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From: Alex Taylor, WSU Puyallup Graduate Research Assistant
Date: February 28, 2018

Subject: Deliverable 3.2 = Report on chemistry of bioretention soil layers

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After the installation of the bioretention cells, a series of field-scale experiments were conducted to determine the baseline saturated hydraulic conductivity (K_{sat}) values of the operational system. These baseline data will be referenced over the course of the study to evaluate temporal changes in bioretention soil mix (BSM) K_{sat} and whether the presence of plants and cultivated fungi impact those properties. In order to ascertain whether the method used to obtain these K_{sat} measurements (back-filling and draining for falling head saturated hydraulic conductivity testing) stratified important chemical parameters in the bioretention soil, soil core samples were collected and analyzed from a surrogate system.

Three eight-inch surrogate columns were constructed with the same soil materials and following the same installation and conditioning protocol used during the installation of the field bioretention columns. Each of the three small soil columns received 18.1 ± 0.004 dry kg of BSM compacted to a depth of 40.9 ± 1.2 cm resulting in a soil bulk density of 1.36 ± 0.04 g/cm^3.

Figure 1: (Above) Field test site including vertical standpipes for K_{sat} testing. (Below) Surrogate columns for destructive soil layer sampling.

For both the field installation and the small surrogate system (Figure 1), each saturated hydraulic conductivity test began by using a peristaltic pump to slowly transfer municipal water into the standpipe to saturate the soil from below. Complete saturation of soil is one of the challenges in testing saturated hydraulic conductivity and it is typically regarded as best practice in controlled settings to saturate soil from below so that air can rise with the rising water level and escape the soil matrix (ASTM D2434). After filling, the field bioretention cells and the surrogate columns were left to saturate for 24-72 hours. Saturation time beyond 24 hours did not alter the K_{sat} values but was a consequence of staggering operations within a 5-day work schedule.

After saturating the soil, each field bioretention cell was tested three times. For each test, the water level was raised above the soil surface (19.7 ± 1.5 cm in field bioretention cells; 21 ± 8.7 cm in each small column). A metric ruler was secured in each field cell or column and the water level drop and draining time were recorded. Once the water level drained to just above the soil surface the drain valve was closed and the water level was raised

again by pumping water into the standpipe as previously described. The second and third measurements were repeated immediately thereafter following the same procedure. A single field bioretention cell or surrogate column could be tested 2-3 times in a day with this method. Field cells and surrogate columns were left saturating (water above soil surface) until a set of three (replicate) tests had been conducted. Each column was conditioned with municipal water during K_{sat} testing following the same procedure used at the field test site, however due to the different dimensions of the columns and slightly different soil bulk densities, the surrogate columns received approximately two times more soil pore volume equivalents of conditioning water than the field installation. In total, over the course of the K_{sat} testing, the bioretention soil in each field cell received a total of 0.50 ± 0.03 m^3 of municipal water (9.6 ± 0.9 soil pore volume equivalents), and the small surrogate columns each received 0.14 ± 0.021 m^3 (17.5 ± 2.7 soil pore volume equivalents).

For perspective, the 60/40 default bioretention soil compacted to a bulk density of 1.41 ± 0.04 g/cm^3 per Stormwater Management Manual for Western Washington (SWMMWW) specifications has a porosity of 0.45 ± 0.02 cm^3/cm^3, assuming a sand particle density of 2.65 g/cm^3 and a compost particle density of 2.60 g/cm^3.[1] The 9.6 pore volumes of water used in the field cell K_{sat} testing is equivalent to a soil water equivalent of 4.4 ± 0.3 inches of rainfall directed to a bioretention system at a 20:1 contributing area to bioretention area ratio. This is equivalent to a conditioning period of around 2-6 weeks during the Puget Sound rainy season.

After conditioning, the small surrogate columns were destructively sampled with a 1-cm diameter corer through the entire depth of the soil (40 cm) by randomly coring 15-20 times per column to acquire the necessary soil mass for chemical analysis. Each 40-cm soil core was divided into three separate samples: 0-15.0 cm; 15.1-30.0 cm; 30.1-40 cm. Each column was sampled separately so that each depth was measured in triplicate. Samples were analysed by ARI (Tukwila, WA) for a suite of PAHs and by AmTest laboratories (Kirkland, WA) for nutrients and metals.

