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From Waste to Product: Developing pulp and paper mill biosolids into a marketable resource.

By

Trisha Westman
B.Sc.(Eng.), University of Guelph

A thesis submitted to the Faculty of Graduate Studies and Research in partial fulfillment
of the requirements of the degree of

Master of Applied Science

In Environmental Engineering

Department of Civil and Environmental Engineering
Carleton University
Ottawa, Ontario, Canada

The Master of Applied Science in Environmental Engineering is a joint program with the
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**From Waste to Product: Developing pulp and paper mill biosolids into
a marketable resource.**

Submitted by

Trisha Westman, B. Sc.(Eng.)

In partial fulfillment of the requirements for the degree of
Master of Applied Science

Pascale Champagne, Thesis Supervisor
Department of Civil and Environmental Engineering
Carleton University

A. O. Abd El Halim, Chair
Department of Civil and Environmental Engineering
Carleton University

January 2005

Abstract

Paper mill biosolids were evaluated as a secondary resource. The biosolids were found to have levels of regulated compounds below Ontario limits. Pore water and soil samples from land application sites echoed these findings. Growth studies revealed that fresh biosolids used as a soil alternative did not support plant growth and plants suffered from nitrogen deficiency. Results were consistent with historical findings at land application sites. Significant vegetation growth at sites did not occur until one year following application. Carbon to nitrogen testing done at receiving sites showed that over time the biosolids undergo decomposition and stabilize. Greenhouse studies revealed that fresh biosolids were better suited as an organic additive rather than a soil alternative and improved the growth of Jack Pine seedlings. Composting was studied as a stabilization method. After three weeks, the composted material exhibited characteristics of good quality compost according to Ontario Ministry of Environment guidelines.

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Glossary

Aggregate - Many soil particles held in a single mass or cluster, such as a clod.

Available nutrient - The portion of any element or compound in the soil that can be readily absorbed and assimilated by growing plants.

Biodegradable - Subject to degradation by biochemical processes.

Biosolids – The biological solids growing in or wasted from a wastewater treatment process. Sludge separated from the wastewater.

Beneficial re-use – Biosolids disposal options which involve using the material for a practical use, e.g. agricultural land application, use as a construction aggregate or final landfill cover.

BNQ - Bureau de Normalisation du Quebec

CCME - Canadian Council of Ministers of the Environment

C:N - Carbon to nitrogen ratio.

Compost - Organic residue, or a mixture of organic residue and soil, which has been contained in a pile or vessel and allowed to undergo biological decomposition.

DL - Detection limit

EC - electrical conductivity, an indirect measurement of salt content in soil or solution.

ICP - Inductively couple plasma atomic emission spectroscopy.

Land application – Spreading or integrating of biosolids on agricultural, forest or land reclamation sites for the purpose of soil improvement and biosolids disposal.

Loam - An inorganic soil consisting of equal amounts of clay, silt and sand.

MOE - Ontario Ministry of Environment

ND - Not detected

OCDD - Octachlorodibenzo-*p*-dioxin

PAH - polycyclic aromatic hydrocarbon

PCDD - Polychlorinated dibenzodioxin

PCDF - Polychlorinated dibenzofuran

PeCDD - Pentachlorinated dibenzo-*p*-dioxin

PeCDF - Pentachlorinated dibenzo-furan

ppmb - Pulp and paper mill biosolids

SAR - sodium absorption ratio, $SAR = [Na^+]/(0.5[Ca^{+2}] + [Mg^{+2}])^{0.5}$, a description of the salinity of soil which takes into consideration the moderating effect of the presence of calcium and magnesium on the adverse effects of sodium.

Soil alternative – Organic material to be used in place of topsoil or potting soil.

Soil amendment or additive – A material added to soil to improve its characteristics for sustaining vegetation.

Stabilization - A process which eliminates offensive odours and inhibits, reduces or eliminates the potential for putrefaction of biosolid material.

TEQ - Toxic Equivalents are used to report the toxicity-weighted masses of mixtures of dioxins.

TCLP - Toxicity Characteristic Leaching Procedure - Under this procedure constituents are extracted from the waste in a manner designed to simulate leaching in landfills (using acetic acid with a pH of 5.0 over 24 hours).

1 INTRODUCTION

1.1 Preamble

As society continues to grow, goods are consumed at escalating rates. There is waste associated with this increased consumption and accompanying production and processing of consumer goods. Waste is an inevitable by-product of human existence. In the quest for sustainable development, there are an increasing number of challenges surrounding the management of this byproduct. With the arrival of the industrial age, the complexity of air, water and solid waste streams have increased dramatically. New technology is often followed by a supporting cast of synthetic materials and man-made chemicals. The implications of new additions to the waste stream fuels the advancement of environmental technology, however not with enough to stay ahead of waste management issues. Waste generation currently exceeds the capacity of the present infrastructure for management. One way of meeting this issue is to rethink the traditional idea of what constitutes a waste product. Many waste products still contain valuable recoverable materials, which are being lost. Rather than prematurely disposing of these materials they should be thought of as secondary resources and harvested as such. Not only would this reduce the amount of waste generated, it would provide new production opportunities and financial reward.

Focusing on the solid waste stream, materials disposed of in landfills build over time and can ultimately have negative effects on water, air and soil quality. The life of a landfill is finite. The drive to reduce strain on current landfill sites is tremendous. Suitable areas to locate new landfills are scarce and the task of opening new sites is daunting in a public arena where the "not in my backyard" attitude is common. For environmental, social and economical reasons, it is in society's best interest to divert as much waste as possible from ultimate disposal sites. Initiatives such as waste reuse research and development can offer scientific solutions to society's environmental problems.

Solid wastes such as wastewater treatment sludges are an example of a waste stream which holds great value as a secondary resource. If properly pronounced the word "sludge" can take on an almost onomatopoeic quality. For the general public, the

Larousse Dictionary definition of sludge is given as "a suspension of solid matter in liquid." In the realm of wastewater and water treatment, the word sludge takes on a more specific definition. It typically refers to the solid and semisolid residuals removed from water and wastewater during their respective solids separation processes (Metcalf & Eddy, 1991). As advancements in water treatment are made, it becomes possible to remove more residuals. As the conservation of mass rules, larger and larger volumes of sludge are produced due to the advancements in wastewater treatment technology. Although not exclusively derived from sewage treatment, sludge is often thought of by the public to be an unsightly topic. Other environmental issues like the "greenhouse effect" and "acid rain" are more glamorous next to the challenge of sludge disposal. While the average family may actually discuss such issues over the dinner table, sludge management is more often a topic left out of the headlines.

"Sludge, in my opinion, should be thought of as a waste product with value (no contradiction) and a material which should find its proper use, not just a method of disposal...to some people sludge is still an ugly four letter word. To others (and to me) it is a residual of our society which must be treated and used to the maximum benefits of mankind, recognizing that mankind is but one species on this wonderful planet." (Vesilind, 1980). The word biosolids was invented to replace the term sludge and facilitate the transition of public opinion called for by Vesilind in the above quote. The term "biosolids" was thought to capture the idea that the residual solids are another biomass stream available for use as a resource (Spellman, 1997).

In some texts, sludge and biosolids have been assigned distinct definitions. Sludge can be referred to as the unprocessed solids stream consisting of 0.25 to 12 percent solids by weight (Metcalf & Eddy, 1991). Biosolids are then referred to as the resultant material after measures have been taken to further process the sludge. The methods of sludge processing, though vast and varied, are focused primarily on stabilization as well as volume and weight reduction. For the purpose of this body of work, the two terms; biosolids and sludge, will be used interchangeably.

Biosolids research, perhaps driven by public inquiry, is centered primarily on residuals derived from municipal wastewater treatment plants. There is however another source of biosolids which produces sludge at nearly the same production rate, the pulp and paper

industry. In 1998, 6.9 million tons (dry weight) of municipal biosolids were produced in the United States according to a U.S. EPA Report (U.S. EPA, 1999). In 1995, the American pulp and paper industry alone produced 5.8 million tons of biosolids (dry weight) (Knuzler, 2001).

The bulk of research available on municipal sludge management is considerable. Although much of the theories and waste management strategies currently developed for municipal biosolids are applicable to pulp and paper mill biosolids, there is a need to identify these two as independent waste streams. Their characteristics are considerably different, which affects their reuse potential as well as their environmental impact. Unfortunately, the public and regulatory agencies rarely distinguish one from the other and limitations are placed upon reuse applications for pulp and paper mill biosolids based on risks which are not necessarily associated with the biosolids of this industry.

In the case of St. Marys Paper, a ground wood pulp and paper mill in Sault Ste. Marie Ontario, the company produces 7000 m³ of combined primary and secondary biosolids per month. The mixed daily ratio is 20 tonnes primary to 3 tonnes secondary material. This material is currently used as a final cover at closed local landfill sites and as a soil amendment at abandoned mine tailings sites. Currently, the highest cost associated with the disposal of the sludge is the transportation fees. This expense is slowly growing, as the mill explores opportunities further outside of the local vicinity for new land application sites. In the near future, the supply of biosolids will outweigh the demand by the land reclamation projects. Another issue with the current strategy is that receiving sites are approved for land application by the provincial government on a case by case basis. This exercise requires significant time and effort by the mill. Ultimately, paper mills like St. Marys are looking to convert their biosolids stream from a financial burden to a lucrative by-product. Based on their success at land application sites, this particular mill is interested in investigating the feasibility of developing a soil amendment from the biosolids, which could be classified as a product and, ultimately, available for unrestricted use.

St. Marys Paper Ltd. understands the need for sustainable industrial practices in order to maintain the health of Canadian business. They are dedicated to environmentally responsible operation. By investing in this research, St. Marys Paper hopes to reduce

their waste disposal costs and help develop new market opportunities which will bring both profit and jobs to the pulp and paper industry.

1.2 Purpose

The main purpose of this research was to investigate the nature of the biosolids produced by St. Marys Paper Ltd. and explore potential opportunities to convert this material into a marketable resource for the pulp and paper industry.

1.3 Scope and Scientific Approach

In order to fulfill the above purpose, the following specific project objectives were established:

- 1. Characterize the chemical and physical nature of the pulp and paper mill biosolids.**

Rationale

Laboratory characterization of the biosolids could assist in the assessment of potential environmental impacts; the prediction of behaviour over time in different environments and the development of re-use alternatives. Analysis of historical and chronological data with respect to the biosolids would indicate variations and changes in biosolids characteristics with time, as well as their range and magnitude.

Approach

A review of existing reports was undertaken to obtain a detailed characterization of the sludge stream produced by St. Marys Paper Ltd. In the past, a number of outside parties, in addition to St. Marys Paper, have been involved in St. Marys Paper biosolids initiatives. The information previously collected and documentation of work to date is somewhat scattered. A detailed review of previously collected data and documentation of past research and projects undertaken will prevent unnecessary duplication of research.

2. Determine alternative end uses of paper mill biosolids as a value-added resource, which do not pose environmental threats.

Rationale

Through the re-use of St. Marys Paper biosolids, waste production can be reduced, a secondary resource can be utilized decreasing the dependency on primary resources and financial and employment opportunities can be created.

Approach

St. Marys has indicated a strong interest in investigating potential avenues for the re-use of the biosolids generated as a by-product of their industry.

A small-scale vegetable growth study undertaken by a summer student at St. Marys Paper in the late nineties (Lemcke, 1998) suggested that the biosolids material could be used as an alternative to potting soil without further processing. A larger scale potted plant study was designed to further investigate the conclusions drawn from this earlier study. The St. Marys Paper biosolids were investigated as a growth media over one growing season. Annuals were planted in various soil/biosolids mixes and their growth compared. In addition to plant growth, soil and leachate quality were also monitored.

In order to evaluate the potential use of the St. Marys Paper biosolids material as an organic additive or amendment, a laboratory-scale greenhouse growth study was performed. This study was designed to determine the effect of St. Marys Paper biosolids application on the growth of Jack Pine. The data collected was interpreted and used to assess the effectiveness of the biosolids as an organic additive for the silviculture industry. Jack Pine was selected as the study's plant species based on its robustness and its importance as a fiber source to the pulp and paper industry.

3. Determine processes required to convert biosolids into an end use product.

Rationale

Based on the results of the growth studies and field testing, it was concluded that in order to use the biosolids as an alternative for topsoil, the material required further

stabilization. Composting is a stabilization method which, if performed adequately, could produce a material which could be classified as a product from a regulatory perspective. Currently, the biosolids are considered a processed organic waste by the MOE. This classification hinders use of the material without a certificate of approval specific to the application. If the material were to be reclassified as a product, it could become available for unrestricted public use.

Approach

Previous efforts by a company called Agribond in 1996 to compost St. Marys material using open windrows were successful however public acceptance of the operation was poor according to B. Wilson, Sr. Materials Specialist for the Ontario Ministry of Environment (Wilson, 1997). Residents within the vicinity of the operation were concerned with air quality issues. Although the public concerns were determined to be unfounded by the Ontario Ministry of the Environment (MOE) and local health officials, St. Marys Paper elected to seek a re-use strategy which could enlist strong public support. The application of in-vessel composting technology could mitigate public concern. Using a pilot scale in-vessel composter, whether or not St. Marys Paper biosolids could be biologically stabilized yielding a lower volume, odour-free product was assessed. In the event that in-vessel composting did not prove successful or economically suitable, other processes could be investigated as methods of converting the biosolids into a useable end-product.

4. Assess the impact on the soil and water of using the biosolids as a soil amendment on the surrounding environment.

Rationale

St. Marys Paper has a social responsibility to be aware of the impacts on receiving environments associated with the application of their biosolids onto land. This will assist them in making informed management decisions associated with current and future land application projects. An impact analysis would also provide required data to evaluate whether or not the biosolids have added value to sites where they have been applied in previous land application initiatives. This information could also identify potential

challenges which may require consideration in assessing the course of action necessary to further develop the biosolids waste material into a value-added product.

Approach

Sites having previously received biosolids were used to generate a body of information with respect to the potential environmental impacts associated with reintroducing the St. Marys Paper biosolids into the natural environment.

A time series study was undertaken at the Goulais Landfill site which had received St. Marys Paper biosolids over a three year period from 1997 to 1999, inclusively, in order to identify time-related variations in the biosolids cover and long-term impacts of the material application. Site monitoring was completed to assess the effects of land application of the untreated biosolids over a number of growing seasons.

Soil samples were collected to quantify metal accumulation and other changes in the soil properties with time. Samples were compared to baseline data collected from the area. Samples were collected at different areas of the site which received biosolids at different points in time. By assuming that the main variable between the sampling locations was time, the data collected would reflect the changes in the site over time due to the application of the St. Marys Paper biosolids.

Once biosolids are applied to land, natural decomposition begins to take place. Samples from different application sites receiving St Marys Paper biosolids at different times during the past five years were collected and analysed for carbon to nitrogen ratio, metals and macronutrients. Comparing the carbon to nitrogen ratio of biosolids of different ages may provide a comparison of the effectiveness of natural decomposition process *in-situ*. The examination of the biosolids from a number of different sites would provide a more comprehensive understanding of the impact of the land application of the biosolids materials in various receiving environments.

In order to assess potential impacts on water quality, pore water from the soil was collected using lysimeters and analyzed for pH, metals and dissolved nutrients from the land applied biosolids at the Goulais landfill site. In addition to the field experiment, leachate from fresh biosolids was also investigated. In an outdoor setting, fresh biosolid

material was placed in false bottom pails. Over the course of eight weeks, leachate was periodically collected and examined for nitrate, ammonia and phosphate levels.

This study is particularly relevant to current concerns over land application of biosolids and the impact they may have on the surrounding ecosystems. By investigating the fate of the metals and nutrients as they are transported through the biosolids material and surrounding soil and water following land application, the environmental impact will be assessed.

2 LITERATURE REVIEW

2.1 Characteristics of pulp and paper biosolids

The world's quest for clean water has driven the field of water and wastewater treatment to new heights. Science and engineering experts are now able to purify even the most dismal of waste streams. There is a darker side to treatment improvements which is the emerging issue of increased biosolids production. Unfortunately the law of conservation of mass binds these two like a hero and his alter ego, because it is difficult for one to exist without the other. The pulp and paper industry alone generates a considerable quantity of biosolids due to the water intensive nature of the paper making process. The pulp and paper industry uses more water to produce a ton of product than any other industry (http://www.livingtreepaper.com/about_pulp.html, Accessed: December 16, 2004). Because of their high water use, pulp and paper mills generally have their own wastewater treatment systems to collect, treat, and reuse their own process and/or cooling waters. Some mills, like St. Marys Paper Ltd., maintain separate systems for their process and human generated wastewater. In 1995, Canada alone produced 7.1 dry Mt/a of pulp mill biosolids (Reid, 1998). Primary and secondary sludges comprise the largest component of the pulp and paper industry's solid waste stream (Scott & Smith, 1995).

2.1.1 General Characteristics

Pulp and paper mill biosolids can in some instances pose less of a challenge for disposal than municipal biosolids because the influent wastewater stream is more isolated and controlled. They have considerably less metal content than municipal biosolids as can be seen from the data in Table 2-1 which outlines the variation of heavy metal concentrations found within biosolids. The first column lists median values obtained for municipal biosolids, while the second column outlines the U.S. EPA's regulated levels. The third column represents the average concentrations of metals in the St. Marys biosolids.

Table 2-1 - Variation in concentration of heavy metals in wastewater biosolids

Metal	Dry Biosolids, mg/kg		
	Median_a	EPA 503 Reg	STMP_b
Arsenic	10	41	0.7
Cadmium	10	39	1.3
Chromium	500	1200	15
Copper	800	1500	20
Lead	500	300	7.5
Mercury	6	17	0.05
Molybdenum	4	18	<1
Nickel	80	420	17
Selenium	5	36	0.6
Zinc	1700	2800	158

a - Metcalfe & Eddy (1991)

b - STMP - St. Marys Paper average values

Comparing sludges to other materials that are land applied puts into perspective the metals concentrations presented (O'Connor, 1996). Table 2-2 compares St. Marys' metal levels with averages for combined kraft sludge, municipal sludge, manure and soils.

Table 2-2 - Comparison of metals in paper mill biosolids and other material

Parameter	Sludges			Canadian Cow Manure	Ontario soil
	STMP_a	Kraft combined	Ont. Municipal		
Cadmium	1.3	2.2	10	0.5	0.7
Chromium	15	38	530	3	14
Copper	20	22	970	15	25
Lead	7.5	16	375	9	14
Mercury	0.05	0.18	2		
Nickel	17	31	120	3	16
Zinc	158	182	1600	117	54

All values reported as mg/kg dry weight

a - St. Marys average values

Adapted from O'Connor, 1996

The table suggests that St. Marys biosolids chromium, copper, lead and nickel concentrations are similar to those of Ontario soil. The zinc and cadmium levels in St. Mary's material are higher than the levels in the cow manure and Ontario soils. Metal levels in municipal sludge in Ontario are approximately an order of magnitude greater than that of St. Marys sludge.

Pathogens

Typically pulp and paper biosolids are primarily comprised of wood fibers, water and clay. Pathogenic viruses and bacteria concentrations are non-existent if the waste stream is isolated from sanitary sewers (Reid, 1998; Archibald, 1999). In a survey done in B.C. by Organix Waste Solutions Inc. in 2000 for the B.C. Pulp and Paper Association, six different mills were investigated including mechanical and kraft mills. All sludge samples tested positive for fecal coliform and some tested positive for *E. Coli*. The report stressed that the tests made use of indicator organisms for pathogens. They detect both pathogenic and non-pathogenic organisms which are inherent to biological wastewater treatment. No salmonella were detected in any samples.

The nature of biological treatment can cause high positive test results for indicator organisms without the presence of actual pathogens. For example, *Klebsiella* has been known to exist in pulp and paper wastewater streams. This bacterium is non-pathogenic but tests positive in a fecal coliform test. Because of the conflicting results of indicator tests, and the literature citing the absence of pathogens in paper mill biosolids, provinces like Quebec have opted for testing specific groups of pathogens such as *Salmonella* as a more appropriate method of pathogen identification.

Organics

The public concern over re-use and disposal of pulp and paper mill biosolids (ppmb) is focused on dioxins and furans which in the past have been an issue for bleached kraft mills. As mills update their process to use chlorine-free lower impact chemicals, the dioxin and furan hurdle is quickly becoming an issue of the past and concentrations are falling below detectable limits. Environment Canada has taken the stance that dioxins and furans are no longer an issue in pulp and paper mill residuals (Organix, 2000).

There are only a few other organic chemicals which periodically appear in detectable concentrations in ppmb. Compounds which have been found in mills above 10 mg/kg include naphthalene, some phthalates, chloroform, PCBs and wood extractive or derivatives (Scott & Smith, 1995). The PCB's are exclusively related to de-inking sludges; recycled carbonless copy paper acting as the source of this contaminant. As its production stopped in the 1970's, PCB's appearance in reported data has been on a rapid decline (Belsito, 1999).

Wood extractives such as plant sterols, fatty acids and resins naturally occur in wood. They result from the chemical reactions such as oxidation and hydrolysis which occur once the tree cells die. For example, phenol is a result of the degradation of parahydroxybenzoic acid which is associated with lignin (Samis et al., 1999). Through the process of pulping, they become concentrated in the mills wastewater and biosolids. Their presence in wastewater can cause toxic effects on aquatic ecosystems. Some extractives, such as sterols, are endocrine disrupting chemicals which are related to physiological and morphological abnormalities in fish (Mahmood-Khan & Hall, 2003). The presence of extractives in land applied biosolids could lead to detrimental effects on vegetation and surrounding aquatic environments through leachate contamination (Samis et al., 1999).

The Organix survey (2000) focused particularly on organics because of their sordid past in association with pulp and paper mill waste and effluent. They found that none of the residuals tested contained chlorinated organic compounds and that dioxin and furan concentrations were below the standards of the Pulp Mill Sludge Regulation Draft 3 for Class 1 (PSR Draft 3) put forth by the B.C. Ministry of Environment, Lands and Parks (BCE) (Organix, 2000). Some samples in the survey showed concentrations for polycyclic aromatic hydrocarbons (PAHs), some metals and some BTEX compounds slightly above those in the PSR Draft 3 standards.

Variability is an issue for ppmb producers. Approvals for management options could be more easily obtained if mills could show governing bodies that their residue characteristics could be predicted over time within a given range or confidence interval and could be shown to consistently stay within the guidelines. The biosolid material generated by pulp and paper mill wastewater treatment plants is also unique to each mill, depending on the type of product manufactured, the manufacturing process used and the type of wastewater treatment system implemented.

2.1.2 Type of product

Table 2-3 outlines the differences in waste production based on paper grade and source of fibre used to generate the pulp. Both the paper grade and the source of the raw material used for fibre effect the residual production. St. Marys Paper uses only virgin fibre to create their pulp.

Table 2-3 - Pulp and paper solid residue production based on fibre source and paper grade

Paper Grade	Residue Amt (kg/ton)		
	Virgin fibre	Recycled paper fibre	Both virgin and recycled fibre
Newsprint	57	164	69
Tissue	33	406	382
Printing & writing	62	187	165
Specialty	45	12	11

Scott & Smith, 1995

2.1.3 Manufacturing Processes

The manufacturing of pulp and paper starts with the collecting, debarking, washing and grinding of wood. Wood scraps from the yard and bark contribute to the solid waste stream of a mill. The debarked logs are then ground and cooked. Pulping is achieved chemically, thermally or physically using a variety of different processing techniques. Following cooking, a number of steps follow which vary with the type of pulping process used. With each step, short fibres are washed into the wastewater stream and make their way into primary and secondary sludge. In some mills, wood debris collected along the way is burned as "hog fuel" to recover energy and fuel the mill processes (Das et al., 2001). Paper is produced by spreading a watery suspension of fibrous material (the pulp) over a screen and drying the material so that it forms a sheet. Many different materials can be used to supply the fibrous material, but most commonly, the cellulose from timbers is used.

As imagined, the above is a gross simplification of the actual process. There are a number of processes which are a part of producing the final product, which include:

- Raw material preparation
- Pulping

- Delignification and bleaching
- Paper making
- Wastewater treatment

Of particular relevance to biosolids quality is the pulping process. This stage can either be performed chemically or mechanically. Mechanical pulping as practiced at St. Marys Paper has the advantages of high pulp yield (more than 90%) and lower associated waste emissions. The fiber produced from this process however, is deficient in strength and because of the high lignin content in pulp; the paper may discolor with time. Moreover, it is quite energy intensive. On the other hand, chemical pulping yields much less pulp (about 45%) and is associated with greater emissions and effluent, but it produces high quality paper. There are two types of chemical pulping, namely, sulfate (kraft) and sulfite. In Canada, kraft pulping accounts for 91% of chemical pulping and 75% of all pulp. Compared to the sulfite process, kraft pulping yields much higher strength pulp, and it can also handle a wider variety of tree species than the sulfite pulping process because it is more effective at removing impurities such as resin (Westman et al., 2003).

Chemical pulping

The goal of chemical pulping is to dissolve the lignin binding together the cellulose fibres of wood which are used to make paper. The kraft process achieves this by cooking wood chips in a mix of caustic soda and sodium sulphide at high temperature and pressure. The ether bonds of the lignin are broken during this digestion. Upon completion, the pulp is washed to remove the dissolved organics from the mixture and moved onto the bleaching process. Pulping chemicals can be separated from the wash stream and recycled. The lignin is not entirely removed from the pulp during this phase. The remainder is removed during the pulp bleaching process.

