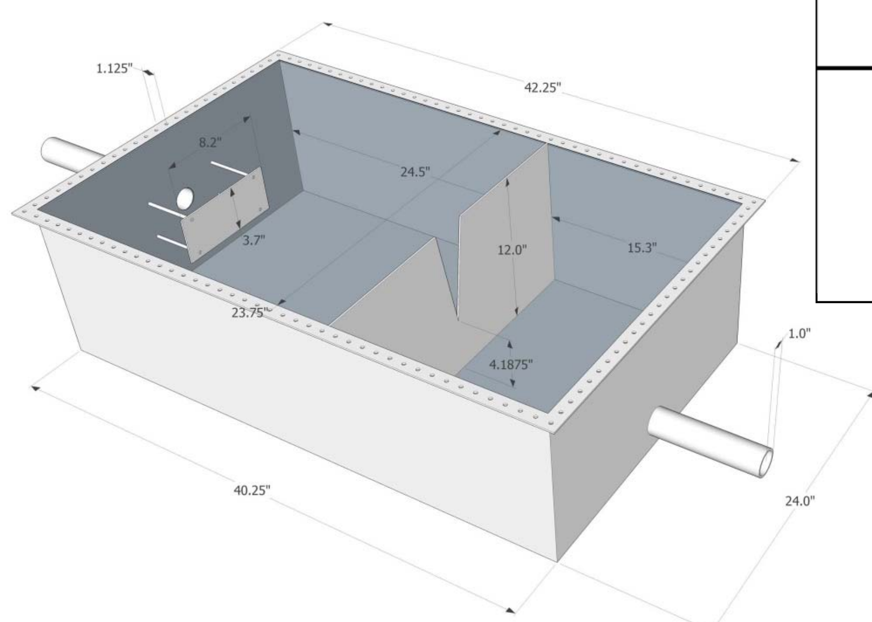


Table 9. Hydraulic conductivity data table with associated graph for biochar.

Biochar (8 < x< 6)												
		Temp (°C)	Length (in.)	Dia. (in)	Area (in^2)		k ave tot (in/s)	k ave tot (cm/s)	k graph (in/s)	k graph (cm/s)		
		12.5	8.00	3.94	12.18		0.2158	0.5482	0.2150	0.5462		
Trial		Vol. (mL)	Vol. (in^3)	Δh (in.)	Δt (sec.)	k (in/s)	k ave (in/s)	Q (cis)	Q ave (cis)	i (in/in)		
1	A	1060	64.7	64.06	3.1	0.2147	0.207	20.93	20.16	8.01		
	B	1100	67.1		3.4	0.2049		19.98				
	C	1075	65.6		3.4	0.2008		19.58				
2	A	1130	69.0	61.06	3.4	0.2169	0.215	20.16	19.95	7.63		
	B	950	58.0		2.9	0.2143		19.92				
	C	1400	85.4		4.3	0.2128		19.78				
3	A	1160	70.8	58.06	3.7	0.2182	0.216	19.29	19.13	7.26		
	B	1215	74.1		3.8	0.2196		19.41				
	C	1020	62.2		3.3	0.2115		18.69				
4	A	1030	62.9	55.06	3.4	0.2193	0.217	18.38	18.16	6.88		
	B	1140	69.6		4.0	0.2096		17.57				
	C	1310	79.9		4.3	0.2213		18.55				
5	A	1060	64.7	52.06	3.6	0.2243	0.224	17.77	17.78	6.51		
	B	1190	72.6		4.1	0.2224		17.63				
	C	1180	72.0		4.0	0.2266		17.96				



6.2: Weir box Dimensions and Calibration



Requirements for Partial Contraction
$h1/P1 \leq 1.2$ $h1/B1 \leq 0.4$ $0.05 < h1 \leq 23.6$ inches $P1 \geq 3.9$ inches $B1 \geq 23.6$ inches

h1 max	7 in
P1	4.1875 in
B1	23.625 in
h1/p1	1.67
h1/B1	0.3
p1/B1	0.18
ht	11.1875 in

Figure 27. Weir box dimensions and partial contraction verification.

Table 10. 10° Weir plate calibration table with associated graph.

Plate 1: θ= 10°								
Height (in)	t (sec)	vol (mL)	Q (mL/s)	Stdev (mL/s)	Stdev (gpm)	Qave (mL/s)	Q (gpm)	Q (cfs)
5	2.02	1910	945.5	64.9	1.03	1012.9	16.1	0.036
	2.4	2580	1075.0					
	2.21	2250	1018.1					
3	2.97	990	333.3	22.1	0.35	325.7	5.2	0.012
	3.12	1070	342.9					
	3.89	1170	300.8					
1	6.21	330	53.1	1.4	0.02	51.5	0.8	0.002
	7.46	380	50.9					
	6.73	340	50.5					

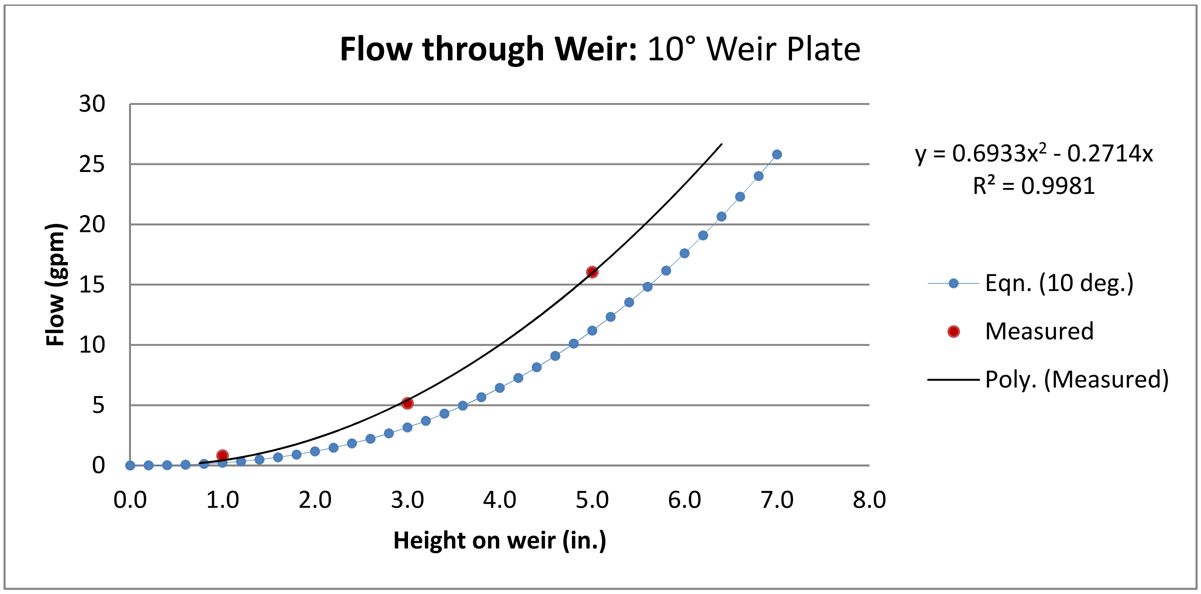


Table 11. 20° Weir plate calibration table with associated graph.

Plate 2: θ= 20°								
Height (in)	t (sec)	vol (mL)	Q (mL/s)	Stdev (mL/s)	Stdev (gpm)	Qave (mL/s)	Q (gpm)	Q (cfs)
4	3.16	3340	1057.0	66.2	1.05	1050.1	16.6	0.037
	2.13	2370	1112.7					
	2.08	2040	980.8					
3	2.6	1600	615.4	19.4	0.31	593.0	9.4	0.021
	2.81	1630	580.1					
	2.57	1500	583.7					
2	3.64	880	241.8	2.5	0.04	243.5	3.9	0.009
	3.3	800	242.4					
	3.49	860	246.4					

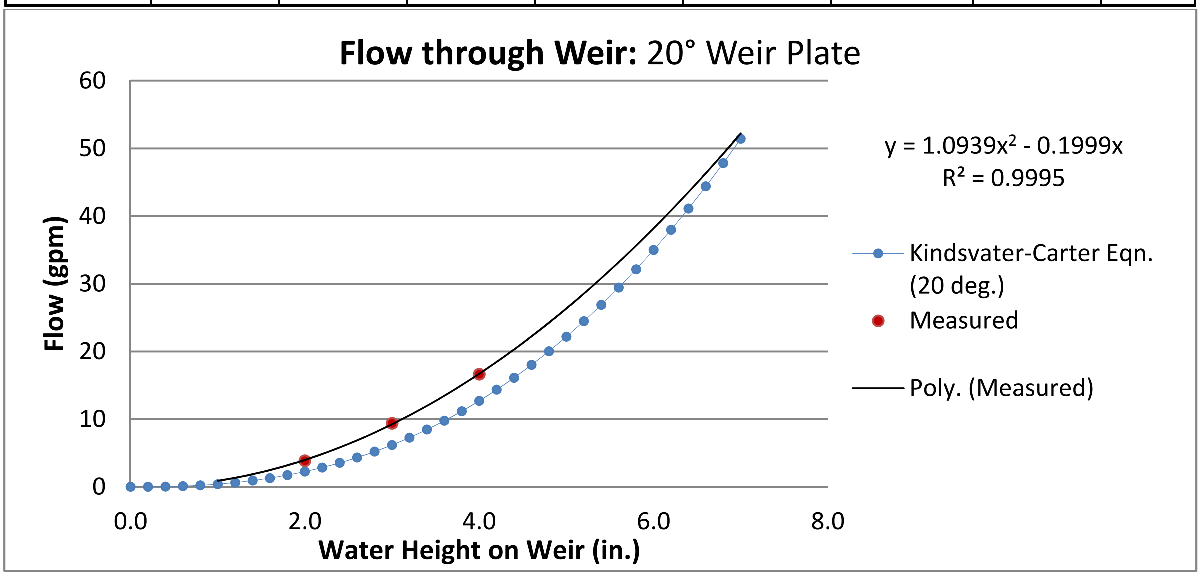


Table 12. 45° Weir plate calibration table with associated graph.

Plate 3: θ= 45°								
Height (in)	t (sec)	vol (mL)	Q (mL/s)	Stdev (mL/s)	Stdev (gpm)	Qave (mL/s)	Q (gpm)	Q (cfs)
4	1.74	3500	2011.5	63.5	1.01	1959.8	31.1	0.069
	1.44	2720	1888.9					
	1.44	2850	1979.2					
3	1.99	1880	944.7	31.9	0.51	981.6	15.6	0.035
	1.96	1960	1000.0					
	2.18	2180	1000.0					
2	2.26	880	389.4	7.8	0.12	381.3	6.0	0.013
	2.26	860	380.5					
	3.45	1290	373.9					

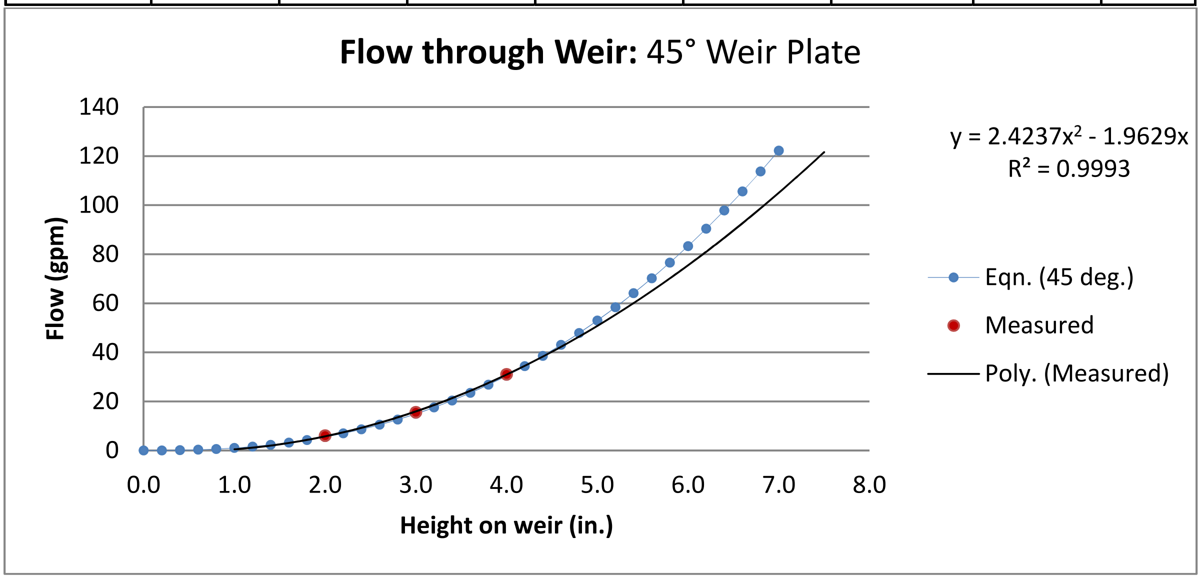


Table 13. 60° Weir plate calibration table with associated graph.

Plate 4: θ= 60°								
Height (in)	t (sec)	vol (mL)	Q (mL/s)	Stdev (mL/s)	Stdev (gpm)	Qave (mL/s)	Q (gpm)	Q (cfs)
4	1.3	3020	2323.1	88.7	1.41	2415.4	38.3	0.085
	1.4	3500	2500.0					
	1.3	3150	2423.1					
3	2.07	3300	1594.2	25.2	0.40	1623.3	25.7	0.057
	1.83	3000	1639.3					
	2.09	3420	1636.4					
2	2.86	1740	608.4	16.5	0.26	616.6	9.8	0.022
	3.4	2060	605.9					
	2.36	1500	635.6					

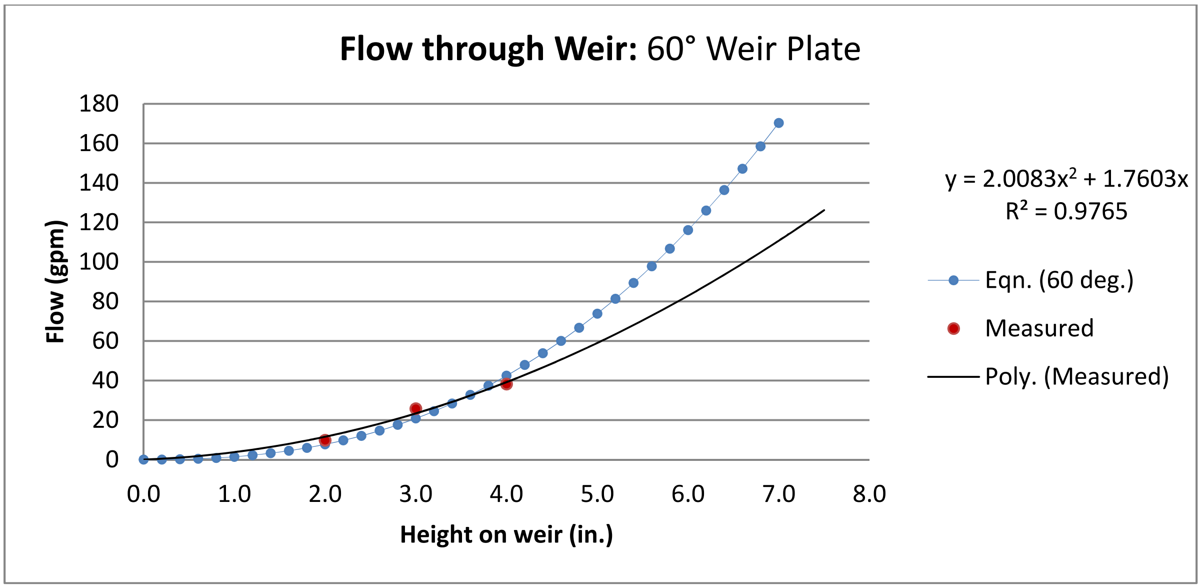
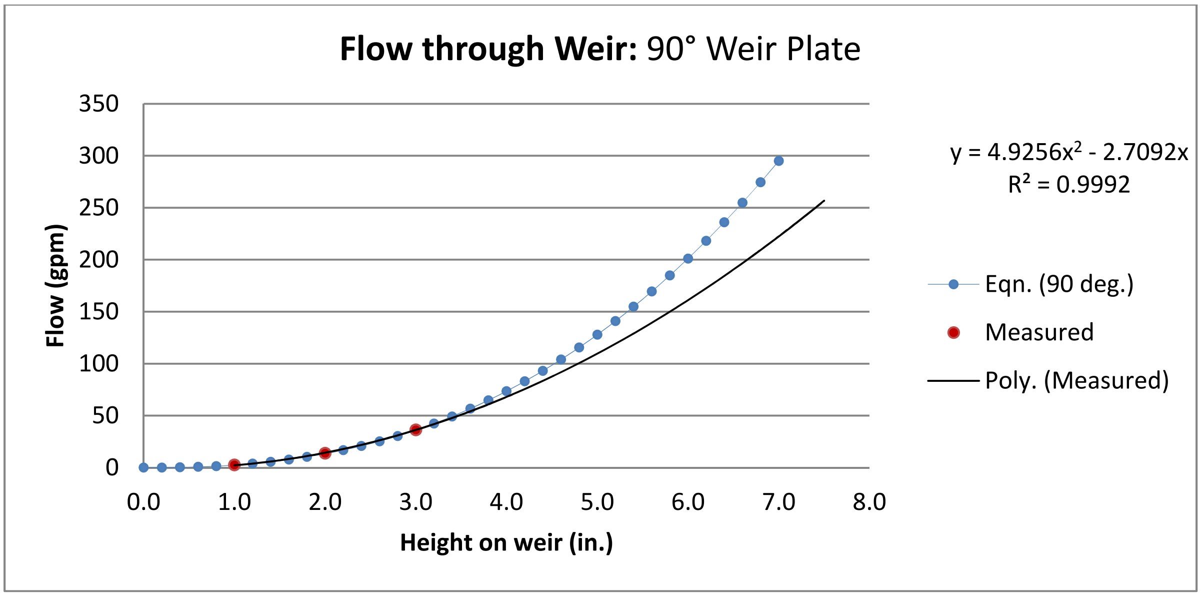


Table 14. 90° Weir plate calibration table with associated graph.

Plate 5: θ= 90°								
Height (in)	t (sec)	vol (mL)	Q (mL/s)	Stdev (mL/s)	Stdev (gpm)	Qave (mL/s)	Q (gpm)	Q (cfs)
3	1.54	3230	2097.4	225.2	3.57	2293.8	36.4	0.081
	1.35	3030	2244.4					
	1.26	3200	2539.7					
2	2.43	2100	864.2	7.7	0.12	871.8	13.8	0.031
	2.49	2190	879.5					
	2.26	1970	871.7					
1	5.34	940	176.0	7.3	0.12	169.2	2.7	0.006
	6.7	1140	170.1					
	8.36	1350	161.5					



6.3: Laboratory Column Tests

Table 15. Phase I laboratory column data for composite samples.

