ENVIRONMENTAL ISSUES IN ORGANICS RECYCLING: REED BED BIOSOLIDS REUSE AND LEACHATE FROM WOOD MULCH STOCKPILES

by

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ABSTRACT OF THE DISSERTATION

ENVIRONMENTAL ISSUES IN ORGANICS RECYCLING: REED BED BIOSOLIDS REUSE AND LEACHATE FROM WOOD MULCH STOCKPILES

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Dissertation Director:

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Despite numerous economical and environmental benefits associated with recycling, improper recycling practices can have an adverse impact. In the first part of this dissertation, reuse of reed bed biosolids containing *Phragmites australis* (common reed), considered an invasive species, was explored. It was hypothesized that the high temperatures achieved during composting could destroy the plant rhizomes as well as pathogenic microorganisms, making the biosolids eligible for USEPA Class A status for unrestricted land application. However, prior anaerobic digestion followed by stabilization of reed bed material occurring over 10 years deprived the material of enough available carbon for composting to occur spontaneously. Several inexpensive and easily available organic materials were tested in the laboratory for their ability to stimulate composting of the reed bed biosolids. *Phragmites* above ground biomass, available abundantly on site, was determined to be a suitable amendment. When tested at 1:2 ratio (dry weight basis) *Phragmites* above ground biomass to biosolids in the field, although they were effective in killing the rhizomes, high composting temperatures did not last long enough for the product to achieve Class A status.

In the second part of this work, water quality issues associated with the wood recycling industry in New Jersey were studied. Leachate and runoff samples from 3 different wood recycling facilities were tested for wastewater parameters over a 15 month period. The concentration ranges were highly variable, but often similar to raw sewage values. However, since this was an uncontrolled study in terms of drainage area, precipitation, and wood mulch volume, no definite conclusions could be drawn.

To account for these limitations a controlled study determining leachate concentrations and volumes from definite sized wood mulch stockpiles was carried out over a 2 year period. Correlations were found for loads but not concentrations for several parameters with rain volume and intensity, but not usually with age of the piles. Using these relationships simple equations predicting pollutant and nutrient loads were developed. Dose-response studies done on the leachate samples using zebrafish embryos showed little toxicity. Polynuclear aromatic hydrocarbons and pentachlorophenol concentrations were below detection limits, and Cu, Cr, As, Pb, and Zn concentrations were likewise low.

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Dedication

To my dear Amma and Nanna

Thank you for your unconditional love and support. I hope I have lived up to your sacrifices.

Table of Contents

List of Tables

List of Figures

Chapter I. Introduction

In the year 2012, 7.4 million dry tons of organic waste (biomass in the form of sugar/starch, ligno-cellulose, and bio-oils materials) was generated in New Jersey (Brennan-Tonetta et al., 2014). Thus New Jersey's population of 8.7 million generates 0.85 dry tons of organic waste per person/year. Out of the total generated, approximately 20% (~1.5 million dry tons) was recycled. Recycling of organic waste material is desirable as it is not only an environmentally friendly way to dispose of wastes but also recovers valuable resources and saves landfill space. However, large scale recycling processes and technologies, if mismanaged, can pose an environmental risk.

The research conducted in this dissertation addressed two organic waste materials processed in New Jersey, providing insight into the problems that might arise specifically in two types of large scale organic recycling facilities. The findings can be utilized by policy makers as well as recyclers to help formulate and put into effect best management practices to prevent environmental pollution from these facilities.

Chapter II discusses problems associated with disposal of large volumes of reed bed biosolids, and tested composting as an efficient and environmentally friendly treatment method. In this study composting of reed bed biosolids containing live *Phragmites* plant material was explored to achieve federal and state mandated regulatory limits for unrestricted land application of the product. The problem associated with lack of enough readily degradable carbon material for successful composting to occur was overcome by adding *Phragmites* above ground biomass available abundantly on site without increasing the volume of the total waste material. A field composting study using a recommended ratio of *Phragmites* above ground biomass to reed bed biosolids obtained from laboratory studies examined the potential to destroy *Phragmites* rhizomes and pathogenic microorganism indicators via composting. Metal concentrations were measured in the reed bed biosolids to determine its suitability for land disposal. Lack of enough readily biodegradable carbon material, mainly due to the prior biosolids treatment (i.e., anaerobic digestion followed by stabilization of reed bed material occurring for over 10 years) before composting, precluded it from achieving USEPA Class A requirements for unrestricted land application. However, this research was able to shed light on the compostability, and destruction of *Phragmites* plant material and pathogenic microorganisms.

In Chapters III, IV and V environmental issues associated with the wood recycling industry have been addressed. Large scale outdoor storage of wood for time periods ranging from a few months to a year has been a common practice at wood recycling facilities all over the country. Instances of environmental contamination from these facilities have been reported. In Chapter III, the current literature dealing with the problem, the constituents of wood that could be of concern, and other physical and chemical factors have been discussed.

In Chapter IV, a study of the quality of leachate from 3 wood recycling facilities in New Jersey for several basic wastewater parameters was presented. The results of this work helped in better understanding the concentration ranges that could be expected in wood leachate samples. They also pointed out the limitations of an observational field project and stressed the need for a more controlled study.

Chapter V deals with a controlled study to determine leachate quality and quantity from wood mulch stockpiles of a specific size. This chapter provides the first field controlled study done to determine leachate concentrations and loads from wood mulch stockpiles. The results were used to develop simple equations that help in predicting leachate quantity and pollutant loads if the sizes of the stockpiles and rain depth are known. This information can be used by regulatory agencies and recyclers in developing best management practices for handling leachate from wood mulch stockpiles.

I.1. Literature cited

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Chapter II. Composting as a Treatment Option for Reed Bed Biosolids

II.1. Introduction

Reed beds are a type of constructed wetlands that are commonly used to dewater and remove nutrients from wastewater sludge (Toet et al., 2005, Kuusemets et al., 2005). The vegetation commonly used in these treatment systems are emergent aquatic vegetation such as cattails (*Typha latifolia*), rushes (*Scirpus ancistrochaetus*), and common reeds (*Phragmites australis*) (Gersberg et al. 1985). Typically, reed beds can reduce sludge water content from 95% to <55%, and volatile solids to 25% of the initial concentration. Begg et al. (2001) reported that reed beds have over 90% removal efficiency for sludge dewatering, total suspended solids and biochemical oxygen demand. They also showed that nitrates and total phosphorus removal rates were 90% and 80%, respectively. This is accomplished through the combined action of microbial degradation, percolation through root channels, surface evaporation and leaf transpiration. The reeds are capable of transmitting oxygen from the leaf to the roots creating aerobic microsites in the rhizosphere, helping in aerobic microbial sludge stabilization and mineralization. The root system of the vegetation absorbs water from the sludge, which is then transported to the leaves and lost through transpiration. The penetration of the plant stems and root system also provides a pathway for continuous drainage of water from the sludge layer. It was reported that among the different wetland vegetation, *Phragmites* has better ability to transmit oxygen to the rhizospehere compared to cattails and other species (Reed et al., 1988).

A wastewater treatment plant in New Jersey with 9 million gallons/day capacity has utilized14 *Phragmites australis* reed beds (1000 wet tons sludge/bed) for over a decade to de-water anaerobically digested sewage sludge. These reed beds were filled to capacity and the accumulated biosolids needed to be removed and disposed of or economically recycled so that the beds could be reused. Since *Phragmites* is considered a nuisance species in New Jersey, presence of live *Phragmites r*hizomes precluded the material being categorized as acceptable clean fill under current New Jersey Department of Environmental Protection (NJDEP) land use regulations. In addition, should any pathogens be present the material would not meet the Class A disposal standards set forth by the United States Environmental Protection Agency (USEPA) regulations.

Land application of sewage sludge is regulated by the USEPA under Title 40 Code of Federal Regulations Part 503 (USEPA, 1994). Part 503 defines sewage sludge as a solid, semi-solid, or liquid residue generated during the treatment of domestic sewage in treatment works. Although the terms sewage sludge and biosolids are sometimes used interchangeably, a more appropriate definition of biosolids would be sewage sludge that has undergone some form of treatment. For the purpose of land application of sludge, Part 503 classifies sewage sludge into exceptional quality (EQ) and non exceptional quality (non-EQ) based on meeting the USEPA standards for metals (As, Cd, Cr, Cu, Pb, Hg, Mo, Ni, Se, Zn) (USEPA, 1993), pathogen requirements (bacteria, viruses, parasites) and attractiveness to disease vectors (rodents, flies, mosquitoes). Sewage sludge that meets the most stringent limits for all three is referred to as exceptional quality (EQ) sewage sludge and can be either surface disposed of or land applied without any restrictions. Sewage sludge that does not meet any one or more of the parameters is referred to as non exceptional quality (non-EQ) sewage sludge and this places restrictions on either its surface disposal or land application. Part 503 also makes a distinction between surface disposal and land application of sewage sludge; the former is placed on the land for the purpose of final disposal without regard for the soil enhancing qualities of the sludge while in the latter case it is applied to take advantage of its soil enhancing qualities.

In addition, based on the process used for pathogen reduction, Part 503 classifies biosolids into Class A and Class B. Biosolids subjected to treatment technologies classified as processes to further reduce pathogens (PFRP) are Class A biosolids for the pathogen requirement. There are no restrictions on the use of PFRP treated sludge on land. These processes include heat treatment (180ºC for 30 min), irradiation, high temperature composting, thermophilic aerobic digestion (10 days at 55-60ºC) and heat drying. Biosolids subjected to treatment technologies classified as processes to significantly reduce pathogens (PSRP) are Class B biosolids. Land application of Class B sludge limits its use for food crop production within 18 months of application, grazing for at least 1 month by animals that provide products that are consumed by humans, and public access for at least 12 months. These processes include aerobic digestion (60 days at 15ºC to 40 days at 20ºC), anaerobic digestion (60 days at 20ºC to 15 days at 35-55ºC), lime stabilization (pH= 12 after a 2 hr contact time), mesophilic composting, air drying and low temperature composting (minimum 40ºC for at least 5 days).

Specific goals of this research project were to 1) determine if composting the reed bed biosolids would result in 100% mortality of the *Phragmites* rhizomes; and 2) determine if composting would result in meeting the highest USEPA/NJDEP designated class for land application of this material, i.e., EQ quality for the three parameters and Class A status for pathogen reduction.

According to the 503 rule, in windrow composting, for the product to be considered as EQ quality or class A biosolids, the temperature of the sewage sludge should be maintained at 55ºC (131ºF) or higher for 15 consecutive days or longer, during which it should be turned five times.

Composting is a microbial self-heating process in which the heat, generated through microbial metabolism at the expense of the organic material, accumulates in the material, increasing its temperature (Finstein et al., 1987a). Finstein et al. (1987a) further added that unlike backyard composting of leaves and garden residue, which is easy to achieve, large scale composting of wastewater sludge is highly demanding and should fully exploit the biological potential of the process. Successful composting occurs as a result of the interactions among a number of environmental parameters such as moisture content, C:N ratio, oxygen concentration, pH, temperature and the type of material being composted and the composting system being used (Bitton, 1994). Temperature, which is dependent on moisture and aeration, is the most important factor affecting microbial activity (Polprasert, 1989). The optimum temperature for microbial activity in composting of sewage sludge is 55-60ºC and temperatures above 60ºC are detrimental (Strom, 1985). For optimal microbial activity, oxygen concentrations should be above 10%, carbon/nitrogen ratio at 26:1 to 30:1, volatile solids over 30%, moisture content 50-60% and pH at 6-11 (Reed et al., 1988).

Bacterial pathogens found in sewage sludge include *Salmonella, Shigella, Campylobacter, Yersinia, Leptospira, and Escherichia coli* (Bitton, 1994). The types of viruses detected in anaerobically digested sludge include polioviruses, coxsackie A and B viruses, echoviruses, and reoviruses. The parasites most often found in sludge are *Ascaris lumbricoides* (human intestinal round worm), *Ascaris suum* (pig's roundworm), *Taenia saginata, Toxocora, and Trichuris* (Little, 1986). Polprasert (1989) showed that composting inactivates pathogens and transforms organic forms of nitrogen and phosphorus into inorganic forms that are more bioavailable for uptake by agricultural crops. The technique of composting has been previously used to kill pathogens found in sewage sludge (Pourcher et al., 2005). According to Finstein et al. (1987b) three types of pathogen destruction methods are in operation during the composting process. They are microbial antagonism due to competition between pathogenic and non pathogenic microorganisms for a limited supply of nutrients, disinfective properties of decomposition products such as ammonia, and high temperature inactivation.

II.2. Materials and methods

To determine if the reed bed biosolids material would self-heat, a preliminary test was done by setting up a test pile with dimensions of 7 ft. x 6 ft. x 6 ft. (L x W x H). The pile was regularly monitored at selected depths and heights (above ground) for increase in pile temperature. The pile was set up on January 18, 2008, and temperature readings were taken on January 22, 26, and 31, February 8, and March11. Later, to verify the laboratory results under field conditions, a small composting pile approximately 6 ft long x 6 ft wide x 3 ft high was constructed on September 12, 2008, and temperature was measured on September 15, 18 and 24 from the top, west, east and south faces of the pile; however, sampling locations within a side on different days were not exactly the same. On October 6, 2008, a larger composting pile, approximately 12 ft long x 12 ft wide x 6 ft high and composed of a 1:2 (w/w) *Phragmites*:biosolids mixture was constructed. Temperature measurements were made on 9 different days including at set up. Heights at which temperature were measured are shown in Figure II.1. At each height, temperature was measured at up to 7 different insertion depths (1, 2, 3, 4, 5, 6 and 7 ft). Temperature measurements for all three piles were made using a compost temperature measuring thermocouple (Type T, Omega Engineering, Inc., Stamford, CT).

Oxygen measurements were made in the largest pile. Readings were taken on the same days and at the same locations as temperature measurements using a model 630 oxygen analyzer and compost oxygen probe (Woods End Research Laboratory, Inc., Mt. Vernon, ME).

For fecal coliform determination, a composite sample made from several samples taken from each height was used. The sample collection and preparation were carried out according to the USEPA 503 rule for solids sample preparation for fecal coliforms analysis (USEPA, 2013). A 300 mL suspension was prepared by transferring 270 mL of sterile dilution water into a sterile container with 30 g of well mixed biosolids sample. This was blended at high speed for 2 min. One mL of this mixture contained 0.1 g of the original sample. Serial 10-fold dilutions up to 10^{-5} were made from this stock suspension. The *Standard Methods for the Examination of Water and Wastewater* (Clesceri et al., 1998) multiple tube fermentation technique employing presumptive and confirmed tests was used, with 5 tubes per dilution including for controls where dilution water only was added. The most probable number (MPN) calculated at each time was compared to the USEPA regulatory limit for land application of sewage sludge (USEPA, 1994).

Standard operating procedures were developed and followed for rhizome mortality experiments conducted in the laboratory (Appendix B). This involved protocols for harvesting rhizomes, heating them in the oven, and growing them in the greenhouse afterwards.

Concentrations of metals (As, Cd, Cr, Cu, Pb, Hg, Mo, Ni, Se, Zn) before and after the composting treatment process were determined by the wastewater treatment facility by sending samples to a certified analytical laboratory.

II.3 Hypotheses

The major hypotheses of this study were:

1) The reed bed biosolids can be composted;

2) Temperatures reached during composting can destroy the *Phragmites* rhizomes;

3) The temperatures achieved might kill pathogenic microbes, allowing unrestricted land application according to USEPA 503 rule.

II.4. Preliminary evaluation

The objective of the pile set up on January 18, 2008, was to see if the reed bed biosolids would self heat when provided with the moderate aeration that occurred during its setting up. The results showed that there was no substantial temperature increase. We hypothesized that the material had been stabilized to a considerable extent during anaerobic digestion and then lying in the reed beds for more than 10 years. Biosolids samples were sent to a soil testing laboratory for nutrient and carbon content analysis. The report (Appendix D) showed the sludge to be acidic with a pH value of 4.5 whereas the optimum pH for composting is 6-8. The moisture content and C:N ratio were near optimum values for composting despite the fact that the C/N for sewage sludge is usually much lower. However, the low organic matter content of 43.7% suggests that the biosolids had been considerably stabilized and there was very little readily available carbon remaining. Usually, primary sludge has an organic matter content of ~85%. Accordingly, it was decided that suitable amendments be tested to provide enough available carbon for self-heating processes to occur.

II.5. Laboratory carbon amendment experiments

When selecting an amendment for the reed bed material, the main criteria were its ease of availability and use, cost effectiveness, and not increasing the amount of material that would require disposal. Amendment addition laboratory experiments started on February 21, 2008. The first amendments tried were dry *Phragmites* above ground biomass, primary sludge, and digested sludge, which were all available at the wastewater treatment facility, and saw dust. The mixtures were placed in one gallon jars with little insulation (plastic thermos-type containers). When no substantial temperature increase was observed (Table II.1) in any of the containers over a week's time period, moisture was adjusted to 60% and pH to 7 in the dry *Phragmites* and saw dust amended jars and these were incubated for a few more days with temperature monitored regularly. Adjusting moisture and pH did not help raise the temperature in these two jars.

Thereafter, materials were placed in covered containers with additional insulation added. An insulated jar containing only horse manure (known to compost easily) was monitored for four days. Lack of temperature increase in this jar prompted additional modifications. These included adjusting pH to 7 using pelletized lawn lime (lime stone) and aerating the jars using 5-10 gallon fish tank air pumps (Aquatic Gardens air pump 8000, Petco, Milltown, NJ). Although liming the jars amended with dry *Phragmites* above ground biomass and saw dust (added 70 g lime to raise pH to 7) did not help in increasing the temperature, aeration was found to increase the temperature in cat food amended jars (used as positive control) even without adjusting the moisture content to 60% (Table II.1).

When the moisture content was adjusted to 60% coupled with aeration, cat food mixed with reed bed material at 1:1 (v/v) ratio showed a temperature increase to 56.5ºC within 4 days. The same set of conditions was repeated with other amendments. However, only horse manure and vegetable oil amended jars self-heated to any considerable extent (showed an increase of 14ºC and 20ºC respectively). This prompted an increase in the ratio of amendment added to reed bed biosolids material by making mixtures on a dry weight rather than volume basis. When green *Phragmites* above ground biomass was added at 1:1 (w/w) ratio to reed bed biosolids material and aeration was provided, temperature rose to 35ºC in less than 24 hours.

II.6. Onsite composting experiments

To verify the laboratory results under field conditions, a small composting pile approximately 6 ft long x 6 ft wide x 3 ft high was constructed on September 12, 2008. Above ground green *Phragmites* was mixed with reed bed biosolids in a 1:1 ratio (w/w *Phragmites*:biosolids), and the interior temperature of the pile reached a maximum of 54ºC after 6 days (Appendix A.1). While successful in stimulating self-heating, a 1:1 (w/w) *Phragmites*:biosolids ratio presented a problem. The bulk density of the above ground material was much lower than that of the biosolids, so that a ratio of 4:1 (v/v)

Phragmites above ground material:biosolids was required to achieve the 1:1 (w/w). In an effort to find a more efficient ratio that would self-heat, while using less *Phragmites* above ground biomass, on October 6, 2008, a larger composting pile, approximately 12 ft long x 12 ft wide x 6 ft high and composed of a 1:2 (w/w) *Phragmites*:biosolids mixture was constructed. The pile temperature was monitored at multiple locations (Figure II.1) and within a week, temperatures > 55ºC were observed in the pile interior (Appendix A.2 and Figure II.2). The pile was then turned (day 9) and temperature monitoring continued. Within a week the center interior of the pile exceeded 50ºC, and so the pile was turned a third time. After the third turning, the overall pile temperature remained at approximately 35ºC. Based on the results of the field experiments, it appears that a 1:2 (w/w) ratio would not provide enough readily available carbon to allow the existing reed bed material to self heat and maintain the 55ºC temperature through multiple turnings required by the USEPA to demonstrate pathogen destruction.

Even though the interior of the pile appeared to be anaerobic in some cases (Figure II.3), there were no odor problems associated with the field test compost pile. Minimum oxygen concentrations were observed on the third day after setting up the pile, with oxygen concentrations falling below 10% (Figure II.3). These low levels continued through the first and second turns with the inside of the pile (4, 5, 6, and 7 ft depths) showing anaerobic conditions. A slight increase in oxygen concentrations was observed on the last day of measurement. Although, oxygen concentrations below 10% are not ideal for composting to occur, they are not uncommon as observed in the windrow composting of leaves (Strom, 1986).

II.7. Rhizome mortality experiments

Live *Phragmites* rhizomes were placed within the large compost test pile constructed on October 6, 2008. Three rhizomes, each containing new buds and three intact nodes, were housed in mesh bags, and 5 replicates bags each were placed at 1 ft, 3 ft, and 5 ft heights within the pile when it was being constructed. Three of the five replicates from each height were removed when the pile was turned on October 15. The 6 remaining bags, plus 9 bags to replace the ones that were retrieved, were again incorporated into the pile that was reconstructed after turning. These 15 bags were retrieved a week after the second turning on October 29.

Rhizomes recovered from the pile were transported to Rutgers and planted in potting soil. Because control rhizomes were no longer regenerating outdoors (perhaps due to cooling ambient temperatures), on October 20 the rhizomes retrieved from the composting pile on October 6 were placed in the Rutgers experimental greenhouse, where ambient temperatures are maintained at 60-65^{O}F, and light levels are 90 μEinsteins for 16 daylight hours. Under these conditions, untreated control rhizomes were able to re-generate, and so all further rhizome experiments were conducted utilizing the greenhouse facility. The first set of rhizomes (9 bags x 3 rhizomes/bag = 27) were placed in the greenhouse on October 20. The second set of rhizomes (15 bags x 3/bag = 45) were placed in the greenhouse on October 29. Although controls placed in the greenhouse on Day 0 re-sprouted after approximately 20 days, no re-growth was observed in the other rhizomes retrieved from the compost pile. Results of these rhizomes taken out from the composting pile are shown in Table II.2.

To determine the temperature and time required to achieve complete destruction of *Phragmites* rhizomes, laboratory experiments were conducted in a temperature controlled drying oven. The temperatures tested included 30, 35, 40, 45, 50 and 55ºC. The time periods tested for exposure to these temperatures were 2, 6, and 24 hours. Test results where at least 4 out of 5 controls survived are shown (Table II.3). Rhizomes survived at temperatures up to 45ºC for 24 hr, but not at 55ºC or higher temperatures.

To confirm the results obtained from using rhizomes dug out from the wastewater treatment facility, additional viable rhizomes were obtained from Mr. Scott Davis of Constructed Wetlands Group (CWG), a reed bed technology firm, and subjected to rhizome-temperature experiments. The results (Table II. 4) showed that rhizomes can survive at temperatures of 40 and 45ºC for up to 24 hr. However, at 50ºC they regenerated after 12 hr but not after 24 hr of heating. At 55ºC, none of the replicates survived either after 12 hr or 24 hr of heating.

Ambient temperatures in the reed beds were observed to reach 33ºC during the summer months, so it was to be expected that re-growth would be observed in rhizomes treated at 30-35ºC for 4 hr. However, the routine survival at 45ºC was unexpected. Prolonged exposure (24 hr) at 50ºC was lethal, as was short exposure (2 hr) at 55ºC.

II.8. Fecal coliform tests

For land application of biosolids, USEPA regulations require that the density of fecal coliforms be less than 1,000 MPN (most probable number) per gram of total solids on a dry weight basis. Composite sludge samples were collected from: i) the undisturbed reed beds (10/10/08); ii) immediately after the compost pile was set up (10/6); iii) just before first pile turning (10/15); iv) just before second pile turning (10/22); v) after second pile turning (10/29). All the MPN tests were conducted within the stipulated 6 hr holding time from collecting of samples except the samples collected after the second turning, which were tested after 24 hr during which time they were refrigerated.

The MPN counts varied greatly over the course of the field composting experiment (Table II.5). The lowest MPN counts (175 MPN/g dry weight solids) were seen in the reed bed biosolids material prior to the composting experiment and on Day 29 after the compost pile stabilized at approximately 35ºC. On Day 9, the MPN count was 550 MPN/g dry weight solids, which meets the USEPA regulatory limit. However, on Day 0 and on Day 16, observed MPN counts were above the regulatory standard. Other than the MPNs observed on Day 16, the counts are within the MPN range observed by the facility's NJDEP certified laboratory. The abnormal counts observed on Day 16, which did not meet holding time, could represent a "hotspot," or this number could result from the presence of non-coliform bacteria. Growth during sample storage is also possible, but the low temperatures from refrigeration likely limited this.

Although temperature is the main factor in controlling destruction of pathogens during composting, due to the heterogeneous nature of the material and the dynamics of self-heating it is difficult to maintain a uniform temperature throughout the pile. Results from Day 23 MPN counts showed that the composting treatment can result in MPN counts that meet the USEPA criteria.

II.9. Heavy metal concentrations in biosolids

In addition to pathogen and vector attraction requirements, monitoring heavy metal concentrations in the reed bed biosolids determines their suitability for land application. Processes such as organic matter mineralization and metal solubilization due to decreases in pH occurring during composting can release bound heavy metals. Metal biosorption by the microbial biomass and metal complexation with the humic substances also affect the final metal concentrations (Cai et al., 2007). Appendix C shows the metal concentrations in the reed bed material before and after the composting study. The table shows that for samples after the composting process (12/24/08) metal concentrations were well below the USEPA ceiling concentrations limit for biosolids applied to land, USEPA limits for pollutant concentrations in biosolids and NJDEP soil limits for cumulative loading.

II.10. Conclusions

Anaerobically digested sludge that had been lying in reed beds for a long period was stabilized, and not expected to have enough readily degradable organic matter for composting to occur on its own. In the present case, the organic matter content value of 43.7% in the sludge from the reed beds was less than what is usually found in finished compost (45%), suggesting that the organic matter had been well stabilized.

Although a temperature that appears to kill the rhizomes was achieved, composting would be labor intensive for a wastewater treatment facility that is not equipped to carry out this process on an industrial scale.

To maintain the 55ºC temperature for a longer time period to meet the USEPA's requirement for pathogen kill the necessary ratio of above ground *Phragmites* material to biosolids would be greater than 1:1 (w/w).

Based on the bulk densities of these materials, acquiring enough aboveground biomass to compost all the material housed in the 14 reed beds at the facility could be problematic as it requires 3-4 parts green material per 1 part of biosolids by volume.

Mixing the *Phragmites* above ground biomass with leaves from the fall collection could be an option.

Instead of allowing the biosolids to accumulate and stabilize while in the reed beds for an extended period, composting them more frequently would overcome the problems of lack of enough available carbon and the inability to handle large quantities of material for composting.

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Table II.1. Amendments tested to induce self-heating of reed bed biosolids in laboratory.

Amendment	% Amend	Moisture & pH	Aeration	Days	Temp.change(C)		Increase	Comments
					From	**To**		
Experiments in Open Containers								
DPAGB	50 (v/v)	NA	Y	4	20	23	No	Not insulated enough
DPAGB	50 (v/v)	60% M +75 g 'L'	Y	4	18	21	No	Not insulated enough
Primary sludge	5 (v/v)	NA	Y	4	16	19	No	Not insulated enough
Primary sludge	10 (v/v)	NA	Y	6	16	18.6	No	Not insulated enough
Digested sludge	10 (v/v)	NA	Y	4	16	18	No	Not insulated enough
Digested sludge	15 (v/v)	NA	Y	6	14.4	18.5	No	Not insulated enough
Saw dust	50 (v/v)	NA	Y	4	20	21	No	Not insulated enough
Saw dust	50 (v/v)	60% M + 75 g 'L'	Y	4	18	21.5	No	Not insulated enough
Experiments in Insulated Containers								
Oak leaves	33.3 (v/v)	NA	N	4	18	18.5	No	No aeration
Horse manure	100	NA	N	4	24	24	No	No aeration
Experiments in Insulated Containers with Aeration								
Dry cat food	50 (v/v)	NA	DA	4	19	50	Yes	Positive control
Dry cat food	50 (v/v)	60% moisture	Y	4	18	56.5	Yes	Positive control
Horse manure	100	NA	DA	6	21	35	Yes	
Oak leaves	67 (v/v)	60% M	Y	5	18.5	18.5	No	Resistant to degradation
Primary sludge	10 (v/v)	60% M	Y	5	16	17	No	Little solids as C source(<5% solids)
Digested sludge	10 (v/v)	60% M	Y	5	16	17	No	Little solids as C source (<5% solids)
Saw dust	67 (v/v)	60% M	Y	4	19	17.5	No	Not a readily available carbon source
Vegetable oil	71 (DWB)	60% M	Y	5	16.5	36	Yes	Readily available carbon (food grease)
Glass cullet	50 (DWB)	60% M	Y	4	18	18	No	
PCC	50 (DWB)	60% M	Y	3	18	18.5	No	Material not characterized
GPAGB	63(V/V)*	60% M	Y	4	19	20.5	No	Retest with higher ratio
GPAGB	50 (DWB)	60% M	Y	<24 h	19	35	Yes	Chosen for field test
GPAGB	33(DWB)	60%	Y	<24 h	19	27	Yes	Chosen for field test

DPAGB & GPAGB = Dry and green *Phragmites* above ground biomass, respectively; % Amend = % amendment used in relation to total of biosolids plus amendment; NA = Not adjusted; M = Moisture content; L = Garden lime used in adjusting pH; DWB = Dry weight basis; PCC = Pre-cured compost; Y= Continuous aeration; DA = Discontinuous aeration; N = No aeration; * approximately 16% dry weight basis.

Table II. 2. Number of rhizomes still viable after removal from the compost pile.

Date removed	Height removed from (ft)	# of rhizomes removed	Growth by 11/3/08
10/15/08	1	9	0
10/15/08	3	9	0
10/15/08	5	9	0
10/29/08	1	15	0
10/29/08	3	15	0
10/29/08	5	15	0
Controls	Incubated in potting soil	3	3

Table II.3. Oven kill rhizome temperature experiments on rhizomes dug from reed beds*

	Time heated (hrs).					
Temp	2		6		24	
	Cntrl	Trmt	Cntrl	Trmt	Cntrl	Trmt
30	4/5	4/5	-	-	-	-
35	4/5	3/5	-	-	-	-
40	8/10	3/10	-	-	-	-
45	4/5	3/5	8/10	9/10	8/10	9/10
50	7/10	0/10	9/10	2/10	13/15	0/15
55	-	-	4/5	0/5	12/15	0/15

* Only results of tests where at least 4 out of 5 or 7 out of 10 controls (kept at room temperature) survived are shown

** Numerator is number survived out of the total number in the denominator

Table II.4. Summary of survival results from experiments conducted on rhizomes sent by CWG, (a reed bed technology company).

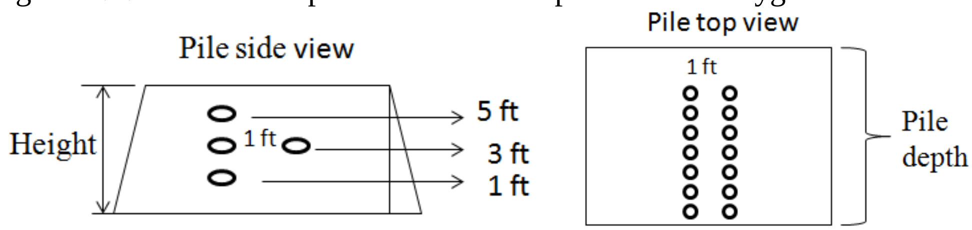
Temp (C)	Time (hrs)	Contrl	Treatments
40	6	5	5
40	12	5	5
40	24	5	5
45	12	5	5
45	24	5	5
50	12	5	5
50	24	5	0
55	12	5	0
55	24	5	0

Table II.5. Fecal coliform test results.

Sampling date	Sample location*	MPN#/dry wt.
10/6/08	reed bed biosolids	175
10/10/08	Day 0	4000
10/15/08	Day 9 (3 ft height)	550
10/22/08	Day 16 (3 ft height)	> 225000**
10/22/08	Day 16 (1 ft height)	> 225000**
10/29/08	Day 23 (3 ft height)	175

* Composites of several samples collected at each height
# Most probable number
** Holding time of 6 hr exceeded

Figure II.1. Schematic representation of temperature and oxygen measurement locations.



Probes inserted at 1, 3, and 5 ft heights (from the ground), in the center of the pile length and also at 3 ft height 1 ft to the right of center, all to depths of up to 7 feet (1,2, 3, 4, 5, 6, 7 ft depths).

Figure II.2. Temperature measurements in the compost pile

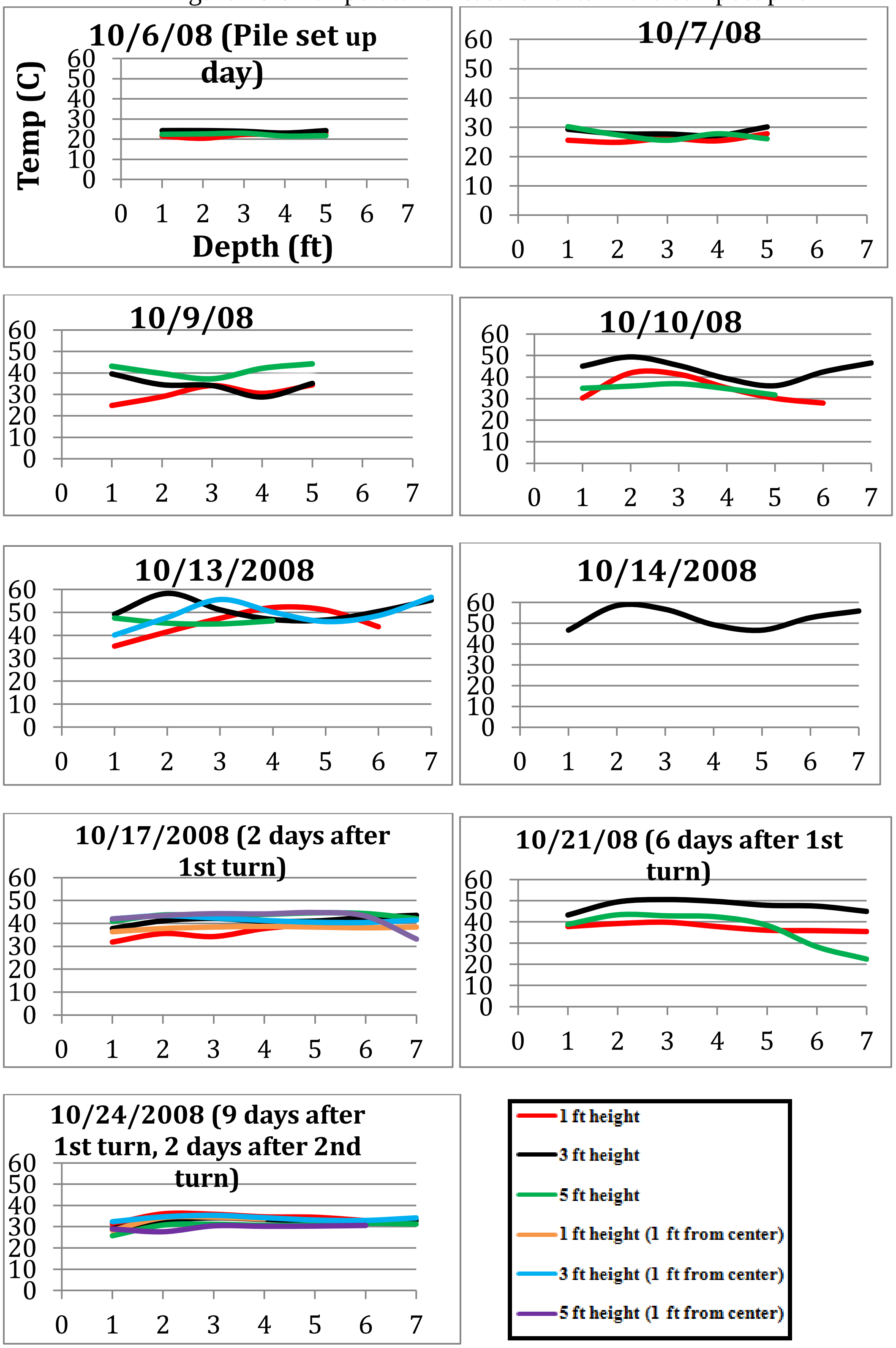
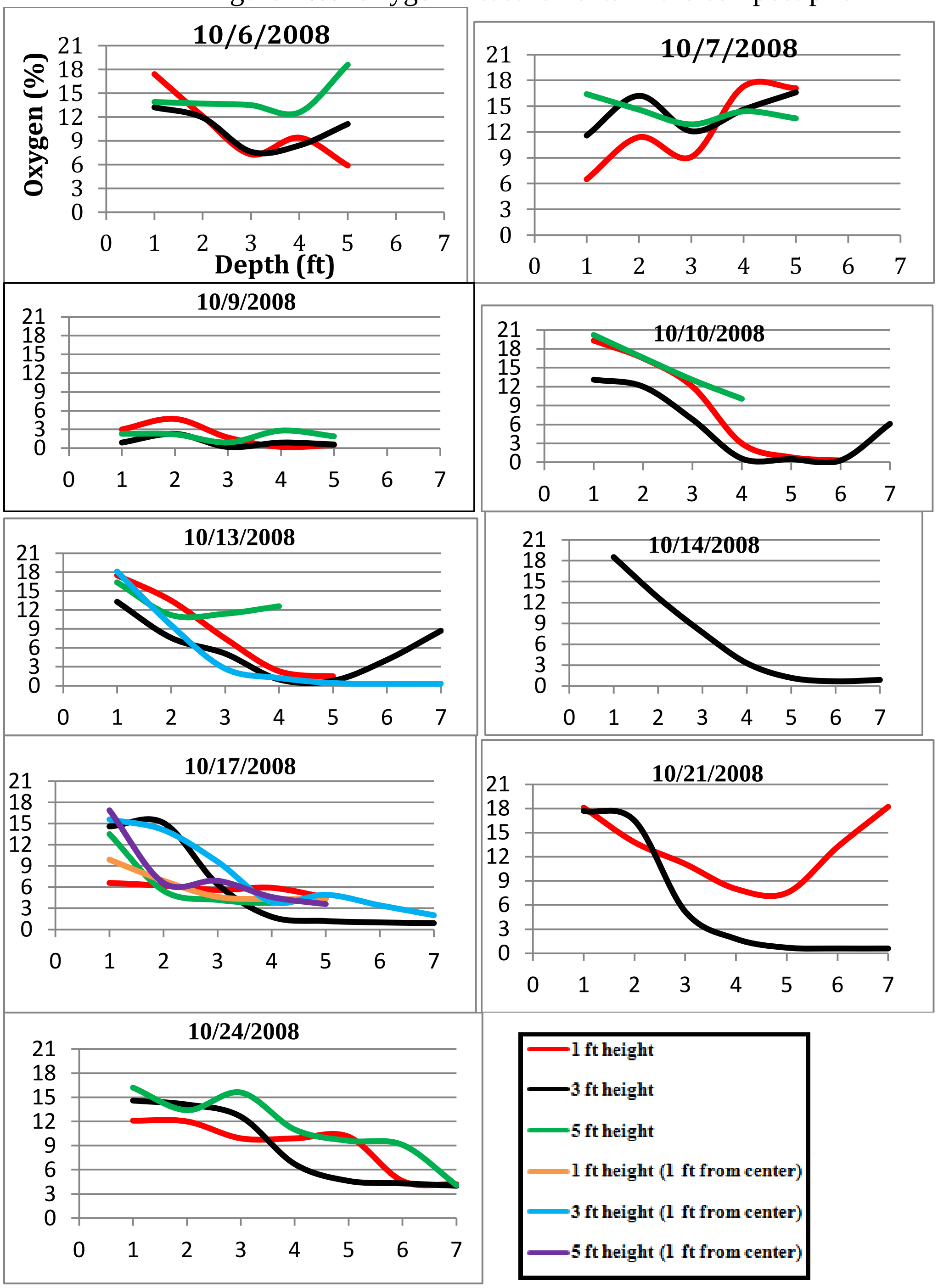


Figure II.3. Oxygen measurements in the compost pile



Chapter III. Literature Review of Leachate and Runoff from Wood Recycling Activities

III.1. Introduction

In the year 2010, 15.9 million tons of wood waste was generated as part of municipal solid waste in the USA (USEPA, 2013). Out of the total, 2.3 million tons was recycled. During the same period 0.76 million tons (combined total for brush/tree parts, stumps, wood scraps) of wood waste was generated in New Jersey (NJDEP, 2013a). In the year 2003, 92,800 tons of wood waste was recycled out of 650,000 tons generated in New Jersey (NJDEP, 2013b). Large scale storage of wood in the open for an extended period of time is a common practice at wood recycling facilities all over the country. During rainstorms and snow melt soluble compounds and particles from bark and wood are taken up by water and become part of the site runoff (Bailey 1999a). A look at the mass of wood being recycled gives an idea on the quantity of leachate and runoff that might be released from these facilities. Since not all recycling facilities have an effective stormwater management plan on site, the runoff may be released directly into nearby surface waters.