The wastewater generated by the kraft pulping process includes cooking waste and condensate from the digesters. The cooking liquor can consist of lignin, polysaccharides and wood extractives which can represent about 55% of the original wood mass (Belsito, 1999). Condensate can consist of ketones, phenols, reduced sulphur compounds, methanol, resin, fatty acids, terpenes and ethanol.

The sulphite process is similar to that of the kraft method the difference being that different chemicals are used. The sulphite process is acidic while kraft pulping is alkaline. Wastewater from a mill pulping with a sulphite process can contain lignosulphonates, carbohydrates, acetic acid, and methanol. In lesser concentrations it would not be uncommon to see formaldehyde, formic acid, acetaldehyde and methylglyoxal.

Bleaching

As previously mentioned, chemical pulping can not remove all of the lignin from the fibre without compromising pulp quality. Hence, the bleaching stage not only brightens the pulp but takes care of the remaining lignin. The lignin is depolymerised using oxidising agents such as peroxide, chlorine dioxide and hypochlorite. During this stage the lignin is converted to alkaline soluble compounds. Sodium hydroxide is used to wash the compounds from the pulp (Belsito, 1999). Boron makes its way into ppmb wastewater during the bleaching process where borate is used as a bleaching compound (Organix, 2000).

Elemental chlorine traditionally has been used as a bleaching agent because it is a very effective delignifying agent. The issue with using elemental chlorine and other chlorinated bleaching agents is that as they break lignin bonds, they attach chlorine ions to degraded products generating large amounts of chlorinated organic material or organochlorines.

Organochlorines are persistent pollutants which fall under the AOX compound category or absorbable organic halides. These halides are highly reactive, bond easily to organic substances and can quickly integrate themselves into the environment and food chain. (Brotten & Ritchlin, 2004). Dioxins and furans (dibenzo-p-dioxins and polychlorinated dibenzofurans) are two particularly infamous and highly toxic organochlorines which result from the use of chlorine compounds in the bleaching process. A number of organochlorines have been linked to health problems. These include cancer, birth defects, endometriosis, low sperm counts, and impaired fetal development. Organochlorines have also been shown to bioaccumulate in plants and animals and cause genetic damage and low survival rates of salmon and other fish (Blum, 1996).

Because of environmental and health concerns, regulations such as B.C. Pulp Mill and Pulp and Paper Mill Liquid Effluent Control Regulation, also known as the "Zero AOX" law are now prevalent world wide discouraging the use of chlorine in the pulp and paper industry. Elemental chlorine free technologies are becoming more advanced and widely used. For example, oxygen based bleaching such as practiced at St. Marys Paper uses alternative oxidizing agents such as ozone, hydrogen peroxide and oxygen to brighten and delignify pulp (Blum, 1996). A study done in the mid-nineties showed that mill dioxin effluent levels in Canada had dropped 99% since 1988 (Organix, 2000). Contamination due to organochlorines such as dioxins and furans should no longer be a major concern for typical Canadian pulp and paper mills.

Mechanical pulping

Physical grinding is used by mechanical pulp mills to harvest fibres from wood. In some processes, small additions of chemicals and/or heat are used to assist in the pulping (Belsito, 1999). For example, thermomechanical pulping involves heating the wood chips under pressure prior to grinding. Chemothermomechanical mills pre-treat the wood with sodium sulphite prior to heating and grinding. Mechanical pulp is frequently bleached with hydrosulphites and peroxides under elevated temperatures and pH.

Direct re-pulping and de-inking

The direct re-pulping and de-inking processes use recycled paper products as their fibre source. Mills which directly re-pulp tend to have lower BOD effluent, while de-inking mills have effluent with less colour bodies and higher metal content. Both direct re-pulping and de-inking mills produce considerably more sludge per unit of pulp than virgin pulp mills. They generally produce three times as much sludge in comparison to conventional mills (Belsito, 1999).

Recyclers produce more waste than mills that use virgin wood as a fibre source. Fillers in the paper which is recycled are not recovered and contribute to the waste stream. Fillers may be contaminated, difficult to recover, not required for the new product or may have changed during the processing, making it unsuitable for the new recycled product.

In contrast to municipal sludges, high metal concentrations are not usually the problem for mills. De-inking and wastepaper mills are the exception. Metals are often present in

the compounds used to remove the inks and the inks themselves. The presence of metals found in de-inking sludges has led to the use of lead, chromium and cadmium free inks (Belsito, 1999). De-inking and wastepaper mills may also have PCBs in their sludges as a result of recycling old carbonless copier paper.

2.1.4 Wastewater treatment systems

The wastewater stream in a mill passes through many stages prior to reaching the treatment plant. Influent wastewater streams to the treatment system are generally comprised of only 0.1% dissolved and suspended solids (Spellman, 1997), which are removed and create the basis of biosolids.

Primary sludge is recovered by the first stage of the processing at the primary clarifier. Wastewater generally is screened and then passed through primary treatment to remove solids. Primary clarification is usually carried out by sedimentation or dissolved air floatation. These solids consist primarily of cellulose, hemicellulose, lignin and to a lesser extent fillers such as clay and lime as well as boiler ash and inks. The overflow is passed on to the secondary treatment system (Jokela et al., 1997).

Secondary treatment is generally biological in nature using micro-organisms to convert waste into carbon dioxide and water. One of the most common techniques is the activated sludge process. It lowers the biological oxygen demand (BOD) of the wastewater and is an aerobic process. The wastewater is introduced into a reactor containing an activated mass of microorganisms. This bacterial mass converts the organic matter in the wastewater into new cells, carbon dioxide, ammonia, and other stable end products (Metcalf & Eddy, 1991). The bacterial cells are settled out from the activated sludge by a secondary clarifier following the reactor in the treatment train. The secondary sludge solids are typically 70-75% biomass and 25-30% fine fillers such as clay and lime (Belsito, 1999). Lignin and cellulose are also present in secondary sludge (Jokela et al., 1997). In general, primary sludges have lower nutrient values than secondary and the biological treatment of the secondary system concentrates some nutrients. The organic matter associated with sludge is perhaps its most valuable component (Kunzler, 2001).

The sludge from the secondary and primary treatment systems are generally combined and dewatered prior to disposal. The nature of primary sludge makes it easier to dewater than the secondary sludge stream. The biological nature of the secondary sludge stream makes it difficult to dewater and this process is more effective when the streams are combined. Table 2-4 outlines typical characteristics of primary, secondary and combined paper mill sludges.

Some mills are required to stockpile biosolids onsite for short periods of time prior to disposal. There can be odour problems associated with this practice. Odours emitted from stored sludge are primarily due to organic sulfur compounds such as indole and skatole and other organics such as propionic and butyric acids. If anaerobic conditions are avoided the biological activity responsible for the smell will be halted. Aeration or nitrate addition can solve the problem. Alkalinity addition in the form of lime can also stop bioactivity and fix compounds in non-volatile forms (Webb, 2000).

Table 2-4 - Typical pulp and paper mill sludge characteristics

Ranges				
Variable	Primary	Secondary	Deinking	Combined
pH	6.4-7.6	6.6-7.9	7.8-9.1	6.2-8.8
EC (dS/m)	0.19-0.7	3.9	0.09-0.12	0.29
Dry density (g/cm ³)			0.11-0.3	
Ash	4.2	9.9	18-40.2	6.8
Organic C (%)	16-40	42-43.1	32.8-44.1	34.6-44.7
N (%)	0.08-0.4	4.3-7.7	0.15-0.3	0.1-2.5
C:N	111-478	5-10	126-344	16-250
all values in mg/kg				
P	580-1000	7700-12000	60-100	200-2500
K	120-800	2000-6000	500-1100	15-2000
Ca	2100-8100	6300	8312	3712
Mg	610-3150	2300	623	1594
Fe			428	
S	1500	7000	786	2557
Mo	0.5-<2		<2	<0.5-5
Ba	1.1	1.8	<5	1.3
Na	440	1300	974	521
Pb	4-9.2	11-82	<20	1-59
Ni	5-24	6-36	<100	6-34
Cu	7-58	23-519	46-200	1-270
Cd	0.3-1.6	0.4-1.6	<0.2-2	<1-2
Zn	30-94	88-144	39-180	2-450
Ext. Ca	45-1780	3800	7600	2280
Ext. Mg	13-2800	1215	311	510
Ext. K	0.4		59	
Ext. P	228		38	
Cr	1.9-34	10-32	7-30	1-30
Mn	55-1400		19.6	
Al	1000-10000			1000-5000
As	<0.005-<10		<0.005	<0.1-3
B				5-15
Hg	<0.001-0.2		<0.001	<0.001-0.2
Se	<0.005-<5		<0.005	<0.005-<1
Co	<1-3		1-4	<0.6-5

Information gathered from WESA (2002), Norrie & Fierro (1998)

It is important to note that perhaps an effective way to mitigate sludge management issues is to reduce biosolids production in the first place. A few of the methods which can be used to decrease sludge production include (Webb, 2000):

- Reduction by exposure of the returned activated sludge to low pH in order to hydrolyze the biomass

- Anoxic conditioning
- UV treatment and then anoxic conditioning of the return activated sludge (RAS)

The majority of disposal options exercised by mills require pre-processing which, at the very least, involves dewatering. Rotary sludge thickeners and gravity thickeners can be used as an initial step decrease the volume of sludge prior to further processing (Belsito, 1999). The final dewatering can be achieved with screw, belt or V-belt presses, as well as centrifuges. The most common method is the belt press (Scott & Smith, 1995). Combined sludges can be dewatered to a solids content of around 25 - 35% (Belsito, 1999).

In summary, the characteristics of biosolids can vary considerably depending on the unit operations of the wastewater treatment plant, the type of mill and paper product it produces. For this reason, biosolids management strategies need to be uniquely tailored to each biosolids generator in order to address the particular challenges their biosolids pose.

2.2 Disposal of pulp and paper mill biosolids

2.2.1 Current state of affairs

In the past, methods of treatment and disposal often involved only a change of location. Pollutants were removed from the wastewater and relocated to a disposal site. The material then had free reign to wreak havoc on its new neighborhood be it an ocean, river, landfill or atmosphere (if incinerated). A better approach to disposal involves a realization of sludge's potential hazards and its potential benefits. Through responsible treatment and reuse, its negative qualities can be reduced or removed and its desirable traits exploited.

Today, management options for biosolids include land application, composting, incineration, land filling, land reclamation and reincorporation into new products. Figure 2-1 illustrates the break down of disposal options used by the pulp and paper industry in Canada in 1995 (Reid, 1998). As the chart indicates, landfilling and combustion were, at the time, the most popular methods. Land applications programs however are on the

rise. A more recent survey carried out in 2001, showed that 51% of Canadian mills surveyed practiced some sort of land application. This accounted for more than 95% of their biosolids. Seventy percent of this material was used for agricultural purposes, 26% for land reclamation and 4% for silviculture (Veleva, 2004).

Figure 2-1 - Disposal of pulp and paper mill biosolids in Canada in 1995.

Land application in British Columbia is less prevalent than in Ontario, Quebec and Alberta. There are only a small number of land application projects which have been given the authorization to move ahead by the provincial government under special permits (Organix, 2000). The B.C. government and the industry are trying to establish a regulatory framework for land application initiatives which will be aimed to support this disposal option.

Data from the industry in the U.S. reflects similar trends to the 1995 Canadian survey. In 1995, the U.S. pulp and paper industry produced about 5.8 million dry tons of wastewater treatment residuals. Of this about half were beneficially reused – 26% for energy recovery, 12% directly land applied and one percent composted (Kunzler, 2001).

None of these options provide the perfect answer for every situation. Each pulp and paper mill presents a unique case and biosolids managers should look at a number of factors when selecting a disposal method such as those suggested by Spellman (1997):

- 1) Characteristics of the biosolids
- 2) Land availability
- 3) Suitability of biosolids disposal by dilution
- 4) Local possibilities for use as a fertilizer or soil conditioner
- 5) Climate
- 6) Capital and operating costs
- 7) Size and type of mill and wastewater treatment plant (WWTP)
- 8) Proximity of mill to residential areas and local air quality control regulations

It is important to note that the options discussed in the following chapters all have disadvantages and advantages making them suitable for particular situations. By evaluating and weighting the above considerations, different solutions are generated by different challenges the pulp and paper industry faces. Despite the popularity of landfilling and incineration, there is particular focus on management options geared towards the reuse of biosolids as opposed to ultimate disposal. Landfilling and incineration are not sustainable practices. The future of biosolids management lies not in technologies developed to rid the planet of sludge but rather in research developed to harness the useful aspects of biosolids and put the material back to work.

2.2.2 Landfilling

Sludge landfilling is described by Davis and Cornwell (1991) as "the planned burial of wastewater solids including processed sludge, screenings, grit, and ash at a designated site." In this method solids are deposited, sometimes into a trench, and covered with soil. The cover material reduces odours and the disturbance of material by pests such as rats, insects and birds. As a method of disposal for sludge it has lost its popularity because of the high premium put on landfill space. Methods to divert waste streams are sought after to preserve the life of existing landfills and prevent the necessity to open new sites. It is however a disposal option still exercised. In fact the U.S. EPA estimated that in 1999, 46% of all biosolids were still being incinerated or landfilled.

Producing a safe biosolids product to dispose of in a landfill is not an issue with the technology available today. The issue is that there is no space available in the landfills to accept the material. Opening new landfills in a public arena haunted by the “Not in My Backyard” (NIMBY) syndrome can be very difficult. One third of the material received by landfills is organic (Gardner, 1997). Many argue that this organic portion contributes significantly to the environmental issues surrounding landfills including the toxicity of the leachate, odour problems, release of methane gas and the spread of pathogens. Biosolids are organic wastes and adding them to the landfill theoretically supports the problems organic waste creates.

Currently most paper mill sludge is dewatered and landfilled. Landfilling can be associated with tipping fees unless the mill owns the site. In Manitoba, the tipping fees range from \$17 to 40\$/tonne (www.gov.mb.ca/conservation/pollutionprevention/wastereg/solidwaste.html). In Southern Ontario, the range is considerably higher at 45 - 55\$ / tonne (Velema, 2004). Even if the site is owned by the mill, transportation fees can still be substantial (Scott & Smith, 1995). Thus, although it is the most widely practiced disposal, landfill space is at a premium and the drive to divert waste streams is increasing and will continue to do so.

2.2.3 Incineration

If biosolids can not be disposed of by other means, incineration or combustion is an alternative. It reduces biosolids to ash by evaporating the moisture and combusting the organic solids. In order to minimize the amount of fuel required, biosolids need to be sufficiently dewatered. This method of disposal is not really an ultimate method of disposal as much as it is a temporary method of storage until the residual moves back to the ground from the atmosphere (Davis & Cornwell, 1991). One could argue that the exhaust from incinerators can be treated to reduce air quality impacts, but then again what is left is ash and residue, which must be disposed of further.

To be fair, biosolids do have a caloric value that can be used to do useful work as fuel but this disposal option should only be thought of as an option in the absence of any other feasible alternatives. In order for combustion to be efficient, the feedstock should meet certain criteria. It should have a minimum heating value of 14 MJ/kg, ash content of

less than 33% and solids content between 40 and 45%. Shortcomings in solids levels can be overcome with the addition of wood waste to the sludge. De-inking sludges tend to be less favourable for combustion because of their high ash content (O'Connor, 1996). This method is generally not favourable because of the low fuel value of paper mill biosolids (Scott & Smith, 1995).

Advances in incineration have made it possible to design modern facilities which can be run more economically than in the past, but are still costly ventures with little investment return. With flue gas treatment and proper combustion, air quality impacts can be mitigated but not removed entirely. What is removed from the air must then be dealt with as solid waste once again. On another note, concern over greenhouse gases is currently a hot issue. As a result, combustion activities of every sort have been blacklisted by the public. Incineration also can emit gaseous NO_x and SO_2 as well as cause problems for mills using chlorinated compounds.

2.2.4 Land application

History has begun to repeat itself as interest in land application of biosolids has increased. Air quality issues have made incineration less attractive. Landfill space is highly restricted. Land application of municipal biosolids has now become the most popular method of disposal in North America. Approximately half of Canadian pulp and paper mills practice some form of land application (Velema, 2004). Through land application, the lifecycle loop can be closed with the renewed cycling of nutrients.

Through land application, biosolids and the receiving lands enter into a symbiotic relationship. The biosolids undergo further treatment as they are exposed to sunlight and naturally occurring microorganisms. The material not only begins to dry out but destruction of microorganisms and toxins also occurs. Metals in the biosolids are incorporated into the soil profile. In return, the biosolids offer numerous benefits to the soil including the addition of nutrients. Ash content, mainly in the form of Kaolin clay, has been shown to improve the water retention of soils (Scott & Smith, 1995). Organic matter addition reduces wind and water erosion, improves soil structure and adds biomass.

The organic content, nutrients, metals and toxic organics are all characteristics of concern when considering disposal by land application of paper mill biosolids. Despite the odour absorbing nature of wood ash present in the material (Kunzler, 2001), odours can be generated from the organic fraction as it decomposes. Methods to stabilize the biosolids prior to disposal via land application may be necessary to minimize environmental impacts. Close attention is given to plant nutrients such as nitrogen and phosphorous in order to determine appropriate loading rates for land application. Potassium is generally of lower concentration in biosolids and overloading is less of a concern. Bioaccumulation of metals and organics also must be considered when land applying biosolids. A full characterization of the biosolids is necessary to determine the potential risk of metals and organics to plants and animals. Plants are exposed through uptake and surface absorption while animals can be affected by direct ingestion (Metcalf & Eddy, 1991).

Receiving lands are typically agricultural, forest lands or disturbed areas requiring reclamation. Lands ideal for application have a high infiltration and percolation rate, are well drained, aerated and possess a pH of around 7 (Spellman, 1997). As different treatment processes yield different sludge characteristics, some processes yield more suitable biosolids for land application. For example, heat-dried, raw activated biosolids are ideal for land applications chemically whereas heat-dried, digested biosolids contain less nitrogen but provide better conditioning for the soil. If land application is found to lower the soil pH over time, lime may be added to correct this shift.

Regardless of the scientific research backing the benefits of biosolids, success or failure often rides on the opinion of the public. The importance of public confidence in the land application system can not be over emphasized. All successful strategies of biosolids reuse should involve adequate communication programs to keep the public well educated and informed. Generally, this is a weak spot for all biosolids generators, pulp and paper related and otherwise.

2.2.4.1 Agricultural land application

The U.S. EPA estimated in 1999 that 54% of all biosolids were agriculturally land applied. Biosolids have been attributed to higher or equivalent yields and higher quality

grains than that produced by crops using inorganic fertilizers (Draeger et al., 1999). As with all types of land applications, biosolids have a great deal to offer the agricultural industry.

Responsible, well managed use is the key to performance increases and risk reduction. This is the case when using any type of fertilizer. There are surface water, groundwater, ecosystem and food chain implications which should all be incorporated into the development of the fertilizing strategy to avoid adding nutrients at a rate higher than the uptake by vegetation or crops involved.

Over-fertilization has a number of detrimental effects on these systems. Surface water can be contaminated with high nitrogen and phosphorous through surface run-off and soil erosion. This can cause a phenomenon called eutrophication which involves algae blooms in water bodies. The blooms not only cause odour problems, but more seriously, increase water turbidity and can consume dissolved oxygen at high enough rates to suffocate other aquatic life including fish. Leaching occurs when the input of water to the ground is higher than the loss through evapo-transpiration. The soil can become saturated and some nutrients like nitrogen in the form of nitrates can make their way down through the soil profile and affect the groundwater quality. The process by which nitrogen is converted to nitrate, its most mobile form, is called nitrification. Over-fertilization can also cause reduced species diversity of the surrounding ecosystem and has been associated with increased plant disease (Gardner, 1997). The food chain becomes affected either by surface water contamination from trace elements or by plant uptake. All of these problems can be avoided by proper nutrient management strategies. In situations where leaching potential is high, soil nitrogen is high or plant nutrient requirements are low, fertilizers of any sort should be used with extreme caution. By implementing sound management plans, farmers can realize maximum growth return and minimize the risk of water contamination.

Nitrogen

Nitrogen is commonly the nutrient around which paper mill biosolids applications are designed. It exists in many forms; organic and inorganic (ammonium and nitrate nitrogen). The latter form is readily available for plant usage. Sludge is typically 1-6% organic and inorganic nitrogen (dry weight) (NRC, 1996). Organic nitrogen is mineralized

into ammonium and nitrate before it becomes available. This occurs over long periods of time, typically one to two years which is why organic nitrogen is termed a slow release fertilizer (Draeger et al., 1999). Secondary sludge application has been shown to cause prolonged increase in soil total nitrogen (Scott & Smith, 1985).

When looking at the nitrogen levels of organic additives such as paper mill biosolids, it is important to look at the nitrogen concentration relative to the organic carbon content. The carbon to nitrogen ratio is an important characteristic of organic residuals added to soils for two reasons as described by Brady & Weil (1999):

1. Intense competition between microorganisms for available nitrogen results from adding organic material with high C:N to soils.
2. The C:N ratio indicates the rate of decomposition of the organic residual and at what rate nitrogen is made available to plants.

Soil microorganisms require carbon in order to build essential organic compounds and generate energy in order to carry out cell processes. They also require nitrogen to carry out a number of tasks including synthesis of DNA, amino acids and enzymes. For every 24 parts carbon they metabolize, they require one part nitrogen, i.e. their ideal food would have a C:N ratio of 24:1. Should the C:N ratio of the soil be in excess of approximately 25, the microorganisms will be forced to scavenge the soil solution in order to fulfill their nitrogen needs. The soluble nitrogen concentration will drop causing higher plants to suffer from nitrogen depletion. A second consequence of high C:N additive addition is a decreased rate of organic decomposition. If there is not enough nitrogen in the organic material added to the soil or the soil solution to support the microbial population, they can not effectively decay the organic material (Brady & Weil, 1999).

Primary sludge tends to have a higher C:N ratio than secondary sludge and can cause nitrogen limited growth. Secondary sludges with C:N ratios of 20:1 or less have been shown to have positive effects on plant growth. Often the problem with paper mill biosolids is not too much nitrogen, it is not enough in relation to the addition of organic carbon.

When determining application rates, the mineralization of the organic nitrogen must be factored into the total nitrogen load. Proper nitrogen management involves biosolids analysis, determination of crop requirements and review of previous biosolids and fertilizer treatments, leading to safe and effective loading rates, which can be determined on a crop by crop basis.

Land application of lower nutrient biosolids can lead to temporary immobilization of nutrients in the soil, particularly nitrogen. The carbon to nitrogen ratio of paper mill biosolids is typically high due to their wood-based origin. Though secondary sludge tends to have a more moderate C:N ratio, even combined sludge may require supplemental fertilizer for land application.

Primary sludge application alone has been shown by a Wisconsin study (Scott & Smith, 1995) to exhibit a negative growth response. This was thought to be caused by the immobilization of nitrogen by the low nitrogen sludge. With decomposition the nitrogen may be released and immobilization difficulties may be overcome with timing, crop selection and sludge application rates. Forest lands tend to be more tolerant of periods of immobilization than agricultural lands (Scott & Smith, 1995).

Phosphorous

Phosphorous should be managed in a similar fashion as nitrogen. It is not as mobile as nitrogen as it tightly adheres to soil particles. Plants, however, still absorb phosphorous from solution and it can become a limiting factor in their growth if not properly monitored.

Nitrogen and phosphorous often exist in similar concentration in all biosolids. Crops generally need more nitrogen than phosphorous. If application rates are designed solely based on nitrogen, an overload of phosphorous could result (Draeger et al., 1999). Phosphorous is often responsible for surface water contamination and accelerated eutrophication and should not be overlooked. Unfortunately, there are few tools available for farmers to determine the phosphorous available for plant absorption as it is not as well researched as nitrogen.

Trace elements

A number of metals may exist in biosolids at low concentrations including: arsenic, cadmium, lead, mercury, nickel, sulfur, calcium, iron, magnesium, manganese, potassium, sodium, boron, copper, molybdenum, selenium, and zinc. Most of these metals also exist in natural soils in low concentrations. Problems arise when the metals creep into the water cycle or contaminate the food chain. For this reason continuous monitoring of metals is required. Food chain contamination can occur through uptake by crops or by aquatic plants and species via contact with contaminated surface water. The water contamination can occur through surface water run-off and/or soil erosion. Runoff is associated with poorly drained fields, impermeable soil and areas where the water table is close to the soil surface.

Groundwater risk is low as metals are not usually mobile in soils with neutral pH. As the pH decreases, metals become more soluble and the potential for leaching increases. Pulp and paper mill biosolids use is not associated with acidification of soils, but pH should be monitored to ensure it is maintained at a fairly neutral pH. The US EPA Toxicity Characteristic Leaching Procedure (TCLP) assesses the extractability of 8 metals and various organics under slightly acidic conditions. Using this method many studies have found that most metals are undetectable in simulated leachate from paper mill biosolids (Webb, 2000).