Phase I - Non filtered				Influent			Ave. Biochar											Ave. T.W.										
Day	Event	Ave. Cum. Vol.		Zn	Cu	pH	Zn				Cu				pH			Zn				Cu				pH		
		Gal.	Liter	(ppb)	(ppb)	(pH)	(ppb)	(stdev)	(95% CI)	%Rmv	(ppb)	(stdev)	(95% CI)	%Rmv	(pH)	(stdev)	(95% CI)	(ppb)	(stdev)	(95% CI)	%Rmv	(ppb)	(stdev)	(95% CI)	%Rmv	(pH)	(stdev)	(95% CI)
1	1	4.2	16.0	-	-	6.14	-	-	-	-	-	-	-	-	6.69	0.3	0.7	-	-	-	-	-	-	-	-	3.94	0.1	0.3
2	2	8.2	30.9	349.7	78.3	5.77	62.0	9.8	24.4	0.8	6.5	0.9	2.2	0.9	6.52	0.1	0.4	299.9	43.4	107.7	0.1	40.6	8.5	21.1	0.5	3.94	0.1	0.3
3	3	12.3	46.5	354.5	75.8	5.76	67.8	15.1	37.6	0.8	6.4	1.4	3.5	0.9	6.58	0.1	0.3	197.8	19.8	49.2	0.4	19.2	3.5	8.6	0.7	4.39	0.0	0.1
4	4	16.4	62.0	330.2	75.8	5.79	75.2	1.6	3.9	0.8	6.1	0.2	0.4	0.9	6.61	0.1	0.2	206.3	15.6	38.6	0.4	19.9	1.5	3.7	0.7	4.59	0.1	0.2
5	5	19.3	72.9	332.7	83.9	6.2	79.9	9.0	22.3	0.8	6.1	0.9	2.2	0.9	6.73	0.0	0.0	212.1	17.3	42.9	0.4	19.4	3.0	7.6	0.8	4.59	0.1	0.2
8	6	23.2	87.7	275.1	77.8	6.35	59.0	5.0	12.3	0.8	5.6	0.4	1.1	0.9	6.91	0.1	0.3	204.5	48.8	121.1	0.3	23.2	8.1	20.2	0.7	4.61	0.3	0.6
9	7	27.1	102.7	278.5	79.9	6.15	77.2	3.0	7.5	0.7	7.0	0.3	0.6	0.9	6.67	0.0	0.1	127.9	26.3	65.2	0.5	11.8	3.6	8.8	0.9	4.92	0.2	0.6
10	8	31.1	117.6	282.6	69.6	6.28	68.7	4.4	10.9	0.8	4.7	0.5	1.1	0.9	6.56	0.1	0.2	107.8	8.5	21.1	0.6	7.7	0.9	2.4	0.9	5.01	0.2	0.5
11	9	35.0	132.6	296.6	75.6	6.24	82.3	8.0	20.0	0.7	5.6	0.9	2.3	0.9	6.65	0.0	0.1	122.9	9.8	24.3	0.6	9.8	1.2	2.9	0.9	5.19	0.1	0.1
12	10	38.8	146.9	300.6	85.8	6.35	94.7	12.6	31.3	0.7	6.9	1.9	4.8	0.9	6.58	0.1	0.3	119.1	9.9	24.5	0.6	10.2	1.4	3.4	0.9	5.43	0.1	0.2
15	11	42.9	162.4	412.8	124.9	5.69	131.9	8.8	21.8	0.7	10.6	2.1	5.2	0.9	6.58	0.0	0.0	255.1	19.1	47.5	0.4	27.8	3.4	8.4	0.8	4.98	0.1	0.1
16	12	47.0	177.9	445.8	135.5	6.16	151.3	14.4	35.7	0.7	12.2	3.2	8.0	0.9	6.66	0.1	0.2	190.8	8.0	19.8	0.6	18.8	1.4	3.5	0.9	5.29	0.0	0.1
17	13	51.0	193.2	298.5	93.9	6.08	99.3	8.0	20.0	0.7	37.3	1.6	4.0	0.6	6.61	0.1	0.3	121.0	10.5	26.0	0.6	16.4	0.7	1.7	0.8	5.28	0.0	0.1
18	14	55.1	208.6	300.1	87.8	5.97	111.3	6.0	14.9	0.6	34.4	1.5	3.7	0.6	6.20	0.0	0.1	121.1	8.4	20.8	0.6	22.5	1.6	4.1	0.7	5.11	0.4	1.0
19	15	58.6	221.7	330.1	101.3	6	128.3	7.5	18.6	0.6	33.6	2.3	5.6	0.7	6.30	0.2	0.5	144.3	22.6	56.0	0.6	30.3	2.7	6.8	0.7	5.18	0.1	0.3
20	16	62.8	237.6	277.0	80.5	5.98	114.4	17.3	43.0	0.6	31.1	2.5	6.2	0.6	6.44	0.1	0.2	101.2	6.7	16.6	0.6	15.0	0.9	2.3	0.8	5.27	0.1	0.2
21	17	66.7	252.4	293.7	88.4	5.83	128.4	7.5	18.6	0.6	22.8	1.3	3.2	0.7	6.24	0.0	0.1	107.3	6.6	16.5	0.6	13.1	0.6	1.5	0.9	5.05	0.2	0.6
22	18	70.7	267.7	297.1	69.1	5.91	134.3	6.9	17.1	0.5	15.1	1.4	3.6	0.8	6.22	0.0	0.1	119.4	21.2	52.6	0.6	8.4	2.5	6.3	0.9	5.22	0.1	0.2
23	19	74.8	283.1	327.2	89.3	5.96	160.9	5.7	14.1	0.5	17.7	1.7	4.3	0.8	6.31	0.1	0.3	154.9	38.3	95.1	0.5	13.7	3.3	8.2	0.8	5.42	0.2	0.4
24	20	78.7	297.9	333.3	108.9	5.89	172.0	8.8	21.8	0.5	17.6	2.3	5.7	0.8	6.27	0.1	0.2	126.2	8.3	20.7	0.6	11.3	2.1	5.2	0.9	5.38	0.0	0.1
35	21	82.6	312.7	276.8	84.0	5.86	121.3	11.6	28.8	0.6	11.7	1.9	4.6	0.9	6.39	0.1	0.3	250.1	43.6	108.2	0.1	30.5	4.9	12.2	0.6	5.14	0.3	0.8
36	22	86.6	327.8	270.2	83.8	5.99	130.3	12.0	29.7	0.5	11.5	2.3	5.6	0.9	6.50	0.2	0.4	158.4	29.6	73.6	0.4	15.5	3.7	9.1	0.8	5.11	0.1	0.3
37	23	90.5	342.7	275.2	79.0	5.99	112.2	12.0	29.8	0.6	36.5	1.8	4.5	0.5	6.20	0.1	0.4	98.4	12.4	30.9	0.6	16.6	2.6	6.5	0.8	5.14	0.1	0.2
38	24	94.3	357.1	280.4	79.4	5.96	130.7	9.4	23.3	0.5	28.5	1.5	3.8	0.6	6.25	0.0	0.1	106.8	7.9	19.7	0.6	21.5	1.7	4.2	0.7	5.29	0.1	0.2
39	25	98.3	372.1	285.2	82.3	5.96	145.7	16.1	39.9	0.5	25.2	3.3	8.1	0.7	6.30	0.0	0.1	98.6	8.0	20.0	0.7	18.4	0.6	1.4	0.8	5.23	0.1	0.3
42	26	102.3	387.2	274.3	80.0	5.64	129.6	9.2	22.9	0.5	30.9	2.1	5.1	0.6	5.73	0.2	0.4	153.7	18.7	46.5	0.4	22.0	4.2	10.4	0.7	5.17	0.1	0.2
43	27	106.3	402.3	277.2	81.6	5.36	146.5	13.3	32.9	0.5	26.6	1.7	4.3	0.7	6.06	0.0	0.1	95.1	8.6	21.5	0.7	10.6	0.5	1.3	0.9	5.34	0.1	0.2
44	28	110.2	417.0	279.6	80.0	5.86	131.4	12.4	30.9	0.5	36.9	0.7	1.7	0.5	6.00	0.0	0.1	92.4	10.0	24.8	0.7	13.6	1.2	2.9	0.8	5.27	0.1	0.1
45	29	114.2	432.3	266.2	77.2	5.76	150.3	8.6	21.4	0.4	27.8	0.8	2.1	0.6	6.15	0.1	0.2	89.0	4.5	11.1	0.7	11.2	0.4	1.0	0.9	5.32	0.1	0.1
46	30	118.2	447.3	306.4	87.3	6.08	161.9	6.1	15.2	0.5	14.3	1.1	2.6	0.8	6.16	0.1	0.4	112.9	6.6	16.4	0.6	5.7	0.7	1.7	0.9	5.29	0.1	0.1
47	31	122.2	462.5	306.0	80.2	5.95	180.6	10.3	25.5	0.4	14.2	2.1	5.1	0.8	6.11	0.1	0.2	120.6	10.4	25.7	0.6	6.0	0.7	1.7	0.9	5.28	0.2	0.5
48	32	125.8	476.4	307.5	89.3	5.82	195.2	12.3	30.7	0.4	16.7	3.2	7.9	0.8	6.20	0.0	0.1	128.1	5.1	12.7	0.6	6.9	0.8	2.0	0.9	5.43	0.2	0.4
49	33	129.9	491.6	282.5	78.2	6.32	159.8	12.5	31.0	0.4	12.2	2.6	6.4	0.8	6.32	0.1	0.2	94.7	2.2	5.5	0.7	3.6	0.2	0.5	1.0	5.73	0.1	0.3
50	34	133.8	506.6	279.3	78.7	6.07	180.2	8.9	22.1	0.4	14.0	2.0	4.9	0.8	6.12	0.1	0.1	115.7	12.0	29.9	0.6	4.9	0.9	2.2	0.9	5.54	0.1	0.4
51	35	137.8	521.8	302.5	80.7	6.13	179.1	3.7	9.1	0.4	14.5	0.8	2.1	0.8	6.06	0.0	0.1	114.2	16.0	39.8	0.6	4.6	1.1	2.8	0.9	5.46	0.1	0.1
52	36	141.9	537.1	296.5	73.6	6.01	186.2	13.4	33.2	0.4	14.8	2.7	6.8	0.8	6.14	0.1	0.3	124.8	12.1	30.0	0.6	5.0	0.8	2.0	0.9	5.55	0.2	0.4
53	37	145.5	550.8	299.1	81.6	5.9	204.6	8.2	20.3	0.3	17.6	3.1	7.7	0.8	6.19	0.1	0.1	131.1	13.5	33.5	0.6	5.3	0.8	2.0	0.9	5.48	0.1	0.3
54	38	149.5	565.8	287.8	76.4	6.13	167.8	6.0	14.8	0.4	12.5	0.9	2.3	0.8	6.20	0.0	0.1	140.7	9.5	23.5	0.5	6.6	0.9	2.3	0.9	5.29	0.1	0.3
55	39	153.4	580.8	285.5	77.5	5.83	185.3	6.1	15.2	0.4	15.4	1.5	3.7	0.8	5.87	0.1	0.3	126.2	11.7	29.1	0.6	4.9	0.6	1.6	0.9	5.57	0.1	0.2
56	40	157.6	596.5	303.6	92.8	6.01	175.0	9.9	24.7	0.4	15.6	2.3	5.6	0.8	6.08	0.2	0.5	113.2	9.0	22.5	0.6	4.1	0.5	1.3	1.0	5.55	0.2	0.6

Table 16. Phase I filtered and unfiltered discrete samples

Day	Biochar																	
	1 min						10 min						20 min					
	Not Filtered			Filtered			Not Filtered			Filtered			Not Filtered			Filtered		
	#	Zn (μg/L)	Cu (μg/L)	#	Zn (μg/L)	Cu (μg/L)	#	Zn (μg/L)	Cu (μg/L)	#	Zn (μg/L)	Cu (μg/L)	#	Zn (μg/L)	Cu (μg/L)	#	Zn (μg/L)	Cu (μg/L)
4	31	45.7	5.5	32	40.0	4.2	33	89.1	7.6	34	84.3	4.9	35	78.1	4.8	36	68.8	2.9
11	117	62.1	5.0	118	139.2	10.7	119	86.2	6.1	120	75.8	3.5	121	88.6	4.9	122	87.0	3.4
18	45	82.8	33.4	46	87.8	2.3	47	112.7	35.4	48	104.5	2.6	49	112.9	32.6	50	118.4	4.3
23	131	122.5	12.8	132	114.7	3.6	133	149.8	15.5	134	147.6	4.9	135	173.1	17.3	136	155.3	6.2
39	59	114.0	18.7	60	106.2	3.4	61	136.9	22.6	62	133.0	5.5	63	156.2	23.4	64	141.4	7.1
46	145	143.0	11.2	146	143.9	4.8	147	169.5	15.4	148	163.9	12.4	149	171.4	13.9	150	156.1	9.7
51	9	155.7	8.0	-	-	-	10	161.7	11.3	-	-	-	11	173.1	12.6	-	-	-

Day	Torrefied Wood																	
	1 min						10 min						20 min					
	Not Filtered			Filtered			Not Filtered			Filtered			Not Filtered			Filtered		
	#	Zn (μg/L)	Cu (μg/L)	#	Zn (μg/L)	Cu (μg/L)	#	Zn (μg/L)	Cu (μg/L)	#	Zn (μg/L)	Cu (μg/L)	#	Zn (μg/L)	Cu (μg/L)	#	Zn (μg/L)	Cu (μg/L)
4	43	405.7	42.3	44	397.3	40.4	45	143.7	11.0	46	125.0	9.1	47	153.3	12.5	48	137.4	10.2
11	129	212.0	17.0	130	73.7	4.9	131	89.8	6.7	132	2757.0	0.1	133	96.6	7.7	134	89.7	4.6
18	57	142.0	28.2	58	135.1	9.6	59	91.3	18.5	60	85.5	3.6	61	85.0	16.1	62	68.1	2.6
23	143	139.1	11.5	144	151.7	9.3	145	115.6	11.3	146	101.6	6.2	147	131.2	13.6	148	111.2	7.7
39	71	-	-	72	159.8	10.0	73	102.7	20.2	74	88.9	7.3	75	97.8	18.6	76	80.5	3.8
46	157	167.3	8.8	158	153.8	8.1	159	101.8	4.8	160	89.6	3.9	161	107.8	5.4	162	96.6	4.4
51	15	165.4	7.0	-	-	-	16	107.7	4.1	-	-	-	17	112.4	4.5	-	-	-

Table 17. Phase I filtered and unfiltered influent and biochar data.

Event	Influent (Single Sample)						Biochar, Column 1 (Composite Samples)						Biochar, Column 2 (Composite Samples)						Biochar, Column 3 (Composite Samples)					
	Not Filtered			Filtered			Not Filtered			Filtered			Not Filtered			Filtered			Not Filtered			Filtered		
	#	Zn (µg/L)	Cu (µg/L)	#	Zn (µg/L)	Cu (µg/L)	#	Zn (µg/L)	Cu (µg/L)	#	Zn (µg/L)	Cu (µg/L)	#	Zn (µg/L)	Cu (µg/L)	#	Zn (µg/L)	Cu (µg/L)	#	Zn (µg/L)	Cu (µg/L)	#	Zn (µg/L)	Cu (µg/L)
1	15	-	-	16	270.0	45.0	-	-	-	17	90.2	13.5	-	-	-	18	68.6	6.1	-	-	-	19	47.5	7.0
2	1	349.7	78.3	2	336.0	63.0	3	68.9	7.2	4	63.2	9.4	5	69.1	6.9	6	66.0	5.3	7	48.2	5.2	8	42.6	3.8
3	15	354.5	75.8	16	316.0	57.0	17	62.4	6.0	18	81.9	4.8	19	88.5	8.3	20	79.1	6.4	21	52.6	5.0	22	50.2	4.0
4	29	330.2	75.8	30	312.9	58.4	37	76.0	6.1	38	69.7	4.8	39	76.6	6.3	40	76.6	5.3	41	73.0	5.9	42	69.0	4.8
5	55	332.7	83.9	56	312.4	66.8	57	78.8	6.0	58	72.7	5.2	59	91.4	7.2	60	86.9	5.5	61	69.5	5.0	62	67.8	4.2
6	73	275.1	77.8	74	246.0	52.1	75	65.1	6.2	76	60.8	3.9	77	59.0	5.4	78	50.8	3.4	79	52.9	5.2	80	47.6	3.5
7	87	278.5	79.9	88	249.5	57.6	89	78.4	7.0	90	67.4	3.7	91	80.1	7.3	92	73.0	4.5	93	73.1	6.7	94	67.9	4.2
8	101	282.6	69.6	102	269.7	48.8	103	64.7	4.2	104	57.8	2.5	105	66.5	4.6	106	58.4	2.9	107	74.8	5.3	108	68.0	4.3
9	115	296.6	75.6	116	274.3	53.7	123	71.7	4.4	124	68.2	3.0	125	6.7	91.2	126	79.3	2.6	127	84.1	5.8	128	78.2	4.1
10	141	300.6	85.8	142	280.7	64.5	143	87.9	5.9	144	78.8	4.0	145	83.9	5.2	146	73.6	3.3	147	112.4	9.6	148	93.4	5.1
11	1	412.8	124.9	2	411.8	101.8	3	120.2	7.9	4	108.1	5.2	5	134.3	11.1	6	131.9	8.0	7	141.2	13.0	8	135.9	9.5
12	15	445.8	135.5	16	408.5	104.3	17	138.1	8.7	18	123.4	6.1	19	144.6	11.4	20	157.2	8.1	21	171.3	16.4	22	172.4	12.1
13	29	298.5	93.9	30	278.1	36.7	31	88.1	35.0	32	87.3	8.3	33	103.0	38.7	34	94.1	9.0	35	106.7	38.0	36	103.4	9.4
14	43	300.1	87.8	44	263.8	38.0	51	103.2	32.3	52	92.1	2.2	53	112.9	35.8	54	111.4	4.2	55	117.6	35.0	56	112.8	3.7
15	69	330.1	101.3	70	317.6	54.5	71	117.8	30.7	72	115.4	3.7	73	134.7	33.7	74	127.4	5.9	75	132.5	36.3	76	116.2	3.3
16	83	277.0	80.5	84	272.3	40.8	85	92.4	27.8	86	88.7	9.9	87	134.8	33.8	88	117.6	11.2	89	115.9	31.7	90	159.1	7.6
17	101	293.7	88.4	102	273.1	56.1	103	117.8	21.0	104	113.9	5.3	105	132.5	23.3	106	138.1	7.5	107	134.7	24.1	108	120.6	5.9
18	115	297.1	69.1	116	288.4	42.6	117	127.0	13.4	118	123.2	3.4	119	132.4	14.9	120	135.6	4.8	121	143.5	17.0	122	136.6	5.4
19	129	327.2	89.3	130	309.1	60.8	137	152.9	15.3	138	147.0	5.8	139	165.3	19.3	140	151.6	8.8	141	164.5	18.5	142	151.7	7.1
20	155	333.3	108.9	156	297.3	73.6	157	159.9	14.6	158	161.4	10.9	159	180.5	20.1	160	181.4	12.9	161	175.5	18.2	162	151.0	7.6
21	1	276.8	84.0	2	266.0	67.1	3	104.9	9.1	4	100.5	6.2	5	128.9	12.7	6	122.8	9.3	7	130.1	13.4	8	132.6	9.4
22	15	270.2	83.8	16	260.6	71.7	17	116.0	8.8	18	110.9	6.1	19	129.5	11.3	20	124.0	8.0	21	145.3	14.3	22	142.2	11.0
23	29	275.2	79.0	30	256.8	41.3	31	95.8	34.1	32	100.0	13.0	33	116.6	37.1	34	110.3	12.9	35	124.3	38.4	36	115.7	22.1
24	43	280.4	79.4	44	264.2	44.0	45	117.9	26.5	46	108.1	8.2	47	134.3	28.9	48	129.2	6.0	49	140.0	30.1	50	130.8	6.0
25	57	285.2	82.3	58	277.4	53.5	65	123.5	20.5	66	120.8	5.3	67	152.6	27.2	68	149.8	10.0	69	161.0	27.7	70	153.4	10.5
26	83	274.3	80.0	84	261.7	39.7	85	117.5	28.2	86	114.3	4.2	87	131.4	31.4	88	125.0	5.2	89	139.9	33.2	90	129.0	5.0
27	97	277.2	81.6	98	261.9	43.3	99	127.8	24.3	100	123.2	4.5	101	156.8	28.5	102	154.7	9.2	103	154.9	27.1	104	147.5	7.4
28	111	279.6	80.0	112	264.6	37.6	113	114.0	36.0	114	110.3	11.3	115	141.7	36.8	116	133.5	12.0	117	138.7	37.8	118	132.3	13.2
29	125	266.2	77.2	126	253.6	33.4	127	138.1	26.6	128	122.8	4.5	129	156.3	28.4	130	142.9	5.8	131	156.5	28.3	132	151.5	7.6
30	143	306.4	87.3	144	290.4	69.1	151	154.2	12.8	152	146.3	9.3	153	162.4	14.8	154	152.4	10.8	155	169.1	15.3	156	163.8	12.4
31	169	306.0	80.2	170	301.2	61.9	171	166.6	11.3	172	153.9	6.6	173	184.3	15.1	174	174.6	11.0	175	190.9	16.1	176	177.0	12.1
32	183	307.5	89.3	-	-	-	184	177.7	12.7	-	-	-	185	204.1	20.5	-	-	-	186	203.8	16.8	-	-	-
33	190	282.5	78.2	-	-	-	191	143.0	8.6	-	-	-	192	163.7	13.8	-	-	-	193	172.8	14.3	-	-	-
34	1	279.3	78.7	-	-	-	2	168.3	11.3	-	-	-	3	182.8	14.5	-	-	-	4	189.6	16.1	-	-	-
35	8	302.5	80.7	-	-	-	12	180.6	14.4	-	-	-	13	174.1	13.5	-	-	-	14	182.8	15.5	-	-	-
36	21	296.5	73.6	-	-	-	22	167.4	11.2	-	-	-	23	193.3	15.2	-	-	-	24	197.8	17.9	-	-	-
37	28	299.1	81.6	-	-	-	29	193.1	13.3	-	-	-	30	209.3	20.3	-	-	-	31	211.4	19.3	-	-	-
38	35	287.8	76.4	-	-	-	36	159.4	11.2	-	-	-	37	171.3	13.3	-	-	-	38	172.7	13.0	-	-	-
39	44	285.5	77.5	-	-	-	45	179.5	13.3	-	-	-	46	182.7	16.1	-	-	-	47	193.8	16.7	-	-	-
40	53	303.6	92.8	-	-	-	54	161.7	12.4	-	-	-	55	177.8	17.4	-	-	-	56	185.5	17.1	-	-	-

Table 18. Phase I filtered and unfiltered torrefied wood data.

