ABSTRACT

Title of Thesis: WATER QUALITY IMPACTS DUE TO THE ADDITION OF BIOSOLIDS-DERIVED COMPOST TO BIORETENTION

Colleen Gardina, Master of Science, 2016

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Bioretention is a common stormwater control measure (SCM). While compost, combined with other bioretention soil media (BSM), has the potential for increased pollutant and water uptake and storage, it also may leach harmful nutrients. Limited information is available on the use of compost in SCMs. Therefore, this project seeks to analyze the impacts of the addition of biosolids-derived compost to bioretention. To accomplish this, bioretention mesocosm column studies were conducted to determine the leaching effects of 15%, 30%, and 30% tap water-washed compost, mixed with standard BSM. Synthetic storm runoff was applied to the columns and the effluent was analyzed for total nitrogen (N), phosphorus (P), and their speciation. All three columns leached N and P with maximum total N concentrations of 2,200, 2,100, and 300 mg-N/L and total P concentrations of 12, 4.9, and 4.6 mg-P/L for the 30%, 15%, and 30% washed mesocosms, respectively. Therefore, based on this study, it is not recommended that biosolids-derived compost be added to bioretention media.

WATER QUALITY IMPACTS DUE TO THE ADDITION OF BIOSOLIDS-DERIVED COMPOST TO BIORETENTION

by

Colleen Gardina

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Chapter 1: Introduction

In May 2014, the Maryland General Assembly passed House Bill 878 to increase the use of recycled, reclaimed, and reused materials in state projects. Because the Maryland State Highway Administration (SHA) is one of the state's largest entities with construction projects, it was significantly impacted by this bill. Therefore, the SHA proposed the implementation of compost into stormwater control measures (SCMs), such as bioretention. There is limited knowledge, however, regarding how compost would affect water quality upon its addition to bioretention.

Bioretention (Figure 1) is one of the most widely used SCMs to treat stormwater. Bioretention systems generally include a layer with sand, soil and organic matter, a surface layer with mulch, and vegetation (Davis et al. 2009). Bioretention can serve multiple purposes, such as reduction in runoff velocity and removal of sediments and nutrients, including nitrogen and phosphorus. The system treats stormwater runoff through filtration, sorption, ion exchange, and biological processes (Hsieh et al. 2007).

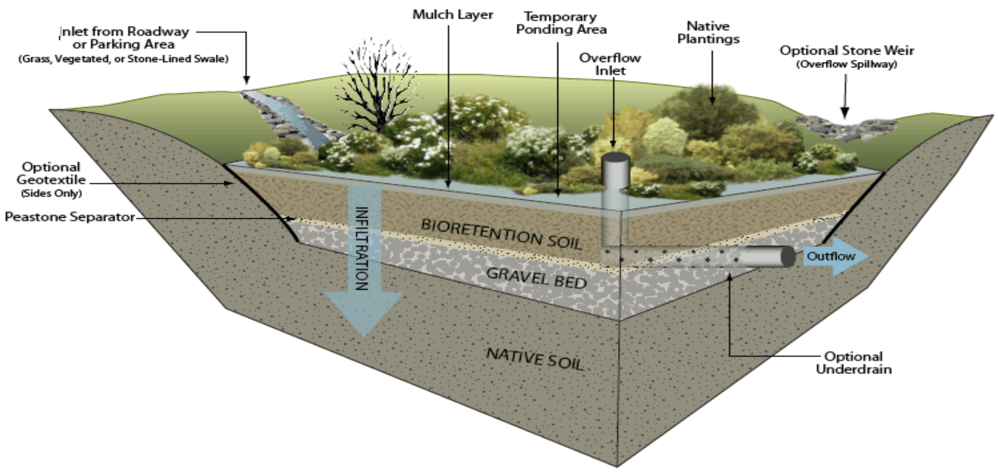


Figure 1. Bioretention cell (Strauch 2014)

In urban environments, large impervious surface areas accumulate pollutants, nitrogen and phosphorus, which quickly wash off into receiving waters. Nitrogen and phosphorus contribute to eutrophication and a decline in water quality. In the state of Maryland, typical stormwater has concentrations of 2.0 mg/L total nitrogen and 0.30 mg/L of total phosphorus (MDE 2009). However, according to the Nutrient Criteria for Rivers and Streams for Ecoregion XIV (Eastern Coastal Plain) set by the EPA, influent total nitrogen concentrations should not exceed 0.71 mg/L and total phosphorus concentrations should not exceed 31.25 µg/L ("Ecoregional Criteria Documents" 2014). Therefore, it is imperative to implement best management practices (BMPs), such as SCMs, to mitigate incoming pollutants.

Many studies have been conducted to determine the efficiency of removing these pollutants. Generally, bioretention is effective at removing phosphorus (Davis et al., 2009), especially in particulate form (Li and Davis, 2015), but its removal of nitrogen has been found to be variable (Li and Davis 2014; Subramaniam et al. 2016). The removal mechanisms of the different forms of both phosphorus and nitrogen vary as well. Particulate phosphorus (PP) is removed through sedimentation and filtration. Dissolved phosphorus (DP), including soluble reactive phosphorus (SRP) is more difficult to remove. DP and SRP are typically adsorbed to the media or precipitated out of solution (Lucas and Greenway 2008).

As previously mentioned, nitrogen removal in bioretention is highly variable. This is especially true because of the complexities of the nitrogen cycle. In a study conducted by Li and Davis (2014), it was found that bioretention is effective at removing particulate organic nitrogen (PON) via sedimentation and filtration, ammonia (NH_3-N) via adsorption, and nitrite (NO_2^--N) via oxidation, but the system leached nitrate (NO_3^-–N). This occurred because NH_3-N was oxidized to NO_3^--N during drying periods in the system. Therefore, it is imperative to find methods, such as amendments to the media, to reduce or stop this from occurring.

By State of Maryland definition, compost is: "a stabilized organic product produced by the controlled aerobic decomposition process in such a manner that the product may be handled, stored, and applied to the land or used as a soil conditioner in an environmentally acceptable manner without adversely affecting plant growth" (COMAR 2014). Compost can consist of many different materials, including biosolids. Biosolids are organic materials produced during the wastewater treatment process. These materials are broken down and stabilized during the composting process to remove odor and harmful pathogens (USEPA 2000).

When added to SCMs, compost increases water holding capacity of the media, which is beneficial for plant growth and facilitates nutrient removal. Additionally, compost increases cation exchange capacity (CEC), which allows the media to retain more metals. However, compost also contains properties that may be counterproductive in SCMS, such as potential to leach N and P (Kirchoff et al. 2003). Therefore, it is imperative to determine the effects that the addition of compost will have on bioretention and other SCMs before it is utilized on a large scale.

Many states, such as Washington and California, allow or require compost in their SCMs. Although they do not allow the use of biosolids-derived compost (Puget Sound Partnership 2009; California Environmental Protection Agency 2014; "Bioretention Components" 2016). Unfortunately, there are very limited studies of the effects of biosolids-derived compost in bioretention. In a column study, conducted by Brown et al. (2016), it was found that bioretention soil media (BSM), amended with biosolids/yard waste compost, leached phosphorus and nitrogen, at least initially. However, effluent concentrations of each declined with time. Phosphorus removal was also observed (Brown et al. 2016). Other previous studies have noted that compost has potential to remove pollutants, but should be added to bioretention in limited amounts because it has the potential to leach nutrients (Iqbal et al. 2015; Mullane et al. 2015). More research must be done to determine how different amounts of biosolids-derived compost affect water quality, as well as long-term impacts of its addition.

1.1 Research Goals and Hypotheses

This project has three primary goals: 1) To characterize biosolids-derived compost properties, 2) To quantify leaching of both nitrogen and phosphorus in a bioretention mesocosm, and 3) To compare biosolids-derived compost's leaching abilities to source-separated compost, biosolids, and bioretention soil media (BSM).

First, extractions of the compost were performed to determine its nitrogen and phosphorus contents. Additionally, moisture contents of the media used were calculated. Next, leaching of nitrogen and phosphorus was quantified through a series of mesocosm studies. Four mesocosm studies were conducted in columns that represented bioretention systems. Three of the columns contained different mixtures of compost and bioretention soil media (BSM) and one contained only BSM as a control. Synthetic storms were applied and effluent was collected and tested for total nitrogen, total phosphorus, ammonium, nitrate, nitrite, organic nitrogen, soluble reactive phosphorus, dissolved organic phosphorus, and particulate phosphorus to determine if the media leached these nutrients or eventually removed them. Each trial lasted for 8 weeks, but one column ran for one year to test long-term leaching effects. Finally, the results from the mesocosm studies were compared with similar studies that utilize either source-separated compost or biosolids.

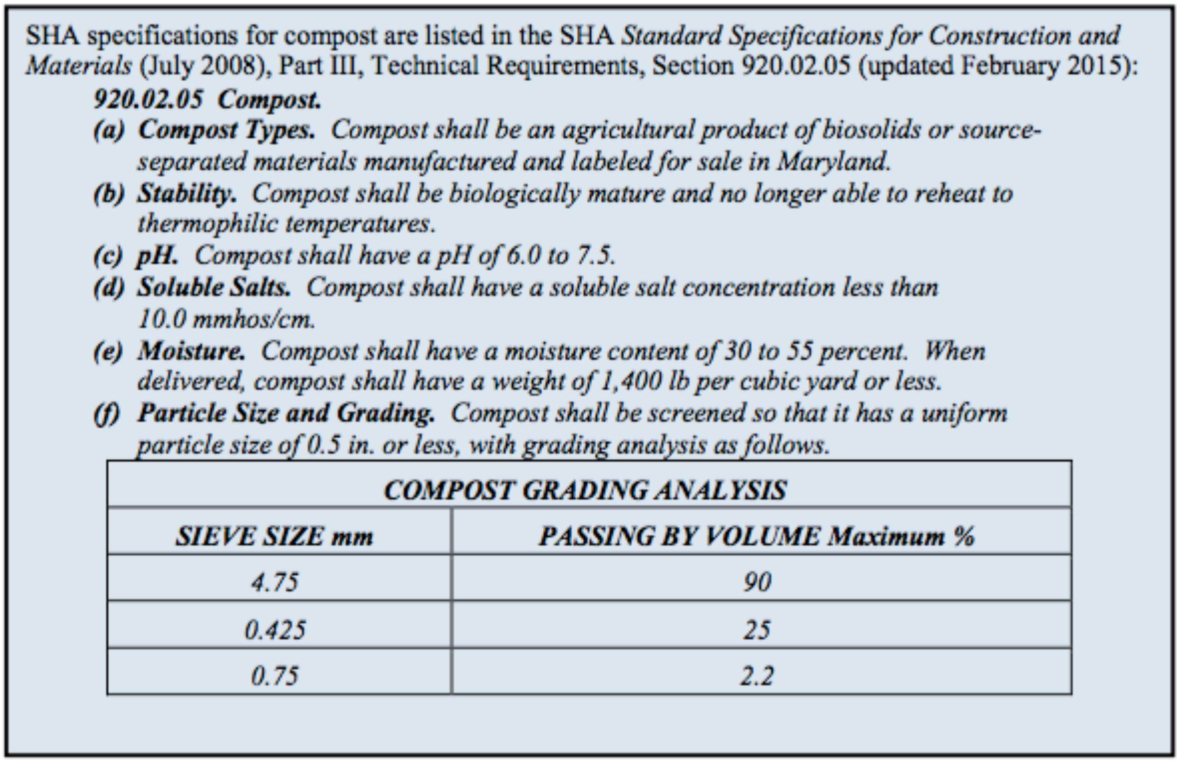
It is hypothesized that the mesocosms will initially leach both N and P, but leaching should taper off and ultimately lead to removal of these nutrients. Additionally, the mesocosms with lower percentages of compost should leach less N and P and show removal more quickly. Ultimately, the media characterization and leaching effects will be used to determine a standard for the amount of compost that can be used in bioretention based on its properties.

Chapter 2: Materials and Methodology

2.1 Materials

The compost chosen for this project was obtained from the Baltimore City Composting Facility. Detailed compost data sheets are provided in Appendix A. The compost is derived from Class A biosolids, originating from the Back River Wastewater Treatment Plant also in Baltimore, MD, and is SHA-approved. Class A biosolids, contains pathogens below detection limit and limited metal content. At the composting facility, the biosolids are placed in a contained vessel. The vessel is agitated and aerated to ensure homogeneity and is monitored for temperature. Once this step is complete, the compost is placed in large aerated static piles (ASPs) for three days ("Baltimore City Composting Facility" 2016). The ASPs must reach temperatures of 55^{o}C for three days in order to be in compliance with EPA's Part 503 Rule to fully destroy pathogens (US EPA 2000). This process is known as the process to further reduce pathogens (PFRP). After the PFRP is complete, the compost remains un-aerated for 30 days, while the material cures ("Baltimore City Composting Facility"). The final, biosolids-derived compost product has a 25-35:1 C:N ratio by weight (US EPA 2000). SHA-approved compost is pursuant to SHA specification 920.02.05 (Figure 2).

The composting facility offered both limed and un-limed compost. Limed compost was used for this study, but $CaCO_3$ concentrations were relatively low (Appendix A).



SHA specifications for compost are listed in the SHA *Standard Specifications for Construction and Materials* (July 2008), Part III, Technical Requirements, Section 920.02.05 (updated February 2015):

920.02.05 Compost.

- ***(a) Compost Types.*** *Compost shall be an agricultural product of biosolids or source-separated materials manufactured and labeled for sale in Maryland.*
- ***(b) Stability.*** *Compost shall be biologically mature and no longer able to reheat to thermophilic temperatures.*
- ***(c) pH.*** *Compost shall have a pH of 6.0 to 7.5.*
- ***(d) Soluble Salts.*** *Compost shall have a soluble salt concentration less than 10.0 mmhos/cm.*
- ***(e) Moisture.*** *Compost shall have a moisture content of 30 to 55 percent. When delivered, compost shall have a weight of 1,400 lb per cubic yard or less.*
- ***(f) Particle Size and Grading.*** *Compost shall be screened so that it has a uniform particle size of 0.5 in. or less, with grading analysis as follows.*

COMPOST GRADING ANALYSIS

SIEVE SIZE mm	***PASSING BY VOLUME Maximum %***
4.75	*90*
0.425	*25*
0.75	*2.2*

Figure 2. Maryland State Highway Association specification for the use of compost in the construction of stormwater control measures on state highway projects (Maryland State Highway Administration 2008).

Paver sand, purchased from a local home supply store, and bioretention soil media (BSM) with SHA specification 920.01.05 (see Appendix B) from Stancill's Inc. in Waldorf, MD were also used in the column trials. To remove fine particles from the sand, the sand was placed in buckets and washed with water until the water ran clear, indicating a lack of fine particles in suspension. Fescue grass, purchased from Behnke Nursery in Beltsville, MD was used to vegetate the column.

2.2 Media Characterization

2.2.1 Water Soluble Phosphorus

Water-soluble phosphorus was extracted from the compost and BSM (the control) in triplicate using the "Water- or Dilute Salt-Extractable Phosphorus in Soil"

$CaCl_2$ standard method (Moore and Joern 2009). Fifty-milliliter standards were prepared in concentrations of 0, 0.05, 0.1, 0.2, 0.5, and 1.0-mg/L (as P) using a stock solution of 5-ppm phosphate as phosphorus. The stock solution was made using Lab Chem Inc. 1000-ppm phosphate as phosphorus (SKU: LC185901). Extracted samples were diluted with deionized water to fit the linear portion of the standard curve. Combined reagent was added to each sample and standard. The standards and samples were read on a Shimadzu UV160U UV Visible Recording Spectrophotometer with a method detection limit of 1.25-mg P/kg.

2.2.2 Mehlich 3-Extractable Phosphorus

Phosphorus from the compost and BSM were extracted using the Mehlich 3 soil extraction method (Mehlich 1984). Fifty-milliliter standards were prepared in concentrations of 0, 0.05, 0.1, 0.2, 0.5, and 1.0 mg/L (as P) using a stock solution of 5-ppm phosphate. The stock solution was made using Lab Chem Inc. 1000-ppm phosphate as phosphorus (SKU: LC185901). Compost extractions were diluted to fit the linear portion of the standard curve. Total phosphorous was measured using the ascorbic acid method (Murphy and Riley 1962). Standards and samples were read on a Shimadzu UV160U UV Visible Recording Spectrophotometer with a method detection limit of 0.5-mg P/kg.

2.2.3 KCl-Extractable Nitrogen

A 2 M KCl solution was used to extract nitrogen from 5 g samples of the compost and BSM for the determination of total inorganic nitrogen (Castle 2009). Standards were prepared using 1000 ppm nitrogen standard as nitrate (CAT #: 5459-

16) from Fisher Scientific in concentrations of 0, 0.05, 0.1, 0.2, 0.5, 1.0, 2.5, and 5.0 (as N)-mg/L. Samples were diluted to fit the linearization of the standard curve and read using a Shimadzu SSM-5000A with Total Nitrogen Measuring Unit with a method detection limit of 0.34 mg-N/kg.

2.2.4 Material Moisture Content

To determine the bulk density of the compost and BSM, a graduated cylinder was filled between 10 and 250 mL with compost and BSM. Masses in grams were recorded and mass to volume ratios were calculated and averaged to obtain average bulk densities.

To determine the dry mass compost, the field moist measurements above were converted using a field moist to dry mass conversion. Samples of each compost and the BSM were weighed, then dried for 24 hours and weighed again to determine the water mass in each field sample. As a quality check, this was done in triplicate and the samples were allowed to sit for 7 additional days to determine if any water remained. No change occurred after the initial 24 hours.

2.3 Bioretention Mesocosms

2.3.1 Construction

Large mesocosm studies were conducted using acrylic columns purchased from Piedmont Plastics in Elkridge, MD. The columns had 19.1 cm inner diameters, were 122 cm long, and were packed with a 7 cm layer of # 7 gravel from Stancill's Inc., a 7 cm layer of sand, and 77 cm of either a 15% compost:85% BSM, 30% compost:70% BSM, 30% washed compost:70% BSM mixture, or 100% BSM as a control column. The compost/BSM mixtures were hand-mixed by volume. Compost, sand, and BSM were sieved with a 1 cm sieve to avoid larger pore volumes while maintaining similar structure to field size. Layers were loosely packed by the weight of the next layer along with light shaking. After the first run, additional media was added to return the media height to 77 cm. A 1 mm diameter mesh, purchased from a local home supply store, was placed between the gravel and sand layers to reduce the flow of media and sand from the column. At the bottom of the column, a 14.7-degree slope led to a 3.8 cm discharge port to prevent pooling and allowed for sample collection.

After packing the columns, foil was wrapped around them to inhibit algal growth from excess sunlight. In the 30% mesocosm, foil was added after 21 days and sod was planted before storm #7. In the 15% mesocosm, foil was added immediately and dead sod was added after storm 3. The dead sod grew weeds throughout the remainder of the trial. Finally, sod was planted at the start of storm 5 in the 30% washed mesocosm, while foil was added at the onset. The delay in sod planting in the mesocosms, was due to the limited availability of sod at the nursery.

Figure 3. Column structure

2.3.2 Compost Washing Procedure

To remove the first flush of nutrients from the compost, a compost sample was soaked in tap water in a 1:1 ratio by volume for one hour in one of the columns. The excess water was drained off and analyzed for total phosphorus (TP), total nitrogen (TN), and their respective speciation. The compost was removed from the column, spread out on a tarp, and allowed to dry overnight. The washed compost was then mixed with BSM in a 30%/70% mixture by volume and packed in the column as described in section 2.2.4.

Figure 4. Compost washing procedure: compost soaking in tap water (left) and draining off of effluent (right)

Figure 5. Air-dried washed compost

2.3.3 Stormwater Preparation

For all column trials, synthetic stormwater solutions were made using the concentrations found in Table 1. Organic N was added as glycine and neither HCl nor NaOH were necessary to add to the stormwater. A concentrated stormwater solution was prepared and added to 50 L of tap water. Because the phosphorus concentration of the tap water exceeded 0.20 mg/L, phosphorus (Na_2HPO_4) was not added to the synthetic stormwater. Moreover, to neutralize the chlorine in the tap water, 2.2 mg/L of sodium bisulfite was also added.

Table 1. Stormwater components used in column studies (O'Neill and Davis 2012).

Component	**Value**	**Source**
pH	7.0	HCl or NaOH
Inorganic Nitrogen: NO_3^-	1 mg/L as N	$NaNO_3$
Organic N	2 mg/L as N	Glycine or other compound
Phosphorus	0.2 mg/L as P	Na_2HPO_4
Copper	0.06 mg/L	$CuCl_2$
Zinc	0.5 mg/L	$ZnCl_2$
Dissolved Solids	80 mg/L	$CaCl_2$
Dissolved Solids (Salts)	0-500 mg/L	NaCl

2.3.4 Storms and Sampling

The median rainfall duration in Maryland is 6 hours and the median rainfall depth is 0.71 cm (0.28 in) (Kreeb 2003). However, to analyze the system under stressed conditions, a 1.9 in (5 cm) rainfall depth was used. Over the course of 6 hours, this is the equivalent of 0.81 cm/hr (0.32 in/hr). However, to account for the 20:1 drainage area-to-SCM ratio, the flow rate increased to 16.3 cm/hr (6.4 in/hr). To make flow rate easier to measure, this was reduced to 15.2 cm/hr or 72 mL/min.

Each column was run 8 separate times for 6-hour intervals over a period of 8 weeks, representing 8 different “storms.” Storms 1, 2, 3, 4, 7, and 8 had a flow rate of 15.2 cm/hr (72 mL/min). The flow rate was halved to 7.6 cm/hr (36 mL/min) for storm 5 and doubled to 31 cm/hr (140 mL/min) for storm 6 to investigate the effects of changing flow rate on effluent nutrient concentrations. Two hundred and fifty-milliliter samples were collected every 30 minutes for the first 2 hours and every hour for the remaining 4 hours. Eight to ten samples were collected during each storm. Additionally, samples of the influent and tap water used to prepare the influent were obtained once per storm. All samples were frozen until analyzed.

To determine long-term water quality effects, tap water was applied weekly for 6-hour durations with a flow rate of 15.2 cm/hr, to the 30% compost column. The effluent was tested for phosphorus, nitrogen, and their respective speciation after 10 applied storms, then again after an additional 10 applied storms.

2.4 Phosphorus Analytical Procedures

2.4.1 Total Phosphorus (TP), Dissolved Phosphorus (DP), and Soluble Reactive Phosphorus (SRP)

For all trials, effluent samples were diluted to fit the linearization of the standard curve and digested using the persulfate oxidation method. Fifty-milliliter standards were prepared in concentrations of 0, 0.05, 0.1, 0.2, 0.5, and 1.0-mg P/L using a stock solution of 5-ppm phosphate and also digested (Clesceri, et al. 2005c). The samples and standards were then read with the Murphy and Riley (1962) colorimetric method on a Shimadzu UV160U UV Visible Recording Spectrophotometer with a method detection limit of 0.025 mg/L P.

To determine DP, effluent samples were filtered using a 0.22-µm filter, and diluted to fit the linearization of the standard curve. Samples were then tested using the same procedure as described above for TP. Twenty-five milliliters of the filtered samples were set aside, not digested, and tested with the Murphy and Riley colorimetric method (1962) to determine SRP.

2.4.2 Particulate Phosphorus (PP)

Particulate phosphorus (PP) was calculated by subtracting dissolved phosphorus (DP) from total phosphorus (TP) using the following formula:

$$PP=TP-DP \qquad (1)$$

2.4.3 Dissolved Organic Phosphorus (DOP)

Dissolved organic phosphorus (DOP) was calculated by subtracting soluble reactive phosphorus (SRP) from dissolved phosphorus (DP) using the following formula:

DOP=DP-SRP (2)

2.5 Nitrogen Analytical Procedures

2.5.1 Total Nitrogen (TN)

For all trials, 20 mL of effluent from the column experiments were diluted to fit the linearization of the standard curve. Standards, diluted from 1000 ppm nitrogen as nitrate stock from Fisher Scientific (CAT #:5459-16), were prepared in concentrations of 0, 0.05, 0.1, 0.2, 0.5, 1.0, and 2.5, and 5.0 mg/L. The samples and standards were then analyzed on a Shimadzu SSM-5000A with Total Nitrogen Measuring Unit with a method detection limit of 0.025 mg-N/L. Standards checks were analyzed every 5-10 samples to ensure consistent functionality of the machine.

2.5.2 Nitrite

Ten-milliliters of effluent were diluted to fit the linearization of the standard curve. Twenty-five-milliliter standards diluted from 5.0 mg-N/L nitrite stock solution were prepared in concentrations of 0, 0.01, 0.02, 0.05, 0.1, and 0.5 mg-N/L nitrite as sodium nitrite. The nitrite stock solution was prepared from J.T. Baker sodium nitrite. The 4500-NO_2^--B Colorimetric Method was used to determine nitrite concentrations in the samples and standards (Clesceri et al. 2005b). Samples were read on a Shimadzu UV160U UV Visible Recording Spectrophotometer with a detection limit of 0.005 mg-N/L NO_2^--N.

2.5.3 Nitrate

Samples of effluent were filtered to 0.22 μm to remove suspended particles.

Nitrate standards were prepared in concentrations of 0, 0.05, 0.10, 0.20, 0.50, and 1.0 mg N/L. The nitrate standards were prepared from 1000 ppm nitrogen as nitrate stock. The samples and standards were poured into 5.0 mL polyvials and sealed with filter caps. A 2 L container of an anion eluent solution was prepared containing 4.5 mM Na_2CO_3 (Fisher Scientific Sodium Bicarbonate CAT #:S233-500) and 1.4 mM $NaHCO_3$ (Fisher Scientific Sodium Carbonate CAT #:S263-500) and connected to the Dionex ICS- 1100 with ASRS 4 mm suppressor and Dionex IonPac AS22 column. The samples were placed in the autosampler and analyzed. The eluent flow in the instrument was set to 1.2 mL/min with a suppressing current of 34 mA. Each sample measuring time was set to a maximum of 12 minutes. Following sample analysis, peaks were checked at enlarged scales to check baseline measurements. The baseline was adjusted, if necessary, as shown in Figure 6. Measurements were then exported to Microsoft Excel to calculate the standard curve and apply the resulting linear equation to measured peaks of samples, achieving the amount of nitrate-N present in mg-N/L.

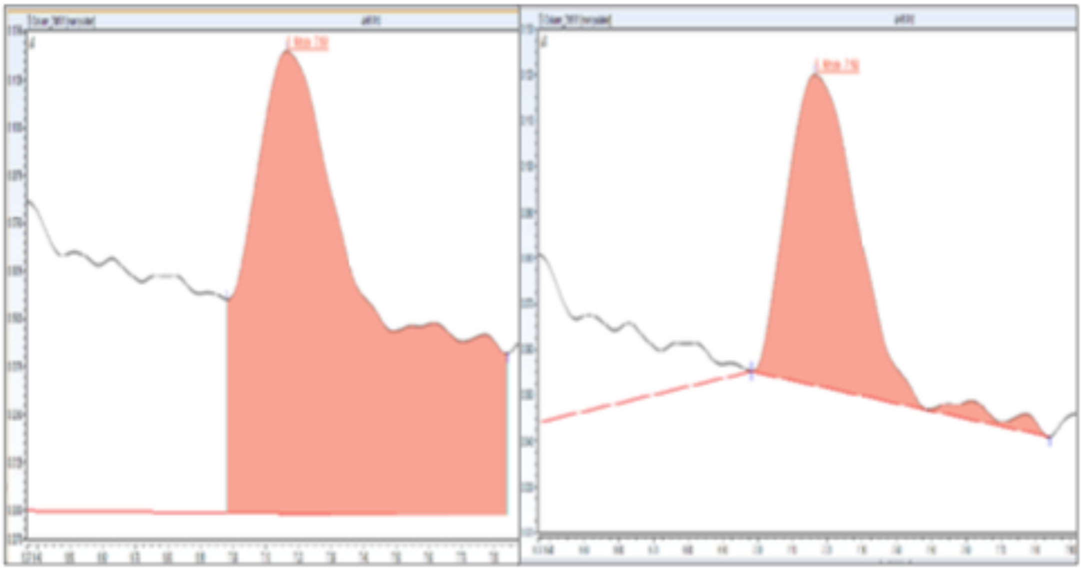


Figure 6. Nitrate baseline adjustment

2.5.4 Ammonium

Ten-milliliter samples of effluent were diluted to fit the linearization of the standard curve. Twenty-five-milliliter standards diluted from 5.0 mg/L ammonium chloride stock solution were prepared in concentrations of 0, 0.05, 0.1, 0.2, 0.5, and 1.0 mg/L ammonium as ammonium chloride from Fisher Scientific (A649- 500). The 4500-NH3 F Phenate Method was used to determine ammonium concentrations in the samples and standards (Clesceri et al. 2005a). Samples were read on a Shimadzu UV 160U UV Visible Recording Spectrophotometer with a detection limit of 0.025 mg-N/L.

2.5.5 Organic Nitrogen

Organic nitrogen was calculated by subtracting nitrate, nitrite, and ammonium from total nitrogen:

$$\text{Org N}=\text{TN}-([NO_3^--N]+[NO_2^--N]+[NH_4^+-N]) \qquad (3)$$

2.6 pH

Two-grams of the compost (by dry weight) were weighed out in triplicated and placed into centrifuge tubes. Forty-milliliters of deionized water were added to each tube. The tubes were centrifuged at 4000 RPM for 10 minutes. pH of the supernatant of each sample was measured using an Orion pH Meter Model 520A.

2.7 Quality Assurance and Control

If any sample measured out of the range of the standard curve, its dilution was adjusted until the measurement was within the range of the standard curve or considered below detection limit. Detection limit was considered to be half of the lowest standard.

All glassware used to contain or deliver the samples was washed with Alconox detergent powder, rinsed with tap water, then deionized water, soaked overnight in a 5 N hydrochloric acid (HCl) bath, rinsed with deionized water three final times, and left to air dry.

2.8 Statistical Methods

2.8.1 Detection Limit

Any values that read below detection limit were considered to be half of the lowest standard for statistical purposes ("AMC Technical Brief" 2001).

2.8.2 Statistical Tests

Two statistical tests were chosen determine if the data were statistically different: t-test on means and F-test on variance. The t-test was used to determine if the means of two data sets are the same. It is typically used to evaluate the performance of two processes or analytical laboratory results (Puppala et al. 2011). The F-test was used to determine if the sample variances were statistically different. A two-tailed test was used for each and a null hypothesis stated that the two sample means or variances were not statistically-different. The null hypothesis was rejected when the calculated critical value was greater than the critical values at the 95% confidence interval ($p<0.05$). All statistical analyses were done using StatPlus statistical software.

2.8.3 First Flush Determination

“First-flush” conditions occur when the initial portion of the effluent is more polluted than subsequent portions. There are many ways to define first-flush conditions, but generally they occur when a fraction of the total pollution is exported with a fraction of the total runoff. For simplicity, the definition of first-flush that was chosen for this paper, was defined by Deletic (1998) and states that first-flush effects are observed when 40% of the pollutants are exported with 20% of the runoff.

Chapter 3: Results and Discussion

3.1 Moisture Content and Bulk Density

Moisture content and bulk density measurements were calculated for 100% washed and unwashed compost and BSM, as well as the 30% washed and unwashed and 15% media (Table 2). For concision, the compost/BSM mixtures will be referred to as media, 100% compost will be referred to as compost, and 100% BSM will be referred to as BSM. The average percent moisture in the compost was 44 ±0.078%, which is consistent with the compost technical data (Appendix A). The washed compost and 30% washed media had reduced moisture contents (7.8±0.36% and 3.5±0.067%, respectively) because the washed compost was allowed to air dry overnight after the washing procedure was complete. The 30% media had a moisture content of 15±0.16%, while the 15% media was just below that value, at 12±0.24%. BSM had a much lower moisture content than the compost (9.4±0.80%), excluding the washed media.

Bulk density measurements were calculated to determine the mass of dry compost, BSM, and media per unit volume, as well as to normalize effluent concentration measurements to mass of nutrient per mass of dry matter. The BSM had the largest bulk density (1,900±470 kg dry BSM/m^3). Additionally, the media all had higher bulk densities (1,100±31, 980±21, and 1,100±54 kg dry media/m^3 for the 30% washed, 30%, and 15% mixtures, respectively) than the compost, due to the addition of BSM. The compost had bulk densities of 340±11 and 430±25 kg/ m^3 dry compost for the unwashed and washed composts, respectively.

Table 2. Water content and wet and dry bulk densities of compost BSM, and media ± standard deviation (SD); n=4 for 100% compost, 30%compost: 70% BSM, and 15% compost:85% BSM for wet and dry bulk densities and n=5 for 100% washed, 30% washed compost:70% BSM and 100% BSM for wet and dry bulk densities

Mixture	**Average Moisture Content (%) n=3**	**Average Wet Bulk Density ($kg/m^{3)}$**	**Average Dry Bulk Density (kg/m^3)**
100% compost	44±0.078	580±18	340±11
100% washed compost	7.8±0.36	470±28	430±25
30% compost:70% BSM	15±0.16	1,200±24	980±21
30% washed compost:70% BSM	3.5±0.067	1,100±32	1,100±31
15% compost:85% BSM	12±0.24	1,200±60	1,100±54
100% BSM	9.4±0.80	2,100±521	1,900±470

3.2 Extractions

3.2.1 Water Soluble Phosphorus

Water soluble phosphorus or $CaCl_2$-extractable phosphorus has been found to correlate with phosphorus concentrations in runoff (Sharpley, 1995; Pote et al. 1996 as cited in Moore and Joern 2009). The compost overwhelmingly had the highest water soluble P content (74±2.6 mg-P/kg dry compost) (Table 3). These results were relatively consistent with a similar study that determined the water soluble P of biosolids, that were also from Back River Wastewater Treatment Plant in Baltimore, was 138 mg-P/kg dry matter (Leytem et al. 2004). However, the results were inconsistent with two other studies which found that water soluble P content of composted biosolids was much lower: 14 mg/kg dry matter (Bøen et al. 2013) or much higher: 352 mg-P/kg in a 1:1 biosolids compost to composted yard waste mixture (Zhang et al. 2004). The 15% and 30% washed media and 100% washed compost all had similar water soluble P values (2.4±0.23 and 1.3±1.4 mg-P/dry media and 1.9±3.6 mg-P/kg dry compost, respectively) (Table 3). However, the 15% media had the highest value among these three mixtures. Therefore, the washing procedure most likely washed out much of the water soluble P from the compost. It is also important to note that reducing the percent of compost from 100% to 30% to 15% did not reduce extractable-P by the same percentages, which suggests that the BSM was able to remove some of the P from the compost, most likely via adsorption. This relationship was also observed in the Mehlich 3-extractable P and KCl-extractable N results.

The BSM used contains calcium and magnesium (Appendix B), both of which can bind to phosphate. Moreover, though not a part of the BSM specifications (Appendix B), BSM containing Fe and Al will also be successful at adsorbing phosphate. The phosphorus saturation index is a ratio of oxalate-extractable phosphate to aluminum and iron and is used to determine a soil's capacity to retain phosphate ("Phosphorus Saturation Index" 2016). Unsurprisingly, the BSM had the lowest dissolved P content (0.049±0.0 mg-P/kg dry BSM).