The results of these analyses are presented in Figures 2 – 5 and qualitatively illustrate that there was no meaningful stratification of nutrients, metals, or PAHs as a result of conditioning the soil with up to 17.5 ± 2.7 soil pore volume equivalents of water.

To quantitatively confirm that soil parameters were not stratified in the soil profile as a result of the conditioning and K_{sat} testing, each category of soil parameters that met the required model assumptions was statistically compared at each depth using one-way ANOVA. This analysis required consolidating the individual PAH congeners and individual metals into a total PAH value and total metals value for each depth in each column. Nutrients were evaluated as individual parameters using the same approach, except for ammonia which was evaluated with a non-parametric Kruskal-Wallis test due to heteroscedasticity. A summary of the statistical results are presented in Table 1 and simultaneous 95% confidence intervals are presented in Figure 6 to help illustrate statistical differences between layers.

[1] Weindorf, D.C., R. Wittie. 2003. Determining Particle Density in Dairy Manure Compost. *Texas Journal of Agriculture and Natural Resources*. 16:60-63.

Table 1: Parameters and statistical results from surrogate column soil stratification experiment.

Parameter	Test Statistic	P-value
PAHs	T = 1.81	0.242
Metals	T = 0.481	0.640
Ammonia	$\chi^2_{df=2} = 1.68$	0.432
Nitrate/Nitrite	F = 0.059	0.943
Total Kjeldahl Nitrogen (TKN)	F = 4.90	0.055
Total Phosphorus	F = 0.529	0.614
Organic Matter	F = 2.45	0.166
Total Organic Carbon	F = 1.71	0.259

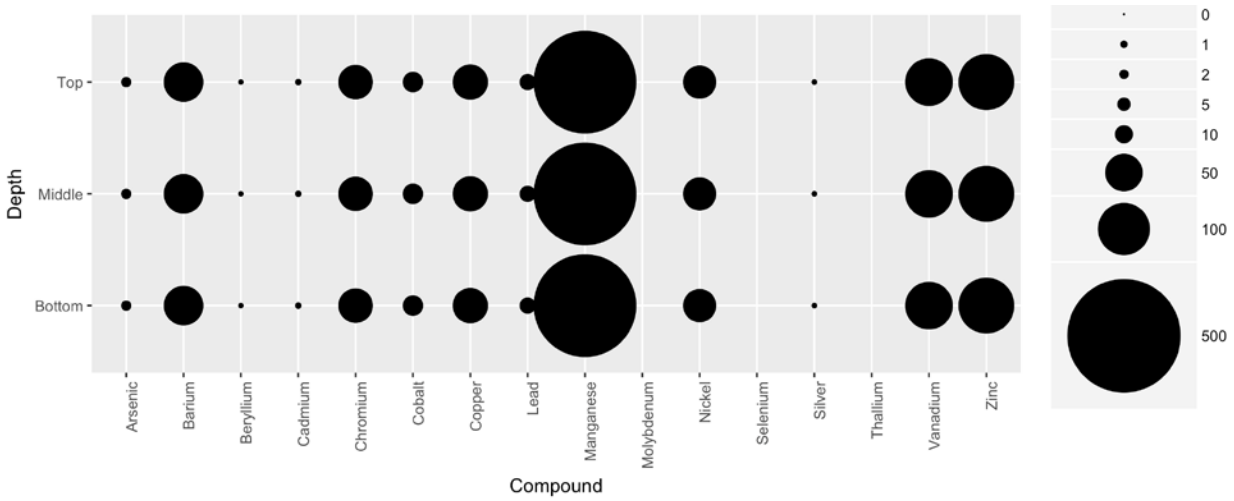


Figure 2: Metal concentrations in µg/kg (ppb) in the top (0-15 cm), middle (15-30 cm), and bottom (30-40 cm) strata of triplicate soil columns after clean water conditioning/K_{sat} testing.