Event	Torrefied Wd., Column 1 (Comp. Samples)						Torrefied Wd., Column 2 (Comp. Samples)						Torrefied Wd., Column 3 (Comp. Samples)					
	Not Filtered			Filtered			Not Filtered			Filtered			Not Filtered			Filtered		
	#	Zn (μg/L)	Cu (μg/L)	#	Zn (μg/L)	Cu (μg/L)	#	Zn (μg/L)	Cu (μg/L)	#	Zn (μg/L)	Cu (μg/L)	#	Zn (μg/L)	Cu (μg/L)	#	Zn (μg/L)	Cu (μg/L)
1	-	-	-	20	209.3	23.7	-	-	-	21	220.3	34.3	-	-	-	22	201.7	34.0
2	9	240.3	29.5	10	247.4	31.8	11	317.2	42.1	12	314.9	42.2	13	342.2	50.1	14	341.4	48.8
3	23	178.2	15.4	24	162.2	13.9	25	224.9	23.8	26	233.2	23.2	27	190.3	18.4	28	209.3	16.5
4	49	218.1	19.5	50	223.2	18.8	51	216.5	21.9	52	206.0	20.4	53	184.3	18.3	54	176.9	16.4
5	63	188.2	15.1	64	193.6	14.6	65	228.5	21.8	66	212.1	20.2	67	219.7	21.3	68	214.8	20.4
6	81	164.5	14.5	82	157.6	15.2	83	273.1	34.1	84	266.1	32.9	85	175.9	21.0	86	181.0	20.4
7	95	92.6	7.0	96	79.3	5.5	97	155.4	15.5	98	133.6	13.1	99	135.7	12.8	100	137.0	12.1
8	109	98.0	6.5	110	94.8	6.2	111	106.6	7.7	112	106.8	7.1	113	118.7	8.9	114	110.5	7.8
9	135	120.1	9.1	136	118.5	8.8	137	136.0	11.4	138	123.3	9.9	139	112.5	8.8	140	101.1	7.6
10	149	132.3	12.1	150	117.1	10.4	151	108.5	8.7	152	207.3	8.7	153	116.6	9.9	154	105.3	8.6
11	9	228.2	23.1	10	218.7	21.5	11	266.8	31.2	12	253.5	30.0	13	270.4	29.0	14	273.0	28.0
12	23	180.0	17.4	24	182.7	16.4	25	198.9	20.8	26	190.3	19.6	27	193.6	18.3	28	175.8	16.7
13	37	126.3	15.5	38	131.6	9.7	39	130.3	17.1	40	116.2	10.5	41	106.3	16.5	42	104.5	7.7
14	63	111.7	21.6	64	87.2	7.0	65	119.6	21.1	66	101.9	7.7	67	132.1	24.8	68	120.4	10.0
15	77	113.7	26.4	78	125.9	4.4	79	167.5	32.5	80	158.2	15.2	81	151.6	32.0	82	127.1	12.2
16	91	93.9	13.8	92	89.4	8.6	93	110.1	16.0	94	91.6	8.0	95	99.6	15.1	96	86.3	8.0
17	109	110.6	13.7	110	102.7	10.6	111	113.4	13.4	112	102.7	10.4	113	98.1	12.3	114	86.8	8.7
18	123	93.6	5.9	124	73.3	3.4	125	145.4	11.9	126	126.7	8.3	127	119.1	7.6	128	98.4	4.9
19	149	117.8	10.0	150	114.3	7.2	151	139.2	13.1	152	131.1	8.8	153	207.6	18.0	154	187.4	14.7
20	163	118.7	10.1	164	107.4	7.5	165	137.8	14.3	166	127.5	11.4	167	121.9	9.6	168	100.9	6.2
21	9	192.5	23.9	10	173.9	22.1	11	297.8	35.8	12	291.9	35.7	13	260.0	31.6	14	236.2	29.3
22	23	176.0	17.5	24	164.9	16.8	25	182.5	18.7	26	161.0	17.2	27	116.7	10.4	28	106.5	9.5
23	37	94.7	14.0	38	88.5	9.8	39	115.1	20.2	40	102.2	12.2	41	85.3	15.5	42	74.9	11.8
24	51	101.4	21.5	52	92.8	9.2	53	118.0	23.6	54	108.5	12.2	55	101.0	19.5	56	86.8	8.5
25	77	108.7	18.9	78	98.0	8.9	79	98.0	18.7	80	83.4	6.9	81	89.0	17.6	82	80.0	7.9
26	91	127.5	16.1	92	117.8	9.5	93	163.5	24.8	94	146.2	16.0	95	170.0	25.1	96	155.6	16.8
27	105	103.8	10.2	106	93.5	5.3	107	98.2	11.3	108	73.7	4.5	109	83.3	10.2	110	70.8	3.8
28	119	85.1	11.9	120	76.5	4.8	121	106.5	14.7	122	92.7	8.9	123	85.7	14.0	124	75.6	6.6
29	133	95.2	10.7	134	88.4	4.3	135	85.1	11.3	136	74.7	4.1	137	86.6	11.7	138	77.4	4.1
30	163	117.7	5.8	164	106.3	4.9	165	117.4	6.5	166	107.5	5.8	167	103.6	4.8	168	87.5	3.8
31	177	122.6	6.6	178	111.3	5.3	179	132.2	6.3	180	110.0	5.5	181	107.0	5.0	182	87.1	4.0
32	187	133.3	7.2	-	-	-	188	129.8	7.6	-	-	-	189	121.1	5.7	-	-	-
33	194	97.7	3.5	-	-	-	195	93.7	3.9	-	-	-	196	92.6	3.4	-	-	-
34	5	119.2	5.0	-	-	-	6	128.3	6.0	-	-	-	7	99.5	3.8	-	-	-
35	18	110.9	4.6	-	-	-	19	135.2	6.0	-	-	-	20	96.4	3.3	-	-	-
36	25	129.0	5.0	-	-	-	26	137.0	5.9	-	-	-	27	108.3	3.9	-	-	-
37	32	146.7	6.1	-	-	-	33	132.7	5.6	-	-	-	34	113.8	4.1	-	-	-
38	39	129.0	5.3	-	-	-	40	152.2	7.5	-	-	-	41	141.0	7.0	-	-	-
39	48	136.3	5.3	-	-	-	49	132.6	5.4	-	-	-	50	109.8	4.0	-	-	-
40	57	103.3	3.6	-	-	-	58	125.2	4.8	-	-	-	59	111.2	3.9	-	-	-

Table 19. Phase II laboratory column data for composite samples

Phase II - Non filtered				Average Influent									Average Biochar									Average Torrefied Wood								
Day	Event	Ave. Cum Vol.		Zn			Cu			pH			Zn			Cu			pH			Zn			Cu			pH		
		Gal.	Liters	µg/L	(stdev)	(95%CI)	µg/L	(stdev)	(95%CI)	-	(stdev)	(95%CI)	µg/L	(stdev)	(95%CI)	µg/L	(stdev)	(95%CI)	-	(stdev)	(95%CI)	µg/L	(stdev)	(95%CI)	µg/L	(stdev)	(95%CI)	-	(stdev)	(95%CI)
1	1	157.8	161.6	289.4	6.404	15.91	92.9	2.713	6.74	6.07	0.037	0.091	98.23	4.705	11.69	55.45	3.173	7.881	6.353	0.041	0.102	406.5	101.1	251.3	73.97	13.88	34.48	5.2	0.12	1.078
		161.6	165.4										150.3	8.001	19.88	49.06	0.603	1.498	6.113	0.066	0.165	146.6	18.17	45.14	37.54	4.873	12.1	5.663	0.172	0.429
		165.6	169.4										176.2	4.042	10.04	50.21	2.527	6.277	6.15	0.057	0.142	148.9	25.22	62.65	37.33	9.404	23.36	5.753	0.084	0.208
		169.6	173.4	284.9	4.339	10.78	90.3	0.824	2.047	6.10	0.029	0.073	175.1	25.59	63.56	47.27	1.035	2.57	6.173	0.038	0.094	123.7	13.94	34.64	27.98	1.088	2.703	5.737	0.076	0.188
		173.6	177.4										195.8	15.18	37.7	49.46	2.794	6.941	6.127	0.021	0.051	129.7	10.07	25.02	25.81	1.662	4.129	5.763	0.033	0.082
2	2	173.8	177.6	296.1	3.428	8.515	92.9	0.293	0.728	6.23	0.106	0.264	143	10.35	25.71	44.26	1.744	4.332	6.367	0.062	0.154	168.3	2.458	22.09	45.17	9.052	22.49	5.36	0.05	0.123
		177.6	181.4										175	5.622	13.97	42.09	1.239	3.078	6.095	0.015	0.037	103.8	6.647	16.51	23.01	1.072	2.664	5.637	0.091	0.226
		181.6	185.4										189	5.419	13.46	43.24	1.061	2.636	6.133	0.025	0.062	108.9	4.965	12.33	20.04	0.799	1.984	5.73	0.067	0.166
		185.6	189.4	292.5	6.661	16.55	92.2	1.668	4.143	6.10	0.048	0.119	196.1	4.895	12.16	43.91	0.943	2.343	6.17	0.07	0.174	112	6.073	15.09	18.1	0.383	0.951	5.667	0.021	0.051
		189.6	193.4										205.1	5.245	13.03	45.82	1.295	3.218	6.14	0.067	0.166	121.9	3.218	7.993	18.75	0.522	1.297	5.78	0.028	0.07
3	3	189.8	193.6	285.3	3.592	8.923	89.2	0.458	1.137	6.20	0.083	0.207	151.8	11.84	29.4	48.01	4.528	11.25	6.373	0.031	0.077	173.6	29.46	73.19	38.01	3.093	7.684	5.46	0.091	0.226
		193.6	197.4										178.7	13.22	32.84	43.95	3.853	9.57	6.153	0.041	0.102	92.59	2.867	7.123	17.56	0.843	2.094	5.707	0.084	0.208
		197.6	201.4										192.9	15.06	37.42	45.35	2.754	6.841	6.15	0.037	0.093	105.3	2.492	22.39	16.82	1.929	17.33	5.733	0.009	0.023
		201.6	205.4	279.7	1.058	2.628	88.2	0.464	1.152	6.09	0.017	0.042	202.3	12.11	30.08	45.41	1.93	4.795	6.147	0.019	0.047	111.8	3.006	7.467	15.67	1.32	3.28	5.8	0.008	0.02
		205.6	209.4										202.5	8.556	21.25	44.95	2.365	5.875	6.137	0.021	0.051	117	4.551	11.31	15.13	1.565	3.888	5.793	0.017	0.042
4	4	205.8	209.6	283.0	1.833	4.554	89.4	0.568	1.412	6.20	0.045	0.112	173.7	6.5	16.15	39.41	1.164	2.893	6.363	0.012	0.031	127.5	10.47	26	24.27	0.783	1.944	5.617	0.04	0.1
		209.6	213.4										197.9	12.55	31.16	39.25	3.023	7.509	6.26	0.037	0.093	100.2	6.256	15.54	11.06	0.254	0.63	5.827	0.031	0.077
		213.6	217.4										206.3	8.783	21.82	41.12	1.666	4.138	6.21	0.07	0.173	111.4	6.31	15.67	11.81	0.12	0.299	5.743	0.054	0.135
		217.6	221.4	289.9	4.361	10.83	91.2	1.852	4.6	6.24	0.078	0.193	215.1	7.893	19.61	43.12	1.751	4.349	6.247	0.029	0.071	118.6	5.792	14.39	12.08	0.368	0.914	5.863	0.021	0.051
		221.6	225.4										215.3	4.722	11.73	43.63	1.135	2.819	6.257	0.062	0.155	123.9	4.813	11.96	12.33	0.79	1.961	5.887	0.029	0.071
5	5	221.8	225.6	286.4	5.44	13.51	86.6	0.972	2.414	5.33	0.042	0.105	501.4	19.8	49.2	79.29	4.724	11.73	6.097	0.037	0.091	266.8	17.9	44.47	12.1	2.117	5.258	5.613	0.017	0.042
		225.6	229.4										444.4	18.49	45.94	148.3	2.935	7.292	5.837	0.031	0.077	282.4	15.8	39.24	19.72	1.93	4.794	5.563	0.012	0.031
		229.6	233.4										388.9	14.6	36.27	134.6	3.69	9.165	5.733	0.012	0.031	282.7	8.975	22.3	25.48	1.973	4.902	5.523	0.029	0.071
		233.6	237.4	287.5	6.562	16.3	87.8	2.734	6.792	5.33	0.041	0.102	365.8	10.35	25.71	119.2	1.678	4.168	5.65	0.016	0.041	277.5	12.9	32.05	28.5	2.114	5.252	5.48	0.016	0.041
		237.6	241.4										346	10.39	25.8	107	1.879	4.667	5.64	0.016	0.041	272.4	12.25	30.43	30.52	2.051	5.095	5.483	0.025	0.062
16	6	237.8	241.6	293.3	5.157	12.81	83.1	0.388	0.964	6.24	0.05	0.123	128.7	7.431	18.46	14.38	1.075	2.67	6.26	0.043	0.107	267.4	29.59	73.51	33.85	8.83	21.93	5.323	0.017	0.042
		241.6	245.4										187.6	10.8	26.82	20.68	4.079	10.13	6.05	0.042	0.105	160.4	7.916	19.66	13.58	1.469	3.65	5.697	0.074	0.183
		245.6	249.4										203.3	5.05	12.54	24.66	1.907	4.737	6.14	0.014	0.035	162.1	4.939	12.27	15.12	0.807	2.004	5.82	0.014	0.035
		249.6	253.4	301.8	4.631	11.5	86.1	0.321	0.798	6.18	0.025	0.062	221.3	1.862	4.626	28.42	2.744	6.818	6.187	0.012	0.031	157.3	3.626	9.008	13.61	0.496	1.231	5.85	0.05	0.123
		253.6	257.4										227.2	10.72	26.62	29.68	2.518	6.255	6.153	0.052	0.13	156.8	2.377	5.904	13.25	0.665	1.652	5.843	0.039	0.096
17	7	253.8	257.6	300.5	2.52	6.261	87.4	2.014	5.003	6.27	0.012	0.031	167.4	5.639	14.01	32.24	1.407	3.496	6.32	0.016	0.041	155.1	13.74	34.14	17.43	2.325	5.775	5.55	0.022	0.054
		257.6	261.4										202.9	1.223	10.99	23.34	16.51	41.02	6.117	0.026	0.065	124.4	5.476	13.6	13.4	1.195	2.968	5.78	0.043	0.107
		261.6	265.4										217	12.37	30.72	39.83	2.279	5.662	6.173	0.041	0.102	135	1.512	3.756	14.2	0.651	1.618	5.88	0.008	0.02
		265.6	269.4	297.7	0.534	1.327	86.2	0.491	1.221	6.27	0.031	0.077	232.8	7.428	18.45	45.52	2.908	7.224	6.237	0.04	0.1	148	4.484	11.14	16.66	1.674	4.159	5.88	0.041	0.101
		269.6	273.4										228.4	7.711	19.16	42.56	0.722	1.794	6.197	0.019	0.047	151.2	9.07	22.53	16.2	2.03	5.042	5.917	0.045	0.112
18	8	269.8	273.6	289.4	4.604	11.44	86.4	1.587	3.942	6.23	0.031	0.077	186.3	6.362	15.8	38.05	1.073	2.666	6.257	0.037	0.091	130.2	17.84	44.31	20.43	2.699	6.704	5.68	0.051	0.127
		273.6	277.4										201.3	9.351	23.23	39.05	0.659	1.637	6.14	0.022	0.054	114.2	8.905	22.12	12.52	1.169	2.904	5.767	0.088	0.219
		277.6	281.4										218.9	8.293	20.6	43.66	1.63	4.049	6.15	0.029	0.073	132.7	7.116	17.68	13.35	1.419	3.525	5.867	0.017	0.042
		281.6	285.4	277.8	5.971	14.83	82.7	2.271	5.642	6.15	0.021	0.051	224.7	5.975	14.84	45.16	0.728	1.808	6.2	0.045	0.113	135.6	8.974	22.29	13.17	1.021	2.536	5.87	0.057	0.142
		285.6	289.4										225.3	4.405	10.94	45.2	0.658	1.634	6.193	0.017	0.042	145	8.477	21.06	14.03	1.324	3.288	5.923	0.073	0.182
19	9	285.8	289.6	283.3	4.654	11.56	84.3	1.046	2.599	6.16	0.021	0.051	201.6	8.442	20.97	20.35	1.647	4.092	6.21	0.028	0.07	124.3	13.61	33.8	5.102	1.225	3.044	5.78	0.016	0.041
		289.6	293.4										224.4	1.15	2.858	30.2	2.782	6.91	6.153	0.026	0.065	130	10.45	25.96	6.138	1.189	2.954	5.86	0.049	0.122
		293.6	297.4										229.3	2.249	5.587	35.77	1.615	4.011	6.173	0.042	0.104	142.7	10.12	25.14	8.275	1.697	4.217	5.91	0.022	0.054
		297.6	301.4	287.8	7.241	17.99	84.9	2.354	5.848	6.18	0.028	0.07	231	1.213	3.014	37.92	0.92	2.286	6.223	0.033	0.082	149.9	7.827	19.44	9.666	1.444	3.588	5.963	0.046	0.115
		301.6	305.4										236	3.897	9.68	42.86	3.145	7.812	6.167	0.012	0.031	156.9	9.695	24.08	10.88	1.319	3.276	5.99	0.024	0.061
20	10	301.8	305.6	289.5	8.057	20.02	83.3	1.977	4.91	6.25	0.041	0.102	179.8	35.44	88.05	32.12	11.5	28.57	6.267	0.005	0.012	156.5	30.64	76.11	23.9	11.02	27.39	5.77	0.075	0.186
		305.6	309.4										222.4	3.9	9.689	41.26	1.199	2.979	6.133	0.019	0.047	129.8	4.687	11.64	10.31	0.792	1.968	5.853	0.052	0.129
		309.6	313.4										228.2	4.61	11.45	44.16	1.29	3.205	6.13	0.028	0.07	144.1	6.272	15.58	11.27	0.875	2.174	5.863	0.053	0.132
		313.6	317.4	293.0	6.68	16.59	85.5	2.484	6.172	6.15	0.024	0.061	234.5	6.222	15.46	45.91	0.755	1.876	6.143	0.012	0.031	149.6	8.278	20.56	12.02	1.156	2.871	5.933	0.024	0.059
		317.6	321.4										229.7	2.292	5.695	45.84	0.34	0.844	6.167	0.012	0.031	157	3.099	7.698	12.84	0.534	1.327	5.947	0.037	0.091
21	11	317.8	321.6	294.2	7.754	19.26	83.6	2.127	5.284	6.22	0.024	0.061	217.4	7.789	19.35	23.05	0.834	2.072	6.257	0.04	0.1	137	1.882	4.676	4.576	0.454	1.127	5.7	0.008	0.02
		325.6	329.4										230.1	3.65	9.066	36.1	2.648	6.577	6.11	0.045	0.113	155.4	6.849	17.01	7.875	0.585	1.454	5.83	0.051	0.127
		333.6	337.4										237.3	5.987	14.87	42.46	2.187	5.433	6.173	0.058	0.144	166.3	3.728	9.262	10.47	0.666	1.655	5.87	0.059	0.146
22	12	333.8	337.6	286.4	0.813	2.021	83.6	0.297	0.739	6.24	0.005	0.012	212.5	8.022	19.93	41.75	3.035	7.539	6.277	0.024	0.059	139.1	4.893	12.16	11.82	0.987	2.453	5.687	0.09	0.223
		341.6	345.4										228.4	4.7	11.68	47.6	0.857	2.129	6.127	0.074	0.184	144.2	2.529	6.283	10.93	1.325	3.292	5.737	0.119	0.296
		349.6	353.4										231.4	6.657	16.54	48.69	2.877	7.147	6.177	0.069	0.173	155.9	10.15	25.2	13.11	2.234	5.548	5.917	0.039	0.096
27	13	349.8	353.6	280.2	0.4	0.993	81.9	0.491	1.221	6.08	0.06	0.15	212.9	5.931	14.73	25.95	1.858	4.616	6.217	0.058	0.144	227.7	17.26	42.87	15.55	2.312	5.743	5.71	0.008	0.02
		357.6	361.4										239.8	5.367	13.33	43	4.222	10.49	6.103	0.025	0.062	162.6	2.127	5.284	8.585	1.134	2.817	5.9	0.016	0.041
		365.6	369.4										242.7	3.982	9.893	48.98	2.109	5.24	6.34	0.21	0.522	173.1	3.728	9.261	11.77	1.256	3.121	5.94	0.073	0.18
28	14	365.8	369.6	284.9	4.302	10.69	81.3	0.939	2.332	6.25	0.042	0.105	202.4	3.003	7.46	38.22	1.634	4.06	6.257	0.009	0.023	153.3	2.66	6.609	13.41	0.847	2.104	5.85	0.107	0.265
		373.6	377.4										227.4	5.365	13.33	47.62	1.804	4.482	6.187	0.047	0.117	157.5	5.607	13.93	11.94	2.757	6.849	5.983	0.074	0.184
		381.6	385.4										237.7	4.626	11.49	51.79	2.153	5.348	6.157	0.038	0.094	172.4	0.748	1.859	14.34	1.744	4.331	6.023	0.033	0.082
30	15	381.8	385.6	281.8	7.032	17.47	82.7	1.296	3.219	6.28	0.094	0.234	212.6	6.997	17.38	30.66	1.591	3.953	6.177	0.197	0.489	169.3	4.218	10.48	6.384	0.625	1.551	5.633	0.218	0.541
		389.6	393.4										232.1	4.984	12.38	45.72	3.511	8.723	6.16	0.014	0.035	170.2	0.866	2.15	10.12	1.007	2.501	5.963	0.026	0.065
		397.6	401.4										239.4	8.06	20.02	50.29	2.876	7.144	6.313	0.07	0.175	174.4	11.63	28.88	12.05	2.746	6.821	6	0.092	0.229
34	16	397.8	401.6	269.0	5.21	12.94	82.1	1.351	3.355	6.44	0.15	0.372	211.7	1.865	4.632	33.59	1.74	4.322	6.267	0.025	0.062	213.2	30.68	76.2	17.81	2.429	6.033	5.787	0.059	0.147
		405.6	409.4										231.7	1.721	4.274	46.3	2.29	5.69	6.16	0.029	0.073	158.6	8.686	21.58	10.3	2.036	5.058	5.96	0.054	0.133
		413.6	417.4										234.8	0.664	1.651	50.85	1.647	4.091	6.21	0.156	0.387	174.6	7.026	17.45	13.7	2.309	5.735	5.993	0.079	0.197
35	17	413.8	417.6	273.5	1.657	4.117	81.2	0.381	0.947	6.18	0.049	0.122	219.9	2.019	5.014	36.42	1.033	2.566	6.177	0.017	0.042	165	14.5	36.01	10.79	1.244	3.089	5.947	0.049	0.122
		421.6	425.4										232.5	4.232	10.51	48.19	1.117	2.774	6.11	0.022	0.054	167	5.532	13.74	9.847	2.041	5.07	5.943	0.012	0.031
		429.6	433.4										235.5	5.999	14.9	52.76	3.549	8.817	6.14	0.036	0.088	178.6	10.56	26.23	12.59	1.476	3.667	5.963	0.017	0.042