Toxicity and environmental contamination in wood leachate presumably can be caused by 1) wood and bark derived organics including bacterial and fungal products; 2) organic chemical compounds used as wood preservatives; 3) metals released from wood preservatives.

There have been several studies on toxicity and other environmental impacts of leachate and runoff from wood processing facilities. However, most of these assume all wood processing facilities as equal and fail to discuss variability. This has resulted in reporting widely variable conclusions ranging from no toxicity and minimal contaminant loads to very high toxicity and large contaminant loads. Many geoclimatic, operational and physical factors contribute to the variability of runoff from wood processing facilities. These factors have a direct effect on the quality and quantity of the generated leachate.

III.2. Source of variability in leachate and runoff at different wood processing facilities

The different sectors where wood is processed include wood recycling facilities, log yards, log storage areas, bark piles, dry load sorts, dry decks, wood waste piles, saw mills, de-barking and bark pressing operations, and pulp and paper mills. The site characteristics, wood waste volumes, types of wood species, particle size, and age of wood waste are some of the factors that are highly variable at these facilities. The particle size of the wood processed at these facilities range from saw dust and wood chips to logs and bark. Kaczala et al. (2012) observed that higher amounts of organic carbon and COD are released from pine saw dust compared to oak wood chips mainly due to the smaller particle size of pine saw dust and consequently higher surface area to volume ratio. Svensson et al. (2013) found that dissolved organic carbon (DOC) released from pine saw dust leachate was 6 times higher than from pine wood chips leachate because of the difference in particle size. McLaughlan et al. (2009) found that the smaller the particle sizes of the wood material, the higher was the amount of DOC released into the water phase.

Site characteristics such as paved or unpaved surfaces also play an important role in the quantity and quality of leachate. Fikart (2002) showed that more runoff was generated at a paved log yard compared to an unpaved log yard during the same rain event. Total suspended solids (TSS) levels tend to be higher in unpaved sites compared to paved sites as they can include soil particles in addition to wood and bark particles (McDougall, 1996). Tao et al. (2005) showed that leachate from young material (< 1 year) from a large open storage area of saw dust, shredded bark, wood chips and process trimmings had much higher oxygen demand, tannin and lignin concentrations compared to leachate from aged material (> 1.5 years).

Type of wood species stored at a facility plays an important role in the quality of leachate. Different tree species contain varying concentrations and types of soluble compounds and differ in the ease with which these compounds are leached (Zenaitis et al., 2002). Svensson et al. (2013) suggested that higher DOC released from oak saw dust leachate compared to pine saw dust is due to anatomical differences between hardwoods (oak) and softwoods (pine). Ribe et al. (2009) found that high concentrations of polyphenolic compounds in oak leachate caused its lower pH compared to pine leachate. Spruce and red cedar were found to be more toxic to pink salmon fry in fresh water than yellow cedar and hemlock (Pease, 1974). He also showed that among the four wood species, COD leaching rate decreased in the order of red cedar, yellow cedar, hemlock and spruce. Tannins, lignins and resin acids are higher in concentration in softwoods than hardwoods (McDougall, 2002).

The part of the tree that is piled up at a facility is also an important source of leachate variability. Bark leachate is known to be darker in color, has more dissolved organic matter and is more toxic compared to wood leachate (Field et al., 1988). Svensson et al. (2012) indicated that bark is one component of the tree that could be potentially hazardous to the aquatic environment. Tannins are highly concentrated in bark compared to other portions of a tree and they are suspected to be the primary toxicants in bark. Taylor et al. (1996) found that phenolic compounds such as tannins were the most abundant compounds in bark causing toxicity in aspen wood leachate.

Other factors causing variability include size of log yard, volume of wood stored, and duration and intensity of precipitation. McDougall (2002) reported that runoff from five log yard sites analyzed for their chemical parameters, the runoff from a log yard site with the highest ratio of logs stored to log yard area showed consistently higher median phenolic compound concentrations compared to other sites. McDougall (2002) also observed that during spring and summer storms, when the precipitation events were intense, the runoff had an increased capacity to carry suspended solids and other contaminants from the log yards depending on the intensity and duration of the precipitation event.

Svensson et al. (2013) observed that based on the leaching tests organic compounds from maple, oak, pine and beech, saw dust (DOC) were mostly (> 90%) released during the first 24 hrs of leaching. Kaczala et al. (2011a) observed that most of the organic compounds and metals showed a higher tendency to be discharged with the initial portion of the runoff. They added that precipitation duration, rainfall depth, and average rain intensity play an important role in the first flush phenomenon.

III.3. Wood chemistry

Most tree species are either angiosperms or gymnosperms. Angiosperms produce seeds that are protected by a covering called fruits whereas seeds of gymnosperms are naked. Angiosperms make up 80% of all the plant species; however, most of the timber and paper products are obtained from gymnosperms (Sjostrom, 1981). Coniferous woods or softwoods are gymnosperms while hardwoods are usually deciduous trees and belong to the angiosperms category. Some examples of softwoods are fir, hemlock, juniper, pine, spruce, and larch. Examples for hardwoods include maple, beech, birch, alder, red gum, wattle, oak, chestnut, acacia and balsa.

The major constituents of both hardwood and softwood trees are carbohydrates, lignins and wood extractives. The actual quantities of these constituents can vary depending on wood species, age, geographical location and part of the tree (McDougall, 2002).

The main forms of carbohydrates in wood are cellulose and hemicelluloses; both function as supporting material. While 40-45% of the dry weight of wood is made up of cellulose, 20-30% is hemicelluloses. Cellulose forms the basic skeleton around which hemicelluloses and lignin materials are formed (Sjostrom, 1981). While celluloses are insoluble in most solvents, hemicelluloses are easily hydrolyzed by acids. Celluloses are homopolysaccharides (made up of monomers of glucose), but hemicelluloses are heteropolysaccharides (made up of glucose, mannose, xylose, and arabinose). The composition and structure of hemicelluloses in the softwoods differ in a characteristic way from the hardwoods. Considerable differences also exist in the hemicellulose content and composition between the stem, branches, roots and bark.

Lignins are polymers of phenylpropane units. These are the major non-carbohydrate constituents of wood. Lignins are highly recalcitrant compounds and are non-degradable in anaerobic environments as they require molecular oxygen for initial fragmentation (Komilis et al., 2003). Cellulose to lignin (C/L) ratio has been used to distinguish between fresh and mature wood wastes. C/L ratios of 4.04 denote fresh refuse while a C/L ratio of 0.8 has been recorded for 8- year old landfill refuse (Komilis et al., 2003).

Wood extractives are the constituents of wood that are lipohilic and can be extracted with organic solvents such as ethanol, acetone and dichloromethane. These include aliphatic compounds such as fats and sterols; terpenes and terpenoids such as resin acids; and phenolic compounds such as flavonoids, lignans, tannins and stilbenes. Softwood and hardwood can be distinguished by their tannin content. Softwood tannins, unlike hardwood tannins, do not have identifiable major phenolic compounds and their tannin concentrations are much less than those of the hard woods (Bianco and Savolainen, 1997). Bark contains higher percentages of extractives compared to stem wood (Tatum et al., 2005). Resin acids are present in softwood species but are absent in hardwood species (Dorado et al., 2000).

Based on soil chemistry, tree species and climatic conditions, wood can have various inorganic elements such as calcium, magnesium, potassium, aluminum, manganese, silicon, barium, zinc and nickel (Tatum et al., 2005). The ash or inorganic content of wood is usually 1% but it can increase due to contamination from soil and rock (Tatum et al., 2005).

III.4. Chemical characterization of wood leachate and runoff

Wood leachate can be generated through extraction in the laboratory or collected from wood stockpiles in the field. Leachate extracted in the laboratory does not represent field conditions and misses the effects of several natural factors. However, having control over all the field variables is impossible and it affects the quality of the assessment. Although cumbersome, a controlled study in the field is ideal and includes the advantages of both laboratory and field studies. This literature review will include both laboratory studies and field studies. Leachate and runoff from wood waste piles is more relevant to this study. However, there is more information available on log yard runoff, and log yard industries are more universally distributed. Leachate and runoff from these facilities will also be discussed along with wood waste leachate and runoff.

Wood waste leachate has been characterized as dark, acidic, of very high oxygen demand, and toxic to aquatic organisms (Bailey et al., 1999b; Field et al.,1988; Hedmark., 2002; Peter et al., 1976; Tao et al., 2005; Taylor et al., 1996; Taylor and Carmichael, 2003; Woodhouse and Duff, 2004; Zenaitis et al., 2002). McDougall (1996) suggested that increase in color (darker) could be due to destruction of light organic acids during decomposition of wood and the formation of stable polycyclic organic compounds from phenolic compounds. Tannins, lignins and humic substances are highly colored compounds, which can be a major source of wood waste leachate color (Tao et al., 2005). Weak organic acids such as fatty acids from wood extractives are mainly responsible for the low pH (Tao et al., 2007). Samis et al. (1999) suggested that carbon dioxide produced during decomposition of wood contributes partially to the acidity of the leachate as carbonic acid. The high oxygen demand is due to decomposition of the organic carbon in wood leachate, which is a mixture of tannins and lignins, volatile fatty acids (C2-C6), and carbohydrates in the form of cellulose and hemicelluloses (Tao et al., 2005; Taylor et al., 1996; Taylor and Carmichael, 2003; Woodhouse and Duff, 2004; Zenaitis et al., 2002).

The constituents of concern in wood leachate are mainly oxygen depleting organic compounds; nutrients such as ammonia, nitrate, nitrite, organic nitrogen and phosphorus are usually very low. In two field studies (Tao et al., 2005 and 2007), of leachate from tree trimmings, off-specification wood chips, saw dust, shredded roots, and bark from cedar processing mills, the COD values ranged from 416 to 4000 mg/L, tannins and lignins from 148 to 3000 mg/L and volatile fatty acids from 82 to 1600 mg/L. Nutrient concentrations were found to be low except ammonia concentrations, which showed a maximum value of 11.3 mg/L. In the first study (Tao et al, 2005), which lasted for 6 years, the initial leachate in the first two years, called young leachate, was amber in color, acidic, had high oxygen demand and was nutrient poor. The older leachate, which was collected in the last year of the study, had low oxygen demand, was less acidic and had a darker color. Similar results were found in the second study which lasted for a year, and samples were collected twice, once in November 2002 and again in February 2003. The COD, tannin and lignin, and volatile fatty acid (VFA) concentrations were less but comparable to the first study. Concentrations of COD, tannins and lignins, and VFAs collected in November were four times higher than in February. Leachate collected over a

34- week time period from a wood waste storage site had high oxygen demand, tannin and lignin concentrations, and volatile fatty acid levels but low pH and nutrient concntrations (Masbough et al., 2005). These concentrations were similar to levels observed by Tao et al. (2005). Masbough et al. (2005) found higher COD concentrations during low rainfall and high temperatures.

Similar COD concentrations were measured in a laboratory study conducted by Kaczal et al. (2012) with leachate extracted from pine saw dust and oak chips. Although, the COD concentrations were significantly higher in extract from pine sawdust (565 mg/L), compared to oak chips (419 mg/L), the range of values was similar to those found by Tao et al. (2007). Kaczal et al. (2012) explained higher COD concentrations in pine saw dust extract with the higher wood resin acids in softwood (pine) than hardwoods (oak) and the smaller particle size of saw dust compared to chips and thereby higher surface area to volume ratio. In a similar laboratory study by Svensson et al. (2013), leachate was extracted from oak, maple, pine, and beech sawdust and from oak and pine wood chips. The authors observed no difference in dissolved organic carbon (DOC) concentrations between oak and pine wood chips leachate. However, DOC released from oak saw dust leachate was significantly higher than pine saw dust leachate indicating the role of tree species in the release of organic contaminants. The authors suggested that when the particle size is reduced, the anatomical differences between hardwoods (oak) and softwoods (pine) play a role in the release of DOC. They hypothesized that softwoods lack the transport vessels that hardwoods have, thereby decreasing the diffusion from the core of the particles in softwoods. However, they pointed out that DOC released from other hardwood species such as maple and beech was less than from pine.

Taylor and Carmichael (2003) studied leachate characteristics from wood piles of trembling aspen for two years and found that BOD, COD, total organic carbon (TOC) and phenols showed higher initial concentrations that declined over time. The ranges of concentrations were similar to those measured by Tao et al. (2005).

Woodhouse and Duff (2004) collected nine runoff samples from a saw mill for a 12- month period. The BOD ranged from 25 to 745 mg/L, the COD from 125 to 4610 mg/L, tannins and lignins from 10 to 1505 mg/L and total suspended solids from 65 to 2205 mg/L. The large range of concentrations for organic constituents was similar to leachate concentrations found other studies. DeHoop et al. (1998) measured the BOD, COD, and TSS, and 123 priority pollutants in stormwater samples from a log storage handling facility over a 6-month period. Very wide range of concentrations for COD (0 to 14,724 mg/L) and TSS (6.7 to 20,078 mg/L) were measured. The BOD concentrations ranged from below detection to 49 mg/L. No substantial concentrations of priority pollutants were found. The pH of the samples ranged from 6.7 to 8.1. No relationship was found between different parameter concentrations and rainfall totals. COD was positively correlated to TSS.

III.5. Toxicity of wood leachate and runoff

Toxicity from wood leachate can be either direct or indirect. Direct toxicity is caused when inorganic chemicals and/or organic compounds present in wood leachate cause direct toxic effects on the test organisms or the environment. Indirect toxicity can be caused when high concentrations of organic constituents decreases dissolved oxygen in aquatic environments or release of highly colored compounds decreases light penetration and thereby obstruct photosynthesis. Another interesting indirect effect reported in the literature was that wood leachate appears to support abundant growth of the filamentous bacteria *Sphaerotilus*, which can cover and entangle aquatic invertebrates and fish in early life stages. (Schuytema and Shankland, 1976)

Several studies have been conducted with a wide range of organisms to test the toxicity of leachate and runoff from wood products. The organisms used for these studies included both invertebrates and vertebrates. The toxicity ranged from a very low toxicity or no effects to very high toxicity and mortality. Toxicity from wood leachate can be attributed to several organic and inorganic compounds that are released from wood products during decomposition.

Masbough et al. (2005) suggested that wood waste leachate degrades into compounds such as phenols and methylated phenols, benzoic acid and benzyl alcohol, terpenes, and tropolones that can be toxic to aquatic life. Becker et al. (2001) found that alcohols and ketones in the leachate extracts from pine wood originated from the lignite and polyose fraction of the wood which are toxic to fish. Peters et al. (1976) reported that tropolones found in western red cedar leachate are the primary cause of leachate toxicity to fish. Tao et al. (2007) attributed the acute toxicity of wood leachate to tannins, lignin, tropolones, terpenes, and low pH. Samis et al. (1999) measured high concentrations of resin acids in Douglas fir and spruce leachate as the primary toxicants in leachate from these species. The toxicity of westerm hemlock bark has been attributed to its tannin content (Samis et al., 1999).

Tao et al. (2005) reported that initial leachate collected in 1991 from a wood waste pile exerted acute toxicity to rainbow trout at a 96-h median lethal concentration of 0.74% (v/v) full strength leachate. They speculated that this toxicity could be due to tannins, lignins, zinc and low pH. Bailey et al. (1999b) tested stormwater samples from nine saw mills for acute toxicity with juvenile rainbow trout over a 23 month period. Forty-two of the 58 samples exhibited acute toxicity and 57% of the samples produced 100% mortality at full strength. The LC_{50} values ranged from 13 to >100% of the sample. Tannin and lignin concentrations of these samples showed strong correlation (R^2=0.94) with the toxicity results. Resin acids did not show significant correlation with the toxicity results. The authors reported that the effect of pH on toxicity is consistent with the identification of weak organic acids such as tannins and lignins as the cause of toxicity in these samples. They concluded that divalent cations, mainly zinc, were the cause of toxicity in most of the samples. Copper was another metal that might have caused toxicity on an occasional basis. They suggested that toxicity caused by tannins and lignins can be decreased by increasing pH. However, this was found to be ineffective in samples having tannin and lignin concentrations greater than 50 mg/L. Pease (1974) investigated toxicity of wood leachate extracts of hemlock, spruce, red cedar, and yellow cedar on pink salmon fry in a 96 hr acute toxicity study. Freeze dried extracts were prepared by soaking 1 kg of wood shavings in 6 L water for 4 days and then freeze drying the resultant solution. In fresh water, the LC_{50} values for the resultant solution from Sitka spruce, red cedar, and hemlock extracts ranged from 25 to 90 mg/L. When dissolved in salt water, the LC_{50} values for all of them were higher than the highest concentration tested, which was 200 mg/L.

Taylor et al. (1996) carried out toxicity studies using fresh aspen leachate derived from a 1:9 mixture of wood and water. Median acute toxicity concentrations for trout and *Daphnia* were 1 to 2% of full strength. Bacterial metabolism was inhibited at leachate concentrations below 0.3% and algal growth was inhibited at concentrations of 12 to 16%. The authors suggested that presence of aspen bark, which is a source of toxic phenolics, could be the reason for the high toxicity. It was also hypothesized that the use of chipped wood, from which leaching is quicker, rather than logs, could be a reason for the high toxicity.

Kaczala et al. (2012) tested toxicity of leachate from pine and oak on the freshwater microalgae *Desmodesmus subspicatus.* The effects were studied based on growth rate inhibition after exposure to leachate concentrations of 50, 12.5, 3.13, 0.79, and 0.2% (v:v) for 24, 48, 72 and 96 h. The results showed that both wood species caused growth inhibition with oak being more toxic than pine. Oak wood chips produced leachate with algaecide properties indicated by a decrease in the original number of cells at 50% concentration. Even though pine leachate was less toxic than oak, inhibitory effects on growth were observed (30 and 79% inhibition at 24 h and 72 h exposures, respectively). Kaczal et al. (2012) suggested that higher inhibitory effects caused by oak leachate could be due to higher concentrations of polyphenolic compounds and pH of 4.

III.6. Toxicity of chemically treated wood

Wood is treated with different inorganic and/or organic chemicals to protect it from both biotic and abiotic agents of deterioration. Abiotic agents of deterioration include chemicals, physical wear and fire. Biotic agents include bacteria, fungi, insects and vertebrates (Morrell, 2006). Although wood relevant to this study is untreated, contamination from chemically treated wood is considered possible. Since the 1970s, the majority of the wood used in outdoor residential settings has been treated with chromate copper arsenate (CCA). The most common formulation of CCA, Type C, contains 47.5% as CrO_3, 18.5% as CuO, and 34% as AS_2O_5 (Tao, 2012). Although CCA use has been banned in the USA since 2003, wood previously treated with CCA is still in use and wood mulch derived from discarded CCA treated wood could still be in use. The other commonly used wood preservatives are creosote and pentachlorophenol. Creosote is an organic mixture derived from coal tar and contains 85% polynuclear aromatic hydrocarbons (PAHs), and 10% phenolic compounds with the remaining 5% nitrogen, sulfur and oxygen containing heterocyclic aromatic hydrocarbons (Engwall et al., 1999). Pentachlorophenol (PCP), another commonly used preservative, was banned for residential use in 1987. The main contaminants of concern during PCP production are dioxins, which are more toxic than PCP itself.

Leduc et al. (2008) mixed leachate generated from wood preserved with CCA and alkaline copper quaternary (ACQ) with artificial rain water to generate leachate containing arsenic, chromium and copper. This leachate was applied to two soils at rates of 13-169 mg arsenic/kg, 12-151 mg chromium/kg, and 10-216 mg copper/kg. Metal bioavailability was evaluated after 28 days using the earthworm, *Eisenia fetida*. After 28 days, metal concentrations in earthworm tissue ranged from negligible to 80 mg As/kg, 89 mg Cr/kg, and 90 mg Cu/kg. These concentrations did not cause any mortality in the earthworms.

Rice et al. (2002) reported that a mass balance in a freshwater lake indicated that leaching from CCA treated lumber was a major source of arsenic in the lake sediments. Weis et al. (1992) reported that green algae growing attached to treated wood in Long Island, New York, had four times as much copper, twice as much chromium, and five times as much arsenic as the algae growing away from the treated wood. Weis et al. (2006) reported that most of the deleterious effects reported on aquatic organisms are in the marine environment. Wood intended for marine use is treated with very high concentrations of CCA with up to 2.5 lb/ft^3. The presence of inorganic ions in marine waters increases the leaching CCA from treated wood resulting in much higher leaching rates than in fresh waters.

Other chemicals applied to wood as antimicrobial and antifungal agents are antisapstain chemicals. The two most commonly used antisapstain chemicals are didecyl dimethyl ammonium chloride (DDAC) and 3-iodo-2-propynyl butyl carbamate (IPBC) (Bailey et al., 1999 b). Bailey et al. (1999 b) tested DDAC and IPBC for acute toxicity on juvenile rainbow trout. The 96-h LC_{50} values were 537 µg/L for DDAC and 67 µg/L for

IPBC. When these two chemicals were tested together as a mixture, they did not pose any synergistic effect on the juvenile rainbow trout.

III.7. Conclusions

The magnitude of leachate and runoff pollutant loads to the environment from wood processing facilities is site specific. According to the current literature, wood species, particle size, volume of wood stored, age, and precipitation volumes and duration play an important role on the quality and quantity of leachate and runoff. High concentrations of organic substances seem to be the main problem associated with leachate from wood processing facilities. These substances show up as high values for BOD, COD, TSS, DOC, and tannins/lignins/phenolics in the leachate chemical analysis. In most cases the pH of leachate was acidic. Even though in laboratory studies the acidic pH of leachate can have an effect on test organisms, in most natural waters this effect would be expected to be minimal because of the water's buffering capacity. In general, nutrients were found to be of little concern. The effect of leachate with high organic strength on the receiving water bodies is dependent on the proximity of the water body to the source, size of the water body and other physical and hydrological properties.

The literature reports cases of toxicity to aquatic organisms because of naturally occurring substances present in wood. However, the results are variable and several factors such as part of the wood that is stockpiled, age of the pile and fate and transport of toxic organic substances to the receiving water body play an important role in determining the extent of toxicity. More research addressing this problem is required. No cases of toxicity at wood sites because of contamination of wood with preservatives and antisapstain chemicals were reported. However, laboratory tests and field studies involving pressure treated wood showed that chemically treated wood can release high quantities of metals and organic chemical compounds. This indicates that contamination with these preservatives at unregulated wood processing facilities could pose an environmental risk.

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Chapter IV. Characterization of Wood Mulch, Leachate and Runoff from Three Wood Recycling Facilities in New Jersey

IV.1. Introduction

In July of 1999, two incidents of water pollution involving wood recycling facilities in New Jersey were reported to the New Jersey Department of Environmental Protection (NJDEP, 2009). The first incident involved a fish kill and an outbreak of avian botulism in a New Jersey lake receiving runoff from a wood recycling facility. The runoff leaving this facility was found to have a high oxygen demand level (BOD > 2500 mg/L and COD > 5400 mg/L) and high nutrient loads. In the second incident, *Sphaerotilus* (a filamentous bacterium) growth, which is characteristic of organic wastewater contamination, was observed in a stream receiving runoff from a wood recycling facility. These incidents coupled with several others prompted the NJDEP to sponsor a detailed study to scientifically determine if unregulated and mismanaged wood recycling facilities pose a risk to the environment.

IV.1.1. Objectives

As a first step to address the problem of water pollution concerns from wood recycling facilities, samples of wood mulch and leachate and runoff were collected and analyzed from three different class B wood recycling facilities in New Jersey during 2010 and 2011.

IV.1.2. Wood recycling in New Jersey

According to NJDEP regulations, Class B recycling facilities are those that accept source separated recyclable, non-putrescable material subject to NJDEP approval prior to receipt, storage, processing or transfer at a recycling center (NJDEP, 2013). Class B wood recycling facilities receive, store, process and transfer source separated wood materials (non-chemically treated and unpainted) such as whole trees, limbs, brush, tree chips, stumps, stump grindings, root mat, pallets and pallet grindings. They do not accept pressure treated or painted wood. As of 2013, there were 51 class B wood recycling facilities in New Jersey (NJDEP, 2013).

In the actual process of wood recycling, the wood is subjected to two grinds before being sold as wood mulch. In the first grind the wood material is coarsely ground and piled up in the open. In the second grind the wood materials are more finely ground, and then sold as mulch. Typical particle sizes of Grinds 1 and 2 material is highly variable over time and also among sites. How long Grind 1 material is left piled in the open is dependent on the demand for wood mulch. Usually, wood material is stockpiled as Grind 1 and is then ground the second time just before it is sold. However, this is not strictly followed and the time gap between Grinds 1 and 2 varies with facility. In general, grinding and sale of wood mulch is more rapid in the spring, summer and fall. In the winter, wood mulch is left on site as un-ground or Grind 1 material.

IV.2. Materials and methods

IV.2.1. Description of facilities

The main factor taken into consideration in selecting a recycling facility for this study was the facility's willingness to participate and the assistance available. The three wood recycling facilities selected for this study are located in different geographical regions of the state and have different topographies. While site B is located in the coastal plain, sites C and D are located in hilly areas. All three sites are NJDEP Class B wood recycling facilities.

Site B also accepts concrete, brick, and asphalt. Although both recycling processes are located on the same site, leachate and runoff from these two processes discharge into separate retention ponds. However, runoff and leachate from leaf recycling (composting) located on site flows into the same retention pond as wood recycling. Among the three sites, this site had the most closed system in relation to runoff collection as all runoff from the site was directed to the retention pond.

Site C prepares and sells top soil in addition to wood mulch. They grind leaves along with wood material to prepare mulch and top soil. The site does not have a retention pond and run off from the facility flows into a stream located below a cliff at the property edge. Among the three sites, site C had the highest ratio of volume of wood mulch stored to the area of the recycling facility.

At Site D the leaves are not mixed into wood mulch but are used in top soil preparation. Runoff from wood mulch stockpiles and leaf stockpiles is directed to the same retention pond. Compared to the other two sites, runoff at site D appeared to infiltrate more into the ground than run overland to the retention pond. The retention pond at this site is located just below a cliff covered with dense vegetation. During precipitation events runoff from that area also drains into this retention pond.

IV.2.2. Sampling

IV.2.2.1.Wood mulch

In total 15 representative wood mulch samples, each in duplicate, were collected over seven different occasions from the three sites. Table IV.1 shows an overview of the wood mulch samples collected. All samples were collected according to Test Methods for the Examination of Composting and Compost, which provides detailed protocols to verify the physical, chemical and biological characteristics of composting feed stocks (US Composting Council, 2010). Each pile was opened in the middle using a front end loader. From the opened face of a pile, samples were collected from three equidistant horizontal planes, with the lowest and highest sampling planes being 1 foot from the ground and 1 foot from the top of the pile. A total volume of 20 gallons of sample was collected in the ratio of approximately 3:2:1 (bottom: middle: top). This resulted in collection of 10 gallons from the bottom plane, 7 from the middle plane, and 3 from the top plane. The collected material was well mixed before coning and quartering twice, and each time one randomly chosen quarter was discarded. Out of the remaining 11 gallons of material, 1-gallon was placed in each of two separate 1 gallon plastic bags, which were then taken to the laboratory for further analysis.

IV.2.2.2. Leachate and runoff

A total of 26 leachate and runoff samples from 13 different rain events were collected from the three sites (Table IV.2). The samples were collected either during or soon (<24 hr) after a rain event. Collection location at each facility varied based on availability. In general, samples were collected from up to three locations: i) a puddle immediately next to a Grind 1 or Grind 2 pile, ii) the runoff flow leaving a pile area (not used for site D), and/or iii) any infiltration pond located on the site (none at site C). Samples were refrigerated and analyzed within specified holding times.

Unlike wood mulch samples, leachate samples could not be differentiated into samples collected from Grind 1 and Grind 2 piles. This is because there was no well defined drainage path and the puddles from which leachate samples were collected could receive leachate from either or both grind piles.

IV.2.3. Wood mulch analysis

Out of the two one-gallon size samples collected, one was shipped overnight in a cooler to the Agricultural Analytical Services Laboratory in University Park, PA, for analysis of the chemical characteristics of the samples. The other was used to determine the initial moisture content using the methods set forth in the American Society for Agricultural Engineers (ASAE) standards for moisture measurement of forage (ASAE, 1992).

IV.2.4. Leachate and runoff analysis

IV.2.4.1. Physical, chemical and microbiological analysis

The leachate samples were analyzed in the laboratory for pH, biochemical oxygen demand (BOD), chemical oxygen demand (COD), color (luminance, dominant wavelength, hue, and purity), settleable solids (Sett.S), total suspended solids (TSS), total Kjeldahl nitrogen (TKN), total phosphate-phosphorus (TP), tannin/lignin/phenolic (T/L/P) compounds, and fecal coliforms. COD and T/L/P were carried out using a HACH kit (Hach Company, Loveland, CO), followed by spectrophotometric measurements (Spectronic® 20 Genesys^{TM} for COD and Hach DR/850 for T/L/P). All other tests were conducted following methods set forth in Standard Methods for the Examination of Water and Wastewater (Clesceri et al., 1998). Method 5210 was followed for the BOD test and Method 2540 D for TSS. For TSS determination, at least 50 mL of sample was vacuum filtered in most cases and a smaller volume was used only if the filtration took more than 10 minutes. Spectrophotometric Method 2120 was used for color determination. The samples were vacuum filtered through 47 mm diameter glass microfiber filters (Whatman™, GE Healthcare UK limited, Buckinghamshire, UK). A laser spectrophotometer (Aquamate, Thermo Scientific, USA) was used to measure the transmittance values at 30 different wavelengths to calculate and determine dominant wavelength, luminance (%), purity (%) and hue at the field pH of the samples. Method 4500-N_{org} C without the distillation step followed by Method 4500-NH_3 D for ammonia measurement were used for determining TKN. For total phosphate-phosphorus measurement, Method 4500-P B (digestion) followed by Method 4500-P E (ascorbic acid colorimetric determination) was used.

Fecal coliform testing, performed using a 5 tube per 10-fold serial dilution multiple tube fermentation procedure (Clesceri et al., 1998), was done only on samples from 2011 (n=12). The most-probable-number (MPN) was estimated using the tables of Meynell and Meynell (1970) if the MPN index for the combinations of positive results was available**,** or else the table from Standard Methods (Clesceri et al., 1998). The settleable solids test was discontinued as values were usually below detection (<0.5 mL/L).

IV.2.4.2. Aquatic toxicity dose-response studies

Dose-response studies using zebrafish (*Danio rerio*) embryos were conducted under the guidance of Prof. Keith Cooper in the Dept. of Microbiology and Biochemistry at Rutgers University using his laboratory's standard operating procedures for zebrafish embryo larval assays (Cooper, 2009).

Zebrafish embryos are either in the blastula or early gastrula stage when they come out of the parent body, but tests were conducted on embryos that were 8-24 hr old. Zebrafish strain AB, which is well studied and described in Dr. Cooper's laboratory, was used. The dilution water used was dechlorinated tap water filtered by an automatic sand filter and two 25 µm particle filters, then passed through an activated carbon column (Cooper, 2009). The water was aerated for 15 minutes before use for dilution. Sterilized glassware was used in all experiments.

The evening before the eggs were needed for the study, 5-6 zebrafish males were transferred into tanks containing several females. The eggs laid were collected from the bottom of tanks that were covered with glass marbles**.** Eggs were observed under a stereomicroscope and any that were not dividing properly or appeared damaged were discarded. Viable eggs were placed in glass Petri dishes and incubated at 25ºC for 4 hrs or less prior to use (Cooper, 2009).

Refrigerated leachate and runoff samples were allowed to reach room temperature before dilutions were made. Dilutions (0.625 – 50% leachate) were chosen based on a visual estimation of sample strength, which varied due to differences in materials on site, rain volumes, and time of sample collection. For samples that looked more diluted, higher sample concentrations were used and vice versa. Dilutions (unless noted) were adjusted to pH 7 using 10N HCl or NaOH, and 10 mL portions of each was transferred to 20 mL scintillation vials. Using a micropipette, five embryos were transferred into each vial. Each concentration (including controls with dilution water only) had three vials (15 embryos in total for each concentration). After recording the stage of each embryo, all vials were incubated at 25ºC. Observations were made daily and any abnormal development or mortality was recorded until the control embryos reached the "protruding mouth" post hatch stage (usually 5 days). Abnormalities that were looked for included: 1) abnormal circulation, 2) pericardial edema, 3) yolk sac edema, 4) kink tail, 5) abnormal spine curvature, 6) decreased body and retinal pigmentation, 7) size of head, 8) delay in development, and 9) death. Percentages reported for 1-7 are based on the survivors at each time period. Delay in development (8) was measured as the number of the growth stage reached compared to the controls.

The LC_{50} is the leachate concentration at which mortality is observed in 50% of the exposed embryos by the end of the incubation period. It was determined by plotting percent mortality vs. concentration (% of original leachate) on probability vs. 3-cycle log graph paper and determining the concentration at which there was 50% mortality based on the manually drawn best-fit line (Reish and Oshida, 1986). Similarly, EC_{10} is the leachate concentration at which a specific developmental effect is observed in 10% of the exposed embryos, and was determined in the same way. In addition, the concentration at which there was a one stage delay in development compared to controls was determined. This was done by assigning a numerical value in increasing order to each stage (based on

Kimmel et al., 1995) before the final "protruding mouth stage", which was expected to be achieved by healthy embryos usually within 5 days after fertilization. A numerical value was also assigned to controls in which the final protruding mouth stage was not reached at the end of the experiment. This value was subtracted from the treatment values to determine "delay". The weighted (by percentage of surviving fish) averages of the delays among embryos at each concentration compared to the control were then used to determine (by linear regression) the concentration at which there was a one stage delay in development.

Except for Sample C-2 from April 5, 2010, pH was adjusted to 7. All the concentration values are expressed in percentages. Each concentration including controls had 15 embryos exposed.

IV.2.5. Statistical analysis

One-way and two-way unbalanced ANOVA were carried out on wood mulch and leachate samples using SAS 9.3 (SAS Institute Inc. Cary, NC). A post-hoc Tukey-Kramer test was done to determine the means that were significantly different from each other. Coefficients of determination (R^2) obtained from simple linear regressions using Excel 2007 were used to test correlations between values of different leachate parameters.

IV.3. Results and discussion

IV.3.1. Wood mulch

Appendices E.1, E.2, and E.3 show the complete results of the analysis of the wood mulch samples from sites B, C and D. Tables IV.3, IV.4 and IV.5 show minimum, maximum, mean and median values for each site and grind. A 2-way (site and grind) unbalanced ANOVA showed that among the 22 parameters analyzed, 17 (conductivity, solids, moisture, organic matter, carbon, total nitrogen, organic nitrogen, phosphorus, potassium, calcium, magnesium, sulfur, sodium, aluminum, iron, manganese and lead) showed significant differences in concentrations among the three sites (Table IV.6). Conductivity values and sulfur concentrations also differed significantly with grind of the material, and conductivity and lead differed based on the interaction between site and grind.

For most of the parameters, differences among sites played an important role in the differences in their concentrations, indicating differences in the material being processed at each site, the processing itself, and/or site geography. The analysis showed there was no effect of grind on most of the parameters. Because of the 5% chance of finding a significant difference even when there is only random variation (at 95% significance level), the “significant” differences observed for 2 out of 22 tests (9%) based on grind can probably be disregarded.

Wood mulch samples were slightly acidic with the average value ranging from 5.8 to 6.8 among the three sites. Total nitrogen occurred mostly in the organic form as ammonia nitrogen concentrations were found to be negligible. Samples from Site C had significantly higher carbon concentrations compared to the other two sites (Table IV.6). Samples from Site B had significantly higher nitrogen, phosphorus, potassium and calcium content compared to the other two sites. Samples from Site D had significantly higher magnesium, sulfur, sodium and aluminum concentrations compared to the other two sites. Samples from Site D had significantly higher iron concentrations than Site B, which had higher iron concentration than Site C. Site D samples had the highest manganese concentrations, followed by Site C. The higher metal concentrations and lower organic matter observed in Site D samples could be due to incorporation of more soil in the mulch.

The moisture content of the samples (on a wet basis) varied from 33% to 59% with an average value of 47%. The average initial moisture content was about the same for sites B and D (44% and 42%, respectively), but higher for site C (52%).

IV.3.2. Leachate and runoff

IV.3.2.1. Physical, chemical and microbiological analysis

Appendix F shows the complete results of the physical, chemical and microbiological analysis for the leachate and runoff samples. A summary of these results in Table IV.7 shows the minimum, maximum, mean and median values for all samples combined from all three sites.

In general, BOD, COD, and TSS median concentrations were often comparable to those of untreated domestic wastewater, although both lower and higher individual values were observed. TKN, TP and fecal coliform median values were usually a little lower than typical untreated domestic wastewater values. BOD, COD, TKN and TP median values were found to be in the range of typical urban stormwater runoff values, while TSS median values were generally less than urban stormwater runoff values. These findings are similar to those reported by Hedmark and Scholz (2008) in their review of runoff mainly from log yards.

Since the leachate concentrations were highly variable and found not to be normally distributed, a 2-way ANOVA (site and location) was run on logarithmic transformed leachate concentrations (Table IV.8). The analysis showed that pH, BOD, and COD differed significantly among the three sites. Different sampling locations within a site did not show significant differences in the logarithmic means of the concentrations. In light of location within a site not being significant, all the samples from a specific site, irrespective of the location from which they were collected, were pooled and a one-way ANOVA was run to see if the increase in sample size would allow detection of significant differences. The results showed that for pH, BOD and COD the mean for site C was significantly higher than those for sites B and D. Other potential sources of variability, which were not included in the statistical analysis, are particular materials on site, their age and processing, storm intensity and duration, and the site geology and hydrology.

IV.3.2.2. Aquatic toxicity dose-response studies

Detailed toxicity results for each sample are shown in Appendix G. Lethal concentration (LC_{50}) values for mortality and effective concentration (EC_{10}) values for developmental defects were calculated for each sample where possible. The results are shown in Table IV.9.

The high mortality and developmental effects at low sample concentrations observed in the first sample C-2 can likely be attributed to the low pH (3.44) of the sample. Natural waters would likely be better buffered than the dilution water used, so that addition of stormwater runoff would not have such a dramatic effect on pH. For this reason, all later samples were adjusted to pH 7. In the other samples, where pH was adjusted to neutral conditions, mortality and developmental effects, if observed at all, occurred at higher leachate concentrations. The main developmental effects observed were yolk sac/pericardial edema, abnormal spine curvature, kink tail, and delay in development. Only delay in development regularly occurred at low leachate concentrations.