3.2.2 Mehlich 3-Extractable Phosphorus

The Mehlich 3-extractable phosphorus test was chosen because it is suitable for extracting phosphorus from acidic and neutral soils (NRCS 2016). Compared to water soluble phosphorus concentrations, every mixture had a significantly higher Mehlich 3-extractable phosphorus content. The compost had the highest value of Mehlich 3-extractable P (820±200 mg-P/kg dry compost) (Table 3). A three-year field study showed biosolids-derived compost had a Mehlich 3-extractable P range of 66.8-110 mg-P/kg (Spargo et al. 2006), which the compost in this study far exceeded. The 30% media had the next largest value of P (420±51 mg-P/kg dry media). The washed compost and 15% media had very comparable values on a dry mass basis (250±50 mg-P/kg dry compost and 260±8.3 mg-P/kg dry media, respectively). The 30% washed had the lowest value among the compost mixtures (73±16 mg-P/dry media) (Table 3). The BSM only had 1.0±0.080 mg-P/kg dry BSM of Mehlich 3-extractable P.

3.2.3 KCl-Extractable Nitrogen

KCl was used to extract total inorganic nitrogen from the compost and BSM. As expected, the compost had the highest N value (16,000±270 mg-N/kg dry compost), while BSM had the lowest (4.3±0.64 mg-N/kg dry BSM) (Table 3). The nitrogen content in this study was much more than in similar studies where the total nitrogen (TN) content of biosolids compost was found to be 11,500 mg/kg dry matter (Bøen et al. 2013). The washed compost had 5,900 mg-N/kg dry compost, which was 37% of the nitrogen content of the unwashed compost. The 30% washed media had reduced N from the 30% unwashed media by 66%: 410±25 mg-N/kg dry media in washed vis-à-vis 1,200±100 mg-N/kg dry media in the unwashed. Lastly, the 15% media had a slightly higher value of N than the 30% washed media, with 530±26 mg-N/kg dry media.

Table 3. KCl-N, $CaCl_2$-P, and Mehlich 3-P extractions summary (mg-X/L ±SD and mg-X/dry matter ±SD; n=3)

	KCl-Extractable N		**$CaCl_2$-Extractable P**		**Mehlich 3-Extractable P**	
Mixture	**(mg-N/L)**	**(mg-N/kg dry matter)**	**(mg-P/L)**	**(mg-P/kg dry matter)**	**(mg-P/L)**	**(mg-P/kg dry matter)**
100% compost	2,200±68	16,000±270	1.7±0.058	74±2.6	46±12	820±200
100% washed compost	1,400±160	5,900±710	0.071±0.17	1.9±3.6	23±3.7	250±50
30% compost:70% BSM	260±21	1200±100	$0.18\pm6.3\text{x}10^{-3}$	5.3±0.17	36±0.050	420±51
30% washed compost:70% BSM	99±6.1	410±25	0.050±0.065	1.3±1.4	7.0±1.2	73±16
15% compost:70% BSM	120±6.1	530±26	$0.087\pm7.7\text{x}10^{-3}$	2.4±0.23	23±0.020	260±8.3
100% BSM	0.98±1.2	4.3±0.64	$1.8\text{x}10^{-3}\pm0.0$	0.049±0.0	0.093±0.15	1.0±0.080

3.2.4 Washed Compost Effluent Phosphorus Characteristics

The compost leachate from the washing procedure was tested for phosphorus species (Table 4). The leachate had a comparable TP (79±17 mg-P/kg dry compost) to water soluble P (74±2.6 mg-P/kg dry compost). DOP (45±6.3 mg-P/kg dry compost) was found to be lower than water-soluble P. However, Mehlich 3-extractable P (820±200 mg-P/kg dry compost) was much higher than TP in the effluent. It is understandable that extracted water soluble P would relate to TP in the effluent since the compost was flushed with tap water and that Mehlich 3-P would be higher than P in the effluent. Mehlich 3 extractant is strongly acidic, as well as a chelating agent that is effective at extracting multiple forms of P (NCAGR 2016). Finally, PP and SRP (orthophosphate) averaged 10±13 and 29±6.6 mg-P/kg dry compost, respectively. Neither value was relatable to the extraction data. It is important to note that the P species concentrations were highly variable due to the high concentrations. The samples had to be diluted multiple times to fall within the range of the standard curve and detection limit of the UV-Vis spectrophotometer.

Table 4. Phosphorus characteristics of washed compost effluent (reported as average values ±SD; n=5)

	Total Phosphorus (TP)	**Soluble Reactive Phosphorus (SRP)**	**Dissolved Organic Phosphorus (DOP**	**Particulate Phosphorus (PP)**
Concentration (mg-P/L)	27±5.8	9.8±2.2	15±2.2	3.52±4.5
mg-P/kg dry compost	79±17	29±6.6	45±6.3	10±13

3.2.5 Washed Compost Effluent Nitrogen Characteristics

The nitrogen leachate concentrations for the compost were high for all forms of nitrogen, except nitrite (Table 5). Total nitrogen had an average of 11,000 mg-N/kg dry compost, which was less than KCl-extractable N (16,000±270 mg-N/kg dry compost). It was expected that KCl-extractable N would have been less than or closer to the leached TN because KCl extracts mineralized N (ammonium and nitrate), but TN measures all forms of N, combusted to inorganic forms.

However, the TN in the leachate agreed with the previously mentioned study by Bøen et al. (2013) that found TN in biosolids-compost to be 11,500 mg/kg dry matter. The majority of the leachate consisted of ammonium, which averaged 7,300 mg-N/kg dry compost. Organic nitrogen was the next most prevalent component, with a concentration of 3,100±2,800 mg-N/kg dry compost. Finally, nitrate and nitrite were much lower than ammonium and organic N: 230±790 mg-N/kg dry compost and 0.47 mg-N/kg dry compost, respectively. The samples had to be diluted multiple times due to the high concentrations so that they would fall within the range of the standard curve and detection limits of the TOC/TN Analyzer, UV-Vis spectrophotometer, and IC. This most likely led to the high variability of concentrations among the samples.

Table 5. Nitrogen characteristics of washed compost effluent (reported as average values ±SD; n=3)

	Total Nitrogen	**Ammonium**	**Nitrate**	**Nitrite**	**Organic Nitrogen**
Concentration (mg-N/L)	3,640±1,600	2,500±610	79±27	0.16±0.040	1,100±950
mg-N/kg dry compost	11,000±4,600	7,300±1,800	230±790	0.47±0.12	3,100±2,800

3.3 pH Values

pH values were taken from the 100% compost only and averaged 6.54±0.031, which was slightly acidic. This was unexpected because the compost was limed, but concentrations of $CaCO_3$ were low (Appendix A). Moreover, pH was tested by the composting facility and found to be 7.29 (Appendix A). However, other studies have concluded that biosolids-derived compost can be slightly acidic (Zhang et al. 2004; Spargo et al. 2006). The compost analyzed for pH was taken from a compost batch that had been stored for 5 months in a sealed container. The compost could have been undergoing anaerobic decomposition, which produced organic acids, and lowered the pH (Trautmann et al. 2016).

3.4 30% and 15% Mesocosm Results

The 30% mesocosm trial was a short-term trial, lasting 8 weeks, which was extended into a long-term trial, lasting 10 months. Approximately 7.9 m and 28 m of synthetic stormwater were applied to the short-term and long-term trials, respectively. For clarity, these values were also discussed in months and years of rainfall, based on the average annual rainfall in Maryland, in addition to depth of applied water. Therefore, the short-term storm had the equivalent of 4.6 months of applied MD rainfall, while the long-term study extended to 1 year and 4 months of MD rainfall. The following equation was used to calculate these values:

$$\frac{depth\ of\ applied\ rainfall}{average\ annual\ rainfall\ in\ Maryland} * \left(\frac{1}{20}\right) \qquad (4)$$

Depth of applied rainfall depended on the mesocosm trial, but was approximately a total of 8.0 m of applied stormwater per column trial, average annual rainfall in Maryland is 1.04 m (40.76 in) (Papenfuse 2016) and 1:20 is the assumed ratio of bioretention area to column area.

During the 30% mesocosm trial, synthetic stormwater was applied to the column at a rate of 15.2 cm/hr for storms 1-4 and 7-8. Flow rate was halved to 7.6 cm/hr during storm 5 and doubled during storm 6 to 31 cm/hr. Samples were collected every 30 minutes for the first 2 hours and every hour for the remaining 4 hours. For storms with a flow rate of 15.2 cm/hr, it took approximately 45 minutes after the start of the water application to begin collecting the first sample and it took an average of 4 minutes to fill each sample bottle (250 mL). However, the first sample taken typically took longer than 4 minutes to collect. For the halved flow rate storm, it took over an hour from the time water was applied to the column to begin collecting the first sample and approximately 20 minutes when the flow rate was doubled. Effluent continued to flow out of the column, but began to trickle approximately 15 minutes after water application ceased. Samples from the first storm were turbid and brown in color (Figure 7), but lightened to a pale yellow by the end of the trial. For comparison, Figure 8 shows the samples collected during the first applied storm to the control. They were clear and essentially colorless. Moreover, by the end of the long-term trial, roots from the sod had permeated the media approximately half-way (38.5 cm) down the column.

Figure 7. 30% mesocosm storm 1 samples collected during 0.92 m of applied stormwater (0.50 month of MD rainfall). The first 4 samples were collected every 30 minutes, the next 4 were collected every hour, and the remaining 2 were collected immediately after water application to the column ceased.

Figure 8. Control storm 1 samples collected during 0.91 m of applied stormwater (0.50 month of MD rainfall). The first 4 samples were collected every 30 minutes, the next 4 were collected every hour, and the remaining 2 were collected immediately after water application to the column ceased.

In the 15% mesocosm trial, the amount of compost used was reduced from 30% to 15%, with the remainder of the mixture as BSM. Every other variable was kept the same including stormwater composition, flow rate adjustments, and sampling. However, this column was not run for a long-term period. Sampling ended after 8 storms, upon which, 7.8 m of stormwater were applied (4.5 months of MD rainfall). Like in the 30% mesocosm trial, it took approximately 40 minutes for the influent to flow through the column during the 7.6 cm/hr storms, over an hour for the halved flow rate storm, and approximately 20 minutes for the doubled flow rate storm, 4 minutes to collect each sample (for the 7.6 cm/hr storms), and 15 minutes for the effluent to begin to trickle after water application ended (for the 7.6 cm/hr storms). The samples from the first storm were also brown in color, but less opaque than the 30% mesocosm samples (Figure 9).

Figure 9. 15% mesocosm storm 1 samples collected during 0.91 m of applied stormwater (0.50 month of MD rainfall). The first 4 samples were collected every 30 minutes, the next 4 were collected every hour, and the remaining 2 were collected immediately after water application to the column ceased.

3.4.1 Total Phosphorus

The 30% mesocosm demonstrated consistent total phosphorus leaching effects throughout the duration of the trial (Figure 10). Initially, 12 mg-P/L leached during the first storm. The effluent TP concentrations dropped to 1.6 mg-P/L by the end of the short-term trial, but never dropped below influent concentrations, which averaged 0.32±0.088 mg-P/L. Additionally, TP effluent concentrations from the 30% mesocosm far exceeded those of the control mesocosm. The control mesocosm had a maximum TP concentration of 0.44 mg-P/L and a final concentration of 0.030 mg-P/L, with an average of 0.11±0.09 mg-P/L.

Other studies have have shown either much higher or lower TP concentrations in runoff from biosolids compost. A comparable column study evaluated the effects of compost feedstock on bioretention, analyzing a mixture of 60% sand/40% biosolids and yard waste, by applying 900-1600 mL of stormwater per storm event. The compost leached a total TP concentration of 23.3 mg-P/L across all biosolids compost BSM mixtures studied. However, 35% TP removal, from an 89% sand/7%

biosolids and yard waste compost/4% water treatment residual (WTR) BSM, was observed by the 4th storm event, even though the influent concentrations of TP were much higher than in this study (1.0 ±0.2 mg-P/L vis-à-vis 0.32±0.088 mg-P/L). No removal was observed from the 91% sand/9% compost mixture, even though TP concentrations decreased during 12 leachings with either 900 or 1600 mL of synthetic stormwater (Brown et al. 2016).

In a field study that analyzed runoff from biosolids compost-amended soil, Puppala et al. (2011), determined the TP concentration from 20% biosolids compost and 80% control soil averaged 1.9 mg-P/L, which was significantly lower than the the average TP concentration in the 30% meosocosm study or found by Brown et al. (2016), but still relatively high.

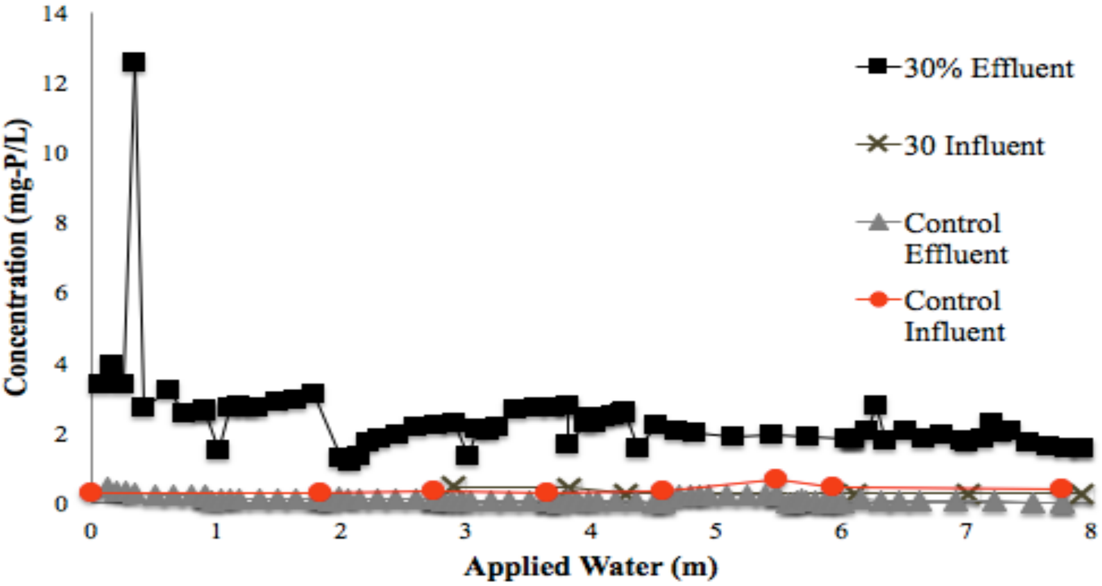


Figure 10. 30% mesocosm total phosphorus concentration (mg-P/L) during 7.9 m of applied MD stormwater (4.6 months of MD rainfall)

Phosphorus continued to leach from the 30% mesocosm after 28 m of applied water equivalent to over 1 year of rainfall (Figure 11). The effluent TP concentration reduced to 0.72 mg-P/L, but was still above influent concentrations.

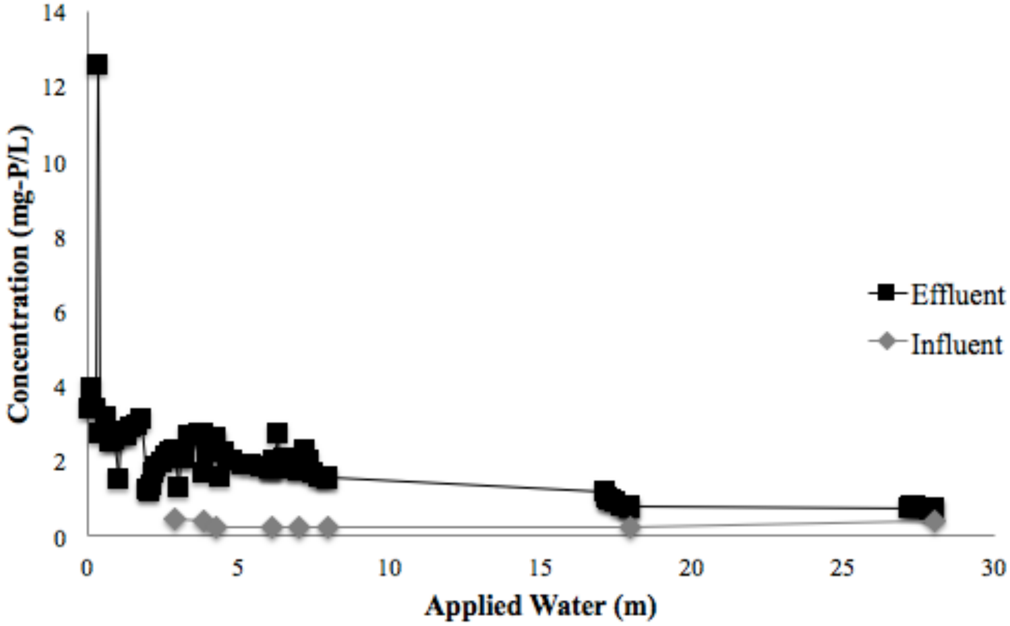


Figure 11. 30% mesocosm total phosphorus concentrations (mg-P/L) during 28 m of applied MD stormwater (1 year and 4 months of MD rainfall)

Maximum total phosphorus for the 15% mesocosm reached only 4.9 mg-P/L (Figure 12). The concentration declined during the first storm to 0.8 mg-P/L, but spiked during the second storm to 2.4 mg-P/L. However, during the remaining 6 storms, TP leveled off to an average concentration of 0.51±0.13 mg-P/L. This average concentration is consistent with Brown et al. (2016) who found a TP concentration of 0.648 mg-P/L during the 4th storm event applied to the sand/compost/WTR column. However, final average TP concentration was lower than the average TP in runoff leachate from biosolids compost-amended soil (Puppala et al. 2011). Influent TP concentrations averaged 0.21±0.049 mg-P/L, which was lower than the column TP effluent concentration. Moreover, the 15% effluent remained above that of the control.

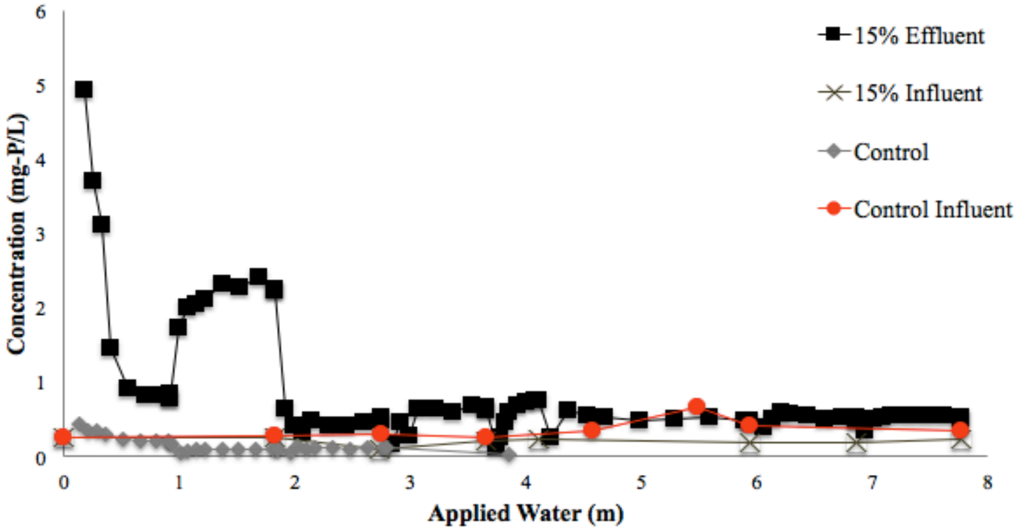


Figure 12. 15% mesocosm total phosphorus concentration (mg-P/L) during 7.8 m of applied stormwater (4.5 months of MD rainfall)

By using 50% less compost, the overall average TP was reduced by 62% (0.89±0.84 vis-à-vis 2.4±1.3 mg-P/L), compared to the 30% mesocosm. It is clear that the 15% mesocosm had consistently lower TP concentrations than the 30% mesocosm (Figure 13). Despite this, removal was still not observed in either column. Additionally, the t-test ($p=4.2x10^{-13}$) and F-test (p=0.00018) both determined that the two columns had statistically-different mean TP effluent concentrations (0.90±0.85 vis-à-vis 2.3±1.3 mg-P/L for the 15% and 30% mesocosms, respectively).

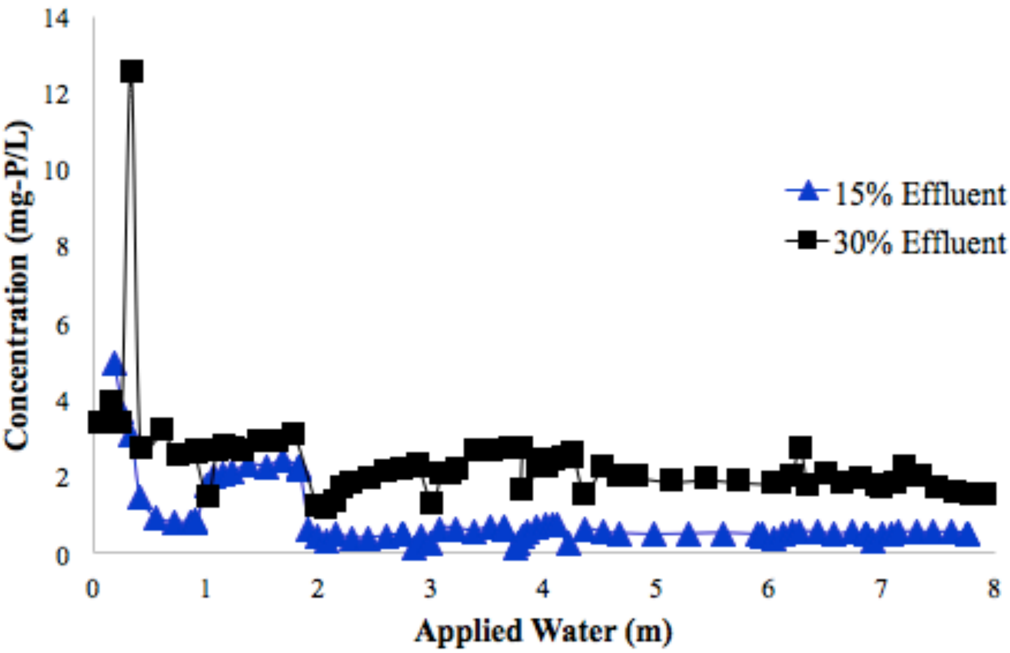


Figure 13. Comparison of total phosphorus concentrations (mg-P/L) from the 15% and 30% mesocosms during 7.8 m of applied stormwater (4.5 months of MD rainfall)

The 30% mesocosm exported a total of 470 mg-P (210 mg-P/kg dry media) after 7.9 m of applied water (4.6 months of MD rainfall) (Figure 14). This mesocosm trial continuously exported a significant mass of TP, which increased to 1.1 g-P (470 mg-P/kg dry media) by the end of the long-term trial (Figure 15). Long-term export that occurred between storms 8 and 19 and storms 19 and 29 was assumed to be linear. The long-term export agreed with the Mehlich 3-extractable P in the 30% compost mixture (420±51 mg-P/kg dry media). On the contrary, the control only exported 23 mg-P (5.1 mg-P/kg dry BSM) after 7.8 m of applied water, whereas 52 mg-P were applied to the mesocosm by the end of the trial. Therefore, removal was observed in the control column. The BSM leachate did not agree with either $CaCl_2$-extractable P (0.049±0.25 mg-P/kg dry BSM) or the Mehlich 3-P (1.0±0.080 mg-P/kg dry BSM). However, this makes sense because the BSM should have a very low P content, so the influent was the source of most of the P in the mesocosm effluent, rather than leached from the BSM itself.

Cumulative mass export was also used to calculate Event Mean Concentration (EMC) for the overall trial (equation 5).

$$EMC = \frac{cumulative\ mass\ export\ (mg)}{total\ applied\ volume\ (L)} \qquad (5)$$

The EMC for the short-term trial was 2.1 mg-P/L and the long-term EMC was 1.3 mg-P/L. These values were representative of the effluent mean TP concentrations (2.4±1.3 and 2.0±1.3 mg-P/L for the short and long-term trials, respectively). For comparison, the BSM EMC was only 0.10 mg-P/L.

To place P export into perspective, cumulative export was converted to years of watershed P export, based on the average annual input load of P to a bioretention system (3.0 kg/ha/year) (Liu and Davis 2013), area of the column (285 cm^2), and drainage area size the column can treat (assumed to be 20 times the area of the column), using the following equation:

$$Years\ of\ watershed\ P = \left(\frac{P\ export}{(A\ of\ column)(20)}\right)/(3.0\ kg/ha/year) \qquad (6)$$

Using equation 6, 3.0 years of watershed P were exported after 4.5 months of MD rainfall and 6.4 years of watershed P were exported after over 1 year of MD rainfall from the 30% mesocosm. Only 1.6 months of watershed P were exported from the control mesocosm after 4.5 months of applied MD rainfall.

The 15% mesocosm exported 170 mg-P (1 year of watershed P) after 7.8 m of applied stormwater, which was much more than the control mesocosm and mass applied in the influent (45 mg-P) (Figure 14). However, when compared to Mehlich 3-extractable P in the 15% media (260±8.3 mg-P/kg dry media), the amount exported from the mesocosm was much less (65 mg-P/kg dry media). Additionally, the 15% mesocosm exported 64% less TP than the 30% mesocosm. The 15% mesocosm EMC was 0.77 mg-P/L, which was slightly lower than the mean effluent concentration of 0.89±0.84 mg-P/L.

Unlike the 30% mesocosm, the 15% mesocosm exhibited first flush effects because 67 mg-P (40% of total P export) were exported during the first 20% or 1.5 m of applied stormwater. This was surprising because the maximum concentration of TP in the 15% mesocosm was not much higher, relative to the subsequent concentrations. There was a more gradual TP decline, rather than a high initial TP spike that quickly decreased.

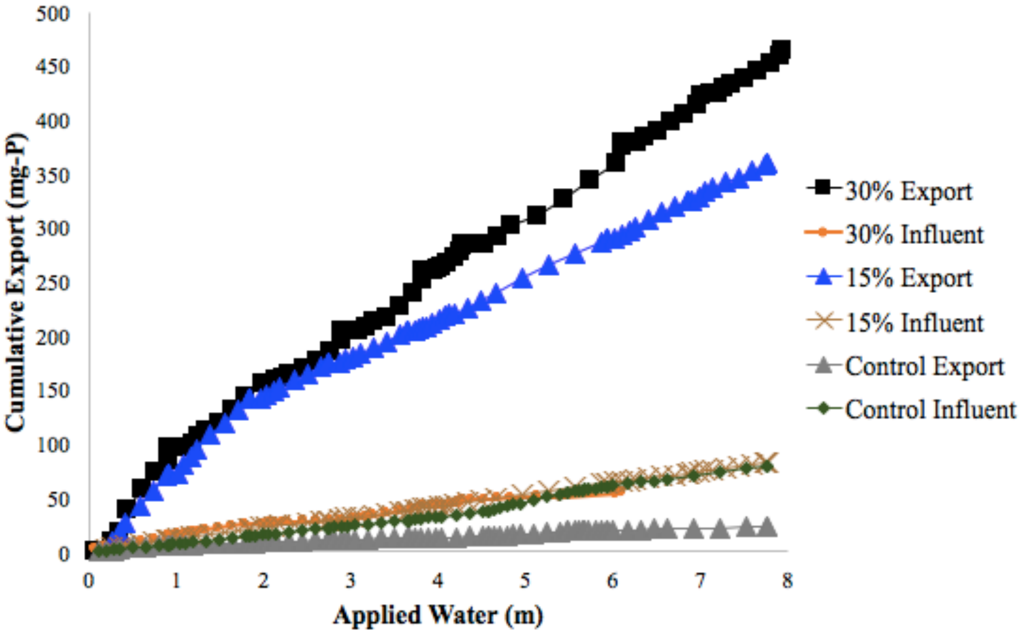


Figure 14. 15% and 30% mesocosm total phosphorus cumulative export (mg-P) during 7.8 m of applied stormwater (4.5 months of MD rainfall)

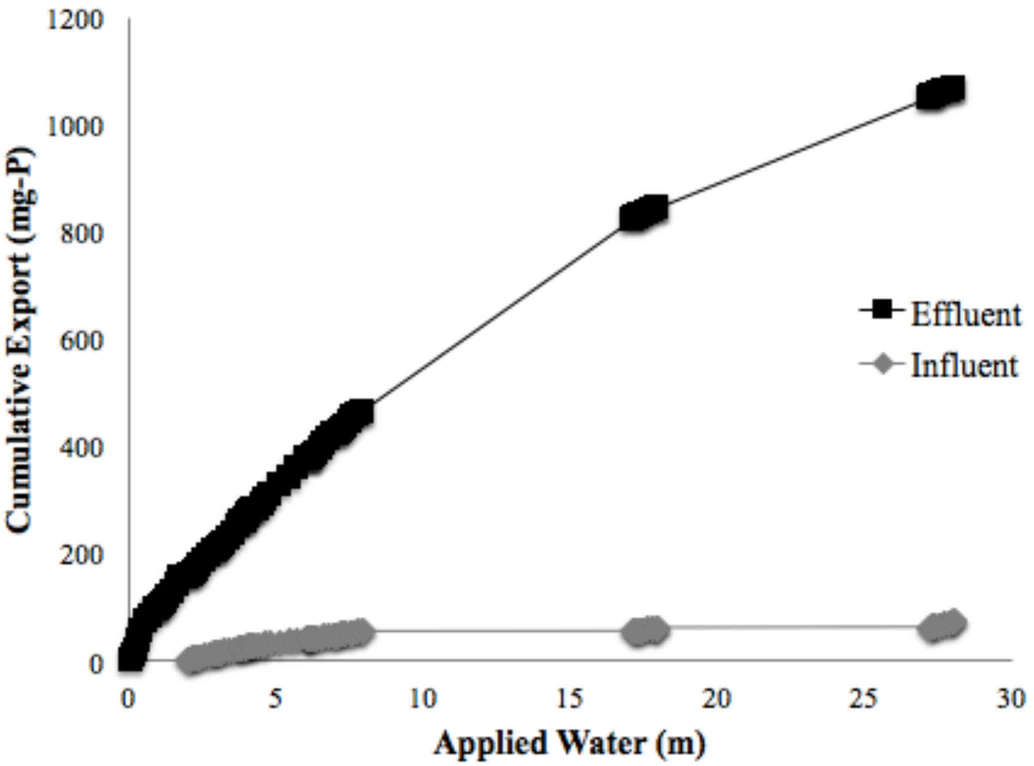


Figure 15. 30% mesocosm long-term total phosphorus cumulative export (mg-P) during 28 m of applied stormwater (1 year and 4 months of MD rainfall)

3.4.2 Phosphorus Speciation

In the first storm applied to the 30% mesocosm, a large washout of particulate phosphorus (PP) and dissolved organic phosphorus (DOP) was observed, with a maximum PP concentration of 10 mg-P/L and maximum DOP of 3.5 mg-P/L (Figure 16). Dissolved phosphorus (DP) is mechanistically more difficult to remove than PP. It is typically removed through adsorption to metal oxides such as Al and Ca oxide, but these reactions are highly pH dependent (Li and Davis 2016). However, in this study, the DOP component of DP dropped to below detection limit (0.025 mg-P/L). As the trial progressed, soluble reactive phosphorus (SRP) or orthophosphate, was the predominant species and leached continuously, with a concentration of 2.2 mg-P/L after 7.9 m of applied stormwater. This is consistent with a column study on biosolids compost used for agriculture. The study determined that 100 mg/ha of biosolids compost mixed with municipal solid waste leached between 1.12-6.65 mg/L of phosphate after being flushed with 34 cm of deionized water (Li et al. 1997). However, the results are inconsistent with another column study that observed a rapid, rather than gradual, leaching of phosphate from 25-100% 1:1 biosolids/yard waste compost mixed with peat-based medium, used for horticulture (Xia et al. 2013).

The control mesocosm leached an average SRP concentration of 0.02±0.0063 mg-P/L, 0.020±0.030 mg-P/L of DOP, and 0.030±0.010 mg-P/L of PP, which were all below the P species concentrations in the 30% mesocosm effluent.

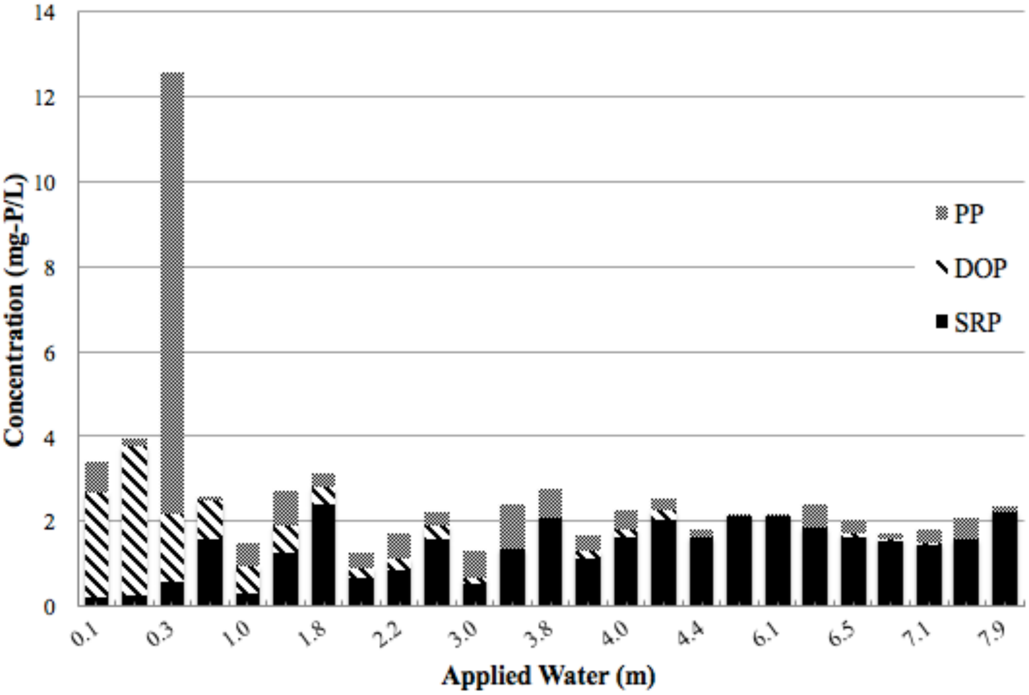


Figure 16. 30% mesocosm phosphorus speciation concentrations (mg-P/L) during 7.9 m of applied stormwater (4.6 months of MD rainfall)

By the end of the long-term trial, DOP concentrations remained below 0.025 mg-P/L and PP was just above detection limit at 0.030 mg-P/L (Figure 17). However, SRP continuously leached, with a final concentration of 0.62 mg-P/L after 28 m of applied water.