Table 20. High flow and deicer flush column data.

Tests After Phase II - Non filtered					Average Influent									Average Biochar									Average Torrefied Wood								
Type	Day	Event	Ave. Cum Vol.		Zn			Cu			pH			Zn			Cu			pH			Zn			Cu			pH		
			Gal.	Liters	µg/L	(stdev)	(95%CI)	µg/L	(stdev)	(95%CI)	-	(stdev)	(95%CI)	µg/L	(stdev)	(95%CI)	µg/L	(stdev)	(95%CI)	-	(stdev)	(95%CI)	µg/L	(stdev)	(95%CI)	µg/L	(stdev)	(95%CI)	-	(stdev)	(95%CI)
2X Flow	1	1	429.8	433.6	279.1	5.133	12.75	85.1	2.282	5.668	5.99	0.048	0.119	223.1	7.998	19.87	38.66	1.43	3.553	6.153	0.05	0.124	216.3	19.5	48.44	15.02	2.494	6.195	5.877	0.045	0.112
			437.6	441.4										235.9	5.999	14.9	52.46	1.834	4.555	6.023	0.037	0.091	183.1	5.502	13.67	16.52	2.372	5.893	5.877	0.159	0.396
			445.6	449.4										237.1	2.221	5.516	54.58	1.293	3.212	5.94	0.033	0.081	182.7	8.855	22	18.38	2.386	5.926	5.643	0.236	0.587
	2	2	445.8	449.6	274.9	6.867	17.06	83.8	1.333	3.312	6.16	0.029	0.073	215.6	7.196	17.88	36.07	1.257	3.122	6.24	0.029	0.073	264.1	33.03	82.06	21.48	3.181	7.901	5.8	0.073	0.18
			449.6	453.4																											
			453.6	457.4																											
			457.6	461.4										240.4	4.623	11.49	50.66	1.824	4.532	6.147	0.054	0.135	178.7	6.679	16.59	15.11	1.496	3.717	6.01	0.016	0.041
			461.6	465.4																											
	3		465.6	469.4	282.8	11.64	28.91	85.5	3.69	9.167	6.21	0.175	0.434																		
			469.6	473.4										222.3	9.209	22.88	54.16	2.554	6.344	6.21	0.099	0.247	172.1	9.247	22.97	20.26	2.479	6.157	5.86	0.227	0.564
			473.6	477.4																											
			477.6	481.4										237.2	6.641	16.5	57.06	0.967	2.403	6.15	0.094	0.234	179.7	6.605	16.41	21.08	2.017	5.011	5.97	0.091	0.226
4X Flow	1	1	487.6	491.4	288.9	13.57	33.71	83.2	1.326	3.293	6.15	0.092	0.228	212.2	2.429	6.035	50.79	0.735	1.826	5.99	0.071	0.177	179.1	6.338	15.74	28.24	3.826	9.504	5.72	0.071	0.177
			503.6	507.4	286.3	13.16	32.68	78.9	1.5	3.727	6.24	0.2	0.498	217	7.013	17.42	33.61	2.12	5.265	5.75	0.202	0.502	175.6	2.361	5.864	14.06	0.624	1.551	5.51	0.219	0.545
Salt Flush	1	1	509.8	513.6	2.751	0.249	0.618	14.69	0.1	0.249	6.087	0.031	0.077	1936	164.9	409.6	526.3	26.8	66.57	6.187	0.109	0.27	4873	312	776	395	8.3	20.6	4.47	0.14	0.36
			513.6	517.4										434.1	54.06	134.3	178	12.98	32.25	6.157	0.18	0.447	1048	87.04	216.2	92.7	6.272	15.6	5.11	0.62	1.55
			517.6	521.4										269	13.68	33.99	130.1	6.161	15.31	6.16	0.177	0.439	591	26.05	64.72	63.37	3.162	7.85	5.32	0.58	1.45
			521.6	525.4	3.2	0.453	1.126	14.74	0.576	1.43	6.13	0.091	0.226	212.1	17.24	42.84	110.8	7.489	18.6	6.173	0.218	0.542	467.3	46.12	114.6	54.88	4.206	10.4	5.45	0.59	1.47
			525.6	529.4										167	8.984	22.32	93.49	4.831	12	6.173	0.169	0.419	347	7.388	18.35	48.63	2.385	5.92	5.55	0.57	1.42
Post Salt Flush	2	1	525.8	529.6	259.8	5.251	13.04	73.06	2.883	7.161	6.24	0.036	0.088	354.5	73.28	182	19.2	2.141	5.319	6.05	0.083	0.206	3915	208.3	517.5	40.81	2.269	5.64	5.02	0.11	0.27
			529.6	533.4										143.6	14.47	35.96	7.417	3.625	9.006	5.983	0.026	0.065	118	15.21	37.78	4.597	3.634	9.03	5.91	0.13	0.33
			533.6	537.4										150.3	3.649	9.065	11.93	0.683	1.698	6.01	0.036	0.088	71.65	2.435	6.05	1.855	0.21	0.52	5.89	0.1	0.24
			537.6	541.4	258.7	3.293	8.181	72.49	0.584	1.451	6.167	0.049	0.122	154.4	11.99	29.78	13.31	1.947	4.838	6.05	0.008	0.02	75.2	5.543	13.77	2.188	0.271	0.67	5.95	0.07	0.17
			541.6	545.4										133.6	30.88	76.72	10.11	5.051	12.55	6.013	0.052	0.13	105.6	49.74	123.6	7.226	7.617	18.9	6.07	0.03	0.07

Table 21. Acid extraction data table for biochar (BC) and torrefied wood (TW). Crossed out values were considered outliers and omitted from calculations. “Rock” refers to the covering layer of pea gravel.

Column	Level	Mass (g)	MC	UnFiltered					Filtered				
				#	Zn (µg/L)	Cu (µg/L)	Zn (mg/g)	Cu (mg/g)	#	Zn (µg/L)	Cu (µg/L)	Zn (mg/g)	Cu (mg/g)
BC 1	Rock	15.1524	0.0	232	12564	4167	0.083	0.028	256	13205	4384	0.087	0.029
	Top	1.0056	0.45	233	2742	1848	0.496	0.334	257	2710	1843	0.490	0.333
	Mid	1.0071	0.45	234	2617	1232	0.472	0.222	258	2608	1235	0.471	0.223
	Btm	1.0104	0.45	235	2346	1060	0.422	0.191	259	2359	1070	0.425	0.192
BC 2	Rock	15.0311	0.0	236	13169	4648	0.088	0.031	260	13289	4655	0.088	0.031
	Top	1.0055	0.45	237	3149	2069	0.569	0.374	261	3148	2087	0.569	0.377
	Mid	1.0023	0.45	238	2076	1073	0.377	0.195	262	2228	1158	0.404	0.210
	Btm	1.0083	0.45	239	3261	1146	0.588	0.207	263	3336	1171	0.601	0.211
BC 3	Rock	15.1188	0.0	240	14528	5520	0.096	0.037	264	14970	5631	0.099	0.037
	Top	1.0000	0.45	241	2364	1836	0.430	0.334	265	2380	1844	0.433	0.335
	Mid	1.0011	0.45	242	2518	1403	0.457	0.255	266	2546	1420	0.462	0.258
	Btm	1.007	0.45	243	12654	940	~~2.285~~	0.170	267	13001	923	~~2.347~~	0.167
TW 1	Rock	15.0005	0.0	244	13394	4811	0.089	0.032	268	13388	4807	0.089	0.032
	Top	1.0116	0.45	245	4257	5083	0.765	0.914	269	4292	5181	0.771	0.931
	Mid	1.0177	0.45	246	3177	2505	0.568	0.448	270	3422	2698	0.611	0.482
	Btm	1.0084	0.45	247	2749	1249	0.496	0.225	271	3101	1406	0.559	0.254
TW 2	Rock	15.0273	0.0	248	14422	5134	0.096	0.034	272	14439	5208	0.096	0.035
	Top	0.9986	0.45	249	4077	4882	0.742	0.889	273	4087	4886	0.744	0.890
	Mid	1.0118	0.45	250	3603	2732	0.647	0.491	274	3826	2939	0.688	0.528
	Btm	1.0035	0.45	251	2883	1292	0.522	0.234	275	2884	1311	0.523	0.238
TW 3	Rock	15.0066	0.0	252	11170	4214	0.074	0.028	276	11375	4239	0.076	0.028
	Top	1.0037	0.45	253	50599	3930	~~9.166~~	0.712	277	54703	4262	~~9.909~~	0.772
	Mid	0.9994	0.45	254	3366	2674	0.612	0.487	278	3434	2751	0.625	0.501
	Btm	0.9986	0.45	255	3051	1421	0.555	0.259	279	3055	1445	0.556	0.263

Table 22. Acid extraction calculations table to determine total mass of zinc and copper contained on the media layers (top, mid, btm) and covering pea gravel (rock).

Level	Density	Vol.	Mass	Biochar - Unfiltered									
				Zn					Cu				
	g/L	L	g	mg/g	stdev	95 CI	mg	±	mg/g	stdev	96 CI	mg	±
Rock	1581.1	0.362	572	0.089	0.005	0.014	51	7.8	0.032	0.004	0.009	18	5.3
Top	98	0.483	47	0.498	0.057	0.142	24	6.7	0.347	0.019	0.047	16	2.2
Mid	98	0.483	47	0.435	0.042	0.104	21	4.9	0.224	0.025	0.061	11	2.9
Btm	98	0.483	47	1.098	0.842	2.091	52	98.9	0.189	0.015	0.038	9	1.8

Level	Density	Vol.	Mass	Torrefied Wood - Unfiltered									
				Zn					Cu				
	g/L	L	g	mg/g	stdev	95 CI	mg	±	mg/g	stdev	97 CI	mg	±
Rock	1581.1	0.362	572	0.087	0.009	0.022	50	12.8	0.031	0.003	0.006	18	3.6
Top	172	0.483	83	0.754	0.011	0.102	63	8.5	0.838	0.090	0.223	70	18.5
Mid	172	0.483	83	0.609	0.033	0.081	51	6.7	0.475	0.019	0.048	39	4.0
Btm	172	0.483	83	0.524	0.024	0.061	44	5.0	0.239	0.014	0.035	20	2.9

Level	Density	Vol.	Mass	Biochar - Filtered									
				Zn					Cu				
	g/L	L	g	mg/g	stdev	95 CI	mg	±	mg/g	stdev	96 CI	mg	±
Rock	1581.1	0.362	572	0.092	0.005	0.01	52	8	0.032	0.004	0.01	19	5.0
Top	98	0.483	47	0.497	0.056	0.503	24	23.8	0.349	0.020	0.051	16	2.4
Mid	98	0.483	47	0.446	0.030	0.074	21	3.5	0.230	0.020	0.050	11	2.4
Btm	98	0.483	47	0.513	0.088	0.795	24	37.6	0.190	0.018	0.045	9	2.1
					Total mg Zn =		121	72		Total mg Cu =		55	11.9

Level	Density	Vol.	Mass	Torrefied Wood - Filtered									
				Zn					Cu				
	g/L	L	g	mg/g	stdev	95 CI	mg	±	mg/g	stdev	97 CI	mg	±
Rock	1581.1	0.362	572	0.087	0.008	0.02	50	12.0	0.032	0.003	0.01	18	3.7
Top	172	0.483	83	0.758	0.014	0.122	63	10.2	0.864	0.067	0.168	72	13.9
Mid	172	0.483	83	0.641	0.033	0.083	53	6.9	0.504	0.019	0.047	42	3.9
Btm	172	0.483	83	0.546	0.017	0.041	45	3.4	0.251	0.011	0.026	21	2.2
					Total mg Zn =		211	32.4		Total mg Cu =		153	23.7

Table 23. Total suspended solids data table for laboratory tests.