Significant negative correlation (Table IV.10) was observed between stage delay concentrations and COD. The negative slope for this relationship indicates that with increased COD concentration in a sample, volume of the sample causing stage delay is decreased (higher toxicity). However, this correlation likely indicates leachate concentration rather than direct toxicity of COD. Only further tests aimed at determining the source of toxicity can establish the specific compounds of concern. COD is also positively correlated with tannins/lignins/phenolics, BOD, TKN and pH. A strong positive correlation was observed between BOD and tannins/lignins/phenolics, TKN and pH.

IV.4. Conclusions

Considerable variability was found among samples for most parameters tested. However, most of the leachate physical, chemical and microbiological concentrations tested were found to be similar to concentrations found in urban stormwater runoff and/or domestic wastewater influent. LC_{50}, EC_{10} and stage delay concentrations were high indicating low acute toxicity. Lack of control over site geology, hydrology, wood material stored on site, age, processing, and storm intensity and duration precludes making a detailed assessment of pollutant loads. These results further point out the need for controlled experiments in order to be able to better predict the potential impact of stormwater runoff from wood recycling facilities.

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Table IV.1. Summary of the wood mulch samples collected

Sampling Date	Site#	Sample ID*	Grind**
10/12/2010	C	1 A & B	2
10/12/2010	C	2 A & B	1
10/13/2010	D	3A & B	1
10/13/2010	D	4 A & B	2
11/10/2010	B	5 A & B	2
11/10/2010	B	6 A &B	1
11/10/2010	B	7 A & B	2
11/16/2010	B	8 A & B	1
11/16/2010	B	9 A & B	2
11/16/2010	B	10 A & B	2
11/22/2010	C	11 A & B	1
11/22/2010	C	12 A & B	2
4/19/2011	B	13 A & B	1
4/19/2011	B	14 A & B	2
4/22/2011	C	15 A & B	2

* A & B are replicates of the same sample; samples with different sample IDs collected on the same date a
re from different piles of the same grind.
** Grind 1: ground once; Grind 2: ground twice.
# B, C and D in Site column are three different wood recycling facilities.

Table IV.2. Summary of leachate samples collected.

Sampling Date	Site & Location	Sampling Location
6/10/2010	C-1	Puddle next to a Grind 2 material pile
6/10/2010	C-2	Runoff leaving the site
8/25/2010	C-1	Puddle next to a Grind 2 material pile
8/25/2010	C-2	Runoff leaving the site
7/29/2010	D-1	Retention pond
7/29/2010	D-2	Puddle next to a Grind 1 material pile
9/17/2010	B-1	Puddle between Grind 1 and Grind 2 piles
10/1/2010	B-2	Runoff leaving the site
10/1/2010	B-3	Retention pond
11/5/2010	B-1	Puddle between Grind 1 and Grind 2 piles
11/5/2010	B-2	Runoff leaving the site
11/5/2010	B-3	Retention pond
12/1/2010	C-1	Puddle next to a Grind 2 material pile
12/1/2010	C-2	Runoff leaving the site
4/13/2011	B-2	Runoff leaving the site
4/13/2011	B-3	Retention pond
5/5/2011	B-1	Puddle between Grind 1 and Grind 2 piles
6/15/2011	C-1	Puddle next to a Grind 2 material pile
6/15/2011	C-2	Runoff leaving the site
7/19/2011	D-1	Retention pond
7/19/2011	D-2	Puddle next to a Grind 1 material pile
8/15/2011	B-1	Puddle between Grind 1 and Grind 2 piles
8/15/2011	B-2	Runoff leaving the site
8/15/2011	B-3	Retention pond
9/7/2011	C-1	Puddle next to a Grind 2 material pile
9/7/2011	C-2	Runoff leaving the site

Table IV.3. Range, mean and median values for wood mulch samples from Site B

Parameter	Grind 1 (n= 6)				Grind 2 (n=10)				SRS
	Min	Max	Mean	Median	Min	Max	Mean	Median	(mg/kg)
pH	5.3	6.1	5.8	5.9	4.6	6.8	6.2	6.4	
C:N ratio	58	93	73	66	53	118	77	73	
Cond. (mS/cm)	0.2	0.3	0.3	0.3	0.3	0.8	0.4	0.4	
Moisture(%)#	32	49	39	39	31	60	48	52	
Moisture*(%)#	33	43	38	38	34	59	48	52	
Org.matter(%)	53	81	71	74	65	83	75	76	
C (g/kg)	279	374	320	321	278	416	366	386	
Total N	3700	5800	4483	4350	3200	7500	5000	5150	
Org. N	3700	5800	4483	4350	3200	7500	4970	5100	
NH_4^+-N**	<4.9	48.5		<4.9	<4.9	<5	<4.9	<4.9	
P	253	546	405	400	271	502	391	406	
K	1250	3000	1972	1958	1417	3083	2000	1917	
Ca	3300	6300	4750	4700	3000	8800	4930	4800	
Mg	600	2200	1283	1200	600	2800	1190	900	
S	300	500	367	350	300	500	410	400	
Na	58	127	85	80	55	187	97	72	
Al	1615	7430	3724	3407	1056	13662	3135	1830	78,000
Fe	2705	9136	5684	6117	1728	11589	5189	4643	
Mn	75	133	102	97	46	148	71	65	11,000
Cu	16	168	54	36	10	482	74	20	3,100
Zn	29	77	47	47	25	171	47	32	23,000
Pb	9	26	16	17	9	24	14	13	400

Except for pH, parameters are in mg/kg dry weight unless noted.
*Moisture content measured in the laboratory at Rutgers University immediately after collection.
SRS: Soil remediation residential direct cleanup standards (NJDEP, 2011).
** All values below detection limit except for one.
# Wet weight basis

Table IV.4. Range, mean and median values for wood mulch samples from Site C

Parameter	Grind 1 (n=4)				Grind 2 (n=6)				SRS
	Min	Max	Mean	Median	Min	Max	Mean	Median	(mg/kg)
pH	5.3	6.1	5.8	5.9	4.6	6.8	6.0	6.3	
C:N ratio	58	93	72	69	53	118	80	75	
Cond. (ms/cm)	0.2	0.3	0.3	0.3	0.3	0.8	0.5	0.4	
Moisture (%)#	32	49	40	39	31	60	48	50	
Moisture* (%)#	33	43	38	38	34	59	48	50	
Org.matter (%)	53	81	70	73	65	83	75	76	
C (g/kg)	279	374	323	320	278	416	362	376	
Total N	3700	5800	4583	4417	3200	7500	5213	5075	
Org. N	3700	5800	4583	4417	3200	7500	5193	5035	
NH_4^+-N**	<4.9	<5		<4.9	<4.9	109		<5	
P	253	546	401	402	271	502	393	399	
K	1250	3000	2045	1965	1417	3083	2104	1958	
Ca	3300	6300	4763	4725	3000	8800	5383	4865	
Mg	600	2200	1321	1242	600	2800	1373	1045	
S	300	500	379	358	300	500	403	405	
Na	58	127	87	82	55	187	103	84	
Al	1615	7430	4044	3566	1056	13662	4921	2483	78,000
Fe	2705	9136	5911	5900	1728	11589	5787	4916	
Mn	75	133	102	100	46	148	83	68	11,000
Cu	16	168	68	45	10	482	146	47	3,100
Zn	29	77	50	47	25	171	69	39	23,000
Pb	9	26	17	17	9	24	15	13	400

Except for pH, parameters are in mg/kg wet weight basis unless noted.
*Moisture content measured in the laboratory at Rutgers University immediately after collection.
SRS: Soil remediation residential direct cleanup standards (NJDEP, 2011).
** All values below detection limit except 2.
# Wet weight basis

Table IV.5. Range, mean and median values for wood mulch samples from Site D

Parameter	Grind 1 (n=2)				Grind 2 (n=2)				SRS
	Min	Max	Mean	Median	Min	Max	Mean	Median	(mg/kg)
pH	6.7	6.8	6.8	6.8	5.6	6.2	5.9	5.9	
C:N ratio	39	73	56	56	33	56	45	45	
Cond. (ms/cm)	0.3	0.6	0.4	0.4	0.9	2.2	1.5	1.5	
Moisture (%)#	44	49	46	46	39	41	40	40	
Moisture* (%)#	45	46	46	46	36	42	39	39	
Org.matter (%)	52	57	55	55	61	65	63	63	
C (g/kg)	305	317	311	311	251	397	324	324	
Total N	4400	7900	6150	6150	7100	7600	7350	7350	
Org. N	4400	7900	6150	6150	6900	7600	7250	7250	
NH_4^+-N	<4.9	<4.9		<4.9	20	172	96	96	
P	681	983	832	832	738	987	862	862	
K	2333	3417	2875	2875	3333	3750	3542	3542	
Ca	6600	9000	7800	7800	9000	10600	9800	9800	
Mg	2900	3500	3200	3200	3100	3200	3150	3150	
S	500	800	650	650	600	800	700	700	
Na	155	298	227	227	212	362	287	287	
Al	6653	7082	6867	6867	4521	4729	4625	4625	78,000
Fe	10797	11304	11050	11050	7111	8569	7840	7840	
Mn	264	332	298	298	254	255	255	255	11,000
Cu	38	40	39	39	31	35	33	33	3,100
Zn	61	77	69	69	59	72	65	65	23,000
Pb	25	35	30	30	18	22	20	20	400

Except for pH, parameters are in mg/kg dry weight basis unless noted.
*Moisture content measured in laboratory at Rutgers University immediately after collection.
SRS: Soil remediation residential direct cleanup standards (NJDEP, 2011).
Wet weight basis

Table IV.6. Means for wood mulch samples (all grinds) and significant differences among sites (Tukey-Kramer test)

Parameter	Site B	Site C	Site D
Electrical Conductivity (ms/cm)	0.34 a*	0.85 b	0.97 b
Moisture (%)	43.5 a	53 b	43 a
Organic matter (%)	73 b	91 c	59 a
Carbon (g/kg)	343 a	451 b	317 a
Total Nitrogen	4741a	6383 b	6750 b
Organic Nitrogen	4726 a	6375 b	6700 b
Phosphorus	398 a	508 b	847 c
Potassium	1986 a	2614 b	3208 b
Calcium	4840 a	7866 b	8800 b
Magnesium	1237 a	958 a	3175 b
Sulfur	388 a	425 a	675 b
Sodium	90 a	114 a	257 b
Aluminum	3429 a	986 a	5746 b
Iron	5436 b	1515 a	9445 c
Manganese	87 a	143 b	276 c

* Within a row, means followed by the same letter are not significantly different ($p<0.05$).
Unless noted, parameters are in mg/kg

Table IV.7. Summary of the physical, chemical and microbiological analysis for leachate and runoff samples for all the sites combined.

	pH	BOD	COD	Sett. S	TSS	TKN	TP	T/L/P	FC
n	26	24	26	14	26	26	26	26	12
min	4.8	<20	134	<0.5	69	1.3	0.18	6	≤450
max	7.6	≥2900	5991	0.9	401	70	8	690	>$1.6x10^6$
mean*	6.74	433	1247	-	171	12.7	3.2	74	-
median	6.75	107	566.5	<0.5	145	6.3	2.6	44	<1800
USWRO**	-	10-250	20-600	-	630	3-10	0.2-1.7		10^1-10^6
DWWI#	-	110-350	250-800	5-20	100-400	20-70	4-12	-	10^3-10^8

Except for pH, settleable solids (sett. S, mL/L) and fecal coliforms (FC, most probable number (MPN) per 100 mL of sample) the rest are in mg/L units.
*Calculated mean for BOD excludes two values reported as greater than or less than a value.
** Urban stormwater runoff values (Novotny and Chesters, 1981).
#DWWI = domestic wastewater influent values (Tchobanoglous et al., 2003).

Table IV.8. Results of 2-way ANOVA run on leachate samples*

Parameter	Significant factor#
pH	Site
BOD	Site
COD	Site
TSS	None
TKN	None
TP	None
T/L/P	None

* Since the data was not normally distributed, ANOVA was run on logarithmic transformed data.

The independent factors that the dependent chemical parameters were tested against are Site, Location, and interaction between site and location (Site*Location)

Table IV.9. Concentrations lethal to 50% of population (LC_{50}), effective concentration causing an abnormality in 10% of population (EC_{10}) and concentration causing a one stage delay

	Sample*	Date Collected	Test Date	Tested Concentrations (%)	LC_{50}** (%)	EC_{10}*** (%)	% Conc. for 1 Stage delay (R^2)
1	C-2	4/5/10	4/26/10	0.625, 1.25, 2.5, 5, 10	2.7		0.8 (0.99)
2	C-2	6/10	6/24/10	0.625, 1.25, 2.5, 5, 10	>10	4.9 (YSE), 1.4 (ASC)	0.88$^{@}$ (0.88)
3	D-1	7/29	8/17/10	1.25, 2.5, 5, 10, 20	>20	3.3 (YSE)	0.001 (0.7)
4	D-2	7/29	9/29/10$^{\#}$	1.25, 2.5, 5, 10, 20	>20	9(KT)	2.49$^{\$}$ (0.01)
5	B-1	9/17	9/29/10	1.25, 2.5, 5, 10, 20	>20	ND	0.28$^{\$}$ (0.51)
6	B-2	10/1	10/18/10	2.5, 5, 10, 20	>20	26 (ASC)	1$^{@}$ (0.7)
7	B-1	11/5	11/16/10	2.5, 5, 10, 20, 30	>30	16 (ASC)	1.83$^{@}$ (0.92)
8	B-2	11/5	11/16/10	5, 10, 20, 30	>30	ND	7.34 (0.67)
9	B-3	11/5	11/16/10	5, 10, 20, 30	> 30	ND	6.1 (0.69)
10	C-1	12/1	12/7/10	5, 10, 20, 30, 50	>100	ND	2.97(0.78)
11	C-2	12/1	12/7/10	5, 10, 20, 50	>27	ND	3.23$^{\$}$ (0.65)
12	B-2	4/13/11	4/26/11	5, 10, 20, 30, 40	19	ND	2.2(0.92)
13	B-3	4/13	4/26/11	2, 4, 8, 10, 20	>20	14 (ASC)	2.85$^{\$@}$ (0.57)
14	B-1	5/11	5/24/11	2, 5, 10, 30	8.5	ND	2.7 (0.99)
15	C-1	6/15	6/20/11	2.5, 5, 10, 20	4.5	3 (ASC)	1.27 (0.99)
16	C-2	6/15	6/20/11	5, 10, 20, 30, 50	40	29 (ASC)	6.2 (0.71)
17	D-1	7/19	7/26/11	5, 10, 20, 30, 40	33	>20 (ASC), 35 (YSE)	2.6 (0.96)
18	D-2	7/19	7/26/11	10, 20, 30, 50	9	19 (ASC)	5.16$^{\$}$ (0.080)

* Samples B-1, B-2 and B-3, collected from site "B", are from a puddle between *Grinds* 1 and 2 piles, runoff stream, and retention pond, respectively. Samples C-1 and C-2, collected from site "C", are from a puddle next to a *Grind* 2 pile and the runoff leaving the site, respectively. Samples D-1 and D-2, collected from site "D", are from the retention pond and a puddle next to a *Grind* 1 pile, respectively.

** In many cases (indicated by ">"), 50% mortality did not occur at highest concentration tested.

***YSE = Yolk sac edema; ASC = Abnormal spine curvature; KT = Kink tail; ND = not detected.

$^{\#}$ Normal holding time exceeded.

$^{@}$Stage delay concentration calculated based on stages from the 6th day compared to controls. For other samples, stages from the 5th day were used.

$^{\$}$ Regression not significant (p<0.05).

Table IV.10. The p-values from simple regression analysis correlations among variables for 18 samples.

	1-Stage Delay Conc.*	BOD	COD	TSS	T/L/P	TKN	TP
BOD	0.09						
COD	**0.04**	**0.0002**					
TSS	0.33	0.27	0.61				
T/L/P	0.07	**$1.3*10^{-5}$**	**$2.5*10^{-5}$**	0.11			
TKN	0.47	**0.002**	**$8.1*10^{-5}$**	0.80	0.10		
TP	0.76	0.83	0.56	0.80	0.49	0.46	
pH	0.28	**0.0002**	**0.003**	0.38	0.93	**0.04**	0.58

* Correlation coefficient is negative.
Bold values indicate significance at $p < 0.05$.

Chapter V. Leachate Characterization and Pollutant Loads from Controlled Wood Mulch Stockpiles

V.1. Introduction

To decrease uncertainty regarding the quality and quantity of leachate from wood mulch stockpiles due to site geology, hydrology, volume of material stored, and storm intensity, a controlled experimental study was carried out. Eight wood mulch piles divided into three runs were set up and monitored at the Burlington County Resource Recovery Complex (BCRRC) in New Jersey, USA, from July 2011 to November 2012.

V.2. Materials and methods

V.2.1. Source of the wood mulch

For all three runs, wood mulch was obtained from the wood mulch recycling facility located on site. The facility accepts trees, branches, brush, and twigs, but no pressure treated wood. The wood material can be from any tree species and can be received from anywhere but is generally from within the state.

V.2.2 Set-up, operation and monitoring of wood mulch stockpiles

V.2.2.1. Set-up of stockpiles and sampling of leachate

Run 1 lasted from July 6 to November 16, 2011. Run 2 lasted from November 17, 2011 to April 24, 2012. Run 3 lasted from April 25 to November 1, 2012. Run 1 consisted of two stockpiles made of Grind 2 material. Run 2 and Run 3 consisted of three piles each, two of Grind 2 material and one of Grind 1 material.

The piles were set up on a large concrete pad with three circular 24-foot diameter graded experimental stockpile areas (Figure V.1a and V.1b). Based on their position on the concrete pad as viewed from the control shed, the three piles were named left (L), right (R), and far (F). Each stockpile area is peaked in the center and graded towards a circular 1-inch deep gutter that conveyed leachate to two drains located in each gutter. The leachate from each pile separately flowed through 3 inch polyvinyl chloride (PVC) pipe to 5- gallon pails, used as reservoirs holding ~ 2 gallons each (Fig. V.2a and V.2b) and located in a shed. Leachate samples for analysis were collected from the reservoirs via a Teledyne ISCO (Lincoln, Nebraska) automatic sampler (model no. 6712) triggered by a bubbler type pressure sensor (ISCO 730 bubbler flow module).

The ISCO samplers contained 24 one-liter polypropylene bottles. The samplers were programmed to collect a sample every half hour for the first three hours of flow and thereafter a sample was collected every 3 hr. This way samples were collected more frequently in the initial stages of a leachate-producing rain event and samples could be collected for leachate flow events that lasted up to a maximum of 57 hours. From each reservoir the leachate flowed to a separate 1 L tipping bucket flow gauge. The number of tips was recorded in a data logger. As an additional precaution for Run 3, all leachate from a rain event from each pile was collected in a separate 500-gallon reservoir.

Run 1 was a trial run to test the equipment set up. It contained two piles of second grind material, and samples were collected for physico-chemical analysis for only two rain events during this time. On September 9, 2011, 24 bottles from stockpile L were collected during and after a rain event. Only pH and BOD were determined for a composite of these samples (Table V.8). On October 17, two additional sets of samples were collected: a single sample from pad L and seven samples from pad R. Bottles 2-6 from this set were composited for analysis.

To estimate the mass of the piles for Runs 2 and 3, 3 loader buckets of mulch were placed on a truck that was then weighed using the on-site truck scale, and the number of buckets of wood materials used to construct each pile was recorded.

V.2.2.2 Monitoring of temperature and moisture levels in the stockpiles

Sixteen temperature sensors (model CS107, Campbell Scientific, Logan, UT) and 16 water content reflectometers (model CS616, Campbell Scientific) were installed at 1, 3, 5, and 7 feet above the ground in each pile during set up. The number of sensors at each height and their positions in the piles are shown in Figure V.3. According to the manufacturer’s specification, the water content reflectometers perform with an error of ± 2.5% volumetric water content (VWC) in a range of 0% to 50% VWC. The temperature sensors function best in a range from -35°C to 50°C, with a worst case error of ±0.9°C. In the range of -24° to 48°C, the temperature sensors have a worst case error of ± 0.4°C. Above 60^{o} C, the temperature probes tend to underestimate the readings with an error of 1.7ºC at 60ºC (Anon., 2000). These sensors were connected to an AM 16/32 B multiplexer mounted on a steel pipe next to each pile. All multiplexers (Campbell Scientific) were connected to a CR1000 datalogger (Campbell Scientific) located in the shed. The CR1000 datalogger stored all data.

V.2.2.3. Monitoring of oxygen levels in the stockpiles

Oxygen levels were monitored (model 630 oxygen analyzer, compost oxygen probe, Woods End Research Laboratory, Inc., Mt. Vernon, ME, USA) on 5/8/12 for Run 2 piles and on four occasions (6/1/12, 8/21/12, 11/14/12, and 1/30/13) for Run 3 piles. Measurements were taken at 1, 3, 5 and 7 feet heights and at 1, 3, and 5 feet depths into the pile at each height. The oxygen probe was calibrated to 20.9% oxygen concentration (air) before taking the measurements and several times between measurements.

V.2.2.4. Measuring pile dimensions and change in pile sizes

Next to each pile, X and Y axes with 4 foot divisions on each axis from 0 to 24 feet were marked. At each of the 49 X, Y coordinates, height of the pile was measured using rotating laser surveying equipment (CST/Berger Lasermark Wizard LM 30 series). The rotating laser source was set on a flat surface at a height greater than the piles. At each coordinate, vertical distance from the pile surface to this reference height was measured and subtracted from the reference height to get the height of the pile at that point. The volume of each 4-foot by 4-foot rectangular solid was determined by multiplying 4 ft length and 4 ft width with average height of the rectangular solid. The volume of the pile was calculated by adding up volumes of all the rectangular solids. The pile measurements obtained were also utilized to generate pile dimension graphics using MATLAB software (Version 7.14, The MathWorks, Inc. Natick, MA, USA). Using the mass of piles obtained when setting up the piles and volumes determined from the pile dimensions, bulk density of the wood mulch was calculated, which was then compared to the bulk density values determined in the laboratory.

V.2.2.5. Precipitation and leachate quantities

Precipitation was determined based on a rain gauge (8"siphoning tipping bucket rain gauge, Intermountain Environmental, Inc., Logan, UT) installed on the concrete pad next to the left pile (Fig.V.1b). Each tip of the rain gauge corresponded to 0.01 cm of rain. Leachate quantities were determined for all the rain events by adding leachate tipping bucket information and the leachate collected by the ISCO samplers (which was removed before reaching the tipping buckets). Figures V.2a and V.2b show a photograph and a schematic of the leachate measurement and sampling arrangement.

V.2.3. Leachate sampling and compositing

Samples were collected after each rain event (within 24 hr in most cases) from the ISCO samplers. When ISCO samplers malfunctioned, samples were taken from the 500 gallon reservoirs if possible. Before taking samples from the 500 gallon reservoirs, the leachate was vigorously mixed using a sump pump. The reservoirs were emptied but not washed between rain events. When samples were taken from the ISCO samplers, the bottles were composited based on the leachate flow rate, utilizing flow information from the tipping buckets and time stamp on the automatic samplers. In most cases all leachate samples from one rain event for a pile were composited into a single sample for analysis. Appendix H shows an example of compositing done on samples collected from Run 2. The samples were immediately taken to the laboratory in a cooler for analysis.

V.2.4. Wood mulch sampling and compositing

Representative wood mulch samples were collected from all three runs. One sample each was collected from the left and right piles during Run 1 set up on July 29, 2011. No samples were taken during the removal of Run 1 pile on November 16, 2011. In Run 2, three samples, one each from the left, right and far piles, were taken during pile set up on November 17, 2011. However, since left and right piles were made of Grind 2 material they were equally composited to make a single LR composite sample for analysis. Three replicate samples from each pile were taken during the removal of Run 2 piles on May 18, 2012. During the set up of Run 3 on May 25, 2012, two replicate samples were taken from each pile. It is planned that additional replicate samples will be taken from Run 3 when those piles are removed.

The samples were collected according to the Test Methods for the Examination of Composting and Compost, which provides detailed protocols to verify the physical, chemical and biological characteristics of composting feedstocks (US Composting Council, 2010). Each pile was exposed in the middle using a front end loader. From an exposed face of a pile, samples were collected from three equidistant horizontal planes with the lowest and highest sampling planes being 1 foot from the ground and 1 foot from the top of the pile. A total volume of 20 gallons of sample was collected in the ratio of approximately 3:2:1 (bottom:middle:top), or 10 gallons from the bottom plane, 7 gallons from the middle plane and 3 gallons from the top plane. The collected material was well mixed before coning and quartering twice, and each time one randomly selected quarter was discarded. Out of the remaining 11 gallons of material, 2 gallons was transferred to two separate 1-gallon sealable plastic bags, which were taken to the laboratory for further analysis.

V.2.5. Analyses of wood mulch and leachate

V.2.5.1. Wood mulch

Out of the two one-gallon size samples, one was shipped overnight in a cooler to the Agricultural Analytical Services Laboratory in University Park, PA, for analysis of the chemical characteristics of the samples. The parameters analyzed were pH, carbon to nitrogen ratio, conductivity, moisture, organic matter, carbon, total nitrogen, organic nitrogen, ammonium, phosphorus, potassium, calcium, magnesium, sulfur, sodium, aluminum, iron, manganese, copper, zinc and lead. The other sample was used to determine the initial moisture content using the methods set forth in the ASAE standards for moisture measurement of forage (ASAE, 1992).

A one-way analysis of variance was carried out for the samples from Run 2 to see if there were significant differences among the materials tested, which included two different grinds and samples when setting up the piles and when removing the piles. A post-hoc Tukey's analysis (SAS 9.3) was carried out to determine which sample means were statistically different ($p<0.05$) from each other.

V.2.5.2. Leachate

Leachate samples were analyzed in the laboratory for pH, biochemical oxygen demand (BOD), chemical oxygen demand (COD), color, total suspended solids (TSS), total Kjeldahl nitrogen (TKN), total phosphate-phosphorus (TP), fecal coliforms, and tannin/lignin/phenolic (T/L/P) compounds.

COD and T/L/P were carried out using a HACH kit (Hach Company, Loveland, CO), followed by spectrophotometric measurements (Spectronic® 20 Genesys™ for COD and Hach DR/850 for T/L/P). The remaining tests were conducted according to the Standard Methods for the Examination of Water and Wastewater (Clesceri et al., 1998). Method 5210 was followed for the BOD test and Method 2540 D for TSS. For TSS determination, at least 50 mL of sample was vacuum filtered in most cases and a smaller volume was used only if the filtration took more than 10 minutes. Spectrophotometric Method 2120 was used for color determination. The samples were vacuum filtered through 47 mm diameter glass microfiber filters (Whatman™, GE Healthcare UK limited, Buckinghamshire, UK). A laser spectrophotometer (Aquamate, Thermo Scientific, USA) was used to measure the transmittance values at 30 different wavelengths to calculate and determine dominant wavelength, luminance (%), purity (%) and hue at the original pH of the samples.

Method 4500-NH_3 D was used to measure ammonia using an ammonia gas sensing electrode (Cat. # 27502-00, Cole-Parmer, Vernon Hills, IL). Method 4500-N_{org} C without the distillation step followed by Method 4500-NH_3 D for ammonia measurement were used for determining TKN. For total phosphate-phosphorus measurement, Method 4500-P B (digestion) followed by Method 4500-P E (ascorbic acid colorimetric determination) was used. For fecal coliforms, multiple tube fermentation most probable number (MPN) Method 9221 B (presumptive phase) followed by Method 9221 E (confirmed phase) was carried out. The MPN was estimated using the tables of Meynell and Meynell (1970) where the index for the combinations of positive results was available**,** or else the table from Standard Methods (Clesceri et al., 1998) was used. All analyses other than color were performed in triplicate.

Selected samples were sent to a certified commercial laboratory (Garden State Laboratories, Inc., Hillside, NJ) for selected elements (arsenic, chromium, copper, lead, and zinc), polynuclear aromatic hydrocarbons (PAHs), pentachlorophenol (PCP), and nitrate analyses. Samples for metals analysis were collected in plastic containers and samples for PCP and PAH analyses were collected in glass containers. These samples were transported to the laboratory in a cooler within 24 hr of collection.

In addition, on selected samples, dose-response studies using zebrafish (*Danio rerio*) embryos were carried out. All dose-response studies were conducted under the guidance of Prof. Keith Cooper in the Department of Microbiology and Biochemistry at Rutgers University. Standard operating procedures for zebrafish embryo larval assays developed by Dr. Keith Cooper were followed in carrying out these studies (Cooper, 2009).

V.2.6. Statistical analysis

One-way analysis of variance (ANOVA) was conducted using Excel 2007 (Microsoft Office 2007). SAS 9.3 (SAS Institute Inc. Cary, NC) was used for carrying out two-way ANOVA. A post-hoc Tukey-Kramer test was done determine the means which are significantly different from the other. Simple and multiple regression analysis were carried out using Excel 2007.

V.3. Results and discussion

V.3.1. Precipitation intensities and leachate volumes

Tables V.1 and V.2 show the leachate quantities generated from each pile for Runs 2 and 3. These tables also show the maximum rain intensity for each rain event over 10-minute, 1-hour and 2-hour periods. The last columns in these two tables show how long it had been since the previous rain event stopped or since the leachate produced by the previous rain event had stopped. Figures V.4a and V.4b. show the cumulative rain depth and cumulative leachate volumes plotted against time for Runs 2 and 3. As seen in the figures, leachate collection equipment failure for Far pile in Run 2 underestimated leachate generation compared to the other two piles. Otherwise, leachate generation from all the piles in both runs show similar patterns.

V.3.2. Characterization of wood mulch

Results of the analysis of wood mulch samples collected for Runs 1, 2 and 3 when setting up the piles are shown in Table V.3. Results from Run 2 during the removal of the piles are shown in Table V.4. This table will include the results from Run 3 wood mulch samples when the piles are removed. A 2-way ANOVA done on Run 2 samples showed that among the 21 parameters tested, only sodium and sulfur concentrations and conductivity significantly differed based on the interaction between time and grind. Because of the 5% chance of finding a significant difference even when there is only random variation (at 95% significance level), the “significant” difference observed for 3 out of 21 tests (14%) based on interaction between grind and time can probably be neglected.

V.3.3. Pile dimensions

Measurements of pile dimensions are shown in (Appendix I.1 to I.12). Tables a, b, and c for each set of measurements indicate vertical distance from pile surface at that position to reference height in meters, the pile height, and the volume calculations based on the average height within each 4’ by 4’ grid square. Table V.5 is a summary table of volumes calculated for each pile on four different dates and shows the bulk density for Run 3 piles calculated from mass of the piles determined by weighing the trucks when setting up the piles and the volume from the date that is closest to the piles set up date. The calculated bulk densities are compared to the average values of laboratory determined bulk densities for Grinds 1 and 2.

The one measurement done for Run 2 is a week before the piles were removed, which can be assumed to be the final pile measurements. Lack of previous measurements for Run 2 prevents calculation of the change in pile size with time. However, the measurements on May 10, 2012, shows that the right pile is smaller compared to the other two. Data from Run 3 shows that there seems to be a decrease in pile size in the left pile, whereas the change is not very pronounced in the right and far piles. The data also shows that the Grind 1 pile (left) had decreased more in volume compared to the Grind 2 piles (right and far). The decrease in pile size could be due to compaction and biodegradation of organic material. The greater decrease in left pile size did not appear to be associated with any difference in temperature elevation among piles, but no formal analysis was done.

V.3.4. Temperature, moisture and oxygen levels

V.3.4.1.Temperature levels

Temperature data was collected every 10 min. For plotting convenience, the 16 probes (see Figure V.3 for location) were divided into base probes (1 to 7) and upper level probes (8 to 16). Temperature graphs plotted against time for Runs 1, 2 and 3 are shown in Figures V.5a, V.5b and V.5c. Data from malfunctioning probes was omitted.

Table V.6 shows the minimum (after day 1, to avoid start up period) and maximum temperature values for each pile in a run and the probe that achieved this value. Maximum values in 5 of the 8 cases were observed in probes located at the center of the piles at 3- (#8), 5- (#14) and 7- (#16) foot heights. This could be due to more metabolic heat being released due to more microbiological activity at the center of the pile, but more likely reflects less loss of heat to the surroundings. Aerobic decomposition is faster and produces 20 times more heat than in anaerobic decomposition (Evans, 1973). As observed from high ambient oxygen values seen in these piles (see below), it can be concluded that the major decomposition processes occurring are aerobic. Samis et al. (1999) observed that biological oxidation can raise the temperature within a wood residue pile or landfill to $60^{o}C$ to $85^{o}C$.

The temperatures in Runs 1, 2 and 3 show the same overall pattern. Temperatures at the base probes (1-7) were mostly lower than the upper probes. Temperatures near the outside were lower than those further inside, except for probe 4 in Run 1. Low temperatures for probe 7, which is located at the edge of the pile, likely reflect exposure to outside weather and loss of heat generated in the pile. Among the top probes (probes 8 to 16), probes 10, 11 and 16 showed lower temperatures compared to other probes.

Probes 10 and 11 are located close to the pile edge where heat loss is expected to be more. Low temperatures in probe 16 could be due to its shallow location on top of the pile.

V.3.4.2 Moisture analysis

Figures V.6a and V.6b. show the moisture probe readings for Runs 2 and 3. In most cases, probes located at the edge of the pile (probe #s 1, 7, 10, 11, 13, 15) showed larger fluctuations in readings because of greater wetting and drying soon after a rain event. The inner probes showed more constant values. Also, Run 2 readings were mostly during winter months when there were fewer or smaller precipitation events. Run 3 had higher moisture concentrations and more fluctuations were observed during warmer months, probably due to more intense precipitation events and also higher evaporation.

V.3.4.3. Oxygen levels

Figure V.7 shows the oxygen levels in the piles for Runs 2 and 3. In general, oxygen concentrations remained high. However, measurements at 3 feet and 5 feet insertion depths at all the different heights showed lower oxygen concentrations compared to 1 feet depth. Among the different heights, 1 and 3 foot heights had lower oxygen concentrations compared to 5 and 7 foot heights. From Table V.7 the median oxygen concentrations in Run 2 were much less at the end of the run compared to the median concentrations in Run 3 at the end. In Run 3, the minimum oxygen concentrations increased gradually for all three piles indicating decreased rates of microbial activity with time.

V.3.5. Leachate characterization

V.3.5.1. Physical, chemical, and microbiological characterization of leachate

The concentrations of the parameters tested for Run 1 samples (Table V.8) were low to moderate, perhaps because there was a two month time lapse between setting up of the piles and collection of the first sample. The pH range was within the New Jersey surface water quality criteria, while the TSS, BOD, TKN and TP concentrations were comparable to or lower than urban stormwater runoff concentrations. Moderately high

COD values two months after setting up of the piles indicate the presence of recalcitrant organic compounds or continuing release of slowly degradable organics.

Runs 2 and 3 were more extensive and the complete results of the physico-chemical analyses are shown in Appendix J.1 and J.2. Table V.9 gives the ranges and medians for the 6 piles.

The pH values ranged from 5.3 to 7.0 with median values ranging from 6.4 to 6.5 among the six piles. This result is consistent with literature values (Hedmark and Scholz, 2008), where it was reported that one of the main problems with wood leachate is acidic pH. The main components in wood causing acidic pH are the volatile fatty acids (VFAs) present in the decomposing wood. In both runs, more acidic pH values were observed in the earlier rain events, although no formal analysis was done to confirm this observation.

The BOD_5 values ranged from <20 mg/L to 420 mg/L, with median values ranging from 50 to 66 mg/L. In Run 2, for the first three rain events in which the BOD_5 test was done, the concentrations were much higher in the left pile compared to the other two piles. The BOD ranges in both runs fall in the range of urban stormwater runoff concentrations and are below or within the lower end of the range for domestic wastewater influent (DWWI) values.

The COD concentrations ranged from 119 to 4376 mg/L with median values ranging from 414 to 543 mg/L among the six piles. The median COD concentration ranges in both runs fall in the ranges of urban stormwater runoff and typical DWWI values. The low BOD/COD ratio indicates the presence of less readily biodegradable organic compounds. The extremely high concentration of 4376 mg/L observed on 11/23/11 in Run 2 is abnormal for a rain event of that size. A very high concentration is seen with other parameters also for this particular rain event. The 11/23/11 sample is for the second rain event after the piles were set up on 11/18/11. Since the 11/23/11 rain event happened to be a much larger (57 mm) compared to the first one (3 mm), the leachate samples could have been contaminated with materials left from activities carried out during setting up of the piles including front end loader and manual operations.

The TSS median values ranged between 17 and 21 mg/L among the six piles, with maximum values of 128 mg/L and 89 mg/L in Run 2 and Run 3, respectively. The median TSS values in both runs are well below the typical DWWI values, but are comparable to the New Jersey surface water quality criteria. The T/L/P median concentration was 20 mg/L with maximum values of 105 mg/L and 55 mg/L in Runs 2 and 3, respectively.

As for nutrients, the TKN median concentrations were between 3.1 and 3.8 mg/L among the six piles with maximum values of 56 and 12 mg/L in Runs 2 and 3, respectively. The median TKN values are lower than DWWI values but fell in the range of urban stormwater runoff values. Ammonia-nitrogen median concentrations were between 0.1 to 0.56 mg/L with maximum values of 9.3 mg/L and 2.5 mg/L in Runs 2 and 3, respectively. The median ammonia values in both runs are well below the DWWI values but fell in the range of urban stormwater runoff. Ammonium/TKN ratio average values were between 0.09 and 0.16 among the six piles with maximum values of 0.66 and 0.49 in Runs 2 and 3, respectively. The low values of ammonium/TKN ratio indicate that most of the nitrogen is present in organic form. Nitrate-N concentrations determined in leachate samples from four rain events in Run 3 have a median value of 0.9 mg/L among the three piles with a maximum value of 3.29 mg/L (but this sample exceeded holding times) and a minimum value of <0.2 mg/L. The nitrate values are in the range of urban stormwater runoff values and slightly higher than DWWI concentrations.

TP median concentrations ranged from 2.2 to 3.5 mg/L among the six piles with maximum concentrations of 10.7 mg/L and 9.02 mg/L in Runs 2 and 3, respectively. Median TP concentrations in both runs are just below the DWWI range but higher than the urban stormwater runoff range.

Fecal coliforms were below the detection limit in all the samples tested.

Results for color analysis done on Runs 2 and 3 samples are shown in Tables V.10 and V.11. In the color analysis, the average dominant wavelength ranged from 574 to 577. The dominant wavelength designates the hue of the sample, i.e., red, green or yellow. The hue of the samples across both runs ranged from greenish yellow to yellowish orange. The saturation of a sample (e.g., pale, pastel) is designated by purity. Percent purity averaged between 22 and 32% with maximum values of 70% and 72% for Runs 2 and 3, respectively. The degree of brightness of the samples is designated by % luminance. Luminance average values ranged from 73.6 to 82.6% with maximum values of 98.3 and 91.0% for Runs 2 and 3, respectively.

On the whole, as seen from Figure V.8, concentrations of leachate from the experimental site are generally of the same order of magnitude as the concentrations found at the Class B facilities sampled (Section IV). However, TSS was higher at field sites, possibly from the suspension of solids caused by on-site activities, and Site C did show higher concentrations for several parameters.

V.3.5.2. Loads of COD, nitrogen, phosphorus, total suspended solids and tannins/lignins/phenols

Loads of COD, nitrogen, phosphorus, TSS and T/L/P were determined from each pile for both runs. The loads were determined by multiplying concentrations of these parameters by volume of leachate generated from these samples up to sampling time (Tables V.12 and V.13).