The bioavailability of metals varies. Studies by Sloan et al. (1997) found that for romaine lettuce cadmium was more available for uptake than the other metals studied. They concluded the following trends for bioavailability: Cd >> Zn >> Ni >= Cu >> Cr >> Pb. Cadmium is a closely monitored element because of its carcinogenic nature and higher bioavailability. Metals may not accumulate in seeds, but they will appear in other plant tissue.

Metal accumulation in soils may also have an effect on microbial activity. Microbial activity is essential for organic matter decomposition and nutrient cycling. Metals associated with long-term application were shown to affect nitrogen fixation and vesicular-arbuscular mycorrhizae. This fungus is important to plants as it assists them in obtaining phosphorus and zinc (NRC, 1996).

Organic contaminants

Although toxic organic chemicals, such as polychlorinated biphenyls (PCBs), are highly persistent pollutants and have significant human health implications, the environmental risk associated with paper mill biosolids use and persistent organics is very low. This is due to the low levels of organic contaminants in the biosolids to begin with due to new bleaching and pulping techniques which do not result in to dioxin and furan emissions. Regulations exist in both Canada and the U.S. for maximum allowable dioxin levels for land application operations. These levels are presented in Table 2-5.

Table 2-5 - Allowable dioxin concentrations of soils at land application sites

Parameter	Maximum allowable concentrations of dioxin TEQ^a (ppt, dry wgt.)		
	Ontario^b	Maine^b	U.S. EPA^c
Soil residue	100	250	50
Soil	10	27	10

O'Connor, 1996

a – total 2,3,7,8 – TCDD toxic equivalents

b – TEQ calculated from the tetra-octa isomers using international toxic equivalency factors

c – TEQ calculated as (2,3,7,8-TCDD + 0.1*2,3,7,8 – TCDF)

Despite the emergence of new processing techniques and alternative chemicals, there are some organics present in biosolids which are a result of their natural presence in wood. As previously mentioned wood extractives can appear in biosolids as a result of the wastewater treatment process. If they are present, toxic organics are typically not of concern with respect to ground water contamination because they are volatilized, degraded or tightly sorbed onto the surface of the soil particles (NRC, 1996).

Pathogens

Many of the regulations and guidelines controlling biosolids land application are designed with respect to municipal biosolids. Pathogens are one of the chief environmental concerns surrounding municipal biosolids. For this reason, suggested loading rates are often designed to mitigate the risk of pathogenic contamination of groundwater, surface water, soil, air, plants and animals. For mills which do not mix their process effluent with their sanitary sewer lines, pathogens should not be an environmental concern limiting their land application.

Groundwater contamination by way of pathogens is unlikely because in the rare event they were present initially in the paper mill biosolids, they would be tightly sorbed on the

surface of soil particles. Surface water contamination could be an issue if pathogens were present in the biosolids and for this reason governing bodies such as the U.S. EPA classify all biosolids depending on their associated pathogen risk. Under the EPA's Part 503 Rule, sludge is classified as either Class A (unrestricted use) or B (site and crop restrictions apply). Class A products are tested for bacteria, viruses and helminths. Salmonella or Fecal Coliform tests are used as indicators to determine quality. Class B biosolids require a waiting period between application and crop harvest and or land use for grazing when used in agricultural settings. This is to ensure die off of pathogenic organisms.

Organic matter

Despite biosolids beneficial nutrient contributions, the main nutrient value of biosolids is generally carbon. Organic matter gives soil particles more stability, better water retention and tilth which improves aeration and workability. The loss of organic matter in soils is a considerable threat to soil fertility. Pulp and paper mill biosolids' role in rebuilding soils is a key argument in the defense of its use in agricultural applications.

For agricultural applications, it is common to distribute biosolids annually before planting and allow the material to dry out partially. Disking or plowing is then used to mix the material into the soil prior to planting. The entire procedure is then repeated after harvesting (Metcalf & Eddy, 1991).

While biosolids can not provide all of the macronutrients required by crops, they can supplement a portion of the requirements and reduce fertilizer loading. All of the industrial and municipal biosolids produced in North America could supply but a fraction of the nitrogen requirements of the agricultural industry. Supply has definitely not surpassed the demand in this market. To further put this into perspective, if all the biosolids in the U.S. were agronomically applied, they would still only treat 1.9% of the available crops (NRC, 1996). The feasibility of this option, of course, varies with geographical location. Some pulp and paper mill regions have little or no agricultural activity.

Though studies have shown paper mill biosolids to be beneficial to plant growth, it is more difficult for farmers to use than chemical fertilizers. Fertilizers are engineered

specifically for the crops, whereas biosolids characteristics vary widely depending on suppliers. Financial incentives are required by some farmers before they will use sludge of any nature (NRC, 1996).

2.2.4.2 Forest land application

Forestland possesses a number of characteristics which make it an excellent candidate for paper mill biosolids (ppmb) land application. Often forest productivity is limited by nutrient deficiencies which could be remedied with ppmb. Public health concerns are limited in these areas as they are not used to produce food for mass consumption. Forest soil properties are also ideally suited to receiving biosolids. They are high in organic carbon which immobilizes nitrogen. Their high infiltration rate minimizes surface runoff and issues associated with surface water contamination. Perennial roots can allow year round uptake of nutrients (Draeger et al., 1999). Forest growth is less sensitive to increases in soil salinity which can be associated with some ppmb. As with agricultural applications, biosolids offer a number of positive impacts to the forestland including increased nitrogen mineralization, nutrient availability, addition of organic matter and improved water retention of forest soils.

Forest production

Considerable research has been conducted to illustrate that biosolids can increase forest production if appropriately applied (Draeger et al., 1999, Chong et al., 1998, Chong, 1996, Velema, 1998, Lo et al. 1998). Responses vary with tree species, type of biosolids and application site. Promising results have been seen all over North America with Christmas tree plantations, hemlock, silver fir, red cedar, slash pine, douglas fir, red maple, red oak and white oak. Application rates varied for each study, but biosolids have been most advantageous on sites with existing poor soil (Draeger et al., 1999). Improved growth of understory species has also been demonstrated which can provide better competition for seedlings. In situations where this is of concern, forest management practices such as disking and trunk protection strategies may be implemented.

By stimulating forest floor growth, ppmb improve the quality of surface runoff in forestlands. Water filtering takes place in the vegetative layer of the forest soil. Biosolids encourage growth on the forest floor which improves this natural filtration system. This

improved growth offers organic matter and high cation exchange capacity which both stabilize trace elements. This stabilization reduces leaching and further improves runoff water quality.

Nutrient addition

As with agricultural systems, nitrogen is often the limiting factor in growth performance, at the same time it is also one of the most common environmental concerns. Nitrogen is the most common nutrient added to soils which can potentially leach to the groundwater as nitrates. Both nitrogen and phosphorous can cause surface water contamination.

Nitrogen loading must be investigated thoroughly when developing application rates. Nitrogen cycling in forestlands is considerably different than agricultural settings primarily due to litter fall and the long intervals between harvests. Stands may be harvested every 20-30 years and often even less frequently. Tree species, climate and geographic location are also factors which effect nitrogen loading.

The potential for groundwater contamination from nutrient leaching does exist if loading rates are not responsibly designed. The biggest concerns lie with nitrate movement through the soil profile, as nitrates will travel quickly through coarse, gravelly soils. As the depth to the groundwater decreases, the risk for contamination increases. However, research has shown that it is possible to see improvements in forest production at application rates which do not threaten groundwater quality. Despite the ability of biosolids to assist in surface run-off control, they still contain nitrogen. Buffer zones are recommended for biosolid application to safeguard against surface water contamination. For the same reason, it is also important not to exceed slope regulations.

Trace metals

Forest soils are generally acidic. Under acidic conditions many metals become more soluble. Thus, the mobilization of heavy metals could be of concern in forest soils with low pH. Monitoring pH is required to ensure that it is maintained within a desirable range for biosolids application. Generally however, metals are locked within the soil matrix (Draeger et al., 1999).

For forest land applications, the biosolids may be applied to unforested, cleared land, a young plantation or beneath the canopy of an established stand (Draeger et al., 1999). Depending on the site, all terrain vehicles may be required to negotiate the rougher terrain. These vehicles can be outfitted with spray guns designed to handle biosolids materials. Often dewatered sludge is difficult to distribute over treed areas and after being transported to the site it is re-liquefied and then sprayed over the area. Suggested application rates vary widely from once every 3 to 10 years (Draeger et al., 1999). Each site and biosolid stream present a unique combination and this follows for all land application operations whether forestry related or otherwise. Rates should be set based on local conditions as opposed to relying on other previous decisions made at different sites. Climate, forest slope, soil properties, biosolid properties and land use should all be factors used to determine site suitability and application rates.

2.2.4.3 Land reclamation

Disturbed lands have had vegetation removed either by natural or anthropogenic forces and require significant intervention to assist in returning them to their original state. Examples of disturbance include mining, dam construction, road construction, commercial development, forest fire, flooding and landslides. Though the size and severity of disturbances are highly varied, they all have the potential to alter the landscape and hydrology of surrounding areas because of the removal of topsoil. Disturbed sites are associated with high silt levels, acid mineral run off and toxic pollutants. Natural forces are extremely slow to correct the damage to these sites. For example, the 70 square mile path of destruction left in the wake of Mount St. Helen in 1980 still has not regenerated itself after two decades. As another example; mining activities have caused disturbances which will take centuries for nature to heal if not assisted.

Mine tailing sites pose a significant hurdle for reclamation strategies. Tailings are a waste product of the mining consisting of inorganic material which remains after the desired constituent (e.g. copper, coal, gold, etc) has been removed. The tailings contain little organic matter and are depleted of nutrients. Tailings sites have a slew of characteristics deterring vegetative growth including (Draeger et al., 1999):

- Extreme pH

- Insufficient nutrients
- No organic matter
- No water retention
- Toxic elements
- Low permeability, crusting and compaction
- High surface temperature

Minerals exposed at the ground surface are oxidized producing mineral acids which contaminate soil, ground and surface water. Tailings exposure to wind and rain increase erosion which perpetuates the cycle by exposing new surfaces for oxidation.

In the US, the Federal Mined Land Reclamation Act was passed in 1977 and was amended in 1982. It is the current body of regulation calling for mine reclamation and involves revegetation of sites using native plants. Pulp and paper mill biosolids are well suited to achieve the goals set out in this Act. Although ppmb have been shown to be beneficial agricultural applications, mining companies can at times be hesitant to use the material because of the lack of comprehensive sludge characterization (Belsito, 1999). In silviculture and agricultural settings, the applied biosolids' role is to add nutrients, organic matter and sometimes structure to receiving natural soil. At a mine site, the environment is far from its natural state and the role of ppmb is associated with greater responsibility. Not only is it expected to act as a re-vegetation amendment, but it also can be required to provide the following characteristics depending on the reclamation strategy used (Belsito, 1999):

- moisture barrier
- dust control layer
- physical oxygen barrier
- oxygen consuming material
- reducing medium particularly for sulphates
- reactive barrier in acid mine drainage treatment

Mines may have concerns over the material's geo-mechanical performance over time and how it will be affected by contact with the extreme environments associated with tailings. In short, mine site cleanup is terribly expensive; therefore claim owners are not only looking for value, but long-term performance to avoid continuing costs in the future.

To date, research has shown that the use of ppmb for tailings reclamation is not only effective, but considerably cheaper than conventional methods (Okonski, 2002).

Biosolids have been successful in reclaiming numerous sites including gravel pits, barren lands, coal refuse banks, colliery spoils and forest fire damaged areas. In many cases they have outperformed conventional methods as far as re-establishing vegetative cover and root systems. This is particularly the case in mine reclamation. The high hydraulic resistance of pulp and paper biosolids makes it excellent as a barrier to prevent flushing of acidic materials through the tailings layer of mine sites (Webb, 2000). Biosolids have had a greater effect on productivity than inorganic fertilizers (Draeger et al., 1999).

Organic matter and nutrients

By adding organic matter to the disturbed lands, biosolids increase the pH, moisture retention, and organic carbon content and decrease the bulk density of the soil. Surface temperatures are reduced which allows better seedling establishment (Draeger et al., 1999). They offer a cost effective alternative to conventional topsoil, lime and fertilizer treatments.

As mentioned in previous sections the nutrients in biosolids are more readily available to plants than inorganic forms and also slowly released through mineralization. This slow release minimizes nutrient leaching and loss to the water cycle. Microbes dependent on organic matter as a food source are reintroduced into the system with the use of biosolids. The microbes then assist in the cycling of nutrients through the soil.

Trace metals and pH

Disturbed sites with low pH have increased movement of heavy metals throughout the system. Under acidic conditions, the risk of introduction of metals into the ecosystem and water system are higher. Conventionally, lime has been used to neutralize acidity at sites and must be reapplied to maintain pH control. Biosolids can offer a more permanent solution to the acidity and can more efficiently control pH than lime applications (Sopper, 1990). Pulp and paper mill biosolids can offer buffering capacity in the form of calcium carbonate which is very useful in preventing or lessening the acidic tailings run off (Webb, 2000).

The issue of heavy metals is slightly complicated by the fact that biosolids themselves contain heavy metals and this is one of the reasons that their application is regulated. Disturbed lands can have existing high metals concentrations and adding biosolids to the sites compounds the problem. The effect of metal immobilization through soil neutralization can counter the effect of this additional metal load. Under regulations, the metal load added to the sites in many instances is insignificant compared to the existing levels. In the past this was more of an issue than it is currently. Improved wastewater treatment, improved distribution systems, higher air and water quality standards and increased liability have all helped to decrease heavy metal levels (Draeger et al., 1999).

Because land reclamation is associated with high rates application, some increases in bioaccumulation in plants and animals have been documented. These increases have generally decreased over time and are within established tolerance levels. This phenomenon is an important consideration in disposal decision making and should be evaluated as to whether it is an acceptable risk. It has been shown that application rates associated with increased vegetative performance do not have to compromise food chain and soil health.

Soil soluble salt content is also affected by ppmb application as seen by increases soil conductivity. This also contributes to the ability of ppmb to outperform inorganic fertilizers. Because of the fine organic particulates, the surface area for salt absorption is high in ppmb. By incorporating the salinity into the soil, the plants are protected from the ill effects of salts such as sodium chloride (Draeger et al., 1999).

Vegetation growth

After ppmb application, healthy growth of grasses and legumes can be expected (Draeger et al., 1999, Okonski, 2002) on sites with no previous vegetation. Other studies have shown increases in production of field crops grown on previously disturbed areas.

Trees also benefit from the biosolids application however sometimes their survival is hindered by competition with vigorous herbaceous plants. In a study by Sopper (1993) alder, black locust, black cherry, white pine, larch and hybrid poplar responded most

promisingly to biosolids out of a group of eleven tree species. As can be expected, different species are better suited to the ppmb as a growth medium than others.

The establishment of woody species on disturbed sites is important because of their role in decreasing the negative impacts of biosolids on the food chain. Trees have the ability to store large quantities of heavy metals in their woody tissue. This can reduce their presence in their own leaves and also herbaceous plants which are more commonly introduced into the food chain.

Application Methods

Reclamation usually requires a one time high rate application of dewatered cake biosolids which can be achieved by using bulldozers, loaders and graders. Contouring is often required to create more gentle slopes at disturbed sites.

2.2.5 Composting

Composting is a disposal option that has been well accepted by the public perhaps because of its popularity with home gardeners. Composting is the biological decomposition of organics under controlled conditions which yield a stable product which can be safely handled, stored and land applied. As a treatment for biosolids, it offers the benefits of significant volume and odour elimination. It is possible to convert biosolids into a material of exceptional quality and safe for unrestricted public use through composting. This material can be marketed and sold commercially for landscaping as well as food and vegetable gardening. Between 1988 and 1997, there has been a 327% increase in operational composting facilities in the U.S. (Goldstein & Block, 1997).

The main goals of composting are outlined by Spellman (1997):

- 1) To stabilize the product
- 2) Control odour during process
- 3) Dry material enough to allow handling
- 4) Achieve high enough temperatures to destroy pathogens

Technology developed in the late 1970's has allowed composting operations in North America to grow tremendously in scale. The development of forced aeration has made it possible to operate large-scale process flows even under cold, wet winter conditions.

Depending on the area, both capital and net operating costs associated with composting can be substantial with little prospect of profit. This can be overcome if a high proportion of the material can be bagged for sale to retailers (Webb, 2000). The capital investment can be reduced depending on technology chosen (Scott & Smith, 1995). As a portion of the capital investment is associated with the purchase of land for the operation, this option is best suited to regions where land is not at a premium (e.g. Northern Ontario). It is important to note that despite the capital and operating costs, composting can be achieved at a fraction (nearly 20%) of the cost of incineration (Goldstein, 1977).

Composting takes advantage of a biological process which requires inexpensive equipment and is an environmentally sustainable practice. Because of its biological nature however, it has its limitations. The process is not rapid and involves periods of hours to months to create the final product. As far as time efficiency is concerned, aerobic has been found to be more successful than anaerobic operations (Spellman, 1997). Unfortunately, aeration is one of the most expensive processes involved with composting. Aerobic conditions are also essential to the thermophilic (40-70 °C) conditions required for pathogen destruction and high rate decomposition.

The initial nutrient balance for paper mill biosolids composting is not well defined. Previous guidelines have suggested that a carbon to nitrogen (C:N) ratio of 30 is preferable (Das et. al., 2001). However, low availability of carbon from ppmb also suggests that a higher C:N ratio may be feasible. Some researchers have found that levels around 60 for C:N have been successful (Line, 1995). Depending on the characteristics of the ppmb, nitrogen amendments may be required to supply the nutrient requirements needed. Urea, ammonium nitrate and manures are common sources of additional nitrogen. Ammonium nitrate is preferable (Jackson and Line, 1997) to urea to reduce ammonia emissions. Natural nitrogen sources such as manure have the added benefit of introducing microorganisms into the compost which assist decomposition.

Typically, the compost feedstock's initial volatile suspended solids (VSS) should be within 40-60%, ash content between 35-50% and pH between 5.5-9.5. As the pH increases above 7, volatilization of nitrogen in the form of NH_3 increases and causes nitrogen losses and odour problems. The heavy metal content of the feedstock will not

effect decomposition but could limit the final use of the product. Toxins can be degraded through composting to safe, innocuous products (Scott & Smith, 1995).

Determining the maturity of compost can be difficult since no exact definition of biological stability has been specified with respect to composting, according to the MOE's Interim Guidelines for Production and Use of Aerobic Compost in Ontario (1991). The degree of stability may be dictated by the end use of the product. Complete stability could, by definition, mean that all organic matter has been degraded, in which case there would be little value in use of the compost as an "organic amendment". However, some stability is required in order to prevent negative vegetative growth effects caused by nitrogen depletion. There are a number of indicators used to evaluate stability, which have been deemed acceptable by regulatory bodies. These include volatile solids destruction, spontaneous heating, oxygen uptake, toxin production, C:N ratio, seed germination and growth test, and redox potential. When compared to the raw feedstock, these indicators describe stability in relative terms. One research study has suggested that cation exchange capacity and total humus content could be used as predictors of compost maturity (Campbell et al., 1991).

The end product characteristics and quality can vary widely depending on the feedstock used, the method of production and desired end use. The Ministry of the Environment of Ontario lists the following characteristics as indicators of good quality compost. These are presented Table 2-6.

Table 2-6 - Ranges of characteristics of good quality compost

Parameter	Value
Particle size	<25 mm
Mineral content (% dry wgt)	
Total nitrogen	0.6
Total phosphorus	0.25
Total potassium	0.2
Calcium	3
Magnesium	0.3
Organic matter	30% dry wgt
Typical C:N ratio	22
Total salts	< 3.5 mS/cm
SAR	< 5
pH	5.5 - 8.5
Moisture	30-50%
Water holding capacity	3 X dry wgt

MOE Guidelines for the production and use of aerobic compost. 1991

2.2.5.1 Composting methods

There are a variety of well defined techniques available for large scale composting including windrow, aerated static pile (ASP) and in-vessel systems. Currently, ASP is the most widely practiced technique (Goldstein & Block, 1997) for biosolids composting, followed by windrow and in-vessel systems. Though the details of the techniques vary, each involves the same basic steps which include:

1. Mixing sludge with bulking agent.
2. Aeration by turning or adding forced air
3. Recovery of bulking agent
4. Curing
5. Storage for beneficial use

To effectively compost, wastewater biosolids should consist of 20-40% solids prior to composting. As is common in many aerobic composting techniques, the addition of a bulking agent to the biosolids is typically required to allow for proper aeration. The bulking agent prevents the conglomeration of sludge into large masses. Typical bulking materials can include bark, wood yard waste, brush, leaves, slash from forests, ground wood pallets and clean construction debris. While virgin wood chips continue to be employed by some operators, more creative bulking agents have also been investigated,

including almond shells, chipped rubber tires, coal ash and wood ash, and grease trap residuals to name a few. The bulking material is commonly mixed into the sludge in a 3:1 volume ratio.

For aerobic composting, the goal is to maintain oxygen levels throughout the piles at 5 to 15%. This can be achieved by forced aeration and/or mixing. Under these aerobic conditions, bacteria can stabilize the material in approximately 21 to 28 days in open systems such as ASP and the windrow technique. In-vessel systems can achieve a stable product more quickly than open systems. After the initial mesophilic stage, temperatures in the compost generally exceed 60 °C and can rise above 80 °C short periods of time. Temperatures within the thermophilic range destroy pathogens, if present. The thermophilic phase of composting is associated with a more rapid decomposition rate than the mesophilic stage. The thermophilic stage is followed by a cooling stage in which the microbial degradation is slower. The duration of each phase during composting depends on the system, operating parameters and characteristics of the compost feedstock. After three weeks of aerobic decomposition, the compost is cured in stockpiles for an additional period of time, typically four weeks. The compost is then screened to recapture the bulking agent and ready for use on lawns, crops, gardens, landscaping or as a potting soil. (Metcalf & Eddy, 1991)

Both ASP and windrow are open ended systems. Odours associated with open systems can be disturbing to surrounding neighborhoods, if mitigation measures are not in place. Odour control can be achieved by chemical scrubbers, biofilters, enclosures, stack/fan dispersion or counteractants (such as enzyme-based neutralizers). Treatment schemes can involve any combination of the above or may use only one unit process. The biggest challenge in the composting industry in the past was odour control, but presently, costs and market development present more significant issues for composters.

For in-vessel composting systems, the composting process is done within a closed reactor. By utilizing a closed system, odours and turnover time are significantly reduced. Temperature, oxygen and air flow are much easier to control with these systems. The in-vessel systems are either run as plug flow or completely mixed reactors. The setup for plug flow systems involves a ram rod to move the plugs through the enclosed bins. For

completely mixed systems, rotating drums house the biosolids and bulking agents (Spellman, 1997).

Table 2-7 outlines the disadvantages and advantages of the ASP, windrow and in-vessel composting methods.

Table 2-7 - Comparison of composting types (Spellman, 1997)

Adv/Disadv	Process Type		
	ASP	Windrow	In-vessel
High capital cost			*
Moderate capital cost	*		
Low capital cost		*	
High pathogen destruction	*		
Odor control	*		*
Product stabilization	*	*	
Land requirements	*	*	
Weather affected	*	*	
High labour	*	*	
Capacity to handle high volume		*	
High Equipment & Mtn Cost		*	*
Process control			*
Odor problems	*	*	
Operation reliability	*	*	

Finished composts from each of these methods have desirable qualities as soil conditioners. Nutrients for plant growth, such as nitrogen, phosphorous and potassium and micronutrients are supplied by the compost. The material also retains moisture which reduces watering requirements and promotes plant survival during drought conditions. It also gives soil a friable, loose texture which allows easy root penetration and good transport of water and air. Quality compost can be comprised of 2% nitrogen, 2% phosphorous and 1% potassium and an entire host of trace elements (Spellman, 1997).

Although the finished product maybe harmless, measures must be taken at compost facilities to reduce environmental impacts at the site. Air quality control is an important factor in site design and operation. Although air borne pathogens are not an issue in ppmb composting, as they are in municipal biosolids composting, efforts must still be taken to control odours. Many systems are enclosed to allow easier control of system

parameters. Site run-off and leachate should be monitored in order to limit surface and ground water contamination from nutrients, toxic organics and/or trace metals if present. Noise pollution may also be a factor depending on the proximity to communities.

2.2.5.2 Benefits of compost

Composting as a method of disposal promotes the well being of the planet on numerous levels. Its benefits are evident through its contributions to the environment, resource conservation and role in maintaining public health (Spellman, 1997). From an environmental standpoint, composting offers a means of transforming a waste material into an innocuous, useful material without the use of extensive physical and chemical processes. Micro- and macro- nutrients are returned to the soil matrix through use of compost. Nutrient delivery is achieved in such a way that promotes efficient utilization not only of nutrients supplied by composting but also by other methods such as fertilization. Compost not only creates an environment which promotes good root growth which boost nutrient access, but it presents nutrients in useable forms.