Event	Gal.	Liters	Torrified Wood 1				Torrified Wood 2				Torrified Wood 3				Biochar 1				Biochar 2				Biochar 3			
			Tare Wt. (g)	Dry Wt. (g)	Solids (g)	mg/L	Tare Wt. (g)	Dry Wt. (g)	Solids (g)	mg/L	Tare Wt. (g)	Dry Wt. (g)	Solids (g)	mg/L	Tare Wt. (g)	Dry Wt. (g)	Solids (g)	mg/L	Tare Wt. (g)	Dry Wt. (g)	Solids (g)	mg/L	Tare Wt. (g)	Dry Wt. (g)	Solids (g)	mg/L
FF	4	15	-	-	-	-	-	-	-	-	-	-	-	-	1.4	1.425	0.025	12.35	1.418	1.451	0.033	16.6	1.416	1.447	0.031	15.45
1	8	30	1.394	1.396	0.001	0.75	1.401	1.402	0.001	0.75	1.393	1.395	0.002	1.1	1.406	1.408	0.002	0.75	1.403	1.406	0.002	1.25	1.414	1.416	0.003	1.4
2	12	45	1.406	1.409	0.002	1.2	1.402	1.404	0.002	1	1.404	1.406	0.002	0.9	1.416	1.419	0.002	1.25	1.405	1.409	0.005	2.4	1.404	1.406	0.002	0.8
3	16	60	1.401	1.402	0.001	0.6	1.399	1.401	0.002	0.8	1.401	1.402	0.002	0.8	1.407	1.41	0.003	1.45	1.409	1.411	0.002	1.05	1.4	1.401	0.001	0.6
4	20	76	1.396	1.397	5E-04	0.25	1.398	1.398	4E-04	0.2	1.396	1.41	0.014	7.15	1.398	1.399	0.002	0.85	1.398	1.399	9E-04	0.45	1.405	1.406	1E-03	0.5
5	24	91	1.395	1.396	0.001	0.65	1.399	1.4	0.001	0.55	1.394	1.395	0.002	0.85	1.391	1.392	8E-04	0.4	1.417	1.418	9E-04	0.45	1.425	1.425	5E-04	0.25
6	28	106	1.398	1.4	0.002	1.05	1.403	1.405	0.002	1.1	1.415	1.417	0.002	0.95	-	-	-	-	-	-	-	-	-	-	-	-
7	32	121	1.385	1.386	0.001	0.5	1.411	1.411	6E-04	0.3	1.415	1.416	9E-04	0.45	1.402	1.409	0.007	3.65	1.406	1.409	0.003	1.65	1.413	1.418	0.005	2.65
8	36	136	1.396	1.397	9E-04	0.45	1.409	1.409	8E-04	0.4	1.408	1.409	3E-04	0.15	1.405	1.402	-0	-1.25	1.388	1.388	3E-04	0.15	1.404	1.406	0.001	0.65
9	40	151	1.407	1.408	6E-04	0.3	1.396	1.396	1E-04	0.05	1.399	1.399	1E-04	0.05	1.414	1.415	6E-04	0.3	1.404	1.406	0.001	0.6	1.405	1.405	8E-04	0.4
10	44	166	1.394	1.395	9E-04	0.45	1.402	1.403	0.001	0.55	1.396	1.397	0.001	0.65	1.413	1.414	9E-04	0.45	1.42	1.421	0.001	0.6	1.401	1.402	9E-04	0.45
11	48	181	1.396	1.396	2E-04	0.1	1.379	1.381	0.002	0.85	1.396	1.398	0.001	0.65	1.411	1.411	6E-04	0.3	1.405	1.406	9E-04	0.45	1.397	1.398	7E-04	0.35
12	52	197	1.408	1.408	0	0	1.399	1.399	5E-04	0.25	1.406	1.406	1E-04	0.05	1.407	1.407	5E-04	0.25	1.402	1.402	1E-04	0.05	1.403	1.403	5E-04	0.25
13	56	212	1.395	1.395	0	0	1.395	1.395	0	0	1.413	1.413	0	0	1.401	1.402	8E-04	0.4	1.404	1.405	6E-04	0.3	1.394	1.395	7E-04	0.35
14	60	227	1.404	1.404	2E-04	0.1	1.391	1.391	1E-04	0.05	1.399	1.399	2E-04	0.1	1.407	1.408	8E-04	0.4	1.399	1.4	0.001	0.55	1.395	1.396	9E-04	0.45
15	64	242	-	-	-	-	-	-	-	-	-	-	-	-	1.401	1.402	7E-04	0.35	1.404	1.404	1E-04	0.05	1.408	1.408	3E-04	0.15
16	68	257	-	-	-	-	-	-	-	-	-	-	-	-	1.381	1.381	5E-04	0.25	1.401	1.402	5E-04	0.25	1.394	1.395	3E-04	0.15
17	72	272	-	-	-	-	-	-	-	-	-	-	-	-	1.404	1.404	4E-04	0.2	1.398	1.399	6E-04	0.3	1.408	1.408	2E-04	0.1
18	76	287	-	-	-	-	-	-	-	-	-	-	-	-	1.408	1.408	6E-04	0.3	1.408	1.408	4E-04	0.2	1.394	1.395	6E-04	0.3
19	80	302	-	-	-	-	-	-	-	-	-	-	-	-	1.407	1.408	5E-04	0.25	1.403	1.403	3E-04	0.15	1.401	1.401	2E-04	0.1
20	84	318	1.403	1.403	0	0	1.397	1.397	3E-04	0.15	1.406	1.407	6E-04	0.3	1.396	1.396	0	0	1.398	1.399	3E-04	0.15	1.41	1.41	1E-04	0.05
21	88	333	1.381	1.381	3E-04	0.15	1.399	1.401	0.001	0.7	1.409	1.409	6E-04	0.3	-	-	-	-	-	-	-	-	-	-	-	-
40	164	620	1.403	1.404	8E-04	0.4	-	-	-	-	-	-	-	-	1.399	1.4	6E-04	0.3	-	-	-	-	-	-	-	-

Table 24. Laboratory TSS calculations table and associated graph.

Gal.	Liters	Torrefied Wood			Biochar		
		Ave. (mg/L)	Std. Dev. (mg/L)	95% CI (mg/L)	Ave. (mg/L)	Std. Dev. (mg/L)	95% CI (mg/L)
4	15	-	-	-	14.80	2.20	5.46
8	30	0.87	0.20	0.50	1.13	0.34	0.85
12	45	1.03	0.15	0.38	1.48	0.83	2.05
16	61	0.73	0.12	0.29	1.03	0.43	1.06
20	76	2.53	4.00	9.93	0.60	0.22	0.54
24	91	0.68	0.15	0.38	0.37	0.10	0.26
28	106	1.03	0.08	0.19	-	-	-
32	121	0.42	0.10	0.26	2.65	1.00	2.48
36	136	0.33	0.16	0.40	-0.15	0.98	2.45
40	151	0.13	0.14	0.36	0.43	0.15	0.38
44	167	0.55	0.10	0.25	0.50	0.09	0.22
48	182	0.53	0.39	0.96	0.37	0.08	0.19
52	197	0.10	0.13	0.33	0.18	0.12	0.29
56	212	0.00	0.00	0.00	0.35	0.05	0.12
60	227	0.08	0.03	0.07	0.47	0.08	0.19
64	242	-	-	-	0.18	0.15	0.38
68	257	-	-	-	0.22	0.06	0.14
72	273	-	-	-	0.20	0.10	0.25
76	288	-	-	-	0.27	0.06	0.14
80	303	-	-	-	0.17	0.08	0.19
84	318	0.15	0.15	0.37	0.07	0.08	0.19
88	333	0.38	0.28	0.71	-	-	-
164	621	0.40	-	-	0.30	-	-

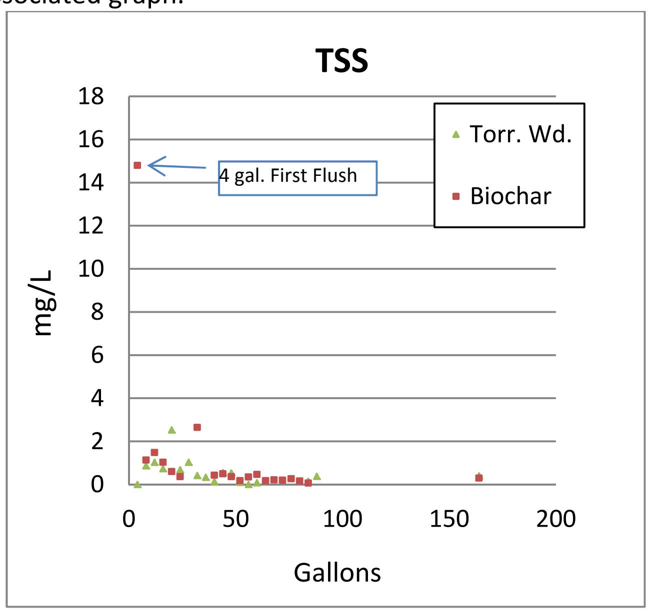


Table 25.1. Raw wood and pea gravel laboratory column tests.

Gal.	L	Average Influent									Ave. Raw Wood									Ave. Pea Gravel								
		Zn			Cu			pH			Zn			Cu			pH			Zn			Cu			pH		
		(µg/L)	stdev	95 CI	(µg/L)	stdev	95 CI	-	stdev	95 CI	(µg/L)	stdev	95 CI	(µg/L)	stdev	95 CI	-	stdev	95 CI	(µg/L)	stdev	95 CI	(µg/L)	stdev	95 CI	-	stdev	95 CI
0.2	0.757	286	6.49	16	86	1.82	4.53	5.94	0.02	0.04	50.6	7.7	19.0	15.5	1.76	4.37	4.24	0.02	0.06	99.5	11.1	27.5	32.3	3.67	9.12	6.47	0.05	0.12
8	30.28	286			86			5.94			10.0	2.0	4.9	3.23	0.32	0.80	4.55	0.03	0.07	52.0	10.3	25.5	11.5	1.84	4.58	6.32	0.04	0.11
16	60.57	286			86			5.94			9.9	1.0	2.5	2.96	0.06	0.15	4.75	0.02	0.04	57.6	8.4	20.9	11.8	1.92	4.76	6.29	0.03	0.08
16.2	61.32	280	1.41	3.51	84	0.04	0.09	6.00	0.05	0.12	7.4	1.6	3.9	4.97	0.81	2.02	4.28	0.05	0.13	46.6	7.7	19.1	15.1	2.33	5.79	6.39	0.03	0.08
24	90.85	280			84			6.00			2.7	0.9	2.3	2.69	1.06	2.63	4.79	0.03	0.07	54.8	2.5	6.2	13.2	0.87	2.17	6.24	0.07	0.17
32	121.1	280			84			6.00			4.9	2.4	5.8	2.92	0.61	1.51	4.95	0.08	0.20	63.7	0.8	2.0	14.4	0.51	1.27	6.25	0.04	0.09
32.2	121.9	290	0.92	2.28	85	1.03	2.56	5.99	0.12	0.29	5.3	1.0	2.4	9.84	1.00	2.48	4.55	0.02	0.05	47.4	9.8	24.3	12.0	2.47	6.14	6.26	0.22	0.55
40	151.4	290			85			5.99			3.3	0.8	2.1	4.66	0.17	0.43	4.94	0.01	0.02	60.8	3.3	8.2	12.9	1.33	3.30	6.05	0.19	0.47
48	181.7	290			85			5.99			2.3	0.2	0.6	3.86	0.15	0.38	5.04	0.04	0.11	66.8	4.3	10.7	13.4	0.61	1.50	6.01	0.19	0.47
48.2	182.5	292	5.59	14	80	2.48	6.16	6.05	0.05	0.14	7.2	2.0	4.9	3.66	0.09	0.21	4.63	0.07	0.17	45.6	4.7	11.6	47.1	4.24	10.5	6.28	0.03	0.08
56	212	292			80			6.05			2.6	0.9	2.1	0.33	0.10	0.25	5.04	0.06	0.14	53.1	2.0	5.1	42.5	0.46	1.13	6.22	0.01	0.03
64	242.3	292			80			6.05			3.6	1.4	3.5	0.44	0.18	0.46	5.18	0.11	0.27	67.2	8.9	22.0	41.8	4.81	11.9	6.13	0.02	0.04
64.2	243	278	8.80	22	81	2.13	5.29	6.04	0.04	0.11	4.6	0.8	2.1	2.20	0.25	0.61	4.79	0.05	0.11	52.4	8.8	22.0	21.7	1.24	3.08	6.43	0.11	0.27
72	272.5	278			81			6.04			4.8	1.5	3.8	0.80	0.16	0.39	5.18	0.06	0.15	61.8	1.3	3.1	13.2	0.59	1.47	6.27	0.08	0.19
80	302.8	278			81			6.04			4.8	1.2	2.9	0.81	0.15	0.38	5.26	0.04	0.10	67.8	3.7	9.2	14.6	0.61	1.52	6.35	0.03	0.07
80.2	303.6	276	4.44	11	78	1.07	2.67	6.04	0.05	0.11	4.8	2.3	5.7	0.94	0.42	1.05	5.28	0.19	0.48	43.8	1.6	4.0	21.1	2.03	5.04	6.26	0.11	0.27
88	333.1	276			78			6.04			7.7	3.0	7.3	0.66	0.19	0.46	5.36	0.09	0.23	59.5	3.2	8.0	21.2	0.44	1.10	6.21	0.10	0.24
96	363.4	276			78			6.04			10.1	3.9	9.7	0.77	0.25	0.61	5.29	0.02	0.05	65.4	2.3	5.7	21.4	1.00	2.47	6.20	0.08	0.21
96.2	364.2	283	8.88	22	83	2.17	5.38	6.05	0.03	0.07	3.2	2.1	5.1	21.3	1.05	2.60	5.15	0.07	0.17	56.7	13.3	33.1	61.8	11.4	28.3	6.35	0.05	0.12
104	393.7	283			83			6.05			4.5	1.1	2.8	6.57	0.20	0.51	5.39	0.07	0.17	60.2	3.3	8.2	44.6	2.03	5.03	6.20	0.16	0.40
112	424	283			83			6.05			12.1	2.3	5.7	5.10	1.85	4.60	5.37	0.04	0.10	64.4	2.3	5.7	42.0	4.30	10.7	6.20	0.14	0.36
112.2	424.7	281	0.67	1.67	80	0.03	0.08	6.13	0.05	0.12	10.1	3.5	8.7	8.72	2.73	6.78	5.08	0.12	0.30	51.8	9.4	23.2	42.5	4.05	10.1	6.39	0.05	0.12
120	454.2	281			80			6.13			7.4	2.2	5.4	0.79	0.15	0.36	5.35	0.07	0.18	53.9	1.9	4.7	30.4	2.33	5.78	6.35	0.10	0.25
128	484.5	281			80			6.13			9.8	4.2	10.5	1.28	0.91	2.27	5.47	0.12	0.31	63.1	3.7	9.2	30.1	2.39	5.95	6.32	0.12	0.30
128.2	485.3	287	3.41	8.48	83	1.70	4.21	6.09	0.05	0.12	10.0	4.2	10.4	7.79	1.71	4.24	5.10	0.06	0.15	53.2	2.8	6.8	19.6	1.14	2.82	6.33	0.05	0.13
136	514.8	287			83			6.09			11.6	0.7	1.8	2.53	0.15	0.37	5.25	0.10	0.24	65.3	2.2	5.6	16.5	0.99	2.47	6.23	0.07	0.18
144	545.1	287			83			6.09			18.4	4.4	10.9	2.69	0.41	1.02	5.33	0.04	0.10	74.3	1.1	2.8	18.1	0.43	1.07	6.23	0.06	0.14
144.2	545.9	261	11	28	82	3.25	8.07	6.08	0.04	0.09	13.1	5.3	13.2	19.7	3.59	8.92	5.12	0.07	0.18	57.1	10.8	26.8	18.9	2.73	6.79	6.43	0.03	0.09
152.0	575.4	261			82			6.08			13.4	3.2	8.0	5.01	0.40	0.99	5.35	0.05	0.13	68.2	7.9	19.7	14.7	1.94	4.83	6.22	0.03	0.06
160.0	605.7	261			82			6.08			18.3	3.5	8.8	5.30	0.81	2.00	5.38	0.08	0.21	63.4	3.0	7.5	12.5	0.81	2.02	6.17	0.05	0.11
160.2	606.4	269	6.35	16	80	1.56	3.86	6.30	0.09	0.21	19.6	7.8	19.3	17.0	0.89	2.20	5.16	0.13	0.34	50.5	6.0	14.8	12.2	2.21	5.50	6.26	0.07	0.16
168.0	635.9	269			80			6.30			17.3	4.6	11.4	3.83	0.41	1.03	5.39	0.04	0.09	72.8	0.9	2.3	15.4	0.29	0.72	6.33	0.03	0.07
176.0	666.2	269			80			6.30			20.7	4.9	12.1	3.59	0.49	1.21	5.56	0.21	0.52	68.7	4.8	11.9	13.7	0.92	2.29	6.31	0.08	0.19
176.2	667	268	1.51	3.76	78	0.53	1.32	6.20	0.04	0.09	16.0	3.3	8.3	7.68	1.97	4.90	5.20	0.13	0.31	53.3	5.0	12.4	12.6	1.28	3.19	6.44	0.05	0.13
184.0	696.5	268			78						19.7	5.6	13.8	1.31	0.27	0.67	5.38	0.03	0.08	67.0	3.2	8.1	13.5	0.78	1.94	6.15	0.09	0.22
192.0	726.8	268			78						22.3	4.6	11.5	1.53	0.26	0.64	5.45	0.04	0.11	74.9	0.8	2.0	15.0	0.30	0.74	6.16	0.03	0.07
192.2	727.6	288	9.00	22	80	0.49	1.22	6.25	0.26	0.65	22.9	4.0	36.3	4.27	1.06	2.62	5.47	0.10	0.24	55.0	3.8	9.3	13.2	0.80	2.00	6.32	0.03	0.08
200.0	757.1	288			80						14.3	7.0	17.3	0.69	0.16	0.41	5.44	0.13	0.32	65.7	3.0	7.4	13.3	1.01	2.52	6.31	0.11	0.26
208.0	787.4	288			80						12.5	2.1	5.3	0.43	0.02	0.05	5.50	0.02	0.05	75.7	5.4	13.4	14.8	1.29	3.21	6.30	0.09	0.23
208.2	788.1	273	6.41	16	78	1.47	3.64	6.32	0.20	0.50	17.4	4.9	12.2	1.62	0.44	1.09	5.34	0.04	0.11	64.1	5.1	12.6	17.4	3.01	7.47	6.41	0.06	0.14
216.0	817.6	273			78						29.0	4.2	10.5	1.10	0.16	0.39	5.46	0.05	0.12	76.6	6.4	15.9	14.9	1.10	2.73	6.29	0.11	0.27
224.0	847.9	273			78						29.2	5.5	13.8	0.92	0.14	0.36	5.45	0.04	0.11	84.9	4.4	11.0	17.0	0.79	1.95	6.27	0.09	0.22
224.2	848.7	270	1.97	4.89	77	0.68	1.70	6.16	0.03	0.07	31.5	2.5	6.3	1.96	1.13	2.81	5.19	0.06	0.16	57.6	6.1	15.2	12.5	1.66	4.12	6.32	0.04	0.10
232.0	878.2	270			77						14.2	5.3	13.1	0.50	0.18	0.44	5.44	0.09	0.22	72.8	3.4	8.4	13.1	1.11	2.76	6.20	0.10	0.24
240.0	908.5	270			77						15.8	3.8	9.4	0.55	0.14	0.36	5.46	0.02	0.05	76.2	5.2	13.0	13.2	1.32	3.27	6.33	0.07	0.17
240.2	909.3	282	2.32	5.77	73	0.30	0.74	6.24	0.11	0.28	31.3	7.7	19.0	3.06	0.60	1.50	5.30	0.11	0.28	56.5	7.5	18.5	39.7	5.25	13.0	6.32	0.04	0.10
248.0	938.8	282			73						30.7	4.3	10.6	1.14	0.25	0.63	5.43	0.08	0.21	71.5	2.5	6.2	39.0	3.12	7.76	6.29	0.12	0.30
256.0	969.1	282			73						34.1	4.4	11.0	1.02	0.07	0.17	5.48	0.04	0.09	73.2	2.9	7.2	37.3	3.14	7.81	6.26	0.03	0.06
256.2	969.8	274	5.36	13	72	0.84	2.10	6.23	0.14	0.35	33.9	7.0	17.5	1.86	0.48	1.20	5.32	0.09	0.22	64.8	2.4	6.1	53.4	2.44	6.06	6.49	0.13	0.32
264.0	999.3	274			72						31.7	5.9	14.6	0.97	0.18	0.44	5.55	0.07	0.17	77.6	5.5	13.6	46.3	3.95	9.82	6.20	0.08	0.19
272.0	1030	274			72						45.7	5.0	12.5	1.47	0.21	0.51	5.53	0.13	0.32	79.0	9.1	22.5	43.2	4.98	12.4	6.23	0.05	0.13

Table 25.2. Raw wood and pea gravel laboratory column tests - continued.