V.3.5.3. Statistical relationship of concentrations and loads with independent parameters

V.3.5.3.1. Simple linear regression

Simple linear regression analysis (Microsoft Excel 2010) was used to determine the relationships between dependent and independent variables. The independent variables considered were total rain (mm), total leachate (L), corrected pile leachate (L), age of pile (days), time since rain stopped (days), time since leachate stopped (days), and maximum rain intensity during 10-min, 1-hr, and 2-hr periods (mm). The 1-and 2-hr rain intensities were calculated by summing up the 10 minute rain depths over a-1 or 2-hour period for a particular rain event. The corrected pile leachate was calculated by taking into consideration the contribution from the open area of the pad that drains directly without passing through the mulch piles. The dependent variables considered were total leachate; corrected pile leachate; COD, TKN, and total phosphorus loads (g); and COD, TKN, and total phosphorus concentrations (mg/L). In addition, rain up to sampling and leachate up to sampling were used as independent variables in Run 2. This was necessary because for a few rain events samples were collected before the rain stopped completely or leaching stopped completely; this did not happen for Run 3. Simple regression analysis was carried out on individual piles (L, R, and F) for each run and also for all 3 piles combined for each run.

Appendices K.1 and K.2 show the results from the simple regression analysis of Runs 2 and 3. Table V.14 lists the independent parameters that the dependent variables had significant correlation with (column labeled "Ind.").

Total leachate and corrected pile leachate were positively correlated with total rain and rain intensity (10 min, 1 hr, 2 hr) in all six piles from Runs 2 and 3. As expected, the larger the rain event, the more leachate was generated. From the linear regression equations from Runs 2 and 3 it is expected that for any rain event bigger than 2.2 mm and 3.1 mm, respectively, leachate is generated from the piles of the size in this study (about 30 m^3 or 10 tonnes). This information may be useful to regulators and recyclers in designing best management practices based on the size of rain events. The Y-intercept of these equations indicates that 56 to 59 L of rain water is retained in these piles before any leachate is produced. However, this information has to be used with caution as other factors such as rain intensity, age of the pile and time since previous rain stopped might influence this value.

Total leachate generated and corrected pile leachate were positively correlated with time since rain stopped and time since leachate stopped in Run 3, but negatively correlated in Run 2. The negative correlations for Run 2 might be expected as with a longer time gap between rain events, the pile presumably would dry out more, and it would then take more rain to saturate it before it produced leachate. The positive correlation observed from Run 3, however, is not expected by this reasoning. Perhaps the drying in Run 3 led to formation of a crust on the pile that increased shedding, rather than infiltration, of water, or perhaps it was a function of some other co-correlated variable. It should also be noted that although statistically significant, the coefficients of determination (R^2) were very low (0.067 and 0.063 for time since rain stopped and 0.062 and 0.055 for time since leachate stopped). R^2 denotes the total amount of variation in the dependent variable (total leachate or corrected pile leachate) that is explained by the variation in the independent variable (time since rain stopped or time since leachate stopped).

Total leachate and corrected pile leachate generation did not show correlation with age of the pile. Thus any expected effect of decrease in volume or increase in density of the piles with time did not have any observed effect on leachate generation.

COD, TKN and TP loads showed significant positive correlations with total rain. Part of this is just that the increased volume brings more mass with it. However, during a bigger rain event, the leachate generated passes through a greater depth of material, thereby dissolving more from the piles. During smaller rain events, the rain water completely infiltrates only the shallow outer portions of the piles, accumulating less material from the piles along this shorter travel path and contact time, resulting in lower loads.

COD loads and TP loads showed significant positive correlation with leachate generation. TKN load showed significant positive correlation with leachate generation in Run 3 but no correlation in Run 2. COD, TKN and TP loads in Run 3 and TP loads in Run 2 showed significant positive correlation with 10 min, 1 hr, and 2 hr rain intensities. In Run 2, TKN loads had no correlation with 10 min, 1 hr and 2 hr rain intensities. COD load was positively correlated with 1 hr and 2 hr rain intensities but not with 10 min intensity. COD, TKN and TP loads in Run 3 and COD and TP loads in Run 2 showed positive correlation with corrected pile leachate. COD, TKN, and TP loads showed no correlation with age of the piles, time since rain stopped, or time since leachate stopped.

COD, TKN and TP concentrations showed significant correlations with the independent variables in only 7 out of 48 cases, and these were different in Runs 2 and 3 (Appendix K).

Overall, simple regression analysis showed that COD, TKN and TP loads but not their concentrations, were significantly correlated with total rain, leachate volume, and rain intensity. If the constituents had been depleted over time by biodegradation or washout, it might be expected that concentrations would be inversely correlated with some of the independent parameters. The absence of correlation observed in this study between COD, TKN and TP loads with age of the pile is in agreement with the study conducted by Tao et al. (2005). In their characterization of leachate from a wood waste pile in Canada, no change was observed in the leachate quality in the first two years, which they called the placement period.

V.3.5.3.2. Multiple Regression Analysis

Using the correlations found significant in simple regression analysis, predictive models for total leachate and for COD, TKN, and TP loads were developed. Forward and backward stepwise multiple regression analysis was performed with Run 2 and 3 data (Appendices L.1 and L.2). The stepwise regression involved testing the significance of these four dependent variables against four independent variables, rain fall, age of the pile, 2-hour rain intensity, and time since rain stopped. Although the dependent variables were found not to be significantly correlated with age of the pile and time since rain stopped in the simple regression analysis, they were used in the multiple regression to see if they would become significant when the influence of more significant variables (such as rain and 2 hr rain intensity) was accounted for.

In the forward stepwise regression, for each dependent variable the first step involved testing the significance of rain as the independent variable, as in most cases rain was found (by simple regression) to have the strongest relationship. (If correlation with another independent variable was found to be stronger than with rain, the following procedure was also repeated by starting with that variable first). In the next step, significance ($p<0.05$) of each of the other three independent variables when separately included in the regression with the first variable was tested. The variable with the lowest significant ($p<0.05$) p-value was added to the regression, and those two then tested again with the third and fourth independent variables added separately. If either of those two variables was found to be significant, it was added, and then a last regression was tested with the fourth variable added. The final regression model was developed by choosing the regression equation in which the dependent variable was significantly related to the most independent variables.

The backward stepwise regression analysis involved running the regression analysis with all four independent variables included as a first step. If one or more of the independent variables did not satisfy the significance criterion ($p<0.05$), the one that was least significant was removed and process repeated with the three remaining variables. This continued until an equation with the maximum number of independent variables with significant relationship to the dependent variable was reached. These variables were used to develop the predictor model for each dependent variable.

Appendices L.1 and L.2 show the correlations obtained from stepwise multiple regression analysis of different dependent variables with independent variables for each pile across both runs. It also lists the coefficient of multiple determination (R^2), the adjusted coefficient of multiple determination (R_a^2), p-values, and the direction of slope. In multiple regression analysis, since adding more independent variables to the regression model always increases R^2, a modified measure is usually used that adjusts for the number of independent variables in the model. The adjusted coefficient of multiple determination (R_a^2), adjusts R^2 by dividing each sum of squares by its associated degrees of freedom (Neter et al., 1996). The adjusted R^2 values can be negative and are always less than or equal to R^2.

Table V.14 shows the variables that the dependent variable was found to be significantly correlated with in the forward and backward regressions on Run 2 and 3 data. From the multiple regression analysis, total rain and 2 hr rain intensity were the significant factors identified in predicting COD, TKN and TP loads from wood mulch piles of the size used in this study. Total rain, age of the pile, 2 hr rain intensity and time since rain stopped all were factors identified in predicting leachate volume.

Table V.14 shows that in a majority of cases independent variables that showed significance for a dependent variable were the same across the piles within a run and also across the two runs. In most cases forward stepwise regression showed the same significant variables as backward stepwise regression. Given the nature of stepwise regression, and the likelihood that the “independent” variables show some covariance, it is not unexpected that there were a few differences in the results of forward and backward stepwise regression. For COD, TKN, and TP loads in the far pile for Run 2, there were too few degrees of freedom (n=5) for backward stepwise regression to be carried out. In a few cases, COD, TKN or TP loads were more strongly correlated to 2-hour rain intensity than to total rain. In these cases, forward stepwise regression was carried out using 2-hr rain intensity with other independent variables.

The full models developed from Run 3 stepwise regressions were:

1) Total leachate = 20.96 (R) + 0.878 (A) – 4.912 (I) + 10.217 (S) – 182.186

2) COD load = 6.516 (R) + 5.308 (I) – 63.285

3) TKN load = 0.0407 (R) + 0.0515 (I) – 0.199

4) TP load = 0.0443 (R) + 0.0422 (I) – 0.399

where R is total rain in mm, I is 2 hour rain intensity in mm, A is age of the pile in days since set up, S is time since rain stopped in days, loads are measured in grams, and total leachate is in liters.

For the sake of convenience and ease of application, models were also developed using only rain as the independent variable in predicting the four dependent variables.

1) Total leachate = 17.933 (R) - 55.795

2) COD load = 9.325 (R) - 54.566

3) TKN load = 0.068 (R) - 0.1146

4) TP load = 0.066 (R) - 0.33

Although stepwise regression is a convenient and a useful method to select the predictor variables in building a model, there has been some criticism about its accuracy. According to Whittingham et al. (2006), some of the drawbacks of stepwise regression analysis include bias in parameter estimation, inconsistencies among model selection algorithms, problems of multiple hypothesis testing, and an inappropriate focus or reliance on a single best model.

As a remedial measure, Mark and Goldberg (2001) suggested that instead of relying on a model's F-statistic, significance of p-value, or R^2, the model be assessed against a set of data that was not used to create the model (validation). In the present study this was done using the model derived from Run 3 data to predict Run 2 data. This was done following the Nash-Sutcliffe efficiency index methodology (Moriasi et al., 2007).

V.3.6. Nash-Sutcliffe Efficiency (NSE) Index

The NSE index is a goodness of fit measure that is widely used for hydrologic models. It "determines the relative magnitude of the residual variance compared to the measured data variance" (Moriasi et al., 2007).

Nash-Sutcliffe efficiency index, E_f,

$$E_f = 1 - \left[\frac{\sum_{i=1}^{n}\left(\hat{Y}_i - Y_i\right)^2}{\sum_{i=1}^{n}(Y_i - \bar{Y})^2}\right]$$

where $\hat{Y}_i$ and Y_i = predicted and measured values of the dependent variable Y, respectively; $\bar{Y}$ = mean of the measured values; n= sample size.

Although the NSE index is mostly used in hydrologic models, its flexibility as a goodness of fit statistic makes it applicable in a wide variety of model types (McCuen et al., 2006). NSE index values range between $-\infty$ to 1. "Values between 0.0 and 1 are considered as acceptable levels of performance and values ≤ 0 indicate that mean observed value is a better predictor than the simulated value, indicating unacceptable performance" (Moriasi et al., 2007).

Appendix M.1 shows the NSE index values obtained for Run 2 results using models developed from Run 3 for COD, TKN, and TP loads and leachate quantity. It includes the predictive efficiency of models developed using all the independent variables that were found to be significant from the multiple regression analysis, as well as the efficiency of models using only total rain as the independent variable. The NSE index is shown with and without an outlier data point in Run 2; on November 23, 2011, the concentrations of COD, TKN and TP were abnormally high. As seen, removing this data point makes a substantial difference in the NSE index for the COD, TKN and TP load model predictions. As mentioned earlier, the November 23, 2011, sample is for the second rain event after the piles were set up (on November 18), and since this happened to be a much larger rain event (57 mm) compared to the first small one (3 mm), perhaps the leachate samples were contaminated with material left from activities carried out (loading and unloading using front end loader, manual operations involving soil) in setting up the piles.

The NSE analysis shows that models developed from Run 3 are reasonably good at predicting COD, TKN, and TP loads for Run 2 after removing the outlier. The models from Run 3 data were even better at predicting total leachate volume compared to the loads. The NSE indexes are good both when multiple factors are used in prediction and also when only rain is used as the predictor variable. In fact, model prediction is better for COD and TKN loads when only rain is used as a predictor variable. For TP load and total leachate volume, addition of other predictor variables to rain made no appreciable difference. This observation has a practical relevance since it indicates that rain data, which is more easily available, can be used to predict COD, TKN, and TP loads and total leachate volume from a wood mulch pile of this size.

Appendix M.2 also shows the NSE index for model prediction among piles for a specific run. This is done using a model developed from a specific pile to predict values for the other two piles in that same run. When the outlier was removed, models from the Left pile (Grind 2) in Run 2 were reasonably good at predicting COD, TKN, TP loads and leachate volumes for Right (Grind 2) and Far (Grind 1) piles.

Similarly, in Run 3, predictive models developed from the Far pile (Grind 2) were used to predict loads and leachate volume for the Left (Grind 1) and Right (Grind 2) piles. As seen in Appendix M.3, the models typically gave good predictions. Although the Left pile is of a different grind, the model better predicted Left pile COD, TKN, and TP loads, whereas it slightly better predicted Right pile (same grind) leachate volume. This reiterates the observation that grind of the material does not appear to substantially influence the nutrient loads or volume leaching out.

The good NSE index seen in prediction among piles within a run gives more confidence when a model developed from all piles combined in one run is used to predict values from all piles combined in another run.

V.3.6. Metals, PAHs and PCP results

Since 1970, considerable amounts of wood have been treated with chromate, copper, and arsenate (CCA). CCA is most commonly used in the form of Type C formulation, 47.5% CrO_3, 18.5% CuO, and 34% AS_2O_5 (Tao, 2012). Creosote, used commercially as a wood preservative, is mainly composed (85%) of polynuclear aromatic hydrocarbons (PAHs). Pentachlorophenol (PCP) was another commonly used wood preservative. USEPA has classified PCP as a Group B2, probable human carcinogen. Table V.15 shows that PAHs and PCP were not detected in the samples tested. Metal concentrations were all low.

V.3.7. Ecotoxicity of leachate

Detailed results of dose-response studies done on samples from Runs 2 and 3 are shown in Appendices N.1 and N.2. Table V.16 shows a summary of dose-response studies showing concentrations tested and LC_{10} and EC_{10} values. As seen from Tables N.1 and N.2, the concentrations causing mortality in 10% of the population were greater than the highest concentration tested in most cases. Abnormal spine curvature was observed in some of the embryos. However, as seen from appendices N.1 and N.2 the concentration causing this defect in 10% of the population is higher than the concentrations tested in most cases. Because of the low toxicity, it was not possible to calculate the concentration that caused a one stage delay in development.

Over all, the dose-response studies have shown that the leachate caused no substantial mortality or developmental effects in zebrafish embryos. However, any ecological effects of the low mortality and developmental defects or delay were not explored.

V.4. Conclusions

Leachate from wood mulch stockpiles is a potential source of organic matter contamination and low levels of nutrients to receiving waterbodies. Best management practices must take into account the volume of the material being stockpiled, proximity and size of the receiving water, and length of stockpiling. Although acute toxicity was found to be low, leachate from wood mulch stockpiles should not be released directly into surface water as the BOD_5 and COD values are comparable to or a little lower than raw sewage values and nutrient values were usually a little lower than the raw sewage range. However, considering that the maximum values for BOD_5, COD, nitrogen, and phosphorus observed were 420, 4400, 56, and 11 mg/L, respectively, and that moderate concentrations continued to be released over many months, it is recommended that the leachate be treated in infiltration ponds, aeration basins, or by other appropriate techniques before release to the surface water. A simple regression model was useful in predicting contaminant loads from the experimental stockpiles based on rainfall.

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Table V.1. Rain and leachate information for Run 2

Date	Rain (mm)	Total Leachate (L)			Intensity (mm)			TSRS[#]	TSLS[##](days)		
		L	R	F	10 min	1 hr	2 hr	days	L	R	F
11/21/11	3.0	21.8	20.8	na	0.5	1.8	2.3	na	na	na	na
11/23/11	57.0	1161.0	na	na	2.5	8.4	13.2	0.6	1.1	na	1.02
11/30/11	14.0	214.2	324.2	na	1.3	3.0	4.8	5.8	6	na	5.9
12/7/11	9.9	148.8	232.4	na	0.5	2.0	3.3	6.8	6.3	6.5	7.2
12/8/11	55.0	1418.4	987.4	na	3.3	15.7	21.3	0.0	0.01	0	0.7
12/20/11	9.4	61.0	13.0	119.0	5.1	5.3	5.3	12.5	na	12.1	12.1
12/23/11	40.0	1210.8	1535.0	957.0	2.8	9.7	18.6	0.8	na	1.3	0.8
12/29/11	20.6	550.8	726.8	449.0	3.0	5.8	10.6	4.3	4.1	3.3	3.2
1/13/12	38.0	1060.0	1034.4	755.0	3.1	13.5	15.5	15.0	14.5	14.5	14.5
1/18/12	8.9	212.0	na	190.0	0.8	3.1	4.6	4.6	3.9	na	4.7
1/25/12	12.4	347.6	475.0	357.4	0.8	2.3	3.8	5.3	4.4	4.4	4.8
1/30/12	13.7	339.0	152.0	268.0	2.3	4.3	8.6	3.0	2.3	1.4	2.4
2/11/12	4.3	34.0	62.0	41.0	0.8	2.3	3.1	14.9	14.7	15	14.6
2/16/12	3.6	45.0	50.0	44.0	0.5	2.1	2.3	4.8	4.7	4.6	4.6
2/27/12	6.6	78.6	128.2	77.0	0.8	2.8	3.3	7.3	7.3	7.1	7.3
3/24/12	4.0	48.0	78.0	44.0	1.0	3.8	4	28.9	29	29	29
3/31/12	7.4	153.0	200.0	112.0	1.3	3.3	5.4	6.1	6.1	6.1	6.1
4/1/12	5.1	74.0	101.0	65.0	0.8	2.0	2.5	1.4	1.3	1.3	1.3
4/21/12	3.8	38.0	63.0	46.0	0.8	3.6	3.8	19.8	19.7	19.7	19.6
4/24/12	51.0	1559.0	1684.0	1244.0	2.04	9.7	16.5	0.4	0.4	0.4	0.4

#TSRS: Time since rain stopped.
TSLS: Time since leachate stopped.
na: Not available because of equipment malfunction (or because first storm for TSRS and TSLS).
Dates in italics are rain events for which no leachate samples were analyzed.

Table V.2. Rain and leachate information for Run 3

Date	Rain (mm)	Total Leachate (L)			Rain Intensity (mm)			TSRS#	TSLS## (days)		
		L	R	F	10	1 hr	2 hr	days	L	R	F
5/30/12	18.3	252.6	168.8	312.4	6.3	10.2	10.1	na	na	na	na
6/5/12	20.0	232.2	275.0	250.2	2.8	9.1	9.9	5.4	5.4	5.4	5.4
6/14/12	13.7	133.6	112.0	145.6	1.0	3.6	6.3	8.3	8.7	8.4	8.9
6/24/12	22.6	305.2	na	419.2	6.3	15.2	17.0	9.7	9.4	na	9.8
7/5/12	7.6	na	145.0	164.0	5.0	7.11	7.3	12.1	11.8	na	11.8
7/17/12	19.3	231.0	na	342.0	11.9	15.8	17.5	10.8	16.9	na	10.8
7/24/12	36.3	285.0	658.0	260.0	7.4	23.6	36.0	2.7	2.3	NA	2.6
8/1/12	44.3	654.0	649.2	860.0	7.6	11.9	17.3	6.3	7.7	7.9	NA
8/6/12	28.2	620.2	611.4	788.8	4.8	10.7	11.7	3.3	3.2	3.2	NA
8/13/12	28.2	381.2	511.2	250.0	13.2	28.0	28.0	4.3	4.0	4.1	4.2
8/14/12	5.1	42.0	39.0	42.0	1.0	3.6	5.1	3.9	3.9	3.7	4.0
8/21/12	11.9	141.4	160.8	111.8	2.8	3.8	4.8	3.5	3.4	3.4	3.4
8/27/12	9.7	117.0	178.0	na	5.1	9.2	9.2	9.1	9.1	9.1	9.1
8/28/12	13.7	137.2	230.0	150.0	1.0	3.1	4.0	0.6	0.8	0.6	0.8
9/6/12	51.6	920.0	1045.0	702.0	5.1	18.5	19.6	6.2	6.7	6.2	6.6
9/11/12	5.8	46.4	57.8	35.0	0.8	2.6	3.6	2.7	3.1	3.0	NA
9/20/12	32.8	660.0	594.6	780.2	6.9	20.6	24.9	9.2	9.3	9.2	NA
9/22/12	23.6	326.0	240.0	348.0	14.2	21.3	23.4	3.7	3.7	3.7	3.6
9/27/12	4.6	25.0	29.0	38.0	1.0	2.7	2.7	4.1	4.1	3.9	3.8
10/1/12	10.6	184.0	109.0	181.0	3.3	5.8	5.8	1.4	1.4	1.5	1.4
10/2/12	4.1	13.0	25.0	27.0	1.1	2.6	3.1	3.4	3.4	3.5	3.2
10/7/12	4.6	14.0	29.0	21.0	0.7	1.3	2.5	4.6	5.2	4.9	5.1
10/9/12	3.3	11.0	18.0	13.0	0.5	1.0	1.2	1.4	2.2	1.4	2.0
10/15/12	5.3	50.0	66.0	75.0	2.8	3.0	5.3	5.5	5.4	5.5	5.6
10/19/12	27.7	402.0	746.0	587.0	4.8	16.5	27.7	3.7	3.6	3.7	3.6

#TSRS: Time since rain stopped.
TSLS: Time since leachate stopped.
na: Not available because of equipment malfunction (or because first storm for TSRS and TSLS).
Dates in italics are the rain events for which no leachate samples were analyzed.

Table V.3. Wood mulch sample analyses results from Runs 1, 2 and 3 during setting up of the piles**

Parameter	Run 1		Run 2		Run 3					
Sample ID	L	R	LR	F	L #1	L #2	R #1	R #2	F #1	F #2
Date	7/29/11	7/29/11	11/7/11	11/7/11	5/25/12	5/25/12	5/25/12	5/25/12	5/25/12	5/25/12
pH	6.6	6.6	4.8	5.9	6.5	6.6	6.5	6.4	6.4	6.4
C:N ratio	56	44	44	46	52	55	53	55	52	47
Cond.(ms/cm)	0.4	0.4	2	0.9	0.6	0.5	0.7	0.7	0.7	0.6
Moisture (%)	23	28	58	51	40	35	33	32	32	35
Moisture*(%)	24	26	48	40	37	37	33	33	34	34
Org.matter(%)	83	88	79	62	77	69	79	85	83	82
C (g/kg)	442	399	344	314	380	307	330	342	349	339
Total N	7900	9100	7700	6900	7300	5600	6300	6200	6700	7200
Org. N	7900	9100	7600	6900	7300	5600	6300	6100	6600	7200
NH_4^+-N	16	22	132	0	21	25	22	35	33	38
P	371	437	594	712	956	812	511	677	799	686
K	2167	2083	1917	3417	3500	3083	2667	2833	2917	3083
Ca	5400	5700	19700	14800	10300	9900	5600	7400	9000	7700
Mg	1000	900	3300	4200	2700	2600	900	1400	1900	1400
S	400	400	1000	700	700	700	400	500	600	500
Na	132	71	111	1680	149	180	125	113	130	123
Al	592	492	2005	6904	2702	3641	3411	1704	2052	1699
Fe	948	827	3592	10113	6144	7763	1894	3795	4072	3184
Mn	76	89	183	201	169	166	83	121	118	110
Cu	6	7	25	41	21	32	91	14	27	20
Zn	35	44	73	88	92	74	76	64	62	56
Pb	5	7	16	32	40	39	23	26	28	23

** Results are reported on a dry weight basis; except for pH, parameters are in mg/kg unless noted.
*Moisture content measured in the laboratory at Rutgers University immediately after collection.

Table V.4.Wood mulch sample analyses results from Run 2 collected during removal of piles**

Parameter	Run 2								
Sample ID	L#1	L #2	L#3	R#1	R#2	R#3	F#1	F#2	F#3
Date	5/18/12	5/18/12	5/18/12	5/23/12	5/23/12	5/23/12	5/18/12	5/18/12	5/18/12
pH	7.4	7.5	7.8	7.5	6.8	7.5	7.5	6.1	7.4
C:N ratio	30.8	40.1	37.7	41.7	49.5	55.8	31.5	31.9	23.1
Cond.(ms/cm)	0.6	1.1	1.0	0.6	1.0	0.7	1.0	1.2	0.6
Moisture(%)	56.9	0.6	51.7	64.3	0.3	62.3	47.3	0.4	39.2
Moisture*(%)	57	0	0	57.1	0	0	50.4	0	0
Org.matter(%)	54.9	88.5	64.7	75.6	87	73.8	70.1	72.3	45.7
C (g/kg)	267	396	378	378	445	376	308	210	185
Total N	8700	9900	10000	9100	9000	6700	9800	6600	8000
Org. N	8700	9900	10000	9100	9000	6700	9800	6600	8000
NH_4^+-N	<5.1	7.9	<5	<5.0	<4.9	<4.9	<4.7	6	<5
P	873	541	830	624	550	803	886	878	1017
K	3417	2583	3000	2167	2417	2167	3667	3417	4833
Ca	10900	9200	15300	19300	15000	13800	13500	13800	12200
Mg	3200	2500	4100	6700	1900	4500	3200	4600	3600
S	800	600	800	700	500	800	1000	800	800
Na	260	287	186	151	132	112	227	325	224
Al	4376	2830	2814	2515	906	3776	2553	12604	5391
Fe	9101	24260	5295	4237	1907	7019	4736	9295	13959
Mn	166	178	197	162	131	224	189	193	237
Cu	36	65	36	30	12	33	27	238	54
Zn	89	74	96	72	52	102	98	163	106
Pb	203	12	21	21	10	24	18	43	39

* Moisture content measured in the laboratory at Rutgers University immediately after collection.

** Results are reported on a dry weight basis; except for pH, parameters are in mg/kg unless noted.

Table V.5. Pile volumes, mass and bulk density.

Run 2				
	Date	Left	Right	Far
Volume (m^3)	5/10/2012	29.65	21.04	27.18
Mass (kg)	11/17/2011	13853	14905	12583
Run 3				
Volume (m^3)*	6/8/2012	31.96	28.4	30.09
Mass (kg)	5/25/2012	11705	9398	9398
Bulk density (g/cm^3)		0.36	0.33	0.31
Volume (m^3)	8/28/2012	28.54	27.07	29.74
Volume (m^3)	2/15/2013	26.56	27.64	29.84
Laboratory Determined Bulk Density (g/cm^3)**				
Grind 1	0.22			
Grind 2	0.25			

* Volume measurements from day closest to set up (when mass measurements were made).

** Bulk density values determined in the laboratory using mulch collected from the piles.

Table V.6. Temperature (ºC) ranges summary table.*

Run 1			
	Left	Right	Far
Min	7.5 (#16)	12.1 (#10)	
Max	74 (#14)	74.3 (#16)	
Run 2			
Min	5.0 (#16)	6.6 (#13)	3.2 (#13)
Max	72.8(#14)	68.9 (#13)	78 (#13 & #15)
Run 3			
Min	12.3 (#16)	10.9 (#16)	21.6 (#1)
Max	85.6 (#8)	75.5 (#11)	69.7 (#14)

*Minimum value is for period after day 1 of each run. Probe # is given in parentheses.

Table V.7. Oxygen measurements summary table.

Run2									
	Left Pile			Right Pile			Far Pile		
Date	Median	Min.	Max.	Median	Min.	Max.	Median	Min.	Max.
5/18/12	6	4.1	13.2	16.7	12.7	18.4	7.2	3	12.7
Run 3									
6/1/12	15.5	5.3	20.5	19.1	12.6	20.9	13.5	2.6	20.7
8/21/12	15.6	11.4	20.6	17.9	11.7	20.9	17.9	9.2	20.9
11/14/12	19.9	16.7	20.6	19.6	15.8	21.4	18.6	13.9	19.1
1/30/13	19.8	18.6	20.6	17.9	16.6	20.4	19.6	17.4	20.3

Table V.8. Leachate analysis results for Run 1 (September - November 2011).

	Sample	pH	BOD (mg/L)	COD (mg/L)	TSS (mg/L)	TKN (mg/L)	TP (mg/L)	T/L/P (mg/L)	MPN/ 100 mL
9/9	Pad-L	7.2	130	ND	ND	ND	ND	ND	ND
10/17	Pad-L	6.91	63	350	37	2.1	<0.15	12	<1800
	Pad-R (1)*	6.7	<50	450	<2.5	2.0	<0.15	10	<1800
	Pad-R (26)#	7.1	<50	650	2	2.3	<0.15	30	<1800
	Pad-R (7)$	6.98	<50	276	11	1.3	<0.15	10	<1800

* ISCO sample bottle 1 only.
# Bottles 2 to 6 composited equally.
$ ISCO sample bottle 7 only.
ND = Not determined.

Table V.9. Summary of ranges and medians of values from physical and chemical analysis for the 6 piles in Runs 2 and 3.*

	This Study**			NJSWQC[1]	USWRO	DWWI[2]	GWQS[3]
	Min.	Max.	Median				
pH	5.3-5.8	6.9-7.0	6.46-6.57	6.8-8.5			6.5-8.5
TSS	3-8.3	37-128	17-21	25	630[4]	100-350	
BOD	<40	420	50-66		10-250[4]	110-400	
COD	119-247	633-4376	414-543		20-600[4]	250-1000	
TP	<0.01-1.1	3.2-10.7	2.2-3.5	0.1	0.2-1.7[5]	4-15	
TKN	0.1-1.6	5.4-56.2	3.1-3.8		3-10[4]	20-85	
NH_4^+-N	0.02-0.05	0.26-9.3	0.1-0.56		0.1-2.5[6]	12-50	3
T/L/P	5-12.5	25-104.8	20				
NO_3^--N	<0.2	3.29#	0.9		0.01-1.5[4]	0-1	10

*Except pH, parameters are in mg/L.
** Values are minimum, maximum and median concentrations among six piles from Run 2 and Run 3.
Note: The range of 5.3-5.8 for minimum pH indicates that among the 6 piles, the lowest minimum was 5.3 and the highest minimum was 5.8.
#Sample exceeded holding time.
[1]New Jersey Surface Water Quality Criteria: N.J.A.C. 7:9 B (NJDEP, 2010c)
[2]Typical range of domestic wastewater influent (sewage) values, adapted from Tchobanoglous et al. (2003).
[3]Ground water quality standards class II A by constituent: NJDEP (2012) N.J.A.C 7:9 C.
[4]Novotny and Chesters (1981).
[5]USEPA (1999).
[6]Wanielista (1978).

Table V.10. Run 2 color results.

	Left Pad					Right Pad					Far Pad				
Date	Bottle#	DW	P(%)	Hue	L(%)	Bottle#	DW	P(%)	Hue	L(%)	Bottle#	DW	P(%)	Hue	L(%)
11/21/11	All*	575	25	Y	79	All	575	15	Y	86	All				98
11/23/11	1 -12	570	10	Y	89	1 - 3	570	5	Y	95					
	13-18	576	45	Y	63	4-9, 12-19	574	22	GY	79					
	19&20	575	40	Y	65	20-22	576	50	Y	57					
11/28/11	All	578	50	Y	47	All	578	70	Y	38					
11/30/11	All	575	18	Y	84	All	575	23	Y	83	All	575	14	Y	88
12/7/11	All	580	18	Y	86	All	572	25	GY	78	All	572	10	GY	88
12/8/11	All	576	35	Y	70	All	570	23	GY	83	All	575	35	Y	64
12/23/11	All	575	35	Y	75	All	577	27	Y	78					
12/29/11	All	580	25	Y	80	All	580	35	Y	75	All	575	38	Y	72
1/13/12	All	580	30	Y	82	All	581	25	YO	84					
1/18/12	All	578	23	Y	83	All	576	40	Y	70					
1/25/12	1 -7	569	14	GY	89	All	575	18	Y	84	1 -11	573	30	GY	74
	8 - 24	575	7	Y	91						12 - 24	575	7	Y	89
1/30/12	All	579	27	Y	82	All	575	25	Y	82	All	575	25	Y	82
2/27/12	All	570	30	GY	92	All	570	7	Y	93	All	570	5	Y	96
4/24/12	All	579	32	Y	76	All	576	30	Y	77	All	575	35	Y	74

* All: Analysis done on all bottles combined (flow-weighted composites).
DW: Dominant wavelength; P(%): Purity; L(%): Luminance.
GY: Greenish yellow; Y: Yellow; YO: Yellowish orange.
Blank cells indicate no sample available.

Table V.11. Run 3 color results

	Left Pad					Right Pad					Far Pad				
Date	Bottle#	DW	P(%)	Hue	L(%)	Bottle#	DW	P(%)	Hue	L(%)	Bottle#	DW	P(%)	Hue	L(%)
5/30/12	All	570	25	GY	85	All	570	25	GY	83	All	570	25	GY	87
6/5/12	All	580	15	Y	88	All	580	18	Y	79	All	580	18	Y	76
6/14/12	All	580	15	Y	89	All	580	15	Y	83	All	580	15	Y	87
6/24/12	All	580	15	Y	81	All	580	15	Y	77	All	580	15	Y	80
7/17/12	All	575	30	GY	74						All	575	30	GY	79
7/24/12	All	579	66	Y	42	All	576	56	Y	50	All	577	50	Y	55
8/1/12	All	577	30	Y	78	All	580	25	Y	79	All	575	25	Y	79
8/6/12	All	575	30	Y	77	All	570	20	GY	81	All	573	23	GY	78
8/13/12	All	580	35	Y	70	All	572	18	GY	86	All	575	30	Y	74
8/21/12	All	578	38	Y	65	All	579	35	Y	71	All	578	35	Y	68
8/28/12	All	575	10	Y	91	All	575	10	Y	90	All	580	10	Y	89
9/6/12	All	575	30	Y	76	All	582	22	YO	82	All	576	43	Y	69
9/11/12	All	577	30	Y	74	All	577	30	Y	69	All	580	30	Y	70
9/20/12	A**	575	18	Y	82	D	578	21	Y	87	X	581	25	YO	80
	B	578	43	Y	65	E	578	30	Y	80	Y	576	43	Y	66
	C	583	72	YO	43	F	578	65	Y	52	Z	577	58	Y	54
10/1/12	All	578	42	Y	70	All	576	35	Y	71	All	572	23	GY	82

* All: Analysis done on all bottles combined (flow-weighted composites).
DW: Dominant wavelength; P(%): Purity; L(%): Luminance.
GY: Greenish yellow; Y: Yellow; YO: Yellowish orange.
Blank cells indicate no sample available.
** A, B, and C are flow composited samples of bottles 1 to 9, 10 to 13 and 14 to 16, respectively, for left pile (see Appendix J.2).
D, E, and F are flow composited samples of bottles 1 to 9, 10 to 13 and 14 to 17, respectively, for right pile.
X, Y, and Z are flow composited samples of bottles 1 to 11, 12 to 15 and 16 to 19, respectively, for far pile.

Table V.12. Loads (g) of selected parameters from Run 2.*

	Pile	Leachate (L)	COD	TKN	TP	TSS	T/L/P
11/21/11	Left	21.8	6.3	0.047	0.044	0.35	0.44
	Right	20.8	7.4	0.034	0.04	0.29	0.31
11/23/11	Left	1161	5080	65	12.5	149	122
11/30/11	Left	214.2	244	1.8	0.88	14.6	5.4
	Right	323.4	187	2.3	1.32	11.6	4.9
12/7/11	Left	148.8	85	0.29	0.33	3.87	3.6
	Right	232.4	125	0.40	0.79	4.18	5.8
12/8/11	Left	1391.4	1128	4.6	4.17	98.8	56
	Right	968.4	459	3.0	3.3	98.8	17
12/23/11	Left	1197.8	826	3.4	2.75	45.5	34
	Right	1503	771	5.4	6.01	51.1	30
12/29/11	Left	550.8	322	2.6	1.2	16.5	12
	Right	726.8	473	2.8	2.18	18.9	18
	Far	449	284	1.3	1.45	16.6	14
1/13/12	Left	1060	569	0.10	1.59	19.1	21
	Right	1034	424	0.20	2.27	8.3	20.7
1/18/12	Left	212	114	0.97	0.3	22.3	4.6
1/25/12	Left	347.6	86	0.38	0.29	2.8	3.5
	Right	475	170	0.38	0.9	3.8	4.7
	Far	357.4	82	0.53	0.63	1.07	3.6
1/30/12	Left	339	163	1.6	0.6	4.4	5.1
	Right	152	63	0.73	0.31	1.52	2.3
	Far	268	102	1.4	0.66	3	4.0
2/27/12	Left	78.6	21	0.28	0.02	0.49	0.79
	Right	128.2	25	0.33	< 0.001	0.42	1.3
	Far	77	9.2	0.13	<0.001	0.4	0.38
4/24/12	Left	1559	806	3.6	0.98	32.7	33
	Right	1684	770	5.7	0.37	18.5	30
	Far	1244	601	2.4	3.5	27.4	26

*For concentrations below detection limits, load is calculated as flow times detection limit.

Table V.13. Loads (g) of selected parameters from Run 3.*

Date	Pile	Leachate (L)	COD	TKN	TP	TSS	T/L/P
5/30/12	Left	253	67	1.6	0.52	3.8	3.8
	Right	169	55	0.89	0.26	2.8	4.2
	Far	312	89	1.6	0.43	28	3.1
6/5/12	Left	232	72	1.3	0.73	7.4	4.6
	Right	269	156	1.6	1.34	15	12
	Far	247	153	1.1	0.91	18	14
6/14/12	Left	134	28	0.78	0.29	8.4	2.7
	Right	112	28	0.52	0.34	1.9	1.7
	Far	146	32	0.96	0.33	4.5	0.73
6/24/12	Left	305	85	0.49	1.09	5.2	6.1
	Far	419	143	0.9	1.51	10	8.4
7/17/12	Left	231	99	1.4	0.78	4.6	5.7
	Far	342	121	1.8	1.23	6.1	8.5
7/24/12	Left	285	337	2.5	2.19	8.5	11
	Right	658	773	7.6	5.93	18	21
	Far	260	209	1.9	2.01	7.0	5.9
8/1/12	Left	654	251	1.9	2.60	6.5	14
	Right	649	232	1.3	2.28	<1.3	16
	Far	860	301	2.4	3.30	11	19
8/6/12	Left	620	268	2.6	2.23	16	12
	Right	611	186	2.3	1.38	9.8	9.1
	Far	789	270	2.8	2.43	11	16
8/13/12	Left	381	214	1.2	1.63	5.2	9.5
	Right	511	113	0.56	0.67	5.3	7.7
	Far	250	95	0.40	0.87	2	4.5
8/21/12	Left	141	79	0.45	0.55	2.3	3.4
	Right	161	67	0.47	0.60	1.1	4.0
	Far	112	50	0.45	0.38	0.92	2.8
8/28/12	Left	137	25	0.37	0.12	1.4	1.4
	Right	230	48	0.52	0.13	4.6	3.5
	Far	150	36	0.37	0.17	3.9	3.0
9/6/12	Left	920	400	3.1	2.32	16	14
	Right	1045	342	2.5	1.67	12	13
	Far	702	410	2.6	2.17	8.4	12
9/11/12	Left	46	21	0.24	0.19	0.38	0.92
	Right	58	26	0.21	0.19	0.23	1.3
	Far	35	16	0.15	0.12	0.10	0.96

9/20/12	Left	595	359	4.0	2.40	16	14
	Right	661	267	2.3	1.50	19	12
	Far	780	507	3.7	3.10	21	21
10/1/12	Left	184	109	0.56	0.69	2.1	3.8
	Right	109	60	0.42	0.30	1.0	1.6
	Far	181	63	0.27	0.29	2.7	2.7

*For concentrations below detection limits, load is calculated as flow times detection limit.

Table V.14. Independent variables found significant (p<0.05) from simple and stepwise regression analysis of Run 2 and Run 3 data.