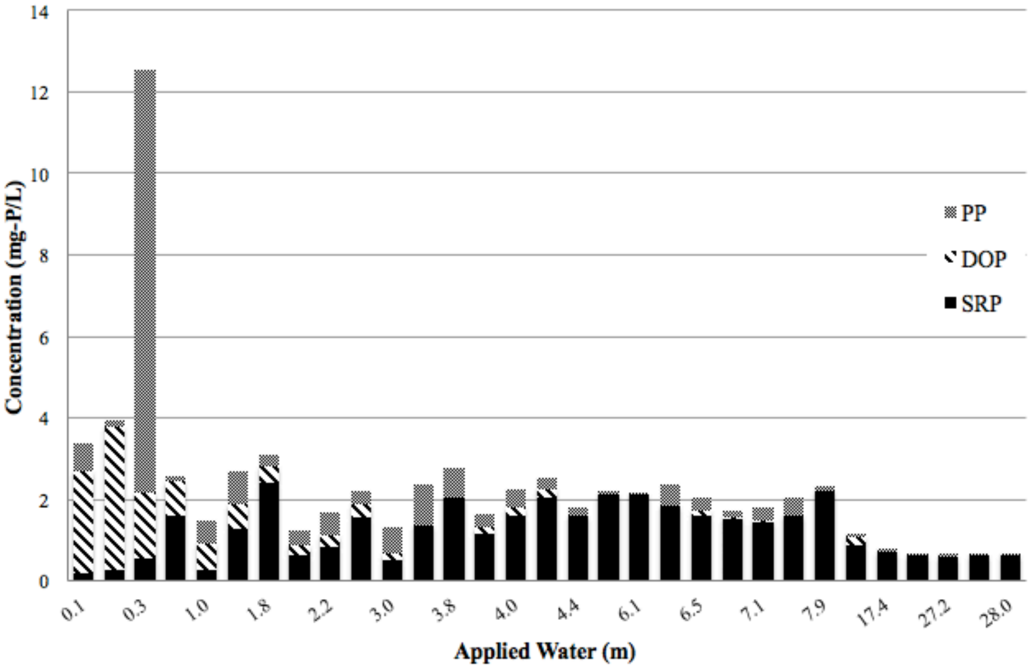


Figure 17. 30% mesocosm long-term phosphorus speciation concentrations (mg-P/L) during 28 m of applied stormwater (1 year and 4 months of MD rainfall)

During the short-term trial, 64% (110 out of 180 mg-P) of PP and 65% (41 out of 64 mg-P) of DOP were exported in the first storm, but both were exported at a slower rate thereafter (Figure 18). SRP was continuously exported during the entire short-term trial, with a final cumulative export of 300 mg-P. For comparison, the control mesocosm exported 3.5 mg-P of SRP, 5.1 mg-P of DOP, and 14 mg-P of PP, all of which the 30% mesocosm exceeded.

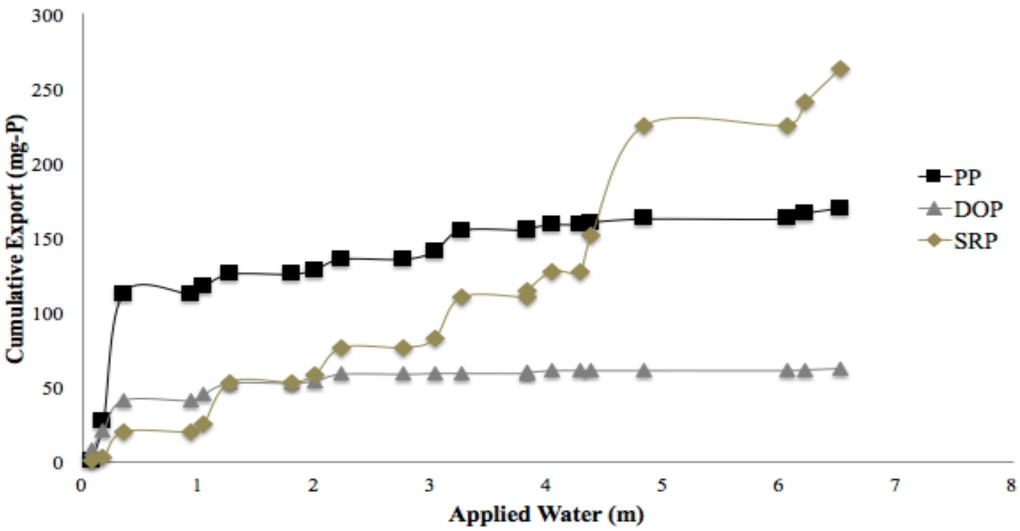


Figure 18. 30% mesocosm phosphorus speciation cumulative export (mg-P) during 7.9 m of applied stormwater (4.6 months of MD rainfall)

During the long-term trial, SRP export tripled, with a final cumulative export of 900 mg-P. DOP and PP had final exports of 87 mg-P and 230 mg-P, respectively (Figure 19). Long-term export that occurred between storms 8 and 19 and storms 19 and 29 was assumed to be linear for each P species. Mass of PP and DOP appeared to stop accumulating during the long term trial. However, this observation was due to the scale of the graph, not due to a halt in accumulation of export. Export during the first 4.0 m was much more rapid than that during the long-term storms.

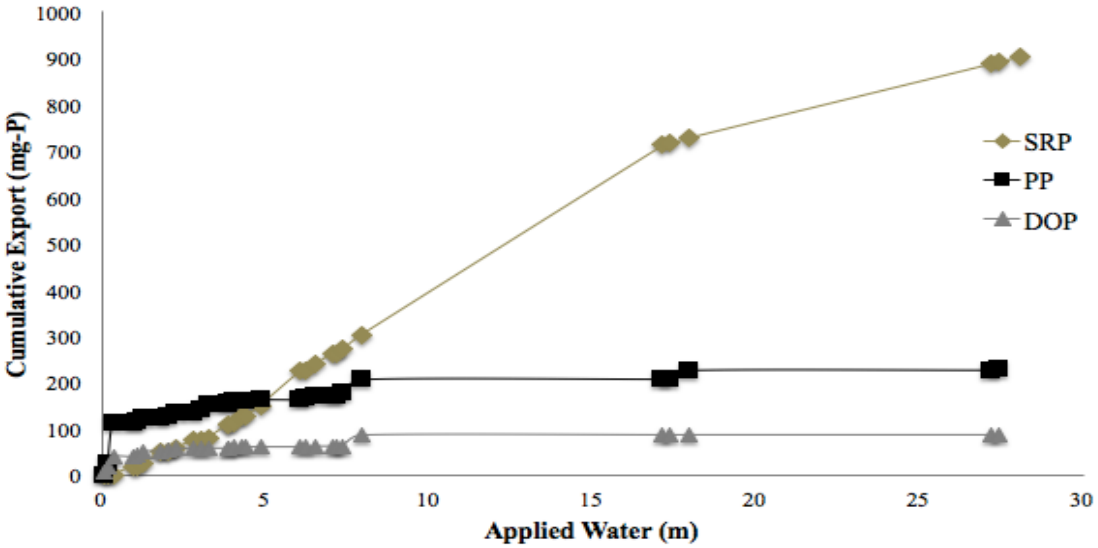


Figure 19. 30% mesocosm long-term phosphorus speciation cumulative export (mg-P) during 28 m of applied stormwater (1 year and 4 months of MD rainfall)

The 15% mesocosm saw an 83% reduction in maximum PP concentration (1.8 mg-P/L vis-à-vis 12 mg-P/L) and a more constant leaching of PP was observed, rather than a big washout at the beginning of the trial, compared to the 30% mesocosm (Figure 20). The final PP concentration remained well above detection limit at 0.15 mg-P/L. The maximum DOP concentration of 3.6 mg-P/L was comparable to the maximum concentration of 3.5 mg-P/L in the 30% mesocosm. However, DOP also remained just above detection limit with a final concentration of 0.030 mg-P/L. Finally, though SRP continuously leached in the 15% mesocosm, the overall concentration was much lower than that of the 30% mesocosm (average of 0.31±0.16 vis-à-vis 1.4±0.65 mg-P/L for the 15% and 30% mesocosms, respectively). This was much lower than orthophosphate concentrations found by Xia et al. (2013) leached from 20-30% biosolids compost mixed with 70-80% municipal solid waste and from land-applied biosolids compost (Puppala et al. 2011). Moreover, the 15% mesocosm phosphorus speciation leaching far exceeded that of the control.

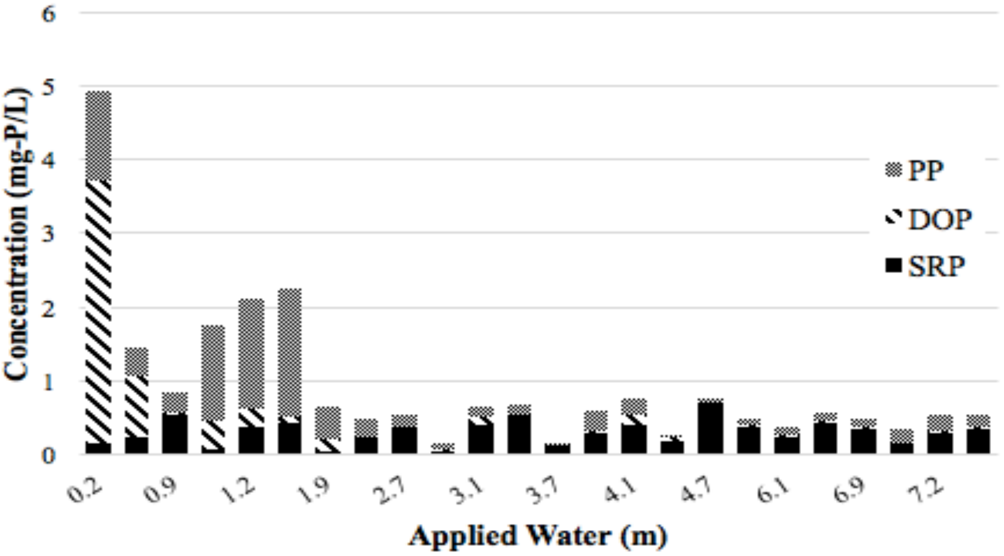


Figure 20. 15% mesocosm phosphorus speciation concentrations (mg-P/L) during 7.8 m of applied stormwater (4.5 months of MD rainfall)

Even though a higher concentration of DOP was observed, as opposed to SRP, SRP exported a larger mass (76 vis-à-vis 30 mg-P) after 7.8 m of applied stormwater (Figure 21). Compared to the 30% mesocosm, the 15% mesocosm had a 75% and 54% reduction in SRP and DOP, respectively. Sixty-eight mg-P of PP were exported by the end of the trial, which was a 62% reduction over the 30% mesocosm. Even though P export reduced overall, compared to the 30% mesocosm, the 15% mesocosm still exported much more P than the control mesocosm.

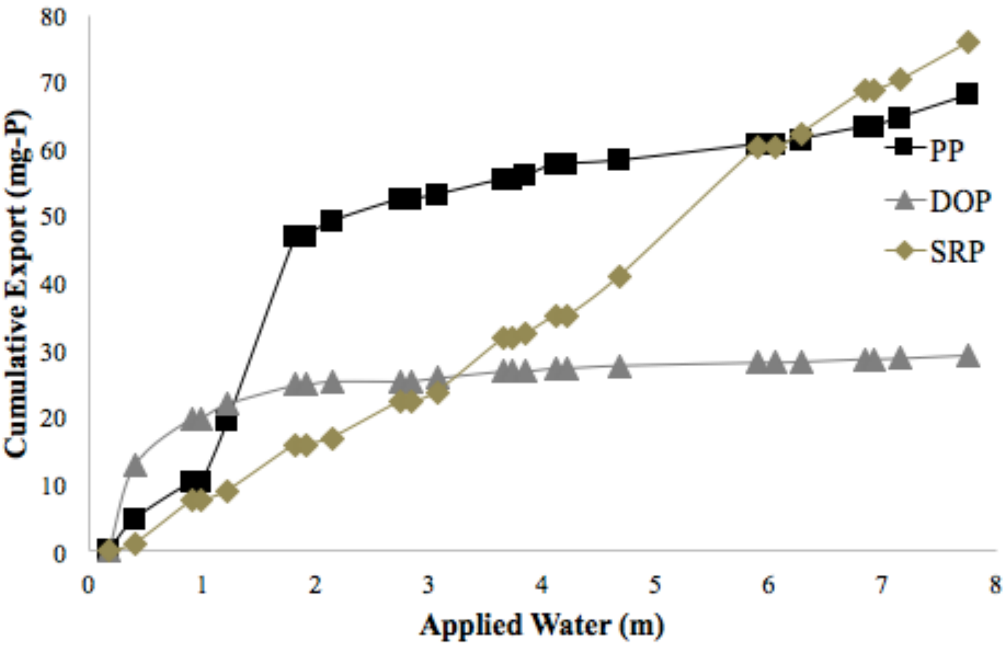


Figure 21. 15% mesocosm phosphorus speciation cumulative export (mg-P) during 7.8 m of applied stormwater (4.5 months of MD rainfall)

3.4.3 Effect of Flow Rate on Phosphorus Leaching

The F-test was chosen to determine which t-test to use: homoscedastic or heteroscedastic. The homoscedastic t-test was used when the variances were equal and the heteroscedastic t-test was used when the variances were unequal. Either of these two t-tests were used to make comparisons between the different mesocosms (as discussed later). The paired t-test was chosen to determine differences in nutrient leaching as caused by a change in flow rate applied to the mesocosm. Samples were deemed to be statistically-different if $p<0.05$ (95% significance). However, statistical difference was more certain as the p value decreased.

To determine if flow rate had an effect on phosphorus leaching, flow rate was halved to 7.6 cm/hr during storm 5 and doubled to 31 cm/hr during storm 6 (Figure 22). Mean total phosphorus concentration for each storm was calculated. Storm 5 (halved flow rate) had a mean TP concentration of 2.4±0.27 mg-P/L and storm 6 (doubled flow rate) had a mean TP concentration of 1.9±0.15 mg-P/L. The F-test determined that the two variances were statistically the same ($p=0.068$). The t-test determined that the two sample means were different ($p=1.0 \times 10^{-7}$), so flow rate did have an effect on TP leaching. It is important to note that these storms were run sequentially and not simultaneously. Therefore, any differences between the two data sets could have occurred because column conditions were not replicated.

SRP and PP were both unaffected by flow rate ($p=0.59$ and 0.73 for the F test and $p=0.12$ and 0.059 for the t-test). The statistical similarities for SRP between the two storms can be explained because SRP was the only P species to consistently leach, even during the long-term storms. Moreover, the halved flow rate was ineffective at washing out PP, so it was still detectable during the doubled flow rate storm. DOP had statistically different mean concentrations and variances ($p=2.2 \times 10^{-19}$ and 0.00012 for the F and t-tests, respectively). DOP dropped to below detection limit (0.025 mg-P/L) during the doubled flow rate storm. Therefore, it is likely that the increase in applied water during the doubled flow rate storm significantly removed DOP from the column.

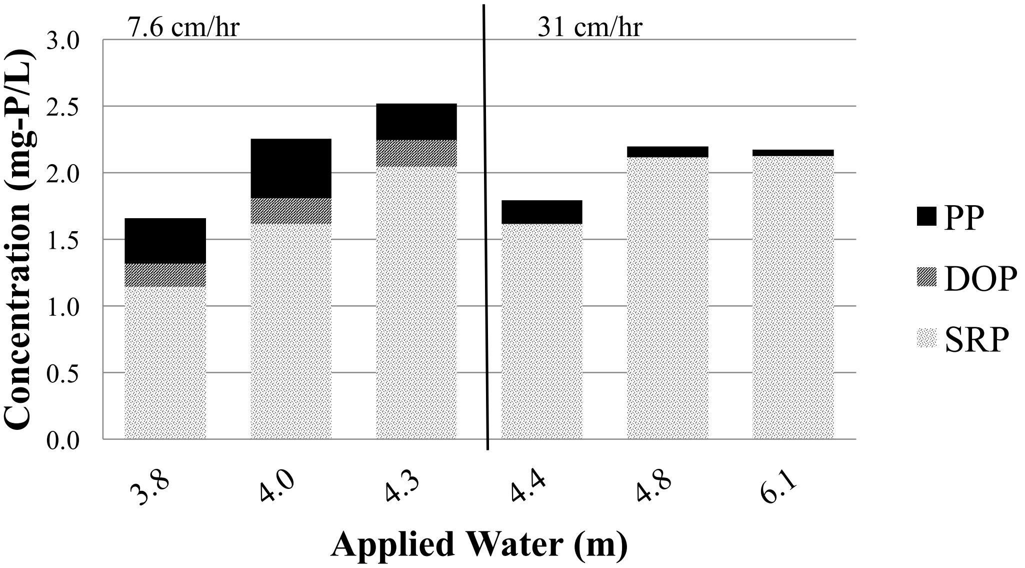


Figure 22. 30% mesocosm phosphorus speciation concentrations (mg-P/L) for halved (7.6 cm/hr) vis-à-vis doubled flow rate (31 cm/hr)

For the 15% mesocosm, the mean TP concentration for the halved flow rate (7.6 cm/hr) storm was 0.55±0.24 mg-P/L. This was not statistically different than the mean concentration of 0.49±0.092 mg-P/L in the doubled flow rate (31 cm/hr) storm (p=0.52). However, the variances were found to be statistically-different (p=0.011). This is understandable because the TP concentration leached during these two storms approached steady state, so the variance (0.058) in the halved storm was larger than the variance (0.0086) in the doubled storm.

Moreover, flow rate was not found to have an effect on mean concentrations of any of the phosphorus species: SRP, PP, and DOP (p=0.38, 0.20, and 0.25, respectively). The mean SRP concentration for the halved and doubled flow rate storms were 0.28±0.15 and 0.42±0.27 mg-P/L, the mean PP concentrations were 0.17±0.14 and 0.050±0.034 mg-P/L, and the mean DOP concentrations were 0.17±0.15 and 0.031±0.042 mg-P/L, respectively. Additionally, the F-test also proved that all three species had statistically-similar variances: p= 0.46, 0.15, and 0.15 for SRP, PP, and DOP, respectively.

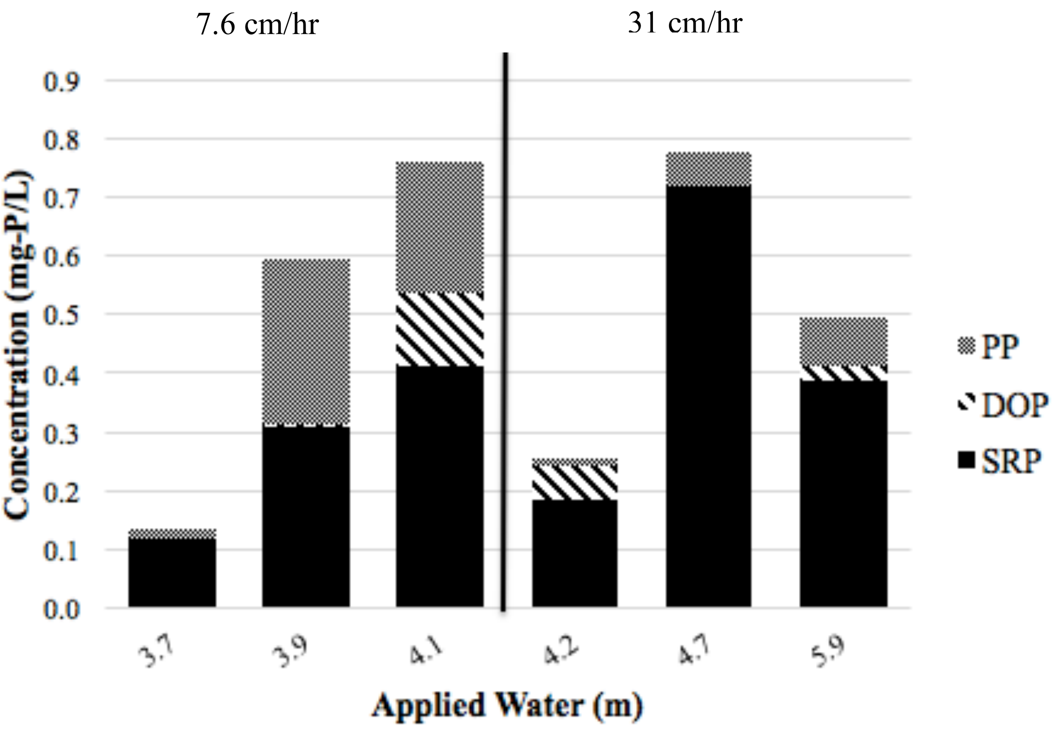


Figure 23. 15% mesocosm phosphorus speciation concentrations (mg-P/L) for halved (7.6 cm/hr) vis-à-vis doubled (31 cm/hr) flow rate

3.4.4 Total Nitrogen

Nitrogen leaching in the 30% column was much higher than leaching from phosphorus (Figure 24). The maximum concentration of TN in the effluent was 2,200 mg-N/L during the first storm. TN concentrations dropped to 2.8 mg-N after 7.9 m of applied water. Influent N concentrations averaged 5.2±2.4 mg-N/L. For comparison, the control mesocosm had a maximum TN concentration of 3.6 mg-N/L, but this did not occur until the last storm. The maximum concentration was just below the average influent TN concentration of 4.3±0.34 mg-N/L. Moreover, the control mesocosm had an average TN concentration of 1.9±0.75 mg-N/L, supporting the presence of more N removal than leaching.

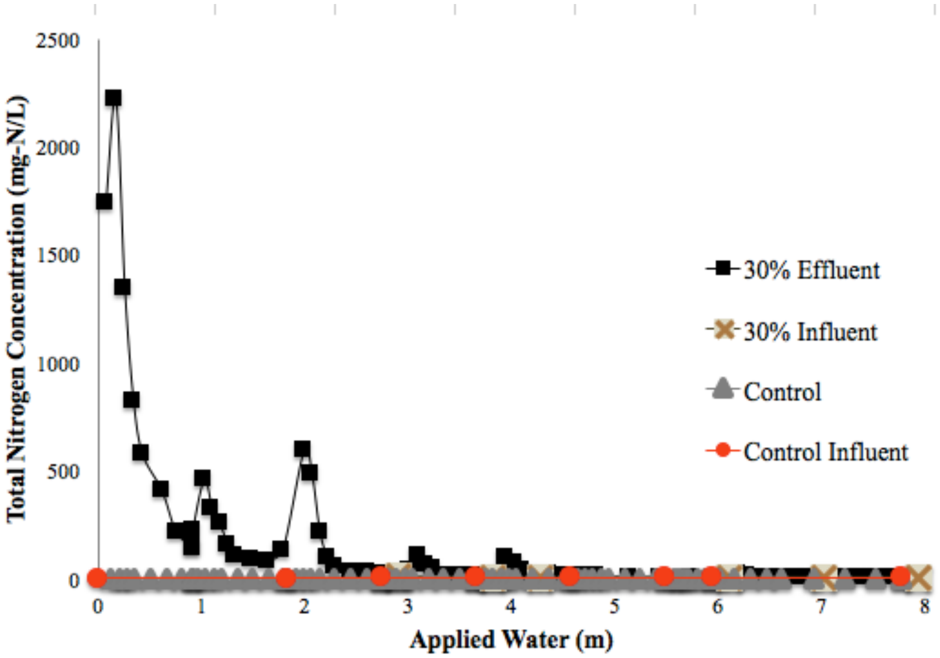


Figure 24. 30% mesocosm total nitrogen concentration (mg-N/L) during 7.9 m of applied stormwater (4.6 months of MD rainfall)

During the long-term trial, N maintained a steady, average concentration of 4.4±1.3 mg-N/L (Figure 25). While the average TN in the effluent was slightly under the average influent concentrations in the long-term storms, because initial leaching was so high, any observed removal was insignificant.

Because the initial TN concentrations were so high, the data were also plotted on a log-scale (Figure 26). From this plot, it is clear that the effluent TN remained above the influent TN for the majority of the trial. Additionally, an alternating pattern of decreasing and increasing TN concentrations is apparent. This was most likely due to nitrification occurring in the media and will be discussed in more detail later.

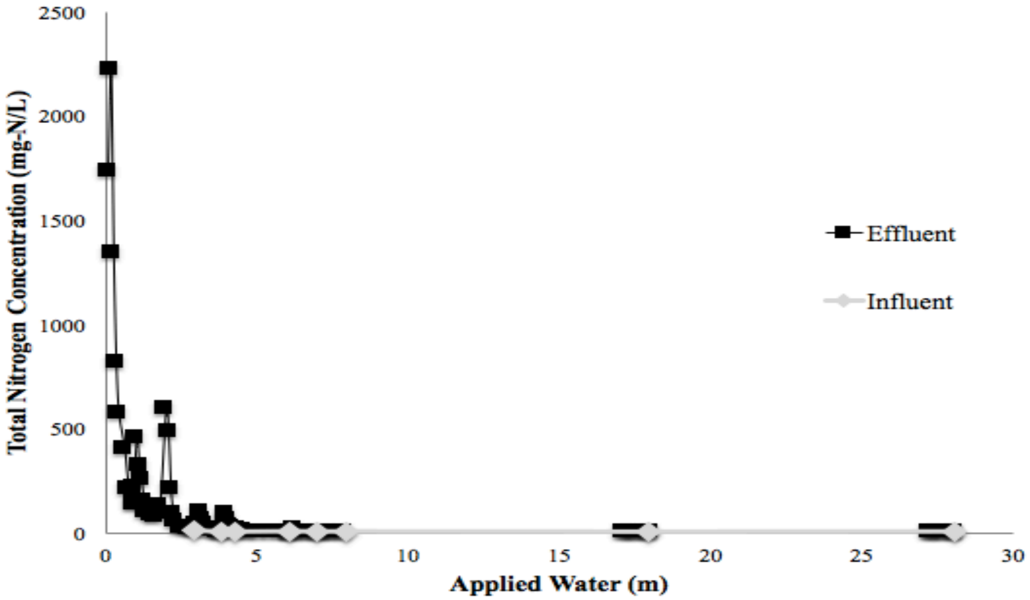


Figure 25. 30% mesocosm long-term total nitrogen (mg-N/L) during 28 m of applied stormwater (1 year and 4 months of MD rainfall)

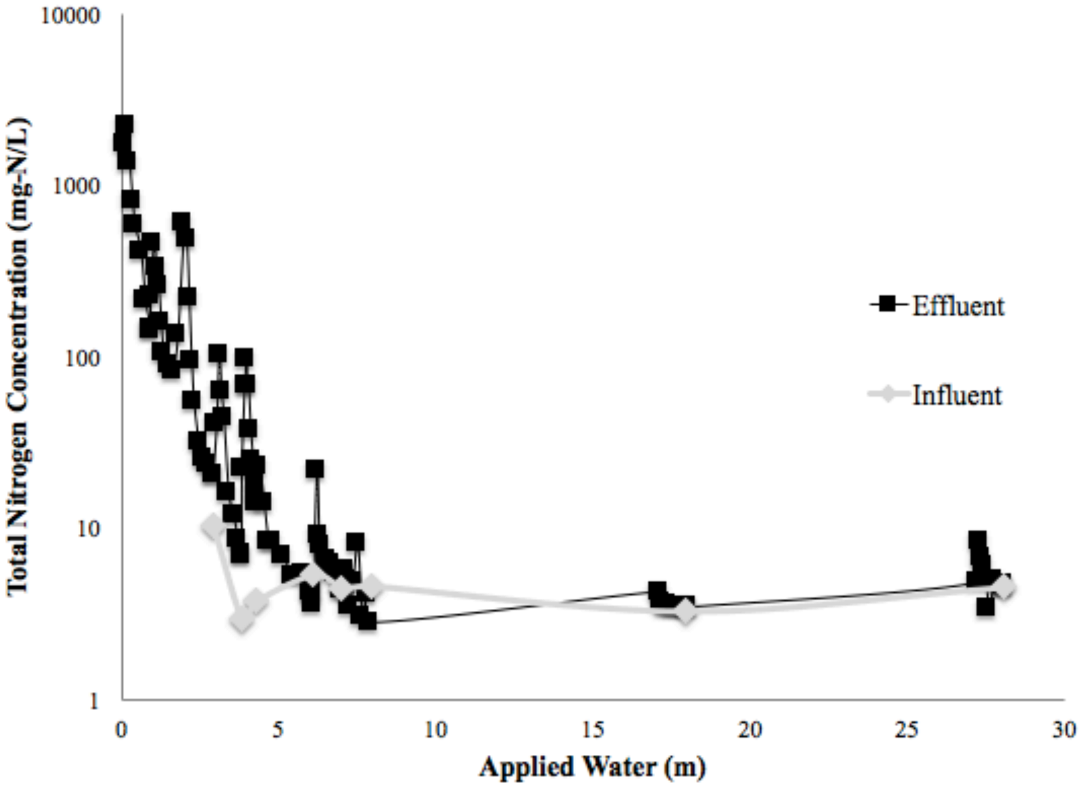


Figure 26. 30% mesocosm long-term total nitrogen (mg-N/L) on a log scale during 28 m of applied stormwater (1 year and 4 months of MD rainfall)

While the variances were statistically-different (p=0.020), the 15% mesocosm leached statistically-equal mean TN concentrations compared to the 30% mesocosm, during the 8-week trial (p=0.29) (Figure 27). During the trial, TN averaged 102±290 mg-N/L, compared to 160±380 mg-N/L in the 30% mesocosm. From Figure 28, the maximum concentration leached was 2,100 mg-N/L, which reduced to 5.2 mg-N/L after 7.8 m of applied stormwater. This was well above the average influent concentration of 3.7±0.86 mg-N/L and previously discussed average control mesocosm effluent TN.

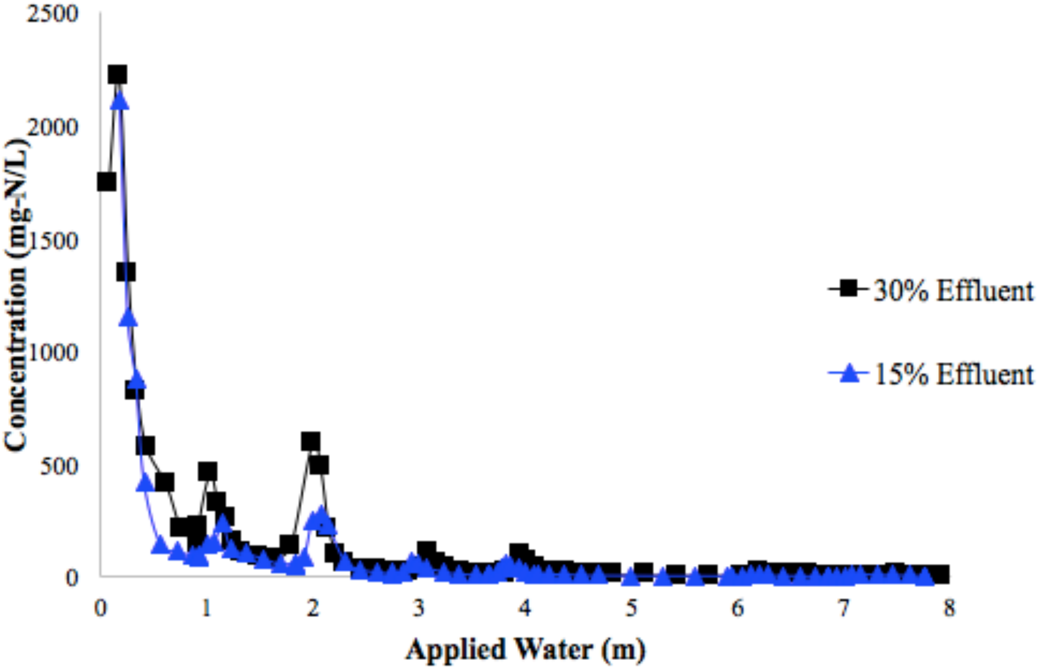


Figure 27. Comparison of total nitrogen concentrations (mg-N/L) from the 15% and 30% mesocosms during 7.8 m of applied stormwater (4.5 months of MD rainfall)

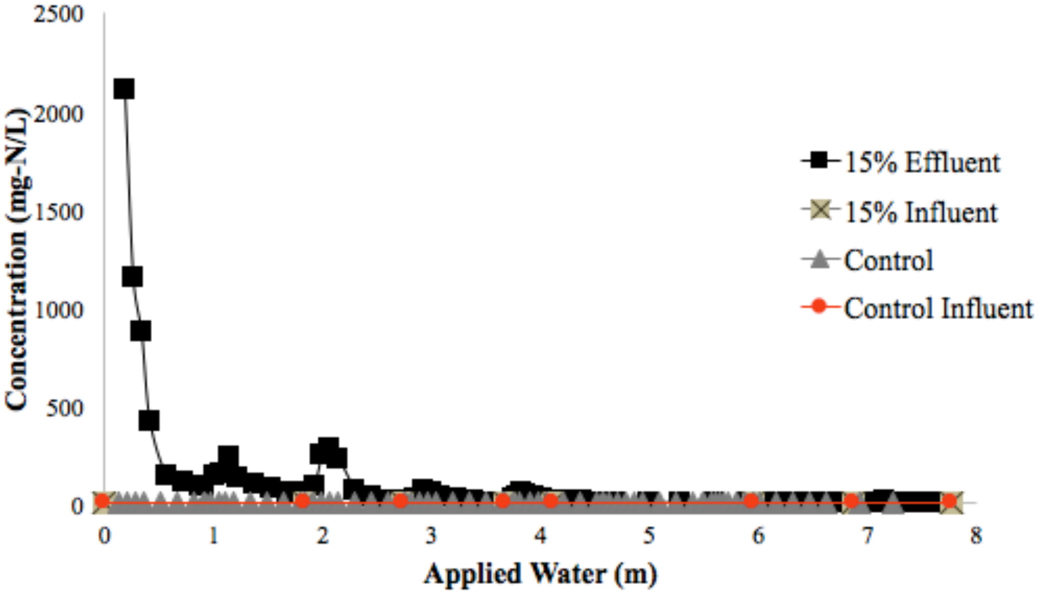


Figure 28. 15% mesocosm total nitrogen concentration (mg-N/L) during 7.8 m of applied stormwater (4.5 months of MD rainfall)

The nitrogen export from the 30% mesocosm showed a strong first-flush effect. Nineteen grams-N were exported within the first 0.92 m of stormwater. This accounted for 69% of the TN exported (27 g-N) after 7.9 m of applied water (Figure 29) and 64% of the total N exported (30 g-N) after 28 m of applied water (Figure 30). Only 1.2 g-N were applied to the columns via 28 m of stormwater application, so cumulative export far exceeded applied TN. Cumulative export after both 7.9 m and 28 m of applied water (12,000 and 13,000 mg-N/kg dry media, respectively) far exceeded KCl extractable-N (1,200±200 mg-N/kg dry media), as well. This was unexpected because the extracted N should correlate with leached N. However, it is possible that the organic N that was not extracted by the KCl, mineralized to ammonium, which nitrified to nitrate in the column media, thus increasing N in the leachate. For comparison, the control only exported 0.44 g-N (99 mg-N/kg dry BSM) after 7.8 m of applied water. This did not agree with the KCl-extractable N data, which was much lower (4.3±0.64 mg-N/kg dry BSM). However, like with the P content, the difference between the extraction data and the effluent N content is expected because the N most likely originates from the influent and not from the BSM itself.

Using the cumulative mass export and equation 6, the short-term EMC was 121 mg-N/L and the long-term EMC was reduced to 37 mg-N/L. Neither EMC agreed well with the respective average effluent TN concentrations, which were much higher (160±370 mg-N/L and 130±340 mg-N/L).

Cumulative export was converted to years of watershed N export, based on the average annual input load of N to a bioretention system (14.0 kg/ha/year) (Li and Davis 2014), area of the column (285 cm^2), and drainage area size the column can treat (assumed to be 20 times the area of the column), using the following equation:

$$Years\ of\ watershed\ N = \left(\frac{N\ export}{(A\ of\ column)(20)}\right)/(14.0\ kg/ha/year) \qquad (7)$$

Based on Equation 7, after 4.6 months of MD rainfall, 34 years of watershed N were exported from the 30% mesocosm. This increased to 37 years after 1 year and 4 months of MD rainfall. For comparison, the control mesocosm only exported 0.44 g-N after 4.5 months of rainfall (0.55 years of watershed N), while 1.4 g-N were applied to the control column.

Despite the similarities in TN concentration leached, the 15% mesocosm exported 40% less nitrogen than the 30% mesocosm (Figure 30). Like the 30% mesocosm, the 15% mesocosm exhibited strong first flush behavior. More than 66% of the total N exported, were exported during the first 20% of applied stormwater. The 15% mesocosm exported 16 g-N after 7.8 m of applied stormwater. This is the equivalent of 20 years of watershed N. For comparison, only 0.81 g-N were applied cumulatively, after the 8 storms, so no removal was observed. The 15% mesocosm also exported significantly more nitrogen than the control, which only exported 0.44 g-N. On a dry mass-basis, 6,000 mg-N/kg dry media were exported, which was more than ten-times the amount of KCl-extractable N in the 15% compost mixture (530±26 mg-N/kg dry media).