Through incorporation of nutrients into microbial protoplasm and organic compounds, composting converts soluble forms of nutrients to slowly soluble and temporarily insoluble forms. This insolubility prevents leaching of nutrients through the soil. Leaching causes major concerns for surface and ground water contamination and is a problem which plagues chemical fertilizer use. Up to 35% of nitrogen applied as chemical fertilizer can be lost through leaching (Spellman, 1997). In contrast, microbes and organic compounds slowly breakdown and make available nutrients at a rate better suited to that of nutrient uptake by plants. The compost material also has the ability to biologically incorporate a portion of the fertilizer supplied nutrients into protoplasm further diminishing leaching.

Nutrients in compost are available in partially organic complexes which are available to plants. For example, during composting inorganic phosphorous complexes with organic acids generated from microbial metabolic activity. In this new state, phosphorous is now readily available for absorption by plant roots.

Resource conservation is directly achieved by returning organic material and nutrients to the land. The use of compost reduces the use of fertilizers, which reduces the amount of fertilizer manufacturing. Indirectly, energy is then conserved via the reduction of this production, which is an energy intensive process. If properly managed, a composting operation can provide a disposal method for ppmb which stabilizes the product making it suitable for unrestricted public use and reclassification by the provincial government as a product. This is really the major advantage of composting over land application.

2.3 Legislation & biosolids beneficial reuse

There are no specific federal government guidelines pertaining specifically to the re-use of pulp and paper mill residues in Canada. Approvals for re-use strategies including land application, reclamation and composting are generally based on municipal or industrial guidelines which contain criteria for allowable heavy metal and dioxin concentrations (O'Connor, 1996). There are a number of guidelines available which have been compiled by independent consultants for a variety of parties, which are of use when developing re-use strategies involving land application and reclamation. These include:

- Guidelines for the Utilization of Pulp and Paper Mill Biosolids on Agricultural Lands. Prepared for the Ontario Forest Industries Association by Water and Earth Sciences Assoc. Ltd in 2002.
- Guidelines for the Utilization of Pulp and Paper Mill Biosolids in Silviculture and Land Reclamation. Prepared for the Ontario Forest Industries Association by Water and Earth Sciences Assoc. Ltd in 1999.
- Alberta Standards and Guidelines for the Land Application of Mechanical Pulp Mill Sludge to Agricultural Land. Prepared by the Environmental Sciences Division of the Province of Alberta government in 1999.
- Use of Paper Mill Sludge in Mine Tailings Reclamation: A literature review. Prepared for the Northern Ontario Mines and Mills Alliance by Kevin Belsito in 1999.
- Final report: Pulp Mill Residual Chemistry and Options for Regulation. Prepared for B.C. Pulp and Paper Association by Organix Waste Solutions, Inc. in 2000.

In Canada, for the most part, regulations and guidelines for the use of all biosolids are managed at the provincial, as opposed to federal, level. There are however, some federal acts which indirectly govern biosolids use as described below.

Following the success of the Canadian Water Quality Guidelines released in 1987, work began in 1996 by the Canadian Council of Ministers of the Environment (CCME) to establish guidelines for all environmental media. These guidelines cover not only water, but also soil, sediment, tissue residue and air. The guidelines represent an immensely diverse scientific collaboration involving a variety of different task forces and federal and provincial government teams. The guidelines “are numerical concentration or narrative statement recommended to support or maintain” a designated use of water, soil, air, etc. (http://www.ccme.ca/assets/pdf/e5_001.pdf). The guidelines affecting biosolids and their re-use are those established for soil quality.

The Canadian Fisheries Act also impacts biosolid reuse and disposal activities. It prohibits unauthorized release of any deleterious substance to waterways which support fish or flow to feed other waters act as fish habitats. Deleterious substances could include compost, paper mill biosolids, manure and runoff from compost production.

Though some provinces refer to the United States EPA's Part 503 for biosolids reuse, Ontario has created its own laws and guidelines. In Ontario, the Environmental Protection Act (R.R.O. 1990, REGULATION 347), amended to O. Reg. 326/03, stipulates the laws governing the operation of waste disposal sites such as landfills and the practice of land application at organic soil conditioning sites. “Organic soil conditioning sites” are the designation given to sites receiving land applied waste materials.

There are two steps which must be taken before biosolids can be applied to land in Ontario. The first step is to ensure that the biosolids are suitable for land application under a set of guidelines which outline maximum allowable levels for eleven heavy metals as outlined in Table 2-8, which for as a basis of comparison also includes the regulation levels for Quebec, Maine and the U.S. EPA. The biosolids are also assessed by their degree of decomposition. Depending on the nature of the biosolids (e.g.

anaerobic or aerobic) they must adhere to a stabilization schedule, e.g. 15 days at a temperature ≥ 35 deg. Celsius for anaerobic biosolids.

Table 2-8 - Comparison of permissible heavy metal limits for biosolids

Parameter	Maximum permissible heavy metal conc. (mg/kg dry wgt)			
	Quebec	Ontario	Maine	U.S. EPA
Arsenic	30	170		75
Cadmium	15	34	10	85
Chromium	1000	2800	1000	3000
Cobalt	100	340		
Copper	1000	1700	1000	4300
Lead	500	1100	700	840
Mercury	10	11	10	57
Molybdenum	25	94		75
Nickel	180	420	200	420
Zinc	2500	4200	2000	7500

O'Connor, 1996

The second step of the process is the approval of the receiving site by the MOE. A Certificate of Approval (C of A) must be obtained for each location to become an "organic conditioning site". Applicants must submit:

- Written approval of land owner
- Soil analysis results obtained within the last three years
- Site location, land and soil characteristics
- Site plan outlining well locations, waterways, residents
- Purposed site management methods

The MOE approves sites on a case by case basis taking into consideration the crops grown, the nature of the site and the characteristics of the biosolids to be applied. Approval is granted under a given set of conditions. The C of A will dictate the minimum set backs from wells, etc. and they will also specify allowable rates of application. Should a generator or biosolids user violate the guidelines and/or C of A, fines may result.

Ontario's Nutrient Management Act (Bill 81) is the legislative document used to govern the use of nutrients specifically for agricultural purposes which includes horticulture, aquaculture and silviculture operations. Under this act, nutrients include not only chemical fertilizers, but also organic material, such as biosolids and compost. The Act was released in June 2002 by Ontario Ministry of Agriculture and Food (OMAF) and the Ontario Ministry of the Environment (MOE). Its goal was to establish the framework from

which Nutrient Management Plans could be developed by farmers and Nutrient Management Strategies could be developed by nutrient generators.

The Nutrient Management Plan requires:

- Facility description and approval information
- Material characterization and storage information
- Five year projected strategy for material management
- Nutrient analysis
- Contingency planning
- Material destination
- Annual report of material management

The above must be repeated every five years or as dictated by the Act in the event of a change in quantity or quality of the biosolids.

Previous to the Nutrient Management Act, there existed the Ontario Guidelines for Land Application of Biosolids, which were developed in Ontario in 1970 by the Biosolids Utilization Committee (BUC). Since their creation, land application has become a more popular disposal option. The BUC was formed to act as an advisory board for the Ministry of the Environment, the Ministry of Health and the Ministry of Agriculture and Food. The committee developed the guidelines in order to establish quality standards for agricultural lands. Over the past thirty years, many studies have supported the use of biosolids by illustrating that they pose minimal environmental and health risks.

The aim of the guidelines is to ensure that land applied biosolids do not degrade the environment or threaten the health of humans, animals and crops. They outline testing and analytical procedures to be used to evaluate the suitability of biosolids for land application. They also offer information about separation distances, metal and pathogen criteria, nutrient loading, farming practice for biosolids users and receiving site limitations. The guidelines supplement the Ontario Regulation 347 under the Environmental Protection Act which contains the regulations governing biosolids management activities.

Biosolids Regulations Specific to Composting

In Canada, there are a number of organizations involved in the regulation of the composting industry. These include Agriculture and Agri-Food Canada (AAFC), provincial governments through the Canadian Council of Ministers of the Environment (CCME) and the Standards Council of Canada (SCC). The SCC is involved in building standards for composting through the Bureau de Normalisation du Quebec (BNQ) which is a standard writing organization accredited by the SCC. All three of these governing bodies are working together to maintain the national composting standards, the guidelines for compost set by the CCME and the mandatory criteria for compost. Currently the BNQ's national standard is only a voluntary standard and accreditation system for compost producers. If their product adheres to the criteria set by the standard and their practices abide by the standards methodology, the compost product will receive a stamp of approval from the BNQ as a certified product. The Canadian Environmental Protection Act Section 8(1)(b) outlines further guidelines which if adhered to will allow manufactures or importers to use the "Environmental Choice EcoLogo" on their product.

Because compost is a form of fertilizer, it also falls under the Canadian Fertilizer Act. Sections of this Act which are applicable to composted biosolids are as follows:

- Exemptions from Registration
- Registration
- Standards
- Regulations
- Guaranteed Analysis
- Labeling

As far as the provincial level is concerned, regulations vary across the country. In Ontario, composting operations must heed to the regulations established in the Environmental Assessment Act (EAA), Environmental Protection Act (EPA) and the Ontario Water Resources Act (OWRA) if any wastewater is to be discharged to water or ground. Under the EAA, an environmental assessment is required for all operations that generate 200 or more tonnes per day of residual waste from their facility. Regardless of this rule, the Ministry of the Environment may require an EA if the site is deemed

environmentally significant. Part V of the EPA outlines the regulations pertinent to waste management which include regulations 101 through 104, 347, among others.

The Ontario Ministry of the Environment established the Interim Guidelines for the Production and Use of Aerobic Compost in Ontario in November of 1991. If compost producers adhere to the guidelines their compost will be deemed a "product" by the Ministry and they will be exempt from the EPA Part V with respect to site and transportation approvals. The guidelines are aimed at achieving high quality product while suggesting measures to protect the environment and human health. It offers a framework from which to determine whether the compost can be deemed as a "product" or a "waste."

2.4 St. Marys Paper Ltd. – A historical overview of biosolids management.

St. Marys Paper Ltd. is a groundwood pulp mill located in Sault Ste. Marie, Ontario. The mill produces 240,000 tonnes of specialty papers per year from groundwood pulp and purchased kraft pulp. The mill treats its process water on site using a system consisting of primary clarification and secondary treatment in the form of activated sludge. The secondary treatment system was commissioned in November, 1995.

The mill produces roughly 7000 cubic meters of biosolids each month. Since the mid-nineties, the mill has avoided landfilling any of this material. Over the past decade, St. Marys exercised many disposal alternatives including composting, land application and land reclamation. These initiatives are described in detail in the following sections.

2.4.1 Composting

In 1995, a local entrepreneur was granted MOE approval to open a waste disposal site designed to compost St. Marys' biosolids consisting of primary and secondary sludge and scrubber ash. The business was called Agribond and handled 3000 tonnes of material per month. Using windrows, the material composted over a period of approximately 2 months into a fertile, inert soil. The composted material was available to the municipality, local businesses and the public to be used as a soil conditioner and

also as a structural material. The material met Ontario guidelines for compost quality and was available for unrestricted use. St. Marys paid a fee to Agribond for the composting service which was less than the landfill tipping fee. Originally the end product was available to the public free of charge. In 1997, neighbouring residents raised concerns over air quality surrounding the Agribond site. The residents worried about odours and elevated levels of *Aspergillus fumigatus* which they felt could result from the operation of Agribond. As such, they felt the business posed a public health threat.

In its defense, Agribond and St. Marys cited the results of a MOE funded bioaerosols study undertaken at a similar composting operation in Sarnia. The study concluded that public health issues resulting from the exposure to bioaerosols on and off of the composting site were minimal. St. Marys organized an informative presentation outlining the operations at the composting site and delivered it to an audience including local politicians, the MOE and the local Health Canada representative. Both Health Canada and the MOE endorsed the composting project. The MOE concluded that the with the high moisture content of the material being composted and the forest buffer surrounding the site, the generation of bioaerosols would not be an issue at the Agribond site. Analytical testing of the material itself revealed that the Agribond product, Agrisoil, tested below all parameters monitored by the MOE. Despite the support from the provincial government, St. Marys opted to avoid further public scrutiny and stopped supplying Agribond with their biosolids. The mill by this time had found more financially feasible opportunities for disposal. They had begun working together with a number of nearby municipalities to provide biosolids material to cap landfills awaiting closure.

2.4.2 Landfill capping

In 1996, St. Marys Paper and Avery Construction, a contracting business in Sault Ste. Marie, were approached by the Ontario Ministry of the Natural Resources (MNR) with a proposal to assist in the closure of the Goulais landfill site which served a community north of Sault Ste. Marie. St. Marys was to provide their biosolids as a final cover to the project and the only expense the mill would incur would be the cost of hauling the material to the site. The hauling and application was to be done by Avery under contract through St. Marys. The proposal was accepted and a Certificate of Approval was granted by the MOE for the project. Over the course of three years the site was covered

with clay, due to pre-existing leachate problems, and then covered with St. Marys biosolids. The cap consisted of three layers: 30 cm of sand, 60 cm of clay and a top layer of 50 cm to 1 m of biosolids.

The year following the construction of the cap and cover, the area was hydroseeded to prevent tree growth which could damage the integrity of the clay cap. Within two growing seasons, vegetation on the site was thriving. Now, after eight years of growth, the landfill has developed into a diverse ecosystem sustaining many species of plants, insects and animals. The success of the Goulais project opened the door for other similar projects. Since 1996, St. Marys and Avery have capped and covered over a dozen local landfills with biosolids. After the success of Goulais and testing done of the material's hydraulic conductivity, the material was approved by the MOE as a landfill cap and cover. Sites covered since have not required the impermeable clay barrier used at Goulais to control landfill leaching at the site causing the need for closure.

2.4.3 Tailings reclamation

In 1972, Rio Algom Ltd. closed the Pronto Mine site located between Sault Ste. Marie and Sudbury, Ontario. In its prime, the mine had uncovered a lucrative supply of uranium and copper. Upon its closure, all that remained was a vast expanse of tailings. A lake basin had been retrofitted in order to accommodate the tailings slurry created by the mine. The nature of the site caused the tailings to distribute themselves by size over the site. Coarse grained tailings remained at the higher end of the site, while the fine grained tailings settled out at that the lower end of the basin.

After the closure, efforts were made in the early seventies to re-vegetate the area using conventional methods. The area received lime and fertilizer. The lime addition was an attempt to neutralize the acidity generated by the tailings. Initially the treatment worked and vegetation did establish itself on the site. However after a few seasons, the acid began to percolate through the soil and the vegetation died off and the site reverted back to its barren state. This die-off was particularly evident at the lower half of the site on the fine grained tailings. The die off has been attributed to (Okonski, 2002):

- Lack of organic matter
- High acidity
- Lack of nutrients (especially nitrogen)

- Phytotoxicity caused by aluminum, water soluble salts and heavy metals in pore water and tailings surface
- Poor physical properties (crusting, high compaction and poor structure)

In 1998, reclamation efforts commenced again with a new strategy with the help of Dr. Alexander Okonski and his team from the Elliot Lake Research Field Station of Laurentian University. The coarse grained tailings area had managed to re-establish vegetation with repeated lime and fertilizer applications. The fine grained pyretic copper tailings however were proving to be a more of a challenge. The new plan was to neutralize the area again with lime and cover the tailings with at least 30 cm of pulp and paper mill biosolids supplied by St. Marys Paper Ltd. The application rate of the biosolids was 500 m³/ha or 200 t/ha on a dry weight basis.

The project team hoped that the application of the biosolids would achieve the following:

- Protection against tailing oxidation
- Wind/water erosion reduction
- Decrease in salts at tailing surface
- Vegetation with species diversity and stability
- Aesthetically pleasing surroundings with the addition of vegetation

Over the next three years, approximately 13 hectares of tailings were covered with biosolids. Data collected over the course of the study revealed that the biosolids proved to be successful as a growing medium for vegetation. The biosolids not only reduced erosion but also improved groundwater quality in the area.

By measuring the pH of the top and bottom layers of the biosolids it was shown that acidification was not occurring in the biosolids layer, and also that the top layer of tailings was becoming less acidic over time. Pore water collected from the biosolids treated areas had a higher pH and considerably less heavy metals than that collected over the barren tailings area. The biosolids and tailings were tested for dioxins and furans and were not found in concentrations which exceeded levels associated with industrial and commercial land use. Petroleum hydrocarbons however, did in some cases, exceed those established for parkland and recreational area use by the Canadian Council of Ministers of the Environment (CCME).

Soil nutrient levels were greatly improved in the areas receiving paper mill biosolids as illustrated by the increase of pore water levels of nitrates, ammonium and organic carbon. The biosolids were able to sustain healthy, diverse vegetation over the entirety of the receiving area and continues to do so to this day. In conclusion, the study stated that with the help of St. Marys' biosolids, the mine site was transformed from a barren wasteland into a thriving, vibrant ecosystem.

The work at the Pronto site encouraged St. Marys and Avery to investigate opportunities with other mine sites in the area. The search proved fruitful uncovering two abandoned mine sites in the region in need of clean up and reclamation. At the present time, work is underway with the Ministry of Northern Development and Mines to initiate clean up Copper Lake and Sill Lake mine sites. Both of these abandoned sites lie just north of Sault Ste. Marie close to the shores of Lake Superior. Pending approval from the MOE, Avery should start to haul St. Marys biosolids within the year.

2.5 Disposal solutions at other paper mills

St. Marys Ltd. is not alone in their quest to divert biosolids from a fate of final disposal. Pulp and paper industries worldwide are searching and implementing re-use strategies not only as a means of saving money, but in an effort to develop more sustainable industry practices. An example of one such company is Menasha Packaging Company. Menasha's Ostego, Michigan mill produces corrugated media. The mill uses recycled corrugated and wood chips to produce their paper product. They have partnered with Renewed Earth Inc. to compost half of their yearly 60,000 m³/y of biosolids on a site located adjoining the mill. The remaining half is directly land applied. They have not relied on a landfill since 1974. Experimenting with composting began in 1992 and reached full scale in 1996. The operation uses hardwood fines and sludge to produce a soil amendment and also topsoil made from sludge and sand. Their consumers are primarily landscapers, departments of transportation, golf courses and other private business and government agencies (Kunzler, 2001).

Domtar Papers Inc. is well known in the pulp and paper industry as a driving force behind biosolids re-use strategies. Domtar mills in Cornwall and Ottawa are both involved heavily in land application and biosolids recycling programs. These mills and other Domtar mills have been involved in a number of research projects involving different universities in Canada including University of Guelph and Ecole Polytechnique of Montreal. The projects have been focused on establishing the biosolids as a soil amendment for agricultural and forestry purposes. Results from the research have reported increased production of grain and potato crops grown on sludge amended land.

Further to Menasha's and Domtar's efforts, outlines the disposal options exercised by a number of mills investigated during this study. Table 2-9 illustrates the prevalence of land application across the industry.

Table 2.9 - A survey of disposal options exercised by pulp and paper industry

Mill	Type of product	Method of disposal	Biosolids	Reference	Location
Pine Falls Paper Co.	Newsprint	Composting	primary, secondary, deinking	Larsen & McCartney, 2000	Manitoba
Abitibi-Price - Alma	Newsprint & directory paper	Landfill	primary, secondary, deinking	Lagace et al., 1996	Quebec
Abitibi-Price - Beupre	Specialty paper	Composting, landspreading, land reclamation	primary, secondary	Lagace et al., 1997	Quebec
Abitibi-Price - Chandler	Newsprint	Landfill	primary, secondary	Lagace et al., 1998	Quebec
Abitibi-Price - Fort William	Newsprint & specialty paper	Mill operated landfill	primary, secondary	Lagace et al., 1999	Thunder Bay, ON
Abitibi-Price - Iroquois Falls	Newsprint & specialty paper	Primary - incineration, Secondary - Landfill	primary, secondary, deinking	Lagace et al., 2000	Iroquois Falls, ON
American Fiber Resources		Land reclamation	primary, secondary, deinking	Webb, 2000	West Virginia, U.S.
SCA Hygiene Products	Hygiene products incl. tissue, diapers, etc.	Land reclamation	primary, secondary, deinking	Webb, 2000	Northumberland, U.K.
Slave Lake Pulp Corp.	Pulp	Land application	primary, secondary	Province of Alberta, 1999	Slave Lake, AB
Alberta Newsprint Co.	Newsprint	Land application	primary, secondary	Province of Alberta, 1999	Alberta
Glatfelter	Specialty paper	Composting	primary, secondary	Carter, 1983	Pennsylvania, U.S.
Domtar Inc.		Land application (80%)	primary, secondary	Velema, 2004	Cornwall, ON
Domtar Inc.		Land application & Landfill	primary, secondary	Velema, 2005	Ottawa-Hull, ON

2.6 Public perception & biosolids reuse

In 2000, an outbreak of *Escherichia coli*. 0157:H7 in Walkerton, Ontario's drinking water claimed seven lives and caused many others to suffer illness. In this case, negligent water treatment caused poor disinfection and allowed pathogens to freely flow from a groundwater source to distribution systems to the public where they wreaked havoc. It is thought that the pathogens entered the groundwater system originally because of heavy agricultural activity in the area. There is no question pathogens such as E. Coli. can be lethal to humans. However since the Walkerton tragedy, the public has been bristling about the re-use of biosolids for agricultural purposes, even if the biosolids are ppmb which are not associated with pathogen risks. This public perception is the reality of the arena in which all biosolids managers, both industrial and municipal, must negotiate their treatment strategies.

Decades of research provide in great scientific detail the pros and cons of biosolids re-use. If this information is not effectively delivered to the public, they are left to the mercy of persuasive opposition who proliferate negative press for biosolids re-use. Horror stories are always an effective way to draw a crowd. Activist groups highlight isolated incidents of illness and even deaths and attempt to attribute them directly biosolids reuse. With a closer look through a scientific lens, many of these accusations do not hold up to technical scrutiny (Logan, 1995). In some cases, abuse of biosolids material may have played a part in a series of unfortunate events. However, so may have the abuse of other publicly acceptable farming practices such as use of chemical fertilizers and/or manure. The bottom line is that natural systems need to be treated with respect and a level of responsibility. Those involved in not only agriculture, but also horticulture, forestry and reclamation need to operate with a level of understanding of the consequences of their actions when they are using soil conditioners, amendments and fertilizers regardless of their origin. Most any material and practice used for most any application can be associated with risks if not used responsibly.

In order to mainstream biosolids reuse there is much work to be done. The "Not In My Back Yard" syndrome must be eliminated at both public and corporate levels. As an example, if the food industry refuses to grow their crops on land that has ever been

treated with biosolids, public perception becomes that the material is not safe. Organized education efforts are required and more energy needs to be put towards public relations as a part of successful biosolids management strategies. Also, generators and biosolids users should be held to accountability standards, which could direct the management of biosolid material. Enforcement of a standard level of treatment of biosolids would also help dissolve the mistrust that is harbored by environmental activists groups, the public and farmers against the reuse of biosolids. Generators need to reach a certain level of stabilization before any reuse of the material is permitted (Draman, 1995).

The public is more aware of biosolids and the issues surrounding their reuse than they have ever been. Unfortunately, much of the attention biosolids have received has been negative up to this point. Fear is now at its peak as the public has enough information to know that risk is involved, but no understanding about the extent of the impact and the controls in place to mitigate them (Logan, 1995).

For biosolids reuse to become a successful waste management strategy, public acceptance is required. Before acceptance, there must be education. The public needs to be given the facts of the matter. With decades of research under their belts, the scientific community agrees that the risks associated with biosolids reuse are low. This information needs to be transferred to the average citizen.

Dr. Terry Logan from Ohio State University (Logan, 1995) suggests that acceptance can only be possible if public has been given three vital pieces of information including:

1. Provincial/state and federal legislature is in place regulating the use and disposal of biosolids and guards human health and the environment with a considerable safety margin.
2. Biosolids quality is higher than it has ever been because of the advanced treatment systems now available. Pathogen reduction and elimination is achievable with proper digestion and stabilization. Heavy metal concentrations are often lower than that of chemical fertilizers and other non regulated products.

3. Re-use over disposal offers many benefits which include improved soils, lower agricultural production costs, expanding landfill life expectancy from reduced loading and elimination of ash and air pollution caused by incineration.

In order to deliver the above information, efforts should be concentrated at the local level. Provincial government, universities, pulp and paper industries and other individual agencies such as Water Environment Federation of Ontario (WEO) can provide leadership for this initiative. All parties involved must show an ongoing commitment to responsible biosolids management.

2.7 Concluding remarks

The quantity of municipal and industrial biosolids produced by the world will continue to increase. The quantity of pulp and paper mill biosolids disposed of through land application and composting is also going to continue to increase as incineration and landfilling become unfeasible. A heightened responsibility for the industry is associated with this increase. The industry goal should be to maximize the positive impacts and mitigate the dangers involved with reintroducing paper mill biosolids into the biocycle.

Composting offers a promising business opportunity and its popularity is on the rise as its market becomes established. There are costs associated with building and operating compost facilities which need to be offset by profits for composting to become a reasonable business venture for the private sector. Pilot studies to determine the compostability of individual pulp mill's biosolids stream are required to assess the feasibility of composting.