Loads (g)	Run 2												Run 3											
	All piles			Right Pile			Left Pile			Far Pile			All piles			Right Pile			Left Pile			Far Pile		
	Ind.	F	B	Ind.	F	B	Ind.	F	B	Ind.	F	B	Ind.	F	B	Ind.	F	B	Ind.	F	B	Ind.	F	B‡
COD	R	R	R	R	R		R	R	R	R	R		R	R	R	R	R		R	R	R	R	R	R
	I	I	I	I	I	I		I	I	I	I		I	I	I	I*	I*	I	I	I	I	I		
		A	A																	A	A			
TKN	R	R	R	R	R	R		R	R	R			R	R	R				R	R	R	R	R	R
		I	I	I	I			I	I	I*			I*	I	I	I*	I*	I*	I					
		A	A																					
				S	S	S				S*	S*													
TP	R	R	R		R		R	R	R	R	R		R	R	R	R	R		R	R	R	R	R	R
	I*	I	I	I*	I*	I		I	I	I			I	I	I	I*	I*	I	I			I		
		A	A		A	A		A	A		A													
										S														
Leachate (L)	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
	I			I	I		I	I	I	I			I	I	I	I			I	I	I	I		
			A					A	A						A						A			
	S						S						S		S									

R = Total rain (mm); I = 2 hr rain intensity (mm); A = Age of the pile (days); S = Time since rain stopped.
* More significant than rain; ‡ = Degrees of freedom too few to carry out backward stepwise regression for COD, TKN, and TP loads.
Ind. = Simple regression; F = Forward and B = Backward stepwise multiple regression.

Table V.15. Leachate analysis results for metals, polynuclear aromatic hydrocarbons (PAHs), and pentaclorophenol (PCP).

Metals (ppb)							PAHs*	PCP
Date	Pile	As	Cr	Cu	Pb	Zn	(ppb)	(ppb)
DWS		5	100	1300	15	5000		1
GWQS		0.02(3)	70(1)	1300(4)	5(5)	2000(10)		0.3(0.1)
SWQS		0.02	92	1300	5	7,400		0.27
TCLP		5000	5000		5000			100000
4/24/12	L	<8	<4	39	<10	82	NT	ND
	R	<8	<4	50	11	125	NT	ND
	F	23	5	42	<10	80	NT	ND
6/5/12	L	12	9	39	27	258	ND	ND
	R	10	<4	21	<10	104	ND	ND
	F	14	4	22	<10	84	ND	ND
11/9/12	L	<40	<20	56	<50	<150	ND	ND
	R	<40	<20	54	<50	<150	ND	ND
	F	<40	<20	<50	<50	<150	ND	ND

NT = Not tested; ND = Not detected.
DWS:Drinking water standards (NJDEP, 2010a).
GWQS: Groundwater quality standards - health based groundwater quality limits and practical quantitation level (in brackets); standard is the higher of these two values (NJDEP, 2010b).
SWQS: Surface water quality standards (NJDEP, 2010c).
TCLP: Toxicity characteristic leaching procedure limits for hazardous wastes in 40 CFR 261.24 (USEPA, 2012).
*The 25 different species of PAHs tested in the samples were all below the GWQS (below detection).

Table V.16. Dose response toxicity results for Runs 2 and 3.

		Run 2		
Date Collected	Pile	Concs. Tested (%)	LC_{10} (%)	EC_{10} (ASC)
11/21/11	Left	5, 10,20,40	>40	>40
	Right	5, 10,20,40	>40	>40
	Far	5, 10,20,40	38	>40
12/29/11	Left	10, 20, 40, 60	39	>60
	Right	10, 20, 40, 60	>60	>60
4/24/12	Left	5, 10, 20, 40	>40	>40
	Right	5, 20, 40	*	25
		Run 3		
5/30/12	Left	10, 20, 40	>40	>40
	Right	10, 20, 40	>40	>40
	Far	10, 20, 40	>40	>40
9/11/12	Left	10,20, 40	18	34
	Right	10,20, 40	>40	>40
	Far	10,20, 40	>40	>40
10/1/12	Left	10,20, 40	>40	>40
	Right	10,20, 40	>40	>40
	Far	10,20, 40	>40	>40

ASC: Abnormal spine curvature.
*Lower concentrations (5 and 20%) showed 27% mortality while the highest concentration (40%) showed no mortality.

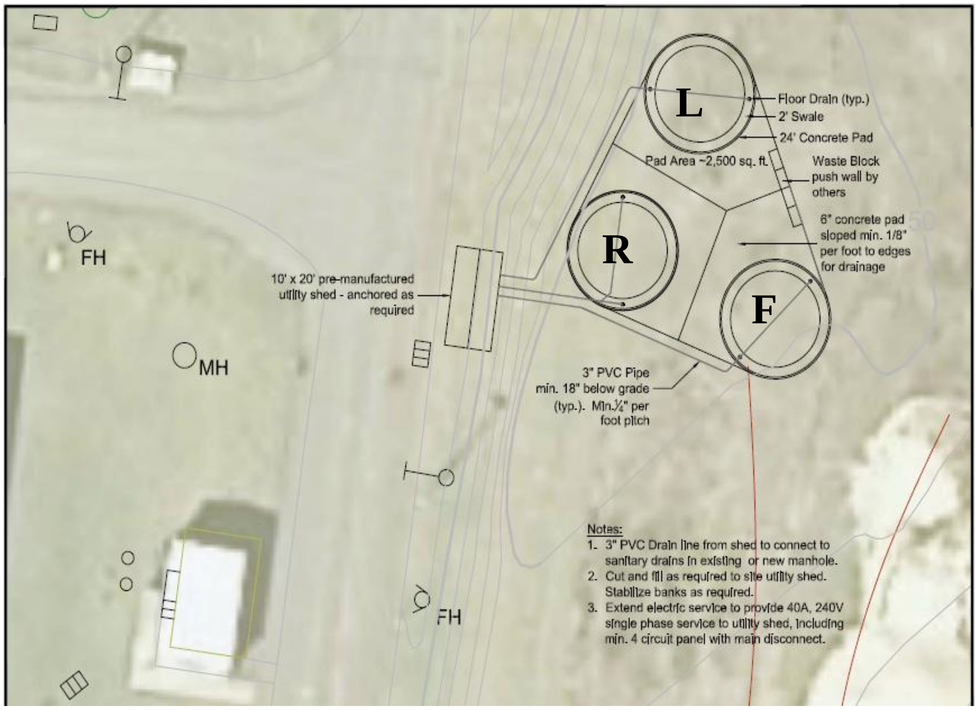

Figure V.1a. Schematic of the concrete pad.

Figure V.1b. Photograph of the piles with their position and rain gauge location on the concrete pad.

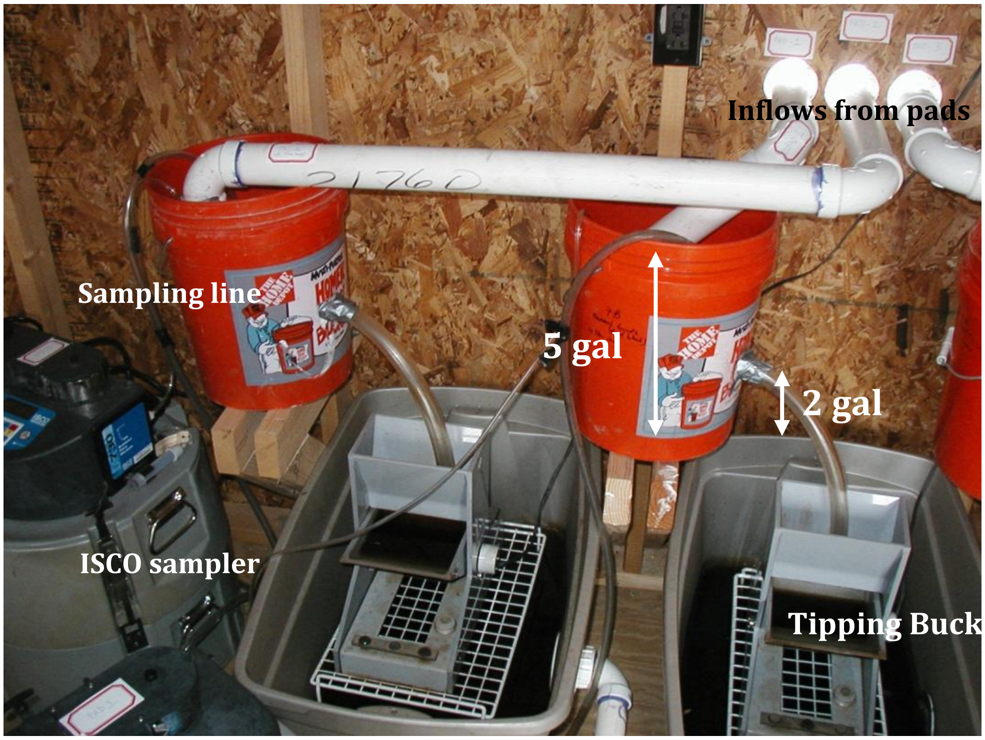

Figure V.2a. Photograph of the flow measurement and sampling set up.

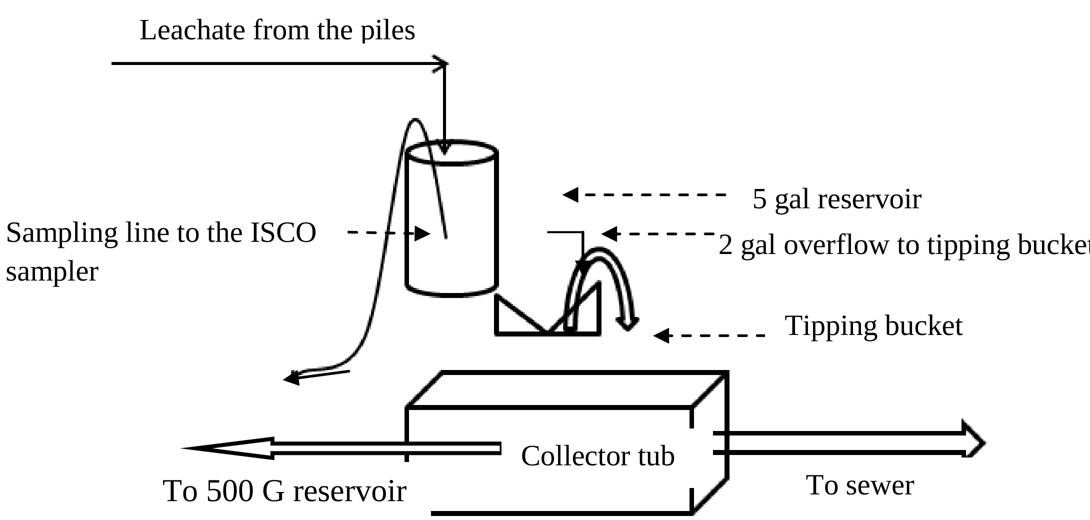

Figure V.2b. Schematic of leachate collection system.

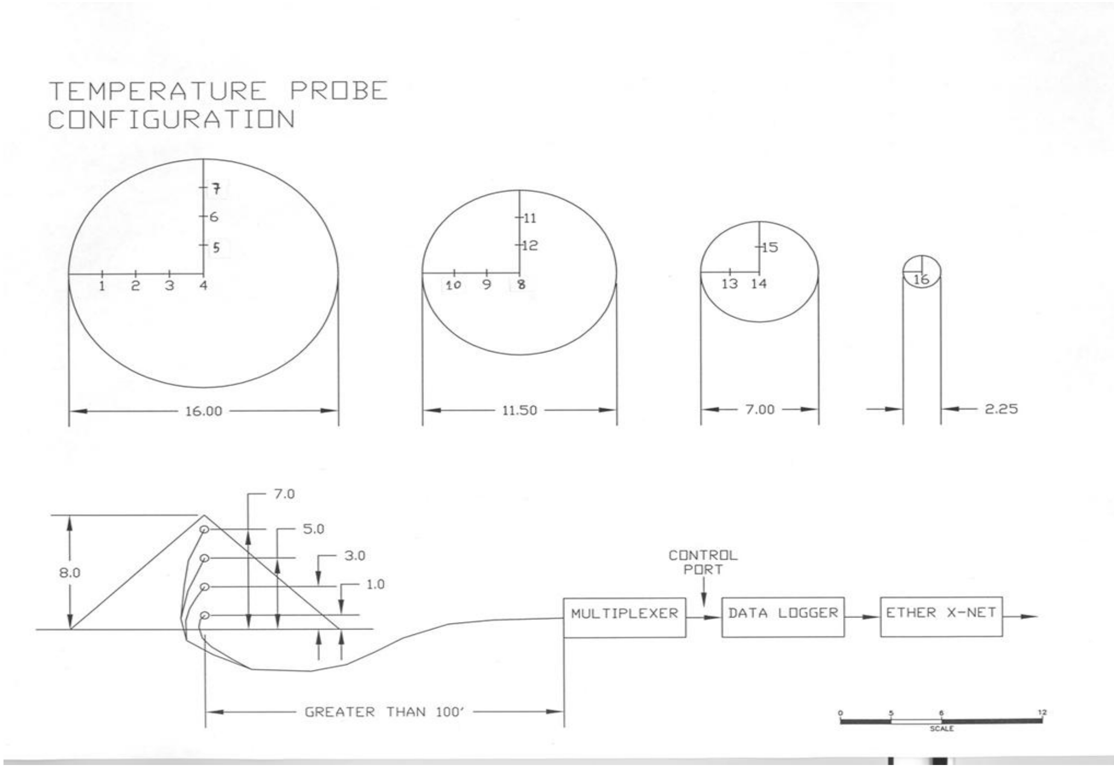

Figure V.3. Schematic showing temperature and moisture probe positions in the pile.

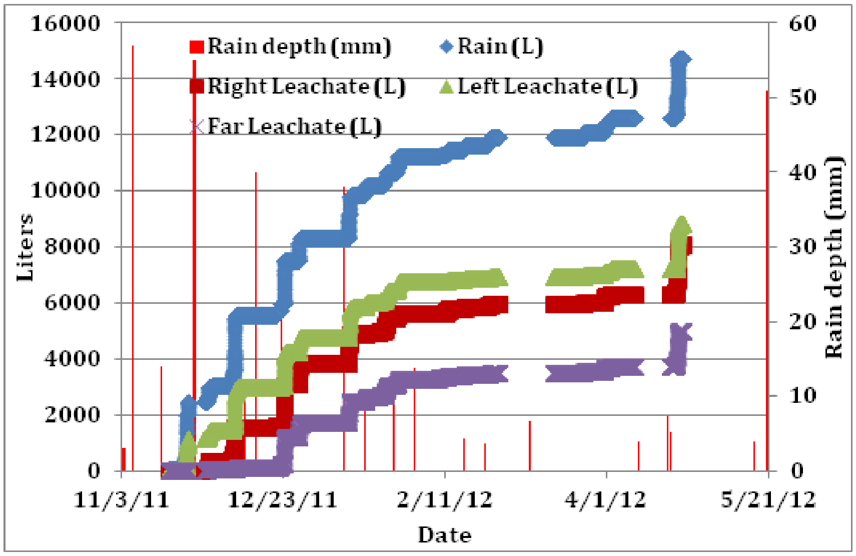

Figure. V.4a. Cumulative rain and leachate generated for Run 2.

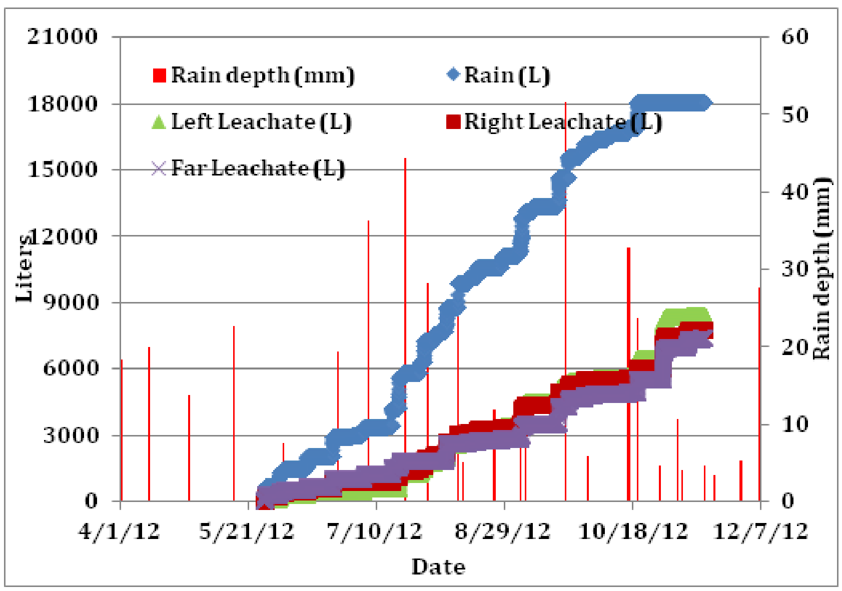

Figure V.4b. Cumulative rain and leachate generated for Run 3.

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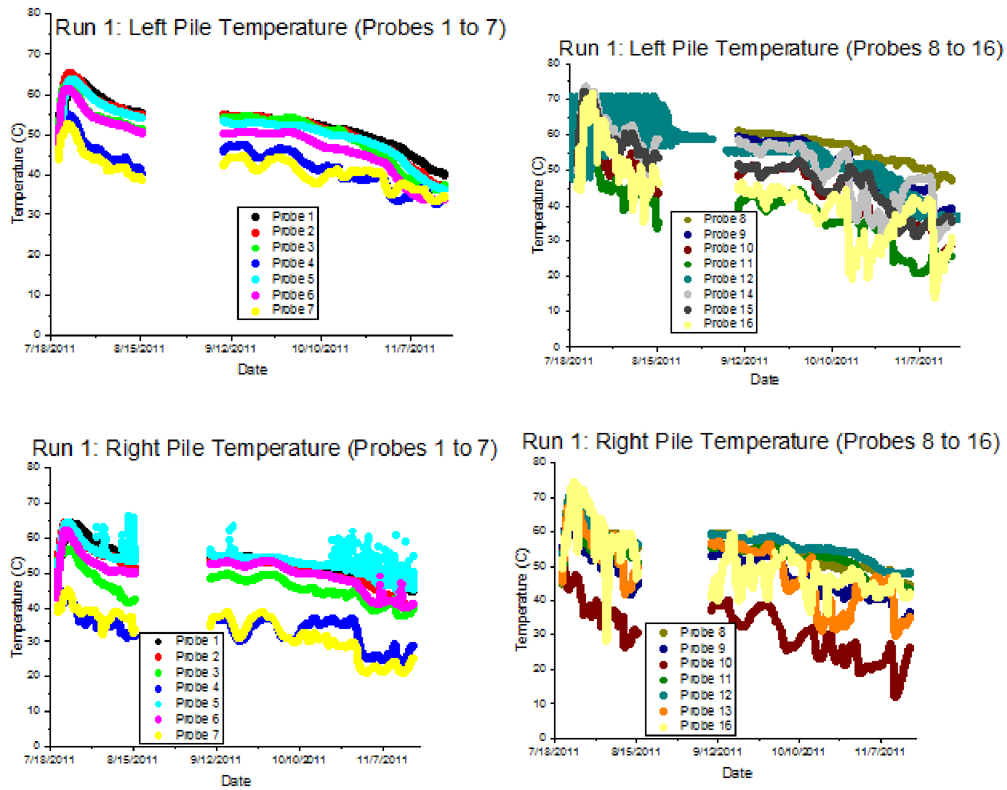


Figure V.5a. Run 1 Temperature Graphs.

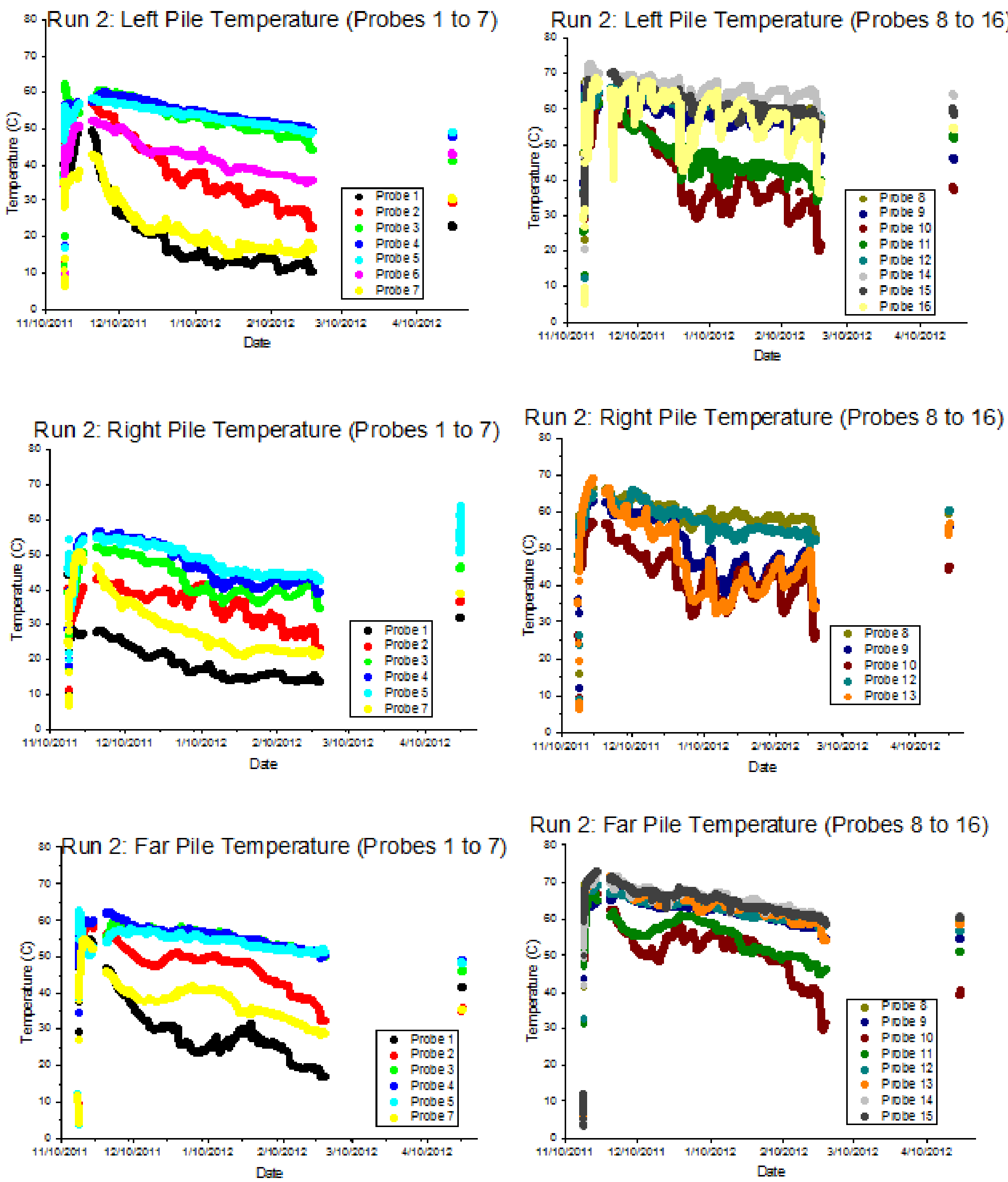


Figure V.5b. Run 2 Temperature Graphs.

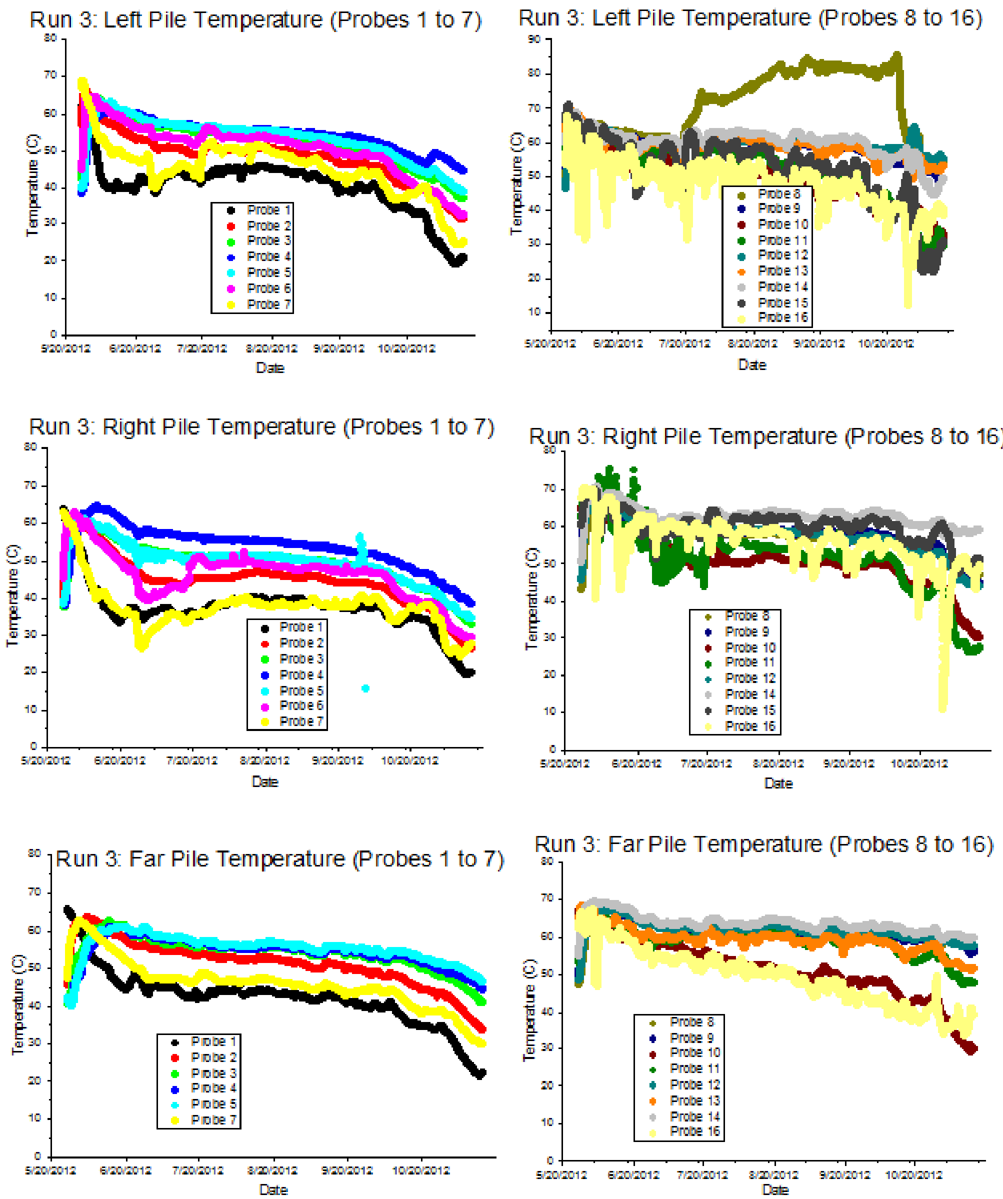


Figure V.5c. Run 3 Temperature Graphs.

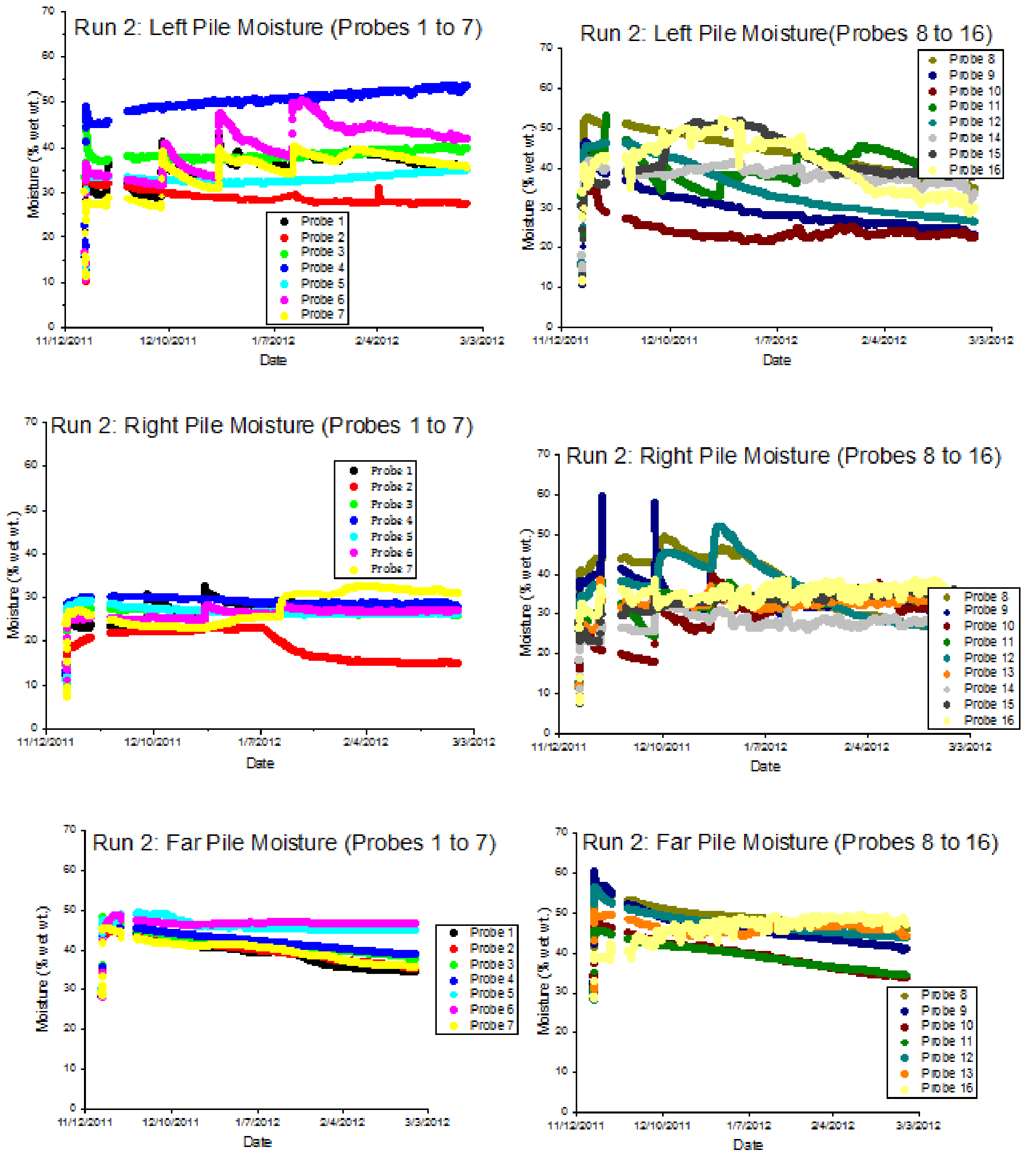


Figure V.6a. Run 2 Moisture Graphs.

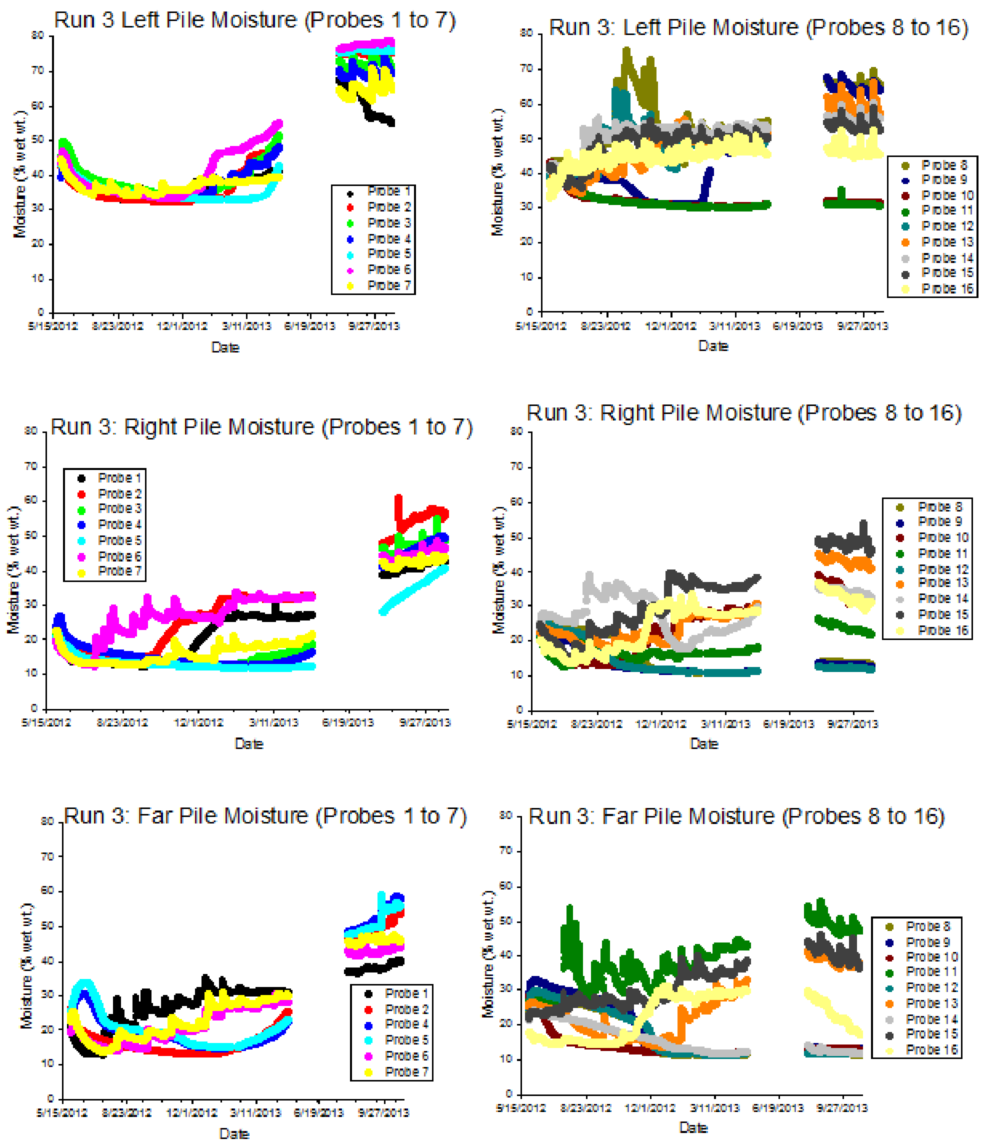


Figure V.6b. Run 3 Moisture Graphs.

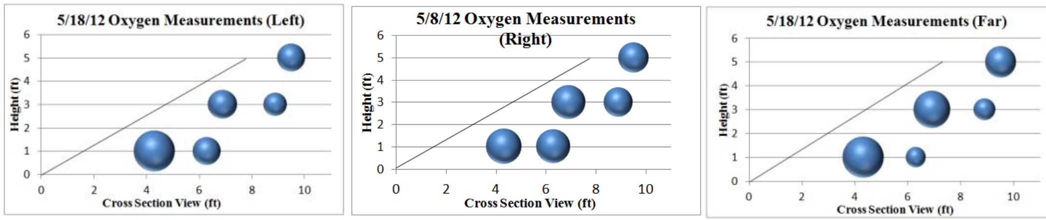
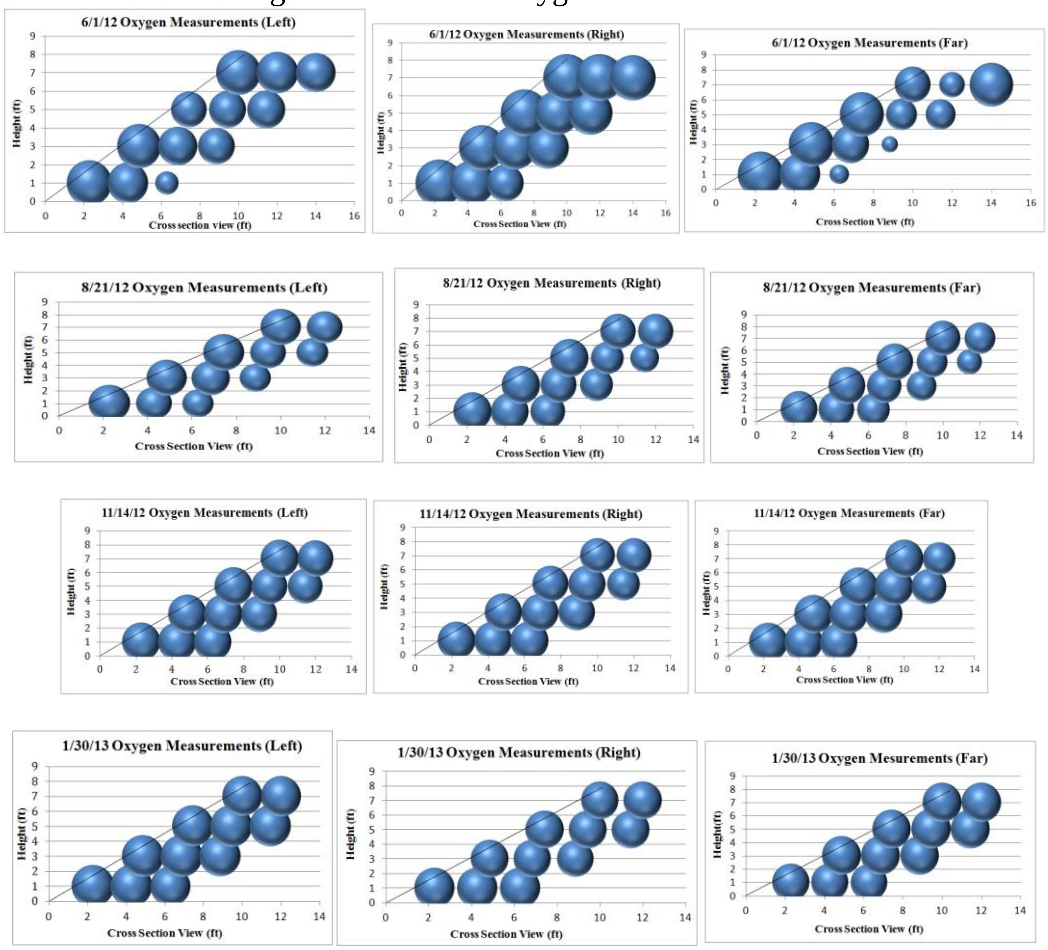


Figure V.7a. Run 2 Oxygen Measurements.



Cross section view: Distance from outside of the pile to individual depths in feet. Size of bubble indicates oxygen conc.; line represents edge of pile.

Figure V.7b. Run 3 Oxygen Measurements.