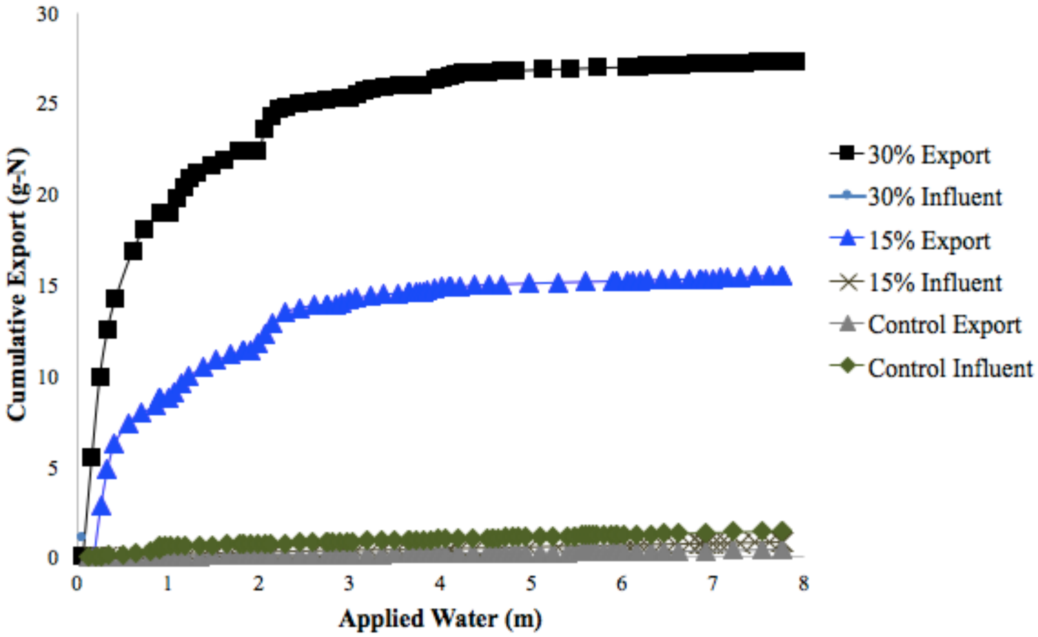


Figure 29. 30% and 15% mesocosm nitrogen cumulative export (g-N) during 7.9 m of applied stormwater (4.6 months of MD rainfall)

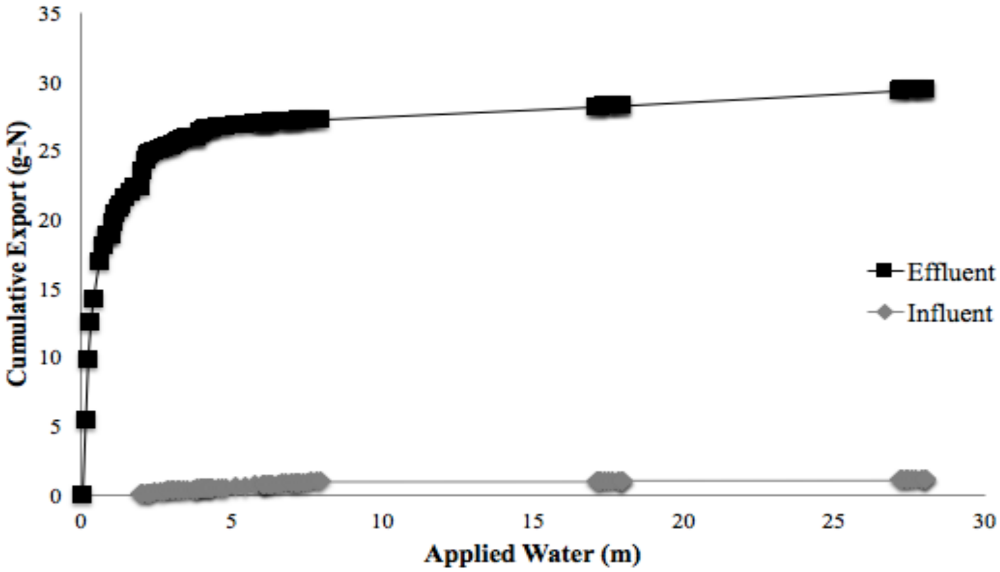


Figure 30. 30% mesocosm long-term total nitrogen mass export (g-N) during 28 m of applied stormwater (1 year and 4 months of MD rainfall)

3.4.5 Nitrogen Speciation

Initially, ammonium was the predominant species that was washed out with the first flush of nitrogen from the 30% mesocosm, with a maximum concentration of 1,300 mg-N/L (Figure 31). As the trial progressed, the ammonium concentration fell below the detection limit (0.025 mg-N/L) after 8 applied storms. In the control mesocosm, ammonium averaged 0.072±0.024 mg-N/L, maintaining this concentration during the trial. This average was calculated from ammonium data from storms 1 and 5-8. Storms 2-4 were not tested for ammonium. However, no statistical difference in mean ammonium concentration was found (p=0.13) between storms 1 and 5, so concentration was assumed to be linear. Ammonium was continuously detected because the BSM lacked a sufficient supply of clay particles. Clay particles contain negatively charged surfaces that adsorb the positively charged ammonium. Without clay, the ammonium did not bind to the BSM and was thus washed out.

In the control mesocosm, nitrate was the dominant species, with an average of 1.0±0.59 mg-N/L. However, nitrate was the second most prevalent species in the 30% mesocosm, leaching a maximum concentration of 710 mg-N/L during storm 3. The nitrate and ammonium concentrations were inconsistent with Brown et al. (2016) and Li et al. (1997) who found maximum ammonium concentrations of 0.9±0.3 and 28 mg-N/L, respectively and maximum nitrate concentrations of 10.9±2.7 and 245.9 mg-N/L, respectively in biosolids-compost leachate. However, Xi et al. (2013) found a much higher nitrate concentration of 1,996 mg-N/L, which leached from 100% biosolids/yard waste compost.

Nitrate continued to leach throughout the trial and showed a "rise and fall" trend. In 5 out of 8 storms, nitrate concentrations in the first sample collected were higher than in the last sample collected from the previous storm. This phenomenon has been observed in a number of other column studies (Li and Davis 2014; Mullane et al. 2015; Subramaniam et al. 2015) and is caused by nitrification in the media in between storms. The nitrate forms from ammonium that binds to the media and is nitrified under aerobic conditions that occur during drying periods in between storms. The formed nitrate then washes out in the first sample of the next storm.

Washout of organic N occurred sporadically throughout the trial, with a maximum concentration of 240 mg-N/L in the second storm, followed by another washout during storm 5 (62 mg-N/L, halved flow rate). This inconsistent organic N leaching pattern was also observed in the control mesocosm. The control mesocosm had an average organic N concentration of 0.48±0.50 mg-N/L, calculated from storms 1 and 5-8. Lastly, nitrite mostly remained below detection, not exceeding a concentration of 1.8 mg-N/L found in storm 3. Nitrite remained below detection limit (0.005 mg-N/L) in the control mesocosm.

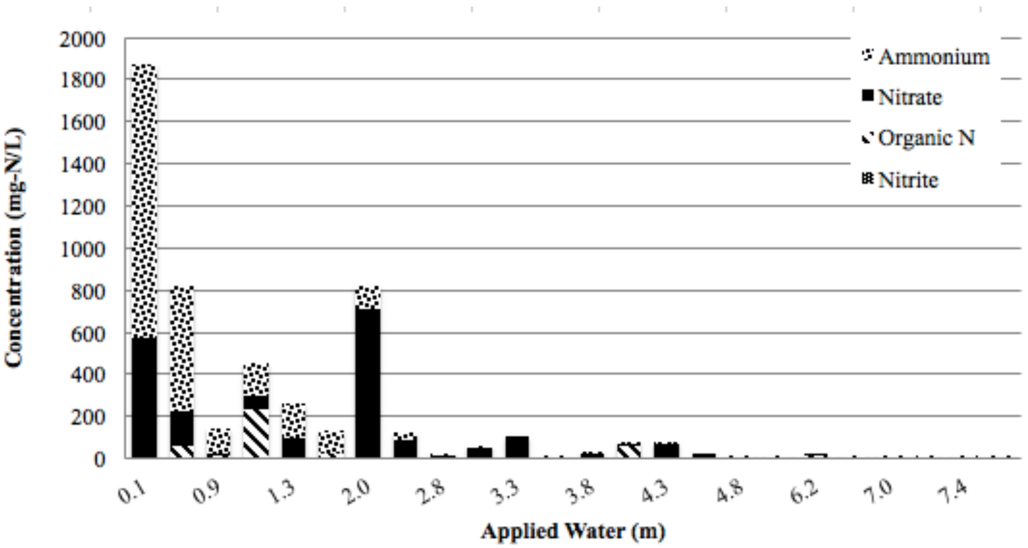


Figure 31. 30% mesocosm nitrogen speciation concentration (mg-N/L) during 7.9 m of applied stormwater (4.6 months of MD rainfall)

Figure 32 focuses on nitrogen speciation leaching in the final two long-term storms. Nitrate was detected in all samples, with an average concentration of 2.9±0.79 mg-N/L. However, as previously mentioned, because nitrate is highly mobile and washed out relatively quickly, the nitrate found in these final samples most likely was due to nitrification and not direct leaching from the compost. Additionally, the long-term storms saw a spike of organic-N. It is possible that the organic matter in the compost began to break down and leach out into the effluent during the long-term trial. Finally, a small spike of ammonium was detected in the final applied storm.

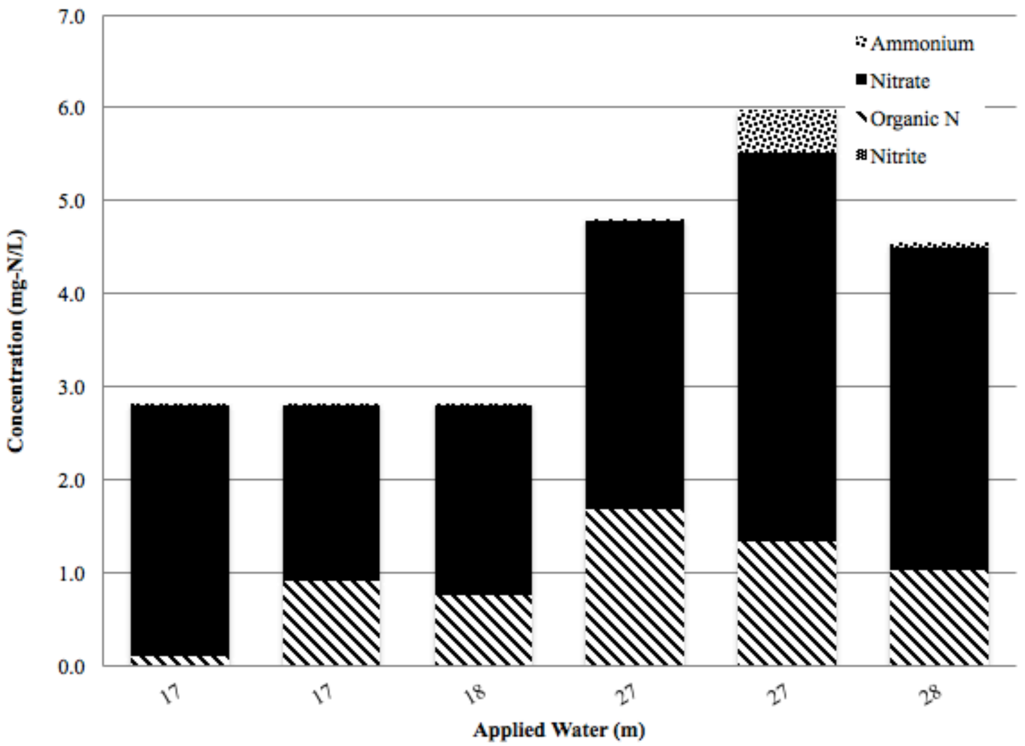


Figure 32. 30% mesocosm nitrogen speciation concentrations (mg-N/L) for the two analyzed long-term storms

Figure 33 shows the nitrogen speciation concentrations leached from the 15% mesocosm during the 8 storms. Unlike the 30% mesocosm, there was a large washout of organic N in the first storm (980 mg-N/L). This was 3.2 times the maximum organic N leached in the 30% mesocosm. Organic N was mostly undetectable in the subsequent 7 storms, however. Ammonium also leached significantly in the first storm, with a maximum concentration of 960 mg-N/L, only 26% lower than the maximum concentration leached in the 30% mesocosm. Ammonium concentrations began to decline thereafter, with a final concentration of 0.13 mg-N/L, which was above detection limit (0.025 mg-N/L). Both Li et al. (1997) and Puppala et al. (2011) found much lower overall ammonium concentrations in biosolids/municipal solid waste compost (28 mg-N/L) and in average TKN in biosolids compost (4.8 mg-N/L), respectively. TKN is Total Kjehldahl Nitrogen and is organic N/ammonium combined.

Nitrate leached a maximum of 160 mg-N/L during the first storm, a 78% reduction in peak nitrate over the 30% mesocosm. The maximum nitrate concentration was consistent with the maximum nitrate leached from the 91% sand/9% compost mixture with a phosphorus saturation index (PSI) of 1.0, which was just below 150 mg-N/L (Brown et al 2015). Concentrations generally declined with each storm. However, the first sample had higher nitrate concentrations than in the last sample of the previous storm in 5 out of 8 storms, indicating nitrification in pooled stormwater at the bottom of the column (Li and Davis 2014; Mullane et al. 2015; Subramaniam et al. 2015). This phenomenon was also observed in the 30% mesocosm. Finally, nitrite had a slightly higher maximum concentration, which leached during storm 4, than the 30% mesocosm (3.8 vis-à-vis 1.8 mg-N/L). However, with respect to the other N species, nitrite was significantly lower overall.

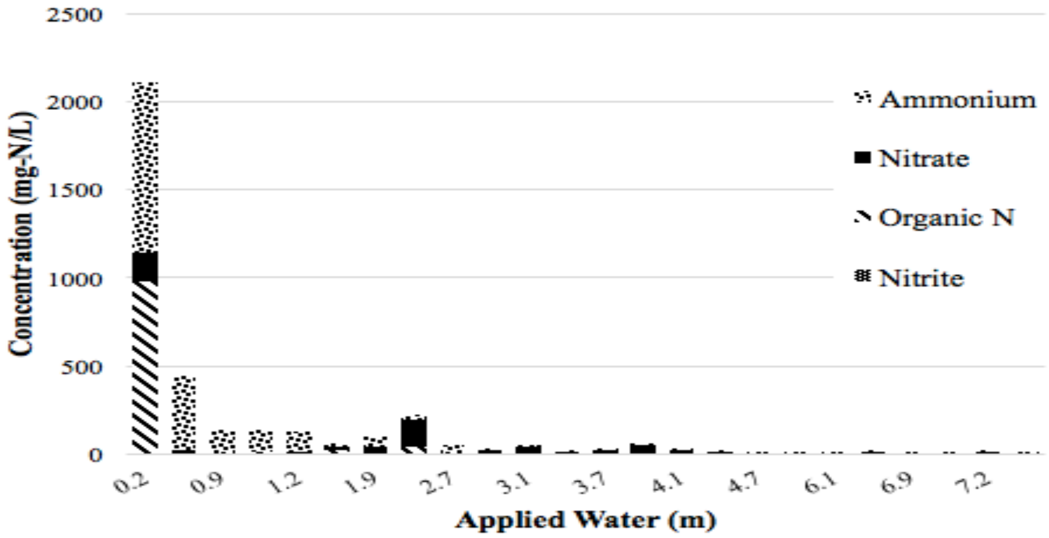


Figure 33. 15% mesocosm nitrogen speciation concentration (mg-N/L) during 7.8 m of applied stormwater (4.5 months of MD rainfall)

Nitrate accounted for over half of N exported from the control mesocosm (210 mg-N), whereas only 0.84 mg-N of nitrite were exported by the end of the trial. Storms 2-4 were not tested for ammonium, so TKN was calculated using equation 8:

$$TKN=TN-NO_3^- -NO_2^- \qquad (8)$$

Total TKN export was 97 mg-N. However, because ammonium was found to be exported at a constant rate, assumed ammonium export was calculated between storm 1 and storm 5 corresponding to 0.91 and 3.6 m of applied stormwater. Therefore, ammonium contributed 14 mg-N of the 97 mg-N TKN exported.

Ammonium accounted for 63% of total cumulative N export from the 30% mesocosm (Figure 34) during the first 4.6 months of rain and 58% after 1 year and 4 months (Figure 35). Over 17% of the short-term storm TN export consisted of nitrate, but this increased to 19% long-term. Organic N only made up 7.8% and 8.4% of the short and long-term exports, respectively. Finally, nitrite export was insignificant, compared to the other species. Less than 0.30% of N exported, either short or long-term, consisted of nitrite.

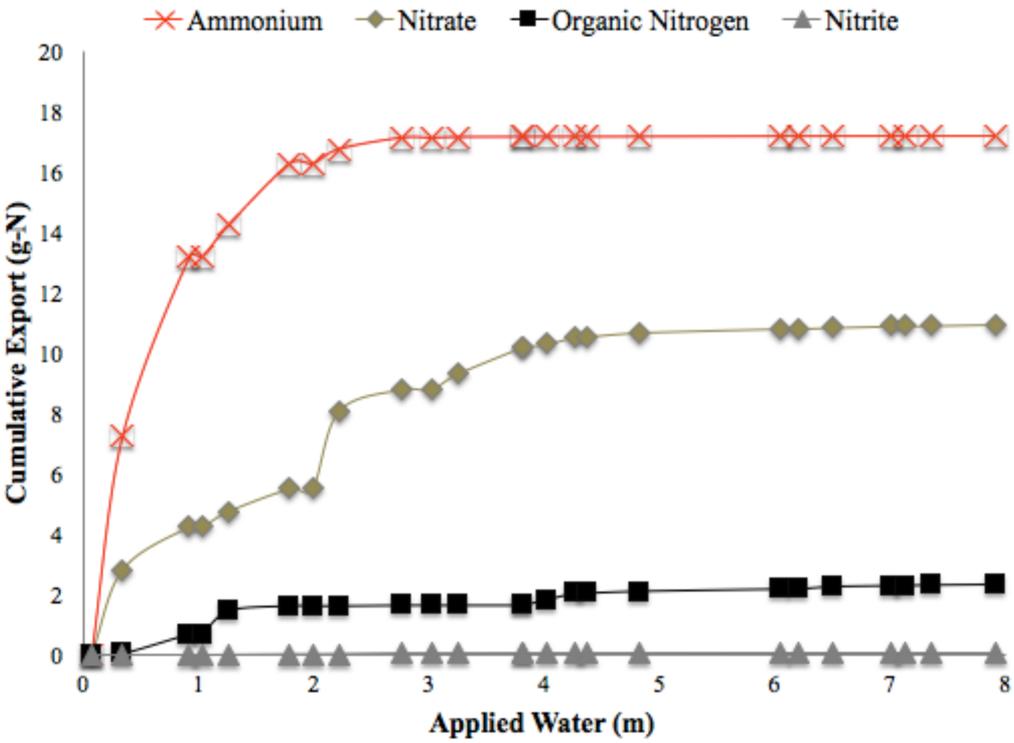


Figure 34. 30% mesocosm nitrogen speciation cumulative export (g-N) during 7.9 m of applied stormwater (4.6 months of MD rainfall)

Long-term nitrogen species export appeared to level off (Figure 35). However, this observation was due to the scale of the graph. The nitrogen species were exported at a slower rate during the long-term portion of the trial compared to the export rate during the first 4 m of applied stormwater, which was much more rapid.

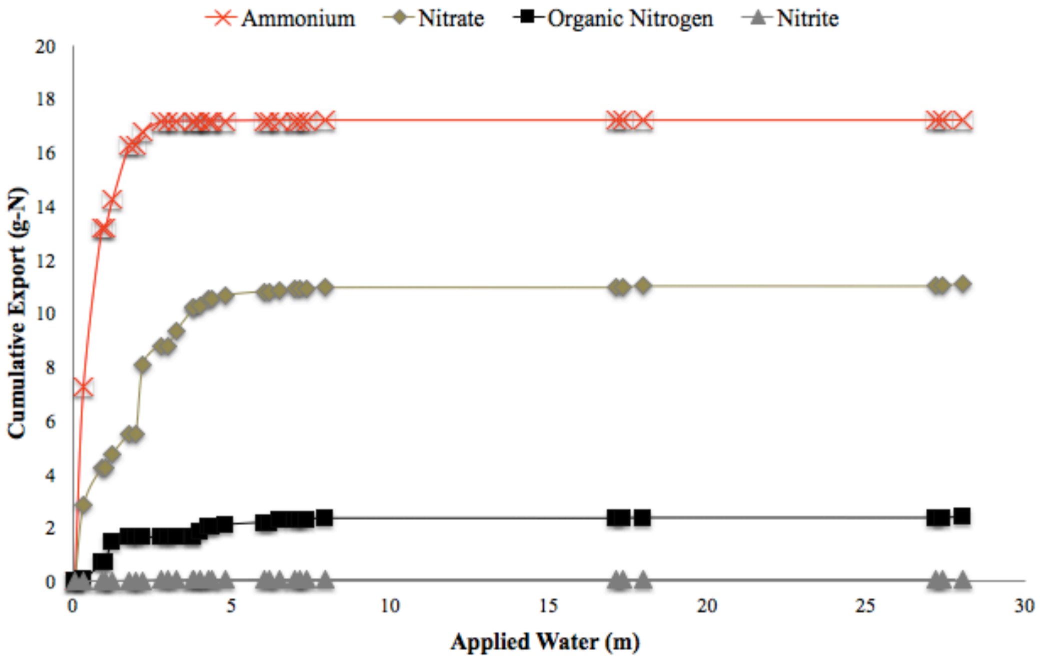


Figure 35. 30% mesocosm long-term nitrogen speciation cumulative export (g-N/L) during 28 m of applied stormwater (1 year and 4 months of MD rainfall)

Overall, the 15% mesocosm exported 58% less nitrate (4.6 g-N), 32% less ammonium (12 g-N), the same amount of nitrite (0.070 g-N), and 51% more organic N (3.6 g-N) than the 30% mesocosm (Figure 36).

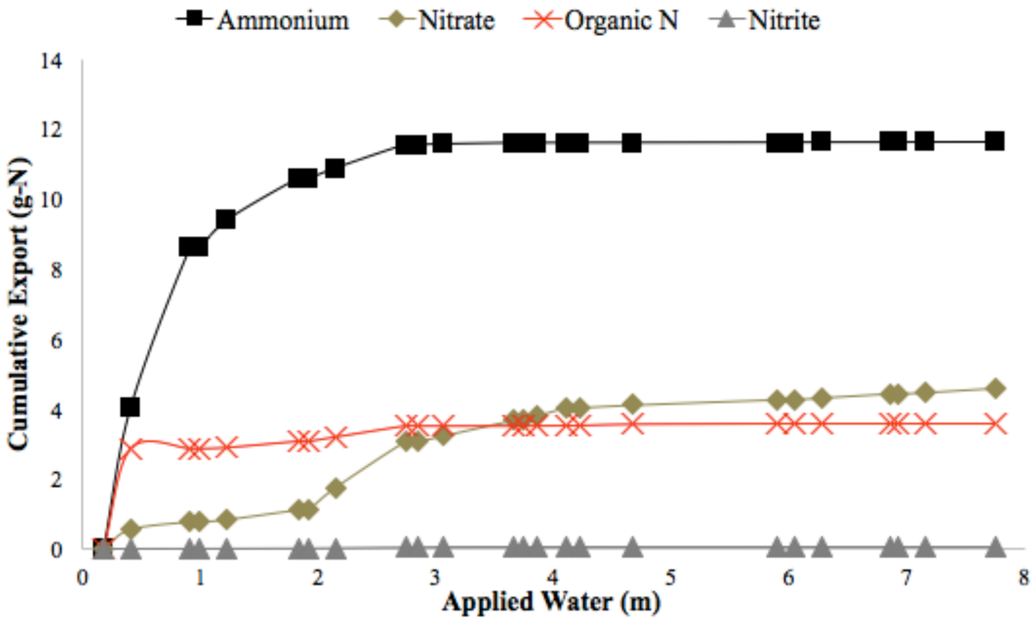


Figure 36. 15% mesocosm nitrogen speciation cumulative export (g-N) during 7.8 m of applied stormwater (4.5 months of MD rainfall)

3.4.6 Effect of Flow Rate on Nitrogen Leaching

The null hypothesis was rejected for both the t-test (p=0.014) and F-test ($p=3.6x10^{-6}$). Both the halved and doubled storms showed statistically-different mean TN concentrations and variances in the 30% mesocosm. This is not surprising because as the trial progressed, TN concentrations showed a generally decreasing trend, reducing the likelihood that two storms would be statistically-equivalent, regarding leaching.

Despite differences between TN, when comparing differences in N species concentrations between the two storms (Figure 37), ammonium was statistically the same (0.21±0.10 vis-à-vis 0.24±0.25 mg-N/L) according to both the t-test (p=0.82) and F-test (p=0.27). This was understandable because there were low concentrations of ammonium in both storms. Moreover, the statistical tests failed to reject the null hypothesis for the t-test (p=0.36) and F-test (p=0.27) for nitrate concentrations. This was surprising because the halved flow rate storm had a much bigger washout, with an average concentration of 32±32 mg-N/L, of nitrate than in the doubled flow rate storm (average concentration of 8.0±8.0 mg-N/L).

For nitrite, both tests determined that the concentrations were not statistically-different (p=0.56 and 0.45 for the t and F-tests, respectively). These results were expected because nitrite concentrations were consistently at or below detection limit for these two storms. Finally, organic N concentration means were statistically the same (21±36 vis-à-vis 3.4±2.5 mg-N/L) by the t-test (p=0.49) but had statistically-different variances according to the F test (p=0.0094). This is consistent with the observation that organic N concentrations were variable throughout the entire 30% column trial. Therefore, flow rate did not have a significant effect on organic N.

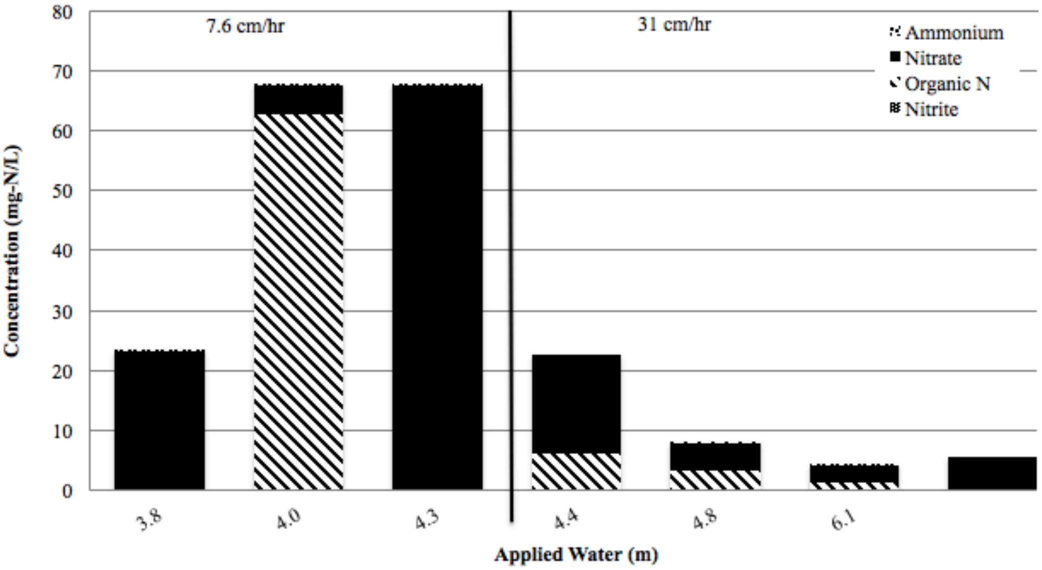


Figure 37. 30% mesocosm nitrogen speciation concentrations (mg-N/L) for halved (7.6 cm/hr) vis-à-vis doubled (31 cm/hr) flow rate

The average TN concentration for the halved flow rate storm was 32±16 mg-N/L, which reduced to 6.3±2.9 mg-N/L during the doubled flow rate storm in the 15% mesocosm. The t-test determined that the means were statistically-different

($p=1.0x10^{-4}$). The F-test also confirmed that the variances were statistically-different ($p=3.0x10^{-5}$).

However, flow rate did not impact the N species individually (Figure 40). The t-test did not find significant difference in the means of nitrite (0.019±0.0054 vis-à-vis 0.034±0.024 mg-N/L; p=0.33), nitrate (0.63±0.31 vis-à-vis 0.21±0.061 mg-N/L; p=0.083), ammonium (0.25±0.21 vis-à-vis 0.19±0.049 mg-N/L; p=0.68), or organic N (0.74±1.3 vis-à-vis 1.9±2.5 mg-N/L; p=0.25). Moreover, the F test confirmed that there was no statistical difference in the variances of any N species (p=0.10, 0.074, 0.11, 0.41 for nitrite, nitrate, ammonium, and organic N, respectively).

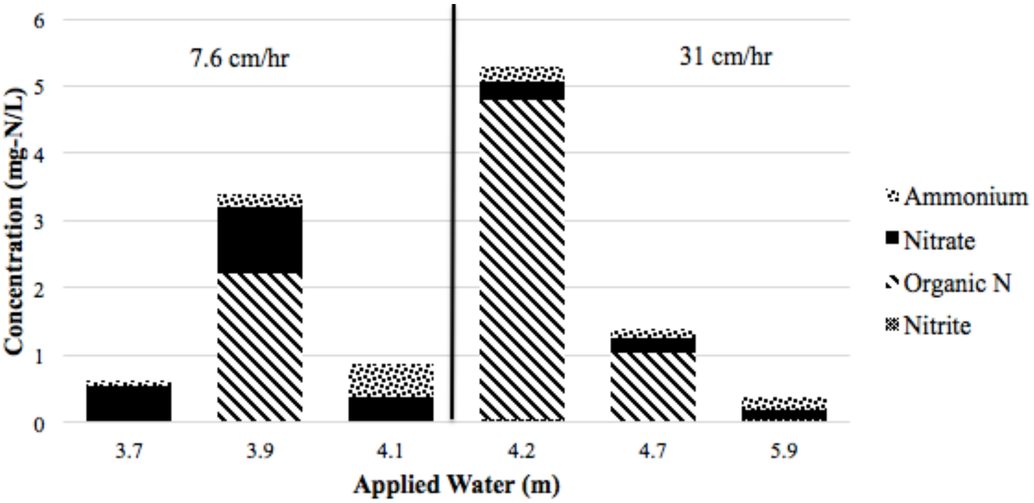


Figure 38. 15% mesocosm nitrogen speciation concentrations (mg-N/L) for halved (7.6 cm/hr) vis-à-vis doubled (31 cm/hr) flow rate

3.5 30% Washed Mesocosm Results

To reduce or remove the first flush of nutrients, especially nitrogen, the compost was washed with tap water. The effluent was drained off and tested for phosphorus and nitrogen (Tables 4 and 5). The compost was allowed to dry and mixed with BSM in a 30%:70% ratio by volume. The remaining variables (flow rate adjustments and sampling) were kept constant with the other two mesocosms.

Additionally, this column was only run short-term for 8 storms. There was no observable difference in how long it took the stormwater to reach the effluent port regardless of flow rate, how long it took to fill a 250 mL sample bottle, or how long it took for the effluent to be reduced to a trickle, compared to the other two mesocosms. 7.8 m of stormwater or 4.5 months of MD rainfall were applied to the column by the end of the trial. The first samples were very dark brown in color. Because the compost was dry and dusty, it more easily washed out into the samples. However, by the third storm, the samples were more similar in color (Figure 39) to the first samples from the other two mesocosms.

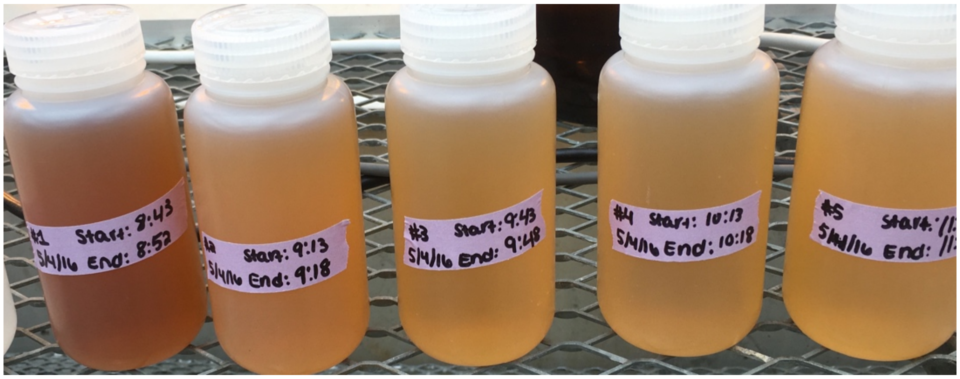


Figure 39. 30% washed mesocosm storm 3 samples collected between 1.8 and 2.7 m of applied stormwater. The far left sample was the first flush, the middle 3 samples were taken every 30 minutes, and the 5th sample was taken an hour after the 4th sample.

3.5.1 Total Phosphorus

Comparable to the other two mesocosms, the 30% washed mesocosm also continuously leached TP (Figure 40). Storm 1 leached a peak concentration of 4.6 mg-P/L. Concentrations steadily declined until the end of the trial, reaching 1.2 mg-P/L after 7.8 m of applied stormwater. TP consistently exceeded that of the control mesocosm, as well as the average influent concentration (0.37±0.046 mg-P/L).

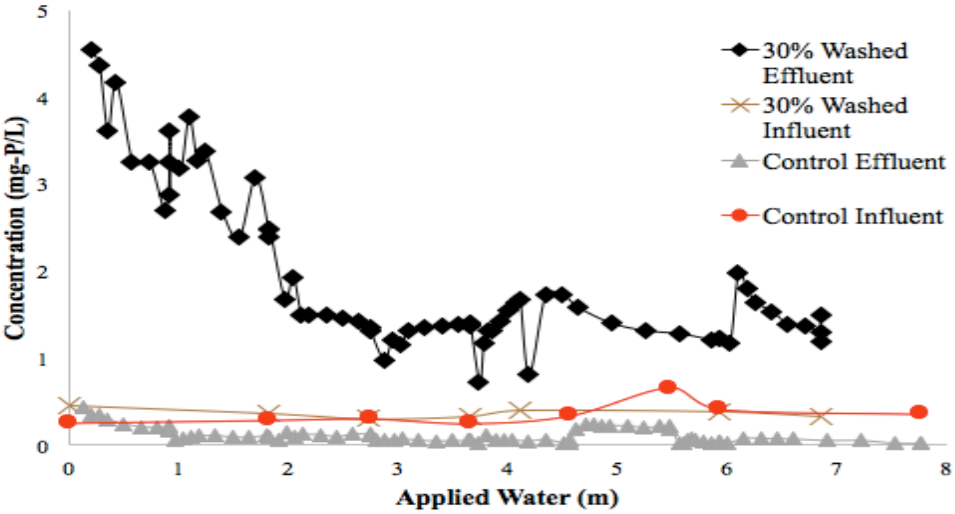


Figure 40. 30% washed mesocosm total phosphorus concentration (mg-P/L) during 7.8 m of applied stormwater (4.5 months of MD rainfall)

The mean TP concentration for the 30% washed mesocosm was 1.9±0.89 mg-P/L, which was statistically-different (p=0 and 0.012) than the mean concentrations for the 15% (0.89±0.85 mg-P/L) and 30% mesocosms (2.3±1.3 mg-P/L), respectively (Figure 41). However, the mean TP concentration is identical to that found by Puppala et al. (2011) in biosolids compost runoff. Overall, the 15% mesocosm had the lowest average TP concentration, even though no mesocosm effluent fell below their respective influent concentrations.