Land application will continue to be a popular method of disposal. There are more than one hundred years of research available on effects of general biosolids re-use from which to make disposal and re-use decisions. Pulp and paper mills biosolids should have less negative implications than municipal biosolids as they do not contain pathogens, and have lower heavy metal concentrations. However, due to the complexity of re-use and reintegration of this material into the natural environment, it is important to

take a wide angle approach to include all areas of impact. The atmosphere, watershed, ecology, food chain and soil effects are all areas of interest when dealing with the implications of biosolids use (Draeger et al., 1999). As with most environmental issues, multidisciplinary approaches are necessary for sound research and implementation.

Continuous monitoring of sites which have received biosolids in the past is required in order to study the long term effects of land application. Long term watershed effects of paper mill biosolids need to paid particular attention to in studies to facilitate improvements to the knowledge base of biosolids impacts. This will assist sound decision making for application rate design. As well as watershed impacts, ecological impacts should also be further studied on a long term basis. This research should include impacts of paper mill biosolids on animals which is particularly poorly understood.

Further risk reduction associated with all methods of disposal can be achieved by improved paper mill biosolids (ppmb) characterization and composition monitoring at the treatment plant level. By following the quality of the ppmb over time, industries will be able to illustrate whether their material consistently falls below regulatory limits. Such data will assist in gaining government approval for re-use applications and identify ppmb as a resource stream independent of municipal biosolids.

Public education and continued research are the keys to safe and effective biosolids reuse strategies. Knowledge is a society's greatest defender of health, happiness and longevity. In this age of information, rapid growth and radical change, we should strive for an educated society above all else. Not only will it allow us to defeat our waste management issues, but an entire army of other environmental problems and beyond.

3 CHARACTERIZATION OF ST. MARYS BIOSOLIDS

The objective of this study was to review existing analytical reports and conduct laboratory testing in order to obtain a detailed characterization of the sludge stream produced by St. Marys Paper Ltd.

3.1 Methodology

Regular testing has been conducted on St. Marys biosolids material over the past nine years. The St. Marys takes grab samples periodically throughout each year from the outlet of the vacuum filter at the mill and they are shipped in a cooler to Envirotest Laboratories, a private analytical lab, for testing. Samples are received by the lab within 48 hrs of sampling.

The results from this testing from the previous five years was collected. Average, range and standard deviation were determined for each parameter analyzed. In many instances, samples were analyzed for different parameters in past studies. The result is that for some parameters, such as the regulated heavy metals, there are many data points, while for others there is considerably less historical data. For the well documented parameters, graphs are presented in the results section outlining data from six samples collected over the test period from 2000 - 2004. In the event that a parameter was found to be below the detection limit, it was assigned a value of half of the detection limit unless otherwise specified.

Toxic Equivalents (TEQ) were used to report the dioxin and furan concentration. This method is a toxicity weighted mass expression developed by the World Health Organization. Using this practice, dioxins were assigned a Toxic Equivalency Factor, or TEF (see appendix for values) which denotes its toxicity relative to 2,3,7,8-TCDD (TEQ = 1), the most toxic compound of the class. To obtain the number of grams-TEQ of dioxin in the biosolids, the dioxin mass was multiplied by its TEF and then the sum of all of the dioxin components was calculated to determine the total TEQ in pg/g (<http://www.c3.org/sitedata/test3/def.html>).

The characteristics of the biosolids as determined from this investigation have been compared to a variety of other materials, including:

- Other pulp and paper mill biosolids
- Ontario MOE Guidelines for the use of biosolids and other wastes on agricultural land
- MOE Quality aerobic compost characteristics
- Commercial compost, topsoil and cow manure
- Canadian Council of Ministers of the Environment (CCME) Environmental Quality Guidelines for soil

The data collected were compared to published data from other mills to determine the nature of St. Marys material in reference to the industry.

The characterization of the material was approached from the perspective of developing the biosolids into an organic amendment. Characteristics were evaluated in terms of how they relate to plant growth and re-introduction into a natural soil setting. This was done by comparing the material to other land applied products such as compost, manure and topsoil.

The CCME soil quality guidelines are split into four categories based on land use. These include agricultural, residential/parkland, commercial and industrial. For some metals such as arsenic, the level has been set at the same limit for all types of land. There are others such as cadmium, whose level varies across land use. Because the agricultural limits are the most stringent they have been used for comparative purposes in this investigation. Agricultural land use also best suits the application of the end product which St. Marys wishes to develop from their biosolids stream.

The bulk density for the material was determined by loosely packing a 2 L graduated cylinder with biosolids and dropping it from a height of 5 cm five times before weighing (Jackson & Line, 1997). Each analysis was done in triplicate. The bulk density was monitored once every three days for a period of 12 days. The moisture content for each of the samples was also determined in triplicate in order to examine fluctuations in bulk density with changes in moisture content.

The moisture content was determined by placing pre-weighed crucible containing biosolids in a drying oven set at 60 °C for 65 hours. After this drying period, the samples were cooled in a dessicator for one hour before they were again weighed. The moisture content was then determined using the equation below:

$$MC = (wetmass - drymass) / (wetmass - crucible) * 100\%$$

where:

MC	= moisture content
wetmass	= mass of wet biosolids including crucible
drymass	= mass of dry biosolids including crucible
crucible	= mass of empty crucible

3.2 Results and discussion

3.2.1 Physical properties

The bulk density of the biosolids material varies as the moisture level of the biosolids fluctuates. Tests conducted on site at St. Marys yielded a bulk density of approximately 680 kg/m³ at a moisture content of 70%. This coincided with testing St. Marys had had done by Trow Consulting Engineers in April 1997.

Trow was also commissioned to do a falling head permeability test on the biosolids material mixed with yard wood waste in a 2:1 volume ratio. This was roughly the ratio of the mixture being used to cap and cover local landfills. The testing revealed a permeability of $1.5 * 10^{-5}$ cm/sec.

The permeability of the biosolids is classified as slow (i.e. < 0.06 inch/hr) (Franzen et al., 1996). Reduced permeability is ideal for minimizing risk of groundwater contamination from surface pollutants. For plant growth, different species have different requirements. The lower permeability of the biosolids may be best suited to plants which do not require a well drained soil.

A study undertaken by Gore and Storrie concluded that St. Marys biosolids material comprised of 30% clay on a dry weight basis (Shrive, 1999). The remaining fraction consisted primarily of organic components including microbial cells and cellulose fibers. The clay is a result of the kaolin clay added to the pulp during the papermaking process to give the paper a smooth, shiny finish. Clay is a collection of colloids. The colloid surfaces have associated adsorbed cations such as Ca^{+2} and K^{+} and a number of other essential nutrients. Through ion exchange with ions such as H^{+} , Ca^{+2} and K^{+} can be released into the soil solution and, therefore, be available to plants. The high cation exchange capacity of the clay may assist the biosolid material to act as a reservoir for certain plant nutrients. The high clay content in the absence of significant sand or silt may result in shrinking and swelling cycles. The high organic matter content may offset this property, however, from the characterization alone, it is difficult to determine what the behaviour of the material will exhibit when subjected to wetting and drying.

3.2.2 Agronomic parameters

Table 3-1 outlines the biosolids physical characteristics and nutrient quality. As can be seen, the nutrient content of St. Marys biosolids material is very close in composition to the percentages specified by the MOE as characteristics of good quality compost. The salinity and pH of the material also falls within the limits suggested by the MOE. The carbon to nitrogen ratio, as well as moisture levels, are considerably higher for the St. Marys biosolids in comparison to the MOE guidelines, but are similar to the levels of commercial compost as reported by Velema (2004).

Typically topsoil quality is governed by soluble salts, pH, sodium absorption ratio (SAR), organic matter and texture. According to Koenig & Isaman (1997), good quality topsoil has an electrical conductivity (EC) level of less than 2 ms/cm, a pH between 5.5 and 7.5 and a SAR < 2. The CCME guidelines for agricultural soil suggest an EC which coincides with Koenig and Isaman. The CCME suggestions for pH and SAR are 6-8 and < 5, respectively. St. Marys biosolids are well within these suggested limits.

The organic matter in soil provides it with a favorable structure for plant growth. Organic soils resist compaction and retain micro and macro nutrients more easily. Topsoils with

organic contents of greater than 2% by dry weight are considered ideal. St. Marys biosolids, on average, is approximately 54% organic matter. This value is less than the listed values for topsoil and compost and above the MOE's suggestions for good quality compost and cow manure.

Table 3-1 - Summary of agronomic parameters of St. Marys biosolids and other land applied material.

Parameter	St. Marys Paper Biosolids	MOE quality compost guidelines	Composted cow manure*	Commercial organic compost*	Commercial topsoil *
% Solids	32.3			34	32
% Moisture	71	30-50			
% Organic matter (dry wgt)	54	30	63	90.2	72
C:N	64.6	22	61.1	67.6	44.1
Electrical conductivity (mS/cm)	1.4	< 3.5			
SAR	0.6	< 5			
Sodium (mg/kg dry wgt)	500		3800	1300	94
pH	7.2	5.5-8.5	7	6.4	7.6
Macronutrients (% dry weight)					
Total Nitrogen	0.61	0.6			
Total Kjeldahl Nitrogen	0.59		0.97	1.00	1.40
Total Phosphorus	0.17	0.25	1.00	0.48	0.06
Potassium	0.17	0.20	1.80	0.19	0.05
Calcium	2.9	3.00	4.10	2.30	4.40
Magnesium	0.1	0.30	0.52	0.13	0.19
Sulfur	0.18		0.45	0.27	0.43
Micronutrients (mg/kg dry wgt)					
Boron	23		49	9.4	16
Hot water ext. Boron	7				
Manganese	908				

* Velema, 2004

The biosolids were analyzed for micronutrients including boron, copper, manganese, molybdenum and zinc. Copper, molybdenum and zinc are government regulated metals and are presented in the following section. The remaining two micronutrients, boron and manganese are presented in this section.

Boron is phytotoxic if applied in excessive amounts and there is a narrow range between levels associated with plant deficiency and toxicity (WESA, 2002). The majority of the boron present in pulp and paper biosolids is not available to the plants. For this reason,

hot water extractable boron is a better indicator of available boron. It is recommended that not more than one kilogram of hot water soluble boron/ha be applied to agricultural soils each year for boron tolerant crops and 0.5 kg/ha/yr for intolerant crops (WESA, 2002). Using this guideline, a biosolids application rate of approximately 71 t/ha would be appropriate for boron intolerant crops.

Manganese becomes a plant toxin for vegetation in acidic soils. It has a limited solubility in neutral pH, well drained soils. Natural soil concentrations of manganese can vary from 40 to 900 mg/kg according to the U.S. EPA. Though the biosolids were on the high side of this range, the neutral pH of biosolids should limit their solubility and plant availability within the soil profile. There are a number of crops such as soy beans and cereals, which are typically deficient in manganese grown in Ontario soils which could benefit from its addition.

In summary, the fresh biosolids appeared to have macro and micro nutrient levels well suited for use as an organic soil medium or amendment. The moisture content was higher than conventional organic media such as compost and peat. The high moisture level material may be expensive to transport and unfeasible for bagging because of weight limitations, however this in itself would not cause harm to vegetation. The issues with the use of the fresh material may prove to be with the high carbon to nitrogen level. Once added to soil, the material, in its current state, could cause the soil microbes to scavenge the plant available nitrogen in the soil solution. In theory, the high C:N ratio (above 25) could result in nitrogen deficiency for plants and slowed organic decomposition of the biosolids (Brady & Weil, 1999). Further stabilization may be required to design an effective organic soil media or additive.

3.2.3 Metals

Table 3-2 outlines the average metal levels of St. Marys biosolids in comparison to levels at other mills and the MOE Guidelines for use of biosolids and other organic wastes on agricultural lands (MOE Biosolids Guidelines & MOE Long-term targets).

Table 4-2 illustrates that the metals found in St. Marys biosolids were below the current regulatory limits for biosolids and also the provincial government's long-term targets. The

levels were similar to those found in both Domtar mills listed and within the typical range for pulp and paper combined biosolids. Table 3-3 compares the average metal concentration of the biosolids to a number of other land applied materials including manure, compost and topsoil. Arsenic, copper, mercury, molybdenum and zinc were all either within the range of the other listed materials or below. Cadmium, cobalt and selenium were all slightly above the range of the other material. Nickel and chromium were the only two metals whose average concentrations were considerably higher than the other listed materials. They exceeded the values found in cow manure by approximately 50% and 68%, respectively.

Table 3-2 - Summary of metals concentrations in pulp and paper mill biosolids

Regulated Metals (mg/kg)	St. Marys Paper	Domtar Cornwall *	Domtar Ottawa Hull*	Combined Biosolids Range**	MOE Biosolids Guidelines	MOE Long term target
Arsenic	0.65	0.8	ND @ 6	<0.1-3	170	35
Cadmium	1.3	1.7	ND @ 1	<0.2-2	34	4
Chromium	14.95	13.6	22.1	<1-20	2800	530
Cobalt	3.75	ND @ 2	ND @ 2	<0.6-5	340	77
Copper	20	25.1	27.7	<5-300	1700	380
Lead	7.5	5.3	ND @ 5	<1-30	1100	220
Mercury	0.05***	0.03	0.02	<0.001-0.2	11	1.4
Molybdenum	<1	2.2	2.2	<0.5-5	94	1.2
Nickel	16.83	6.5	5.8	<1-15	420	80
Selenium	0.6	ND @ 1	ND @ 1	<0.005-<1	34	6
Zinc	157.6	135	47.8	<10-450	4200	840
Other (mg/kg)						
Aluminum	3400	3317	3289	1000-5000		
Barium	296	110	11.1			
Beryllium	ND @1	ND @ 0.5	ND @ 0.5			

* - Velema (2004), ** - Belsito (1999) & WESA (2002), *** - 4 of 6 readings ND and were assigned 0.5DL to calculate average

Table 3-3 - Average metal concentrations compared to other land applied materials

Parameter (mg/ dry kg)	St. Marys Paper	Composted cow manure *	Commercial Organic Compost *	Commercial Topsoil *
Arsenic	0.65	1.5	1.1	3.4
Cadmium	1.3	ND @ 1	ND @ 1	ND @ 1
Chromium	14.95	10	3.3	8.6
Cobalt	3.75	3		3.3
Copper	20	90	7.9	16
Lead	7.5	ND @ 5	ND @ 5	ND @ 5
Mercury	0.05	0.03	0.05	0.1
Molybdenum	<1	ND @ 2	ND @ 2	ND @ 2
Nickel	16.83	10	2.7	8.5
Selenium	0.59	ND @ 0.5	ND @ 0.5	ND @ 0.5
Zinc	157.6	350	98	41

* Velema, 2004

Note - avg. values in bold include ND readings which were assigned to 0.5DL

Figures 3-1 to 3-10 illustrate the fluctuation of the metals measured in the fresh biosolids sampled between 2000 and 2004. The figures also include the MOE's biosolids long-term targets for land applied biosolids and the MOE aerobic compost regulatory limits, as well as the CCME soil quality limits for agricultural lands. The MOE's long term biosolids targets were used in these figures because they are considerably more stringent than the presently applicable levels.

From Figure 3-1 it would appear that although the arsenic levels fluctuate from 0.8 mg/kg to 5 mg/kg, all of the values were consistently below the three limits shown. It is also important to note that the two data points recorded at 5 mg/kg during March and October of 2002 were ND points and therefore assigned to half of the detection limit which for those particular tests was 10 mg/kg.

Figure 3-1 - Arsenic levels - 2000-2004.

The data plotted in Figure 3-2 illustrate that the cadmium concentrations recorded were consistently below the MOE's regulatory limits for compost and biosolids. The values were slightly above the CCME suggested soil quality guidelines for agricultural land. The range of the data over the testing period was 0.6 - 2.3 mg/kg.

Figure 3-2 - Cadmium levels 2000 -2004.

The CCME soil quality guidelines do not include any value for cobalt. Figure 3-3 shows that, over the test period, the cobalt levels in the biosolids were, as with the other metals, far below the MOE's regulatory limits. The range for this data set was <1 - 15. On three occasions; Oct. 2002, Feb. 2003 and May 2004, cobalt levels were non detectable at <1 mg/kg and were assigned concentrations of 0.5 mg/kg or half of the detection limit.

Figure 3-3 - Cobalt levels 2000 -2004.

For chromium, the CCME soil quality guidelines and the MOE compost levels are very close at 64 and 50 mg/kg, respectively. The biosolids were measured below these concentration limits as illustrated in Figure 3-4. The range of the data was found to be fairly substantial at 6 to 32.1 mg/kg.

Figure 3-4 - Chromium levels 2000 -2004.

From Figure 3-5, the data for copper looks much like the results presented for chromium. The CCME and MOE compost limits are very similar and the copper concentration of the biosolids was below all the limits shown. The range for this data set was 8 to 32 mg/kg.

Figure 3-6 outlines the lead concentration of the biosolids. For this metal, the CCME and MOE limits vary considerably. The range of lead concentrations from 2000 to 2004 was <5 - 26 which was well below the limits which range from 70 to 220 mg/kg. On two occasions: Oct. 2002 and Feb. 2003, lead was not detected in the samples. For these dates, concentrations of 2.5 mg/kg (0.5*DL) were assigned.

Figure 3-5 - Copper levels 2000 -2004.

Figure 3-6 - Lead levels 2000 - 2004.

From Figure 3-7, it is evident that the biosolids are well below the CCME guidelines for agricultural soils and the long-term MOE biosolids targets. The MOE's mercury limit for aerobic compost is 0.15 mg/kg. On one occasion in October 2000, the mercury concentration of the biosolids approached this and was measured at 0.11 mg/kg. Four

other samples over the test period were reported as ND and assigned values of half of the detection limit. Oct. 2002, Feb. 2003 and May 2004, as a result, were all assigned as 0.025 mg/kg and March 2002 was assigned as 0.1 mg/kg.

Figure 3-7 - Mercury levels 2000 - 2004.

As illustrated in Figure 3-8, with the exception of one sample taken on October 2002 (46 mg/kg), all of the samples were well below all of the limits shown for nickel. The range of the data set was 4 to 46 mg/kg.

Figure 3-8 - Nickel levels 2000 - 2004.

The selenium concentrations outlined in Figure 3-9 were found to be, on average, less than half the MOE composting limit and significantly lower than the biosolids long-term target levels. The CCME soil quality guideline level is set at 1 mg/kg. There were three occasions where selenium was not detected in the biosolids samples. These dates were March 2002, October 2002 and February 2003. For the March and October samples, the detection limit was 2 mg/kg, therefore the samples were assigned a concentration of 1 mg/kg which is the same value as the CCME level. The February sample was assigned a value of 0.05 as the detection limit at that time was considerably lower. The range of the whole data set was <0.1 to <2 mg/kg.

Figure 3-10 outlines the concentration of zinc recorded in the biosolids. The range of the data was from 60 to 280 mg/kg. During May of 2004, the zinc concentration was measured at 280 mg/kg which is above the CCME soil quality guideline. All data points were, however, well below the MOE limits for biosolids and aerobic compost.

Figure 3-9 - Selenium levels 2000 - 2004.

Figure 3-10 - Zinc levels 2000 - 2004.

Molybdenum was not graphed because levels were consistently below detection limits, i.e. < 1 mg/kg. The MOE long-term biosolids limit is set at 1.2 mg/kg, the compost limit is 2 mg/kg and the CCME soil quality guidelines are set at 5 mg/kg.

The metals levels did not exceed any of the provincial regulations for metals for either biosolids or aerobic compost. As a feedstock for aerobic composting, the qualities of the biosolids appear to be appropriate. During the composting process, the organic fraction of the feedstock was reduced as part of the decomposition of the material. The metals concentrations are however, unaffected by the microbial degradation. At this stage, none of the metals levels were above the limits of finished compost.

3.2.4 Organics

The biosolids were tested for numerous organics, however only three were consistently measured at concentrations above detection limits. These three include p-cresol, naphthalene and phenol. The next three figures outline the levels of these organics over the test period and compare them to the CCME soil quality limits. The MOE has not set guidelines for organic compounds within biosolids and they are not regulated within compost.

The data in Figure 3-11 showed that levels of p-Cresol were significantly below the levels suggested by the CCME for commercial and industrial lands, but above those for residential/park areas and agricultural lands. The range of the data was 0.6 to 4.4 mg/kg.

From Figure 3-12, with the exception of the sample taken during January 2001, the levels of naphthalene were close to the CCME agricultural and residential/park levels. The range for the data set was found to be 0.5 to 17 mg/kg.

From Figure 3-13, there were two instances of elevated phenol concentrations over the test period. Other than these samples from January 2001 and May 2004, the three other samples were close to the CCME soil quality limit. The range of this data set was found to be 3.8 to 45 mg/kg.

There were six other organic compounds which were detected on more than one occasion but not as consistently as the previously mentioned compounds. Table 3-4 lists this group of compounds.

Figure 3-11 - p-Cresol concentrations 2000 - 2004.

Figure 3-12 - Napthalene concentrations 2000 - 2004.

Figure 3-13 - Phenol concentrations 2000 - 2004.

Table 3-4 - Other organics detected between 2000 and 2004.

Parameter	Sample date				CCME Soil quality guidelines		
	Jan-01	Feb-03	Aug-03	May-04	Agr.	Res./Park	Ind./Comm.
	concentration in mg/ dry kg						
Benzene	0.11			0.1	0.05	0.5	5
Carbon disulfide		0.12	0.03	0.2	NA	NA	NA
Dichloromethane			0.01	0.14	0.1	5	50
m-Cresol	1			0.9	0.1	1	10
o-Cresol	3.3			2.8	0.1	1	10
Phenanthrene	8.6			0.7	0.1	5	50

There are no CCME guidelines available for carbon disulfide. All of the other compound concentrations fall below the CCME guidelines for industrial and commercial land use. Benzene, dichloromethane, m-cresol were also found to be at or below the CCME guidelines for residential/park land use.

Table 3-5 lists compounds which were only detected once over the test period which involved six different sampling dates. The total TEQ measurements reflect total dioxin levels which were found to be well below the CCME guidelines for soil quality. 23478 PeCDF and 12378 PeCDF are both furans and represent 2,3,4,7,8 pentachlorinated

dibenzo-furan and 1,2,3,7,8 pentachlorinated dibenzo-furan. OCDD represents octachlorodibenzo-*p*-dioxin.

Table 3-5 - Single detections in fresh biosolids between 2001 and 2004

Parameter	Value	CCME Soil quality guidelines			Sample date
	pg/g	Agricultural	Residential/ Park	Industrial/ Commercial	
Total TEQ (ND=0)	0.287	4	4	4	5/21/2004
Total TEQ (ND=0.5DL)	1.12	4	4	4	"
23478 PeCDF	0.5	N/A			"
OCDD	7	N/A			"
12378 PeCDF	0.6	N/A			"
	mg/kg				
Benzo(a)anthracene or Chrysene	1.9	0.1	1	10	1/26/2001
Bis(2-ethylhexyl)phthalate	0.7	N/A			"
Diethylphthalate	6	N/A			"
Ethanol	60	N/A			"
Fluoranthene	8.5	N/A			"
Fluorene	0.8	N/A			"
m+p-Xylenes	0.08	0.1	1	17/20	"
Pyrene	6.8	0.1	10	100	"
Toluene	0.12	0.1	0.8	0.8	"
Acenaphthylene	6.3	N/A			"
Anthracene	1.3	N/A			"

The presence of naphthalene and the occasional single detections of other polycyclic aromatic hydrocarbons (PAHs) including anthracene, phenanthrene, pyrene, acenaphthylene, chrysene and fluorene in the biosolids should not pose significant concerns for the re-use initiatives of this project. With the exception of naphthalene, their levels were inconsistently detected and at low concentrations. Naphthalene levels, with the exception of one high reading, were close to the CCME soil quality targets.

There are a variety of combustion activities which occur at pulp and paper mills which explain the presence of PAHs and other organics in the wastewater stream and ultimately the biosolids. For example, St. Marys uses high pressure steam to drive turbines to generate electricity. Boilers used to create the steam are fueled by the combustion of hog fuel (wood residuals). The exhaust gases are treated prior to release using wet scrubbers. The wastewater from the scrubbing system is laden with contaminants removed from the boiler off gases which include PAHs and other organic contaminants.

PAHs have a tendency to accumulate within sludge during wastewater treatment because of their hydrophobic and lipophilic nature. This partitioning behaviour to sludge solids seems to be consistent across treatment system processes and wastewater types (e.g. municipal, petroleum or pulp and paper industry based) (Rogers, 1996).

PAHs once introduced to the environment through land application of biosolids tend to be fairly stable within the soil profile (Wild et al., 1992). They have a limited rate of desorption which minimizes the risk of ground and surface water contamination. It also positions them as relatively unavailable for plant uptake. Unfortunately, the characteristics which make PAHs low risk for plant uptake, also render them difficult to biodegrade through microbial means and contribute to their persistence within the environment. Composting as a method of PAH biodegradation has shown promise for the pulp and paper mill industry (Westman, 2003).

The carbon disulfide and p-cresol found in the biosolids may contribute to the odour which at times is associated with the material, particularly if poorly aerated. However, according to the EPA Air Toxics website carbon disulfide, however, quickly evaporates and is not very water soluble. It should therefore not pose significant concerns as a persistent problem in the biosolids. (www.epa.gov/ttn/atw/hlthef/carbondi.html). Though carbon disulfide vapours can be toxic, in an open air processing situation as currently exists at St. Marys at the outlet for the biosolids, they should not be present in high enough concentrations to be considered an environmental or health risk (Clark et al. 1983).