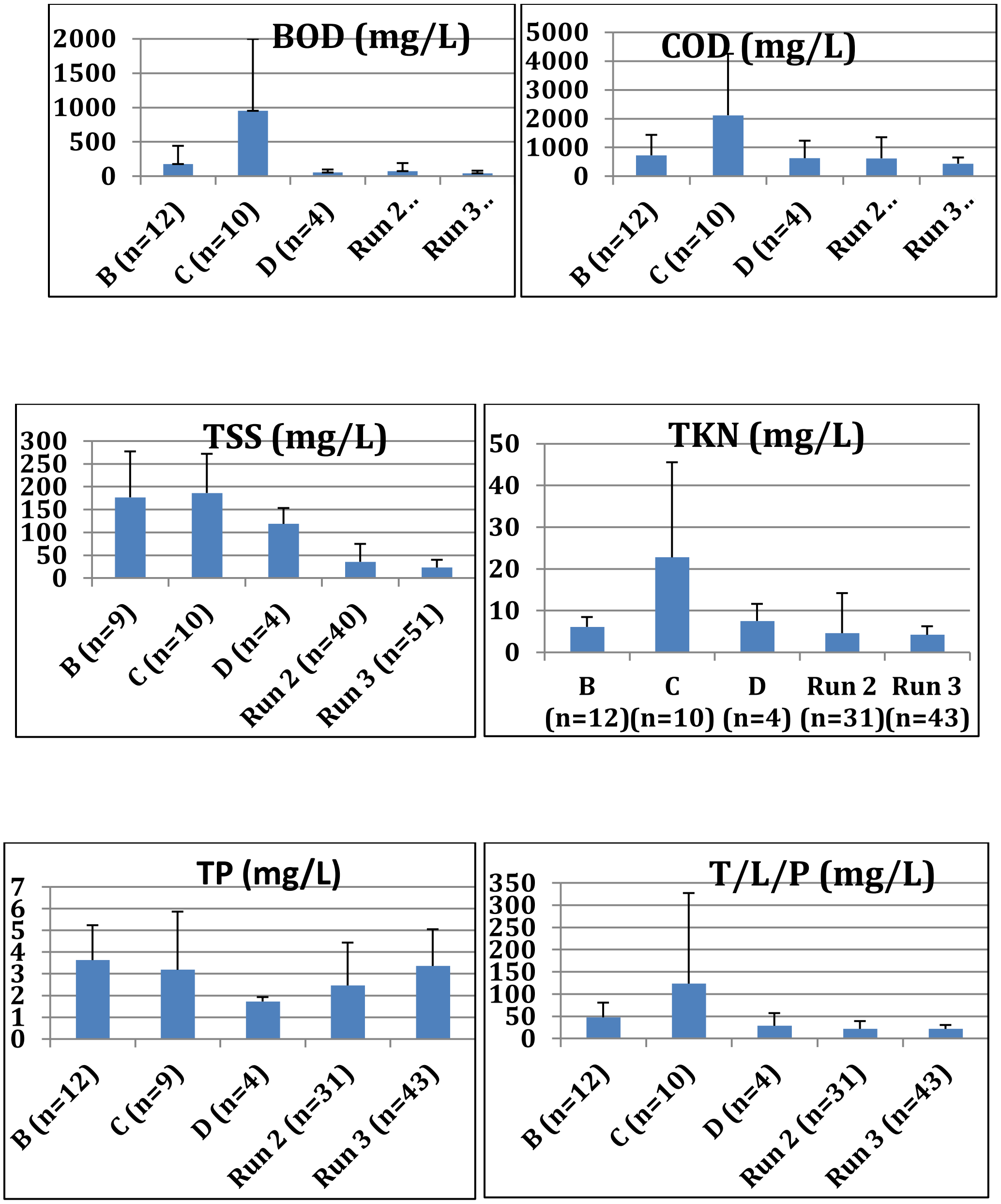


Figure V.8. Comparing sample concentrations among field sites and controlled stockpiles

APPENDICES

Appendix A. Composting field results.

Table A.1. Smaller compost pile set up on September 12, 2008
Dimensions of the pile: 6 ft L, 6 ft W, 3 ft H
Phragmites above grind biomass: Reed bed biosolids = 1:1 (W/W) which translated to 4 buckets (front end loader) of chipped *Phragmites* to 1 bucket if reed bed sludge.
Initial pile temperature: 22^{o}C
Ambient air temperature: 23.9^{o}C
Moisture content of chipped Phragmites used in the pile: 58%
Moisture content of reed bed sludge used in the pile: 53.8%
Moisture content of the mixture : 55.4%

Temperature readings for the smaller pile

Date	Place	Sampling #	Temp
9/15/2008	Top	1	31.2
9/15/2008	Top	2	30.2
9/15/2008	Top	3	30.4
9/15/2008	Top	4	32.1
9/15/2008	Top	5	30.6
9/15/2008	Top	6	30.8
9/15/2008	West	1	30.3
9/15/2008	West	2	30.2
9/15/2008	East	1	32.1
9/15/2008	East	2	33.3
9/15/2008	South	1	37.4
9/15/2008	South	2	40.2
9/15/2008	South	3	37.6
9/15/2008	South	4	44.8
9/15/2008	South	5	45.7
9/15/2008	South	6	45.6
9/15/2008	South	7	43.2
9/18/2008	Top	1	35.8
9/18/2008	Top	2	39.1
9/18/2008	Top	3	50.7
9/18/2008	Top	4	47.7
9/18/2008	Top	5	48.5
9/18/2008	Top	6	42.3
9/18/2008	West	1	32.1
9/18/2008	West	2	36
9/18/2008	West	3	32.8
9/18/2008	East	1	41.8
9/18/2008	East	2	40.3
9/18/2008	South	1	33.2
9/18/2008	South	2	49.1
9/18/2008	South	3	53.1
9/18/2008	South	4	52.5

9/18/2008	South	5	53.9
9/18/2008	South	6	39.4
9/18/2008	South	7	34.9
9/18/2008	South	8	35.7
9/24/2008	Top	1	38.4
9/24/2008	Top	2	39.1
9/24/2008	Top	3	34.7
9/24/2008	Top	4	36.6
9/24/2008	Top	5	37.9
9/24/2008	West	1	31.2
9/24/2008	West	2	32.2
9/24/2008	West	3	32
9/24/2008	East	1	36.4
9/24/2008	East	2	34.5
9/24/2008	East	3	35.1
9/24/2008	South	1	31.6
9/24/2008	South	2	37.1
9/24/2008	South	3	38.4
9/24/2008	South	4	43.5
9/24/2008	South	5	39.9
9/24/2008	South	6	40.1

Table A.2. Temperature and oxygen readings of larger compost pile set up on October 6, 2008.
Dimensions of the pile: 12 ft L, 12 ft W, 6 ft H.
Phragmites above ground biomass : Reed bed biosolids = 1:2 (w/w) which translated to 4 buckets (front end loader) of chipped *Phragmites* to 2 buckets of reed bed biosolids (2:1, v/v).
Ambient air temperature: 23^{o}C.
Moisture content of the mixture containing reed bed sludge and chipped Phragmites: 57%.
Three node length rhizomes in replicates of three were placed inside the pile at 1, 3, and 5 ft heights with 3 ft between each set of rhizomes.
Turning occurred on 10/15/08 and 10/22/08.

			At center		1 ft right of center	
Date	Height	Depth	Temperature (C)	Oxygen (%)	Temperature (C)	Oxygen (%)
10/6/08	1	1	21.5	17.4		
10/6/08	1	2	20.4	12.1		
10/6/08	1	3	22.3	7.3		
10/6/08	1	4	22.3	9.4		
10/6/08	1	5	23.1	5.9		
10/6/08	3	1	24.3	13.2		
10/6/08	3	2	24.3	11.9		
10/6/08	3	3	23.9	7.6		
10/6/08	3	4	23	8.4		
10/6/08	3	5	24.3	11.1		
10/6/08	5	1	22.4	13.9		
10/6/08	5	2	22.6	13.7		
10/6/08	5	3	22.9	13.5		
10/6/08	5	4	21.6	12.6		
10/6/08	5	5	21.8	18.6		
10/7/08	1	1	25.6	6.5		
10/7/08	1	2	24.9	11.4		
10/7/08	1	3	26.2	9.1		
10/7/08	1	4	25.4	17.3		
10/7/08	1	5	27.8	17.1		
10/7/08	3	1	29.3	11.6		
10/7/08	3	2	27.8	16.2		

10/7/08	3	3	27.7	12.1		
10/7/08	3	4	27.2	14.6		
10/7/08	3	5	30.1	16.6		
10/7/08						
10/7/08	5	1	30.2	16.4		
10/7/08	5	2	27.4	14.6		
10/7/08	5	3	25.6	12.9		
10/7/08	5	4	27.8	14.4		
10/7/08	5	5	26.1	13.6		
10/9/08	1	1	24.8	3		
10/9/08	1	2	28.9	4.7		
10/9/08	1	3	34.1	1.7		
10/9/08	1	4	30.5	0.2		
10/9/08	1	5	34.4	0.5		
10/9/08	3	1	39.5	0.9		
10/9/08	3	2	34.5	2.3		
10/9/08	3	3	34.1	0.2		
10/9/08	3	4	28.8	0.9		
10/9/08	3	5	35.1	0.6		
10/9/08	5	1	43.1	2.3		
10/9/08	5	2	39.7	2.2		
10/9/08	5	3	37.2	0.9		
10/9/08	5	4	42.1	2.8		
10/9/08	5	5	44.2	1.9		
10/10/08	1	1	30.3	19.3		
10/10/08	1	2	41.9	16.5		
10/10/08	1	3	41.3	12		
10/10/08	1	4	35	3		
10/10/08	1	5	30.2	0.8		
10/10/08	1	6	28	0.3		
10/10/08	1	7	28.5	0.2		
10/10/08	3	1	45.1	13.1	39.9	
10/10/08	3	2	49.4	12	45.9	
10/10/08	3	3	45.4	6.8	46.4	
10/10/08	3	4	39.3	0.6	42.2	

10/10/08	3	5	36	0.5	40.7	
10/10/08	3	6	42.4	0.3	46.5	
10/10/08	3	7	46.6	6.1	52	
10/10/08	5	1	34.8	20.2		
10/10/08	5	2	35.8	16.6		
10/10/08	5	3	36.9	13.1		
10/10/08	5	4	34.6	10.1		
10/10/08	5	5	31.7			
10/13/08	1	1	35.2	17.5		
10/13/08	1	2	41.5	13.5		
10/13/08	1	3	47.4	7.5		
10/13/08	1	4	52.1	2.3		
10/13/08	1	5	51	1.5		
10/13/08	1	6	43.7			
10/13/08	1	7				
10/13/08	3	1	49.2	13.3	40.1	18.1
10/13/08	3	2	58.2	7.6	47.8	9.6
10/13/08	3	3	51.1	5.1	55.6	2.7
10/13/08	3	4	46.9	1	50.1	1.2
10/13/08	3	5	46.7	0.8	46	0.4
10/13/08	3	6	50.4	4.1	48.6	0.3
10/13/08	3	7	55.3	8.7	56.6	0.3
10/13/08	5	1	47.5	16.4		
10/13/08	5	2	45.3	11.2		
10/13/08	5	3	45	11.4		
10/13/08	5	4	46.3	12.6		
10/14/08	3	1	46.7	18.5	44.1	17.5
10/14/08	3	2	**58.5**	12.7	55.6	12.4
10/14/08	3	3	56.7	7.7	53.1	6.6
10/14/08	3	4	49.3	3.3	47.5	1.2
10/14/08	3	5	46.7	1.2	43.7	0.9
10/14/08	3	6	52.7	0.7	47.7	0.4
10/14/08	3	7	55.9	0.9	56.9	0.4

First Turning of the Pile on 10/15/08						
10/17/08	1	1	31.9	6.6	36.4	9.9
10/17/08	1	2	35.6	6.2	37.8	6.9
10/17/08	1	3	34.3	5.6	38.4	4.6
10/17/08	1	4	37.8	5.9	38.7	4.3
10/17/08	1	5	39.6	4.5	38.4	4.3
10/17/08	1	6	41.1		38.1	
10/17/08	1	7			38.4	
10/17/08	3	1	37.8	14.6	42	15.6
10/17/08	3	2	41.2	15.1	43.4	14.1
10/17/08	3	3	42.2	6.4	42.4	9.6
10/17/08	3	4	41	1.8	41.3	3.9
10/17/08	3	5	41.1	1.2	40.5	4.9
10/17/08	3	6	42.6	1	40.4	3.4
10/17/08	3	7	43.6	0.9	41.5	2
10/17/08	5	1	41	13.5	42	16.9
10/17/08	5	2	43.7	5.5	43.5	6.6
10/17/08	5	3	43.3	4.2	44.3	6.9
10/17/08	5	4	43.9	3.8	44.2	4.6
10/17/08	5	5	44.6	4.8	44.8	3.6
10/17/08	5	6	44.3		43.2	
10/17/08	5	7	42.1		33.2	
10/21/08	1	1	37.8	18.1	38.2	14.7
10/21/08	1	2	39.2	13.8	42.3	13.4
10/21/08	1	3	39.8	11.1	46.7	6.9
10/21/08	1	4	37.8	8	49.8	4.2
10/21/08	1	5	36.1	7.5	48.1	5.1
10/21/08	1	6	35.9	13.2	46.4	0.9
10/21/08	1	7	35.5	18.2	46.7	0.9
10/21/08	3	1	43.2	17.7	45.5	16.2
10/21/08	3	2	49.4	16.5	49.8	11.9
10/21/08	3	3	50.5	5.2	51.6	6
10/21/08	3	4	49.6	1.8	50.6	0.9
10/21/08	3	5	47.8	0.7	49.6	0.6
10/21/08	3	6	47.4	0.6	48.6	0.5

10/21/08	3	7	44.9	0.6	47.6	0.6
10/21/08	5	1	38.9	18.1	43	17.5
10/21/08	5	2	43.4	13.8	46.4	11.2
10/21/08	5	3	42.9	11.1	47.1	6.4
10/21/08	5	4	42.4	8	47.1	6.5
10/21/08	5	5	38.4	7.5	46.3	9.7
10/21/08	5	6	28.3	13.2	43.2	16.2
10/21/08	5	7	22.5	18.2	34	16.9
Second turning of the pile on 10/22/08						
10/24/08	1	1	31.3	12.1	28.3	
10/24/08	1	2	36	12	34.3	
10/24/08	1	3	35.8	9.9	34.5	
10/24/08	1	4	34.6	9.9	33.7	
10/24/08	1	5	34.4	10.1		
10/24/08	1	6	32.8	4.6		
10/24/08	1	7		4.2		
10/24/08	3	1	29.1	14.6	32.3	
10/24/08	3	2	32.8	14.1	34.6	
10/24/08	3	3	34.1	12.6	35.3	
10/24/08	3	4	33.4	6.7	34.2	
10/24/08	3	5	32.6	4.6	33.1	
10/24/08	3	6	32.7	4.3	32.9	
10/24/08	3	7	33	4	34.1	
10/24/08	5	1	25.7	16.2	28.9	
10/24/08	5	2	30.7	13.4	27.6	
10/24/08	5	3	31.1	15.6	30.4	
10/24/08	5	4	30.6	11	30.2	
10/24/08	5	5	30.8	9.6	30.3	
10/24/08	5	6	31.6	9.1	30.6	
10/24/08	5	7	31.2	4.1		

Appendix B. Protocol for rhizome mortality experiments in the laboratory

Field Sample Collection

1) All rhizomes collected for each laboratory experiment will be collected from same site (treatment plant reed beds, woods behind Cook Campus Center, New Brunswick, or field compost pile).
2) Rhizomes will be dug out in such a way that they are not broken at the growing points or too small to grow. Only those rhizomes that are visually identified to be viable (showing shoots and bud growth) will be collected.
3) Rhizomes will be transported to the laboratory with the bed material attached to them and stored in the cold room at 4˚C until the beginning of the experiment.

Laboratory Planting Protocols for Rhizomes Collected from Reed Beds and Compost Pile

4) To demonstrate rhizome viability, all rhizomes collected from reed beds or compost pile will be planted in potting soil in the laboratory, fertilized, and left under sunlight and watered every day. Rhizome growth will be monitored over a 1 week time period before they are used in the mortality experiments.
5) All rhizomes will be washed to remove adhering bed material before the beginning of experiments.
6) Rhizomes will be cut to have a three node length and buds in each fragment will be counted. All the old stems and leaves will be cut to monitor only new growth.
7) There will be five controls and five replicates for each set of temperature points tested.
8) The weight of all the rhizomes tested will be recorded before subjecting them to temperature treatment.
9) Controls will be placed in the same room at ambient temperature as the oven in which the heat treatment is carried out for the replicates.
10) Replicates will be heat treated in a digitally controlled iso-temperature oven (Fisher Scientific). A mercury thermometer will be placed inside the oven to confirm the oven temperature is consistent.
11) Room temperature will be monitored using a mercury thermometer placed next to the controls.

12) After heat treatment for specific time periods both the replicates and controls will be weighed to determine weight loss.
13) All the rhizomes will be planted in pots with definite amounts of commercially available potting soil (Miracle Grow) and will be left to grow in the greenhouse.
14) A measured amount of water will be added daily to all pots (200 mL/day).
15) Growth of rhizomes will be monitored every day by measuring length of tallest shoot and counting number of new shoots. Mortality of the rhizomes will be determined by monitoring the growth or lack of growth over a 2 week period (14 days).

Appendix C. Heavy metal concentrations (mg/kg) in reed bed biosolids

Metals	A	B	12/24/08	5/20/08							7/21/05	12/29/99	
Sample ID			Bed #1	Bed # 1	Bed#2	Bed #4	Bed #5	Bed#6	Bed#12	Bed#14	Sample 1	Sample 1	Sample 2
Arsenic	75	41	ND	6.93	ND	5.72	8.28	6.41	ND	ND	5.66	<1.08	7.69
Cadmium	85	39	7.76	ND	ND	ND	ND	ND	ND	ND	ND	<0.541	<2.74
Chromium	3,000	1,200	32.5	26.5	31.7	28.9	28.8	30	35.4	22.7	22.3	<0.541	23
Copper	4,300	1,500	586	743	759	769	807	815	881	714	535	10.8	491
Lead	840	300	42.7	60.2	54.6	56.8	67.2	54.5	60.5	43.8	36.7	<1.36	30.1
Mercury	57	17	4.11	ND	5.53	3.73	5.69	5.48	4.84	3.67	2.03	<0.091	4.69
Molybdenum	75	NA	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	3.68
Nickel	420	420	23.5	32.1	31.9	33.1	30.6	26.9	35.1	30.8	32.2	0.805	18
Selenium	100	36	ND	ND	ND	ND	ND	ND	ND	ND	ND	<1.36	8.88
Zinc	7,500	2,800	1910	ND	2550	2800	2760	2130	2720	2830	2540	206	1350

A: EPA Ceiling concentration limit for biosolids applied to land (USEPA, 1993).
B: EPA Limits for pollutant concentration in biosolids (USEPA, 1993)
Samples from 7/21/05and 12/29/99 are randomly selected samples from different beds
ND: Not detected

Appendix D. Soil testing laboratory report on reed bed biosolids.

THE STATE UNIVERSITY OF NEW JERSEY
RUTGERS
COOPERATIVE
EXTENSION
New Jersey Agricultural Experiment Station

Rutgers Soil Testing Laboratory
P.O. Box 902
Milltown, NJ 08850
(732) 932-9295 x 4231
FAX (732) 932-9292
www.rce.rutgers.edu/soiltestinglab

Soil Test Research Report

Rutgers, Dr. Elizabeth A. Ravit (Cook)
ENR, Environmental Sciences
Room 356, 14 College Farm Road
New Brunswick, NJ 08901

Serial No -

Date Reported: 02/13/2008

					Mehlich3 Values (lbs/A)				Micronutrients (ppm)				
LabNo	**Sample ID**	**Texture**	**pH**	**LRI**	**P**	**K**	**Mg**	**Ca**	**Cu**	**Mn**	**Zn**	**B**	**Fe**
0352	W M U A 1/31/08		4.55	6.85	718	91	266	7092	32.3	57.62	32.5	5.4	327.6

Electrical Conductivity: Soluble Salt Level = 1.21 mmho/cm (High)
Loss On Ignition: Organic Matter = 43.72%, Organic Carbon = 25.36%
Total Kjeldahl Nitrogen: 0.80%. (Ammonia nitrogen + org. nitrogen)
Inorganic Nitrogen: Nitrate-N = 170 ppm, Ammonium-N = 80 ppm

Rough estimate

Converting pounds/Acre to ppm
Acre furrow slice of soil = 2 million pounds
So, divide lb/A by 2 to get ppm.

So,

P = 718/2 = 359 ppm
K = 91/2 = 45.5 ppm
Mg = 266/2 = 133 ppm
Ca = 7092/2 = 3546 ppm

Whether they are capturing all Nitrate & Nitrite

RUTGERS
New Jersey Agricultural
Experiment Station

Soil Testing Laboratory
Rutgers, The State University
P.O. Box 902
Milltown, NJ 08850-0902
Phone: (732) 932-9295

Soil Test Report

Lab No: 2008-**0352**

Name: Rutgers, Dr. Elizabeth A. Ravit (Cook)
ENR, Environmental Sciences
Address: Room 356, 14 College Farm Road
New Brunswick, NJ 08901

Phone: (732) 932-9763
Fax: (732) 932-8965

Referred To: Rutgers Cooperative Ext.

Date Received: 02/04/2008
Date Reported: 02/13/2008
Serial No: -
Sample ID: W M U A 1/31/08

Crop or Plant

Soil Tests and Interpretation

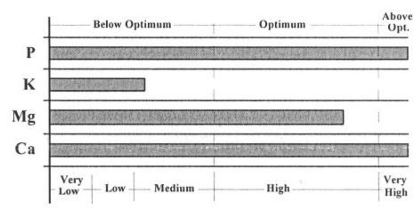
pH: 4.55 Very strongly acidic, suitable for blueberry, cranberry, azalea, rhododendron, and holly, but too acidic for most other plants.

Lime Requirement Index: 6.85
Adams-Evans LRI is a measure of the soil's buffering capacity (resistance to change in pH). It is used to determine liming rate, when necessary.

Macronutrients (pounds/acre)

Phosphorus:	718	(Above Optimum)
Potassium:	91	(Below Optimum)
Magnesium:	266	(Optimum)
Calcium:	7092	(Above Optimum)

by Mehlich 3 extraction



Micronutrients (parts per million)

Zinc:	Copper:	Manganese:	Boron:	Iron:
232 (High)	32. (High)	57. (Adequate)	5.4 (Adequate)	327 (High)

Special Tests and Results

Electrical Conductivity: Soluble Salt Level = 1.21 mmho/cm (High soluble salt content -- may 'burn' plant roots, causing drought-like symptoms)
Loss On Ignition: Organic Matter = 43.72%, Organic Carbon = 25.36%
Total Kjeldahl Nitrogen: 0.80%
Inorganic Nitrogen: Nitrate-N = 170 ppm, Ammonium-N = 80 ppm

Appendix E. Wood mulch analysis.

Table E.1.Wood mulch analysis results for samples from Site B

	Grind 1						Grind 2									
Parameter	6A	6B	8A	8B	13A	13B	5A	5B	7A	7B	9A	9B	10A	10B	14A	14B
pH	6.1	5.3	5.9	5.9	6	5.7	4.6	6.3	6.3	6.5	6.6	6.5	5.3	6	6.7	6.8
C:N ratio	62	58	93	64	68	92	79	118	53	74	108	81	72	54	70	62
Cond. (ms/cm)	0.3	0.3	0.3	0.3	0.2	0.2	0.8	0.3	0.4	0.4	0.4	0.4	0.5	0.4	0.4	0.4
Moisture(%)	39	34	32	38	42	49	31	43	52	52	57	51	41	35	60	59
Moisture*(%)	42	35	33	33	40	43	34	46	52	52	55	54	38	37	59	59
Org.matter(%)	53	70	80	81	62	79	65	82	79	82	83	70	77	75	71	70
C(g/kg)	279	338	374	303	285	338	392	380	397	397	416	344	405	319	278	332
Total N	4500	5800	4000	4700	4200	3700	5000	3200	7500	5400	3800	4200	5700	5900	4000	5300
Org. N	4500	5800	4000	4700	4200	3700	4900	3200	7500	5400	3800	4200	5600	5900	3900	5300
NH_4^+-N	<4.8	<4.8	<4.9	<4.9	<5	<5	48.5	<4.9	<5	<4.9	<4.9	<4.9	<4.9	<5	<5	<4.9
P	546	362	467	397	402	253	498	389	271	301	297	424	485	502	441	306
K	3000	2000	2250	1917	1417	1250	2333	2000	1667	1833	1667	3083	2333	2167	1500	1417
Ca	6300	3300	6200	4900	4500	3300	5200	4300	3000	3300	3300	5400	4400	5600	8800	6000
Mg	2200	700	1100	1800	1300	600	900	800	600	600	600	2800	900	1200	1700	1800
S	500	300	400	400	300	300	400	400	300	400	300	400	500	500	500	400
Na	127	58	65	77	98	82	75	55	67	66	84	187	65	68	162	137
Al	4674	1615	7430	3414	3400	1812	1611	1180	2245	1056	1058	2944	1809	3937	13662	1851
Fe	9136	3802	6224	6137	6097	2705	4346	2939	1728	2348	4578	8359	4708	5432	11589	5869
Mn	129	75	97	133	98	79	67	61	48	48	46	82	67	85	148	64
Cu	37	16	168	39	35	28	16	10	57	12	12	21	19	89	482	23
Zn	49	29	77	48	45	33	32	32	35	25	25	31	34	58	171	29
Pb	18	9	16	18	26	11	15	12	9	10	10	11	15	19	24	14

Except for pH, parameters are in mg/kg dry weight basis unless noted.
*Moisture content measured in the laboratory at Rutgers University immediately after collection.

Table E.2. Wood mulch analysis results for samples from Site C

	Grind 1				Grind 2					
Parameter	2A	2B	11A	11B	1A	1B	12A	12B	15A	15B
pH	6.2	5.5	6.7	5.9	6	5.8	6.2	6.1	3.8	3.7
C:N ratio	104	62	66	59	68	116	69	75	62	60
Cond. (ms/cm)	0.6	0.7	0.6	0.6	0.8	0.9	0.8	0.8	1.5	1.9
Solids(%)	46	55	43	45	46	48	49	51	46	42
Moisture(%)	54	45	57	55	54	52	52	49	55	58
Moisture*(%)	52	45	58	51	52	52	53	53	53	53
Org.matter(%)	91	92	93	95	87	90	88	93	87	87
C(g/kg)	499	445	396	471	483	461	451	438	436	429
Total N	4800	7200	6000	8000	7100	4000	6500	5800	7000	7200
Org. N	4800	7200	6000	8000	7100	4000	6500	5800	7000	7100
NH_4-N	<5	<4.9	<4.9	<4.9	<5	<4.9	<4.9	<4.9	7.9	109
P	524	485	432	362	528	655	603	445	546	616
K	2667	2333	2583	2167	2667	2917	3167	2750	2583	2667
Ca	8500	6600	6800	6900	6700	9400	9300	7600	9000	9200
Mg	1000	800	800	600	1000	1100	1100	900	1300	1300
S	300	400	400	300	400	600	500	400	500	600
Na	106	102	75	152	103	117	115	87	131	168
Al	999	940	839	313	913	1318	1127	664	1455	1724
Fe	1729	1111	1045	374	1645	1931	1818	965	2767	2664
Mn	158	113	193	87	142	155	153	128	158	161
Cu	9	14	11	8	9	14	15	10	17	21
Zn	33	33	30	23	34	46	42	33	40	45
Pb	10	9	7	4	13	20	17	11	19	20

Except for pH, parameters are in mg/kg dry weight basis unless noted.
*Moisture content measured in the laboratory at Rutgers University immediately after collection.

Table E.3. Wood mulch analysis results for samples from Site D

	Grind 1		Grind 2	
Parameter	3A	3B	4A	4B
pH	6.8	6.7	5.6	6.2
C:N ratio	39	73	56	33
Cond. (ms/cm)	0.6	0.3	2.2	0.9
Solids(%)	56	51	61	59
Moisture(%)	44	49	39	41
Moisture*(%)	45	46	36	42
Org. matter(%)	52	57	65	61
C(g/kg)	305	317	397	251
Total N	7900	4400	7100	7600
Org. N	7900	4400	6900	7600
NH_4-N	<4.9	<4.9	172	20
P	983	681	987	738
K	3417	2333	3750	3333
Ca	9000	6600	10600	9000
Mg	3500	2900	3100	3200
S	800	500	800	600
Na	298	155	362	212
Al	6653	7082	4521	4729
Fe	10797	11304	7111	8569
Mn	332	264	255	254
Cu	40	38	35	31
Zn	77	61	72	59
Pb	35	25	22	18

Except for pH, parameters are in mg/kg dry weight basis unless noted.
*Moisture content measured in the laboratory at Rutgers University immediately after collection.

Appendix F. Analysis of leachate and runoff samples from wood recycling sites

Date	Sample*	pH	BOD	COD	Sett. S.	TSS	TKN	TP	T/L/P	FC
6/10/2010	C-1	4.8	1520	3366	<0.5	161	35	0.18	100	ND*
	C-2	6.6	>2340	5991	<0.5	103	70	ND	140	ND
8/25/10	**C-1**	5	2900	5620	0.6	304	24	1.3	690	ND
	C-2	6.8	267	786	<0.5	111	5	1.6	80	ND
7/29/10	**D-1**	6.7	67	437	<0.5	150	10	1.9	14	ND
	D-2	7.6	ND	1522	<0.5	74	12	1.5	70	ND
9/17/10	B-1	7.2	700	2466	<0.5	258	11	3.5	125	ND
10/1/10	**B-2**	7.5	43	470	<0.5	138	6	5.3	20	ND
	B-3	7.4	ND	397	0.7	401	5	3.5	23	ND
11/5/10	B-1	6.9	776	1942	<0.5	139	2	6.6	90	ND
	B-2	7.6	102	472	<0.5	94	5	4.3	15	ND
	B-3	7.4	91	342	<0.5	69	4	5.1	15	ND
12/1/10	**C-1**	6.6	105	660	<0.5	85	30	4	50	ND
	C-2	6.3	338	987	0.9	332	46	8	100	ND
4/13/11	B-2	7.14	99	681	ND	ND	6.9	2.6	30	3500
	B-3	7.15	33	409	ND	ND	5.6	1.9	45	17,000
5/5/11	B-1	6.56	<20	134	ND	ND	6.3	4.6	70	17,000
6/15/11	C-1	5.65	1545	1995	ND	133	8.5	6.9	37	35,000
	C-2	6.67	38	393	ND	167	6.3	3.2	11	450
7/19/11	D-1	6.2	109	385	ND	142	4.3	1.6	25	$>1.6\times10^6$
	D-2	7.17	36	163	ND	109	3.8	1.9	6	<1800
8/15/11	B-1	6.7	109	540	ND	145	5.6	3	47	<1800
	B-2	6.63	96	460	ND	160	6.3	2.1	50	<1800
	B-3	7.2	76	430	ND	192	9.6	1.1	43	<1800
9/7/11	C-1	6.57	257	784	ND	237	1.3	2.3	16	<1800
	C-2	7.17	221	593	ND	230	1.6	1.2	12	<1800

* Samples B-1, B-2 and B-3, collected from site "B", are from a puddle between *Grind* 1 and *Grind* 2 piles, the runoff stream, and retention pond, respectively. Samples C-1 and C-2, collected from site "C", are from a puddle next to a *Grind* 2 pile and the runoff leaving the site, respectively. Samples D-1 and D-2, collected from site "D", are from the retention pond and a puddle next to a *Grind* 1 pile, respectively. Sample numbers in bold collected during a rain event; ND = Not determined. Except for pH, settleable solids (sett. S, mL/L) and fecal coliforms (FC, most probable number per100 mL of sample), the rest are in mg/L units.

Appendix G. Summary of toxicity results for each sample

Conc. (% leachate)	Death (%)	YSPCE (%)	ASC (%)	Kink tail (%)	# of stages delayed**
1-Sample C-2		Collected on 4/5/10; pH not adjusted			
0	0	0	0	0	0.27
0.625	0	0	0	0	2
1.25	0	0	0	0	4
2.5	47	33	40	0	2
5	100	0	0	0	ND
10	100	0	0	0	ND
2-Sample C-2		Collected on 6/10			
0	13	0	0	0	0
0.625	0	0	6.7	0	1
1.25	20	0	6.7	0	1.2
2.5	6.7	0	0	0	1.3
5	20	13	20	0	2
10	33	40	27	0	2
3-Sample D-1		Collected on 7/29			
0	13	0	13	0	0
1.25	0	0	0	0	1
2.5	33	0	13	0	2.1
5	0	13	0	0	1.3
10	0	0	0	0	1
20	0	27	0	0	1
4-Sample D-2		Collected on 7/29			
0	0	0	0	0	1
1.25	0	6.7	0	0	2.7
2.5	0	0	0	0	2
5	0	0	0	6.7	1.6
10	13	6.7	0	0	1.6
20	13	0	0	13	3.5
5-Sample B-1		Collected on 9/17			
0	0	0	0	0	1
1.25	0	0	0	20	2.7
2.5	0	6.7	0	20	3
5	0	0	0	0	3.1
10	0	0	0	0	3
20	100	0	0	0	ND
6-Sample B-2		Collected on 10/1			
0	27	0	0	0	0
2.5	27	0	0	0	1.3
5	0	0	0	0	2.4
10	27	6.7	0	0	2.8
20	33	0	0	0	2.6

7-Sample B-1		Collected on 11/5			
0	13	0	0	0	1.4
2.5	0	13	0	0	2
5	0	6.7	6.7	0	2.5
10	0	6.7	6.7	0	2.5
20	0	0	13	0	4.4
30	67	20	20	0	4.5
8-Sample B-2*		Collected on 11/5			
5	6.7	0	6.7	0	2
10	0	0	0	0	2
20	0	0	6.7	0	2.5
30	0	0	20	0	2
9-Sample B-3*		Collected on 11/5			
5	13	0	0	0	2
10	0	13	20	0	2
20	13	0	0	0	2
30	6.7	6.7	13	0	2.1
10-Sample C-1		Collected on 12/1			
0	0	0	0	0	1
5	0	0	20	0	1
10	0	0	0	0	1
20	6.7	0	0	0	1
30	0	0	0	0	1
50	0	0	0	0	2
11-Sample C-2*		Collected on 12/1			
5	0	0	0	0	1
10	0	0	0	0	1.1
20	0	0	0	0	1
50	100	0	0	0	ND
12-Sample B-2		Collected on 4/13/11			
0	0	0	0	0	3
5	0	0	0	0	3.7
10	0	0	0	0	4.9
20	66.6	0	0	0	8.3
30	100	0	0	0	ND
40	100	0	0	0	ND
13-Sample B-3		Collected on 4/13			
0	0	0	0	0	2.0
2	0	0	0	0	2.5
4	0	0	0	0	3.0
8	0	0	46	0	3.0
10	0	0	26.6	0	3.0
20	0	0	66.6	0	3.0

14-Sample B-1		Collected on 5/5			
0	0	0	0	0	2.0
2	0	0	0	0	2.3
5	0	0	0	0	2.7
10	66.6	0	0	0	3.0
30	100	0	0	0	ND
15-Sample C-1		Collected on 6/15			
0	0	0	0	0	7.1
2.5	0	0	0	0	7.9
5	66.6	0	100	0	7.5
10	100	0	0	0	ND
20	100	0	0	0	ND
16-Sample C-2		Collected on 6/15			
0	0	0	0	0	7.1
5	13.3	0	0	0	3.6
10	13.3	0	0	0	6.4
20	20	0	0	0	7.0
30	46.6	0	53.3	0	7.0
50	53.3	0	86.6	0	7.0
17-Sample D-1		Collected on 7/19			
0	0	0	0	0	3.3
5	0	0	0	0	3.3
10	0	0	0	0	4.0
20	13.3	26.6	0	0	6.0
30	40	33.3	13.3	0	7.0
40	73.3	53.3	20	0	7.5
18-Sample D-2		Collected on 7/19			
0	0	0	0	0	3.3
10	73.3	0	20	0	3.5
20	73.3	53.3	53.3	0	4.0
30	93.3	0	46.6	0	5.1
50	100	46.6	86.6	0	ND

***** Where no separate control (0% concentration) is shown, samples run the same day shared controls. ND = Not determined because all the embryos were dead.

** Number of stages delayed was calculated from the 5th day except for sample # 13 for which it was calculated from the 6th day.

Appendix H. Leachate flow-based compositing done on samples from Right pile on 12/8/11.

Bottle #	Time*	Volume Represented (L)**	Volume Used for Composite (mL)***
1	11:19	48.8	81.6
2	11:49	34.8	58.2
3	12:19	29.8	49.8
4	12:49	16.8	28.1
5	13:19	9.8	16.4
7	14:49	66.8	111.7
8	17:49	285.8	477.7
9	20:49	379.8	634.8
10	23:49	21.8	36.4
11	2:49	0.8	1.3
12	5:49	0.8	1.3
13	8:49	0.8	1.3
14	11:49	0.8	1.3
	Total	897.4	1500

* Time stamp from the automatic sampler when the sample was collected.
** Volume of leachate collected in that specific time period out of the total leachate collected.
*** Volume from the fraction used to make 1500 mL required for laboratory analysis

Appendix I. Pile Dimension Measurements.