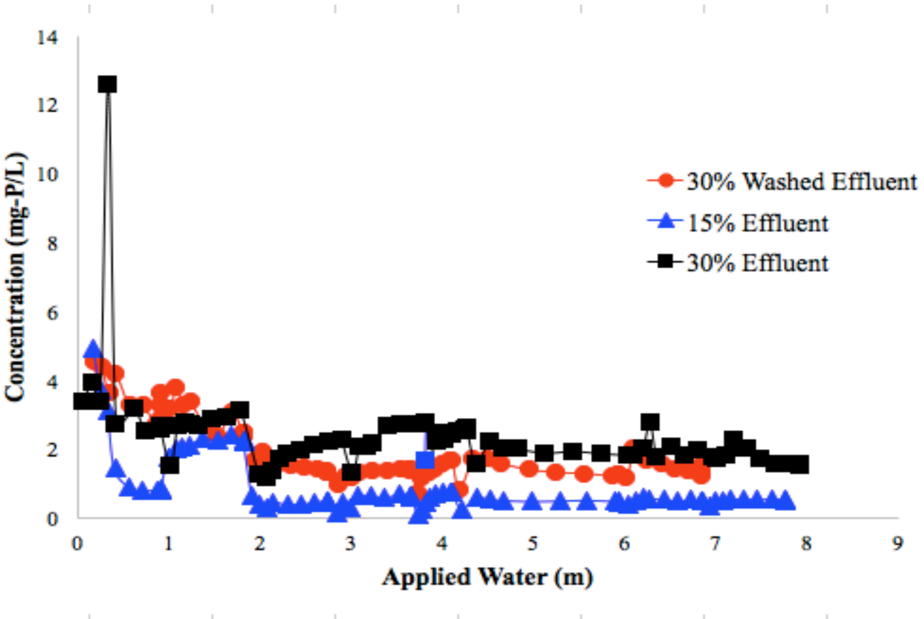


Figure 41. Comparison of total phosphorus concentrations (mg-P/L) from the 30% washed, 15%, and 30% mesocosms during 7.8 m of applied stormwater (4.5 months of MD rainfall)

The 30% washed mesocosm exported 360 mg-P (2.1 years of watershed P, from equation 5) after 7.8 m of applied stormwater (Figure 42), which was 1.1 times more than the 15% mesocosm and 23% less than the 30% mesocosm. On a dry mass-basis, 150 mg-P/kg dry media were exported, which was much higher than Mehlich 3-extractable P. This was not expected, but was understandable. Generally, extractions agree with leaching, but are not a perfect predictor as they do not account for how the nutrients move through the media (Maguire and Sims 2002). Moreover, the EMC for the 30% washed mesocosm was 1.6 mg-P/L, comparable to the average effluent TP concentration (1.9±0.89 mg-P/L). The only mesocosm that agreed with the P extractions was the 15% mesocosm. Finally, the 30% washed mesocosm significantly exported more P than the control column and more than the mass of P applied in the influent (83 mg-P total applied after 8 weeks).

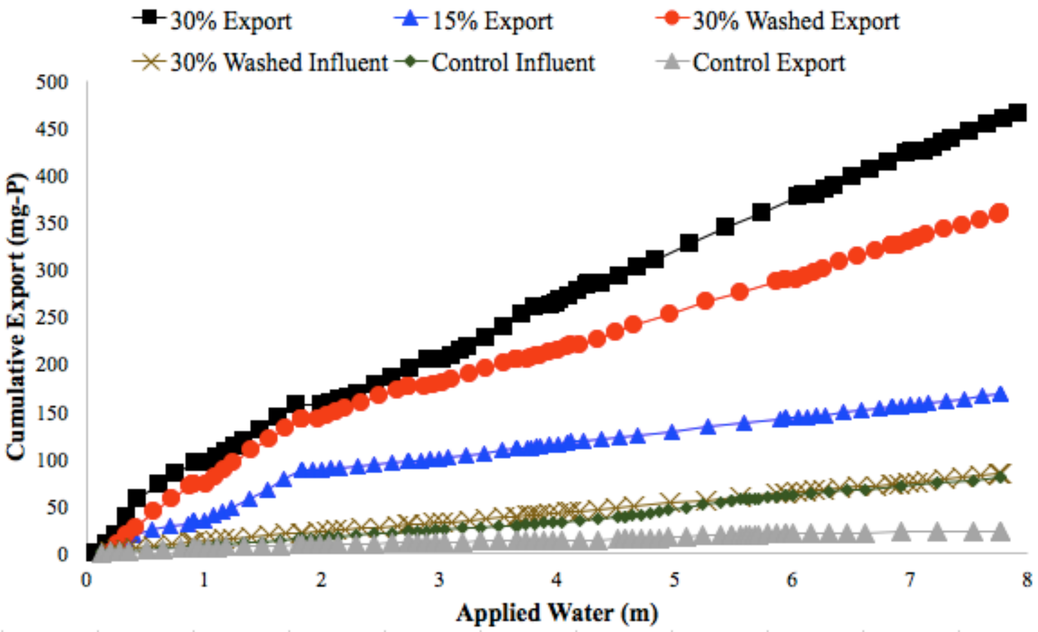


Figure 42. Comparison of 30% washed, 15%, 30% mesocosm total phosphorus cumulative export (mg-P) during 7.8 m of applied stormwater (4.5 months of MD rainfall)

3.5.2 Phosphorus Speciation

Like in the 15% mesocosm, the 30% washed had an initial flush of DOP (2.2 mg-P/L) (Figure 43). However, unlike the 15% mesocosm, but similar to the 30% mesocosm, DOP declined as the trial progressed, but remained well above the detection limit (0.025 mg-P/L), with a final concentration of 0.14 mg-P/L. Moreover, there was also a steadier leaching of PP (initial concentration of 1.81 mg-P/L and final of 0.30 mg-P/L), which was observed in the 15% mesocosm. However, in the 30% mesocosm, a large initial washout of PP occurred, but then concentrations significantly decreased thereafter. Lastly, SRP steadily leached in the 30% washed mesocosm, as it did in the other two mesocosms. The average SRP concentration (0.84±0.29 mg-P/L) in the 30% washed mesocosm was greater than that in the 15% mesocosm (0.31±0.17 mg-P/L), but less than that in the 30% mesocosm (1.4±0.65

mg-P/L). Moreover, the 30% washed mesocosm P species concentrations consistently exceeded those of the control mesocosm.

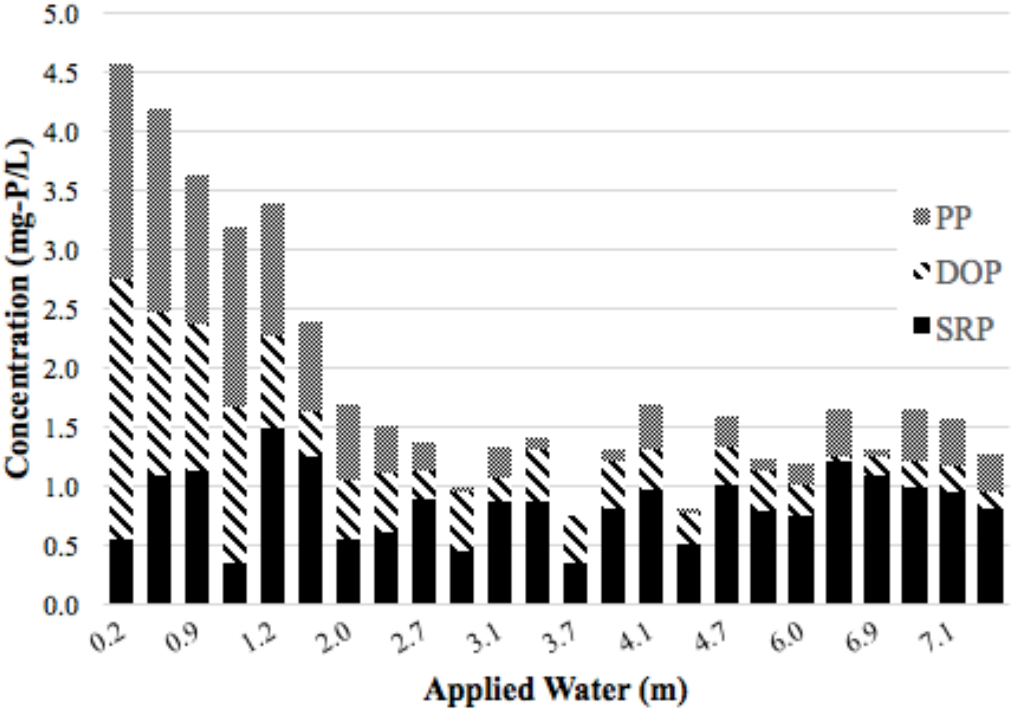


Figure 43. 30% washed mesocosm phosphorus speciation concentrations (mg-P/L) during 7.8 m of applied stormwater (4.5 months of MD rainfall)

From Figure 44, 180 mg-P of SRP were exported after 7.8 m of applied stormwater from the 30% washed mesocosm. This was 1.4 times that of the 15% mesocosm, but an 80% decrease compared to the 30% mesocosm. Ninety-three milligrams-P of PP were exported, but this was not significantly more than from the other two mesocosms. A large difference was found in PP exported among the three mesocosms: 89 mg-P were exported from the 30% washed mesocosm, which was a twice that of the 15% mesocosm, but a 61% decrease compared to the 30% mesocosm. Finally, P species export from the 30% washed mesocosm far exceeded that from the control mesocosm.

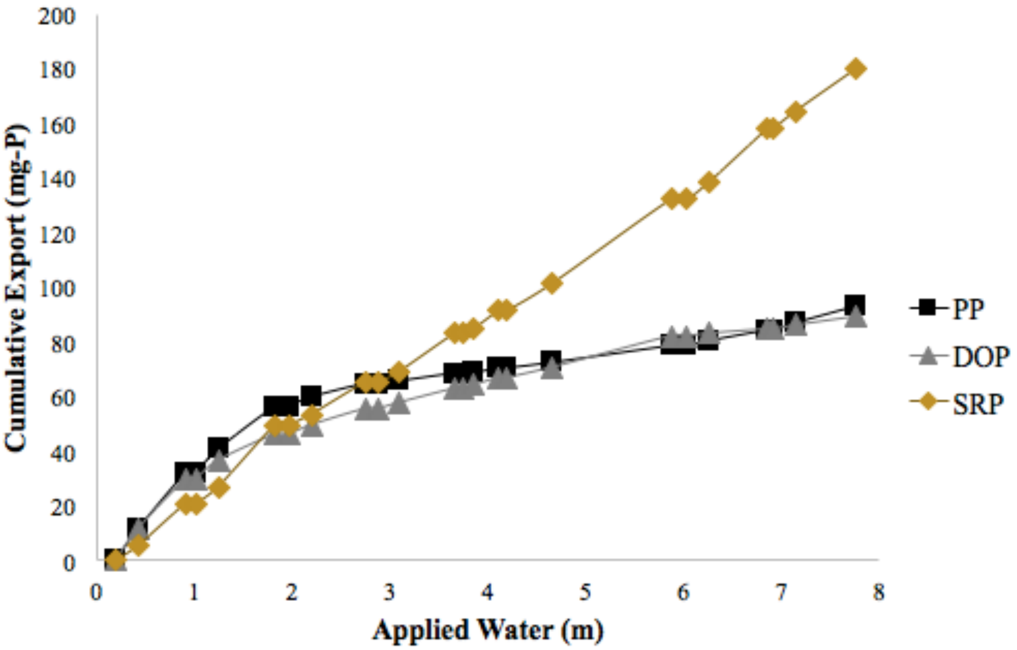


Figure 44. 30% washed mesocosm phosphorus speciation cumulative export (mg-P) during 7.8 m of applied stormwater (4.5 months of MD rainfall)

3.5.3 Effect of Flow Rate on Phosphorus

Halving and doubling the flow rate did have a statistical significance on mean TP effluent concentrations (3.9±0.14 vis-à-vis 5.1±0.68 mg-P/L; $p=2.9 \times 10^{-4}$), as well as on the variances ($p=1.9 \times 10^{-4}$). However, changing the flow rate did not affect leaching of any individual phosphorus species (Figure 45). The mean concentrations for the halved and doubled flow rates, respectively were: 0.71±0.32 vis-à-vis 0.76±0.24 mg-P/L for SRP (p=0.72 for the t-test and p=0.73 for the F test), 0.16±0.18 vis-à-vis 0.14±0.14 mg-P/L for PP (p=0.83 for the t-test and p=0.73 for the F test), and 0.38±0.034 vis-à-vis 0.30±0.047 mg-P/L for DOP (p=0.29 for the t-test and p=0.69 for the F test). Therefore, because of the conflicting results, it is inconclusive whether flow rate affected TP leaching in the 30% washed mesocosm.

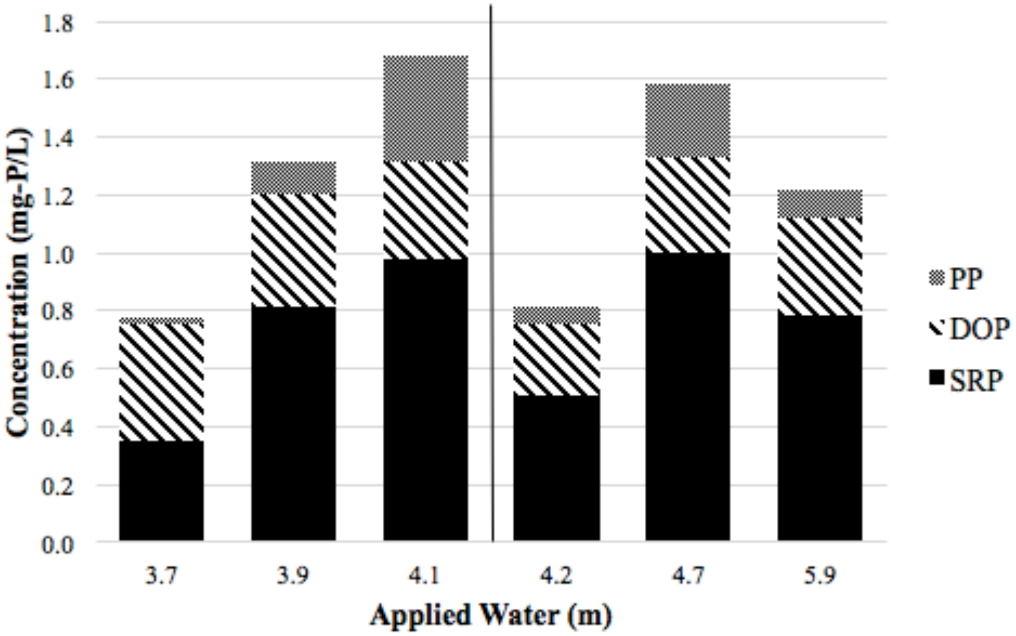


Figure 45. 30% washed mesocosm phosphorus speciation concentrations (mg-P/L) for halved (7.6 cm/hr) vis-à-vis doubled (31 cm/hr) flow rate

3.5.4 Total Nitrogen

The 30% washed mesocosm leached a maximum TN concentration (300 mg-N/L) that was almost one-tenth of the maximum concentrations in the other two mesocosms. However, after the initial first flush, the TN showed a very pronounced trend of a higher concentration in the first sample of the next storm (Figure 46), as opposed to the last sample of the last storm. This occurred in the first sample of every storm and was most likely caused by nitrification in the media between storms. Because the 30% washed mesocosm trial ran during the spring and early summer months, temperatures in the greenhouse where the column was stored were higher than during the other two mesocosm trials that were run during the fall and winter (30% and 15%, respectively). The higher temperatures could have facilitated the growth of nitrifying bacteria, leading to increased nitrification. After 7.8 m of applied stormwater, the final TN concentration in the effluent was 5.5 mg-N/L, which was higher than the average influent TN concentration of 4.1±0.37 mg-N/L, as well as greater than the average TN effluent from the control mesocosm.

The mean TN concentration for the 30% washed mesocosm was 75±80 mg-N/L. When compared to the other two mesocosms, the 30% washed mesocosm had statistically the same mean concentration. However, there was a higher probability that the 30% washed agreed with the 15% mesocosm (p=0.33) than with the 30% unwashed mesocosm (p=0.061). Neither comparison had statistically-similar variances (p=0 for both 15%/30% washed and 30%/30% washed comparisons).

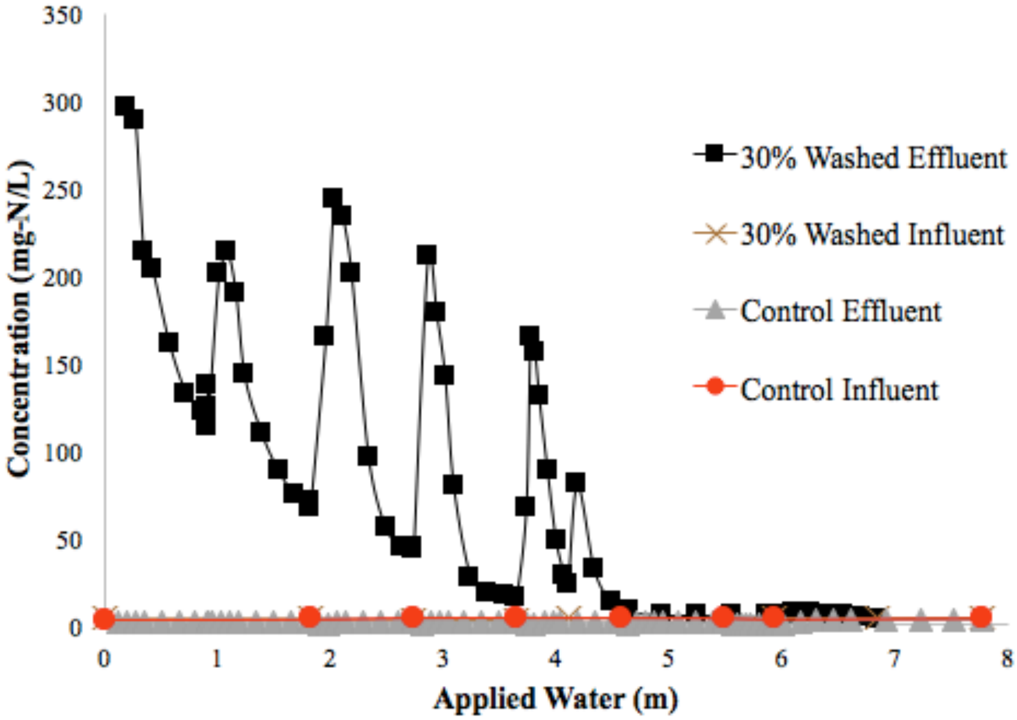


Figure 46. 30% washed mesocosm total nitrogen concentration (mg-N/L) during 7.8 m of applied stormwater (4.5 month of MD rainfall)

The 30% washed mesocosm exported the least amount of TN from the compost-containing media (12 g-N) (Figure 47), which was the equivalent of 16 years of watershed N (equation 7) and 5,100 mg-N/kg dry media. On a dry mass-basis, the 30% washed mesocosm exported more than 10 times as much N from the media as found in the the KCl-extraction (410±25 mg-N/kg dry media). The cumulative mass export was used to calculate the EMC, which was 56 mg-N/L. From Figure 47, it appears as if cumulative nitrogen export levels off during the second half of the trial. However, because nitrogen export in the second half of the trial was substantially less, the increasing export trend is not as apparent as it is in the first half of the trial.

The EMC was much lower than the average TN effluent concentration of 75±80 mg-N/L. Lastly, the mesocosm exported much more than the amount applied (0.91 g-N) and much more than what was exported in the control mesocosm.

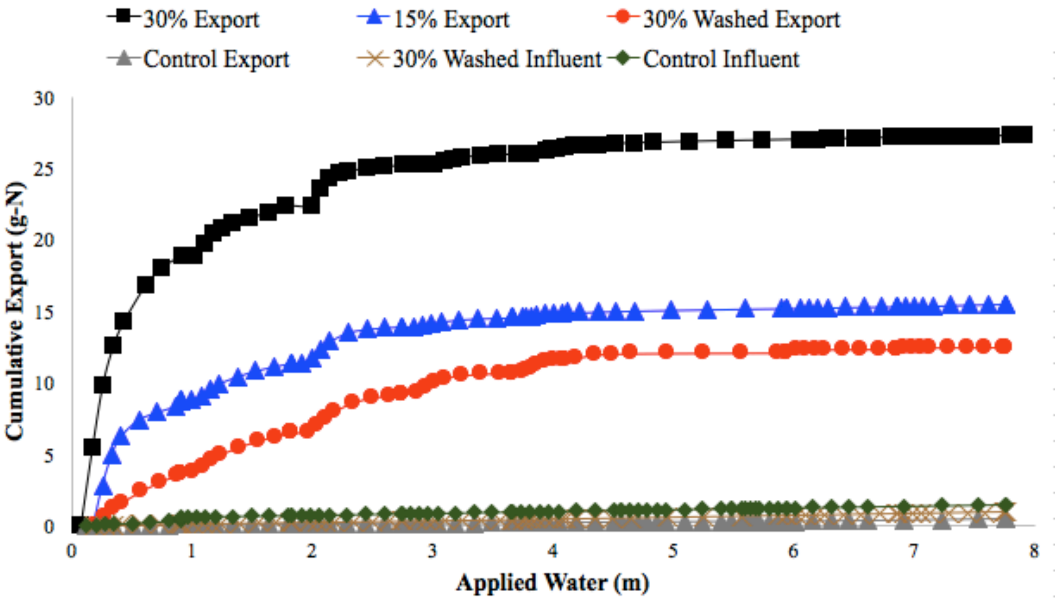


Figure 47. Comparison of 30% washed, 15%, and 30% mesocosm total nitrogen cumulative export (g-N) during 7.8 m of applied stormwater (4.5 months of MD rainfall)

3.5.5 Nitrogen Speciation

Comparable to the other two mesocosms, ammonium was the predominant species, leaching 160 mg-N/L in the first flush (Figure 48), but reducing to concentrations near detection limit (0.025 mg-N/L) by the end of the trial. This trend was also found by Brown et al. (2016). The average ammonium concentration (37±49 mg-N/L) was comparable to maximum ammonium concentration (28 mg-N/L) leached by 30% biosolids compost/70% municipal solid waste compost (Li et al. 1997). Organic N had a similar maximum concentration of 130 mg-N/L in the first flush. However, leaching of organic N was more sporadic, but generally declined over time. Nitrate leached 140 mg-N/L during storm 5. This was unexpected because nitrate is highly mobile in soils and would be expected to wash out quickly. However, in 7 out of 8 storms, the first sample had a higher nitrate concentration than the last sample of the previous storm, supporting the occurrence of nitrification. Lastly, nitrite also had relatively high concentrations in storms 3 (34 mg-N/L) and 5 (26 mg-N/L), but was otherwise near the detection limit (0.005 mg-N/L).

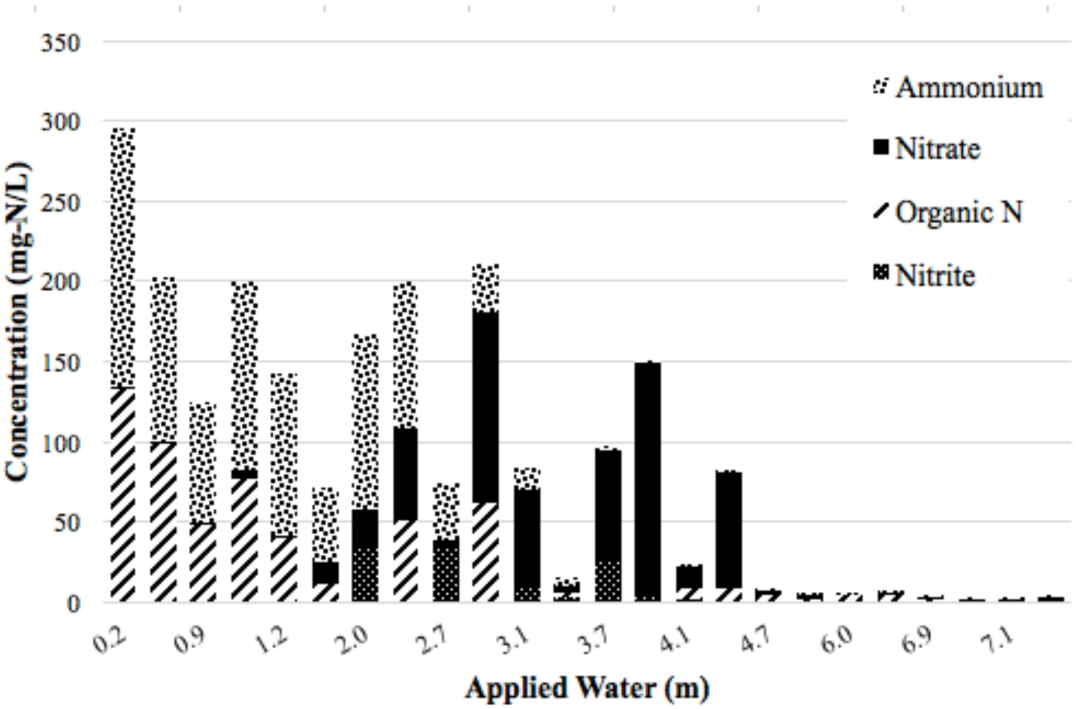


Figure 48. 30% washed mesocosm nitrogen speciation concentrations (mg-N/L) during 7.8 m of applied stormwater (4.5 months of MD rainfall)

In the 30% washed mesocosm trial, 6.1 g-N of ammonium were exported, which was a 48% and 65% decrease over the 15% and 30% mesocosms, respectively.

Nitrate export also reduced to 3.6 g-N, which was 22% less than the 15% mesocosm and 68% less than the 30% mesocosm. Organic N export increased over the two mesocosms by 2.2% for the 15% mesocosm and 55% for the 30% mesocosm. Nitrite export was significantly higher than the other two mesocosms, with a total cumulative export of 0.59 g-N or 7.4 times more than both the 30% and 15% mesocosms. Finally, the 30% washed mesocosm exported much more of each N species than the control mesocosm. As previously mentioned, the control exported 14 mg-N of ammonium, 0.11 mg-N nitrite, 210 mg-N nitrate, and 63 mg-N of organic N.

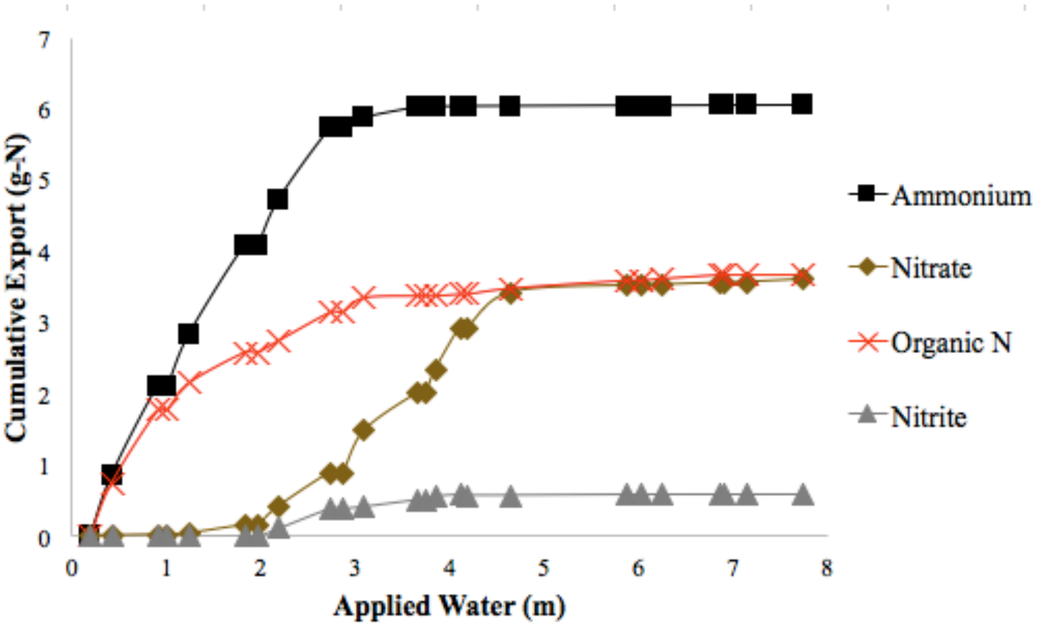


Figure 49. 30% washed mesocosm nitrogen speciation cumulative export (g-N) during 7.8 m of applied stormwater (4.5 months of MD rainfall)

3.5.6 Effect of Flow Rate on Nitrogen

Flow rate did have a significant impact on mean TN concentration. TN in the effluent during the halved flow rate storm averaged 88±56 mg-N/L and 16±24 mg-N/L for the doubled storm. The t-test found these means were statistically-different (p=0.0081) and the F-test found the variances to also be statistically-different (p=0.011). This is not surprising because, even though nitrification caused spikes of TN in each subsequent storm, TN generally decreased. Therefore, it is expected that the doubled flow rate storm would have a lower mean TN concentration than the halved storm.

However, flow rate did not have an impact on any nitrogen species (Figure 50). The mean concentrations for ammonium were 1.6±1.0 and 0.15±0.12 mg-N/L (p=0.15), 11±13 and 0.19±0.22 mg-N/L for nitrite (p=0.31), 76±65 and 26±40 mg-N/L for nitrate (p=0.40), and 2.1±3.6 and 4.9±3.2 mg-N/L for organic N (p=0.54) for the halved and doubled flow rate storms, respectively. This is unexpected because the mean nitrogen concentration for each species was higher in the halved storm than the doubled storm, with the exception of organic N. The variances were statistically-different for ammonium and nitrite (p=0.027 and 5.8×10^{-4}, respectively), but were statistically the same for nitrate and organic N (p=0.54 and 0.88, respectively). Therefore, it is inconclusive as to whether flow rate had an effect on nitrogen in the 30% washed mesocosm. The disagreement between the two statistical tests could possibly be because each nitrogen species is a component of TN, so individually, the concentrations do not vary depending on flow rate, but they do so collectively as TN.

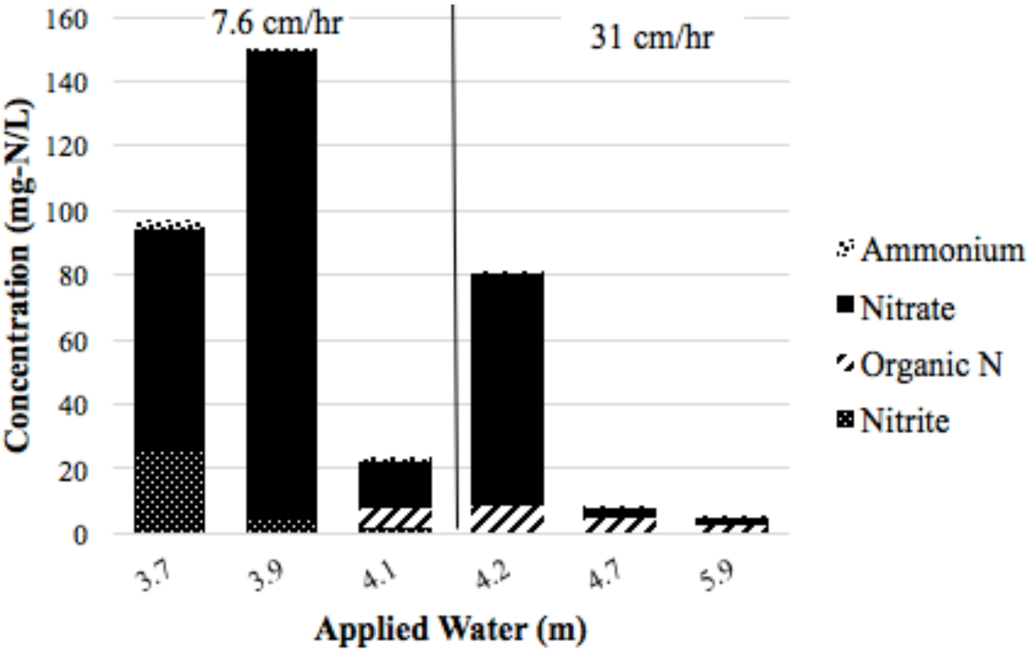


Figure 50. 30% washed mesocosm nitrogen speciation concentrations (mg-N/L) for halved (7.6 cm/hr) vis-à-vis doubled (31 cm/hr) flow rate

3.6 Mesocosm Summary

Figure 51 summarizes the general leaching patterns of nitrogen and phosphorus species from the three bioretention mesocosms. In the first flush, ammonium, DOP, and PP all washed out at high concentrations. However, as the trials progressed, these species were reduced to or below their detection limit (0.025 mg-N/L and mg-P/L, respectively). Nitrate concentrations decreased and increased alternatively as a result of nitrification that occurred between storms. SRP leached continuously, while organic N leached sporadically. Nitrite was present at the lowest concentration and remained at or below detection limit for the duration of the trials

(0.005 mg-N/L).