Gal.	L	Average Influent									Ave. Raw Wood									Ave. Pea Gravel								
		Zn			Cu			pH			Zn			Cu			pH			Zn			Cu			pH		
		(µg/L)	stdev	95 CI	(µg/L)	stdev	95 CI	-	stdev	95 CI	(µg/L)	stdev	95 CI	(µg/L)	stdev	95 CI	-	stdev	95 CI	(µg/L)	stdev	95 CI	(µg/L)	stdev	95 CI	-	stdev	95 CI
272.2	1030	275	5.48	14	66	1.20	2.99	6.24	0.03	0.07	38.0	7.7	19.1	1.65	0.55	1.36	5.34	0.14	0.35	55.8	7.8	19.4	14.5	1.78	4.42	6.31	0.03	0.08
280.0	1060	275			66						39.4	6.1	15.1	1.17	0.18	0.45	5.46	0.06	0.15	69.0	3.1	7.7	13.4	0.70	1.75	6.20	0.14	0.34
288.0	1090	275			66						40.4	12.7	31.6	1.05	0.33	0.81	5.41	0.14	0.35	74.3	5.4	13.5	14.1	1.29	3.21	6.16	0.13	0.33
288.2	1091	277	6.79	17	80	3.06	7.60	6.20	0.05	0.14	37.2	8.2	20.5	20.9	1.24	3.09	5.33	0.09	0.21	54.8	12.1	30.1	31.6	6.96	17.3	6.36	0.05	0.12
296.0	1120	277			80						38.2	9.3	23.1	5.85	1.06	2.64	5.45	0.02	0.05	66.9	10.6	26.2	27.8	5.46	13.6	6.20	0.03	0.06
304.0	1151	277			80						34.6	11.3	28.1	4.54	0.94	2.33	5.52	0.04	0.11	69.2	3.4	8.5	25.6	1.74	4.32	6.24	0.02	0.05
304.2	1152	282	3.77	9.37	80	0.54	1.33	6.17	0.07	0.18	52.2	5.3	13.1	26.3	1.48	3.69	5.36	0.09	0.23	59.3	0.5	1.2	13.7	0.53	1.32	6.30	0.03	0.08
312.0	1181	282			80						41.8	16.0	39.7	7.65	1.33	3.31	5.58	0.04	0.09	68.1	6.1	15.0	14.2	1.16	2.88	6.23	0.03	0.07
320.0	1211	282			80						54.1	17.4	43.2	6.84	1.72	4.28	5.65	0.08	0.21	81.8	4.9	12.2	18.3	0.76	1.88	6.30	0.04	0.10
320.2	1212	250	3.76	9.34	63	0.26	0.64	6.39	0.16	0.39	45.7	4.8	11.9	5.94	1.23	3.07	5.46	0.05	0.13	65.0	8.5	21.1	12.0	5.77	14.3	6.33	0.05	0.13
328.0	1242	250			63						39.9	8.5	21.1	1.18	0.15	0.38	5.48	0.07	0.18	75.7	7.4	18.5	17.2	2.60	6.45	6.15	0.01	0.03
336.0	1272	250			63						51.4	0.2	0.5	1.44	0.18	0.46	5.48	0.19	0.46	76.7	8.7	21.6	16.9	2.73	6.78	6.19	0.03	0.08
336.2	1273	243	1.54	3.83	80	0.19	0.48	6.13	0.09	0.21	40.4	10.5	26.1	12.8	2.19	5.44	5.50	0.02	0.05	66.5	7.5	18.7	17.8	4.25	10.5	6.19	0.08	0.19
344.0	1302	243			80						42.7	15.4	38.2	2.91	1.05	2.60	5.70	0.07	0.16	74.2	8.7	21.6	14.9	1.77	4.39	6.17	0.04	0.10
352.0	1332	243			80						49.6	13.2	32.7	2.53	0.66	1.64	5.63	0.09	0.22	76.1	6.0	14.9	14.8	1.38	3.42	6.23	0.14	0.34
352.2	1333	244	1.30	3.24	76	2.41	5.99	6.19	0.05	0.12	53.4	5.8	14.5	5.45	1.63	4.04	5.52	0.03	0.08	63.9	9.0	22.3	16.4	2.53	6.28	6.16	0.02	0.04
360.0	1363	244			76						57.0	12.4	30.9	1.34	0.29	0.71	5.66	0.06	0.14	79.8	6.6	16.3	17.1	2.08	5.16	6.06	0.06	0.15
368.0	1393	244			76						71.0	10.9	27.1	1.62	0.33	0.82	5.63	0.03	0.07	81.1	1.7	4.2	17.1	0.72	1.80	6.23	0.06	0.14
368.2	1394	250	7.42	18	72	1.00	2.49	6.13	0.07	0.17	64.8	11.6	28.9	4.18	0.59	5.26	5.53	0.05	0.12	61.7	1.9	4.7	12.0	1.05	2.60	6.20	0.03	0.07
376.0	1423	250			72						67.1	9.4	23.3	1.70	0.53	1.31	5.68	0.04	0.10	80.1	3.0	7.5	16.1	1.01	2.50	6.11	0.05	0.12
384.0	1454	250			72						68.2	12.2	30.4	1.65	0.43	1.06	5.68	0.07	0.17	80.2	5.2	13.0	15.9	2.45	6.08	6.22	0.04	0.10
384.2	1454	250	4.09	10	66	1.05	2.60	6.22	0.08	0.20	92.5	15.3	37.9	8.16	4.62	11.5	5.50	0.17	0.41	70.6	11.1	27.5	57.1	4.74	11.8	6.28	0.13	0.31
392.0	1484	250			66						74.3	8.2	20.3	1.73	0.43	1.06	5.63	0.05	0.11	76.7	4.3	10.6	55.9	3.74	9.29	6.40	0.05	0.12
400.0	1514	250			66						74.3	11.3	28.0	1.62	0.37	0.92	5.66	0.04	0.09	75.0	4.7	11.6	50.4	0.20	0.49	6.42	0.11	0.28
400.2	1515	259	11	26	77	0.73	1.81	6.23	0.11	0.28	96.3	4.2	10.4	3.35	0.60	1.48	5.55	0.15	0.36	58.4	4.3	10.6	28.8	8.93	22.2	6.30	0.09	0.21
408.0	1544	259			77						85.8	5.0	12.5	1.93	0.58	1.45	5.67	0.06	0.14	81.2	6.0	14.8	30.7	7.02	17.4	6.45	0.03	0.07
416.0	1575	259			77						62.1	7.7	19.2	1.18	0.11	0.27	5.76	0.12	0.31	78.2	4.1	10.2	27.3	6.17	15.3	6.47	0.06	0.14
416.2	1575	251	1.46	3.62	68	3.57	8.87	6.11	0.03	0.08	81.3	3.9	9.6	1.66	0.23	0.56	5.60	0.04	0.11	71.6	3.2	7.9	33.3	1.08	2.67	6.41	0.03	0.08
424.0	1605	251			68						84.3	1.7	4.3	1.62	0.17	0.43	5.71	0.02	0.05	83.3	3.1	7.8	34.6	0.74	1.84	6.39	0.09	0.21
432.0	1635	251			68						88.8	5.8	14.5	1.52	0.09	0.21	5.77	0.03	0.08	92.0	4.7	11.6	36.3	1.96	4.86	6.38	0.07	0.16

Table 26. Raw wood and pea gravel composite samples.

Composite Samples																				
#	gal.	L	RW 1			RW 2			RW 3			Rock 1			Rock 2			Rock 3		
			#	Zn	Cu	#	Zn	Cu	#	Zn	Cu	#	Zn	Cu	#	Zn	Cu	#	Zn	Cu
1	8	30.28	22	22.04	7.047	24	18.97	7.438	26	24.52	7.7	110	64.13	15.36	112	54.14	12.55	114	56.53	12.73
2	24	90.85	49	7.596	6.767	51	5.043	4.871	53	7.307	2.757	137	53.72	13.25	139	48.52	12.08	141	49.95	12.25
3	40	151.4	76	5.815	7.505	78	3.895	6.12	80	6.375	6.123	164	57.6	12.38	166	55.8	11.46	168	55.49	11.58
4	56	212	109	7.345	2.163	111	5.032	1.594	113	5.708	1.45	191	64.04	45.6	193	50.26	40.39	195	56.5	40.9
5	72	272.5	136	4.905	1.667	138	3.649	2.911	140	6.264	1.425	218	60.23	13.19	220	64	11.25	222	62.17	12.77
6	88	333.1	163	6.648	0.929	165	6.049	0.651	167	15.28	1.801	245	60.85	21.27	247	61.42	21.08	249	62.16	21.01
7	104	393.7	190	10.85	9.529	192	8.057	9.217	194	8.781	8.398	23	61.36	51.07	25	52.41	42.11	27	57.13	39.06
8	120	454.2	217	13.93	1.979	219	12.56	1.587	221	14.63	2.494	50	58.6	31.12	52	54.52	28.64	54	58.78	26.25
9	136	514.8	244	14.21	3.955	246	13.2	3.608	248	19	3.919	77	64.64	15.14	79	63.21	15.08	81	63.14	16.22
10	152	575.4	22	18.9	10.13	24	15.16	6.054	26	19.94	7.137	104	69.17	14.62	106	55.51	11.31	108	63.5	13.49
11	168	635.9	49	21.85	5.82	51	28.73	5.917	53	15.94	4.947	131	71.74	13.84	133	61.74	12.5	135	63.61	13.36
12	184	696.5	76	17.98	2.668	78	32.07	2.484	80	19.49	2.457	158	67.82	13.5	160	59.24	11.68	162	63.86	12.58
13	200	757.1	103	21.83	1.962	105	16.19	1.534	107	16.41	1.404	185	71.08	12.96	187	63.3	11.78	189	66.98	12.71
14	216	817.6	130	35.89	1.369	132	24.78	1.413	134	24.26	1.031	212	81.97	16.87	214	76.3	14.71	216	71.05	13.85
15	232	878.2	157	27.4	1.472	159	32.52	1.57	161	20.51	0.873	239	69.21	12.23	241	65.71	11.08	243	77.21	12.77
16	248	938.8	184	30.34	1.821	186	26.56	1.432	188	30.19	1.461	266	68.61	40.57	268	67.17	35.67	270	68.76	35.15
17	264	999.3	211	40.3	2.004	213	34.7	1.441	215	30.04	1.223	293	84.04	49.07	295	76.51	46.24	297	68.58	39.54
18	280	1060	238	34.24	1.534	240	41.23	1.463	242	36.53	1.139	23	70.44	13.02	25	64.23	12.07	27	67.45	12.91
19	296	1120	265	40.37	7.978	267	38.54	7.494	269	35.26	5.654	50	79.63	33.89	52	58.61	24.64	54	59.7	22.36
20	312	1181	292	47.33	10.97	294	46.09	10.46	296	40.56	8.154	77	76.34	16.74	79	69.26	14.28	81	68.56	15.08
21	328	1242	22	41.13	2.189	24	39.67	2.047	26	41.45	2.125	104	85.17	18.68	106	75.48	16.99	108	65.02	13.36
22	344	1302	49	56.79	6.2	51	44	3.545	53	43.48	3.343	131	75.83	14.59	133	73.5	14.6	135	67.77	12.89
23	360	1363	76	56.37	2.368	78	57.19	2.401	80	54.67	2.087	158	84.92	18.26	160	73.4	14.85	162	75.64	15.96
24	376	1423	103	68.8	2.681	105	63.91	2.481	107	56.16	1.873	185	75.82	14.3	187	74.34	14.93	189	80.26	16.91
25	392	1484	130	105.1	3.146	132	74.21	2.63	134	64.02	2.08	202	70.04	53.06	203	73.14	47.66	204	256.7	92.97
26	408	1544	157	87.49	2.779	159	87	2.26	161	75.09	1.428	217	68.68	36.74	218	274.7	88.48	219	75.91	34.84
27	424	1605	184	70.56	2.158	186	81.25	1.848	188	79.29	1.877	229	84.17	35.7	230	76.56	33.64	231	87.01	33.87

6.4: Field Data

Stormwater runoff quality can vary widely depending on land use which is why reported values often reference the primary land use associated with the runoff. Averaged influent data collected at the Bainbridge Island ferry terminal is displayed in Table 23 next to typical transportation land use values collected in Oregon and Washington State.

Table 27. Average Bainbridge Island stormwater values compared to typical OR and WA transportation land use stormwater values.

Constituent		Bainbridge Island, WA Field Site	Pacific Northwest Typical Values
TSS	(mg/L)	159	169
Dissolved Cu	(µg/L)	10	8
Dissolved Zn	(µg/L)	74	48
Total Cu	(µg/L)	34	35
Total Zn	(µg/L)	189	236

Sources: [19,57]

Most values reported in Table 23 are reasonably comparable with the exception of soluble Zn that is 54% higher than the regional norm. It's likely that this value (74 µg/L) is higher than the actual yearly average because the Aug. 14th event was collected following an atypical 5 month dry spell. The Aug. 14th soluble zinc concentration was 2x higher than the soluble Zn concentrations collected during the following two events. More data should be collected at the site to achieve a more representative mean.

Table 28.1. Flow and rainfall data applicable to the three collected rain events.

Collected Event 1 : Aug 14th 2015					
Level Data		Flow		Rain	
Day / Time	Level (in.)	(gpm)	lpm/cm^2	Rain (in.)	cm/hr
8/14/2015 12:55	0.118	0	0	0	0
8/14/2015 12:56	0.118	0	0	0	0
8/14/2015 12:57	0.118	0	0	0	0
8/14/2015 12:58	0.118	0	0	0	0
8/14/2015 12:59	0.118	0	0	0	0
8/14/2015 13:00	0.118	0	0	0	0
8/14/2015 13:01	0.118	0	0	0	0
8/14/2015 13:02	0.118	0	0	0	0
8/14/2015 13:03	0.118	0	0	0	0
8/14/2015 13:04	0.118	0	0	0	0
8/14/2015 13:05	0.118	0	0	0	0.1524
8/14/2015 13:06	0.118	0	0	0	0.1524
8/14/2015 13:07	0.118	0	0	0	0.1524
8/14/2015 13:08	0.118	0	0	0	0.1524
8/14/2015 13:09	0.118	0	0	0	0.3048
8/14/2015 13:10	0.118	0	0	0.01	0.3048
8/14/2015 13:11	0.118	0	0	0	0.3048
8/14/2015 13:12	0.118	0	0	0	0.3048
8/14/2015 13:13	0.118	0	0	0	0.4572
8/14/2015 13:14	0.118	0	0	0.01	0.4572
8/14/2015 13:15	0.118	0	0	0	0.3048
8/14/2015 13:16	0.118	0	0	0	0.3048
8/14/2015 13:17	0.118	0	0	0	0.3048
8/14/2015 13:18	0.118	0	0	0.01	0.4572
8/14/2015 13:19	0.118	0	0	0	0.3048
8/14/2015 13:20	0.118	0	0	0	0.3048
8/14/2015 13:21	0.118	0	0	0	0.3048
8/14/2015 13:22	0.118	0	0	0	0.4572
8/14/2015 13:23	0.118	0	0	0.01	0.3048
8/14/2015 13:24	0.118	0	0	0	0.3048
8/14/2015 13:25	0.118	0	0	0	0.3048
8/14/2015 13:26	0.079	0	0	0	0.3048
8/14/2015 13:27	0.059	0	0	0.01	0.3048
8/14/2015 13:28	0.059	0	0	0	0.3048
8/14/2015 13:29	0.059	0	0	0	0.3048
8/14/2015 13:30	6.154	3.837202	0.008848	0	0.3048
8/14/2015 13:31	8.709	21.45988	0.049481	0	0.3048
8/14/2015 13:32	8.831	22.65861	0.052245	0	0.1524
8/14/2015 13:33	8.831	22.65861	0.052245	0.01	0.3048
8/14/2015 13:34	8.787	22.22253	0.051239	0	0.3048
8/14/2015 13:35	8.87	23.04868	0.053144	0	0.3048
8/14/2015 13:36	8.85	22.84823	0.052682	0	0.3048
8/14/2015 13:37	8.89	23.25001	0.053608	0	0.3048
8/14/2015 13:38	8.89	23.25001	0.053608	0.01	0.3048
8/14/2015 13:39	8.909	23.44208	0.054051	0	0.3048
8/14/2015 13:40	8.969	24.05381	0.055462	0	0.3048
8/14/2015 13:41	9.067	25.06989	0.057805	0	0.3048
8/14/2015 13:42	9.11	25.52236	0.058848	0	0.3048
8/14/2015 13:43	9.228	26.7848	0.061759	0.01	0.1524
8/14/2015 13:44	9.287	27.42744	0.06324	0	0.3048
8/14/2015 13:45	9.37	28.34439	0.065355	0	0.3048
8/14/2015 13:46	9.429	29.00536	0.066879	0	0.3048
8/14/2015 13:47	9.469	29.45781	0.067922	0	0.3048
8/14/2015 13:48	9.528	30.13156	0.069475	0	0.1524
8/14/2015 13:49	9.567	30.5811	0.070512	0.01	0.3048
8/14/2015 13:50	9.587	30.81292	0.071046	0	0.3048
8/14/2015 13:51	9.606	31.03397	0.071556	0	0.3048
8/14/2015 13:52	9.63	31.31431	0.072203	0	0.3048
8/14/2015 13:53	9.669	31.77255	0.073259	0	0.4572
8/14/2015 13:54	9.689	32.00884	0.073804	0.01	0.3048
8/14/2015 13:55	9.709	32.246	0.074351	0	0.3048
8/14/2015 13:56	9.709	32.246	0.074351	0	0.3048
8/14/2015 13:57	9.728	32.47212	0.074872	0	0.4572
8/14/2015 13:58	9.748	32.71099	0.075423	0.01	0.4572
8/14/2015 13:59	9.728	32.47212	0.074872	0	0.3048
8/14/2015 14:00	9.748	32.71099	0.075423	0	0.3048
8/14/2015 14:01	9.748	32.71099	0.075423	0	0.4572
8/14/2015 14:02	9.748	32.71099	0.075423	0.01	0.4572
8/14/2015 14:03	9.748	32.71099	0.075423	0	0.3048
8/14/2015 14:04	9.768	32.95073	0.075976	0	0.4572
8/14/2015 14:05	9.768	32.95073	0.075976	0	0.6096
8/14/2015 14:06	9.748	32.71099	0.075423	0.01	0.6096
8/14/2015 14:07	9.787	33.1793	0.076503	0	0.4572
8/14/2015 14:08	9.768	32.95073	0.075976	0	0.6096
8/14/2015 14:09	9.768	32.95073	0.075976	0.01	0.762
8/14/2015 14:10	9.787	33.1793	0.076503	0.01	0.762