Run 2

I.1. Left pile dimensions (5/10/12)

a) Measurements: Distances from reference height (m)

Y (m) / X (m)	**0**	**1.2192**	**2.4384**	**3.6576**	**4.8768**	**6.096**	**7.3152**
0	2.3241	2.34315	2.3495	2.35585	2.35585	2.38125	2.39395
1.2192	2.3495	2.3622	2.1844	1.9304	2.1209	2.35585	2.4003
2.4384	2.3495	1.8288	1.1938	0.88265	1.18745	2.30505	2.5654
3.6576	2.35585	1.7907	0.7747	0.2286	0.7112	1.8034	2.36855
4.8768	2.3622	1.87325	0.65405	0.2794	0.97155	1.88595	2.54
6.096	2.4511	2.34315	1.905	1.7399	1.84785	2.3749	2.5654
7.3152	2.4638						

b) Pile heights (m)*

	0	**1.2192**	**2.4384**	**3.6576**	**4.8768**	**6.096**	**7.3152**
0	0.0508	0.03175	0.0254	0.01905	0.01905	0	0
1.2192	0.0254	0.0127	0.1905	0.4445	0.254	0.01905	0
2.4384	0.0254	0.5461	1.1811	1.49225	1.18745	0.06985	0
3.6576	0.01905	0.5842	1.6002	2.1463	1.6637	0.5715	0.00635
4.8768	0.0127	0.50165	1.72085	2.0955	1.40335	0.48895	0
6.096	0	0.03175	0.4699	0.635	0.52705	0	0
7.3152	0	0	0	0	0	0	0

* Obtained by subtracting measurements from reference height: 2.3749 m. Values < 0 indicate slope of pad outside of pile, and are therefore set to 0.

c) Average height (m) within each grid (average of 4 corners)

	0-1.2	1.2-2.4	2.4-3.6	3.6-4.8	4.8-6.1	6.1-7.3	
0-1.2	0.030162	0.065087	0.169863	0.18415	0.073025	0.004763	
1.2-2.4	0.1524	0.4826	0.827088	0.84455	0.382588	0.022225	
2.4-3.6	0.293688	0.9779	1.604963	1.622425	0.873125	0.161925	
3.6-4.8	0.2794	1.101725	1.890713	1.827213	1.031875	0.2667	
4.8-6.1	0.136525	0.681038	1.230313	1.165225	0.604838	0.122238	
6.1-7.3	0.007937	0.125413	0.276225	0.290513	0.131763	0	
Sum	0.900112	3.433763	5.999163	5.934075	3.097213	0.57785	19.94

Volume (m^3) = (height) x $(side)^2$ = 1.486 (h)

29.65 m^3

I.2. Right pile dimensions (5/10/12)

a) Measurements: Distances from reference height (m)

	0	**1.2192**	**2.4384**	**3.6576**	**4.8768**	**6.096**	**7.3152**
0	2.121	2.140	2.146	2.153	2.153	2.172	
1.2192	2.127	2.146	2.038	1.969	2.057	2.184	
2.4384	2.134	1.899	0.933	0.902	1.041	1.994	
3.6576	2.140	1.791	0.673	0.216	0.730	1.867	
4.8768	2.140	1.365	0.813	0.737	1.327	1.899	
6.096	2.159	2.121	1.854	1.842	1.905	2.191	
7.3152	2.178	2.273	2.146	2.172	2.159	2.337	

b) Pile heights (m)*

	0	**1.2192**	**2.4384**	**3.6576**	**4.8768**	**6.096**	**7.3152**
0	0	0	0	0	0	0	0
1.2192	0	0	0.057	0.127	0.038	0	0
2.4384	0	0.197	1.162	1.194	1.054	0.102	0
3.6576	0	0.305	1.422	1.880	1.365	0.229	0
4.8768	0	0.730	1.283	1.359	0.768	0.197	0
6.096	0	0	0.2413	0.254	0.1905	0	0
7.3152	0	0	0	0	0	0	0

* Obtained by subtracting measurements from reference height: 2.3749 m. Values < 0 indicate slope of pad outside of pile, and are therefore set to 0.

c) Average height (m) within each grid (average of 4 corners)

	0-1.2	1.2-2.4	2.4-3.6	3.6-4.8	4.8-6.1	6.1-7.3	
0-1.2	0	0.014	0.046	0.041	0.009	0	
1.2-2.4	0.049	0.354	0.635	0.603	0.298	0.025	
2.4-3.6	0.125	0.772	1.414	1.373	0.687	0.083	
3.6-4.8	0.259	0.935	1.486	1.343	0.640	0.106	
4.8-6.1	0.183	0.564	0.784	0.643	0.289	0.049	
6.1-7.3	0	0.060	0.124	0.111	0.048	0	
Sum	0.616	2.699	4.489	4.115	1.972	0.264	14.15

21.04 m^3

Volume (m^3) = (height) x $(side)^2$ = 1.486 (h)

I.3. Far pile dimensions (5/10/12)

a) Measurements: Distances from reference height (m)

Y (m)	**0**	**1.2192**	**2.4384**	**3.6576**	**4.8768**	**6.096**	**7.3152**
0	2.343	2.343	2.350	2.343	2.343	2.527	
1.2192	2.343	2.356	2.096	1.765	1.816		
2.4384	2.350	1.988	0.718	0.660	1.302		
3.6576	2.350	1.708	0.432	0.464	1.073		
4.8768	2.356	1.651	0.775	0.845	1.276		
6.096	2.375	2.375	2.115	2.057	1.867		
7.3152	2.388						

b) Pile heights (m)*

	0	**1.2192**	**2.4384**	**3.6576**	**4.8768**	**6.096**	**7.3152**
0	0.032	0.032	0.025	0.032	0.032	0	0
1.2192	0.032	0.019	0.279	0.610	0.559	0	0
2.4384	0.025	0.387	1.657	1.715	1.073	0	0
3.6576	0.025	0.667	1.943	1.911	1.302	0	0
4.8768	0.019	0.724	1.600	1.530	1.099	0	0
6.096	0	0	0.260	0.318	0.508	0	0
7.3152	0	0	0	0	0	0	0

* Obtained by subtracting measurements from reference height: 2.3749 m. Values < 0 indicate slope of pad outside of pile, and are therefore set to 0.

c) Average height (m) within each grid (average of 4 corners)

	0-1.2	1.2-2.4	2.4-3.6	3.6-4.8	4.8-6.1	6.1-7.3	
0-1.2	0.029	0.089	0.237	0.308	0.148	0	
1.2-2.4	0.116	0.586	1.065	0.989	0.408	0	
2.4-3.6	0.276	1.164	1.807	1.500	0.594	0	
3.6-4.8	0.359	1.233	1.746	1.461	0.600	0	
4.8-6.1	0.186	0.646	0.927	0.864	0.402	0	
6.1-7.3	0	0.065	0.144	0.206	0.127	0	
Sum	0.965	3.783	5.926	5.328	2.278	0	18.28
							27.17 m^3

Volume (m^3) = (height) x $(\text{side})^2$ = 1.486 (h)

Run 3

I.4. Left Pile measurements (6/8/12)

a) Measurements: Distances from reference height (m)

Y (m)	0	1.2192	2.4384	3.6576	4.8768	6.096	7.3152
0	2.489	2.477	2.477	2.591	2.489	2.502	
1.2192	2.502	2.477	2.457	2.540	2.178	2.489	
2.4384	2.502	2.292	1.626	1.086	1.245	1.861	
3.6576	2.515	2.026	0.686	0.425	0.572	2.121	
4.8768	2.515	1.695	0.635	0.508	0.933	2.000	
6.096	2.591	2.007	1.346	1.549	1.607	2.311	
7.3152	2.743	2.515	2.362	2.007	2.096	2.489	

b) Pile heights (m)*

	0	1.2192	2.4384	3.6576	4.8768	6.096	7.3152
0	0	0	0	0	0	0	0
1.2192	0	0	0.006	0	0.286	0	0
2.4384	0	0.171	0.838	1.378	1.219	0.603	0
3.6576	0	0.438	1.778	2.038	1.892	0.343	0
4.8768	0	0.768	1.829	1.956	1.530	0.464	0
6.096	0	0.457	1.118	0.914	0.857	0.152	0
7.3152	0	0	0.102	0.457	0.368	0	0

* Obtained by subtracting measurements from reference height: 2.3749 m. Values < 0 indicate slope of pad outside of pile, and are therefore set to 0.

c) Average height (m) within each grid (average of 4 corners)

	0-1.2	1.2-2.4	2.4-3.6	3.6-4.8	4.8-6.1	6.1-7.3	
0-1.2	0	0.002	0.002	0.071	0.071	0	
1.2-2.4	0.043	0.254	0.556	0.721	0.527	0.151	
2.4-3.6	0.152	0.806	1.508	1.632	1.014	0.237	
3.6-4.8	0.302	1.203	1.900	1.854	1.057	0.202	
4.8-6.1	0.306	1.043	1.454	1.314	0.751	0.154	
6.1-7.3	0.114	0.419	0.648	0.649	0.344	0.038	
sum	0.918	3.727	6.067	6.242	3.766	0.781	21.50
							31.96 m^3

Volume (m^3) = (height) x $(side)^2$ = 1.486 (h)

I.5. Right Pile (6/8/12)

a) Measurements: Distances from reference height (m)

	0	1.2192	2.4384	3.6576	4.8768	6.096	7.3152
0	2.489	2.502	2.502	2.502	2.502	2.515	2.527
1.2192	2.489	2.515	2.108	1.880	2.038	2.515	
2.4384	2.502	2.229	1.372	1.111	1.041	2.318	
3.6576	2.515	1.975	0.838	0.018	0.730	1.784	
4.8768	2.515	1.746	0.705	0.591	1.016	2.0511	
6.096	2.527	2.216	2.038	1.854	1.9241	2.5146	
7.3152	2.540						

b) Pile heights (m)*

	0	1.2192	2.4384	3.6576	4.8768	6.096	7.3152
0	0	0	0	0	0	0	0
1.2192	0	0	0.356	0.584	0.425	0	0
2.4384	0	0.235	1.092	1.353	1.422	0.146	0
3.6576	0	0.489	1.626	2.446	1.734	0.679	0
4.8768	0	0.718	1.759	1.873	1.448	0.413	0
6.096	0	0.248	0.425	0.610	0.540	0	0
7.3152	0	0	0	0	0	0	0

* Obtained by subtracting measurements from reference height: 2.3749 m. Values < 0 indicate slope of pad outside of pile, and are therefore set to 0.

c) Average height (m) within each grid (average of 4 corners)

	0-1.2	1.2-2.4	2.4-3.6	3.6-4.8	4.8-6.1	6.1-7.3	
0-1.2	0	0.089	0.235	0.252	0.106	0	
1.2-2.4	0.059	0.421	0.846	0.946	0.498	0	
2.4-3.6	0.181	0.860	1.629	1.739	0.995	0	
3.6-4.8	0.302	1.148	1.926	1.875	1.068	0	
4.8-6.1	0.241	0.787	1.167	1.118	0.600	0	
6.1-7.3	0	0	0	0	0	0	
sum	0.783	3.305	5.803	5.930	3.269	0	19.0

28.375 (m^3)

Volume (m^3) = (height) x $(side)^2$ = 1.486 (h)

I.6. Far Pile (6/8/12)

a) Measurements: Distances from reference height (m)

Y (m)	0	1.2192	2.4384	3.6576	4.8768	6.096	7.3152
0	2.4892	2.4892	2.4892	2.5146	2.5146	2.667	
1.2192	2.4892	2.5146	1.8796	1.91135	1.397	2.413	
2.4384	2.4892	2.032	0.90805	0.5461	1.2827	2.0701	
3.6576	2.5019	1.524	0.5334	0.381	0.9144	1.8288	
4.8768	2.5019	1.8288	0.762	0.7747	1.778	2.3114	
6.096	2.5146	2.3241	2.032	1.91135	1.4224	2.286	
7.3152	2.5273						

b) Pile heights (m)*

	0	1.2192	2.4384	3.6576	4.8768	6.096	7.3152
0	0	0	0	0	0	0	0
1.2192	0	0	0.584	0.552	1.067	0.051	0
2.4384	0	0.432	1.556	1.918	1.181	0.394	0
3.6576	0	0.940	1.930	2.083	1.549	0.635	0
4.8768	0	0.635	1.702	1.689	0.686	0.152	0
6.096	0	0.140	0.432	0.552	1.041	0.178	0
7.3152	0	0	0	0	0	0	0

* Obtained by subtracting measurements from reference height: 2.3749 m. Values < 0 indicate slope of pad outside of pile, and are therefore set to 0.

c) Average height (m) within each grid (average of 4 corners)

	0-1.2	1.2-2.4	2.4-3.6	3.6-4.8	4.8-6.1	6.1-7.3	
0-1.2	0	0.14605	0.284163	0.404813	0.2794	0	
1.2-2.4	0.108	0.643	1.153	1.180	0.673	0	
2.4-3.6	0.343	1.214	1.872	1.683	0.940	0	
3.6-4.8	0.394	1.302	1.851	1.502	0.756	0	
4.8-6.1	0.194	0.727	1.094	0.992	0.514	0	
6.1-7.3	0	0	0	0	0	0	
sum	1.038	4.032	6.253	5.761	3.162	0.000	20.25

30.096 m^3

Volume (m^3) = (height) x $(\text{side})^2$ = 1.486 (h)

I.7. Left Pile (8/28/12)

a) Measurements: Distances from reference height (m)

Ɏ (m)	0	1.2192	2.4384	3.6576	4.8768	6.096	7.3152
0	2.426	2.432	2.438	2.445	2.451	2.457	2.489
1.2192	2.438	2.438	2.445	2.318	2.388	2.445	
2.4384	2.445	1.962	1.581	0.832	1.251	1.899	
3.6576	2.445	1.664	0.781	0.565	0.540	1.276	
4.8768	2.457	1.778	0.610	0.470	0.679	1.187	
6.096	2.489	2.045	2.134	1.556	1.524	1.969	
7.3152	2.565	2.54					

b) Pile heights (m)*

	0	1.2192	2.4384	3.6576	4.8768	6.096	7.3152
0	0	0	0	0	0	0	0
1.2192	0	0	0	0.095	0.025	0	0
2.4384	0	0.451	0.832	1.581	1.162	0.514	0
3.6576	0	0.749	1.632	1.848	1.873	1.137	0
4.8768	0	0.635	1.803	1.943	1.734	1.226	0
6.096	0	0.368	0.279	0.857	0.889	0.445	0
7.3152	0	0	0	0	0	0	0

* Obtained by subtracting measurements from reference height: 2.3749 m. Values < 0 indicate slope of pad outside of pile, and are therefore set to 0.

c) Average height (m) within each grid (average of 4 corners)

	0-1.2	1.2-2.4	2.4-3.6	3.6-4.8	4.8-6.1	6.1-7.3	
0-1.2	0	0	0.024	0.030	0.006	0	
1.2-2.4	0.113	0.321	0.627	0.716	0.425	0	
2.4-3.6	0.300	0.916	1.473	1.616	1.172	0	
3.6-4.8	0.346	1.205	1.807	1.849	1.492	0	
4.8-6.1	0.251	0.772	1.221	1.356	1.073	0	
6.1-7.3	0.092	0	0	0	0	0	
sum	1.102	3.213	5.151	5.567	4.169	0	19.20

Volume (m^3) = (height) x $(side)^2$ = 1.486 (h)

28.543 m^3

I.8. Right Pile (8/28/12)

a) Measurements: Distances from reference height (m)

Y (m)	0	1.2192	2.4384	3.6576	4.8768	6.096	7.3152
0	2.426	2.426	2.426	2.438	2.438	2.438	
1.2192	2.432	2.464	2.115	1.899	1.905	2.286	
2.4384	2.445	1.778	1.041	1.016	0.838	1.778	
3.6576	2.445	1.784	1.784	1.778	0.400	1.791	
4.8768	2.445	1.810	0.508	0.514	1.029	1.791	
6.096	2.451	2.457	1.530	1.537	1.797	2.299	
7.3152	2.457						

b) Pile heights (m)*

	0	1.2192	2.4384	3.6576	4.8768	6.096	7.3152
0	0	0	0	0	0	0	0
1.2192	0	0	0.298	0.514	0.508	0.127	0
2.4384	0	0.635	1.372	1.397	1.575	0.635	0
3.6576	0	0.629	0.629	0.635	2.013	0.622	0
4.8768	0	0.603	1.905	1.899	1.384	0.622	0
6.096	0	0	0.883	0.876	0.616	0.114	0
7.3152	0	0	0	0	0	0	0

* Obtained by subtracting measurements from reference height: 2.3749 m. Values < 0 indicate slope of pad outside of pile, and are therefore set to 0.

c) Average height (m) within each grid (average of 4 corners)

	0-1.2	1.2-2.4	2.4-3.6	3.6-4.8	4.8-6.1	6.1-7.3	
0-1.2	0	0.074	0.203	0.255	0.158	0	
1.2-2.4	0.159	0.576	0.895	0.999	0.711	0	
2.4-3.6	0.316	0.816	1.008	1.405	1.211	0	
3.6-4.8	0.308	0.941	1.267	1.483	1.160	0	
4.8-6.1	0.151	0.848	1.391	1.194	0.684	0	
6.1-7.3	0	0	0	0	0	0	
sum	0.933	3.256	4.764	5.336	3.926	0	18.21

Volume (m^3) = (height) x (side)^2 = 1.486 (h)

27.076 m^3

I.9. Far Pile (8/28/12)

a) Measurements: Distances from reference height (m)

Y (m)	0	1.2192	2.4384	3.6576	4.8768	6.096	7.3152
0	2.426	2.432	2.445	2.451	2.451	2.591	
1.2192	2.438	2.438	2.140	1.588	1.346	1.702	
2.4384	2.438	2.369	1.448	0.737	0.603	1.232	
3.6576	2.438	2.235	0.946	0.413	0.667	1.289	
4.8768	2.451	2.216	1.067	0.527	0.838	1.080	
6.096	2.457	2.457	2.096	1.822	1.981	1.988	
7.3152	2.464						

b) Pile heights (m)*

	0	1.2192	2.4384	3.6576	4.8768	6.096	7.3152
0	0	0	0	0	0	0	0
1.2192	0	0	0.273	0.826	1.067	0.711	0
2.4384	0	0.044	0.965	1.676	1.810	1.181	0
3.6576	0	0.178	1.467	2.000	1.746	1.124	0
4.8768	0	0.197	1.346	1.886	1.575	1.334	0
6.096	0	0	0.318	0.591	0.432	0.425	0
7.3152	0	0	0	0	0	0	0

* Obtained by subtracting measurements from reference height: 2.3749 m. Values < 0 indicate slope of pad outside of pile, and are therefore set to 0.

c) Average height (m) within each grid (average of 4 corners)

	0-1.2	1.2-2.4	2.4-3.6	3.6-4.8	4.8-6.1	6.1-7.3	
0-1.2	0	0.068	0.275	0.473	0.445	0	
1.2-2.4	0.011	0.321	0.935	1.345	1.192	0	
2.4-3.6	0.056	0.664	1.527	1.808	1.465	0	
3.6-4.8	0.094	0.797	1.675	1.802	1.445	0	
4.8-6.1	0.049	0.465	1.035	1.121	0.941	0	
6.1-7.3	0	0	0	0	0	0	
sum	0.210	2.315	5.447	6.548	5.488	0	20.007

29.740 m^3

Volume (m^3) = (height) x $(side)^2$ = 1.486 (h)

I.10. Left Pile (2/15/13)

a) Measurements: Distances from reference height (m)

Y (m)	0	1.2192	2.4384	3.6576	4.8768	6.096	7.3152
0	2.426	2.419	2.419	2.438	2.445	2.451	2.489
1.2192	2.451	2.432	2.242	2.038	2.210	2.419	2.464
2.4384	2.451	2.165	1.626	1.499	1.765	2.273	
3.6576	2.451	1.829	0.883	0.622	0.648	2.267	
4.8768	2.464	1.854	0.724	0.546	0.813	2.038	
6.096	2.565	1.530	1.708	1.511	1.727	2.019	
7.3152							

b) Pile heights (m)*

	0	1.2192	2.4384	3.6576	4.8768	6.096	7.3152
0	0.038	0.044	0.044	0.025	0.019	0.013	0
1.2192	0.013	0.032	0.222	0.425	0.254	0.044	0
2.4384	0.013	0.298	0.838	0.965	0.699	0.191	0
3.6576	0.013	0.635	1.581	1.842	1.816	0.197	0
4.8768	0	0.610	1.740	1.918	1.651	0.425	0
6.096	0	0.933	0.756	0.953	0.737	0.445	0
7.3152	0	0	0	0	0	0	0

* Obtained by subtracting measurements from reference height: 2.3749 m. Values < 0 indicate slope of pad outside of pile, and are therefore set to 0.

c) Average height (m) within each grid (average of 4 corners)

	0-1.2	1.2-2.4	2.4-3.6	3.6-4.8	4.8-6.1	6.1-7.3	
0-1.2	0.032	0.086	0.179	0.181	0.083	0.014	
1.2-2.4	0.089	0.348	0.613	0.586	0.297	0.000	
2.4-3.6	0.240	0.838	1.307	1.330	0.725	0.000	
3.6-4.8	0.314	1.141	1.770	1.807	1.022	0.000	
4.8-6.1	0.386	1.010	1.341	1.314	0.814	0.000	
6.1-7.3	0	0	0	0	0	0	
sum	1.060	3.423	5.210	5.218	2.942	0.014	17.87

Volume (m^3) = (height) x $(\text{side})^2$ = 1.486 (h)

26.56 m^3

I.11. Right Pile (2/15/13)

a) Measurements: Distances from reference height (m)

Y (m)	0	1.2192	2.4384	3.6576	4.8768	6.096	7.3152
0	2.413	2.464	2.464	2.438	2.464	2.489	2.5146
1.2192	2.432	2.489	2.407	2.350	2.159	2.350	
2.4384	2.438	1.702	1.232	1.035	1.295	2.165	
3.6576	2.438	1.842	0.559	0.305	0.965	2.178	
4.8768	2.438	1.689	0.908	0.679	1.118	2.407	
6.096	2.464	1.575	1.295	1.232	1.930		
7.3152	2.489						

b) Pile heights (m)*

	0	1.2192	2.4384	3.6576	4.8768	6.096	7.3152
0	0.051	0	0	0.025	0	0	0
1.2192	0.032	0	0.0572	0.114	0.305	0.114	0
2.4384	0.025	0.762	1.2319	1.429	1.168	0.298	0
3.6576	0.025	0.622	1.905	2.159	1.499	0.286	0
4.8768	0.025	0.775	1.5558	1.784	1.346	0.057	0
6.096	0	0.889	1.1684	1.232	0.533	0	0
7.3152	0	0	0	0	0	0	0

* Obtained by subtracting measurements from reference height: 2.3749 m. Values < 0 indicate slope of pad outside of pile, and are therefore set to 0.

c) Average height (m) within each grid (average of 4 corners)

	0-1.2	1.2-2.4	2.4-3.6	3.6-4.8	4.8-6.1	6.1-7.3	
0-1.2	0.021	0.014	0.049	0.111	0.105	0	
1.2-2.4	0.205	0.513	0.708	0.754	0.471	0	
2.4-3.6	0.359	1.130	1.681	1.564	0.813	0	
3.6-4.8	0.362	1.214	1.851	1.697	0.797	0	
4.8-6.1	0.422	1.097	1.435	1.224	0.000	0	
6.1-7.3	0.000	0.000	0.000	0.000	0.000	0	
sum	1.368	3.969	5.725	5.350	2.186	0	18.6

Volume (m^3) = (height) x $(side)^2$ = 1.486 (h)

27.64 m^3

I.12. Far Pile (2/15/13)

a) Measurements: Distances from reference height (m)

Y (m)	0	1.2192	2.4384	3.6576	4.8768	6.096	7.3152
0	2.413	2.438	2.464	2.489	2.489	2.489	
1.2192	2.438	2.489	1.956	1.930	1.676	2.159	
2.4384	2.438	2.261	1.105	0.737	1.003	1.638	
3.6576	2.438	1.689	0.851	0.597	0.762	1.791	
4.8768	2.445	1.651	1.187	0.914	0.991	2.007	
6.096	2.464	2.261	1.626	1.168	1.854	2.362	
7.3152	2.515						

b) Pile heights (m)*

	0	1.2192	2.4384	3.6576	4.8768	6.096	7.3152
0	0.051	0.025	0.000	0.000	0.000	0.000	0
1.2192	0.025	0.000	0.508	0.533	0.787	0.305	0
2.4384	0.025	0.203	1.359	1.727	1.461	0.826	0
3.6576	0.025	0.775	1.613	1.867	1.702	0.673	0
4.8768	0.019	0.813	1.276	1.549	1.473	0.457	0
6.096	0	0.203	0.838	1.295	0.610	0.102	0
7.3152	0	0	0	0	0	0	0

* Obtained by subtracting measurements from reference height: 2.3749 m. Values < 0 indicate slope of pad outside of pile, and are therefore set to 0.

c) Average height (m) within each grid (average of 4 corners)

	0-1.2	1.2-2.4	2.4-3.6	3.6-4.8	4.8-6.1	6.1-7.3	
0-1.2	0.025	0.133	0.260	0.330	0.000	0	
1.2-2.4	0.064	0.518	1.032	1.127	0.845	0	
2.4-3.6	0.257	0.987	1.641	1.689	1.165	0	
3.6-4.8	0.408	1.119	1.576	1.648	1.076	0	
4.8-6.1	0.259	0.783	1.240	1.232	0.660	0	
6.1-7.3	0.000	0.000	0.000	0.000	0.000	0	
sum	1.013	3.540	5.750	6.026	3.747	0	20.076

Volume (m^3) = (height) x $(side)^2$ = 1.486 (h)

29.841 m^3

Appendix J. Leachate physico-chemical analysis results.

J.1. Physico-chemical analysis results for Run 2

Date	**Pad**	**Lcht**	**pH**	**COD**	**BOD**	**TSS**	**L**	**TKN**	**NH_4^+**	**TP**	**T/L/P**
		L		mg/L	mg/L	mg/L	%	mg/L	mg/L	mg/L	mg/L
11/21/11	**Left**	12.8	6.33	288		16	78.9	2.18	0.11	2	20
	Right	14.8	6.29	357		14	85.8	1.64	0.11	1.9	15
	Far	9.0	6.37			3	98.2	0.82	0.1		2.5
11/23/11	**Left***	1161.0		4375		128		56	9.3	11	105
	1 to 12	20.6	6.5	412	190	28	89.1	4.9	0.74	1.8	18
	13 to 18	1049.8	5.27	4656		129	62.5	57.4	9.9	11.3	110
	19 & 20	90.6	5.56	2030	BDL	146	65.2	54	4.39	6.5	65
	Right										
	1, 2 & 3		6.53	177	43	5	95.2	1.8	0.07	1.6	6
	4-9&12-19		6.27	821		34	79.4	7	0.51	6	20
	20, 21&22		6.18	1913	BDL	73	57.3	25.3	0.63	9.7	55
	Far		6.61	83							
11/28/11	**Left**		6.18	3348		167	46.7	24.2	11.15	3.8	25
	Right		6.33	2043		101	38.3	15.2	0.13	4.4	15
11/30/11	**Left**	214.2	6.2	1084	420	68	84.5	8.6	0.19	4.1	25
	1 to 6			1195							20
	7 to 10			1126							35
	11 to 14			1089							30
	Right	323.4	6.6	993	57	36	82.9	7.2	0.27	4.1	15
	1 to 6			549							15
	7 to 10			584							20
	11 to 14			658							35
	Far		6.21		33	20	87.7	2.76	0.12	3.4	20
12/7/11	**Left**	123.8	6.25	572	130	26	86	2	1.32	2.2	24
	Right	221.4	6.58	538	19	18	78	1.76	0.04	3.4	25
	Far	123.8	6.85	193	17	15	88.2	1.05	0.01	5	10
12/8/11	**Left**	1395.4	6.72	811		71	69.7	3.3	0.09	3	40
	Right	897.4	6.41	474		102	82.8	3.14	1.69	3.4	18
	Far		6.6	680		54	64.5		0.11	0.9	36
12/23/11	**Left**	1207.0	6.8	690		38	74.6	2.8	0.17	2.3	28
	Right	1518.0	6.63	513		34	77.9	3.6	0.40	4	20
12/29/11	**Left**	561.8	6.72	584		30	79.9	4.7	0.05	2.19	22.5
	Right		6.78	651		26	74.9	3.8	0.06	3	25

	Far	484	6.87	633		37	71.7	2.8	0.03	3.23	30
1/13/12	**Left**	1060	6.63				81.7		0.70	1.5	
	1 &2 (Even)			1195				0.7			
	3 to 17			537		18		0.1			20
	Right	1034.4	6.6				83.9		0.70	2.2	
	1 to 9 (Even)			1890				0.5			
	10 to 22			410		8		0.2			20
1/18/12	Left	212	6.97	536		105	83.5	4.6	0.03	1.4	22
	Far	190	6.97	870		90	70.4	4	0.04	4.5	30
1/25/12	Left										
	1 to 7		6.72	284		4	88.4	0.27	0.03	1.63	10
	8 to 24	347.6	6.64	247		5	91.5	1.1	0.03	0.85	10
	Right	475	6.67	357		8	84.4	0.81	0.03	1.9	10
	Far										
	1 to 11		6.78	620		7	73.7	4.5	0.16	1.82	25
	12 to 24	357.4	6.76	229		3	89.3	1.5	0.03	1.7	10
1/30/12	Left	339	6.75	482		13	82.4	4.7	0.07	1.78	15
	Right	152	6.22	412		10	82.1	4.8	0.04	2.09	15
	Far	268	6.28	380		11	81.5	5.4	0.05	2.49	15
2/27/12	Left	78.6	6.56	272		6.3	91.6	3.6	0.02	0.3	10
	Right	128.2	6.33	196		3.3	93.3	2.6	0.02	0	10
	Far	77	6.3	119		5.3	96.4	1.8	0.02	0	5
4/24/12	Left	1559	6.46	517	< 40	21	76.2	2.32	0.53	0.63	21
	Right	1684	6.37	457	< 40	11	77	3.39	0.99	0.22	18
	Far	1244	6.6	483	< 40	22	74.3	1.91	0.26	2.8	21

* Calculated composite

BDL = below detection limit

J.2. Physico-chemical analysis results for Run 3

Date	Pile	Leachate	pH	COD	BOD	TSS	L	TKN	NH_4^+	NO_3^-	TP	T/L/P
5/30/12	Left	253	5.93	264	< 60	15	84.9	6.41	1.785		2.08	15
	Right	169	6.43	327	< 60	17	83.4	5.28	1.456		1.58	25
	Far	312	6.82	284	< 60	89	86.9	5.08	0.051		1.39	10
6/5/12	**Left**	232.2	6.10	309*	30	31.6	87.6	5.7*	0.81*		3.15	20
	A (1 to 6)	129		314				5.53	0.596			
	B (7 to 20)	21		355				5.10	1.624			
	C (21 to 24))	82		290				6.22	0.951			
	Right	275	6.20	579*	98	55	78.9	5.8*	1.02*		5.02	45
	D (8 & 9)	185		614				7.31	1.342			
	E(10 & 11)	80		503				2.45	0.366			
	F (12 to 17)	5		517				4.33	0.135			
	Far	250	6.45	619*	117	73	76	4.3*	0.14*		4.41*	55
	X (4,5,7,8)	149		676				4.68	0.108		4	
	Y (9 to 21)	53		614				4.42	0.171		3.73	
	Z (22 to 24)	44		435				2.86	0.251		2.92	
6/14/12	Left	133.6	6.71	212	< 30	63	89.1	6.00	1.911		2.17	20
	Right	112	6.64	250	< 30	16.6	82.9	4.72	1.949		3.03	15
	Far	145.6	6.66	221	35	31	87.5	6.59	1.893		2.26	5
6/24/12	Left	305	6.3	277		16.6	81	1.63	0.273		3.57	20
	Right	Failed	6.14	409		32.6	76.5	3.04	1.212		4.76	30
	Far	419	6.45	341		24	79.6	2.16	1.062		3.62	20
7/17/12	Left	231	6.31	427		20	73.8	5.96	1.623		3.42	25
	Far	Failed	6.10	353		17.7	79.5	5.18	0.814		3.61	25

* Calculated composite.
BDL = below detection limit.

Appendix J.2. continued

7/24/12	Left	285	6.65	1184		30	41.8	9.03	2.073		7.69	37.5
	Right	658	6.18	1175		27	50.0	11.58	2.512		9.03	32.5
	Far	260	6.95	802		27	55.4	7.24	2.145		7.74	22.5
8/1/12	Left	654	6.38	383		10	78.4	2.84	1.208		4	22
	Right	649	6.42	358		BDL	78.5	2.06	0.673		3.52	24
	Far	860	6.32	350		13.3	79.2	2.81	0.752		3.85	22
8/6/12	Left	620	6.54	432		26	76.8	4.21	0.538		3.59	20
	Right	611	6.22	304		16	81.3	3.69	0.583		2.28	15
	Far	789	6.52	342		14	78.1	3.50	0.636		3.10	20
8/13/12	Left	381	6.47	562		13.6	69.9	3.18	0.727		4.29	25
	Right	511	6.07	221		10.3	86.3	1.12	0.244		1.33	15
	Far	250	6.70	381		8	74.5	1.57	0.64		3.51	18
8/21/12	Left	141	6.58	555		16	65.4	3.20	0.103		3.94	27.5
	Right	161	6.71	414		6.6	71.3	2.97	0.116		3.75	25
	Far	112	6.80	447		8.3	68.3	4.07	0.409		3.39	25
8/28/12	Left	137	6.08	181		10.3	91.0	2.69	0.705		0.88	10
	Right	230	5.85	210		19.9	89.6	2.27	0.359		0.59	15
	Far	150	6.37	239		26	89.2	2.49	0.272		1.16	20
9/6/12	Left	920	6.37	435		17.1	76.3	3.35	0.387		2.53	15
	Right	1045	6.0	327		11.3	82.1	2.36	0.386		1.58	12.5
	Far	702	6.64	584		12	69.1	3.80	0.43		3.17	17.5
9/11/12	Left	47	6.55	446		8.3	74.2	5.25	0.58		4.35	20
	Right	58	6.42	442		4	69.0	3.77	0.61		3.34	22.5
	Far	35	6.62	444		3	69.7	4.37	0.54		3.52	27.5
9/20/12	**Left**	660	6.70	604*		26.8*		6.7*	0.1*		4.1*	24*
	A (1 to 9)	68		262		17	81.9	3.30	0.104		3.19	15
	B (10 to 13)	523		644		28	65.0	7.12	0.098		4.22	25
	C (14 to 16)	3.4		1322		46	42.7	14.52	1.47		7.25	42.5

* Calculated composite; BDL = below detection limit

Appendix J.2. continued

	Right	595	6.57	404*		28.3*		3.47*	0.09*		2.3*	18*
	D (1 to 9)	76.2		286		15	86.8	3.48	0.322		1.15	20
	E (10to 13)	581		416		30	80.3	3.44	0.065		2.48	17.5
	F (14 to 17)	3.2		1143		38	52.3	9.96	1.315		4.29	37.5
	Far	780	6.90	650*		27.2*		4.8*	0.21*		4.07*	27*
	X (1 to 11)	75.8		312		10	80.4	3.41	0.079		2.72	20
	Y (12 to 15)	701		684		29	66.1	4.95	0.225		4.22	27.5
	Z (16 to 19)	3.2		1105		37	54.3	10.11	0.070		4.85	35
10/1/12	Left	184	6.65	593		11.3	69.8	3.05	0.053		3.81	21
	Right	109	6.67	553		9.3	71.0	3.87	0.047		2.84	15
	Far	181	6.58	347		14.7	82.5	1.48	0.061		1.60	15

* Calculated composite; BDL = below detection limit.

Appendix K. Simple Regression Analysis.

Appendix K.1. Simple regression analysis results for all piles combined from Run 2.

LEACHATE (L)

Y	x-coefficient	Intercept	R^2	p-value
Total Rain (mm)				
Total Leachate	27.33	**-59.32**	0.91	**$4.9*10^{-29}$**
Corrected Pile Leachate	19.96	**-57.51**	0.84	**$5.48*10^{-22}$**
Rain up to sampling (mm)				
Leachate up to Sampling	26.63	-34.67	0.88	**$2.74*10^{-15}$**
Age of pile (d)				
Total Leachate	-1.329	508.3	0.02	0.34
Corrected Pile Leachate	-0.854	347.85	0.01	0.421
Time since rain stopped (d)				
Total Leachate	-27.56	**639.54**	0.19	**0.001**
Corrected Pile Leachate	-20.66	**457.21**	0.18	**0.001**
Time since leachate stopped (d)				
Total Leachate	-25.02	**608.44**	0.16	**0.004**
Corrected Pile Leachate	-18.4	**434.67**	0.15	**0.006**
10 min rain intensity (mm)				
Total Leachate	171.18	111.46	0.20	**0.0008**
Corrected Pile Leachate	149.1	40.606	0.23	**0.0003**
1 hr rain intensity (mm)				
Total Leachate	104.61	-130.8	0.70	**$8.25*10^{-15}$**
Corrected Pile Leachate	75.46	-99.85	0.63	**$2.21*10^{-12}$**
2 hr rain intensity (mm)				
Total Leachate	76.122	**-164.54**	0.85	**$1.48*10^{-22}$**
Corrected Pile Leachate	55.66	**-132.48**	0.79	**$1.82*10^{-18}$**

Bold values in the p-value and intercept columns indicate significance ($p < 0.05$).

LOADS (g)

Y	x-coefficient	Intercept	R^2	p-value
Rain up to sampling (mm)				
COD load	30.611	-253.49	0.36	**0.0005**
TKN load	0.278	-2.839	0.18	**0.02**
TP load	0.09	-0.48	0.43	**0.0001**
Leachate up to sampling (L)				
COD load	0.854	-44.23	0.23	**0.008**
TKN load	0.006	-0.232	0.09	0.12
TP load	0.002	0.085	0.30	**0.002**
Age of Pile (d)				
COD load	-3.22	672.72	0.02	0.42
TKN load	-0.052	6.943	0.04	0.30
TP load	-0.014	2.579	0.07	0.16
Time since rain stopped (d)				
COD load	-78.05	873.93	0.10	0.11
TKN load	-0.918	8.33	0.09	0.14
TP load	-0.177	2.835	0.10	0.11
Time since leachate stopped (d)				
COD load	-66.6	804.7	0.07	0.21
TKN load	-0.843	7.86	0.07	0.22
TP load	-0.199	2.66	0.08	0.16
10 min rain intensity (d)				
COD load	313.45	-90.86	0.12	0.07
TKN load	2.322	-0.386	0.04	0.30
TP load	0.985	-0.422	0.37	**0.0004**
1 hr rain intensity (mm)				
COD load	77.51	7.82	0.13	**0.05**
TKN load	0.476	0.942	0.03	0.36
TP load	0.255	-0.188	0.46	$\mathbf{5.1*10^{-5}}$
2 hr rain intensity (mm)				
COD load	58.31	-76.012	0.16	**0.03**
TKN load	0.391	0.108	0.04	0.27
TP load	0.183	-0.382	0.50	$\mathbf{1.9*10^{-5}}$
Corrected Pile Leachate (L)				
COD load	0.998	33.41	0.19	**0.02**
TKN load	0.007	0.597	0.06	0.19
TP load	0.003	0.302	0.26	**0.01**

Bold values in the p-value and intercept columns indicate significance ($p < 0.05$).

Concentrations (mg/L)

Y	x-coefficient	Intercept	R^2	p-value
Rain up to sampling (mm)				
COD	13.343	282.14	0.12	**0.05**
TKN	0.17	0.741	0.10	0.07
TP	0.026	1.824	0.06	0.17
Leachate up to sampling (L)				
COD	0.0367	388.5	0.07	0.18
TKN	0.003	3.14	0.02	0.43
TP	0.0008	1.9	0.04	0.27
Age of Pile (d)				
COD	-4.39	864.21	0.07	0.14
TKN	-0.044	7.026	0.04	0.25
TP	-0.023	3.767	0.29	**0.001**
Time since leachate stopped (d)				
COD	-38.73	763.61	0.04	0.33
TKN	-0.685	7.964	0.06	0.21
TP	-0.0954	2.858	0.03	0.38
10 min rain intensity (mm)				
COD	174.66	299.26	0.06	0.17
TKN	1.524	1.962	0.03	0.37
TP	0.33	1.861	0.03	0.34
	1 hr rain intensity			
COD	32.745	414.77	0.04	0.26
TKN	0.191	3.493	0.01	0.64
TP	0.027	2.291	0.00	0.73
2 hr rain intensity (mm)				
COD	23.16	394.9	0.04	0.25
TKN	0.181	2.964	0.01	0.51
TP	0.0327	2.148	0.01	0.55
Corrected Pile Leachate (L)				
COD	0.3848	528.84	0.03	0.34
TKN	0.002	4.198	0.01	0.69
TP	0.0005	2.309	0.01	0.67

Bold values in the p-value and intercept columns indicate significance ($p < 0.05$).

Appendix K.2. Simple regression analysis results for all piles combined from Run 3

LEACHATE (L)

Y	x-coefficient	Intercept	R^2	p-value
	Total Rain (mm)			
Total Leachate	17.93	**-55.8**	0.85	**$6.77*10^{-30}$**
Corrected Pile Leachate	9.93	**-52.3**	0.61	**$1.13*10^{-15}$**
	Age of pile (d)			
Total Leachate	-0.924	358.7	0.02	0.22
Corrected Pile Leachate	-0.158	145.2	0.00	0.74
	Time since rain stopped (d)			
Total Leachate	25.22	**155**	0.07	**0.03**
Corrected Pile Leachate	69	55	0.06	**0.04**
	Time since leachate stopped (d)			
Total Leachate	19.572	**150.2**	0.06	0.051
Corrected Pile Leachate	11.95	53.6	0.06	0.06
	10 min rain intensity (mm)			
Total Leachate	38.35	**117.3**	0.28	**$2.64*10^{-6}$**
Corrected Pile Leachate	16.607	**55.2**	0.14	**0.001**
	1 hr rain intensity (mm)			
Total Leachate	21.13	58.7	0.44	**$4.26*10^{-10}$**
Corrected Pile Leachate	11.22	16.0	0.29	**$1.47*10^{-6}$**
	2 hr rain intensity (mm)			
Total Leachate	17.65	59.75	0.44	**$3.28*10^{-10}$**
Corrected Pile Leachate	9.49	15.02	0.30	**$8.67*10^{-7}$**

Bold values in the p-value and intercept columns indicate significance ($p < 0.05$).