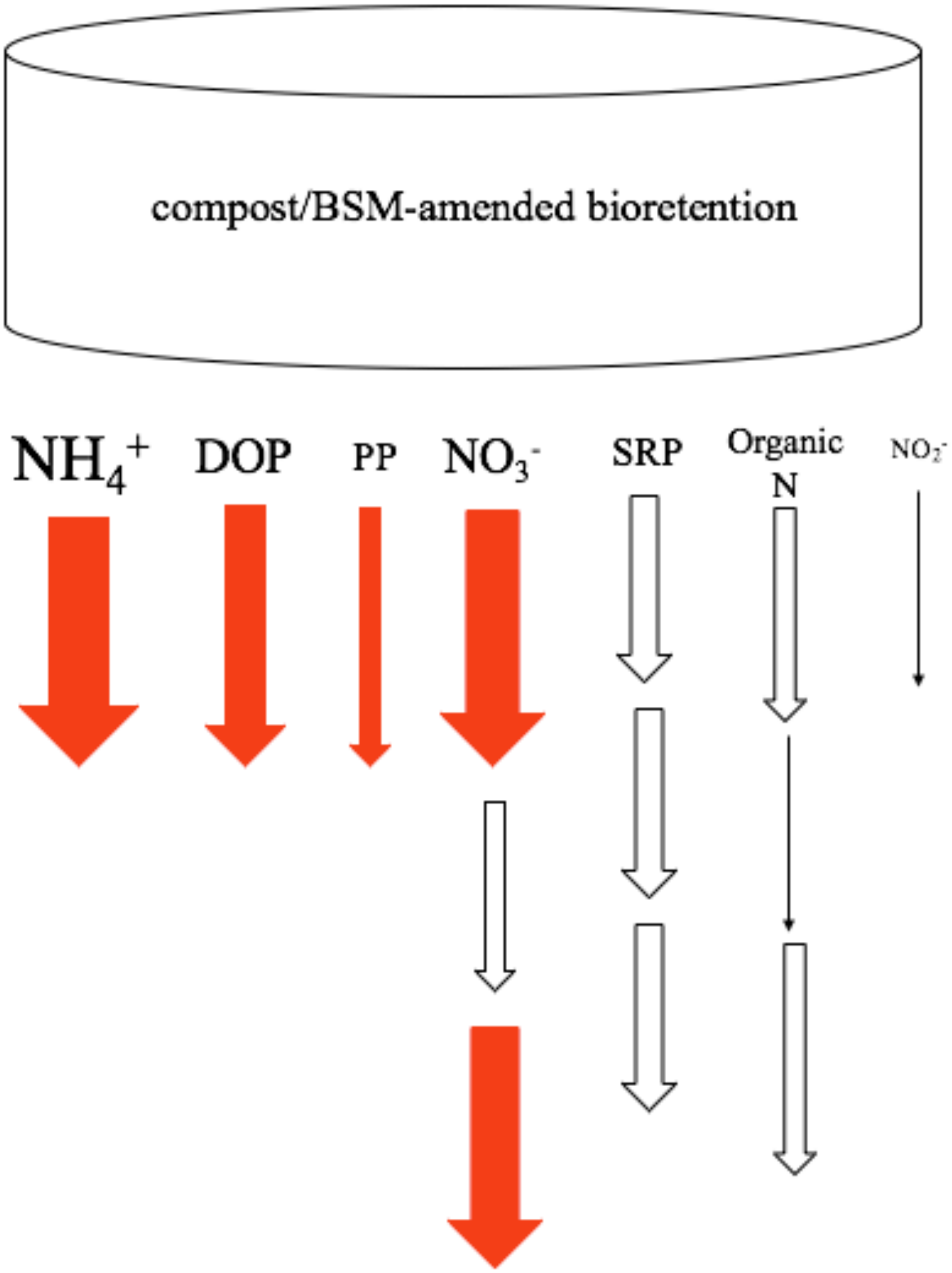


Figure 51. Biosolids compost bioretention mesocosm leaching summary: Generally, all three mesocosms showed a large washout of ammonium, DOP, and PP, increased nitrate due to nitrification, consistent SRP leaching, sporadic organic N washout, and low nitrite concentrations

Chapter 4: Conclusions and Recommendations

Overall, regardless of compost amount, all three mesocosms leached high amounts of phosphorus and nitrogen, without demonstrating any (or very insignificant) removal. The 30% mesocosm exported 1.1 g-P (470 mg/kg dry media) or 6.0 years of watershed P and 30 g-N (13,000 mg-N/kg dry media) or 36 years of watershed N after 28 m of applied stormwater. The 15% mesocosm exported 170 mg-P (65 mg-P/kg dry media) or 1 year of watershed P and 16 g-N (6,000 mg-N/kg dry compost) or 20 years of watershed N after 7.8 m of applied stormwater. The 30% washed mesocosm exported 360 mg-P (150 mg-P/kg dry media) or 2.1 years of watershed P and 12 g-N (5,100 mg-N/kg dry compost) or 16 years of watershed N after 7.8 m of applied stormwater.

Generally, all three mesocosms had statistically-different mean TP concentrations, when compared to each other, but were not statistically-different regarding TN. Moreover, all three mesocosms demonstrated extensive leaching of ammonium, which is toxic, and nitrate and SRP/orthophosphate, which both contribute to eutrophication.

With the exception of the 15% mesocosm P export, none of the mesocosms related to the extraction data. It should be expected that as extractable N or P increases, EMC from the media should increase, but that was not found to be true. The BSM most likely interacted with the compost upon mixture, such as adsorbing phosphate as previously mentioned. When the media mixtures were added to the column and storms were applied, this caused a disproportionate N and P leaching, in comparison with extractable amounts of N and P. (Figures 52-54).

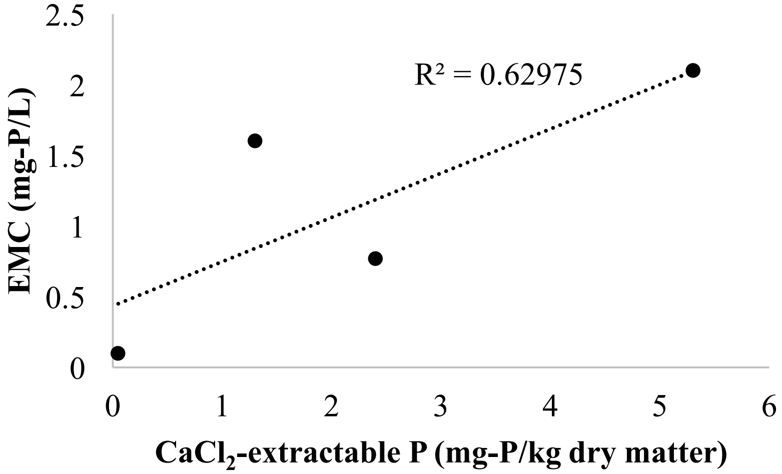


Figure 52. Relationship between EMC (mg-P/L) and CaCl$_2$-extractable P (mg-P/kg dry matter) for the 15%, 30%, 30% washed, and control mesocosms

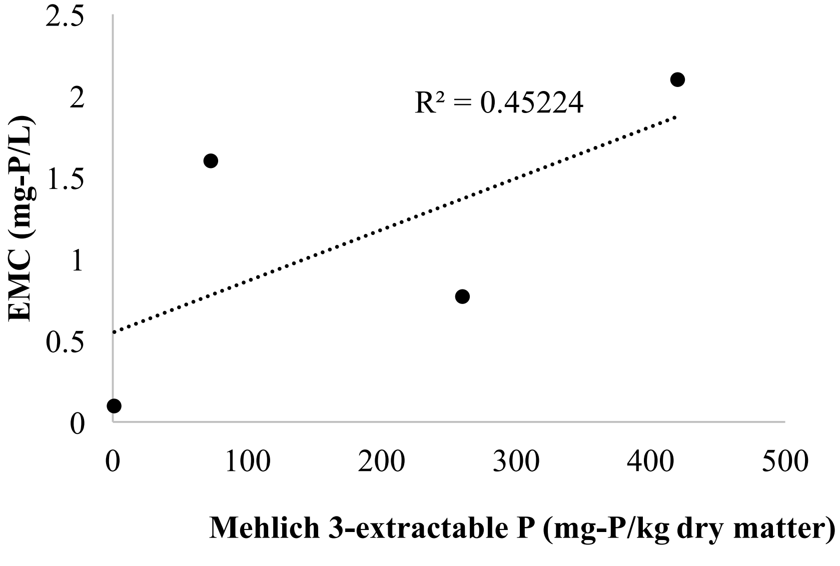


Figure 53. Relationship between EMC (mg-P/L) and Mehlich 3-extractable P (mg-P/kg dry matter) for the 15%, 30%, 30% washed, and control mesocosms

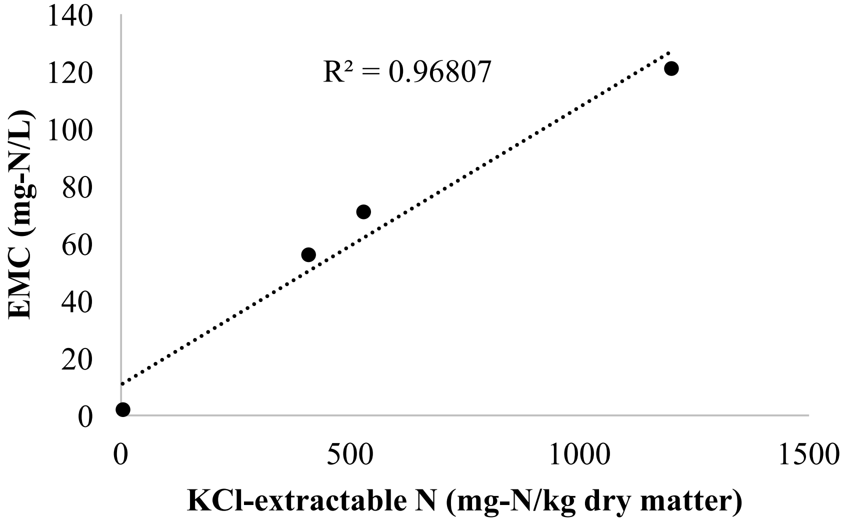


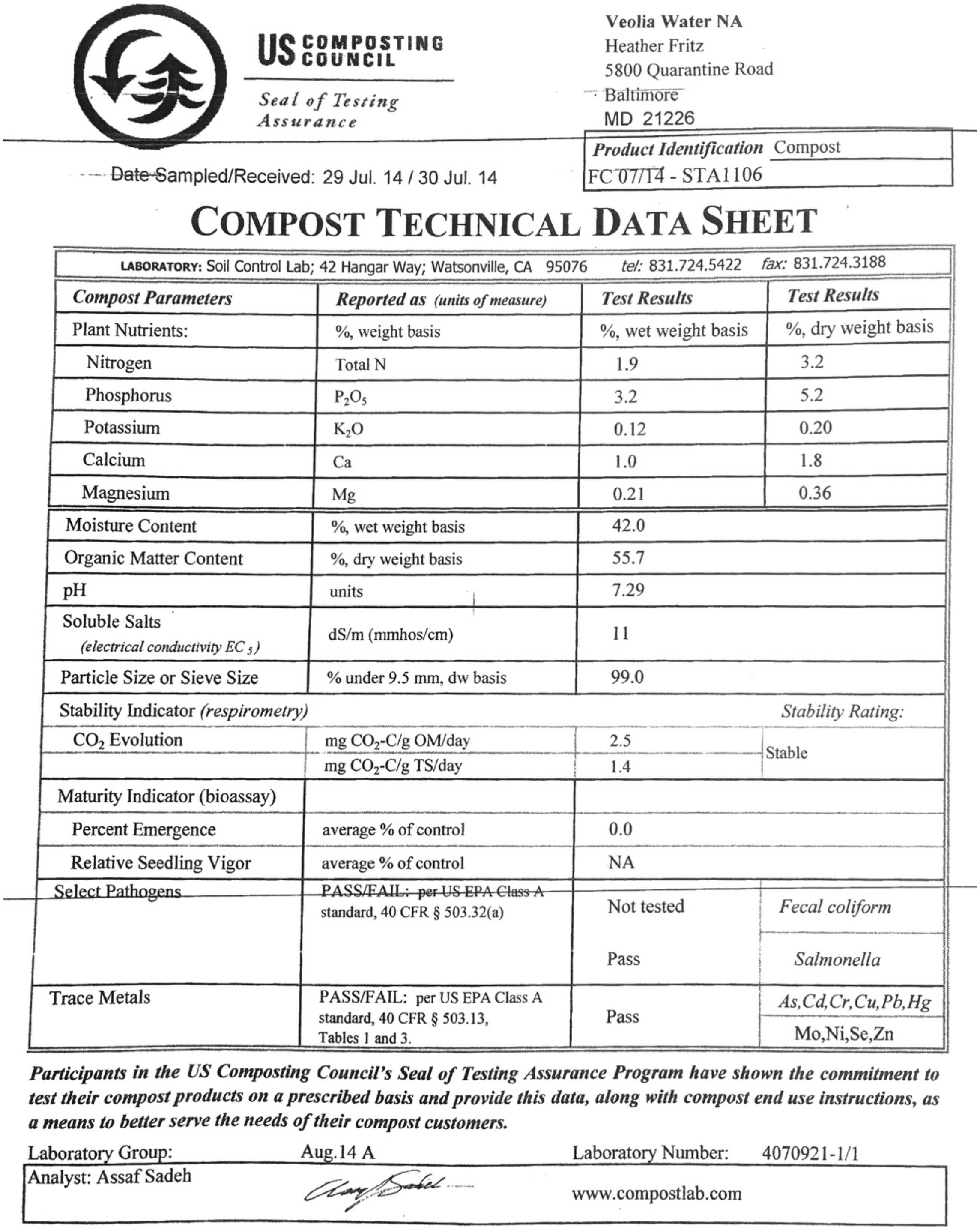
Figure 54. Relationship between EMC (mg-N/L) and Mehlich 3-extractable N (mg-P/kg dry matter) for the 15%, 30%, 30% washed, and control mesocosms

On the contrary, the control mesocosm only exported 440 mg-N (99 mg-N/kg dry BSM) and 22 mg-P (5.1 mg-P/kg dry BSM). These values also did not agree with the extraction data. This was understandable, however, because N and P were applied to the BSM during the mesocosm trials. The added N and P were leached in the BSM effluent, increasing effluent concentrations, compared to extraction values. Despite this, by the end of the trial, removal was observed for both pollutants, but especially phosphorus.

From this study, it is clear that biosolids-derived compost should not be used in bioretention. However, because the control column was able to remove N and P, BSM amended with biosolids-derived compost may also be able to remove N and P if the media KCl, $CaCl_2$, and Mehlich 3 extractions are close to or match those of 100% BSM. Therefore, relationships, such as those shown in Figures 52-54 could be used to predict acceptable extraction values, if a linear relationship were present. Because the extractions were so high, relative to EMC, it is not possible to predict these values using the above graphs. More research will need to be conducted to determine what the acceptable extraction threshold will be. Additionally, previous studies have had success at amending BSM with either WTR (O’Neill and Davis 2012) to remove phosphorus or biochar to remove nitrate (Knowles et al. 2011). Therefore, the effects of these amendments to biosolids-derived compost should also be studied.

Appendices

Appendix A: Compost Technical Data



US COMPOSTING COUNCIL
Seal of Testing Assurance

Veolia Water NA
Heather Fritz
5800 Quarantine Road
Baltimore
MD 21226

Date Sampled/Received: 29 Jul. 14 / 30 Jul. 14

Product Identification	Compost
FC 07/14 - STA1106	

COMPOST TECHNICAL DATA SHEET

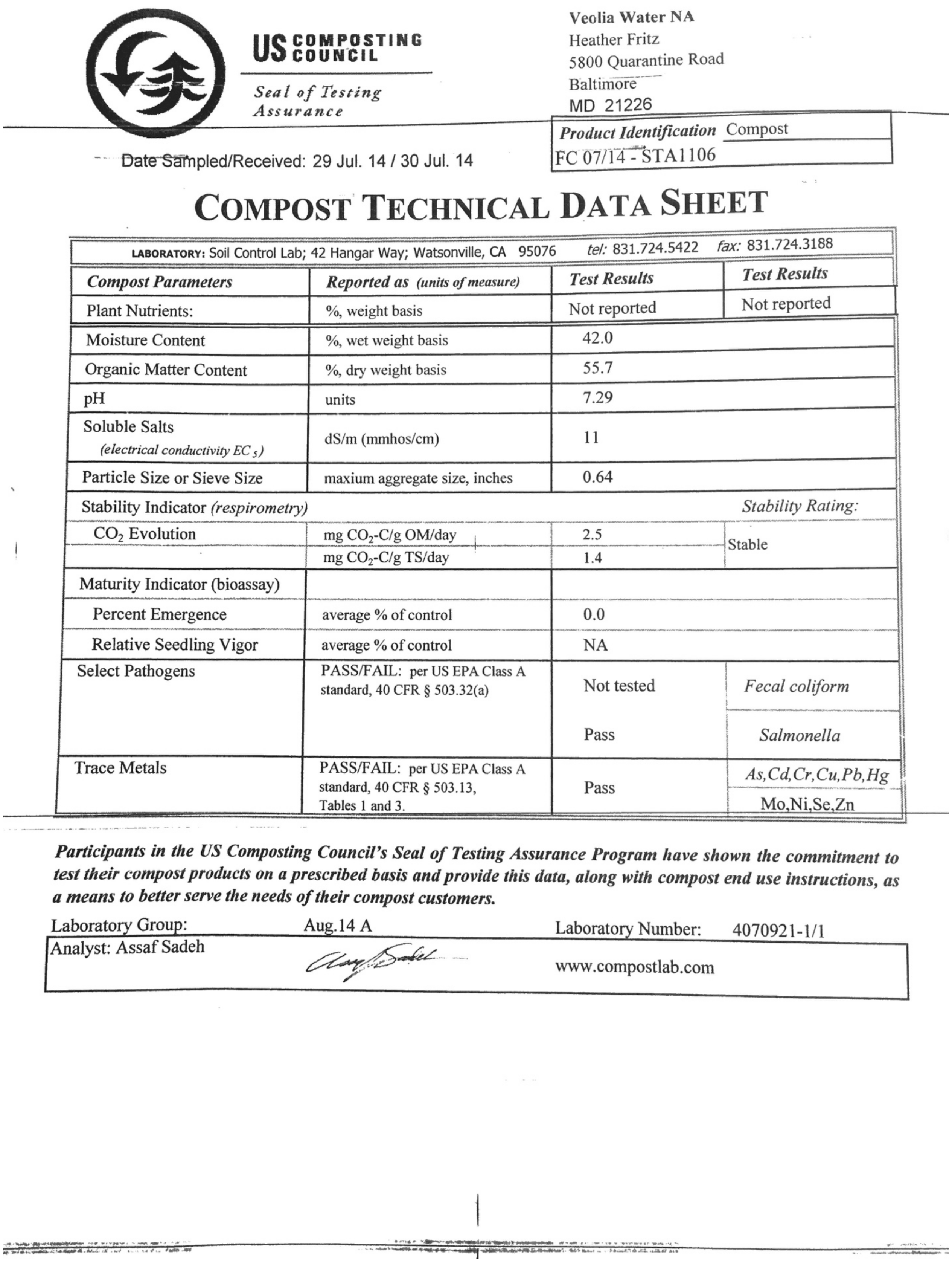
LABORATORY: Soil Control Lab; 42 Hangar Way; Watsonville, CA 95076 *tel:* 831.724.5422 *fax:* 831.724.3188

Compost Parameters	***Reported as*** *(units of measure)*	***Test Results***	***Test Results***
Plant Nutrients:	%, weight basis	%, wet weight basis	%, dry weight basis
Nitrogen	Total N	1.9	3.2
Phosphorus	P_2O_5	3.2	5.2
Potassium	K_2O	0.12	0.20
Calcium	Ca	1.0	1.8
Magnesium	Mg	0.21	0.36
Moisture Content	%, wet weight basis	42.0	
Organic Matter Content	%, dry weight basis	55.7	
pH	units	7.29	
Soluble Salts *(electrical conductivity EC_5)*	dS/m (mmhos/cm)	11	
Particle Size or Sieve Size	% under 9.5 mm, dw basis	99.0	
Stability Indicator *(respirometry)*			*Stability Rating:*
CO_2 Evolution	mg CO_2-C/g OM/day	2.5	Stable
	mg CO_2-C/g TS/day	1.4	
Maturity Indicator (bioassay)			
Percent Emergence	average % of control	0.0	
Relative Seedling Vigor	average % of control	NA	
Select Pathogens	PASS/FAIL: per US EPA Class A standard, 40 CFR § 503.32(a)	Not tested	*Fecal coliform*
		Pass	*Salmonella*
Trace Metals	PASS/FAIL: per US EPA Class A standard, 40 CFR § 503.13, Tables 1 and 3.	Pass	*As,Cd,Cr,Cu,Pb,Hg* Mo,Ni,Se,Zn

Participants in the US Composting Council's Seal of Testing Assurance Program have shown the commitment to test their compost products on a prescribed basis and provide this data, along with compost end use instructions, as a means to better serve the needs of their compost customers.

Laboratory Group: Aug.14 A
Laboratory Number: 4070921-1/1
Analyst: Assaf Sadeh
www.compostlab.com

Figure 55. Compost Technical Data



US COMPOSTING COUNCIL

Seal of Testing Assurance

Veolia Water NA
Heather Fritz
5800 Quarantine Road
Baltimore
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Product Identification Compost
FC 07/14 - STA1106

Date Sampled/Received: 29 Jul. 14 / 30 Jul. 14

COMPOST TECHNICAL DATA SHEET

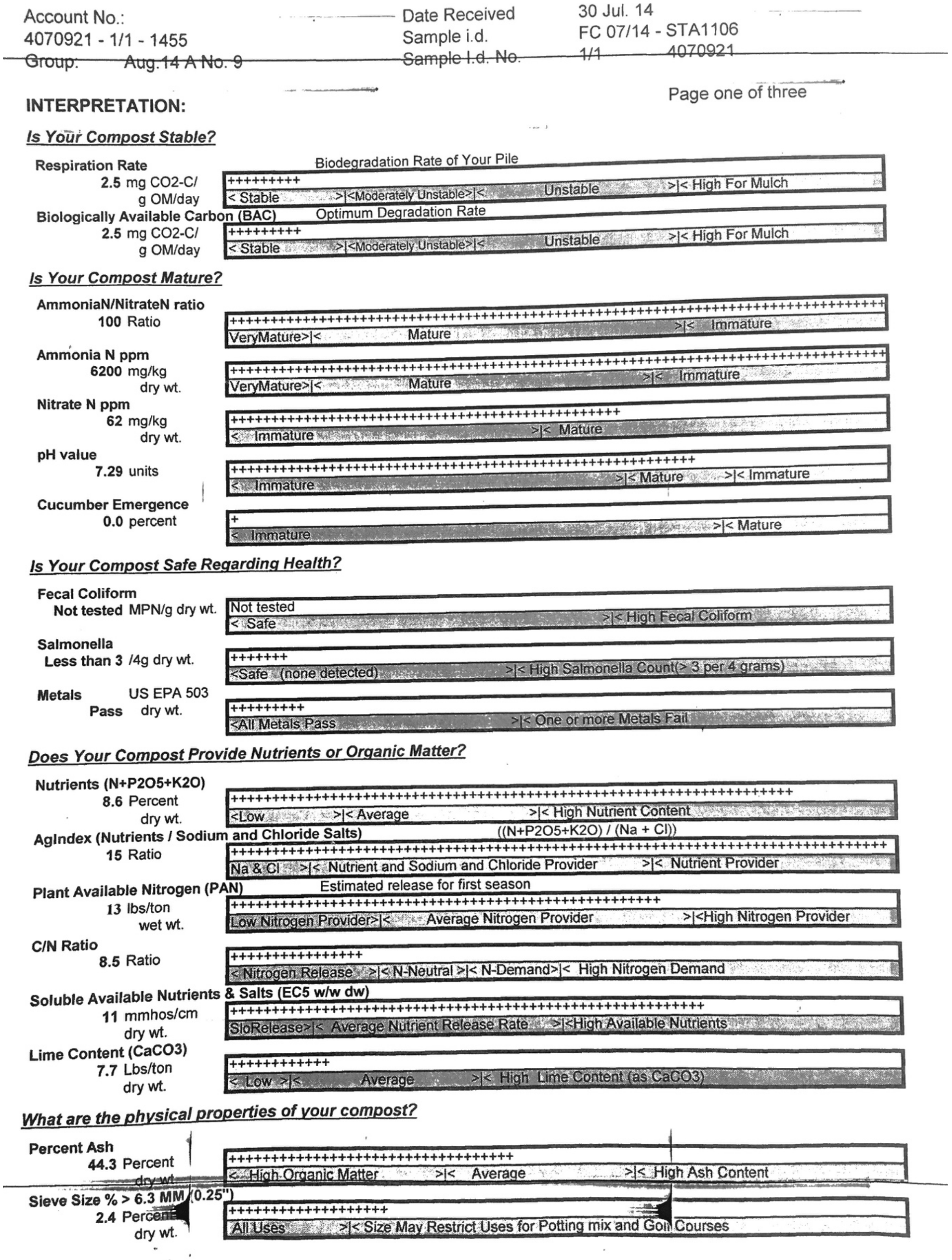
LABORATORY: Soil Control Lab; 42 Hangar Way; Watsonville, CA 95076 *tel:* 831.724.5422 *fax:* 831.724.3188

Compost Parameters	***Reported as*** *(units of measure)*	***Test Results***	***Test Results***
Plant Nutrients:	%, weight basis	Not reported	Not reported
Moisture Content	%, wet weight basis	42.0	
Organic Matter Content	%, dry weight basis	55.7	
pH	units	7.29	
Soluble Salts *(electrical conductivity EC_5)*	dS/m (mmhos/cm)	11	
Particle Size or Sieve Size	maxium aggregate size, inches	0.64	
Stability Indicator *(respirometry)*			*Stability Rating:*
CO_2 Evolution	mg CO_2-C/g OM/day	2.5	Stable
	mg CO_2-C/g TS/day	1.4	
Maturity Indicator (bioassay)			
Percent Emergence	average % of control	0.0	
Relative Seedling Vigor	average % of control	NA	
Select Pathogens	PASS/FAIL: per US EPA Class A standard, 40 CFR § 503.32(a)	Not tested	*Fecal coliform*
		Pass	*Salmonella*
Trace Metals	PASS/FAIL: per US EPA Class A standard, 40 CFR § 503.13, Tables 1 and 3.	Pass	*As,Cd,Cr,Cu,Pb,Hg* Mo,Ni,Se,Zn

Participants in the US Composting Council's Seal of Testing Assurance Program have shown the commitment to test their compost products on a prescribed basis and provide this data, along with compost end use instructions, as a means to better serve the needs of their compost customers.

Laboratory Group: Aug.14 A
Laboratory Number: 4070921-1/1
Analyst: Assaf Sadeh
www.compostlab.com

Figure 56. Compost technical data



Account No.:
4070921 - 1/1 - 1455
Group: Aug.14 A No. 9

Date Received 30 Jul. 14
Sample i.d. FC 07/14 - STA1106
Sample I.d. No. 1/1 4070921

Page one of three

INTERPRETATION:

Is Your Compost Stable?

Respiration Rate
2.5 mg CO2-C/ g OM/day
Biodegradation Rate of Your Pile
< Stable >|<Moderately Unstable>|< Unstable >|< High For Mulch

Biologically Available Carbon (BAC)
2.5 mg CO2-C/ g OM/day
Optimum Degradation Rate
< Stable >|<Moderately Unstable>|< Unstable >|< High For Mulch

Is Your Compost Mature?

AmmoniaN/NitrateN ratio
100 Ratio
VeryMature>|< Mature >|< Immature

Ammonia N ppm
6200 mg/kg dry wt.
VeryMature>|< Mature >|< Immature

Nitrate N ppm
62 mg/kg dry wt.
< Immature >|< Mature

pH value
7.29 units
< Immature >|< Mature >|< Immature

Cucumber Emergence
0.0 percent
< Immature >|< Mature

Is Your Compost Safe Regarding Health?

Fecal Coliform
Not tested MPN/g dry wt.
Not tested
< Safe >|< High Fecal Coliform

Salmonella
Less than 3 /4g dry wt.
<Safe (none detected) >|< High Salmonella Count(> 3 per 4 grams)

Metals US EPA 503
Pass dry wt.
<All Metals Pass >|< One or more Metals Fail

Does Your Compost Provide Nutrients or Organic Matter?

Nutrients (N+P2O5+K2O)
8.6 Percent dry wt.
<Low >|< Average >|< High Nutrient Content

AgIndex (Nutrients / Sodium and Chloride Salts) ((N+P2O5+K2O) / (Na + Cl))
15 Ratio
Na & Cl >|< Nutrient and Sodium and Chloride Provider >|< Nutrient Provider

Plant Available Nitrogen (PAN) Estimated release for first season
13 lbs/ton wet wt.
Low Nitrogen Provider>|< Average Nitrogen Provider >|<High Nitrogen Provider

C/N Ratio
8.5 Ratio
< Nitrogen Release >|< N-Neutral >|< N-Demand>|< High Nitrogen Demand

Soluble Available Nutrients & Salts (EC5 w/w dw)
11 mmhos/cm dry wt.
SloRelease>|< Average Nutrient Release Rate >|<High Available Nutrients

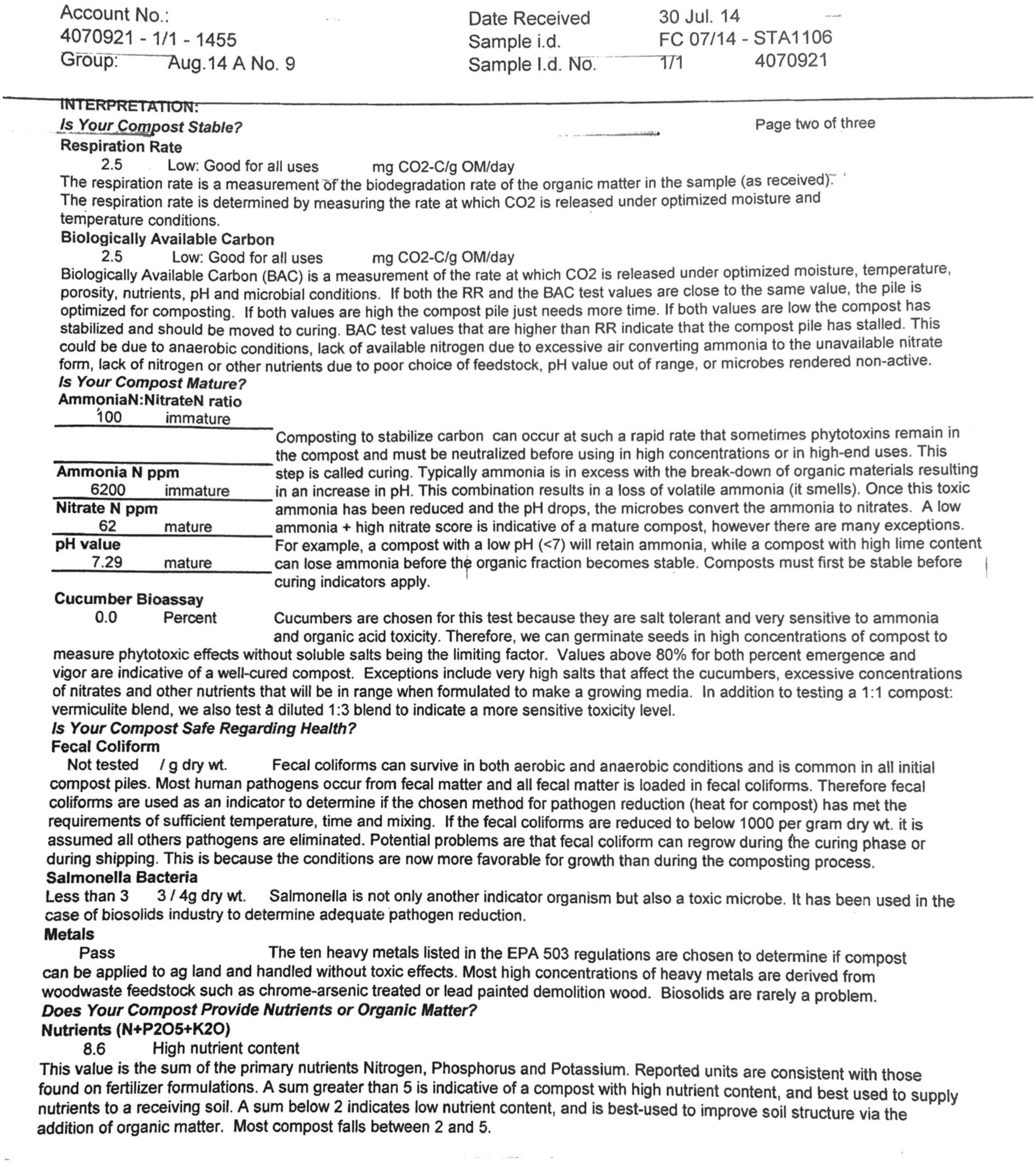
Lime Content (CaCO3)
7.7 Lbs/ton dry wt.
< Low >|< Average >|< High Lime Content (as CaCO3)

What are the physical properties of your compost?

Percent Ash
44.3 Percent dry wt.
< High Organic Matter >|< Average >|< High Ash Content

Sieve Size % > 6.3 MM (0.25")
2.4 Percent dry wt.
All Uses >|< Size May Restrict Uses for Potting mix and Golf Courses

Figure 57. Compost Stability Table



Account No.:		Date Received	30 Jul. 14
4070921 - 1/1 - 1455		Sample i.d.	FC 07/14 - STA1106
Group:	Aug.14 A No. 9	Sample I.d. No.	1/1 4070921

INTERPRETATION:

Page two of three

Is Your Compost Stable?

Respiration Rate

2.5 Low: Good for all uses mg CO2-C/g OM/day

The respiration rate is a measurement of the biodegradation rate of the organic matter in the sample (as received). The respiration rate is determined by measuring the rate at which CO2 is released under optimized moisture and temperature conditions.

Biologically Available Carbon

2.5 Low: Good for all uses mg CO2-C/g OM/day

Biologically Available Carbon (BAC) is a measurement of the rate at which CO2 is released under optimized moisture, temperature, porosity, nutrients, pH and microbial conditions. If both the RR and the BAC test values are close to the same value, the pile is optimized for composting. If both values are high the compost pile just needs more time. If both values are low the compost has stabilized and should be moved to curing. BAC test values that are higher than RR indicate that the compost pile has stalled. This could be due to anaerobic conditions, lack of available nitrogen due to excessive air converting ammonia to the unavailable nitrate form, lack of nitrogen or other nutrients due to poor choice of feedstock, pH value out of range, or microbes rendered non-active.

Is Your Compost Mature?

AmmoniaN:NitrateN ratio

100 immature

Ammonia N ppm

6200 immature

Nitrate N ppm

62 mature

pH value

7.29 mature

Composting to stabilize carbon can occur at such a rapid rate that sometimes phytotoxins remain in the compost and must be neutralized before using in high concentrations or in high-end uses. This step is called curing. Typically ammonia is in excess with the break-down of organic materials resulting in an increase in pH. This combination results in a loss of volatile ammonia (it smells). Once this toxic ammonia has been reduced and the pH drops, the microbes convert the ammonia to nitrates. A low ammonia + high nitrate score is indicative of a mature compost, however there are many exceptions. For example, a compost with a low pH (<7) will retain ammonia, while a compost with high lime content can lose ammonia before the organic fraction becomes stable. Composts must first be stable before curing indicators apply.

Cucumber Bioassay

0.0 Percent Cucumbers are chosen for this test because they are salt tolerant and very sensitive to ammonia and organic acid toxicity. Therefore, we can germinate seeds in high concentrations of compost to measure phytotoxic effects without soluble salts being the limiting factor. Values above 80% for both percent emergence and vigor are indicative of a well-cured compost. Exceptions include very high salts that affect the cucumbers, excessive concentrations of nitrates and other nutrients that will be in range when formulated to make a growing media. In addition to testing a 1:1 compost: vermiculite blend, we also test a diluted 1:3 blend to indicate a more sensitive toxicity level.

Is Your Compost Safe Regarding Health?

Fecal Coliform

Not tested / g dry wt. Fecal coliforms can survive in both aerobic and anaerobic conditions and is common in all initial compost piles. Most human pathogens occur from fecal matter and all fecal matter is loaded in fecal coliforms. Therefore fecal coliforms are used as an indicator to determine if the chosen method for pathogen reduction (heat for compost) has met the requirements of sufficient temperature, time and mixing. If the fecal coliforms are reduced to below 1000 per gram dry wt. it is assumed all others pathogens are eliminated. Potential problems are that fecal coliform can regrow during the curing phase or during shipping. This is because the conditions are now more favorable for growth than during the composting process.

Salmonella Bacteria

Less than 3 3 / 4g dry wt. Salmonella is not only another indicator organism but also a toxic microbe. It has been used in the case of biosolids industry to determine adequate pathogen reduction.

Metals

Pass The ten heavy metals listed in the EPA 503 regulations are chosen to determine if compost can be applied to ag land and handled without toxic effects. Most high concentrations of heavy metals are derived from woodwaste feedstock such as chrome-arsenic treated or lead painted demolition wood. Biosolids are rarely a problem.