Though phenol is volatile at room temperature, within soils and biosolids matrices its volatilization is somewhat slower. Phenol is not likely to become an air quality issue in this case. Within the soil matrix phenol biodegrades into carbon dioxide and methane in both aerobic and anaerobic environments. Half-lives of 3 hours have been reported in aerobic soils (U.K. Dept. of Environment, Food and Rural Affairs, 2003). Anaerobic environments tend to decompose phenol more slowly, but can still completely be biodegraded according to the Agency for Toxic Substances and Disease Registry (ATSDR). With further aerobic processing, such as composting, the phenol in the biosolids should decompose rapidly.

Currently, the levels of carbon disulfide and phenol in biosolids are not regulated. The U.S. EPA however did announce in January, 2004 that this may change in the United States. As part of its biennial review of the Clean Water Act, the EPA has identified 15 pollutants for further review. Among these 15 are: anthracene, barium, beryllium, carbon disulfide, fluoranthene, manganese, phenol, pyrene, and silver. These identified compounds will be further studied to determine whether they exist in concentrations within biosolids which adversely affect human health or the environment. Depending on the outcome of this inquiry, new U.S. regulations may be set (<http://www.biosolids.org>). Whether Canada will follow suit with this investigation is entirely undetermined.

Included in the appendix is a list of other organic compounds which were tested in each of the six samples taken between 2000 and 2004 and never detected above detection limits.

3.2.5 General Conclusions

The characteristics of the biosolids showed a fair degree of variability over the test period. This was to be expected for a number of reasons. The mill uses a number of different tree species to fulfill their fiber needs including black spruce, white spruce, balsam and aspen. The mill tries to keep within set ratios for each species, but the composition of the fibre feedstock can vary. As the fibre stock fluctuates, so do the characteristics of the wastewater being treated and ultimately the biosolids characteristics. As well, the wastewater system itself is a dynamic system dependent on the biology of the activated sludge reactor which fluctuates on a daily basis. The biomass population is in flux, as are the effluent flows in and out of the system. Another reason for the variability in the data could also be due to seasonal fluctuations. For example, in the winter, logs entering the pulping process were generally covered with more sand and gravel from the wood yard than they were in the summer months when the yard dries.

3.3 Summary

Despite the variance in the data over time, the data suggests that St. Marys biosolids constituents should not pose any significant issues for further development of the waste stream into a marketable product in the form of a soil amendment or topsoil alternative.

4 TOMATO TEST PLOT ANALYSIS

The objectives of this investigation were to:

- determine whether fresh biosolids could be used to as a potting medium
- evaluate levels of regulated metals in biosolids used as growth media
- determine whether biosolids leachate poses environmental risks

4.1 Methodology

Tomato plants were chosen for this study because of their sensitivity to toxic environments. The plants were grown from seedlings in false bottomed plastic pails in the four different media selected for examination in this study. The media included:

1. Commercial potting soil

Premier ProMix, a peat moss based potting and seeding mix preferred by a local nursery was chosen for the baseline of the study. The nursery grows the trees used for replanting areas logged for St. Marys Paper Ltd.

2. St. Marys biosolids

Biosolids produced by the mill on July 15th, 2003 were used.

3. St. Marys biosolids and wood waste

A mixture of biosolids collected on July 15th, 2003 and wood waste collected from the yard and debarking activities were used. It is in this form that the sludge is used for land application. The wood waste includes bark, wood chips, evergreen foliage and dirt. The mix was a 1:1 ratio by volume.

4. Municipal biosolids

Cake from the city's municipal wastewater treatment plant was collected on July 14th, 2003. The wastewater treatment plant uses an activated sludge process as its method of secondary treatment which is a similar process to that employed by St. Marys.

Each of these media were used alone and also mixed with loam, with the exception of the municipal biosolids. The municipal biosolids were in short supply; therefore only the municipal biosolids mixed with loam were examined. The reasoning behind the use of the loam was that ideal gardening media are thought to contain a percentage of

inorganic material in the form of clay, silt and sand in addition to organic material. The trials with loam were comprised of a 2:1 ratio of media to loam fill by volume.

Therefore, the test media included:

- Control - ProMix all purpose potting soil (T)
- Control - ProMix & loam mix (TL)
- Biosolids (B)
- Biosolids & loam mix (BL)
- Biosolids & wood yard waste mix (W)
- Biosolids & wood yard waste & loam mix (WL)
- Municipal biosolids & loam mix (ML)

The media above were mixed in a cement mixer and passed through a 2 cm screen before filling the pails. For each of the media, six pails were prepared to hold six tomato plants. The plants were grown from seedlings at the beginning of July and were all purchased from a local nursery.

The pails consisted of 20 L white plastic buckets with a constructed false bottom made from the pail lids to allow free drainage of the media. Holes were drilled into the lower half of the pails, below the false bottom, for the collection of leachate. The holes, when not in use, were plugged with corks.

Once all of the plants were placed into the pails, they were set out in a level, open area of lawn free from shade at all times of the day. The pails were grouped by media type. Because of the open location, it was assumed there would be no need to randomize the pot placement. This grouping also facilitated visual observations regarding plant growth.

All the plants received the same amount of water and the entire group was watered as needed throughout the summer. The height and width measurements of each of the plants were recorded on five scheduled occasions (July 16, August 11, August 29 and September 25) throughout the growth season, which lasted from early July until the end of September, 2003. The study was concluded when it was observed that the plants had stopped growing in height and width due to the cooler temperatures. The height was determined as the distance from the surface of the pot soil to the top of the tallest branch

of the plant when fully extended upwards. The width of each plant was determined by measuring the distance between the two furthest extending branches of the plant. During measurement the branches were gently pulled away from the main plant stem to straighten the bends in the branches. The number of tomatoes growing on each plant was also recorded at the same time the width and height were recorded.

Plants do not directly uptake nutrients and contaminants from the soil particles. They absorb molecules in the soil solution through their roots system. The leachate quality was therefore used as an indicator of nutrient and contaminant levels in the growth media. Leachate samples of 200 mL were collected in plastic bottles on three separate occasions during the study (August 12, 19 and September 24). Upon collection, the samples were filtered and measured for pH. They were then acidified using 1 drop of concentrated nitric acid (HNO_3) per 4 mL of sample for storage. Samples were tested for a number of metals and cations including As, Cd, B, Co, Cr, Cu, Fe, Mg, Mn, Mo, Ni, Pb, Se, Zn, Ca, P, Na and K in the analytical chemistry lab at Carleton University. The technique used was Inductively Coupled Plasma Atomic Emission Spectroscopy (ICP-AES) with a Thermo Jarell Ash 6000 using argon gas at a temperature of approximately 10,000 degrees Kelvin.

Initial media samples were taken from each of the growth media mixtures used in the study. These samples were also analyzed using ICP-AES. The samples were prepared prior to the analysis by drying in an oven set at 100 °C for 24 hours. They were then ground to a fine powder using a stainless steel electrical soil grinder. The ground samples were then digested with concentrated hydrochloric acid (HCl) and concentrated nitric acid. 1 gram of ground media mixture sample and 20 mL each of HCl and HNO_3 were mixed gently in 100 mL glass tubes. The tubes were then placed in a heating block for approximately four days. The digestion was considered complete when the solution within the tubes became transparent and yellowish in colour. Once digested, the samples were cooled, filtered and diluted with deionized water to 25 mL using a 25 mL volumetric flask. The sample solutions were then transferred to 30 mL plastic sample bottles to await ICP-AES analysis.

The results from the ICP-AES analysis were reported in parts per million (ppm) on a mass basis (i.e. 5 ppm = 5 kg of metal X per 1 million kg of *solution*). These results

reflected the mass ratio of each of the metals based on the digested and diluted solution. The results required conversion to reflect the concentration based on the original media sample. A sample calculation of this conversion has been included in the appendix. Because of this conversion step, there are different detection limits for different media being tested for the same metal. The ICP-AES analysis covered ten of the eleven metals regulated by the MOE. It was not possible however, to determine the mercury concentration at the Carleton facility.

In order to put the leachate contaminant levels into perspective, the results from the analysis were compared to acceptable levels in drinking water as specified by the Canadian government and the U.S. EPA. For metals which are not monitored in drinking water, the CCME guidelines for irrigation water and freshwater sources were used as basis of comparison.

4.2 Results and discussion

4.2.1 Tomato plant growth

Figure 4-1 outlines the average change in height and width in the tomato plants over the course of the study. All of the growth averages exhibited a high degree of variance which is expected with a plant study of this nature (Clewer & Scarisbrick, 2001). The test group size for each media type was only six plants. Although growth conditions should have been identical for each plant, the initial health and antecedent conditions experienced by the plants may have varied considerably.

Figure 4-1 - Average tomato plant growth - July 16th - Sept. 25th, 2003.

It is immediately evident from Figure 4-1 that the potting soil and potting soil and loam mix both outperformed all of the media mixtures containing biosolids, including both St. Marys material and the municipal biosolids. There was no significant difference in growth noted for any of the other mixtures. The addition of the loam to the potting soil seemed to have slightly hindered growth. It also appears that the addition of the loam did not have a significant effect on the plant growth in the St. Marys biosolids group (or any of the groups for that matter). Negative growth was recorded for many of the plants grown in the St. Marys biosolids, implying that the plants decreased in size over the course of the study. It should be noted that the error bars shown represent + & - 1 standard deviation for their respective data sets. Of the groups containing St. Marys material, the plants in grown in the St. Marys biosolids alone appeared to exhibit the poorest performance. At the end of the study, the plants in the municipal biosolids and loam mix were all taller than their original height. For each of the groups containing St. Marys material, there were individual plants which decreased in size over the course of the study.

Figure 4-2 outlines the number of plants bearing fruit at the end of the study. All of the plants in the potting soil (T) and potting soil loam mix (TL) bore tomatoes at the end of the study. The remainder of the groups had less than 40% of their plants produce fruit.

Each test group consisted of six plants, therefore the differences between the fruit production over the five groups containing biosolids is not considered to be significant. When examining the growth data, it is clear that the fresh St. Marys biosolids material and fresh St. Marys biosolids material/wood waste mix are not ideal potting media in their present state.

Figure 4-2 - Percentage of tomato plants bearing fruit

4.2.2 Field observations

The plants growing in the potting soil and potting soil loam mix all developed into healthy fruit bearing plants with thick stems and green leaves. Figure 5-3 illustrates this growth in the potting soil group. The plants growing in the all of the St. Marys biosolids mixtures exhibited poor growth. The plant stems were very thin and lacked the strength to stand on their own without the support of a stake. These characteristics are synonymous with nutrient deficiency (Levy & Taylor, 2003). Another indicator of the lack of nutrients, in this case plant available nitrogen, was the appearance of mushrooms in the biosolids pots at various times during the study. On Aug 11th, 2003, 71% of all of the pots containing St. Marys biosolids and biosolids blends (i.e. - B, BL, W, WL media) had mushrooms growing in them.

Figure 4-3 - Healthy plant growth in potting soil.

It is thought that the fungi were decomposing the cellulose and lignin present in the biosolids. Their presence indicates that the biosolids material is not stable and undergoing decay. The fungi utilized the nitrogen in the media to decompose the organic material robbing the tomato plants of this nutrient. Until the biosolids reached a level of stability, this cycle would likely render plant growth very difficult (Brady & Weil, 1999).

Leachate samples collected from the biosolids and biosolids mixtures were less turbid and almost colourless in comparison to the other groups. Figure 4-4 shows leachate samples taken in August, 2003. The clear samples on the left were taken from pails containing St. Marys biosolids and were odourless. The darker samples in the middle of the group were taken from the municipal biosolids and loam group. These municipal biosolids samples smelled very foul. The sample on the far right was taken from a pail containing potting soil. The samples from the groups containing the potting soil were not associated with foul odours.

Over the course of the study, the surface of the media mixtures in the pails in the groups containing St. Marys biosolids became very hard when left to dry out, particularly the pure biosolids group. The surface formed a crust. On two different occasions during the study, an attempt to reduce this crust was undertaken by loosening the surface of the material in the pails with a small spade. This loosening exercise was applied to all the

pails in study. The crusting may have reduced the aeration of the material below the surface and impeded oxygen and water from reaching the roots. The consistency of the material may have also made it difficult for the tomato plants roots to penetrate through the material. Both of these factors would have contributed to nutrient deficiencies in the plants which uptake nutrients through absorption from soil solution through their roots systems.

Figure 4-4 - Leachate samples.

The field observations coincided with the conclusions drawn previously stating that the St. Marys material would require further processing to alter the physical structure and chemical nature of the material and further stabilize the organic matter before it is suitable as a potting medium.

4.2.3 Carbon to nitrogen ratio of study media

Judging from the growth data and visual observations, it was expected that the carbon to nitrogen ratio of the four groups containing St. Marys material would be quite high compared to the groups containing potting soil. The poor growth and appearance of mushrooms indicated that the St. Marys material was nitrogen and phosphorous deficient and actively decomposing. The high C:N ratio (i.e. above 25) exhibited by the groups containing St. Marys material in Figure 4-5, supports these earlier observations. As seen in the previous chapter, the average C:N ratio of the biosolids is around 65 and commercial topsoil around 44. The St. Marys material C:N ratio averaged approximately 55, lower than the earlier average, but still high for an organic growth media. The potting

soil had the highest C:N ratio of all of the groups which was unexpected given the performance of the plants in this media. Unlike the plants grown in soil containing biosolids, the plants in the soil groups containing topsoil did not exhibit signs of nutrient deficiency as illustrated by their growth and appearance. It is thought that despite the elevated C:N ratio of the topsoil, the nitrogen which is present is bioavailable to plants, while the carbon present may not be in a readily biodegradable form. This combination would yield a stable environment in which the microbial population would not be scavenging nitrogen from the soil solution in order to fuel their decomposition of the organic carbon.

As expected, the addition of loam lowered the percentages of carbon and nitrogen for all media to which it was added. What was surprising was the increase in C:N ratio for St. Marys biosolids/wood waste and loam group compared to the same group without the loam. The St. Marys biosolids/wood waste mixture had a C:N ratio of 48. The increase in C:N up to slightly above 60 for the St. Marys biosolids/wood waste and loam group (WL) was unexpected. Upon examination of the data, both the carbon and nitrogen percentages did drop with the addition of the loam which was consistent with the other media. The drop in nitrogen was greater in comparison to the drop in carbon, which resulted in the higher C:N ratio. The municipal biosolids had a C:N ratio well below other soil groups in the study. A C:N ratio of approximately 10 is within the range of published values (Brady & Weil, 1999).

In summary, the C:N ratios support earlier recommendation that the St. Marys material requires stabilization to reduce the carbon to nitrogen ratio to a level better suited for plant growth. The elevated C:N levels in the potting soil do not coincide with the growth data which clearly illustrated that this media recipe is simply designed to be effective at supporting healthy plant growth.

Figure 4-5 - Carbon to nitrogen ratio for study media.

4.2.4 Metals and other ions

Both the media and the leachate were examined for a number of heavy metals and other cations which act as essential plant nutrients.

Media

Lead was not detected in any of the media tested. Arsenic was not found in any samples except for the municipal biosolids and one of the four samples from the biosolids/wood waste and loam mixture groups. Molybdenum was also undetected in all samples except in the pure biosolids (B).

Cobalt, copper, chromium, nickel and zinc were detected in all samples. The levels of all metals detected in the St. Marys biosolids were within their respective ranges as illustrated in Chapter 3, Table 3-2. It was previously concluded in Chapter 3 that concentrations of the ten of the eleven heavy metals by the MOE in the biosolids should not pose a threat to plant growth or human health. These include As, Cd, Cr, Co, Cu, Pb, Mo, Ni, Se, and Zn. For this reason, the poor growth of the tomatoes in this study is not thought to be caused by toxicity from these metals. Mercury, which is also regulated,

was not tested for. Based on the results outlined in Chapter 3, Table 3-2, mercury toxicity was not concluded as an issue affecting plant growth.

Leachate quality

Table 4-1 specifies the metals which were undetected in each media mixtures. Arsenic and molybdenum were both undetectable in all leachate samples. Lead was undetected in all samples except in the municipal biosolids leachate. Results from cadmium, chromium, copper and zinc are outlined in Table 4-2. Cadmium, chromium, copper and zinc were detected in some of the samples however, when detected the concentrations fell below both Ontario drinking water guidelines as well as the U.S. EPA's maximum contaminant level goal (MLCG) for drinking water. The MLCG is the level below which there is no known or expected risk to human health.

Table 4-1 -Undetected metals in study media

Media type	Metals undetected in leachate
Biosolids	As, Pb, Co, Cr, Mo, Mn, Fe
Biosolids & loam	As, Pb, Mo, Mn, Fe
Biosolids & woodwaste	As, Pb, Mo, Mn, Fe
Biosolids, woodwaste & loam	As, Pb, Cd, Mo, Fe
Municipal biosolids & loam	As, Mo

Table 4-2 - Cadmium, zinc, chromium and copper levels

	Cd	Zn	Cr	Cu
	mg/L			
B	0.003	0.12	< 0.0189	0.02
BL	0.002	0.12	0.03	0.03
W	0.002	0.11	0.03	0.02
WL	< 0.0019	0.08	0.03	0.02
ML	0.002	0.04	0.02	0.02
EPA - MLCG	0.004	5	0.1	1.3
Canada - MLCG	0.005		0.05	

Concentrations of nickel and cobalt found in the leachate samples are outlined in Table 4-3. Nickel is not listed in the Canadian drinking water guidelines, however the CCME has suggested guidelines for freshwater and irrigation water sources. The data presented in Table 4-3 suggest that the nickel levels in the leachate samples from all media mixtures fall well below levels set for irrigation water and freshwater. It also

appears that the addition of the wood waste contributed to the nickel levels in the leachate.

In Table 4-3, it would seem that the cobalt levels in the leachate from all media mixtures examined fell well below the levels set for irrigation water published by the CCME.

Table 4-3 - Nickel and cobalt levels in leachate

	Ni (mg/L)	Co (mg/L)
Biosolids	0.013	< 0.0072
Biosolids & loam	0.022	0.010
Biosolids & wood waste	0.069	0.010
Biosolids, wood waste & loam	0.067	0.017
Municipal biosolids & loam	0.026	0.023
CCME Freshwater guideline	0.025-0.15	
CCME Irrigation water guideline	0.2	0.05

The leachate samples were analyzed for selenium; however the results have not been reported as there were analytical problems with the data. In November, 2003 and April, 1997, St. Marys Paper had biosolids and biosolids/wood waste samples analyzed using the Toxicity Characteristic Leaching Procedure (TCLP). In this procedure constituents are extracted from the waste in a manner designed to simulate leaching in landfills using acetic acid with a pH of 5.0 over 24 hours. The 1997 tests did not detect selenium in either the wood waste or the biosolids at a detection limit of 0.01 mg/L (Kresin, 1997). In 2003, selenium was undetected in the leachate samples at a detection limit of 0.005 mg/L (Envirotest report # L137418, 2003). Under natural conditions, the solubility of selenium in the biosolids should be limited considering that the St. Marys biosolids material is of neutral pH, high in organic matter and has significant clay content. These factors should reduce the mobility of the selenium in the soil according to Kabata-Pendias (2001). Looking at the historical data and the nature of the biosolids, selenium was not expected to be a problem in the leachate for the reasons regarding factors that reduce mobility.

Sodium is not currently a regulated drinking water contaminant, nor does it appear in the CCME water quality guidelines. High sodium intake in humans has, however, been associated with heart disease. For plants, high sodium and calcium can be toxic and can

also have an effect on soil alkalinity, salinity and osmotic pressure within the soil solution (Crites et al., 2000).

SAR is a measure of salinity which takes into consideration the moderating effects calcium and magnesium have on the adverse effect of sodium present in soils and leachate. SAR is a calculated value determined using the following formula:

$$SAR = \frac{[Na^+]}{\sqrt{0.5([Ca^{2+}] + [Mg^{2+}])}}$$

where:

SAR = sodium absorption ratio
 $[Na^+]$, $[Ca^{2+}]$, $[Mg^{2+}]$ = concentrations in mmol/L

Table 4-4 are the sodium absorption ratios (SAR) of the leachate for the media examined in this study.

Table 4-4 - Average SAR ratio of leachate from study media

Media type	SAR (leachate)
Biosolids	1.3
Biosolids & Loam	2.9
Biosolids & woodwaste	1.3
Biosolids, woodwaste & loam	2.4
Municipal biosolids & loam	1.5

Note: SAR calculated using avg. $[Na]$, $[Ca]$, $[Mg]$ for each soil type.

According to Bauder et al. (2003), levels of SAR in water between 1 and 9 have a very low sodium hazard to crops and plants. The SAR levels in Table 4-4

Table 4-4 are all low and should not cause negative effects on plant growth.

Phosphorous is also unregulated in drinking water and is absent from the CCME guidelines. The MOE however does regulate the concentration of phosphorous in

wastewater treatment effluent. It can however contribute to surface and groundwater contamination as previously discussed in Chapter 2. Tchobanoglous & Schroeder (1987) stated that treated municipal wastewater typically has a phosphorous concentration of between 10 and 20 mg/L. The levels in the leachate of all media mixtures, with the exception of the municipal biosolids, were well below 10 mg/L as illustrated in Table 4-5.

Table 4-5 - Average phosphorous levels in leachate from study media

	Phosphorous (mg/L)	
	Average	St. Dev
Biosolids	3.7	1.4
Biosolids & loam	2.4	0.4
Biosolids & woodwaste	4.4	1.4
Biosolids, woodwaste & loam	5.0	1.9
Municipal biosolids & loam	27.2	16.4

4.2.5 Leachate pH

Figure 4-6 illustrates the average pH levels of the leachate collected from each of the media mixtures investigated. All of the biosolids mixtures, including the municipal biosolids generated leachate with neutral pH. The potting soil mixtures generated leachate with an average pH below 7. The neutral pH of the leachate from the media groups containing biosolids coincided with pH data collected on St. Marys biosolids and presented in the previous chapter. There should be no issues of high acidity or alkalinity associated with the use of St. Marys material based on this study.

Figure 4-6 - Average pH of leachate.

4.3 Summary

Although St. Marys material would not exhibit a threat to a natural environment based upon salinity, pH and metal levels, the growth study illustrated that the fresh biosolids material does not perform well as a potting media. These results were contrary to work reported by Lemcke (1998). This earlier vegetable study concluded that St. Marys biosolids produced tomatoes and other vegetable crops of the same quality or better than conventional garden soil. The difference between this 1998 study and the work completed here was the age of the biosolids. This experiment used fresh biosolids. Lemcke (1998) used biosolids which had been stored in open piles at the mill for a period of between 6 months to a year. It is likely that during this storage period, the material was actively decomposing much like a compost pile or windrow. When used for the 1998 study, the material had reached a more stable state than the fresh biosolids used in this study.

Nutrients, particularly nitrogen, may not be readily available for vegetation within the fresh biosolids matrix. Evidence of fungi growth in the fresh biosolids indicated active decomposition in fresh biosolids. This microbial activity requires nitrogen which is

obtained from the soil and soil solution. The cost of this decomposition and microbial scavenging for the plants is less plant available nitrogen. The physical structure of the material, particularly on its own without wood waste, may also contribute to vegetation nutrient deficiencies and creates a difficult environment for healthy root growth.

As reported in Chapter 3, wood extractives such as phenol and cresol which have been reported periodically in the biosolids. This may have also contributed to the poor growth of the tomato plants in this study. The biosolids used for this experiment were not analyzed for organics, so it is not possible to verify their presence. Future growth studies should include analysis for these components within the growth media.

5 JACK PINE GROWTH STUDY

The goal of the following experiment was to determine the performance of biosolids as an organic growth additive for trees. The results from the tomato plant study identified that the biosolids on their own may not have the ideal physical and nutrient characteristics to act as a soil replacement. Based on the previous findings, this experiment was used to test different mixing ratios of biosolids and potting soil to identify whether the biosolids have potential as a soil amendment used to promote growth.

5.1 Methodology

The study was conducted in a greenhouse at Sault College of Applied Arts and Technology with the assistance of Professor Mark Harvey and his 2003 Forest Renewal class. Jack pine (*Pinus banksiana*) was selected over tomatoes as the plant species for the study primarily because of its availability at the time of the study, hardiness, prevalence in the local area and relevance to St. Mary's Paper and the pulpwood industry. The jack pine is a small to medium sized coniferous tree and is the most widely distributed pine species in Canada.

The biosolids were hand mixed in different ratios with Premier ProMix, a commercial peat-based potting and seeding material. As discussed in Chapter 4, it is the preferred media of the local nursery which grows seedlings destined for replanting on the lands logged for St. Marys Paper Ltd.

There were five soil mixes used to grow the trees:

- 100% ProMix potting soil (control)
- 75% ProMix, 25% biosolids
- 50% ProMix, 50% biosolids
- 25% ProMix, 75% biosolids
- 100% St. Marys biosolids

Prior to mixing with the ProMix, the biosolids were passed through a 2 cm screen. The above volume ratios were then obtained by mixing the biosolids and potting soil in large buckets.