Collected Event 2 : Aug 29th 2015					
Level Data		Flow		Rain	
Day / Time	Level (in.)	(gpm)	lpm/cm^2	Rain (in.)	cm/hr
8/29/15 7:30	2.118	0	0	0	0
8/29/15 7:31	2.118	0	0	0	0
8/29/15 7:32	2.118	0	0	0	0
8/29/15 7:33	2.118	0	0	0	0
8/29/15 7:34	2.118	0	0	0	0
8/29/15 7:35	2.118	0	0	0	0
8/29/15 7:36	2.118	0	0	0	0
8/29/15 7:37	2.118	0	0	0	0
8/29/15 7:38	2.138	0	0	0	0
8/29/15 7:39	2.118	0	0	0	0
8/29/15 7:40	2.118	0	0	0	0
8/29/15 7:41	2.118	0	0	0	0.1524
8/29/15 7:42	2.094	0	0	0	0.1524
8/29/15 7:43	2.118	0	0	0	0.3048
8/29/15 7:44	2.118	0	0	0	0.4572
8/29/15 7:45	2.118	0	0	0	0.4572
8/29/15 7:46	2.118	0	0	0.01	0.6096
8/29/15 7:47	2.094	0	0	0	0.6096
8/29/15 7:48	2.118	0	0	0.01	0.762
8/29/15 7:49	2.118	0	0	0.01	0.762
8/29/15 7:50	2.118	0	0	0	0.9144
8/29/15 7:51	2.118	0	0	0.01	0.9144
8/29/15 7:52	2.138	0	0	0	0.9144
8/29/15 7:53	3.516	0	0	0.01	0.9144
8/29/15 7:54	5.311	1.156229	0.002666	0	0.762
8/29/15 7:55	5.512	1.654306	0.003814	0.01	0.9144
8/29/15 7:56	5.374	1.302833	0.003004	0.01	0.762
8/29/15 7:57	5.193	0.905002	0.002087	0	0.762
8/29/15 7:58	5.075	0.684238	0.001578	0.01	0.762
8/29/15 7:59	4.953	0.48802	0.001125	0	0.762
8/29/15 8:00	4.894	0.404809	0.000933	0.01	0.762
8/29/15 8:01	4.815	0.305316	0.000704	0	0.6096
8/29/15 8:02	4.772	0.256901	0.000592	0	0.762
8/29/15 8:03	4.693	0.178494	0.000412	0.01	0.6096
8/29/15 8:04	4.673	0.160811	0.000371	0	0.762
8/29/15 8:05	4.614	0.113742	0.000262	0.01	0.6096
8/29/15 8:06	4.614	0.113742	0.000262	0	0.6096
8/29/15 8:07	4.555	0.074289	0.000171	0.01	0.762
8/29/15 8:08	4.555	0.074289	0.000171	0	0.6096
8/29/15 8:09	4.516	0.052391	0.000121	0.01	0.6096
8/29/15 8:10	4.535	0.062644	0.000144	0	0.6096
8/29/15 8:11	4.492	0.040569	9.35E-05	0	0.6096
8/29/15 8:12	4.516	0.052391	0.000121	0.01	0.4572
8/29/15 8:13	4.492	0.040569	9.35E-05	0	0.4572
8/29/15 8:14	4.492	0.040569	9.35E-05	0	0.4572
8/29/15 8:15	4.492	0.040569	9.35E-05	0.01	0.4572
8/29/15 8:16	4.492	0.040569	9.35E-05	0	0.4572
8/29/15 8:17	4.492	0.040569	9.35E-05	0	0.4572
8/29/15 8:18	4.472	0.03168	7.3E-05	0	0.4572
8/29/15 8:19	4.472	0.03168	7.3E-05	0.01	0.4572
8/29/15 8:20	4.472	0.03168	7.3E-05	0	0.3048
8/29/15 8:21	4.472	0.03168	7.3E-05	0	0.4572
8/29/15 8:22	4.492	0.040569	9.35E-05	0.01	0.4572
8/29/15 8:23	4.516	0.052391	0.000121	0	0.4572
8/29/15 8:24	4.516	0.052391	0.000121	0	0.3048
8/29/15 8:25	4.516	0.052391	0.000121	0	0.4572
8/29/15 8:26	4.555	0.074289	0.000171	0.01	0.4572
8/29/15 8:27	4.535	0.062644	0.000144	0	0.3048
8/29/15 8:28	4.555	0.074289	0.000171	0	0.3048
8/29/15 8:29	4.516	0.052391	0.000121	0	0.3048
8/29/15 8:30	4.535	0.062644	0.000144	0.01	0.4572
8/29/15 8:31	4.492	0.040569	9.35E-05	0	0.3048
8/29/15 8:32	4.516	0.052391	0.000121	0	0.3048
8/29/15 8:33	4.492	0.040569	9.35E-05	0	0.4572
8/29/15 8:34	4.492	0.040569	9.35E-05	0	0.4572
8/29/15 8:35	4.492	0.040569	9.35E-05	0.01	0.3048
8/29/15 8:36	4.492	0.040569	9.35E-05	0	0.3048
8/29/15 8:37	4.492	0.040569	9.35E-05	0	0.3048
8/29/15 8:38	4.516	0.052391	0.000121	0.01	0.4572
8/29/15 8:39	4.492	0.040569	9.35E-05	0	0.4572
8/29/15 8:40	4.472	0.03168	7.3E-05	0	0.3048
8/29/15 8:41	4.472	0.03168	7.3E-05	0	0.3048
8/29/15 8:42	4.472	0.03168	7.3E-05	0	0.3048
8/29/15 8:43	4.472	0.03168	7.3E-05	0.01	0.1524
8/29/15 8:44	4.472	0.03168	7.3E-05	0	0.1524
8/29/15 8:45	4.472	0.03168	7.3E-05	0	0.3048

Collected Event 3 : Oct. 10th 2015					
Level Data		Flow		Rain	
Day / Time	Level (in.)	(gpm)	lpm/cm^2	Rain (in.)	cm/hr
10/10/15 9:30	2.256	0	0	0	0
10/10/15 9:31	2.256	0	0	0	0
10/10/15 9:32	2.256	0	0	0	0
10/10/15 9:33	2.256	0	0	0	0
10/10/15 9:34	2.256	0	0	0	0
10/10/15 9:35	2.256	0	0	0	0
10/10/15 9:36	2.256	0	0	0	0
10/10/15 9:37	2.256	0	0	0	0
10/10/15 9:38	2.256	0	0	0	0
10/10/15 9:39	2.256	0	0	0	0
10/10/15 9:40	2.256	0	0	0	0
10/10/15 9:41	2.256	0	0	0	0
10/10/15 9:42	2.256	0	0	0	0
10/10/15 9:43	2.256	0	0	0	0
10/10/15 9:44	2.256	0	0	0	0
10/10/15 9:45	2.256	0	0	0	0
10/10/15 9:46	2.256	0	0	0	0
10/10/15 9:47	2.256	0	0	0	0
10/10/15 9:48	2.256	0	0	0	0
10/10/15 9:49	2.256	0	0	0	0
10/10/15 9:50	2.256	0	0	0	0
10/10/15 9:51	2.256	0	0	0	0
10/10/15 9:52	2.256	0	0	0	0.01524
10/10/15 9:53	2.256	0	0	0	0.03048
10/10/15 9:54	2.256	0	0	0	0.04572
10/10/15 9:55	2.256	0	0	0	0.06096
10/10/15 9:56	2.256	0	0	0	0.0762
10/10/15 9:57	2.256	0	0	0.001	0.0762
10/10/15 9:58	2.256	0	0	0.001	0.0762
10/10/15 9:59	2.236	0	0	0.001	0.09144
10/10/15 10:00	2.236	0	0	0.001	0.10668
10/10/15 10:01	2.417	0	0	0.001	0.10668
10/10/15 10:02	6.453	5.161623	0.011901	0	0.10668
10/10/15 10:03	6.551	5.638273	0.013	0	0.10668
10/10/15 10:04	5.492	1.600787	0.003691	0.001	0.10668
10/10/15 10:05	5.075	0.684238	0.001578	0.001	0.10668
10/10/15 10:06	5.075	0.684238	0.001578	0	0.09144
10/10/15 10:07	4.874	0.37833	0.000872	0.001	0.10668
10/10/15 10:08	4.854	0.352726	0.000813	0.001	0.12192
10/10/15 10:09	4.535	0.062644	0.000144	0.001	0.12192
10/10/15 10:10	4.516	0.052391	0.000121	0.001	0.12192
10/10/15 10:11	4.634	0.128844	0.000297	0	0.12192
10/10/15 10:12	4.575	0.08681	0.0002	0.001	0.10668
10/10/15 10:13	4.173	0	0	0.001	0.10668
10/10/15 10:14	4.453	0.024046	5.54E-05	0.001	0.09144
10/10/15 10:15	4.394	0.005375	1.24E-05	0.001	0.0762
10/10/15 10:16	4.315	-0.0077	-1.8E-05	0	0.0762
10/10/15 10:17	4.173	0	0	0	0.06096
10/10/15 10:18	4.354	-0.00295	-6.8E-06	0.001	0.06096
10/10/15 10:19	4.295	-0.00884	-2E-05	0	0.04572
10/10/15 10:20	4.315	-0.0077	-1.8E-05	0	0.03048
10/10/15 10:21	4.276	-0.00912	-2.1E-05	0	0.03048
10/10/15 10:22	4.256	-0.00856	-2E-05	0	0.04572
10/10/15 10:23	4.232	-0.00673	-1.6E-05	0.001	0.03048
10/10/15 10:24	4.213	-0.00439	-1E-05	0	0.04572
10/10/15 10:25	4.193	-0.00107	-2.5E-06	0	0.04572
10/10/15 10:26	4.173	0	0	0	0.04572
10/10/15 10:27	4.154	0	0	0.001	0.04572
10/10/15 10:28	4.114	0	0	0	0.03048
10/10/15 10:29	4.114	0	0	0.001	0.03048
10/10/15 10:30	4.075	0	0	0	0.03048
10/10/15 10:31	4.055	0	0	0	0.03048
10/10/15 10:32	4.055	0	0	0	0.01524
10/10/15 10:33	4.035	0	0	0	0.01524
10/10/15 10:34	3.996	0	0	0	0
10/10/15 10:35	3.972	0	0	0	0
10/10/15 10:36	3.953	0	0	0	0
10/10/15 10:37	3.933	0	0	0	0
10/10/15 10:38	3.933	0	0	0	0
10/10/15 10:39	3.913	0	0	0	0
10/10/15 10:40	3.894	0	0	0	0
10/10/15 10:41	3.874	0	0	0	0
10/10/15 10:42	3.854	0	0	0	0
10/10/15 10:43	3.835	0	0	0	0
10/10/15 10:44	3.815	0	0	0	0
10/10/15 10:45	3.795	0	0	0	0

Table 28.2. Flow and rainfall data applicable to the three collected rain events – continued.

Collected Event 1 : Aug 14th 2015					
Level Data		Flow		Rain	
Day / Time	Level (in.)	(gpm)	lpm/cm^2	Rain (in.)	cm/hr
8/14/2015 14:11	9.807	33.42075	0.077059	0	0.762
8/14/2015 14:12	9.787	33.1793	0.076503	0	0.762
8/14/2015 14:13	9.787	33.1793	0.076503	0.01	0.9144
8/14/2015 14:14	9.728	32.47212	0.074872	0.01	0.762
8/14/2015 14:15	9.65	31.54889	0.072743	0	0.9144
8/14/2015 14:16	9.508	29.90231	0.068947	0.01	0.9144
8/14/2015 14:17	9.287	27.42744	0.06324	0	1.0668
8/14/2015 14:18	9.067	25.06989	0.057805	0.01	0.9144
8/14/2015 14:19	8.85	22.84823	0.052682	0	1.0668
8/14/2015 14:20	8.61	20.51107	0.047293	0.02	1.0668
8/14/2015 14:21	8.429	18.83182	0.043421	0	0.9144
8/14/2015 14:22	8.268	17.39835	0.040116	0.01	1.0668
8/14/2015 14:23	8.169	16.54505	0.038149	0	0.9144
8/14/2015 14:24	8.091	15.88786	0.036633	0.02	1.0668
8/14/2015 14:25	7.988	15.04043	0.034679	0	0.762
8/14/2015 14:26	7.929	14.56546	0.033584	0	0.762
8/14/2015 14:27	7.87	14.09811	0.032507	0.01	0.762
8/14/2015 14:28	7.811	13.63838	0.031447	0	0.762
8/14/2015 14:29	7.752	13.18626	0.030404	0.01	0.6096
8/14/2015 14:30	7.709	12.86154	0.029655	0	0.762
8/14/2015 14:31	7.65	12.42259	0.028643	0	0.9144
8/14/2015 14:32	7.61	12.12932	0.027967	0.01	0.9144
8/14/2015 14:33	7.571	11.84676	0.027316	0	0.9144
8/14/2015 14:34	7.531	11.56041	0.026655	0.01	0.9144
8/14/2015 14:35	7.492	11.28459	0.026019	0.01	1.0668
8/14/2015 14:36	7.409	10.70866	0.024691	0.01	1.0668
8/14/2015 14:37	7.37	10.44325	0.024079	0.01	1.0668
8/14/2015 14:38	7.35	10.30843	0.023769	0	1.0668
8/14/2015 14:39	7.331	10.18116	0.023475	0.01	1.0668
8/14/2015 14:40	7.252	9.660472	0.022275	0.01	1.0668
8/14/2015 14:41	7.331	10.18116	0.023475	0	0.9144
8/14/2015 14:42	7.272	9.791002	0.022575	0.01	0.9144
8/14/2015 14:43	7.169	9.128124	0.021047	0	1.0668
8/14/2015 14:44	7.031	8.276378	0.019083	0.01	0.9144
8/14/2015 14:45	6.933	7.696814	0.017747	0.01	0.9144
8/14/2015 14:46	6.85	7.222392	0.016653	0	1.2192
8/14/2015 14:47	6.772	6.790287	0.015657	0.01	1.2192
8/14/2015 14:48	6.673	6.261015	0.014436	0.01	1.3716
8/14/2015 14:49	6.63	6.037808	0.013922	0	1.2192
8/14/2015 14:50	6.492	5.348793	0.012333	0.01	1.524
8/14/2015 14:51	6.492	5.348793	0.012333	0.02	1.524
8/14/2015 14:52	6.413	4.97311	0.011467	0.01	1.524
8/14/2015 14:53	6.331	4.597602	0.010601	0.01	1.524
8/14/2015 14:54	6.232	4.163846	0.009601	0	1.6764
8/14/2015 14:55	6.213	4.083053	0.009414	0.03	1.6764
8/14/2015 14:56	6.154	3.837202	0.008848	0	1.524
8/14/2015 14:57	6.091	3.58309	0.008262	0.01	1.3716
8/14/2015 14:58	5.972	3.126794	0.00721	0.01	1.3716
8/14/2015 14:59	5.85	2.691157	0.006205	0.01	1.6764
8/14/2015 15:00	5.791	2.492161	0.005746	0.01	1.3716
8/14/2015 15:01	5.732	2.300782	0.005305	0.01	1.3716
8/14/2015 15:02	5.594	1.882887	0.004341	0	1.3716
8/14/2015 15:03	5.571	1.817289	0.00419	0.01	1.6764
8/14/2015 15:04	5.594	1.882887	0.004341	0.02	1.6764
8/14/2015 15:05	5.551	1.761187	0.004061	0.01	1.524
8/14/2015 15:06	5.472	1.548142	0.00357	0	1.524
8/14/2015 15:07	5.453	1.49894	0.003456	0.01	1.6764
8/14/2015 15:08	5.492	1.600787	0.003691	0.03	1.6764
8/14/2015 15:09	5.531	1.705961	0.003933	0.01	1.3716
8/14/2015 15:10	5.634	1.999728	0.004611	0	1.524
8/14/2015 15:11	5.654	2.059461	0.004749	0.01	1.524
8/14/2015 15:12	5.594	1.882887	0.004341	0.01	1.524
8/14/2015 15:13	5.453	1.49894	0.003456	0.01	1.0668
8/14/2015 15:14	5.272	1.069826	0.002467	0	1.0668
8/14/2015 15:15	5.173	0.865441	0.001995	0.02	1.2192
8/14/2015 15:16	5.114	0.753832	0.001738	0	1.0668
8/14/2015 15:17	5.055	0.64984	0.001498	0.01	1.0668
8/14/2015 15:18	5.012	0.578846	0.001335	0	1.0668
8/14/2015 15:19	4.953	0.48802	0.001125	0.01	1.2192
8/14/2015 15:20	4.894	0.404809	0.000933	0.01	0.9144
8/14/2015 15:21	4.854	0.352726	0.000813	0	1.0668
8/14/2015 15:22	4.835	0.329213	0.000759	0.01	1.0668
8/14/2015 15:23	4.815	0.305316	0.000704	0.01	1.0668
8/14/2015 15:24	4.795	0.282294	0.000651	0.01	1.0668
8/14/2015 15:25	4.772	0.256901	0.000592	0	0.9144
8/14/2015 15:26	4.752	0.23576	0.000544	0.01	1.0668

Collected Event 2 : Aug 29th 2015					
Level Data		Flow		Rain	
Day / Time	Level (in.)	(gpm)	lpm/cm^2	Rain (in.)	cm/hr
8/29/15 8:46	4.472	0.03168	7.3E-05	0	0.3048
8/29/15 8:47	4.453	0.024046	5.54E-05	0	0.3048
8/29/15 8:48	4.453	0.024046	5.54E-05	0	0.1524
8/29/15 8:49	4.453	0.024046	5.54E-05	0	0.1524
8/29/15 8:50	4.453	0.024046	5.54E-05	0.01	0.1524
8/29/15 8:51	4.453	0.024046	5.54E-05	0	0.1524
8/29/15 8:52	4.453	0.024046	5.54E-05	0	0.1524
8/29/15 8:53	4.453	0.024046	5.54E-05	0	0.1524
8/29/15 8:54	4.453	0.024046	5.54E-05	0	0.3048
8/29/15 8:55	4.453	0.024046	5.54E-05	0	0.1524
8/29/15 8:56	4.453	0.024046	5.54E-05	0	0.1524
8/29/15 8:57	4.453	0.024046	5.54E-05	0	0.1524
8/29/15 8:58	4.453	0.024046	5.54E-05	0	0.1524
8/29/15 8:59	4.472	0.03168	7.3E-05	0.01	0.3048
8/29/15 9:00	4.472	0.03168	7.3E-05	0	0.3048
8/29/15 9:01	4.492	0.040569	9.35E-05	0	0.3048
8/29/15 9:02	4.535	0.062644	0.000144	0	0.3048
8/29/15 9:03	4.535	0.062644	0.000144	0	0.4572
8/29/15 9:04	4.555	0.074289	0.000171	0.01	0.3048
8/29/15 9:05	4.535	0.062644	0.000144	0	0.3048
8/29/15 9:06	4.555	0.074289	0.000171	0	0.3048
8/29/15 9:07	4.535	0.062644	0.000144	0	0.3048
8/29/15 9:08	4.555	0.074289	0.000171	0.01	0.3048
8/29/15 9:09	4.535	0.062644	0.000144	0	0.3048
8/29/15 9:10	4.555	0.074289	0.000171	0	0.3048
8/29/15 9:11	4.535	0.062644	0.000144	0	0.3048
8/29/15 9:12	4.555	0.074289	0.000171	0	0.3048
8/29/15 9:13	4.535	0.062644	0.000144	0	0.1524
8/29/15 9:14	4.575	0.08681	0.0002	0.01	0.1524
8/29/15 9:15	4.535	0.062644	0.000144	0	0.1524
8/29/15 9:16	4.555	0.074289	0.000171	0	0.1524
8/29/15 9:17	4.575	0.08681	0.0002	0	0.1524
8/29/15 9:18	4.575	0.08681	0.0002	0	0.1524
8/29/15 9:19	4.594	0.099515	0.000229	0	0
8/29/15 9:20	4.594	0.099515	0.000229	0	0
8/29/15 9:21	4.614	0.113742	0.000262	0	0
8/29/15 9:22	4.634	0.128844	0.000297	0	0
8/29/15 9:23	4.634	0.128844	0.000297	0	0
8/29/15 9:24	4.634	0.128844	0.000297	0	0
8/29/15 9:25	4.634	0.128844	0.000297	0	0
8/29/15 9:26	4.634	0.128844	0.000297	0	0
8/29/15 9:27	4.634	0.128844	0.000297	0	0
8/29/15 9:28	4.634	0.128844	0.000297	0	0
8/29/15 9:29	4.634	0.128844	0.000297	0	0
8/29/15 9:30	4.654	0.144822	0.000334	0	0
8/29/15 9:31	4.654	0.144822	0.000334	0	0
8/29/15 9:32	4.654	0.144822	0.000334	0	0
8/29/15 9:33	4.654	0.144822	0.000334	0	0
8/29/15 9:34	4.654	0.144822	0.000334	0	0
8/29/15 9:35	4.654	0.144822	0.000334	0	0
8/29/15 9:36	4.654	0.144822	0.000334	0	0
8/29/15 9:37	4.673	0.160811	0.000371	0	0
8/29/15 9:38	4.693	0.178494	0.000412	0	0
8/29/15 9:39	4.713	0.197053	0.000454	0	0
8/29/15 9:40	4.713	0.197053	0.000454	0	0
8/29/15 9:41	4.732	0.215495	0.000497	0	0
8/29/15 9:42	4.732	0.215495	0.000497	0	0
8/29/15 9:43	4.732	0.215495	0.000497	0	0
8/29/15 9:44	4.732	0.215495	0.000497	0	0
8/29/15 9:45	4.713	0.197053	0.000454	0	0
8/29/15 9:46	4.693	0.178494	0.000412	0	0
8/29/15 9:47	4.673	0.160811	0.000371	0	0
8/29/15 9:48	4.673	0.160811	0.000371	0	0
8/29/15 9:49	4.654	0.144822	0.000334	0	0
8/29/15 9:50	4.634	0.128844	0.000297	0	0
8/29/15 9:51	4.614	0.113742	0.000262	0	0
8/29/15 9:52	4.614	0.113742	0.000262	0	0
8/29/15 9:53	4.594	0.099515	0.000229	0	0
8/29/15 9:54	4.575	0.08681	0.0002	0	0
8/29/15 9:55	4.555	0.074289	0.000171	0	0
8/29/15 9:56	4.555	0.074289	0.000171	0	0
8/29/15 9:57	4.535	0.062644	0.000144	0	0
8/29/15 9:58	4.535	0.062644	0.000144	0	0
8/29/15 9:59	4.516	0.052391	0.000121	0	0
8/29/15 10:00	4.492	0.040569	9.35E-05	0	0
8/29/15 10:01	4.472	0.03168	7.3E-05	0	0