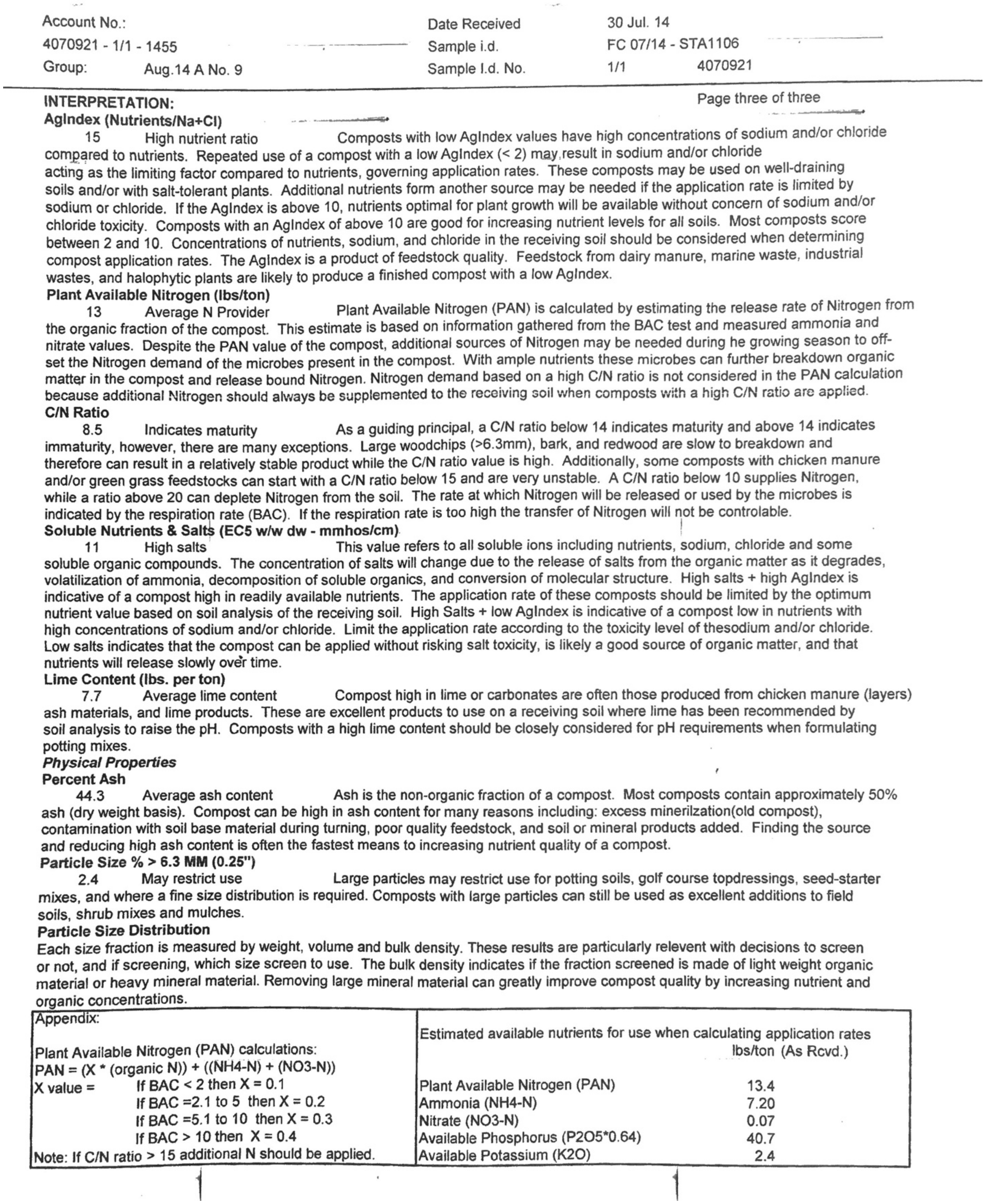
Does Your Compost Provide Nutrients or Organic Matter?

Nutrients (N+P2O5+K2O)

8.6 High nutrient content

This value is the sum of the primary nutrients Nitrogen, Phosphorus and Potassium. Reported units are consistent with those found on fertilizer formulations. A sum greater than 5 is indicative of a compost with high nutrient content, and best used to supply nutrients to a receiving soil. A sum below 2 indicates low nutrient content, and is best-used to improve soil structure via the addition of organic matter. Most compost falls between 2 and 5.

Figure 58. Compost Stability Description



Account No.:		Date Received	30 Jul. 14
4070921 - 1/1 - 1455		Sample i.d.	FC 07/14 - STA1106
Group:	Aug.14 A No. 9	Sample I.d. No.	1/1 4070921

INTERPRETATION: Page three of three

AgIndex (Nutrients/Na+Cl)

15 High nutrient ratio Composts with low AgIndex values have high concentrations of sodium and/or chloride compared to nutrients. Repeated use of a compost with a low AgIndex (< 2) may result in sodium and/or chloride acting as the limiting factor compared to nutrients, governing application rates. These composts may be used on well-draining soils and/or with salt-tolerant plants. Additional nutrients form another source may be needed if the application rate is limited by sodium or chloride. If the AgIndex is above 10, nutrients optimal for plant growth will be available without concern of sodium and/or chloride toxicity. Composts with an AgIndex of above 10 are good for increasing nutrient levels for all soils. Most composts score between 2 and 10. Concentrations of nutrients, sodium, and chloride in the receiving soil should be considered when determining compost application rates. The AgIndex is a product of feedstock quality. Feedstock from dairy manure, marine waste, industrial wastes, and halophytic plants are likely to produce a finished compost with a low AgIndex.

Plant Available Nitrogen (lbs/ton)

13 Average N Provider Plant Available Nitrogen (PAN) is calculated by estimating the release rate of Nitrogen from the organic fraction of the compost. This estimate is based on information gathered from the BAC test and measured ammonia and nitrate values. Despite the PAN value of the compost, additional sources of Nitrogen may be needed during he growing season to off-set the Nitrogen demand of the microbes present in the compost. With ample nutrients these microbes can further breakdown organic matter in the compost and release bound Nitrogen. Nitrogen demand based on a high C/N ratio is not considered in the PAN calculation because additional Nitrogen should always be supplemented to the receiving soil when composts with a high C/N ratio are applied.

C/N Ratio

8.5 Indicates maturity As a guiding principal, a C/N ratio below 14 indicates maturity and above 14 indicates immaturity, however, there are many exceptions. Large woodchips (>6.3mm), bark, and redwood are slow to breakdown and therefore can result in a relatively stable product while the C/N ratio value is high. Additionally, some composts with chicken manure and/or green grass feedstocks can start with a C/N ratio below 15 and are very unstable. A C/N ratio below 10 supplies Nitrogen, while a ratio above 20 can deplete Nitrogen from the soil. The rate at which Nitrogen will be released or used by the microbes is indicated by the respiration rate (BAC). If the respiration rate is too high the transfer of Nitrogen will not be controlable.

Soluble Nutrients & Salts (EC5 w/w dw - mmhos/cm)

11 High salts This value refers to all soluble ions including nutrients, sodium, chloride and some soluble organic compounds. The concentration of salts will change due to the release of salts from the organic matter as it degrades, volatilization of ammonia, decomposition of soluble organics, and conversion of molecular structure. High salts + high AgIndex is indicative of a compost high in readily available nutrients. The application rate of these composts should be limited by the optimum nutrient value based on soil analysis of the receiving soil. High Salts + low AgIndex is indicative of a compost low in nutrients with high concentrations of sodium and/or chloride. Limit the application rate according to the toxicity level of thesodium and/or chloride. Low salts indicates that the compost can be applied without risking salt toxicity, is likely a good source of organic matter, and that nutrients will release slowly over time.

Lime Content (lbs. per ton)

7.7 Average lime content Compost high in lime or carbonates are often those produced from chicken manure (layers) ash materials, and lime products. These are excellent products to use on a receiving soil where lime has been recommended by soil analysis to raise the pH. Composts with a high lime content should be closely considered for pH requirements when formulating potting mixes.

Physical Properties

Percent Ash

44.3 Average ash content Ash is the non-organic fraction of a compost. Most composts contain approximately 50% ash (dry weight basis). Compost can be high in ash content for many reasons including: excess minerilzation(old compost), contamination with soil base material during turning, poor quality feedstock, and soil or mineral products added. Finding the source and reducing high ash content is often the fastest means to increasing nutrient quality of a compost.

Particle Size % > 6.3 MM (0.25")

2.4 May restrict use Large particles may restrict use for potting soils, golf course topdressings, seed-starter mixes, and where a fine size distribution is required. Composts with large particles can still be used as excellent additions to field soils, shrub mixes and mulches.

Particle Size Distribution

Each size fraction is measured by weight, volume and bulk density. These results are particularly relevent with decisions to screen or not, and if screening, which size screen to use. The bulk density indicates if the fraction screened is made of light weight organic material or heavy mineral material. Removing large mineral material can greatly improve compost quality by increasing nutrient and organic concentrations.

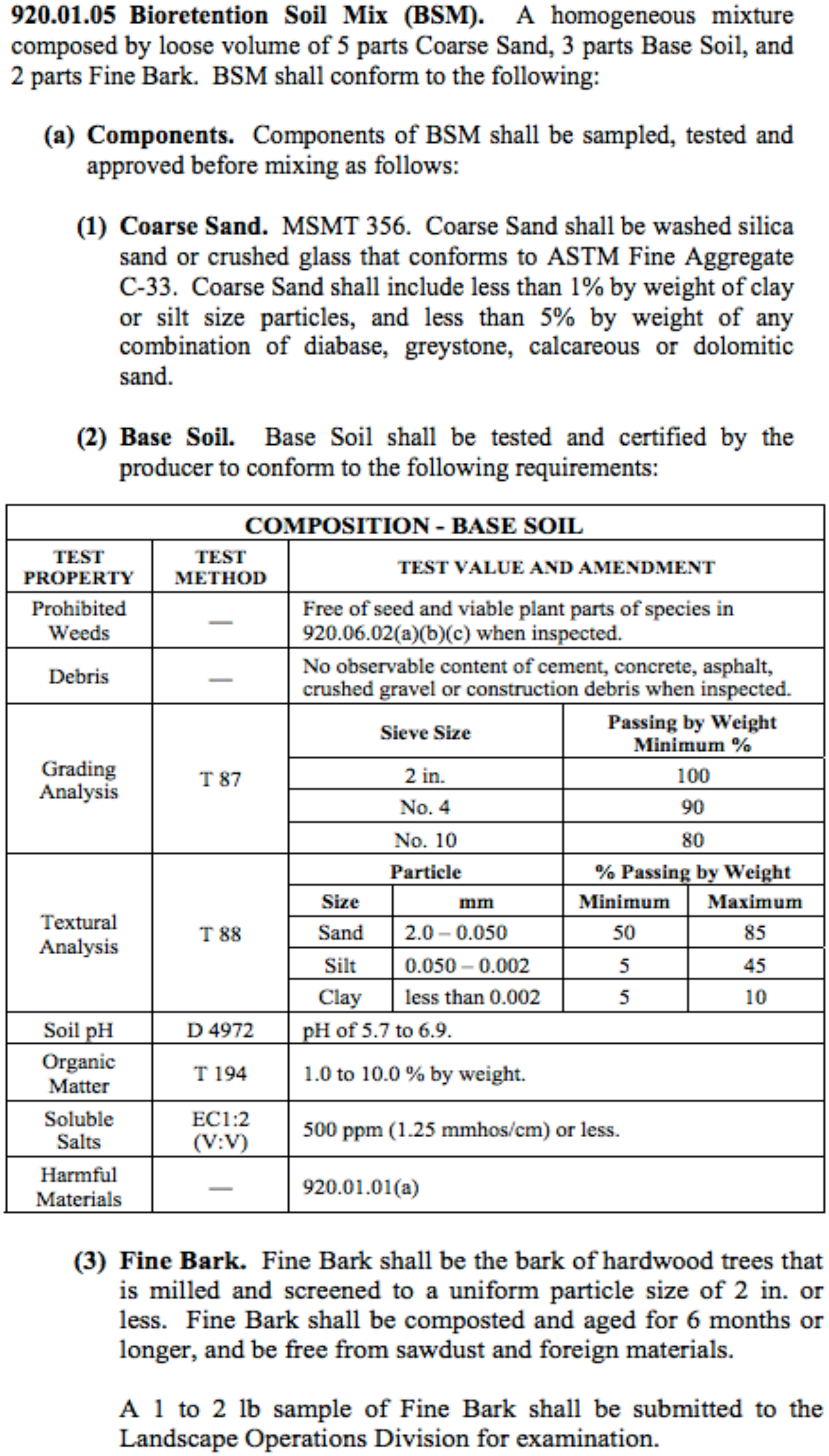
Appendix:

Plant Available Nitrogen (PAN) calculations:
PAN = (X * (organic N)) + ((NH4-N) + (NO3-N))
X value = If BAC < 2 then X = 0.1
If BAC =2.1 to 5 then X = 0.2
If BAC =5.1 to 10 then X = 0.3
If BAC > 10 then X = 0.4
Note: If C/N ratio > 15 additional N should be applied.

Estimated available nutrients for use when calculating application rates	lbs/ton (As Rcvd.)
Plant Available Nitrogen (PAN)	13.4
Ammonia (NH4-N)	7.20
Nitrate (NO3-N)	0.07
Available Phosphorus (P2O5*0.64)	40.7
Available Potassium (K2O)	2.4

Figure 59. Compost Stability Description

Appendix B: Bioretention Soil Media Specifications



920.01.05 Bioretention Soil Mix (BSM). A homogeneous mixture composed by loose volume of 5 parts Coarse Sand, 3 parts Base Soil, and 2 parts Fine Bark. BSM shall conform to the following:

(a) Components. Components of BSM shall be sampled, tested and approved before mixing as follows:

(1) Coarse Sand. MSMT 356. Coarse Sand shall be washed silica sand or crushed glass that conforms to ASTM Fine Aggregate C-33. Coarse Sand shall include less than 1% by weight of clay or silt size particles, and less than 5% by weight of any combination of diabase, greystone, calcareous or dolomitic sand.

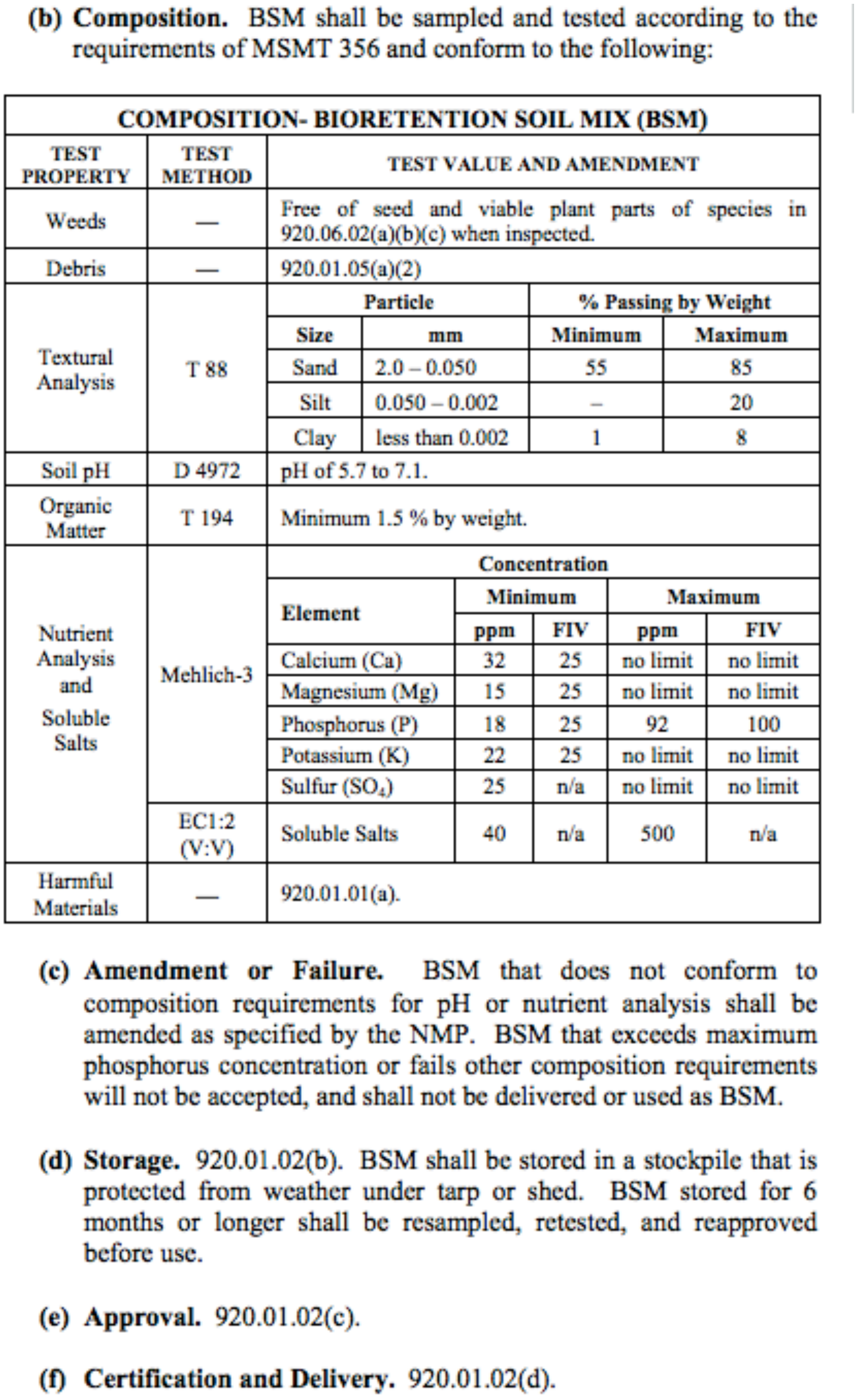
(2) Base Soil. Base Soil shall be tested and certified by the producer to conform to the following requirements:

COMPOSITION - BASE SOIL

TEST PROPERTY	TEST METHOD	TEST VALUE AND AMENDMENT			
Prohibited Weeds	—	Free of seed and viable plant parts of species in 920.06.02(a)(b)(c) when inspected.			
Debris	—	No observable content of cement, concrete, asphalt, crushed gravel or construction debris when inspected.			
Grading Analysis	T 87	Sieve Size		Passing by Weight Minimum %	
		2 in.		100	
		No. 4		90	
		No. 10		80	
Textural Analysis	T 88	Particle		% Passing by Weight	
		Size	mm	Minimum	Maximum
		Sand	2.0 – 0.050	50	85
		Silt	0.050 – 0.002	5	45
		Clay	less than 0.002	5	10
Soil pH	D 4972	pH of 5.7 to 6.9.			
Organic Matter	T 194	1.0 to 10.0 % by weight.			
Soluble Salts	EC1:2 (V:V)	500 ppm (1.25 mmhos/cm) or less.			
Harmful Materials	—	920.01.01(a)			

(3) Fine Bark. Fine Bark shall be the bark of hardwood trees that is milled and screened to a uniform particle size of 2 in. or less. Fine Bark shall be composted and aged for 6 months or longer, and be free from sawdust and foreign materials.

A 1 to 2 lb sample of Fine Bark shall be submitted to the Landscape Operations Division for examination.



(b) Composition. BSM shall be sampled and tested according to the requirements of MSMT 356 and conform to the following:

<table>
<tr><th colspan="7">COMPOSITION- BIORETENTION SOIL MIX (BSM)</th></tr>
<tr><th>TEST PROPERTY</th><th>TEST METHOD</th><th colspan="5">TEST VALUE AND AMENDMENT</th></tr>
<tr><td>Weeds</td><td>—</td><td colspan="5">Free of seed and viable plant parts of species in 920.06.02(a)(b)(c) when inspected.</td></tr>
<tr><td>Debris</td><td>—</td><td colspan="5">920.01.05(a)(2)</td></tr>
<tr><td rowspan="5">Textural Analysis</td><td rowspan="5">T 88</td><th colspan="3">Particle</th><th colspan="2">% Passing by Weight</th></tr>
<tr><th>Size</th><th colspan="2">mm</th><th>Minimum</th><th>Maximum</th></tr>
<tr><td>Sand</td><td colspan="2">2.0 – 0.050</td><td>55</td><td>85</td></tr>
<tr><td>Silt</td><td colspan="2">0.050 – 0.002</td><td>–</td><td>20</td></tr>
<tr><td>Clay</td><td colspan="2">less than 0.002</td><td>1</td><td>8</td></tr>
<tr><td>Soil pH</td><td>D 4972</td><td colspan="5">pH of 5.7 to 7.1.</td></tr>
<tr><td>Organic Matter</td><td>T 194</td><td colspan="5">Minimum 1.5 % by weight.</td></tr>
<tr><td rowspan="9">Nutrient Analysis and Soluble Salts</td><td rowspan="8">Mehlich-3</td><th colspan="5">Concentration</th></tr>
<tr><th rowspan="2">Element</th><th colspan="2">Minimum</th><th colspan="2">Maximum</th></tr>
<tr><th>ppm</th><th>FIV</th><th>ppm</th><th>FIV</th></tr>
<tr><td>Calcium (Ca)</td><td>32</td><td>25</td><td>no limit</td><td>no limit</td></tr>
<tr><td>Magnesium (Mg)</td><td>15</td><td>25</td><td>no limit</td><td>no limit</td></tr>
<tr><td>Phosphorus (P)</td><td>18</td><td>25</td><td>92</td><td>100</td></tr>
<tr><td>Potassium (K)</td><td>22</td><td>25</td><td>no limit</td><td>no limit</td></tr>
<tr><td>Sulfur (SO_4)</td><td>25</td><td>n/a</td><td>no limit</td><td>no limit</td></tr>
<tr><td>EC1:2 (V:V)</td><td>Soluble Salts</td><td>40</td><td>n/a</td><td>500</td><td>n/a</td></tr>
<tr><td>Harmful Materials</td><td>—</td><td colspan="5">920.01.01(a).</td></tr>
</table>

(c) Amendment or Failure. BSM that does not conform to composition requirements for pH or nutrient analysis shall be amended as specified by the NMP. BSM that exceeds maximum phosphorus concentration or fails other composition requirements will not be accepted, and shall not be delivered or used as BSM.

(d) Storage. 920.01.02(b). BSM shall be stored in a stockpile that is protected from weather under tarp or shed. BSM stored for 6 months or longer shall be resampled, retested, and reapproved before use.

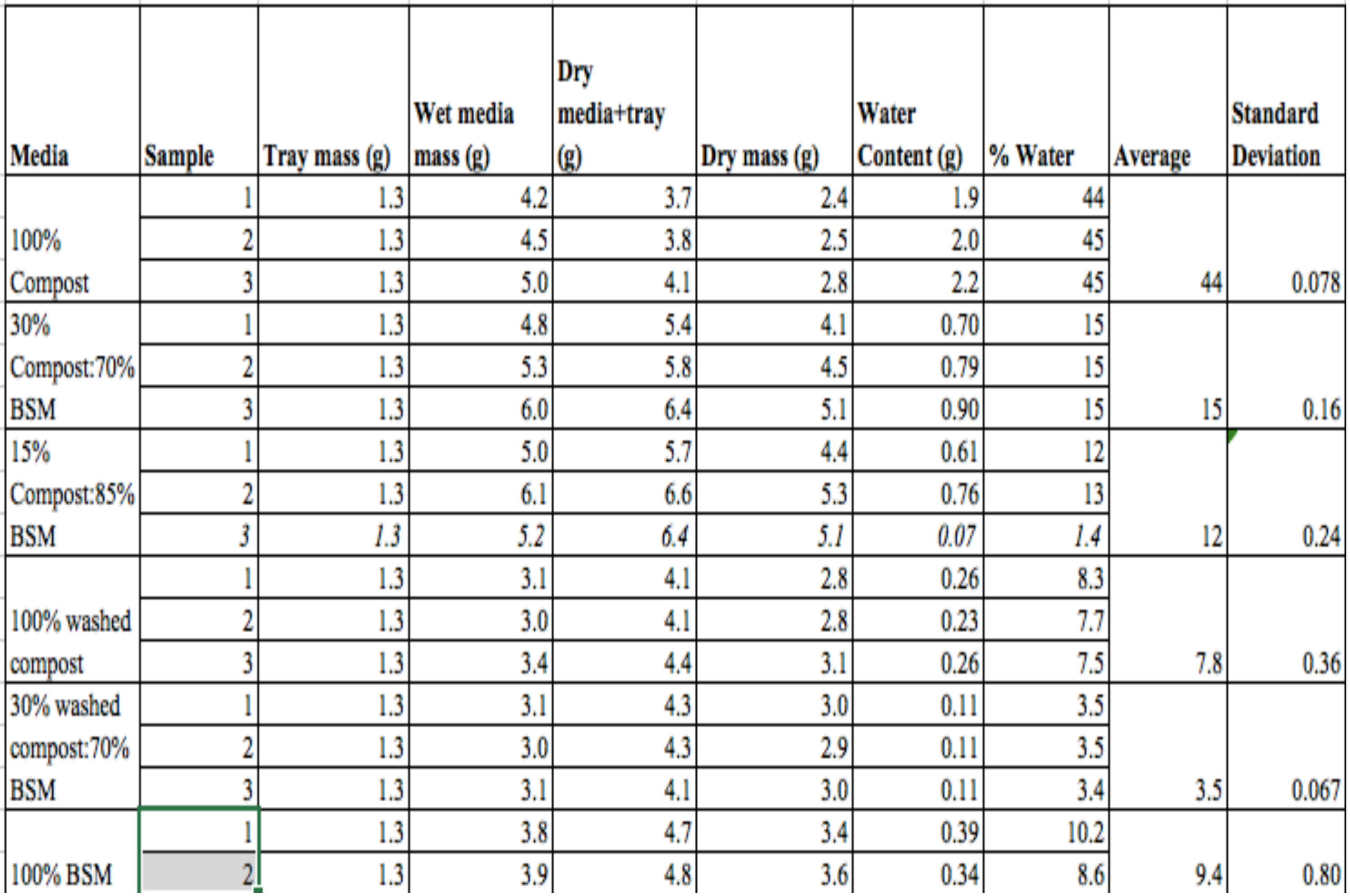
(e) Approval. 920.01.02(c).

(f) Certification and Delivery. 920.01.02(d).

Figure 60. BSM Specifications (Maryland Department of Transportation 2008)

Appendix C: Moisture Content and Extractions Data

Table 6. Moisture content raw data. Italicized values were omitted due to error in measurement



Media	Sample	Tray mass (g)	Wet media mass (g)	Dry media+tray (g)	Dry mass (g)	Water Content (g)	% Water	Average	Standard Deviation
100% Compost	1	1.3	4.2	3.7	2.4	1.9	44	44	0.078
	2	1.3	4.5	3.8	2.5	2.0	45		
	3	1.3	5.0	4.1	2.8	2.2	45		
30% Compost:70% BSM	1	1.3	4.8	5.4	4.1	0.70	15	15	0.16
	2	1.3	5.3	5.8	4.5	0.79	15		
	3	1.3	6.0	6.4	5.1	0.90	15		
15% Compost:85% BSM	1	1.3	5.0	5.7	4.4	0.61	12	12	0.24
	2	1.3	6.1	6.6	5.3	0.76	13		
	3	*1.3*	*5.2*	*6.4*	*5.1*	*0.07*	*1.4*		
100% washed compost	1	1.3	3.1	4.1	2.8	0.26	8.3	7.8	0.36
	2	1.3	3.0	4.1	2.8	0.23	7.7		
	3	1.3	3.4	4.4	3.1	0.26	7.5		
30% washed compost:70% BSM	1	1.3	3.1	4.3	3.0	0.11	3.5	3.5	0.067
	2	1.3	3.0	4.3	2.9	0.11	3.5		
	3	1.3	3.1	4.1	3.0	0.11	3.4		
100% BSM	1	1.3	3.8	4.7	3.4	0.39	10.2	9.4	0.80
	2	1.3	3.9	4.8	3.6	0.34	8.6		

Table 7. Bulk density raw data

Media	Volume (mL)	Field Moist Weight (g)	Wet Bulk Density (kg/m^3)	Average Wet Bulk Density (kg/m^3)	Standard Deviation	dry to wet ratio	Dry Bulk Density (kg/m^3)	Average Dry Bulk Density (kg/m^3)	Standard Deviation
100% Compost	100	56	557	578	18	0.59	328	340	11
	150	85	565				332		
	200	119	593				349		
	250	150	599				353		
30% compost:70% BSM	100	111	1111	1151	24	0.85	946	981	21
	150	173	1155				984		
	200	234	1172				998		
	250	292	1167				994		
15% compost:85% BSM	10	11	1114	1217	60	0.88	1014	1107	55
	25	31	1235				1124		
	50	63	1263				1149		
	100	125	1255				1142		
30% washed compost:70% BSM	10	11	1074	1112	32	0.96	1031	1067	31
	25	29	1152				1105		
	50	54	1078				1034		
	75	83	1113				1068		
	100	114	1141				1095		
100% washed compost	10	4	417	466	28	0.92	385	430	25
	25	11	453				418		
	50	24	489				452		
	75	36	484				447		
	100	49	485				448		
100% BSM	40	125	3134	2136	521	0.91	2852	1944	474
	99	213	2154				1960		
	142	269	1896				1726		
	200	353	1766				1607		
	248	429	1729				1573		

Table 8. CaCl2 extractable P concentration raw data (mg-P/L). Italicized values were excluded due to errors in the data. The BSM concentration has been averaged from 3 samples, but the original data was unavailable.

Media	**Sample**	**Dilution**	**CaCl$_2$ - Extractable P Concentration (mg-P/L)**	**Average**	**Standard Deviation**
100% compost	1	1	1.58	1.7	0.058
	2	1	1.72		
	3	1	1.66		
30% compost/70% BSM	1	1	0.18	0.18	0.0063
	2	1	0.17		
	3	1	0.19		
15% compost/85% BSM	1	1	0.08	0.09	0.0077
	2	1	0.09		
	3	1	0.10		
30% washed compost/70% BSM	1	1:10	1.8	0.050	0.065
	2	1:10	0.3		
	3	1:10	*-1.6*		
100% washed compost	1	1:50	1.5	0.071	0.17
	2	1:50	1.5		
	3	1:50	*-6.2*		
BSM	1	1	1.8*10-3	0.0	0.0

Table 9. Mehlich 3-extractable P concentration raw data (mg-P/L). Sample size was reduced to 2 when not enough sample was available. The BSM concentration has been averaged from 3 samples, but the original data was unavailable.

Media	**Sample**	**Dilution**	**Mehlich 3-Extractable P Concentration (mg-P/L)**	**Average**	**Standard Deviation**
100% compost	1	1:100	35	46	0.062
	2	1:100	57		
30% compost:70% BSM	1	1:50	32	36	0.049
	2	1:50	40		
15% compost:85% BSM	1	1:25	25	23	0.017
	2	1:25	23		
	3	1:25	23		
30% washed compost:70% BSM	1	1:10	5.4	0.050	0.065
	2	1:10	7.0		
	3	1:10	8.5		
100% washed compost	1	1:100	23.7	0.071	0.17
	2	1:100	27.5		
	3	1:100	18.6		
BSM	1	1	0.93	0.93	0.15

Table 10. KCl-extractable N concentration raw data (mg-N/L). The BSM and 100% compost concentrations haves been averaged from 3 samples, but the original data was unavailable.