For each soil mix there were four groups of four repeats for each treatment, totaling 16 jack pine for each soil mix. On Oct. 1st, 2003 the trees were planted in 15 cm diameter pots. Once the pots were loosely filled with soil, three seeds were planted in the center of each pot and gently pushed less than 1 cm below the soil. The seeds were then lightly covered with sand to anchor the seeds during watering.

The groups of four pots were then placed in a green house located at Sault College of Applied Arts and Technology in Sault Ste. Marie, Ontario, according to the randomized block layout shown in the appendix. The temperature of the greenhouse was regulated to 27 °C and set to exhaust once the temperature reached 29 °C. Over head fluorescent lights provided constant illumination to the plants. The trees were initially saturated with water by overhead sprinklers for 3 hrs and then 10 minutes per hour during the first month of growth. After this initial period, plants received 100 mL of water two times per week. Upon germination, excess seedlings were removed from the pots and transplanted to other pots, where necessary, to ensure one germinated seedling per pot. After the first month, the plants were watered manually. They received 100 mL of water two times per week.

Plant heights were recorded over a four month period every two weeks. Height was measured as the distance from the surface of the soil at the base of each plant to the tallest point of the plant. At the end of the study, on Jan. 15th, 2004, half of the group was randomly chosen and destructively sampled to determine dry weight of the tops and roots. Half of the specimens were uprooted and oven dried at 60 °C for 72 hours before weighing to determine the dry weight of both roots and tops.

5.2 Results and discussion

Figure 5-1 outlines the average height of the plants at the end of the study. From these results it would appear that the 50% biosolids mix produced plants of comparable height

to that of the control media. Using single variable ANOVA, there was found to be no significant difference between these two groups ($F=0.002$, $p=0.96$). Both of these groups averaged plants of approximately 6 cm in height. The growth of plants in the 100% biosolids group were found to be significantly less ($p < 0.05$) than the other groups. The average height of this group was only 3.6 cm. The 75% biosolids group and the 25% biosolids group followed closely behind with average seedling heights of 4.2 cm and 4.5 cm, respectively. Using single variable ANOVA, no significant difference was found between the heights of the 75% biosolids and the 25% biosolids groups ($F=1.5$, $p=0.23$). The average heights for 75% and the 25% biosolids groups were significantly lower ($p<0.05$) than the 100% potting soil and 50% biosolids groups. A summary of the results of the ANOVA analysis of the data is included in the appendix.

Figure 5-1 - Average jack pine height - Jan. 25, 2003.

Overall, the plant growth in all of the media groups was slow. After four months of growth, the tallest plants in the study were still under 10 cm in height. Plantation growth rates during the summer months are typically 5 cm per month (Burns & Honkala, 1990). This slow growth can be attributed primarily to the timing of the study. The decreasing daylight over the course of the study is believed to have affected all of the plants.

Although artificial light was provided in the greenhouse, the plants are highly affected by seasonal fluctuations in daylight hours.

Figure 5-2 outlines the average dry mass of the plants which were destructively sampled at the end of the study. The trending of this data is similar to the results illustrated by the plant heights with the exception of the control group. The average plant height suggested that there was no difference between the performance of the 50% biosolids and the 100% potting soil group which was the control. Examination of the dry mass of the roots and tops and single variable ANOVA suggest that the 50% biosolids group produced plants of significantly greater mass than the control group ($F=10.3$, $p=0.006$). For the remaining groups, the trend was similar to that observed in the previous section. The 100% biosolids plants had the lowest dry mass, followed by the 75% biosolids group, the control and the 25% biosolids group. The collected plant height and dry mass data have been included in the appendix of this report.

Figure 5-2 - Average jack pine dry mass.

The dry mass data suggested that St. Marys biosolids material has a positive effect on jack pine growth when mixed with potting soil at a ratio of 50%. This result corroborates the conclusions found by Chong et al. (1998) in a similar study which examined pulp and paper mill biosolids as a rooting medium amendment for deciduous landscape shrub cuttings. They determined that biosolids additions ranging from 30-60% by volume

produced positive results in test species. Earlier research conducted in 1982 by the Province of Alberta's Environmental Sciences Division also reported that the addition of pulp and paper mill biosolids enhanced the growth of potted pine seedlings grown in a greenhouse. (Province of Alberta, 1999)

It is thought that the decrease in growth shown with the addition of greater than 50% biosolids is due to nitrogen deficiencies and poor physical structure of the soil matrix as was seen in the Chapter 4. Throughout this study, it was visually noted that the material in the pots containing greater than 50% biosolids once dried out became very hard and clumpy, while the groups with 50% or less biosolids remained loosely packed even when dry. Over the course of the 15 week study, the material in the 100% biosolids group appeared to shrink in volume. The level of media in the pots was lower than the initial level at the beginning of the study. As well the media within some of the pots had pulled away from the side of the containers. This shrinkage could have been caused either by the compaction of the media particles upon drying out or by decomposition of the fresh biosolids material over the course of the study. Chong et al. (1995) also reported shrinking during their study and attributed it to decomposition of readily degradable organic matter such as simple sugars, amino acids and cellulose.

5.3 Summary

This greenhouse study suggests that the use of St. Marys biosolids as an organic amendment or additive improves the growth performance of jack pine based on the dry mass of the plants at the end of the study. As with the tomato study, the plants grown in 100% fresh biosolids did not perform well. The dry mass data however, indicated that the plants grown in a ratio of 50% biosolids and 50% commercial potting soil weighed significantly more than the plants grown in commercial potting soil (control) and all of the other media groups. The plant height data suggested that both of the 50% biosolids and 50% commercial potting soil and the control group yielded significantly taller plants than the other media groups investigated. There was no significant difference found however between the 50% biosolids and 50% commercial potting soil and the control group. This discrepancy in results between the height and mass data may have been caused by slow height growth in all of the groups caused by a reaction of the plants to the winter's

short daylight period during the study. It is thought that over a full growing season, the results of the study would be amplified and more clearly define a trend in plant performance. The conclusions of this study however warrant further research into this possible reuse of biosolids by mixing it into potting soil as an amendment. There may be a unique prospect to reuse the biosolids as an organic additive within the pulp and paper industry. The use of biosolids in nurseries supplying seedlings for replanting logged areas may be an opportunity for the industry to “close the loop” with respect to organic matter recycling.

6 IN-VESSEL COMPOSTING STUDY

Based on the findings of the tomato plant study discussed in Chapter 4, it was concluded that St. Mary's Paper biosolids would require further processing to stabilize the decomposition of the material and alter the physical structure, before it could be used as an alternative growth media. One method of achieving this stabilization is through in-vessel composting. In-vessel systems offer better control over operating parameters and air quality as well as, higher output than open systems (Dinel et al., 2004). St. Mary's past experience with composting through their association with Agribond had shown that it was possible to generate a stable end product through windrow composting. Public concerns over air quality control had previously led St. Mary's to explore and exercise other methods of disposal and re-use. It was determined during the initial background research phase of this project that there was an opportunity for biosolids reclassification from "waste" to a "product" through aerobic composting. The Ministry of Environment's Interim Guidelines for the Production and Use of Aerobic Compost in Ontario stipulate that if composted biosolids meet a set of criteria outlined in the Guidelines, they may be considered for reclassification and available for unrestricted public use and resale. In light of this information and through the opportunity to utilize a method of composting which offered greater air quality control, St. Mary's interest in composting was renewed. Compost could be a more effective growth media than the fresh biosolids and this type of processing is an avenue which could offer reclassification of the material from a waste to a product. The aim of this study was:

1. Investigate in-vessel composting as a means to generate an organic soil conditioner from the biosolids waste stream.
2. To assess final product quality according to the Ministry of Environment's Interim Guidelines for the Production and Use of Aerobic Compost in Ontario (referred to as the MOE Guidelines in this Chapter) and the Bureau de Normalisation du Quebec Draft Standards for Organic Soil Conditioners - Composts (referred to as the BNQ Standards).

6.1 Methodology

The study consisted of four composting trials each lasting between ten to thirty-four days in duration. Each trial was an attempt to determine the operating conditions of the process which maximized the duration of the thermophilic phase of the compost. Moisture content and temperature were primarily used as a means to assess status composting process, during the study. The temperature increase during composting is caused by exothermic reactions related to microbial respiration; therefore the heat generation is a function of microbial activity (Larsen & McCartney, 2000). Metals, carbon and nitrogen analysis were carried out after the trials were complete. Trials were terminated either when temperature within the unit approached ambient levels or after a period of approximately 4 weeks. Maximum temperatures during composting are typically reached within the first two weeks of the process (Larsen & McCartney, 2000). Operating parameters manipulated during the experiment were:

- moisture level
- type of bulking agent
- ratio of biosolids to bulking agent on a volume to volume basis
- pH
- nitrogen content

All trials were carried out at St. Mary's Paper Ltd. in an in-vessel composting unit roughly 2 meters high, 2 meters long and 1.8 meters wide. The unit was insulated on the sides and bottom. The top of the vessel was covered with a mesh bottomed tray containing a layer of peat moss 5 cm thick. The peat moss acted as a bio-filter to reduce odours.

Inside the composting unit were four motorized augers which were controlled by a timer. The mixing ratio was held constant throughout the study and was set at 15 minutes per hour for the duration of each trial. Bulking agents used included sawdust collected from the mill's saw decks and wood chips provided by the mill's hog fuel supplier. Both materials are readily available to the mill at no charge. The ratio of biosolids to bulking agent was manipulated during this study. Biosolids solids typically require a 2:1 or 3:1 volume ratio of sludge to bulking agent; therefore the starting point for this experiment

was a 3:1 ratio used in Trial 1. It is this volume ratio of the biosolids to bulking agent which is most critical to system design rather than the mass ratio of the bulking agent. (McFarland, 2001)

Concentrated phosphoric acid was used as an additive at the beginning of a number of trials in an effort to drop the pH of the compost in order to prevent ammonia volatilization (Dinel et al., 2004). In the later trials, nitrogen amendments were used improve microbial degradation and increase the temperature of the compost into the thermophilic range (> 40 °C) and increase the rate of organic decomposition. Urea, ammonium nitrate and chicken manure were also used as amendments.

During each trial, the temperature was recorded daily using a 1.5 meter temperature probe consisting of a Type J thermocouple wire housed by a hollow stainless steel tube. The thermocouple was plugged into a Fluke digital multi-meter. For each reading, temperatures were recorded from three different locations within the reactor and averaged. Grab samples were collected every second day from the reactor. Sampling was increased to daily when temperatures were elevated or showed dramatic change. Composite samples were obtained by collecting material from at least four different locations within the unit using a long handled scoop. The collected material was mixed and sealed within a Ziploc bag. Within 4 hours of sampling, the material was tested for pH and prepared for moisture content testing.

The pH was determined by mixing a slurry consisting of the sample and deionized water in a 1:10 ratio. The mixture was left to stabilize for 15 minutes before the pH was measured (Jackson & Line, 1997). Moisture content was determined gravimetrically using an oven set to 60 °C for drying in order to conserve the carbon content of the samples (Middlestead, 2004). Samples were dried for a period of at least 48 hours. The moisture content was calculated in the same fashion as was outlined in the methodology of the tomato study (Chapter 4, Section 4.1).

Once dried, samples were ground using a mechanical soil grinder and stored in a dry location in Ziploc bags to await further analysis. Once the temperature data was reviewed, samples taken on dates when temperature changes occurred (i.e. dates surrounding points of inflection on the temperature curve) were selected for C:N testing.

The C:N ratio was chosen as the method to assess relative stability based on the requirements stipulated by the MOE Aerobic Composting Guidelines (Ministry of the Environment of Ontario, 1991) and availability of testing expertise and cost of the procedure. The C:N testing was carried out at the G. G. Hatch Isotope Laboratory at the University of Ottawa. At the laboratory, samples were weighed into tin capsules and loaded with standards into a Vario EL III elemental analyser made by "Elementar Americas, Inc.", USA. Samples were flash combusted at about 1800°C and carried by helium through columns of reducing/oxidizing chemicals to get N₂ and CO₂. The gases were separated by the "purge and trap" of specific adsorption columns such that the TCD (thermal conductivity detector) could detect each gas separately. The routine analytical precision (2 sigma) was +/-0.1%. The results of the analysis were presented in % N and % C based on dry weight (Middlestead, 2004).

At the beginning and end of the trials, samples were collected and analyzed for metals, sodium absorption ratio (SAR), and macronutrients by Envirotest Laboratories. The bulk density was also determined at the start and completion of each trial. The bulk density was determined by packing a 3 L cylinder with material, then dropping it from a height of 5 cm five times. The compacted volume was recorded and the cylinder weighed. This procedure was conducted in triplicate (Jackson & Line, 1997).

The characteristics of the final products from each of the trials were compared to the MOE Interim Guidelines for the Production and Use of Aerobic Compost in Ontario and the National Standard of Canada entitled: Organic Soil Conditioners - Composts (BNQ). This national standard has been established by the Standards Council of Canada through the Bureau de Normalisation du Québec (BNQ). The standards were designed for voluntary as a means to ensure consistency, high standards and safety within the industry.

6.2 Results and discussion

6.2.1 Trial 1

The initial operating parameters for this preliminary trial are outlined in Table 6-1. A ratio of 3:1 biosolids (B) to wood chips (WC) was used as the feedstock for Trial 1. Figure 6-1

outlines the results from the first trial. In this figure and the others presented in this chapter, the following legend applies:

MC % - moisture content

Amb T - ambient temperature in °C

T - compost temperature in °C

C:N - carbon to nitrogen ratio

The feedstock in the system heated to 35 °C within the first 24 hours and then declined to ambient temperatures within the first week. The C:N, bulk density and pH did not change significantly over the course of the trial. Detailed data collected from this trial and the other three trials is included in the appendix.

Table 6-1 - Trial 1 initial operating conditions.

	Trial 1
Feedstock (Biosolids:Bulking Agent)	3 B : 1 WC
Moisture (%)	69
pH	7.5
C:N	69.6
Nutrient additives	None
Total volume (m3)	3.2
Bulk density (kg/L)	0.73

Figure 6-1 - Trial 1 results.

Though moisture levels for composting can range up to 70% (McFarland, 2001; Arrouge et al., 1999), it was concluded from the first trial that the initial moisture level was too high and had caused the system to become anaerobic. Visually, it appeared as if the wood chips alone were not sufficient to maintain the porosity of the feedstock. Large quantities of the material had aggregated together in clumps. The material was very wet and sticky to the touch. Upon drying, samples resembled small bricks which had to be broken up with a hammer before grinding.

6.2.2 Trial 2

For Trial 2, sawdust was used in addition to wood chips as a bulking agent in order to reduce the moisture content of the feedstock. Table 6-2 outlines the initial conditions for Trial 2. The moisture content of the feedstock was reduced by 5% and the bulk density was lowered from 0.72 to 0.59 kg/L. As a consequence of using the sawdust as a bulking agent, the C:N ratio rose considerably to 94.

Table 6-2 - Trial 2 initial operating conditions.

	Trial 2
Feedstock (Biosolids:Bulking Agent)	2 B : 1WC : 1S
Moisture (%)	63
pH	8.5
C:N	94
Nutrient additives	None
Total volume (m3)	1.6
Bulk density (kg/L)	0.59

Figure 6-2 shows the results from Trial 2 over time. The temperature of the feedstock initially rose up to 41 °C within the first two days of composting, however, it decreased back down to 37 °C on the third day. The compost spent only 2 days within the thermophilic range. The C:N ratio stayed above 100 throughout the trial. The lower reading of the samples taken on the first day may not have been representative and it is suspected that the material in the reactor had not yet been thoroughly mixed. The composting material in this case, appeared very loose and porous. There were no large clumps of aggregated material as there had been in the first trial. Upon drying, the material remained loose and in small particles.

Figure 6-2 - Trial 2 results.

Haug (1993) suggested that for ideal composting conditions, the C:N of the feedstock should be approximately 30. Other studies focusing on pulp and paper mill biosolids composting have suggested that this low level may not apply to pulp and paper mill biosolids because the carbon in the biosolids has a low biological availability (Das et al., 2001). Pulp and paper mill biosolids composting studies conducted by Line (1995) found a C:N ratio of 60 to be successful using nitrogen amendments. Based on previous research and the low temperatures recorded during trials 1 and 2, it was concluded that the C:N ratio of this trial was too high for effective composting.

6.2.3 Trial 3

The feedstock in the third trial was a 4:2:1 ratio of biosolids to wood chips to sawdust. The decrease in sawdust lowered the initial C:N ratio of the feedstock to a more acceptable level of 62. The pH during trials 1 and 2 was consistently recorded to be above 7. Nitrogen in the form of ammonia (NH_3) and NH_4^+ (aq) is affected by the pH. Under acidic conditions, NH_4^+ (aq) is prevalent, while under alkaline conditions NH_3 dominates according to the reaction

below:

In order to conserve nitrogen losses of ammonia through volatilization, the pH of the feedstock in Trial 3 was lowered by adding concentrated phosphoric acid at the beginning of the trial (Dinel et al., 2004). Phosphoric acid obtained from St. Marys Paper was applied to the feedstock using a fertilizer sprayer. Upon contact with the acid, the metal surfaces of the mixing augers and interior walls of the composter became white and corroded. The operating conditions of the trial are outlined in Table 6-3.

Table 6-3 - Trial 3 operating conditions.

	Trial 3
Feedstock (Biosolids:Bulking Agent)	4B : 2WC : 1S
Moisture (%)	60
pH	5.3
C:N	62
Nutrient additives	H ₃ PO ₄ , CH ₄ N ₂ O
Total volume (m ³)	2.8
Bulk density (kg/L)	0.8

The effects of the alteration in feedstock composition and the addition of phosphoric acid were monitored over a period of two weeks to determine their effect on the temperature of the compost. The results from the trial are displayed in Figure 6-3. Despite the change in feedstock, the improvement in performance was only slight. The temperature trend was similar to those seen in the first two trials. The temperature increased quickly to a maximum of 43°C on day 3. This maximum was higher than the earlier trials, but the temperature declined after the third day. Hence, the compost remained in the thermophilic range for only three days.

At the end of day 18, the first of two nitrogen additions were made to determine whether nitrogen deficiency was suppressing microbial activity and the associated temperature. Ten kilograms of pelletized commercial grade urea fertilizer (CH₄N₂O, N:P:K = 46:0:0) was added to the composter. Within 24 hours, the nitrogen caused the temperature of the reactor to increase from ambient temperatures, in the mid twenties, to 37°C. This

increase in temperature was short lived. Within 3 days of the initial spike, temperature sharply declined again. Another 20 kg of urea was added to the composter on day 23 in addition to enough water to bring the moisture level back up to around 50%. This second application had the desired effect of bringing up the temperature into the thermophilic range for another 24 hr period on day 30. The ammonia volatilization associated with this heavy fertilizer use was very apparent. The biofilter was successful at mitigating odours surrounding the composter, however, during sampling when it was removed, respiratory equipment and goggles were required to prevent any irritation due to contact with the ammonia gas.

Figure 6-3 - Trial 3 results.

The trial was concluded after 34 days once the temperature spike from the second nitrogen application began to wane. It was concluded that a lower C:N ratio and nitrogen amendment could improve performance of the composter based on the increased number of days within the thermophilic zone. The decrease in C:N ratio over the course of the study was primarily a results of the addition of nitrogen during the study. Upon reviewing the mass percentage of carbon, it was found that there was no change between the mass percentage of carbon of the initial sample and final samples. The heavy use of additives in this trial led to a disturbing increase in hazardous odours.

There was also an increase in operator risk associated with handling and applying of the concentrated chemicals.

6.2.4 Trial 4

Research done by Jackson & Line (1997) suggests that non-alkali forming nitrogen additives are preferable to urea because they are associated with less ammonia volatilization and associated odours. Das et al. (2001) reported successful use of ammonium nitrate (AN) and poultry manure as amendments for pulp and paper biosolids composting. Based on their positive results, these two amendments were used to increase the nitrogen content of the feedstock in the fourth trial. The initial operating conditions for Trial 4 are outlined in Table 6-4.

Table 6-4 - Trial 4 initial operating conditions.

	Trial 4
Feedstock (Biosolids:Bulking Agent)	3B:1WC:1S
Moisture (%)	61*
pH	8.1
C:N	30.4
Nutrient additives	NH ₄ NO ₃ & poultry manure
Total volume (m ³)	2
Bulk density (kg/L)	0.64

* - Day 2 reading. Initial reading was 68% but was discarded due to incomplete mixing.

Based on the low temperatures recorded during the previous trials, one of the goals of Trial 4 was to attain a conventional C:N ratio of 30 in the initial feedstock. This lower C:N ratio was achieved by altering the ratio of sawdust to biosolids and the addition of nitrogen. Initially 12.5 kg of AN and 45 L of chicken manure were added to the composter. The AN (N:P:K = 34:0:0) was purchased from a local gardening store and the fresh chicken litter was collected from a local farm.

The results from the trial are presented in Figure 6-4. The temperature quickly rose to temperatures within the thermophilic range within 24 hours of initiating the trial. The maximum temperature (52°C) of the trial was recorded on day 5. Over the course of the study, there were twelve days during which the material was recorded to be within the thermophilic range. Between days 7 and 8, the composter motor failed. Before the motor could be restarted, the temperature within the reactor had dropped to 34°C from 46°C the previous day. The ambient temperature on both days was recorded at 18°C,

therefore the rapid decline in temperature was thought to be directly related to the lack of mixing within the compost reactor. The motor was repaired on the morning on Day 8, however, the temperature did not respond to mixing over the course of the day. At the end of the day, an additional 10 kg of AN were added to the compost. Within 24 hours the temperature rose 5°C to 39°C and remained at this temperature for the next two days. On day 12, the temperatures crept into the thermophilic zone and stayed in the low forties for another four days. Ambient temperatures began to decrease sharply around day 16 and appeared to have had an effect on the compost. The compost moved out of the thermophilic range on day 16 and did not re-enter it until day 20. On day 21, another more severe motor failure prematurely ended the trial despite the temperatures appearing once again to be on the rise.

Figure 6-4 - Trial 4 results.

Despite the untimely end of this final trial, it is evident from the results that the composting was more effective during this run. The C:N ratio dropped from an initial 30 to 21. The reactor spent 12 days within the thermophilic range. There were minimal odours associated with the use of the nitrogen amendments and the use of phosphoric acid was not required to achieve positive results.

It is suspected that the outcome of the trial may have been different had the motor failures not occurred, particularly the first failure. Mixing within the first week of

composting is crucial to maintaining aerobic conditions which assists in the establishment of a healthy microbial population. Perhaps the time spent within the thermophilic range may have been prolonged had the motor failure not occurred.

6.2.5 Metals

Testing for metals at the beginning and end of each of the trials revealed that both the feedstock and finished product for Trials 1, 2 and 4 all tested below the MOE and BNQ compost limits. The BNQ standards delineate product quality using a rating system (Type AA, A and B). Trials 1, 2 and 4 all met the metals criteria for the highest rated compost, Type AA. Samples from trial 3 however had elevated levels of three metals. Detailed results from the metals testing have been included in the appendix.

As shown in Table 6-5, the Trial 3 feedstock and final product samples exceeded the MOE guideline limits for cadmium, chromium and molybdenum. Looking at the Type AA BNQ standards, the only metal criteria exceeded was cadmium. Using the BNQ standards, the samples from Trial 3 would have been classified as a Type B compost.

Table 6-5 - Metal levels exceeding regulatory limits in composting trials

Metal (mg/dry kg)	STMP Avg	MOE	BNQ AA, A	BNQ B	T3 Feed	T3 Final
Cadmium	1	3	3	20	10	10
Chromium	15	50	210	-	52	55
Molybdenum	<1	2	5	20	2	3

a - St. Marys biosolids average calculated in Ch. 3.

The reason for the higher readings from Trial 3 is unclear. The readings are higher than the averages of these metals determined for the fresh biosolids in Chapter 3, Table 3-2. The nitrogen addition in this trial took place after the feedstock samples were taken; therefore the elevated metals were not associated with the use of urea. It is possible that the metals may have been associated with use of phosphoric acid. Phosphoric acid is used as a nutrient additive in St. Marys activated sludge process. The concentrated acid used was taken directly from the line feeding the activated sludge tank. It is possible that metals either were in the acid solution prior to addition or that corrosion observed on the metal interior of the composter and augers caused by contact with the acid may have contributed to the elevated metal levels.

6.2.6 Trial overview

Table 6-6 outlines the initial conditions for each of the four trials.

Table 6-6 - Summary of initial conditions for compost trials.

	Trial 1	Trial 2	Trial 3	Trial 4
Feedstock (Biosolids:Bulking Agent)	3 B : 1 WC	2 B : 1WC : 1S	4B : 2WC : 1S	3B:1WC:1S
Moisture (%)	69	63	60	61*
pH	7.5	8.5	5.3	8.1
C:N	69.6	94	62	30.4
Nutrient additives	None	None	H ₃ PO ₄ , CH ₄ N ₂ O	NH ₄ NO ₃ , poultry manure
Total volume (m ³)	3.2	1.6	2.8	2
Bulk density (kg/L)	0.73	0.59	0.8	0.64

Over the course of the four trials, the performance of the composter improved as indicated by the increase in number of days the compost temperature was within the thermophilic range. From Table 6-7, it is evident that Trial 4 was the most successful based on the temperatures observed and the duration of thermophilic conditions. The use of nitrogen amendments to decrease the feedstock C:N ratio to 30 had a positive effect on performance. The use of sawdust and woodchips as bulking agents proved satisfactory to provide porosity and physical structure, however, an ideal feedstock mixing ratio would be difficult to conclude based on the experience of this study. The biosolids moisture level varies daily among other characteristics such as wood fiber content. The optimum feedstock mix is therefore thought to be a dynamic variable, highly dependent on the operating conditions of the wastewater treatment plant.