LOADS (g)

Y	x-coefficient	Intercept	R^2	p-value
	Total Rain (mm)			
COD load	9.32	-54.56	0.59	**$1.75*10^{-9}$**
TKN load	0.068	-0.114	0.40	**$4.53*10^{-6}$**
TP load	0.066	-0.33	0.55	**$1.24*10^{-8}$**
	Total Leachate (L)			
COD load	0.458	-1.33	0.61	**$6.09*10^{-10}$**
TKN load	0.003	0.196	0.47	**$3.56*10^{-7}$**
TP load	0.003	0.062	0.56	**$8.57*10^{-9}$**
	Age of Pile (d)			
COD load	0.76	114.9	0.03	0.23
TKN load	0.0008	1.46	0.00	0.891
TP load	0.0002	1.119	0.00	0.65
	Time since rain stopped (d)			
COD load	8.71	132.06	0.02	0.318
TKN load	0.092	1.05	0.04	0.233
TP load	0.075	0.951	0.04	0.238
	Time since leachate stopped (d)			
COD load	6.25	114.25	0.04	0.271
TKN load	0.086	0.798	0.10	0.06
TP load	0.064	0.749	0.08	0.094
	10 min rain intensity (mm)			
COD load	15.44	87.18	0.12	**0.02**
TKN load	0.114	0.912	0.09	0.054
TP load	0.13	0.582	0.16	**0.007**
	1 hr rain intensity (mm)			
COD load	12.47	19.01	0.39	**$6.91*10^{-6}$**
TKN load	0.092	0.399	0.28	**0.0002**
TP load	0.086	0.227	0.35	**$3.33*10^{-5}$**
	2 hr rain intensity (mm)			
COD load	11.539	3.6	0.50	**$1.12*10^{-7}$**
TKN load	0.09	0.219	0.40	**$6.09*10^{-6}$**
TP load	0.084	0.056	0.49	**$1.65*10^{-7}$**
	Corrected Pile Leachate (L)			
COD load	0.619	**59.2**	0.51	**$9.03*10^{-8}$**
TKN load	0.005	**0.6**	0.43	**$1.62*10^{-6}$**
TP load	0.004	**0.5**	0.46	**$5.41*10^{-7}$**

Bold values in the p-value and intercept columns indicate significance ($p < 0.05$).

Concentrations (mg/L)

Y	x-coefficient	Intercept	R^2	p-value
	Total Rain (mm)			
COD	4.586	327.6	0.08	0.07
TKN	0.003	4.1	0.00	0.884
TP	0.033	2.56	0.06	0.099
	Total Leachate (L)			
COD	0.09	404.43	0.01	0.474
TKN	-0.0007	4.48	0.01	0.554
TP	0.0005	3.157	0.01	0.639
	Age of Pile (d)			
COD	0.849	377.9	0.02	0.318
TKN	-0.017	5.37	0.10	0.035
TP	-0.003	3.58	0.01	0.646
	Time since leachate stopped (d)			
COD	-9.25	478.5	0.03	0.328
TKN	0.106	3.35	0.04	0.228
TP	0.0201	3.165	0.002	0.787
	10 min rain intensity (mm)			
COD	10.95	379.5	0.03	0.239
TKN	-0.01	4.24	0.0003	0.898
TP	0.113	2.79	0.06	0.122
	1 hr rain intensity (mm)			
COD	11.61	297	0.18	**0.004**
TKN	0.034	3.77	0.02	0.397
TP	0.087	2.3	0.16	**0.006**
	2 hr rain intensity (mm)			
COD	12.97	250.8	0.34	**$3.82*10^{-5}$**
TKN	0.067	3.22	0.10	**0.039**
TP	0.103	1.872	0.34	**$2.93*10^{-5}$**
	Corrected Pile Leachate (L)			
COD	0.029	432.6	0.001	0.87
TKN	-0.001	4.46	0.01	0.44
TP	-0.0002	3.36	0.0004	0.903

Bold values in the p-value and intercept columns indicate significance ($p < 0.05$).

Appendix L. Multiple Regression Analysis.

Appendix_L.1. Significance of different parameters from multiple regression analysis of Run 2 results

2nd Run							
Left Pile							
COD Load							
Forward Stepwise Regression							
Ind. Variable	**R^2**	**R_a^2**	**p-value**				**X coeff. sign**
			rain	**age**	**2 hr**	**TSRS**	
Rain*	0.463		**0.01**				+
Age	0.073			0.371			-
2 hr	0.165				0.169		+
TSRS	0.146					0.219	-
rain + age	0.575	0.49	**0.0063**	0.156			+, -
rain + 2 hr	0.767	0.72	**0.0004**		**0.005**		+, -
rain +TSRS	0.479	0.363	**0.04**			0.67	+, -
rain +2 hr + age	0.838	0.784	**0.0003**	0.077	**0.004**		+, -, -
rain+ 2 hr +TSRS	0.769	0.682	**0.002**		**0.013**	0.649	+, -, -
Backward Stepwise Regression							
rain+2hr +age +TSRS	0.844	0.754	**0.001**	0.109	**0.01**	0.572	+, -, -, -
rain + age + 2 hr	0.838	0.784	**0.0003**	0.077	**0.004**		+, -, -
rain + 2 hr	0.767	0.72	**0.0004**		**0.005**		+, -
TKN Load							
Forward Stepwise Regression							
Rain	0.275		0.066				+
Age	0.089			0.321			-
2 hr	0.049				0.464		+
TSRS	0.123					0.264	-
rain + age	0.397	0.277	**0.047**	0.203			+, -
rain + 2 hr	0.698	0.638	**0.0009**		**0.004**		+, -
rain + TSRS	0.302	0.148	0.161			0.626	+, -
rain + 2 hr + age	0.775	0.699	**0.0007**	0.115	**0.003**		+, -, -
rain+2 hr + TSRS	0.708	0.598	**0.004**		**0.01**	0.581	+, -, -
Backward Stepwise Regression							
rain+2 hr +age+TSRS	0.789	0.669	**0.003**	0.143	**0.009**	0.516	+, -, -, -
rain + 2 hr + age	0.775	0.699	**0.0007**	0.115	**0.003**		+, -, -
rain + 2 hr	0.698	0.638	**0.0009**		**0.004**		+, -

TP Load							
Forward Stepwise Regression							
Rain	0.483		**0.0083**				+
Age	0.133			0.219			-
2 hr	0.206				0.119		+
TSRS	0.097					0.113	-
rain + age	0.664	0.597	**0.002**	**0.048**			+, -
rain + 2 hr	0.7	0.64	**0.002**		**0.025**		+, -
rain + TSRS	0.497	0.386	**0.035**			0.64	+, -
rain + 2 hr+ age+TSRS	0.851	0.767	**0.003**	**0.032**	**0.023**	0.496	+, -, -, -
Backward Stepwise Regression							
rain+2 hr + age +TSRS	0.851	0.767	**0.003**	**0.032**	**0.023**	0.496	+, -, -, -
rain + age +TSRS	0.838	0.785	**0.0006**	**0.021**	**0.012**		+, -, -
Total Leachate							
Forward Stepwise Regression							
rain	0.952		**$2.25*10^{-13}$**				+
Age	0.03			0.46			-
2 hr	0.917				**$3.56*10^{-11}$**		+
TSRS	0.215					**0.045**	-
rain + age	0.962	0.957	**$2.01*10^{-13}$**	0.053			+, +
rain + 2 hr	0.97	0.967	**$3.07*10^{-5}$**		**0.004**		+, +
rain +TSRS	0.95	0.944	**$4.6*10^{-11}$**			0.857	+, -
rain + 2 hr + age	0.978	0.974	**$5.88*10^{-6}$**	**0.034**	**0.0034**		+, +, +
rain + 2 hr +TSRS	0.97	0.965	**0.0001**		**0.006**	0.541	+, +, -
Backward Stepwise Regression							
rain+2 hr+ age +TSRS	0.982	0.977	**$1.5*10^{-5}$**	**0.009**	**0.002**	0.211	+, +, +, -
rain + age + 2 hr	0.978	0.974	**$5.8*10^{-6}$**	**0.034**	**0.003**		+, +, +
Right Pile							
Forward Stepwise Regression							
COD Load							
Ind. Variables			**p-value**				
			rain	**Age**	**2 hr**	**TSRS**	
Rain	0.74		**0.0007**				+
Age	0.093			0.361			+
2 hr	0.72				**0.0009**		+
TSRS	0.155					0.259	-

rain + age	0.745	0.681	**0.001**	0.7			+, +
rain + 2 hr	0.746	0.682	0.398		0.671		+, +
rain +TSRS	0.713	0.631	**0.0077**			0.623	+, -
2 hr+age	0.747	0.684		0.386	**0.001**		+, +
2 hr +TSRS	0.694	0.607			**0.009**	0.619	+, -
Backward Stepwise Regression							
rain+2 hr + age+TSRS	0.728	0.511	0.665	0.698	0.658	0.716	+, +, +, -
rain + age+2 hr	0.757	0.653	0.6	0.584	0.568		+, +, +
age + 2 hr	0.747	0.684		0.386	**0.001**		+, +
TKN Load							
Forward Stepwise Regression							
Rain	0.523		**0.011**				+
Age	0.092			0.364			+
2 hr	0.491				**0.016**		+
TSRS	0.497					**0.022**	-
rain + age	0.535	0.419	**0.024**	0.664			+, +
rain + 2 hr	0.524	0.405	0.481		0.943		+, +
rain +TSRS	0.719	0.639	**0.05**			**0.043**	+, -
rain + TSRS + age	0.724	0.587	0.076	0.736		0.063	+, -, +
rain+2 hr+TSRS	0.719	0.578	0.5		0.969	0.063	+, -, -
2 hr + age	0.526	0.408		0.465	**0.026**		+, +
2 hr+TSRS	0.695	0.608			0.07	0.04	+, -
TSRS + age	0.515	0.376		0.624		**0.035**	+, -
Backward Stepwise Regression							
rain+2 hr + age+TSRS	0.725	0.505	0.654	0.752	0.93	0.094	+, +, +, -
rain + age+TSRS	0.725	0.587	0.076	0.735		0.063	+, +, -
rain +TSRS	0.719	0.639	**0.05**			**0.043**	+, -
TP Load							
Forward Stepwise Regression							
Rain	0.335		0.062				+
Age	0.104			0.333			-
2 hr	0.494				**0.015***		+
TSRS	0.06					0.493	+
rain + age	0.586	0.482	**0.015**	0.058			+, -
Total rain + 2 hr	0.623	0.529	0.136		**0.038**		-, +
rain+TSRS	0.285	0.081	0.18			0.852	+, -
rain + 2 hr + age	0.733	0.618	0.361	0.134	0.09		-, +, -
rain+ age +TSRS	0.617	0.426	0.075	0.062		0.704	+, -, -
2 hr+rain	0.623	0.529	0.136		**0.038**		+, -

2 hr+ age	0.696	0.62		**0.05**	**0.004**		+, -
2 hr +TSRS	0.451	0.294			**0.06**	0.977	+, -
2 hr + age+rain	0.732	0.618	0.361	0.135	0.09		+, -, -
2 hr+ age+TSRS	0.715	0.572		0.0565	**0.028**	0.776	+, -, -
Backward Stepwise Regression							
rain+2 hr+ age+TSRS	0.753	0.556	0.416	0.135	0.157	0.772	-, +, -, -
rain + age + 2 hr	0.732	0.618	0.361	0.134	0.09		-, -, +
age+ 2 hr	0.696	0.62		**0.05**	**0.004**		-, +
Total Leachate							
Forward Stepwise Regression							
Rain	0.854		**$4.24*10^{-8}$**				+
Age	0.0029			0.83			-
2 hr	0.795				**$6.73*10^{-7}$**		+
TSRS	0.187					0.083	-
rain + age	0.863	0.845	**$7.29*10^{-8}$**	0.339			+, +
rain + 2 hr	0.844	0.821	**0.044**		0.905		+, -
rain +TSRS	0.849	0.828	**$1.695*10^{-6}$**			0.785	+, -
2 hr+rain	0.844	0.821	**0.044**		0.905		+, -
2 hr+ age	0.809	0.78		0.222	**$5.08*10^{-6}$**		+, +
2 hr+TSRS	0.782	0.746			**$7.2*10^{-5}$**	0.526	+, -
2 hr+rain + age	0.845	0.807	0.078	0.798	0.959		+, -, -
2 hr+rain +TSRS	0.839	0.795	0.073		0.925	0.671	-, +, -
Backward Stepwise Regression							
rain+2 hr+ age+TSRS	0.85	0.791	0.107	0.401	0.907	0.828	+, +, +, -
rain + age+TSRS	0.861	0.829	**$2.41*10^{-6}$**	0.317		0.651	+, +, -
rain + age	0.863	0.845	**$7.3*10^{-8}$**	0.339			+, +
Far Pile							
Forward Stepwise Regression							
COD Load							
Ind. Variable			**p-value**				
			rain	**Age**	**2 hr**	**TSRS**	
Rain	0.971		**0.002**				+
Age	0.361			0.283			+
2 hr	0.908				**0.012**		+
TSRS	0.735					0.063	-

rain + age	0.99	0.98	**0.007**	0.188			+, -
rain + 2 hr	0.981	0.963	0.106		0.402		+, +
rain +TSRS	0.971	0.943	0.054			0.881	+, +
2 hr+ age	0.927	0.854		0.54	0.058		+, +
2 hr +TSRS	0.91	0.821			0.185	0.822	+, +
TKN Load							
Forward Stepwise Regression							
Rain	0.795		**0.0419**				+
Age	0.236			0.405			+
2 hr	0.938				**0.006***		+
TSRS	0.972					**0.001****	-
rain + age	0.838	0.676	0.112	0.544			+, -
rain + 2 hr	0.939	0.878	0.913		0.162		-, +
rain +TSRS	0.974	0.949	0.688			0.063	+, -
TSRS+ age	0.972	0.945		0.85		**0.018**	-, -
TSRS + 2 hr	0.996	0.992			0.072	**0.032**	-, +
TP Load							
Forward Stepwise Regression							
Rain	0.988		**0.0005**				+
Age	0.398			0.253			+
2 hr	0.889				**0.016**		+
TSRS	0.779					**0.047**	-
rain + age	0.999	0.999	**0.0002**	0.014			+, -
rain + 2 hr	0.991	0.983	**0.038**		0.503		+, +
rain +TSRS	0.989	0.978	**0.024**			0.841	+, -
rain + 2 hr + age	0.999	0.999	**0.032**	0.099	0.592		+, -, -
rain+ age+TSRS	0.999	0.999	**0.002**	**0.009**		0.053	+, -, +
Total Leachate							
Forward Stepwise Regression							
Rain	0.98		**$8.86*10^{-13}$**				+
Age	0.014			0.66			-
2 hr	0.876				**$2.8*10^{-7}$**		+
TSRS	0.159					0.14	-
rain + age	0.982	0.98	**$6.1*10^{-12}$**	0.531			+, +
rain + 2 hr	0.984	0.981	**$2.68*10^{-6}$**		0.214		+, -
rain +TSRS	0.982	0.979	**$5.1*10^{-11}$**			0.442	+, -

Backward Stepwise Regression							
rain+2 hr+ age +TSRS	0.986	0.98	**$2.95*10^{-5}$**	0.946	0.175	0.224	+, -, -, -
rain+2 hr+TSRS	0.986	0.982	**$3.6*10^{-6}$**		0.113	0.2	+, -, -
rain + 2 hr	0.984	0.981	**$2.68*10^{-6}$**		0.214		+, -
All Piles							
Forward Stepwise Regression							
COD Load							
Ind. Variable			**p-value**				
			rain	**Age**	**2 hr**	**TSRS**	
Rain	0.359		**0.0005**				+
Age	0.024			0.418			-
2 hr	0.158				**0.032**		+
TSRS	0.101					0.105	-
rain + age	0.447	0.404	**0.0001**	0.064			+, -
rain + 2 hr	0.574	0.541	**$3*10^{-5}$**		**0.001**		+, -
rain +TSRS	0.363	0.31	**0.004**			0.665	+, -
rain + 2 hr + age	0.683	0.645	**$2.01*10^{-6}$**	**0.007**	**0.0002**		+, -, -
rain+ 2 hr+TSRS	0.572	0.516	**0.0001**		**0.002**	0.594	+, -, -
Backward Stepwise Regression							
rain+2 hr+ age+TSRS	0.693	0.637	**$1*10^{-5}$**	**0.007**	**0.0003**	0.396	+, -, -, -
rain + 2 hr + age	0.683	0.645	**$2.01*10^{-6}$**	**0.007**	**0.0002**		+, -, -
TKN Load							
Forward Stepwise Regression							
Rain	0.183		**0.02**				+
Age	0.039			0.301			-
2 hr	0.04				0.273		+
TSRS	0.085					0.139	-
Total rain + age	0.275	0.219	**0.007**	0.093			+, -
Total rain + 2 hr	0.478	0.438	**$8.3*10^{-5}$**		**0.0008**		+, -
rain +TSRS	0.201	0.135	**0.073**			0.516	+, -
rain + 2 hr + age	0.599	0.551	**$7.98*10^{-6}$**	**0.01**	**0.0001**		+, -, -
rain+2 hr+TSRS	0.49	0.423	**0.0003**		**0.001**	0.416	+, -, -
Backward Stepwise Regression							
rain+2 hr + age+TSRS	0.627	0.559	**$3.26*10^{-5}$**	**0.009**	**0.0001**	0.251	+, -, -, -
rain + 2 hr+ age	0.599	0.551	**$7.98*10^{-6}$**	**0.01**	**0.0001**		+, -, -
TP Load							
Forward Stepwise Regression							
Rain	0.434		**0.0001**				+

Age	0.071			0.162			**-**
2 hr	0.497				**$1.9*10^{-5}*$**		+
TSRS	0.097					0.113	-
rain + age	0.607	0.577	**$2.7*10^{-6}$**	**0.002**			+, -
rain + 2 hr	0.497	0.459	**0.002**		0.103		+, -
rain +TSRS	0.431	0.384	**0.001**			0.586	+, -
rain + 2 hr+ age	0.684	0.646	**$8.06*10^{-5}$**	**0.0007**	**0.02**		+, -, -
rain+ age +TSRS	0.616	0.566	**0.0001**	**0.002**		0.364	+, -, -
Backward Stepwise Regression							
rain+2 hr+ age+TSRS	0.703	0.649	**0.0002**	**0.0006**	**0.018**	0.296	+, -, -, -
rain + age+ 2 hr	0.684	0.646	**$8.06*10^{-5}$**	**0.0007**	**0.02**		+, -, -
Total Leachate							
Forward Stepwise Regression							
Rain	0.912		**$4.9*10^{-29}$**				+
Age	0.017			0.34			-
2 hr	0.848				**$1.48*10^{-22}$**		+
TSRS	0.187					**0.001**	-
rain + age	0.916	0.913	**$5.81*10^{-28}$**	0.077			+, +
rain + 2 hr	0.913	0.91	**$1.47*10^{-7}$**		0.234		+,+
rain +TSRS	0.909	0.905	**$9.6*10^{-25}$**			0.473	+, -
Backward Stepwise Regression							
rain+2 hr + age+TSRS	0.921	0.914	**$3.2*10^{-7}$**	**0.031**	0.156	0.231	+, +, +, -
rain + age + 2 hr	0.919	0.914	**$8.1*10^{-8}$**	**0.06**	0.19		+, +, +
rain + age	0.916	0.913	**$5.81*10^{-28}$**	0.077			+, +

Rain = rain up to sampling for run 2 (mm); Age = age of pile (days); 2 hr = 2 hour rain intensity (mm); TSRS = time since rain stopped (days);

R_a^2 = coefficient of determination in simple regression and adjusted coefficient of multiple determination in multiple regression analysis.

Bold values indicate significance ($p<0.05$).

Appendix L.2. Significance of different parameters from multiple regression analysis of Run 3 results

3rd Run							
Left Pile							
COD Load							
Forward Stepwise Regression							
Ind. Variable	**R^2**	**R_a^2**	**p-value**				**X coeff. Sign**
			rain	**Age**	**2 hr**	**TSRS**	
Rain	0.789		**$9.54*10^{-6}$**				+
Age	0.121			0.202			+
2 hr	0.57				**0.001**		+
TSRS	0.011					0.717	+
Rain+ Age	0.87	0.848	**$2.5*10^{-6}$**	**0.018**			+, +
rain+2 hr	0.822	0.793	**0.001**		0.161		+, +
rain + TSRS	0.804	0.768	**$3.51*10^{-5}$**			0.4	+, -
rain +age + 2 hr	0.911	0.886	**0.0002**	**0.0069**	**0.045**		+, +, +
rain+ age + TSRS	0.866	0.826	**$2.67*10^{-5}$**	0.055		0.9	+, +, +
rain+age+TSRS+2 hr	0.91	0.871	**0.001**	0.028	0.063	0.937	+, +, +, -
Backward Stepwise Regression							
rain+2 hr+age+TSRS	0.91	0.871	**0.001**	**0.028**	0.063	0.93	+, +, +, -
rain + age + 2 hr	0.911	0.886	**0.0002**	**0.006**	**0.045**		+, +, +
TKN Load							
Forward Stepwise Regression							
Rain	0.593		**0.0007**				+
Age	0.021			0.601			+
2 hr	0.409				**0.01**		+
TSRS	0.076					0.338	+
rain + age	0.601	0.535	**0.0012**	0.63			+, +
rain + 2 hr	0.612	0.547	**0.027**		0.464		+, +
rain + TSRS	0.615	0.545	**0.002**			0.65	+, +
Backward Stepwise Regression							
rain+2 hr +ageTSRS	0.688	0.549	0.055	0.238	0.464	0.39	+, +, +
rain+age+TSRS	0.667	0.568	**0.003**	0.238		0.335	+, +, +
rain + age	0.601	0.535	**0.001**	0.63			+, +
TP Load							
Forward Stepwise Regression							
Rain	0.819		**$3.41*10^{-6}$**				+
Age	0.052			0.412			+
2 hr	0.541				**0.001**		+

TSRS	0.036					0.515	+
rain + age	0.846	0.82	**$4.45*10^{-6}$**	0.178			+, +
rain + 2 hr	0.838	0.811	**0.0005**		0.26		+, +
rain + TSRS	0.825	0.793	**$2.14*10^{-5}$**			0.784	+, -
Backward Stepwise Regression							
rain+2 hr+age+TSRS	0.862	0.801	**0.001**	0.305	0.265	0.918	+, +, +, +
rain + age + 2 hr	0.868	0.832	**0.0005**	0.144	0.201		+, +, +
rain + age	0.846	0.82	**$4.45*10^{-6}$**	0.178			+, +
Total Leachate							
Forward Stepwise Regression							
Rain	0.88		**$1.5*10^{-11}$**				+
Age	0.023			0.506			+
2 hr	0.4				**0.0008**		+
TSRS	0.065					0.238	+
rain + age	0.895	0.886	**$1.1*10^{-11}$**	0.191			+, +
rain + 2 hr	0.916	0.908	**$1.9*10^{-10}$**		**0.013**		+, +
rain + TSRS	0.887	0.876	**$1.2*10^{-10}$**			0.778	+, +
rain + 2 hr + age	0.928	0.918	**$1.1*10^{-10}$**	0.075	**0.006**		+, +, -
rain+ 2 hr + TSRS	0.917	0.904	**$1.54*10^{-9}$**		**0.016**	0.615	+, -, +
Backward Stepwise Regression							
rain+2 hr+age+TSRS	0.938	0.925	**$2.85*10^{-10}$**	**0.022**	**0.004**	0.138	+, +, -, +
rain + age + 2 hr	0.928	0.918	**$1.1*10^{-10}$**	0.075	**0.006**		+, +, -
rain + 2 hr	0.916	0.908	**$1.94*10^{-10}$**		**0.013**		+, -
Right Pile							
COD Load							
Forward Stepwsie Regression							
Independent Variables	**R^2**		**p-value**				
			rain	**age**	**2 hr**	**TSRS**	
Rain	0.44		**0.013**				+
Age	0.0003			0.956			+
2 hr	0.668				**0.0006***		+
TSRS	0.003					0.859	+
rain + age	0.443	0.332	**0.018**	0.931			+, -
rain + 2 hr	0.679	0.615	0.569		**0.021**		+, +
rain + TSRS	0.492	0.379	**0.016**			0.33	+, -
2 hr +age	0.669	0.602		0.941	**0.001**		+, -
2 hr + TSRS	0.695	0.627			**0.001**	0.382	+, -
Backward Stepwise Regression							

rain+2 hr +age+TSRS	0.747	0.603	0.358	0.44	**0.041**	0.22	+, -, +, -
rain + 2 hr + TSRS	0.723	0.619	0.392		**0.032**	0.278	+, +, -
2 hr + TSRS	0.695	0.627			**0.001**	0.382	+, -
TKN Load							
Forward Stepwise Regression							
Rain	0.287		0.058				+
Age	0.006			0.791			-
2 hr	0.563				**0.003***		+
TSRS	$8*10^{-6}$					0.99	-
rain + age	0.3	0.16	0.067	0.681			+, -
rain + 2 hr	0.563	0.476	0.955		**0.03**		-, +
rain + TSRS	0.342	0.196	0.058			0.381	+, -
2 hr + age	0.575	0.49		0.607	**0.004**		+, -
2 hr + TSRS	0.604	0.516			**0.004**	0.337	+, -
Backward Stepwise Regression							
rain+2 hr +age+TSRS	0.662	0.469	0.691	0.324	**0.05**	0.234	+, -, +, -
2 hr + age+ TSRS	0.653	0.524		0.351	**0.005**	0.228	-, +, -
2 hr + TSRS	0.604	0.516			**0.004**	0.337	+, -
TP Load							
Forward Stepwise Regression							
Rain	0.357		**0.03**				+
Age	0.006			0.794			-
2 hr	0.597				**0.001***		+
TSRS	0.001					0.904	+
rain + age	0.371	0.245	**0.036**	0.658			+, -
rain + 2 hr	0.599	0.519	0.784		**0.034**		+, +
rain + TSRS	0.403	0.27	**0.0306**			0.385	+, -
age + 2 hr	0.608	0.529		0.594	**0.002**		-, +
2 hr + TSRS	0.625	0.541			**0.003**	0.401	+, -
Backward Stepwise Regression							
rain+2 hr +age+TSRS	0.718	0.558	0.47	0.201	**0.05**	0.189	+, -, +, -
age+ 2 hr + TSRS	0.695	0.581		0.21	**0.003**	0.23	-, -, +
age+2 hr	0.608	0.529		0.594	**0.002**		-, +
Total Leachate							
Forward Stepwise Regression							
Rain	0.945		$\mathbf{3.8*10^{-14}}$				+
Age	0.027			0.462			-
2 hr	0.576				$\mathbf{4.17*10^{-5}}$		+
TSRS	0.06					0.283	+
rain + age	0.953	0.948	$\mathbf{5.52*10^{-14}}$	0.1			+, +

rain + 2 hr	0.946	0.94	**$6.05*10^{-10}$**		0.843		+, -
rain + TSRS	0.954	0.948	**$3.07*10^{-13}$**			0.649	+, -
Backward Stepwise Regression							
rain+2 hr +age+TSRS	0.956	0.945	**$4.02*10^{-9}$**	0.37	0.647	0.8	+, +, -, -
rain +age + 2 hr	0.954	0.946	**$4.96*10^{-10}$**	0.097	0.623		+, +, -
rain +age	0.953	0.948	**$5.52*10^{-14}$**	0.1			+, +
Far Pile							
COD Load							
Forward Stepwise Regression							
Ind. Variable	**R^2**		**p-value**				
			rain	**age**	**2 hr**	**TSRS**	
Rain	0.681		**0.0001**				+
Age	0.063			0.363			+
2 hr	0.313				**0.0301**		+
TSRS	0.129					0.206	+
rain + age	0.718	0.671	**0.0001**	0.234			+, +
rain + 2 hr	0.682	0.629	**0.002**		0.847		+, -
rain + TSRS	0.702	0.648	**0.0007**			0.346	+, +
Backward Stepwise Regression							
rain+2 hr + age + TSRS	0.797	0.707	**0.005**	0.075	0.768	0.086	+, +, -, +
rain + age + TSRS	0.795	0.733	**0.0006**	0.059		0.074	+, +, +
rain + age	0.718	0.671	**0.0001**	0.234			+, +
TKN Load							
Forward Stepwise Regression							
Rain	0.546		**0.001**				+
Age	0.002			0.866			+
2 hr	0.25				0.057		+
TSRS	0.192					0.116	+
rain + age	0.546	0.47	**0.002**	0.97			+, -
rain + 2 hr	0.546	0.471	**0.016**		0.885		+, -
rain + TSRS	0.63	0.563	**0.004**			0.18	+, +
Backward Stepwise Regression							
rain+2 hr + age + TSRS	0.674	0.529	**0.029**	0.317	0.794	0.115	+, +, -, +
rain + age + TSRS	0.671	0.573	**0.006**	0.287		0.1	+, +, +
rain + TSRS	0.63	0.563	**0.004**			0.18	+, +
TP Load							
Forward Stepwise Regression							
Rain	0.704		**$9.09*10^{-5}$**				+
Age	0.016			0.647			+

2 hr	0.386				**0.013**		+
TSRS	0.147					0.174	+
rain + age	0.709	0.66	**0.0001**	0.676			+, +
rain + 2 hr	0.706	0.657	**0.003**		0.795		+, +
rain + TSRS	0.738	0.69	**0.0004**			0.26	+, +
Backward Stepwise Regression							
rain+2 hr + age + TSRS	0.751	0.641	**0.01**	0.506	0.933	0.233	+, +, +, +
rain + age + TSRS	0.751	0.676	**0.0008**	0.484		0.202	+, +, +
rain + TSRS	0.738	0.69	**0.0004**			0.26	+, +
Total Leachate							
Forward Stepwise Regression							
Rain	0.748		**4.81810^{-8}**				+
Age	0.018			0.525			-
2 hr	0.37				**0.001**		+
TSRS	0.083					0.18	+
rain + age	0.75	0.727	**$1.09*10^{-7}$**	0.66			+, +
rain + 2 hr	0.762	0.739	**$7.76*10^{-6}$**		0.285		+, -
rain + TSRS	0.766	0.742	**$2.34*10^{-7}$**			0.238	+, +
Backward Stepwise Regression							
rain+2 hr + age + TSRS	0.808	0.765	**$8.47*10^{-6}$**	0.13	0.18	0.064	+, +, -, +
rain + age + TSRS	0.788	0.755	**$1.81*10^{-7}$**	0.173		0.089	+, +, +
rain + TSRS	0.766	0.742	**$2.34*10^{-7}$**			0.238	+, +
All Piles							
COD Load							
Forward Stepwise Regression							
Ind. Variable	**R^2**		**p-value**				
			rain	**age**	**2 hr**	**TSRS**	
Rain	0.59		**$1.75*10^{-9}$**				+
Age	0.034			0.23			+
2 hr	0.5				**$1.12*10^{-7}$**		+
TSRS	0.02					0.318	+
rain + age	0.608	0.589	**$2.28*10^{-9}$**	0.183			+, +
rain + 2 hr	0.643	0.625	**0.0002**		**0.02**		+, +
rain + TSRS	0.589	0.566	**$1.97*10^{-8}$**			0.569	+, -
rain + 2 hr + age	0.664	0.638	**0.0003**	0.122	**0.015**		+, +, +
rain + 2 hr + TSRS	0.644	0.615	**0.0004**		**0.023**	0.404	+, +, -
Backward Stepwise Regression							
rain+2 hr + age	0.655	0.616	**0.0007**	0.3	**0.02**	0.762	+, +, +, -

+TSRS							
rain + age + 2 hr	0.664	0.638	**0.0003**	0.122	**0.015**		+, +, +
rain + 2 hr	0.643	0.625	**0.0002**		**0.02**		+, +
TKN Load							
Forward Stepwise Regression							
Rain	0.404		**$4.53*10^{-6}$**				+
Age	0.0005			0.891			+
2 hr	0.396				**$6.09*10^{-6}$***		+
TSRS	0.037					0.233	+
rain + age	0.405	0.375	**$5.88*10^{-6}$**	0.854			+, **-**
rain + 2 hr	0.468	0.441	**0.025**		**0.035**		+, +
rain + TSRS	0.408	0.376	**$2.47*10^{-5}$**			0.941	+, +
rain + 2 hr + age	0.468	0.427	**0.027**	0.936	**0.037**		+, -, +
rain + 2 hr + TSRS	0.473	0.429	**0.0313**		**0.041**	0.895	+, +, **-**
Backward Stepwise Regression							
rain+2 hr +age+TSRS	0.473	0.413	**0.037**	0.899	**0.044**	0.95	+, +, +, -
rain + 2 hr + TSRS	0.473	0.429	**0.0313**		**0.041**	0.895	+, +, -
rain + 2 hr	0.468	0.441	**0.025**		**0.035**		
TP Load							
Forward Stepwise Regression							
Rain	0.55		**$1.24*10^{-8}$**				+
Age	0.004			0.65			+
2 hr	0.491				**$1.65*10^{-7}$**		+
TSRS	0.036					0.238	+
rain + age	0.551	0.529	**$1.98*10^{-8}$**	0.864			+, +
rain + 2 hr	0.611	0.592	**0.001**		**0.016**		+, +
rain + TSRS	0.546	0.521	**$1.53*10^{-7}$**			0.831	+, **-**
rain + 2 hr + age	0.612	0.582	**0.001**	0.75	0.18		+, +
rain + 2 hr + TSRS	0.608	0.575	**0.001**		**0.022**	0.644	+, +, **-**
Backward Stepwise Regression							
rain+2 hr+age+TSRS	0.61	0.566	**0.001**	0.66	**0.025**	0.55	+, -, +, -
rain + 2 hr + TSRS	0.608	0.575	**0.001**		**0.022**	0.644	+, +, **-**
rain + 2 hr	0.611	0.592	**0.001**		**0.017**		
Total Leachate							
Forward Stepwise Regression							
Rain	0.851		**$6.77*10^{-30}$**				+
Age	0.022			0.216			**-**
2 hr	0.442				**$3.28*10^{-10}$**		+
TSRS	0.067					**0.034**	+
rain + age	0.857	0.853	**$1.039*10^{-29}$**	0.109			+, +

rain + 2 hr	0.861	0.857	**$6.72*10^{-22}$**		**0.036**		+, -
rain + TSRS	0.856	0.851	**$1.07*10^{-27}$**			0.318	+, +
rain + 2 hr + age	0.868	0.862	**$2.9*10^{-22}$**	0.057	**0.02**		+, +, -
rain + 2 hr + TSRS	0.866	0.86	**$8.28*10^{-21}$**		**0.031**	0.266	+, -, +
Backward Stepwise Regression							
rain+2 hr+age+TSRS	0.879	0.871	**7.7810^{-22}**	**0.013**	**0.012**	**0.039**	+, +, -, +

Rain = total rain for run 3 (mm); Age = age of pile (days); 2 hr = 2 hour rain intensity (mm); TSRS = time since rain stopped (days);

R_a^2 = coefficient of determination in simple regression and adjusted coefficient of multiple determination in multiple regression analysis.

Bold numbers indicate significance ($p<0.05$).

Appendix M. Model Predictions and Nash-Sutcliffe Efficiency Index.

Appendix M.1. Nash-Sutcliffe efficiency index results in predicting Run 2 data using equation developed from Run 3 data.

All Piles Combined (Rain only)				
COD Load				
X coeff.	Intercept	R^2	NSE Index*	
			With outlier	No outlier
9.3254	-54.6	0.591	0.073	0.414
TKN Load				
0.068	-0.115	0.405	0.048	0.528
TP Load				
0.0667	-0.330	0.551	0.381	0.497
Total Leachate				
17.933	-55.8	0.852	0.696	0.684
All Piles Combined (Multiple factors)				
COD Load (Rain & 2 hr intensity)				
X_1 coeff.	X_2 coeff.	Intercept	NSE Index	
			With outlier	No outlier
6.516	5.31	-63.3	0.023	0.293
TKN Load (Rain & 2 hr intensity)				
0.0407	0.052	-0.199	0.010	0.413
TP Load (Rain & 2 hr intensity)				
0.0443	0.042	-0.399	0.299	0.500

Total Leachate (Rain, age, 2 hr intensity & time since rain stopped)						
X_1 coeff.	X_2 coeff.	X_3 coeff.	X_4 coeff.	Intercept	NSE Index	
					With outlier	No outlier
21.0	0.878	-4.91	10.2	-182	0.686	0.670

* Shown with all points and without value for 11/23/11 (outlier).

Appendix M.2: Predicting right and far piles in Run 2 using models developed from left pile in Run 2.

	X coeff.	Intercept	R^2	NSE Index	
COD load					
				With outlier*	No outlier
Left Pile	47.1	-469	0.475		
Right Pile				-6	0.438
Far Pile				-7.3	0.50
TKN load					
Left Pile	0.477	-5.59	0.286		
Right Pile				-15.6	0.462
Far Pile				-34.6	0.523
TP load					
Left Pile	0.119	-1.06	0.495		
Right Pile				-0.026	0.275
Far Pile				0.651	0.872
Total leachate					
Left Pile	27.5	-67.0	0.952		
Right Pile				0.846	0.850
Far Pile				0.960	0.909

* Outlier refers to results from 11/23/11 in Run 2.

Appendix M.3. Predicting left and right piles in Run 3 with model developed from far pile in Run 3 (Rain only).

	X-coeff.	Intercept	R^2	NSE Index
COD load				
Far Pile	9.30	-55.2	0.681	
Right Pile				0.439
Left Pile				0.786
TKN load				
Far Pile	0.0619	-0.0478	0.546	
Right Pile				0.270
Left Pile				0.586
TP load				
Far Pile	0.0704	-0.384	0.705	
Right Pile				0.357
Left Pile				0.804
Total leachate				
Far Pile	17.1	-29.1	0.749	
Right Pile				0.924
Left Pile				0.861

Appendix N. Toxicity Assays.

Appendix N.1. Toxicity assay dose-response results, Run 2.

Conc. (%)	Death	Y/P Edema	ASC	Kink Tail	# Stage delay
Left Pile	Sample date: 11/21/11				
0	0	0	0	0	2
5	0	0	0	0	2.4
10	0	0	0	0	2.06
20	0	0	0	0	2.13
40	6.6	0	6.6	0	2
Right Pile	Sample date: 11/21/11				
5	0	0	0	0	3
10	6.6	0	13.3	0	3
20	6.6	0	6.6	0	3
40	0	0	6.6	0	3
Far Pile	Sample date: 11/21/11				
5	6.6	0	0	0	3
10	6.6	0	6.6	0	3
20	0	0	0	0	3.13
40	13.3	0	6.6	0	3
Left Pile	Sample date: 12/29/11				
0	0	0	0	0	1
10	6.6	0	0	0	1
20	0	0	0	0	1.4
40	0	0	0	0	2
60	26.6	0	0	0	2
Right Pile	Sample date: 12/29/11				
10	0	0	0	0	1
20	0	0	0	0	1
40	0	0	13	0	1.06
60	6.6	0	6.6	0	1.36
Left Pile	Sample date: 4/24/12				
0	0	0	0	0	2
5	0	0	0	0	3.13
10	0	0	0	0	3
20	0	0	0	0	3
40	0	0	0	0	3.26
Right Pile	Sample date: 4/24/12				
5	27	0	0	0	3
20	27	0	0	0	3.13
40	0	20	20	0	3

Y/P Edema: Yolk sac and pericardial edema.

ASC: Abnormalspine curvature.Other developmental defects (decreased body and retinal pigmentation, size of head, abnormal circulation) were all 0 %.

Appendix N.2. Toxicity assay dose-response results, Run 3.

Sample date: 5/30/12			
Left Pile			
Conc. (%)	Death (%)	ASC	# Stage delay
0	0	0	2
10	0	0	2.33
20	0	6.6	2.8
40	0	0	2.66
Right Pile			
10	0	0	2
20	0	0	2
40	0	0	2.66
Far Pile			
10	0	0	2
20	0	0	2
40	0	6.66	2.66
Sample date: 9/11/2012			
Left Pile			
0	0	0	1
10	0	0	1
20	13.3	7.7	1
40	13.3	15.4	1
Right Pile			
10	0	0	1
20	0	0	1
40	0	0	1
Far Pile			
10	0	0	1
20	6.66	0	1
40	6.66	0	1
Sample date:10/1/12			
Left Pile			
0	0	0	1
10	0	0	2
20	0	0	2
40	0	0	2
Right Pile			
10	0	0	1
20	0	0	2
40	0	0	2

Far Pile			
10	0	0	2
20	0	0	2
40	0	0	2

ASC: Abnormalspine curvature.
Other developmental defects (yolk sac and pericardial edema, kink tail, decreased body and retinal pigmentation, size of head, abnormal circulation) were all 0 %.