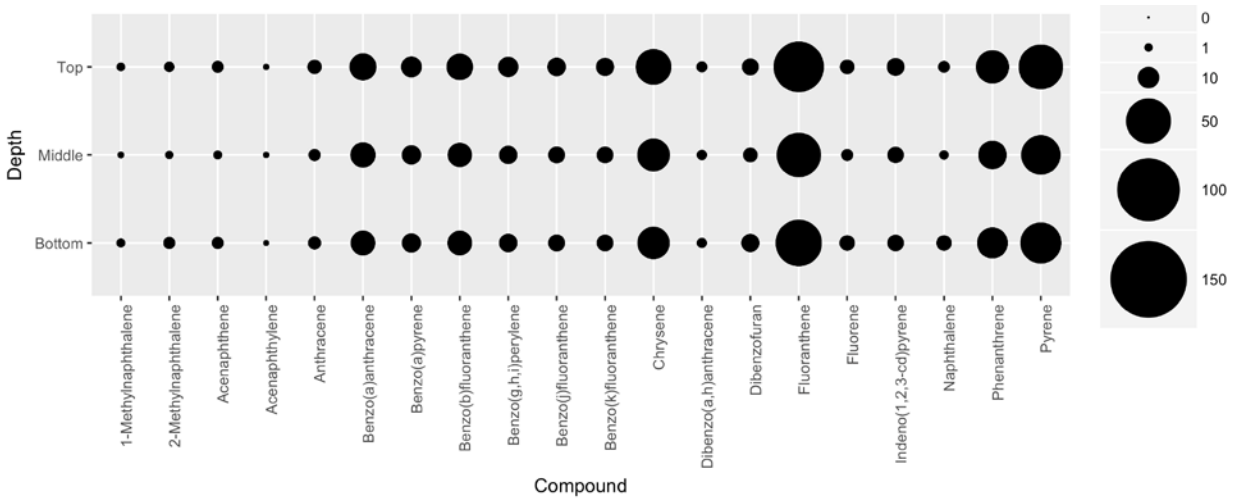


Figure 3: Concentrations of tested PAH congeners in µg/kg (ppb) in the top (0-15 cm), middle (15-30 cm), and bottom (30-40 cm) strata of triplicate soil columns after clean water conditioning/K_{sat} testing.