Collected Event 3 : Oct. 10th 2015					
Level Data		Flow		Rain	
Day / Time	Level (in.)	(gpm)	lpm/cm^2	Rain (in.)	cm/hr
10/10/15 10:46	3.776	0	0	0	0
10/10/15 10:47	3.776	0	0	0	0
10/10/15 10:48	3.756	0	0	0	0
10/10/15 10:49	3.736	0	0	0	0
10/10/15 10:50	3.717	0	0	0	0
10/10/15 10:51	3.693	0	0	0	0
10/10/15 10:52	3.693	0	0	0	0
10/10/15 10:53	3.673	0	0	0	0
10/10/15 10:54	3.654	0	0	0	0
10/10/15 10:55	3.634	0	0	0	0
10/10/15 10:56	3.634	0	0	0	0
10/10/15 10:57	3.614	0	0	0	0
10/10/15 10:58	3.614	0	0	0	0
10/10/15 10:59	3.594	0	0	0	0
10/10/15 11:00	3.575	0	0	0	0
10/10/15 11:01	3.555	0	0	0	0
10/10/15 11:02	3.555	0	0	0	0
10/10/15 11:03	3.535	0	0	0	0
10/10/15 11:04	3.516	0	0	0	0
10/10/15 11:05	3.496	0	0	0	0
10/10/15 11:06	3.496	0	0	0	0
10/10/15 11:07	3.476	0	0	0	0
10/10/15 11:08	3.476	0	0	0	0
10/10/15 11:09	3.457	0	0	0	0
10/10/15 11:10	3.457	0	0	0	0
10/10/15 11:11	3.433	0	0	0	0
10/10/15 11:12	3.413	0	0	0	0
10/10/15 11:13	3.413	0	0	0	0
10/10/15 11:14	3.413	0	0	0	0
10/10/15 11:15	3.394	0	0	0	0
10/10/15 11:16	3.374	0	0	0	0
10/10/15 11:17	3.374	0	0	0	0
10/10/15 11:18	3.354	0	0	0	0
10/10/15 11:19	3.335	0	0	0	0
10/10/15 11:20	3.315	0	0	0	0
10/10/15 11:21	3.335	0	0	0	0
10/10/15 11:22	3.315	0	0	0	0
10/10/15 11:23	3.315	0	0	0	0
10/10/15 11:24	3.295	0	0	0	0
10/10/15 11:25	3.276	0	0	0	0
10/10/15 11:26	3.276	0	0	0	0
10/10/15 11:27	3.256	0	0	0	0
10/10/15 11:28	3.236	0	0	0	0
10/10/15 11:29	3.236	0	0	0	0
10/10/15 11:30	3.217	0	0	0	0
10/10/15 11:31	3.217	0	0	0	0
10/10/15 11:32	3.197	0	0	0	0
10/10/15 11:33	3.197	0	0	0	0
10/10/15 11:34	3.197	0	0	0	0
10/10/15 11:35	3.197	0	0	0	0
10/10/15 11:36	3.154	0	0	0	0
10/10/15 11:37	3.154	0	0	0	0
10/10/15 11:38	3.177	0	0	0	0
10/10/15 11:39	3.134	0	0	0	0
10/10/15 11:40	3.114	0	0	0	0
10/10/15 11:41	3.114	0	0	0	0
10/10/15 11:42	3.114	0	0	0	0
10/10/15 11:43	3.094	0	0	0	0
10/10/15 11:44	3.094	0	0	0	0
10/10/15 11:45	3.075	0	0	0	0
10/10/15 11:46	3.075	0	0	0	0
10/10/15 11:47	3.055	0	0	0	0
10/10/15 11:48	3.055	0	0	0	0
10/10/15 11:49	3.035	0	0	0	0
10/10/15 11:50	3.035	0	0	0	0
10/10/15 11:51	3.016	0	0	0	0
10/10/15 11:52	3.016	0	0	0	0
10/10/15 11:53	3.016	0	0	0	0
10/10/15 11:54	2.996	0	0	0	0
10/10/15 11:55	2.996	0	0	0	0
10/10/15 11:56	2.976	0	0	0	0
10/10/15 11:57	2.976	0	0	0	0
10/10/15 11:58	2.976	0	0	0	0
10/10/15 11:59	2.957	0	0	0	0
10/10/15 12:00	2.957	0	0	0	0
10/10/15 12:01	2.957	0	0	0	0

Table 28.3. Flow and rainfall data applicable to the three collected rain events – continued.

Collected Event 1 : Aug 14th 2015						Collected Event 2 : Aug 29th 2015						Collected Event 3 : Oct. 10th 2015					
Level Data		Flow		Rain		Level Data		Flow		Rain		Level Data		Flow		Rain	
Day / Time	Level (in.)	(gpm)	lpm/cm^2	Rain (in.)	cm/hr	Day / Time	Level (in.)	(gpm)	lpm/cm^2	Rain (in.)	cm/hr	Day / Time	Level (in.)	(gpm)	lpm/cm^2	Rain (in.)	cm/hr
8/14/2015 15:27	4.732	0.215495	0.000497	0.01	1.0668	8/29/15 10:02	4.453	0.024046	5.54E-05	0	0	10/10/15 12:02	2.957	0	0	0	0
8/14/2015 15:28	4.713	0.197053	0.000454	0	0.9144	8/29/15 10:03	4.433	0.016864	3.89E-05	0	0	10/10/15 12:03	2.937	0	0	0	0
8/14/2015 15:29	4.713	0.197053	0.000454	0.01	0.9144	8/29/15 10:04	4.433	0.016864	3.89E-05	0	0	10/10/15 12:04	2.937	0	0	0	0
8/14/2015 15:30	4.713	0.197053	0.000454	0	0.9144	8/29/15 10:05	4.413	0.010557	2.43E-05	0	0	10/10/15 12:05	2.917	0	0	0	0
8/14/2015 15:31	4.713	0.197053	0.000454	0.01	0.9144	8/29/15 10:06	4.374	0.000774	1.79E-06	0	0	10/10/15 12:06	2.917	0	0	0	0
8/14/2015 15:32	4.693	0.178494	0.000412	0.01	0.762	8/29/15 10:07	4.374	0.000774	1.79E-06	0	0	10/10/15 12:07	2.917	0	0	0	0
8/14/2015 15:33	4.654	0.144822	0.000334	0	0.9144	8/29/15 10:08	4.354	-0.00295	-6.8E-06	0	0	10/10/15 12:08	2.894	0	0	0	0
8/14/2015 15:34	4.654	0.144822	0.000334	0.01	0.762	8/29/15 10:09	4.335	-0.00568	-1.3E-05	0	0	10/10/15 12:09	2.894	0	0	0	0
8/14/2015 15:35	4.654	0.144822	0.000334	0	0.9144	8/29/15 10:10	4.315	-0.0077	-1.8E-05	0	0	10/10/15 12:10	2.894	0	0	0	0
8/14/2015 15:36	4.634	0.128844	0.000297	0.01	0.9144	8/29/15 10:11	4.295	-0.00884	-2E-05	0	0	10/10/15 12:11	2.874	0	0	0	0
8/14/2015 15:37	4.634	0.128844	0.000297	0	0.9144	8/29/15 10:12	4.276	-0.00912	-2.1E-05	0	0	10/10/15 12:12	2.874	0	0	0	0
8/14/2015 15:38	4.634	0.128844	0.000297	0.01	1.0668	8/29/15 10:13	4.256	-0.00856	-2E-05	0	0	10/10/15 12:13	2.874	0	0	0	0
8/14/2015 15:39	4.634	0.128844	0.000297	0	0.9144	8/29/15 10:14	4.232	-0.00673	-1.6E-05	0	0	10/10/15 12:14	2.854	0	0	0	0
8/14/2015 15:40	4.654	0.144822	0.000334	0.01	1.0668	8/29/15 10:15	4.232	-0.00673	-1.6E-05	0	0	10/10/15 12:15	2.854	0	0	0	0
8/14/2015 15:41	4.654	0.144822	0.000334	0.01	1.0668	8/29/15 10:16	4.213	-0.00439	-1E-05	0	0	10/10/15 12:16	2.854	0	0	0	0
8/14/2015 15:42	4.654	0.144822	0.000334	0.01	1.2192	8/29/15 10:17	4.193	-0.00107	-2.5E-06	0	0	10/10/15 12:17	2.854	0	0	0	0
8/14/2015 15:43	4.654	0.144822	0.000334	0.01	1.0668	8/29/15 10:18	4.193	-0.00107	-2.5E-06	0	0	10/10/15 12:18	2.854	0	0	0	0
8/14/2015 15:44	4.654	0.144822	0.000334	0	1.2192	8/29/15 10:19	4.173	0	0	0	0	10/10/15 12:19	2.835	0	0	0	0
8/14/2015 15:45	4.634	0.128844	0.000297	0.01	1.2192	8/29/15 10:20	4.154	0	0	0	0	10/10/15 12:20	2.835	0	0	0	0
8/14/2015 15:46	4.654	0.144822	0.000334	0.01	1.0668	8/29/15 10:21	4.154	0	0	0	0	10/10/15 12:21	2.815	0	0	0	0
8/14/2015 15:47	4.614	0.113742	0.000262	0.01	1.0668	8/29/15 10:22	4.134	0	0	0	0	10/10/15 12:22	2.815	0	0	0	0
8/14/2015 15:48	4.614	0.113742	0.000262	0	1.0668	8/29/15 10:23	4.114	0	0	0	0	10/10/15 12:23	2.815	0	0	0	0
8/14/2015 15:49	4.594	0.099515	0.000229	0.01	1.0668	8/29/15 10:24	4.114	0	0	0	0	10/10/15 12:24	2.815	0	0	0	0
8/14/2015 15:50	4.594	0.099515	0.000229	0.01	1.0668	8/29/15 10:25	4.094	0	0	0	0	10/10/15 12:25	2.815	0	0	0	0
8/14/2015 15:51	4.614	0.113742	0.000262	0	0.9144	8/29/15 10:26	4.075	0	0	0	0	10/10/15 12:26	2.815	0	0	0	0
8/14/2015 15:52	4.594	0.099515	0.000229	0.01	0.9144	8/29/15 10:27	4.075	0	0	0	0	10/10/15 12:27	2.795	0	0	0	0
8/14/2015 15:53	4.594	0.099515	0.000229	0.01	1.0668	8/29/15 10:28	4.055	0	0	0	0	10/10/15 12:28	2.795	0	0	0	0
8/14/2015 15:54	4.575	0.08681	0.0002	0	0.9144	8/29/15 10:29	4.055	0	0	0	0	10/10/15 12:29	2.795	0	0	0	0
8/14/2015 15:55	4.575	0.08681	0.0002	0.01	0.9144	8/29/15 10:30	4.035	0	0	0	0	10/10/15 12:30	2.776	0	0	0	0
8/14/2015 15:56	4.555	0.074289	0.000171	0	0.9144												
8/14/2015 15:57	4.535	0.062644	0.000144	0.01	0.9144												
8/14/2015 15:58	4.535	0.062644	0.000144	0.01	0.762												
8/14/2015 15:59	4.535	0.062644	0.000144	0	0.9144												
8/14/2015 16:00	4.535	0.062644	0.000144	0.01	0.9144												

Table 29. Field site data table.

Date	Sampler	Solids (mg/L)							Filtered Sample						Total Metals (ppb)			T.M. Blanks (ppb)		
		Vol. (mL)	Tare (g)	Dried (g)	Muff (g)	TSS (mg/L)	VSS (mg/L)	%VSS (%)	Sample #	Zn (ppb)	Ave. Zn (ppb)	Cu (ppb)	Ave. Cu (ppb)	pH	Sample #	Zn (ppb)	Cu (ppb)	Sample #	Zn (ppb)	Cu (ppb)
Aug. 14	Influent (I1) (Samples 1-12)	80	1.395	1.404	1.399	110	60	45%	1	114.5	122.7	20.7	22.0	-	13	244.9	44.3	17	11.1	2.0
									2	130.9		23.3								
									3	-		-								
	Influent (I2) (Samples 13-24)	500	1.385	1.471	1.435	172	70	59%	4	109.3	108.5	12.8	12.3	6.43	14	295.0	45.7			
									5	106.0		12.2								
									6	110.1		11.9								
	Effluent (E3) (Samples 1-12)	80	1.398	1.406	1.403	97	37	62%	7	114.5	110.0	22.0	21.6	6.21	15	218.2	73.6	18	6.7	1.6
									8	106.7		21.5								
									9	108.7		21.3								
	Effluent (E4) (Samples 13-24)	80	1.398	1.405	1.403	79	26	67%	10	87.5	87.9	15.3	15.4	6.34	16	149.4	26.7			
									11	86.9		14.9								
									12	89.4		16.0								
Aug. 29	Influent (I1) (Samples 1-12)	80	1.395	1.408	1.401	164	79	52%	1	58.5	59.5	8.1	8.0	6.79	13	195.6	31.0	17	5.9	0.5
									2	60.5		8.0								
									3	56.2		7.3								
	Influent (I2) (Samples 13-24)	80	1.408	1.411	1.41	36	9	76%	4	29.1	32.3	5.7	4.3	6.79	14	67.2	11.5			
									5	26.0		3.5								
									6	41.6		3.6								
	Effluent (E3) (Samples 1-12)	80	1.416	1.419	1.418	34	19	44%	7	18.7	18.7	10.2	10.1	7.31	15	47.7	17.0	18	2.8	0.5
									8	18.7		10.2								
									9	18.7		9.9								
	Effluent (E4) (Samples 13-24)	80	1.394	1.395	1.395	11	5	56%	10	10.7	10.7	6.2	6.3	7.33	16	24.1	8.5			
									11	10.6		6.5								
									12	10.8		6.2								
Oct. 10	Influent (I1) (Samples 1-6)	80	1.385	1.41	1.406	312	49	84%	1	31.4	45.1	3.0	3.0	6.66	7	143.2	37.7	9	15.0	4.3
									2	58.8		3.0								
									3	31.2		3.0								
	Effluent (I2) (Samples 1-6)	80	1.412	1.422	1.419	130	46	64%	4	13.4	28.1	2.6	2.6	6.65	8	78.1	15.3			
									5	25.6		2.6								
									6	45.4		2.7								

Table 30. Sludge sample volatile fraction data table.

Solids tests					
Tare wt	Dry wt.	Mass	Muff wt.	Inert	% Volatile
(g)	(g)	(g)	(g)	(g)	(%)
86.3033	93.6872	7.38	91.2458	4.94	33.1%
88.9258	96.0668	7.14	93.6553	4.73	33.8%
66.5243	73.7703	7.25	71.3500	4.83	33.4%
** per EPA 1684 section 11*					

Table 31. Sludge sample total extractable metals data table.

Total Metals Extraction											Blank		
Dry & Ground	HNO3	HCL	Diluted	Sample	Zn	Zn	Ave. Zn	Cu	Cu	Ave. Cu	Sample	Zn	Cu
(g)	(mL)	(mL)	(mL)	#	(µg/L)	(mg/kg)	(mg/kg)	(µg/L)	(mg/kg)	(mg/kg)	#	(µg/L)	(µg/L)
1.0010				19	7644.2	763.7		1120.0	111.9				
1.0020	4	10	100	20	6577.4	656.4	731.2	872.9	87.1	106.5	22	11.2	1.3
1.0023				21	7752.0	773.4		1209.1	120.6				
**per EPA 200.7 section 11.3*													

Table 32. Sludge sample particle size distribution determined using Mastersizer 3000.

Size Classes	Vol. Density	Size Classes	Vol. Density	Size Classes	Vol. Density	Size Classes	Vol. Density
(µm)	(%)	(µm)	(%)	(µm)	(%)	(µm)	(%)
0.0106591	0	0.2592611	0	6.30600575	1.29775642	153.380932	2.25998565
0.01211047	0	0.29456289	0	7.16465104	1.53843527	174.265756	2.07876344
0.01375947	0	0.33467149	0	8.14021214	1.81417333	197.994321	1.94313805
0.015633	0	0.38024139	0	9.24860867	2.11684433	224.953842	1.86942341
0.01776164	0	0.43201624	0	10.5079279	2.43412289	255.584255	1.86579912
0.02018012	0	0.49084091	9.70E-05	11.9387199	2.74994717	290.385399	1.92882987
0.02292791	0	0.55767533	0.00983443	13.5643331	3.04612265	329.925175	2.04308731
0.02604984	0	0.63361013	0.10543824	15.4112947	3.30499549	374.84881	2.18347037
0.02959687	0	0.71988445	0.19649162	17.5097444	3.51214129	425.889386	2.31790744
0.03362687	0	0.81790615	0.26429361	19.8939255	3.65838644	483.879806	2.41064771
0.03820561	0	0.92927479	0.29275381	22.602744	3.7409885	549.76638	2.42896141
0.0434078	0	1.05580773	0.28753311	25.6804037	3.76395442	624.624275	2.35161595
0.04931835	0	1.19956978	0.27135092	29.1771271	3.73755054	709.675053	2.17464018
0.05603369	0	1.36290692	0.26868549	33.1499752	3.6765597	806.306608	1.91227064
0.06366341	0	1.54848455	0.29260493	37.6637786	3.59742747	916.095816	1.59478461
0.07233201	0	1.75933101	0.34137723	42.7921955	3.51476959	1040.83426	1.26336601
0.08218096	0	1.99888698	0.40362933	48.6189135	3.43807613	1182.55748	0.94347007
0.09337098	0	2.27106162	0.466755	55.2390155	3.36959837	1343.57818	0.64798701
0.10608466	0	2.58029642	0.52454597	62.7605311	3.30440123	1526.52395	0.50185668
0.12052948	0	2.93163758	0.57935464	71.3061997	3.23230697	1734.38018	0.45148172
0.13694114	0	3.33081844	0.63855493	81.0154729	3.1409003	1970.53876	0.40107003
0.15558747	0	3.784353	0.71154638	92.0467908	3.01936047	2238.85343	0.33750139
0.17677275	0	4.29964224	0.80738976	104.580167	2.86246955	2543.70265	0.2617642
0.20084267	0	4.88509486	0.93376463	118.820127	2.67350061	2890.06109	0.17731608
0.22819003	0	5.55026452	1.09616388	134.999044	2.46582703	3283.58077	0.08872712
Average of 'BI_Sludge'-9/14/2015 11:03:23 AM. Mastersizer 3000							

6.5 Column Media Characterization

Table 33. Volumetric mass density of the media data table.

Media	Cylinder Wt.	Compacted Media Volume	Cylinder + Media Wt.	Media Wt.	Volumetric Mass Density	Volumetric Mass Density
Units	(g)	(mL)	(g)	(g)	(g/mL)	(g/L)
Biochar	110.88	146	125.79	14.91	0.102	102.1
Torr. Wood	65.57	134	89.5	23.93	0.179	178.6
Raw Wood	85.42	130	106.76	21.34	0.164	164.2
Pea Gravel	85.96	47	154.4	68.44	1.456	1456.2

Table 34. Moisture content of the media data table.

Media	Container	Container + material	Material	Container + dry material	Dry material	MC
Units	(g)	(g)	(g)	(g)	(g)	(%)
Raw Wood	116.6718	136.6821	20.0103	135.1245	18.4527	8.4%
Gravel	106.9549	126.9690	20.0141	126.7540	19.7991	1.1%
Torrefied Wood	108.6804	128.6926	20.0122	127.9980	19.3176	3.6%
Biochar	107.0237	127.0436	20.0199	126.2247	19.2010	4.3%