Media	Sample	Dilution	KCl-Extractable N Concentration (mg-N/L)	Average	Standard Deviation
100% compost	1	1:200	2240.50	2240.50	68
30% compost:70% BSM	1	1:100	269	121	6.1
	2	1:100	282		
	3	1:100	232		
15% compost:85% BSM	1	1:100	117	261	21
	2	1:100	129		
	3	1:100	116		
30% washed compost:70% BSM	1	1:200	107	99	6.1
	2	1:200	99		
	3	1:200	92		
100% washed compost	1	1:500	1357	1363	163
	2	1:500	1167		
	3	1:500	1566		
BSM	1	1	0.98	0.98	1.2

Table 11. Phosphorus species concentrations in washed compost effluent (mg-P/L)

Sample	Dilution	TP Concentration (mg-P/L)	Average	DOP Concentration (mg-P/L)	Average	SRP Concentration (mg-P/L)	Average	PP Concentration (mg-P/L)	Average
1	1:200	99	79	17	15	14	10	3.5	3.5
2	1:200	67		16		10		0.025	
3	1:200	97	Standard Deviation	11	Standard Deviation	10	Standard Deviation	12	Standard Deviation
4	1:200	75	17	17	2.2	7.0	2.2	1.9	4.5
5	1:200	56		16		8.7		0.025	

Table 12. Nitrogen species concentrations in washed compost effluent (mg-N/L)

Sample	Dilution	TN Concentration (mg-N/L)	Average	Nitrite Concentration (mg-N/L)	Average	Ammonium Concentration (mg-N/L)	Average	Nitrate Concentration (mg-N/L)	Average	Organic N Cconcentration (mg-N/L)	Average
1	1:1000	3270	3636	0.11	0.16	2328	2493	116	79	825	1064
2	1:1000	1930	Standard Deviation	0.20	Standard Deviation	1841	Standard Deviation	55	Standard Deviation	33	Standard Deviation
3	1:1000	5709	1564	0.18	0.039	3311	611	65	27	2333	954

Appendix D: Control Mesocosm Data

Table 13. Control mesocosm TN and TP concentration (mg-X/L) and cumulative export (mg-X) raw data

Storm	Influent N Concentration (mg-N/L)	TN Concentration (mg-N/L)	Cumulative Export (mg-N)	Influent P Concentration (mg-P/L)	TN Concentration (mg-P/L)	Cumulative Export (mg-P)
1	3.70	1.60	0.00	0.26	0.44	0.00
		1.79	3.92		0.34	0.90
		1.90	7.65		0.34	1.59
		2.07	11.95		0.30	2.29
		2.14	21.08		0.24	3.46
		2.34	30.79		0.21	4.45
		2.16	40.54		0.21	5.37
		2.19	47.13		0.22	6.01
		2.20	47.13		0.18	6.01
		2.12	47.13		0.17	6.01
2	3.90	1.50	47.13	0.29	0.06	6.01
		2.10	51.04		0.08	6.16
		2.15	55.64		0.10	6.36
		2.39	60.57		0.11	6.60
		2.26	70.64		0.11	7.08
		2.23	80.37		0.10	7.53
		2.29	90.17		0.10	7.94
		2.27	100.06		0.11	8.39
		2.27	102.02		0.10	8.48
		2.32	102.02		0.10	8.48
3	4.60	1.15	102.02	0.31	0.06	8.48
		1.04	104.39		0.15	8.71
		1.23	106.85		0.10	8.99
		1.53	109.84		0.13	9.23
		1.71	116.85		0.12	9.77
		1.69	124.23		0.10	10.25
		1.69	131.59		0.13	10.76
		1.86	139.03		0.13	11.30
		1.83	139.03		0.12	11.30
		1.81	139.03		0.12	11.30
4	4.70	0.92	139.03	0.26	0.06	11.30
		1.42	141.58		0.07	11.44

		1.49	144.73		0.07	11.59
		1.78	148.27		0.07	11.75
		2.01	156.48		0.06	12.05
		1.93	165.03		0.05	12.29
		2.14	173.85		0.05	12.52
		2.21	183.28		0.05	12.75
		2.20	184.08		0.05	12.77
		2.17	184.08		0.05	12.76
5	4.60	0.53	184.08	0.34	0.03	12.76
		1.03	185.60		0.12	12.90
		1.65	188.80		0.06	13.12
		2.13	192.90		0.06	13.26
		2.30	197.71		0.06	13.39
		2.38	207.86		0.05	13.64
		2.26	217.91		0.07	13.90
		2.39	228.49		0.03	14.11
		2.41	232.65		0.03	14.15
		2.34	232.65		0.06	14.15
6	4.40	0.43	232.65	0.66	0.18	14.15
		1.26	234.49		0.25	14.62
		1.46	237.43		0.25	15.15
		1.69	240.85		0.22	15.65
		1.84	244.68		0.23	16.14
		1.93	252.87		0.22	17.11
		2.08	261.58		0.21	18.04
		2.14	270.74		0.22	18.96
		2.22	276.26		0.22	19.51
		2.11	276.26		0.20	19.51
7	4.00	0.38	276.26	0.42	0.03	19.51
		0.53	276.75		0.03	19.53
		0.71	277.43		0.06	19.58
		0.77	278.23		0.08	19.66
		0.77	279.06		0.06	19.74
		0.79	280.75		0.05	19.85
		0.84	282.52		0.03	19.94
		0.83	284.21		0.05	20.02
		0.88	284.21		0.05	20.02
8	4.40	0.61	284.21	0.36	0.03	20.02
		2.27	290.47		0.08	20.25

		2.83	301.55		0.08	20.61
		3.20	314.64		0.08	20.95
		3.31	328.77		0.07	21.27
		3.50	358.31		0.06	21.83
		3.50	388.68		0.06	22.32
		3.53	419.18		0.03	22.67
		3.55	443.25		0.03	22.84
		3.27	443.25		0.03	22.84

Table 14. Control mesocosm nitrogen speciation raw data

Storm	Sample	Applied Water (m)	Ammonium (mg-N/L)	Ammonium Cumulative Export (mg-N)	Nitrite (mg-N/L)	Nitrite Cumulative Export (mg-N)	Nitrate Concentration (mg-N/L)	Cumulative Nitrate Export (mg-N)	Organic N Concentration (mg-N/L)	Cumulative Organic N Export (mg-N)
1	1	0.12	0.10	0.00	0.00	0.00	0.38	0.00	1.11	0.00
	4	0.35	0.06	0.52	0.01	0.05	1.47	6.04	0.53	5.34
	8	0.91	0.05	1.42	0.01	0.14	1.76	32.01	0.37	12.52
2	1	0.96	---	1.45	0.00	0.00	0.79	32.01	---	12.52
	4	1.19	---	1.45	0.00	0.02	1.63	39.88	---	12.52
	8	1.80	---	1.45	0.00	0.05	1.71	68.83	---	12.52
3	1	1.91	---	1.45	0.00	0.00	0.37	68.83	---	12.52
	8	2.74	---	1.45	0.00	0.06	1.35	89.26	---	12.52
4	1	2.81	---	1.45	0.01	0.00	0.09	89.26	---	12.52
	4	3.04	---	1.45	0.01	0.07	1.12	93.19	---	12.52
	7	3.65	---	1.45	0.00	0.07	1.51	116.02		12.52
5	1	3.74	0.11	7.91	0.01	0.00	0.32	116.02	0.10	31.11
	4	3.97	0.07	8.49	0.01	0.03	1.40	121.62	0.66	33.58
	7	4.51	0.08	9.30	0.01	0.05	1.56	137.66	0.61	40.50
6	1	4.63	0.03	9.30	0.01	0.00	0.28	137.66	0.13	40.50
	4	4.86	0.07	9.62	0.01	0.03	1.25	142.62	0.37	42.10
	7	5.40	0.08	10.46	0.01	0.05	1.33	156.58	0.67	47.71
7	1	5.57	0.03	10.46	0.01	0.00	0.27	156.58	0.08	47.71
	4	5.68	0.08	10.63	0.01	0.02	0.46	157.77	0.23	48.21
	7	5.94	0.09	11.09	0.01	0.03	0.63	160.73	0.11	49.12
8	1	6.01	0.06	11.09	0.01	0.00	0.27	160.73	1.94	49.12
	4	6.46	0.11	12.15	0.01	0.07	1.66	173.34	0.04	61.96
	7	7.53	0.07	14.03	0.01	0.11	1.82	211.14	0.03	62.62

Table 15. Control mesocosm phosphorus speciation raw data

Storm	Sample	Applied Water (m)	SRP Concentration (mg-P/L)	SRP Cumulative Export (mg-P)	DOP Concentration (mg-P/L)	DOP Cumulative Export (mg-P)	PP Concentration (mg-P/L)	PP Cumulative Export (mg-P
1	1	0.12	0.03	0.00	0.03	0.00	0.38	0.00
	4	0.35	0.02	0.17	0.02	0.17	0.25	2.04
	8	0.91	0.03	0.38	0.02	0.33	0.17	5.44
2	1	0.96	0.02	0.00	0.02	0.00	0.02	5.44
	4	1.19	0.03	0.16	0.01	0.08	0.07	5.76
	8	1.80	0.02	0.46	0.01	0.21	0.07	7.04
3	1	1.91	0.02	0.00	0.16	0.00	0.03	7.04
	8	2.74	0.01	0.33	0.02	2.17	0.10	8.46
4	1	2.81	0.02	0.00	0.01	0.00	0.03	8.46
	4	3.04	0.01	0.08	0.03	0.13	0.04	8.68
	7	3.65	0.02	0.24	0.01	0.34	0.02	9.22
5	1	3.74	0.02	0.00	0.00	0.00	0.00	9.22
	4	3.97	0.03	0.17	0.04	0.14	0.03	9.30
	7	4.51	0.02	0.29	0.01	0.26	0.04	9.64
6	1	4.63	0.02	0.00	0.00	0.00	0.16	9.64
	4	4.86	0.03	0.16	0.01	0.04	0.18	10.73
	7	5.40	0.02	0.27	0.01	0.10	0.18	12.68
7	1	5.57	0.02	0.00	0.00	0.00	0.02	12.68
	4	5.68	0.03	0.09	0.01	0.01	0.05	12.77
	7	5.94	0.02	0.15	0.01	0.04	0.03	12.96
8	1	6.01	0.03	0.00	0.01	0.00	0.03	12.96
	4	6.46	0.01	0.27	0.04	0.31	0.03	13.30
	7	7.53	0.02	0.32	0.03	0.76	0.01	13.66

Appendix E: 30% Mesocosm Data

Table 16. 30% mesocosm TN and TP concentration (mg-X/L) and cumulative export (g or mg-X) raw data

Storm	Cumulative Applied Water (m)	Influent N Concentration (mg-N/L)	TN Concentration (mg-N/L)	Cumulative N Export (g-N)	Influent P Concentration (mg-P/L)	TP Concentration (mg-P/L)	Cumulative P Export (mg-P)
1	0.07		1738.5	0.0		3.4	0.0
	0.17		2219.4	5.4		3.9	10.1
	0.26		1346.4	9.8		3.4	19.1
	0.34		816.4	12.5		12.6	38.7
	0.43		574.4	14.2		2.7	57.5
	0.62		405.8	16.8		3.2	73.3
	0.75		214.8	18.0		2.5	84.5
	0.92		145.4	18.9		2.6	96.4
	0.92		142.0	18.9		2.7	96.4
	0.92	---	222.8	18.9	---	2.6	96.4
2	1.03		457.9	18.9		1.5	96.4
	1.10		325.5	19.7		2.7	100.9
	1.18		254.5	20.3		2.8	106.8
	1.26		155.8	20.8		2.7	112.8
	1.33		103.8	21.1		2.7	118.6
	1.48		88.3	21.5		2.9	130.7
	1.64		80.9	21.9		2.9	143.4
	1.79	---	133.5	22.3	---	3.1	156.5
3	1.99		595.0	22.3		1.2	153.8
	2.07		483.9	23.5		1.2	155.4
	2.15		215.3	24.3		1.4	157.2
	2.22		94.8	24.6		1.7	159.5
	2.30		54.0	24.8		1.8	162.3
	2.45		31.5	24.9		2.0	168.6
	2.60		25.6	25.1		2.1	175.5
	2.76		23.6	25.2		2.2	182.9
	2.90		20.6	25.3		2.3	190.3
	2.90	10.37	20.1	25.3	0.5	2.3	190.3
4	3.02	2.96	40.8	25.3	0.4	1.3	203.5

	3.10		102.2	25.4		2.1	206.2
	3.17		62.4	25.6		2.1	209.8
	3.25		43.3	25.7		2.2	213.5
	3.40		16.1	25.8		2.7	222.2
	3.55		11.8	25.9		2.7	232.0
	3.71		8.6	25.9		2.7	241.9
	3.82		7.0	26.0		2.7	249.1
	3.82		6.9	26.0		2.8	249.1
5	3.82	3.74	22.4	26.0	0.3	1.7	259.2
	3.95		96.9	26.2		2.2	261.0
	3.99		67.4	26.3		2.4	263.3
	4.03		67.9	26.4		2.3	265.5
	4.10		37.0	26.5		2.4	270.0
	4.18		24.8	26.5		2.5	274.7
	4.26		18.1	26.6		2.6	279.6
	4.27		15.9	26.6		2.5	280.6
	4.27		14.0	26.6		2.6	280.6
6	4.37	5.35	22.7	26.6	0.3	1.6	283.5
	4.53		13.8	26.7		2.2	290.6
	4.68		8.3	26.7		2.0	298.8
	4.83		8.3	26.8		2.0	306.4
	5.14		6.8	26.8		1.9	321.0
	5.44		5.2	26.9		1.9	335.4
	5.75		5.4	26.9		1.9	349.7
	6.05		4.2	27.0		1.8	363.5
	6.10		4.3	27.0		1.8	365.7
	6.10		4.0	27.0		1.8	365.7
	6.10		3.6	27.0		1.8	365.7
	6.10		5.0	27.0		1.8	365.7
7	6.21	4.45	21.5	27.0	0.3	2.0	378.0
	6.28		9.0	27.0		2.8	382.7
	6.36		7.9	27.0		1.8	387.1
	6.51		6.5	27.1		2.1	394.3
	6.66		6.1	27.1		1.8	401.7
	6.81		5.3	27.1		1.9	408.8
	6.97		4.3	27.1		1.8	415.8
	7.02		4.8	27.1		1.7	417.8
8	7.13	4.60	5.7	27.1	0.3	1.8	423.5
	7.21		5.0	27.1		2.3	427.4

	7.28		3.5	27.2		2.0	431.4
	7.36		4.8	27.2		2.0	435.2
	7.51		8.0	27.2		1.7	442.2
	7.66		3.0	27.2		1.6	448.2
	7.81		4.1	27.2		1.6	453.9
	7.93		2.8	27.2		1.5	458.2
	7.93		---	---		1.6	458.2
9	17.12	3.28	4.2	28.2	0.2	1.2	822.0
	17.20		3.7	28.2		1.0	823.9
	17.27		3.5	28.2		1.0	825.6
	17.35		3.6	28.2		0.9	827.1
	17.50		3.5	28.2		0.9	830.1
	17.65		3.5	28.2		0.8	832.8
	17.81		3.5	28.2		0.8	835.2
	17.96		3.4	28.3		0.8	837.5
	17.98		3.5	28.3		0.8	837.9
	17.98		3.4	28.3		0.8	837.9
10	27.20	4.52	4.8	29.3	0.4	0.8	1048.1
	27.28		8.3	29.4		0.8	1048.9
	27.36		6.7	29.4		0.8	1049.7
	27.43		6.0	29.4		0.8	1050.6
	27.58		3.4	29.4		0.8	1052.1
	27.74		5.0	29.4		0.7	1053.5
	27.89		4.7	29.4		0.7	1054.9
	28.04		4.5	29.5		0.7	1056.2
	28.04		4.7	29.5		0.7	1056.2
	28.04		4.6	29.5		0.7	1056.2

Table 17. 30% mesocosm phosphorus speciation raw data

Storm	Sample	Applied Water (m)	SRP Concentration (mg-P/L)	Cumulative SRP Export (mg-P)	DOP Concentration (mg-P/L)	Cumulative DOP Export (mg-P)	PP Concentration (mg-P/L)	Cumulative DOP Export (mg-P)
1	1	0.07	0.2	0.0	2.5	0.0	0.7	0.0
	2	0.17	0.3	0.6	3.5	8.3	0.2	1.2
	4	0.34	0.6	2.7	1.6	20.9	10.4	27.1
	8	0.92	1.6	20.3	0.9	41.3	0.1	112.9
2	1	1.03	0.3	20.3	0.6	41.3	0.6	112.9
	4	1.26	1.3	25.4	0.6	45.4	0.8	117.4
	8	1.79	2.4	53.5	0.4	53.0	0.3	125.9
3	1	1.99	0.7	53.5	0.2	53.0	0.3	125.9
	4	2.22	0.8	58.4	0.3	54.7	0.6	129.0
	8	2.76	1.6	76.7	0.3	59.1	0.3	136.0
4	1	3.02	0.5	76.7	0.2	59.1	0.6	136.0
	4	3.25	1.4	82.8	0.0	59.6	1.0	141.4
	8	3.82	2.1	110.4	0.0	59.6	0.7	155.3
5	1	3.82	1.1	110.4	0.2	59.6	0.3	155.3
	4	4.03	1.6	118.8	0.2	60.7	0.4	157.7
	8	4.27	2.0	131.5	0.2	62.1	0.3	160.2
6	1	4.37	1.6	131.5	0.0	62.1	0.2	160.2
	4	4.83	2.1	155.8	0.0	62.1	0.1	161.8
	8	6.05	2.1	229.4	0.0	62.1	0.0	164.1
7	1	6.21	1.8	229.4	0.0	62.1	0.5	164.1
	4	6.51	1.6	244.5	0.1	62.5	0.3	167.9
	8	7.02	1.5	267.1	0.1	63.6	0.1	171.3
8	1	7.13	1.4	267.1	0.0	63.6	0.3	171.3
	4	7.36	1.6	277.0	0.0	63.7	0.5	173.9
	8	7.93	2.2	308.0	0.0	63.7	0.1	178.7
9	1	17.12	0.9	716.3	0.2	87.3	0.1	207.6
	4	17.35	0.7	721.5	0.0	87.8	0.1	208.3
	8	17.96	0.6	733.1	0.0	87.8	0.0	209.5
10	1	27.20	0.6	893.2	0.0	87.8	0.1	227.3
	4	27.43	0.6	897.2	0.0	87.8	0.1	227.8
	8	28.04	0.6	908.0	0.0	87.8	0.0	228.5

Table 18. 30% mesocosm nitrogen speciation raw data

Date	Sample	Cumulative Volume Applied (m)	Ammonia Concentration (mg-N/L)	Ammonia Cumulative Export (g-N)	Nitrate Concentration (mg-N/L)	Nitrate Cumulative Export (g-N)	Nitrite Concentration (mg-N/L)	Nitrite Cumulative (g-N)	Organic N Concentration (mg-N/L)	Organic N Cumulative Export (g-N)
1	1	0.07	1296.3	0.0	572.6	0.0	0.1	0.0	0.0	0.0
	4	0.34	591.3	7.3	163.9	2.8	0.1	0.0	61.1	0.1
	8	0.92	123.8	13.2	6.2	4.2	0.1	0.0	15.4	0.7
2	1	1.03	158.7	13.2	63.8	4.2	0.3	0.0	235.0	0.7
	4	1.26	162.8	14.2	93.7	4.8	1.4	0.0	0.0	1.5
	8	1.79	106.9	16.3	4.8	5.5	1.1	0.0	20.8	1.6
3	1	1.99	108.5	16.3	706.4	5.5	0.7	0.0	0.0	1.6
	4	2.22	38.0	16.7	82.8	8.1	1.8	0.0	0.0	1.6
	8	2.76	10.6	17.1	9.0	8.8	1.6	0.1	2.4	1.6
4	1	3.02	7.6	17.1	53.1	8.8	0.4	0.1	0.0	1.6
	4	3.25	0.0	17.1	104.4	9.3	0.1	0.1	0.0	1.6
	8	3.82	0.9	17.1	6.1	10.2	0.0	0.1	0.0	1.6
5	1	**3.82**	0.3	17.1	23.2	10.2	0.0	0.1	0.0	1.6
	4	**4.03**	0.3	17.1	5.1	10.3	0.0	0.1	62.5	1.8
	8	**4.27**	0.1	17.1	67.4	10.5	0.1	0.1	0.0	2.0
6	1	**4.37**	0.0	17.1	16.6	10.5	0.0	0.1	6.0	2.0
	4	**4.83**	0.5	17.1	4.6	10.7	0.0	0.1	3.1	2.1
	8	**6.05**	0.2	17.2	2.8	10.8	0.1	0.1	1.1	2.2
7	1	6.21	0.0	17.2	5.5	10.8	0.0	0.1	16.0	2.2
	4	6.51	0.3	17.2	3.4	10.8	0.0	0.1	2.8	2.3
	8	7.02	0.0	17.2	3.1	10.9	0.0	0.1	1.6	2.3
8	1	7.13	0.0	17.2	2.5	10.9	0.0	0.1	3.2	2.3
	4	7.36	0.1	17.2	2.1	10.9	0.0	0.1	2.6	2.3
	8	7.93	0.0	17.2	3.0	10.9	0.0	0.1	0.0	2.3
9	1	17.12	0.0	17.2	2.7	10.9	0.0	0.1	0.1	2.3
	4	17.35	0.0	17.2	1.9	11.0	0.0	0.1	0.9	2.3
	8	17.96	0.0	17.2	2.0	11.0	0.0	0.1	0.8	2.3
10	1	27.20	0.0	17.2	3.1	11.0	0.0	0.1	1.7	2.3
	4	27.43	0.5	17.2	4.2	11.0	0.0	0.1	1.3	2.4
	8	28.04	0.0	17.2	3.5	11.1	0.0	0.1	1.0	2.4

Appendix F: 15% Mesocosm Data

Table 19. 15% mesocosm TN and TP concentration (mg-X/L) and cumulative export (g or mg-X) raw data

Storm #	Applied Water (m)	Influent TN Concentration (mg-N/L)	TN Concentration (mg-N/L)	Cumulative TN Export (g-N)	Influent TP Concentration (mg-P/L)	TP Concentration (mg-P/L)	Cumulative TP Export (mg-P)
1	0.18	4.65	2110.50	0.00	0.25	4.93	0.00
	0.26		1150.80	2.80		3.72	7.43
	0.33		874.20	4.89		3.11	14.47
	0.41		420.90	6.23		1.46	19.19
	0.56		145.70	7.40		0.92	24.09
	0.71		111.70	7.93		0.82	27.68
	0.87		95.35	8.35		0.82	31.06
	0.91		89.29	8.73		0.85	34.51
	0.91		91.76	8.76		0.79	34.73
	0.91		88.11	8.78		0.79	34.95
2	1.00	4.57	140.50	8.78	0.27	1.74	34.95
	1.07		152.60	9.10		2.00	39.01
	1.15		234.95	9.52		2.05	43.40
	1.23		129.50	9.92		2.11	47.91
	1.38		101.85	10.42		2.32	57.52
	1.53		82.15	10.82		2.27	67.47
	1.68		56.75	11.12		2.41	77.63
	1.83		59.40	11.36		2.25	87.25
	1.83		50.30	11.36		2.25	87.25
	1.83		62.35	11.36		2.22	87.25
3	1.92	4.44	86.10	11.36	0.1	0.65	87.25
	1.99		248.68	11.72		0.43	88.42
	2.07		280.75	12.30		0.33	89.24
	2.15		228.08	12.85		0.48	90.12
	2.30		71.25	13.50		0.41	92.06
	2.45		33.78	13.73		0.41	93.85
	2.60		20.41	13.84		0.46	95.75
	2.74		15.43	13.92		0.51	97.70
	2.74		14.88	13.92		0.48	97.70
	2.74		16.67	13.92		0.53	97.70
4	2.84	1.84	23.17	13.92	0.21	0.16	97.70
	2.92		68.03	14.02		0.47	98.39

	2.99		57.00	14.15		0.28	99.21
	3.07		41.00	14.26		0.65	100.23
	3.22		23.02	14.40		0.65	103.07
	3.37		12.36	14.47		0.60	105.79
	3.53		9.17	14.52		0.70	108.59
	3.66		6.53	14.55		0.68	111.13
	3.66		7.32	14.55		0.61	111.13
	3.66		7.14	14.55		0.64	111.13
5	3.74	3.83	21.15	14.55	0.24	0.13	111.13
	3.78		38.65	14.58		0.27	111.34
	3.82		54.65	14.63		0.47	111.75
	3.86		51.23	14.69		0.60	112.33
	3.93		35.75	14.78		0.70	113.73
	4.01		24.12	14.85		0.74	115.29
	4.08		15.28	14.89		0.76	116.91
	4.11		14.83	14.90		0.76	117.54
	4.22	3.71	11.67	14.90	0.2	0.26	117.54
6	4.37		11.16	14.95		0.62	119.45
	4.52		6.93	14.99		0.55	121.98
	4.68		6.44	15.02		0.52	124.31
	4.98		5.48	15.07		0.49	128.71
	5.29		4.60	15.12		0.51	133.06
	5.59		4.63	15.16		0.52	137.53
	5.90		4.19	15.20		0.49	141.95
	5.94		4.45	15.20		0.48	142.59
	5.94		3.57	15.20		0.49	142.59
	6.05	3.352	3.97	15.20	0.19	0.39	142.59
7	6.13		7.27	15.21		0.50	143.55
	6.20		7.84	15.23		0.59	144.75
	6.28		7.25	15.25		0.58	146.02
	6.43		5.09	15.27		0.55	148.47
	6.58		4.52	15.29		0.50	150.75
	6.74		3.59	15.31		0.54	153.02
	6.86		3.96	15.32		0.49	154.77
	6.86		3.14	15.32		0.49	154.77
	6.86		3.27	15.32		0.52	154.77
8	6.93	3.31	2.45	15.32	0.23	0.35	154.77
	7.01		5.06	15.33		0.50	155.70
	7.08		7.41	15.35		0.52	156.82

	7.16		11.13	15.37		0.56	157.99
	7.31		9.14	15.41		0.57	160.42
	7.46		7.62	15.45		0.55	162.85
	7.61		6.20	15.48		0.56	165.26
	7.77		5.17	15.50		0.54	167.65
	7.77		5.62	15.50		0.53	167.65
	7.77		5.20	15.50		0.52	167.65

Table 20. 15% mesocosm nitrogen speciation raw data

Storm	Sample	Applied Water (m)	Nitrite (mg-N/L)	Cumulative Nitrite Export (g-N)	Nitrate Concentration (mg-N)	Cumulative Nitrate Export (g-N)	Ammonium Concentration (mg-N/L)	Cumulative Ammonium Export (g-N)	Organic N Concentration (mg-N/L)	Cumulative Organic N Export (g-N)
1	1	0.18	0.42	0.000	164.08	0.00	963.20	0.00	982.81	0.00
	4	0.41	0.19	0.002	26.05	0.56	414.28	4.02	0.025	2.87
	8	0.91	0.11	0.004	0.00	0.77	138.58	8.59	0.025	2.87
2	1	1.00	0.25	0.004	5.85	0.77	125.29	8.59	9.10	2.87
	4	1.23	0.63	0.007	13.83	0.83	117.91	9.38	0.025	2.90
	8	1.83	0.22	0.014	18.30	1.11	20.06	10.56	20.82	3.08
3	1	1.92	0.76	0.014	41.94	1.11	55.26	10.56	0.025	3.08
	4	2.15	2.79	0.026	151.60	1.74	36.18	10.86	37.50	3.20
	8	2.74	0.42	0.053	4.34	3.07	42.98	11.53	0.025	3.52
4	1	2.84	3.78	0.053	15.48	3.07	4.01	11.53	0.025	3.52
	4	3.07	0.17	0.066	38.42	3.24	2.93	11.55	0.025	3.52
	8	3.66	0.13	0.069	13.55	3.68	1.02	11.59	0.025	3.52
5	1	3.74	0.025	0.069	26.39	3.68	0.08	11.59	0.025	3.52
	4	3.86	0.016	0.069	48.82	3.80	0.19	11.59	2.21	3.53
	8	4.11	0.015	0.069	18.93	4.05	0.48	11.59	0.025	3.53
6	1	4.22	0.051	0.069	6.64	4.05	0.24	11.59	4.74	3.53
	4	4.68	0.007	0.069	5.26	4.12	0.14	11.59	1.03	3.57
	8	5.90	0.045	0.070	3.58	4.28	0.19	11.60	0.025	3.59
7	1	6.05	0.027	0.070	5.20	4.28	1.07	11.60	0.025	3.59
	4	6.28	0.007	0.070	10.77	4.33	0.08	11.60	0.025	3.59
	8	6.86	0.015	0.070	3.61	4.45	0.08	11.60	0.025	3.59
8	1	6.93	0.024	0.070	0.69	4.45	0.82	11.60	0.025	3.59
	4	7.16	0.012	0.070	10.07	4.48	0.14	11.61	0.025	3.59
	8	7.77	0.077	0.071	4.58	4.61	0.13	11.61	0.025	3.59

Table 21. 15% mesocosm phosphorus speciation raw data

Storm #	Sample	Applied Water (m)	SRP Concentration (mg-P/L)	(mg-P)	PP Concentration (mg-P/L)	PP Cumulative Export (mg-P)	DOP Concentration (mg-P/L)	DOP Cumulative Export (mg-P)
1	1	0.18	0.15	0.00	1.23	0.00	3.55	0.00
	4	0.41	0.24	1.14	0.39	4.74	0.82	12.78
	8	0.91	0.54	7.58	0.28	10.30	0.034	19.87
2	1	1.00	0.06	7.58	1.29	10.30	0.39	19.87
	4	1.23	0.38	9.04	1.47	19.28	0.26	21.97
	8	1.83	0.43	15.98	1.75	46.86	0.079	24.85
3	1	1.92	0.05	15.98	0.44	46.86	0.16	24.85
	4	2.15	0.24	16.93	0.24	49.09	0.025	25.44
	8	2.74	0.39	22.27	0.14	52.38	0.025	25.87
4	1	2.84	0.04	22.27	0.09	52.38	0.031	25.87
	4	3.07	0.41	23.74	0.13	53.08	0.12	26.37
	8	3.66	0.55	31.70	0.15	55.38	0.025	27.61
5	1	3.74	0.12	31.70	0.02	55.38	0.025	27.02
	4	3.86	0.31	32.39	0.28	55.86	0.00	27.06
	8	4.11	0.41	35.05	0.22	57.72	0.12	27.52
6	1	4.22	0.18	35.05	0.01	57.72	0.061	27.52
	4	4.68	0.72	40.91	0.06	58.17	0.025	28.08
	8	5.90	0.39	60.09	0.08	60.54	0.027	28.98
7	1	6.05	0.25	60.09	0.13	60.54	0.007	28.98
	4	6.28	0.43	62.31	0.12	61.35	0.028	29.09
	8	6.86	0.37	68.81	0.10	63.21	0.021	29.50
8	1	6.93	0.16	68.81	0.18	63.21	0.009	29.50
	4	7.16	0.30	70.31	0.23	64.55	0.025	29.61
	8	7.77	0.36	75.97	0.15	67.92	0.027	30.07

Appendix G: 30% Washed Mesocosm Data

Table 22. 30% washed mesocosm TN and TP concentration (mg-X/L) and cumulative export (g or mg-X) raw data

Storm #	Applied Water (m)	Influent TN Concentration (mg-N/L)	TN Concentration (mg-N/L)	TN Cumulative Export (g-N)	Influent TP Concentration (mg-P/L)	TP Concentration (mg-P/L)	TP Cumulative Export (mg-P)
1	0.20	4.05	295.40	0.00	0.46	4.55	0.0
	0.27		288.20	0.60		4.37	9.6
	0.35		212.50	1.14		3.62	18.3
	0.42		203.20	1.58		4.18	26.8
	0.58		160.50	2.35		3.25	42.9
	0.73		132.20	2.97		3.25	57.0
	0.88		121.80	3.50		2.69	69.9
	0.91		124.60	3.61		3.62	72.9
	0.91		136.60	3.61		2.88	72.9
	0.91		112.50	3.61		3.25	72.9
2	1.01	4.00	200.10	3.71	0.37	3.18	72.9
	1.09		212.65	4.15		3.77	80.4
	1.17		189.25	4.57		3.28	88.1
	1.24		142.65	4.93		3.38	95.3
	1.39		109.75	5.46		2.69	108.5
	1.55		87.85	5.87		2.39	119.5
	1.70		74.25	6.20		3.08	131.3
	1.83		71.00	6.46		2.39	141.4
	1.83		67.10	6.46		2.49	141.4
	1.83		67.90	6.46		2.49	141.4
3	1.96	3.56	164.55	6.55	0.31	1.69	141.4
	2.04		243.45	6.98		1.94	145.4
	2.12		232.70	7.49		1.51	149.1
	2.19		200.40	7.95		1.51	152.4
	2.34		95.05	8.58		1.51	158.9
	2.50		55.48	8.89		1.47	165.4
	2.65		44.25	9.09		1.43	171.7
	2.74		43.20	9.20		1.36	175.4
	2.74		44.60	9.20		1.33	175.4
	2.74		43.13	9.20		1.33	175.4
4	2.87	3.47	210.60	9.28	0.34	0.98	175.4

	2.95		178.40	9.69		1.22	177.8
	3.02		141.65	10.03		1.16	180.4
	3.10		79.20	10.26		1.33	183.1
	3.25		27.17	10.48		1.36	188.9
	3.40		18.50	10.56		1.38	194.9
	3.55		16.58	10.63		1.40	200.9
	3.66		15.40	10.66		1.40	204.9
	3.66		15.72	10.66		1.38	204.9
	3.66		15.48	10.66		1.42	204.9
	3.74		67.15	10.74		0.73	204.9
	3.78		163.85	10.86		1.17	206.0
	3.82		156.05	11.03		1.31	207.3
	3.86		130.55	11.18		1.31	208.7
	3.93		87.55	11.41		1.43	211.7
	4.01		48.18	11.54		1.56	214.9
	4.08		28.19	11.62		1.64	218.4
5	4.11	4.27	23.68	11.64	0.40	1.68	219.8
	4.19		80.40	11.68		0.81	219.8
	4.35		31.60	11.90		1.74	225.3
	4.50		12.88	11.98		1.74	232.8
	4.65		7.92	12.01		1.58	240.0
	4.96		5.84	12.03		1.40	253.0
	5.26		5.88	12.04		1.32	264.8
	5.56		4.99	12.05		1.29	276.1
	5.87		4.98	12.05		1.22	287.0
	5.94		4.86	12.05		1.24	289.4
6	5.94	4.46	4.82	12.05	0.39	1.24	289.4
	6.03		5.10	12.28		1.18	289.4
	6.11		7.00	12.28		1.99	292.9
	6.18		6.27	12.28		1.80	297.0
	6.26		6.31	12.29		1.65	300.7
	6.41		5.90	12.30		1.54	307.7
	6.56		5.58	12.30		1.39	314.0
	6.71		4.34	12.31		1.37	320.0
	6.85		3.33	12.30		1.30	325.3
	6.85		3.51	12.30		1.20	325.3
7	6.85	4.32	3.69	12.30	0.34	1.50	325.3
	6.91		6.24	12.41		1.65	325.3
8	6.99	4.52	6.33	12.41	0.41	1.79	329.1

	7.06		6.32	12.42		1.72	332.9
	7.14		5.91	12.42		1.56	336.4
	7.29		6.29	12.43		1.38	341.7
	7.44		5.99	12.43		1.42	346.6
	7.60		5.76	12.44		1.32	352.6
	7.75		6.19	12.45		1.26	358.2
	7.77		5.42	12.45		1.23	358.9
	7.77		5.43	12.45		1.24	358.9

Table 23. 30% washed mesocosm nitrogen speciation raw data

Storm #	Sample	Applied Water (m)	Ammonium Concentration (mg-N/L)	Ammonium Cumulative Export (g-N)	Nitrite Concentration (mg-N/L)	Nitrite Cumulative Export (g-N)	Nitrate Concentration (mg-N/L)	Nitrate Cumulative Export (g-N)	Organic N Concentration (mg-N/L)	Organic N Cumulative Export (g-N)
1	1	0.20	161.49	0.00	0.23	0.00	1.41	0.00	132.27	0.00
	4	0.42	103.70	0.86	0.17	0.00	1.41	0.01	97.92	0.75
	8	0.91	75.63	2.12	0.11	0.00	0.39	0.02	48.47	1.77
2	1	1.01	118.31	2.12	0.18	0.00	5.46	0.02	76.15	1.77
	4	1.24	101.80	2.83	0.28	0.00	0.58	0.04	39.99	2.15
	8	1.83	46.48	4.07	0.12	0.01	13.08	0.16	11.32	2.58
3	1	1.96	108.90	4.07	34.33	0.01	23.81	0.16	0.025	2.58
	4	2.19	91.56	4.72	0.39	0.12	57.23	0.42	51.22	2.74
	8	2.74	36.66	5.73	34.33	0.39	3.70	0.90	0.025	3.15
4	1	2.87	30.02	5.73	0.12	0.39	118.35	0.90	62.12	3.15
	4	3.10	13.26	5.87	8.22	0.42	61.66	1.48	0.03	3.35
	8	3.66	5.17	6.02	3.06	0.51	3.89	2.01	3.28	3.38
5	1	3.74	2.83	6.02	26.27	0.51	67.70	2.01	0.025	3.38
	4	3.86	0.89	6.02	4.71	0.56	144.64	2.35	0.025	3.38
	8	4.11	1.22	6.03	1.61	0.58	14.51	2.93	6.33	3.40
6	1	4.19	0.06	6.03	0.05	0.58	71.98	2.93	8.31	3.40
	4	4.65	0.29	6.03	0.07	0.58	3.14	3.42	4.42	3.48
	8	5.87	0.10	6.04	0.46	0.59	2.50	3.52	1.92	3.59
7	1	6.03	0.010	6.04	0.01	0.59	1.06	3.52	4.02	3.59
	4	6.26	0.18	6.04	0.01	0.59	1.99	3.53	4.13	3.62
	8	6.85	0.10	6.04	0.02	0.59	1.11	3.56	2.10	3.67
8	1	6.91	0.067	6.04	0.00	0.59	1.67	3.56	0.025	3.67
	4	7.14	0.14	6.04	0.02	0.59	1.72	3.57	0.025	3.67
	8	7.75	0.07	6.05	0.02	0.59	2.54	3.60	0.025	3.67

Table 24. 30% washed mesocosm phosphorus speciation raw data

Storm #	Sample	Applied Water (m)	SRP Concentration (mg-P/L)	SRP Cumulative Export (mg-P)	PP Concentration (mg-P/L)	PP Cumulative Export (mg-P)	DOP Cumulative Export (mg-P)
1	1	0.20	0.56	0.00	1.81	0.00	0.00
	4	0.42	1.09	5.36	1.71	11.46	11.61
	8	0.91	1.13	20.86	1.25	32.15	29.89
2	1	1.01	0.35	20.86	1.52	32.15	29.89
	4	1.24	1.49	26.86	1.12	40.75	36.64
	8	1.83	1.24	49.69	0.77	56.51	46.22
3	1	1.96	0.54	49.69	0.63	56.51	46.22
	4	2.19	0.60	53.41	0.40	59.86	49.54
	8	2.74	0.88	65.03	0.23	64.80	55.49
4	1	2.87	0.44	65.03	0.04	64.80	55.49
	4	3.10	0.86	69.27	0.25	65.76	57.81
	8	3.66	0.87	83.02	0.10	68.58	62.92
5	1	3.74	0.35	83.02	0.03	68.58	62.92
	4	3.86	0.81	84.90	0.11	68.80	64.22
	8	4.11	0.97	91.43	0.36	70.52	66.89
6	1	4.19	0.51	91.43	0.05	70.52	66.89
	4	4.65	1.00	101.24	0.25	72.53	70.65
	8	5.87	0.78	132.15	0.10	78.68	82.14
7	1	6.03	0.75	132.15	0.16	78.68	82.14
	4	6.26	1.21	138.55	0.41	80.55	83.06
	8	6.85	1.09	158.13	0.04	84.43	84.62
8	1	6.91	0.98	158.13	0.43	84.43	84.62
	4	7.14	0.96	164.43	0.39	87.12	86.08
	8	7.75	0.81	179.77	0.30	93.18	89.15

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