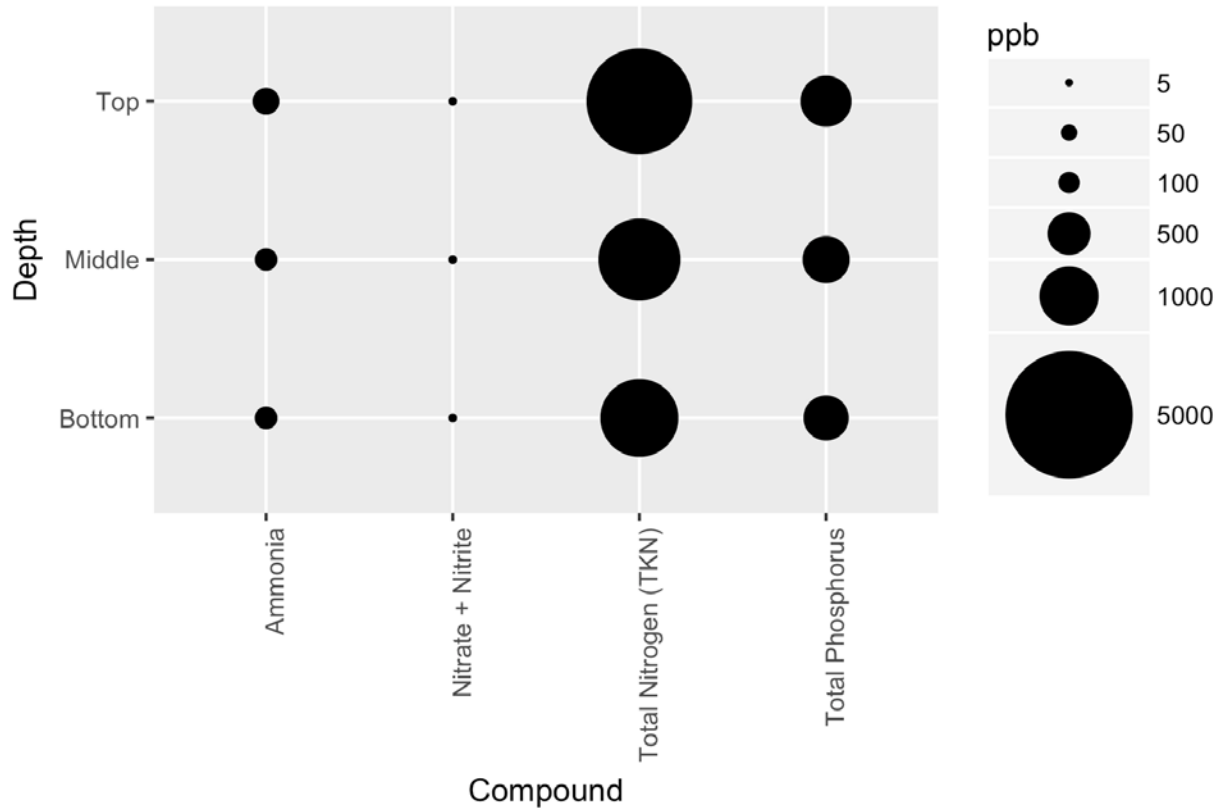


Figure 4: Concentrations of nutrient parameters in µg/kg (ppb) in the top (0-15 cm), middle (15-30 cm), and bottom (30-40 cm) strata of triplicate soil columns after clean water conditioning/K_{sat} testing.

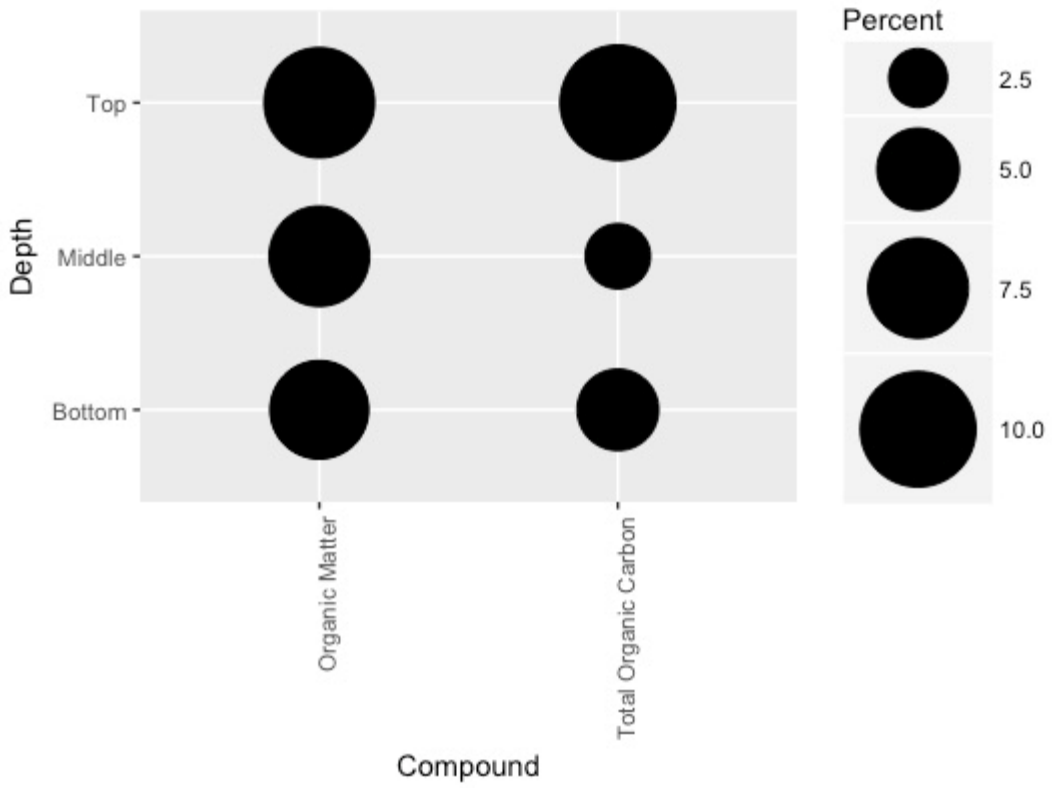
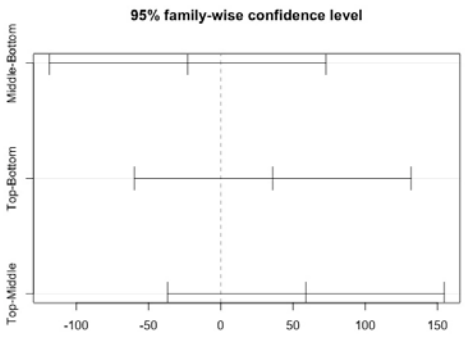
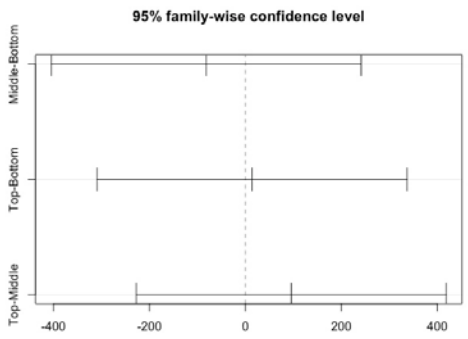


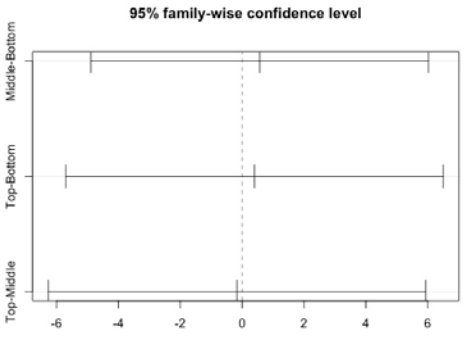
Figure 5: Concentrations of selected conventional parameters expressed as percent of total mass in the top (0-15 cm), middle (15-30 cm), and bottom (30-40 cm) strata of triplicate soil columns after clean water conditioning/K_{sat} testing.



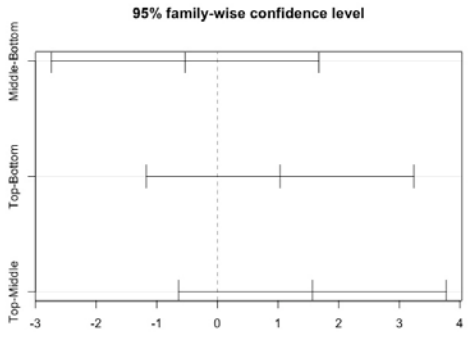
Total PAHs



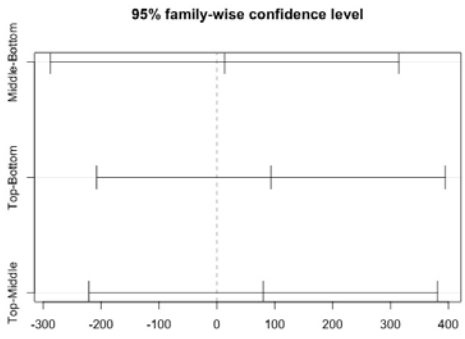
Total Metals



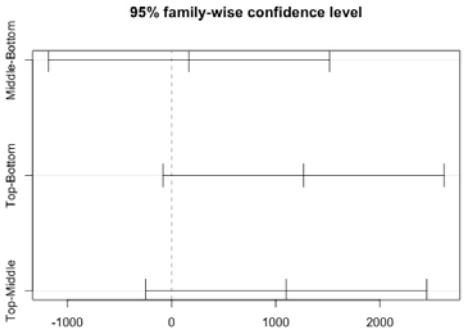
Nitrate-Nitrite



Organic Matter



Total Phosphorus



Total Nitrogen (TKN)

Figure 6: Simultaneous pair-wise 95% confidence intervals for monitored parameters at three soil depths: top (0-15 cm), middle (15-30 cm), and bottom (30-40 cm) of triplicate soil columns after clean water conditioning/K_{sat} testing.

The results of the soil layer analysis in the surrogate column system generally illustrate that most of the parameters of interest in the bioretention soil were not significantly stratified as a result of the clean water conditioning and K_{sat} testing process. A possible exception was Total Kjeldahl Nitrogen which had a nearly statistically significant mean concentration in the top layer of the BSM that was around 1.8-fold greater than in the bottom layer ($F = 4.90$; $p = 0.055$). This difference may have been due to upward movement of fine particles of compost with the advancing water front when the system was saturated from the bottom up during K_{sat} testing. Overall, the results of this experiment generally demonstrate that the BSM soil in the surrogate was not significantly stratified as a result of the conditioning/K_{sat} testing. These data provide a level of assurance that the soil chemical parameters of interest in the field bioretention mesocosms were generally homogenous throughout the soil at the beginning of the stormwater loading experiment.