Table 6-7 - Composting trial summary

Trial	Duration (d)	Max temp (° C)	Days in thermophilic range	Mix*	C:N		Moisture (%)	
					Initial	Final	Initial	Final
1	10	35	0	3B:1WC	70	65	69	69
2	16	41	2	2B:1WC:1S	109	106	63	58
3	34	43	4	4B:2WC:1S	62	29	60	47
4	21	52	12	3B:1WC:1S	30	21	61	55

* B - biosolids, WC - wood chips, S - sawdust

Table 6-8 compares the characteristics of the final product from each of the trials to MOE guidelines, as well as to other research results. The BNQ standard does not apply a quality rating based on nutrient content.

Table 6-8 - Composting results summary & comparison

Parameter	MOE Guideline	**Comm. Organic Compost	Evanylo & Daniels (2000)	Jackson & Line (1997)	T1	T2	T3	T4
Mineral Content (% dry wgt)								
Total Phosphorus	*0.25	0.48	0.31	0.44	0.29	0.14	2.12	0.41
Total Potassium	*0.2	0.19		0.16	0.19	0.14	0.20	0.24
Total Nitrogen	*0.6	1.00	1.75	1.44	0.64	0.34	1.01	1.35
Calcium	*3	2.30		1.12	4.10	2.66	3.17	2.51
Magnesium	*0.3	0.13		0.05	0.29	0.20	0.14	0.10
SAR	< 5				1.10	1.09	3.20	1.20
pH	5.5 - 8.5	6.4	6.73	5.84	8.27	8.31	7.30	6.75
C:N	22	68	21	23	65	106	29	21

* - typical minimum concentration

** - Velema, 2004

As illustrated in the table, the addition of phosphoric acid in Trial 3 was reflected in the high total phosphorus reading. The potassium, calcium and magnesium levels for the trials hovered around the minimum typical content of good quality compost as reported by the MOE. The potassium levels were similar to the levels achieved by studies conducted by Jackson & Line (1997), but the calcium and magnesium levels were higher in St. Marys compost.

The nitrogen levels of the nutrient amended trials (Trials 3 & 4) were approximately double that of the un-amended trials (Trials 1 & 2). The higher nitrogen levels would be a desirable quality for most end use applications. The pH and SAR readings of the St. Marys compost placed the results from all trials well within the ranges suggested by the MOE.

The C:N ratio of trial 4 (21) was very similar to values achieved by other researchers and the MOE suggested level. Interestingly, the organic commercial compost C:N reading is particularly high in comparison to these other mentioned levels. Trial 3 had a C:N level of 29 which is an improvement over the average raw biosolids level of 65. This lower C:N ratio however was a result of the addition of nitrogen amendments as opposed to

effective composting. A significant level of decomposition of organic matter did not occur based on a comparison of the mass percentage of carbon found in initial feedstock and finished product. Based on their high C:N ratio, the finished products from Trials 1 and 2 would probably exhibit similar results to the raw biosolids if used as growth media on their own. They would most likely exhibit further decomposition, self-heating and nitrogen deficiency. Based on the lower C:N ratio alone, the end products from Trials 3 and 4 should be better suited to use as growth media than the finished material from Trials 1 and 2.

6.3 Summary

Because of time constraints, it was necessary to manipulate a number of operational variables over the four months of the study in order to develop a successful end product. By the fourth trial, the end product was deemed acceptable. The evaluated characteristics of the final product from Trial 4 would place this material as high quality compost according to the BNQ standards, as well as the MOE guidelines. The path to this successful final trial was however not without difficulty. For example, frequent motor failure of the mechanical mixing augers threatened the outcome of more than one trial. Also, the fluctuations in the consistency of the biosolids made it difficult to determine an ideal mixing ratio of biosolids and bulking agent. Consistency in the feedstock quality would ensure a more reliable composting process and final product. It was also concluded that effective composting of the biosolids required the use of nitrogen amendments in order to increase microbial activity. Even with the use of nitrogen amendments, achieving thermophilic temperatures within the composter was a continuous challenge, even throughout the fourth trial.

Based on the current MOE regulations however, and the success of Trial 4, this treatment process could lead to reclassification of the biosolids from a "waste" to a "product" with further development of an effective process. This reclassification would allow unrestricted public use of the material and could lead to an opportunity for the development of a revenue generating by-product stream for St. Marys Paper Ltd.

7 TIME SERIES STUDY

Through in-vessel composting, it was possible to stabilize the biosolids over a short period of time. The end-product from the final trial exhibited characteristics typical of good quality compost as outlined in the Ministry of Environment's Interim Guidelines for the Production and Use of Aerobic Compost in Ontario. The process of composting was not however, without its difficulties. It took a number of trials to achieve reasonable results on an experimental level. With a full scale facility, the operational parameters would be complex and the costs of running an in-vessel system would be high. After observing the biosolids' performance at the land application sites, the question was raised whether a product similar to finished compost could be generated by land applying the material and allowing it to stabilize under natural conditions.

St. Marys Paper Ltd. is situated near a number of abandoned farmland sites and exhausted gravel pits. The mill is also not under any time constraints to generate revenue from the biosolids stream. Therefore, the idea of purchasing and developing a site close to the mill where the material could be land applied to decompose over a number of years is of interest to the paper mill. At such a site, once the material would reach the desired level of stabilization, it could be collected, screened and bagged for commercial sale. As pathogens are not an issue associated with St. Marys material, no disinfection should be required. Additional nutrient amendments could be added once the material was screened, prior to bagging.

In order to investigate the feasibility of this option and assess the impact of land application of biosolids at past receiving sites, the following study was undertaken. The investigation focused on the effect of time on the organic component of the biosolids after land application. The objectives of the study were to:

- Investigate changes in the land applied biosolids over time
- Analyze soil and leachate quality at biosolids receiving sites
- Compare the quality of biosolids at the land applied sites to the results of the compost study and the MOE's description of typical compost

7.1 Methodology

A number of biosolids receiving sites were investigated for this study. All sites were closed landfills which had received St. Marys biosolids as a final cover during their closure periods. The sites are referred to using their site ID which is comprised from the initial letter of the site name and the age of the biosolids at the time of sampling. For example, biosolids from the Sowerby Landfill were applied in 2002 and sampled in 2004; therefore the site ID is S(2) which reflects that the biosolids were 2 years old when sampled. The site names and ID's are listed in Table 7-1.

Table 7-1 - Receiving site names and application dates

Site	Year of application	Site ID
Goulais	1996 , 1997, 1998	G(7), G(6), G(5)
Devil's Lake	2001	D(3)
Sowerby	2002	S(2)
Batchawana	2002, 2003	B(2), B(1)
Iron Bridge	2003	I(1)
Goulais	2004	G(0)

At both the Goulais and Batchawana sites, different sections of the landfills were covered during different years. Samples were taken from these different areas which received biosolids at different points in time. Samples were analysed for metals (As, Cd, Co, Cr, Cu, Fe, Mg, Mn, Ni, Pb, Se, Zn and Hg), cations (B, Ca, K, Na and P), carbon and nitrogen. The carbon to nitrogen ratio was used to assess the state of decomposition of the biosolids. By assuming one of the differentiating variables between the sample areas at each of the sites is time, the C:N data collected reflected how time had affected the biosolids.

Sampling of sites G(7), G(6) and G(5) was completed during the summer of 2003. The remaining sites were sampled in the summer of 2004, including additional sampling at the Goulais site at an area which was covered in the spring of 2004, G(0). In the results section the data collected from G(7), G(6) and G(5) are discussed as one group, and the data from all other sites are presented as another because of the different sampling

dates. Although sampled during the same season in consecutive years, it was thought the effects of weather and plant transpiration might have had an impact on the data, from which it would be difficult to draw conclusions from an in depth analysis between the groups (Kabata-Pendias, 2001).

Soil samples were collected from the sites using a soil auger with auger blades 15 cm in length. Samples were taken down to a depth of 15 cm, the top of the auger blades. The original application of biosolids was approximately 30 to 60 cm, however, consolidation over time would have decreased the thickness of the biosolids layer. By passing the auger through the same bore hole two consecutive times it was possible to bore down consistently to a level of 30 cm; however initial sampling to a depth of 30 cm at the Goulais landfill site disturbed the clay cap layer below the biosolids cover. Sampling locations were randomly selected across the entire area of each site. Twelve samples were taken from G(7), G(6) and G(5) and nine samples were taken for the remainder of the sampling sites. The samples weighed between 200 to 300 grams before drying. They were air dried and vegetative matter, such as plant roots, were removed. The samples were then ground and stored in Ziploc bags prior to chemical analysis.

Pore water samples were collected from G(7), G(6) and G(5) using lysimeters. Each lysimeter consisted of a 50 cm long, 6 cm diameter plastic tube with a porous ceramic tip on the bottom end. The top of the tube was closed with a rubber stopper with sampling port. Three lysimeters were randomly placed across each sampling area down to a depth of 25 cm (Hazlett, 2003). An additional three lysimeters were placed in the surrounding undisturbed land adjacent to the landfill to be used as baseline conditions since no other data of this nature was available. The soil auger was used to bore the hole for each lysimeter. The soil removed from the hole was examined for clay and sand which would have indicated that the auger had bored beyond the biosolids layer. Using the soil removed from the bottom of the hole, a slurry of soil and deionized water was made and placed in the bottom of the hole to provide good surface contact between the soil and the ceramic lysimeter's tip (Hazlett, 2003). The lysimeter was then firmly placed in the hole. The space between the sides of the bore hole and the lysimeter were loosely packed with the remaining soil initially removed from the bore hole to prevent surface water infiltration down the sides of the lysimeter (Hazlett, 2003). Once properly placed in the ground, a negative pressure was created within the lysimeter tube by using a hand

pump to draw air out through the sampling port. The lysimeters were then left to collect water for six weeks before samples were collected (Hazlett, 2003). The samples were collected in 250 mL plastic bottles. Within 2 hours of sampling, they were filtered, the pH was measured, and then they were preserved using 2 mL of concentrated nitric acid.

Soil samples were analyzed for carbon to nitrogen ratio at the University of Ottawa's G.G. Hatch Isotope Laboratory using the method previously discussed Chapter 6, Section 6.1. Pore water and soil samples taken from G(7), G(6) and G(5) were analyzed for metals (Cd, Co, Cu, Fe, Mg, Mn, Ni, Pb and Zn), cations (Ca, K, Na and P) at the Carleton University's analytical chemistry laboratory with the assistance of Dr. De Silva, according to the method presented in Section 5.1. Due to a change in the location of Carleton University's ICP equipment and facility, and associated time constraints for this project, an alternate venue was required for soil sample metal and cation analysis. Hence, all of the 2004 soil samples were analyzed by Envirotech Laboratories Inc. in Thunder Bay, Ontario.

Once the chemical analyses were completed, the compiled data from the soil analysis were compared to the CCME Environmental Quality Guidelines for Agricultural Soils, as well as the compost guidelines outlined in the MOE Interim Guidelines for the Production and Use of Aerobic Compost in Ontario.

For the data analysis of heavy metal concentrations, unless all samples taken from a specific site were found to have concentrations of the metal below the detection limit (DL), a value of $0.5 \times \text{DL}$ was assigned to the below DL data points so that average and other statistical operations could be performed on the data sets. The raw data collected during this study can be found in the appendix.

For the data on the pore water and soil samples collected from G(7), G(6) and G(5), single factor ANOVAs were used to determine whether there was a significant difference between the different locations sampled at the site. The same technique was used to assess differences in C:N ratio between areas sampled at the Batchawana Landfill site (B(1) and B(2)) and between B(1) and B(2) and other sites which received biosolids at the same time. Results from statistical analysis are presented in the appendix. ANOVA was not used to compare different sites receiving biosolids at different times. It was

thought that conclusions regarding the aging effect of time on the biosolids could not be drawn solely from differences found between these data sets because application date was only one of the parameters differentiating the data sets.

7.2 Results and discussion

7.2.1 Pore water analysis at Goulais Landfill in 2003

Metals and cations

There were a number of metals found in the biosolids material from St. Marys Paper which were not detected in any of the pore water samples collected from biosolids receiving area or the baseline samples. These include arsenic, boron, cadmium, cobalt, chromium, manganese, molybdenum, nickel, lead and selenium.

Metals and cations which were detected using ICP included calcium, copper, iron, potassium, magnesium, phosphorous, sodium and zinc. Using single factor ANOVA, it was determined that there was no significant difference ($p > 0.05$) between the levels of the metals listed above in the samples collected from different areas of the site (i.e. G(7), G(6) and G(5)) which represented different years of biosolids application.

It was also determined that there was no significant difference between the levels of copper, iron, potassium and zinc in the samples collected from the undisturbed areas and those collected from the landfill site which had received the biosolids as a group. There was a significant difference between the calcium, potassium, sodium and phosphorous levels for these two sample groups. The average levels of these elements for the two groups are displayed in Table 7-2.

Table 7-2 - Pore water cation concentration

	Goulais Landfill	Baseline
	mg/L	
Calcium	29.4	1.4
Magnesium	4.9	0.4
Sodium	3.1	4.2
Phosphorous	1.6	0.1
SAR	0.2	1.13

The sodium absorption ratio (SAR) was calculated using the average sodium, calcium and magnesium concentrations. The SAR for both sample groups was low (< 9) which presents no sodium hazard to vegetation (Bauder et al., 2003). The presence of calcium, magnesium and phosphorous in the biosolids pore water samples at levels higher than the baseline readings could be considered advantageous for vegetation as these elements are all plant nutrients.

pH

The pH range of the pore water samples was found to be between 5.4 and 6.6. The average pH of the entire group of samples collected from the landfill site was 6.2. Using single factor ANOVA, it was determined that there was no significant difference between the pH of the samples collected from G(7), G(6) and G(5) ($F = 1.6$, $p = 0.3$). The pH of the baseline samples from the undisturbed land surrounding the landfill were more acidic than the land receiving biosolids. The average for the baseline group was 4.8 and covered a range of 4.5 to 5.3. The results of ANOVA between the pH of the samples from the area receiving biosolids and the baseline samples indicated that the difference between the data sets was significant ($F=27.4$, $p=0.0004$).

7.2.2 Soil analysis at Goulais Landfill in 2003

Carbon to nitrogen ratio

The carbon to nitrogen ratio of the soil samples taken from G(7), G(6), G(5) and the baseline samples did not vary significantly from one area to another ($F=0.258$, $p= 0.85$). The average C:N ratio for each of the areas including the baseline samples are presented in Figure 7-1.

Figure 7-1 - Average C:N ratios - Goulais Landfill, 2003.

The lack of significant difference between sites could imply that after five years, the biosolids material at the site has reached a level of stability with regards to decomposition of the organic matter. The average C:N ratio from each of the areas were similar to that typically associated with good quality aerobic compost (C:N = 22) as published by the MOE.

Metals and other cations

Molybdenum, cadmium and lead were not detected in any of the soil samples from G(7), G(6), G(5) or the baseline samples at detection limits of 0.5, 0.002 and 0.6 mg/dry kg, respectively. Table 7-3 outlines the average concentration of metals in found in soil samples taken from G(7), G(6), G(5) and the baseline samples from the undisturbed areas.

Table 7-3 - Comparison of metal levels in soil from Goulais Landfill, 2003

Parameter (mg/ dry kg)	*MOE Compost Guidelines	**CCME Agr.	G(7)	G(6)	G(5)	Baseline
Arsenic	10	12			1.1	
Chromium	50	64			15.8	
Cobalt	25	40	7.0	5.0	3.2	7.3
Copper	60	63	31.2	26.0	26.1	7.0
Mercury	0.15	6.6			0.1	
Nickel	60	50	45.0	43.2	9.3	22.5
Selenium	2	1			0.4	
Zinc	500	200	142.7	156.4	104.6	44.8

* -Taken from MOE Interim Guidelines for the Production and Use of Aerobic Compost in Ontario.

** - CCME Environmental Quality Guidelines for Agricultural Soils.

The average concentrations of all metals were below the limits established in both the MOE Interim Guidelines for the Production and Use of Aerobic Compost in Ontario and the CCME Environmental Quality Guidelines for Agricultural Soils. Concentrations of copper and zinc were higher in each of the three areas receiving biosolids compared to the levels in the baseline soil samples. The results from single factor ANOVAs suggested that there was a significant difference ($p < 0.05$) between the cobalt and nickel levels across the three areas. When the baseline was compared to G(7), G(6) and G(5) as a group, there was no significant difference between the two data sets for levels of copper ($F=1.17$, $p=0.3$) or nickel ($F=0.44$, $p=0.5$). Both of these metals decrease in concentration with decrease in age of the biosolids. Variation between the G(7), G(6) and G(5) groups could originate from variation in characteristics of the fresh biosolids initially applied to the areas, or be related to the age of the biosolids. Weathering, plant uptake, seasonal vegetation decomposition could, over time, have an impact on the quality of the biosolids.

The nutrient levels of the soil samples from Goulais Landfill were compared to characteristics typical of good quality aerobic compost as published by the MOE and the results from the fourth trial of the composting study presented in Section 7.2.6. The results of this comparison are shown in Table 7-4.

Table 7-4 - Comparison of nutrient levels in soils from Goulais Landfill, 2003.

Parameter	**MOE Compost Guideline	Compost trial 4	G(7)	G(6)	G(5)	Baseline
Mineral Content (% dry wgt)						
Total P	0.25*	0.41	0.015	0.016	0.014	0.002
Total K	0.2*	0.24	0.016	0.016	0.009	0.012
Total N	0.6*	1.35	0.64	0.89	0.87	0.09
Mg	0.3*	0.10	0.06	0.04	0.04	0.03
SAR	< 5	1.20			0.15	
pH	5.5 - 8.5	6.75			7	
C:N	22	21	24	23	24	23

* - Typical minimum

** -Taken from MOE Interim Guidelines for the Production and Use of Aerobic Compost in Ontario.

Although the average C:N ratio and total nitrogen levels for G(7), G(6) and G(5) are similar to the compost guidelines and the Trial 4 compost, the biosolids samples had lower concentrations of magnesium, potassium and phosphorous. Low levels of these elements are typical for pulp and paper mill biosolids (WESA, 2002). Average concentrations of these nutrients were slightly above those found in the baseline soil samples, with the exception of potassium, where the average potassium concentration found for the G(5) group of 0.009 mg/ dry kg was below the baseline average of 0.012 mg/dry kg.

The single factor ANOVAs detected significant difference across G(7), G(6) and G(5) for potassium only. It is unlikely that this difference is due to the different age of the biosolids in the different areas because the average concentrations of potassium for area G(7) and G(6) were found to be the same at 0.016 mg/ dry kg. The average potassium level of 0.009 mg/ dry kg for the G(5) area is considerably lower than the other two areas receiving biosolids. It is more likely that this difference is due to a variance in the biosolids that were initially applied to this area. A qualitative visual inspection of the vegetation did not reveal any difference in plant species distribution or thickness of vegetative cover which would have suggested that the difference was caused by a variance in plant utilization of this nutrient. The vegetation cover in the areas of G(7), G(6) and G(5) was thick and over 1.5 meters in height.

7.2.3 Soil analysis of other biosolids covered landfill sites

Carbon to nitrogen ratio

The average carbon to nitrogen ratios of the soil samples from each of the sites investigated in 2004 are illustrated in Figure 7-2.

Figure 7-2 - Average C:N ratio for sites sampled in 2004.

The data illustrates that, with time, there appeared to be a decrease in the C:N ratio of the applied biosolids material. Areas B(1) and B(2) received biosolids one year apart and had average C:N ratios of 66 and 53, respectively. ANOVA done between the C:N ratio at B(1) and B(2) showed there was a significant difference between these two sites ($F=7.6$, $p=0.01$). The percent difference between the average C:N ratio for site G(0) and D(3) is 46% and the difference in the age of the biosolids was 3 years. Despite this significant decrease, after three years, the biosolids at D(3) had an average C:N ratio of 34 which is higher than the MOE's suggested typical value for good quality compost of 22. These results coupled with the results presented in Section 7.2.2 suggest that over a number of years, natural decomposition *in-situ* could be an effective application to lower the carbon to nitrogen ratio of the biosolids and yield a stable organic material.

In addition to time, the differences in C:N ratio from site to site were likely caused by other variations including initial characteristics of applied biosolids, receiving site conditions and species variation in vegetative cover. For example, using single variable ANOVAs, there was a difference found between the average C:N ratio of soils sampled from site I(1) and B(1) ($F=27.9$, $p=7.4E-5$) as well as between S(2) and B(2) ($F=26.9$, $p=8.99E-5$). Both of these two groups received biosolids during the same year, yet their average C:N ratios are different.

Metals and other cations

The results of the heavy metal concentration analyses of the soil samples collected from land application sites in 2004 are outlined in Table 7-5. The year above the site ID in the table reflects the year the biosolids were applied to the area.

Table 7-5 - Metals levels in soil samples from land application sites.

Parameter (mg/ dry kg)	*MOE Compost Guidelines	**CCME Agr.	2004 G(0)	2003 B(1)	2003 I(1)	2002 B(2)	2002 S(2)	2001 D(3)
Arsenic	10	12	1.00	1.54	1.51	3.25	2.22	2.06
Cadmium	3	1.4	1.81	1.73	1.28	1.32	0.91	0.82
Chromium	50	64	10.23	10.49	10.48	15.30	9.29	23.71
Cobalt	25	40	1.81	1.67	1.97	2.71	1.62	2.70
Copper	60	63	21.07	21.01	23.08	24.52	21.14	24.09
Lead	150	70	7.65	9.69	10.08	13.66	8.88	12.71
Mercury	0.15	6.6	0.02	0.03	0.08	0.04	0.05	0.04
Molybdenum	2	5	0.81	0.77	0.88	0.88	0.75	1.51
Nickel	60	50	6.08	5.60	6.48	8.70	6.00	11.12
Selenium	2	1	0.31	0.27	0.29	0.23	0.30	0.44
Zinc	500	200	205.33	176.11	145.11	152.56	94.89	91.89

* -Taken from MOE Interim Guidelines for the Production and Use of Aerobic Compost in Ontario.

** - CCME Environmental Quality Guidelines for Agricultural Soils.

The average heavy metal levels from all sites investigated were below the Ontario regulatory limits for aerobic compost. With the exception of cadmium and zinc, all heavy metal concentrations were also below the agricultural soil quality guidelines published by the CCME. At sites G(0) and B(1), the cadmium concentrations were 1.81 and 1.73 mg/dry kg, respectively. These levels slightly exceeded the CCME agricultural cadmium guideline of 1.4 mg/dry kg. At G(0) the average concentration of zinc was 205 mg/ dry kg which just exceeded the CCME agricultural soil guideline of 200 mg/ dry kg. Both of these metals appeared to decrease in concentration over time at the land application

sites. As with the C:N ratio, other factors such as site vegetation variation could have caused the differences in concentration from site to site. Cadmium however has a high bioavailability compared to other heavy metals. It is possible that the cadmium in the biosolids was removed with time through plant uptake. Zinc is readily soluble compared to the other heavy metals and is a plant micronutrient which can be removed from the soil through vegetative biomass production (Kabata-Pendias, 2001). Though zinc can accumulate within the surface soil over time, research has shown that the addition of biosolids to land increases the easily soluble and exchangeable forms of zinc (Kabata-Pendias, 2001). This may explain the decreases in concentrations that were found across the sites as the age of the biosolids increased.

Table 7-6 compares the characteristics of the land applied biosolids to those of Trial 4 compost presented in Chapter 6, Section 6.2.6 and the MOE guidelines.

Table 7-6 - Comparison of characteristics of land applied biosolids and compost.

Parameter	**MOE Compost Guideline	2004 G(0)	2003 B(1)	2003 I(1)	2002 B(2)	2002 S(2)	2001 D(3)	Compost trial 4
SAR	< 5	0.90	0.82	0.20	0.89	0.17	0.66	1.20
pH	5.5 – 8.5	7.9	7.6	7.5	7.7	7.3	7.5	6.75
C:N	22	63.37	58.71	39.36	49.60	35.71	34.24	21
Nutrient Content (% dry wgt)								
Total P	0.25*	0.18	0.15	0.16	0.14	0.13	0.13	0.41
Total K	0.2*	0.18	0.16	0.15	0.13	0.12	0.14	0.24
Total N	0.6*	0.56	0.62	0.68	0.67	0.86	0.73	1.35
Mg	0.3*	0.58	0.40	0.26	0.40	0.38	0.61	0.10
Ca	3*	4.65	3.71	2.75	2.71	2.67	3.78	2.51

* - typical minimum content

** - Taken from MOE Interim Guidelines for the Production and Use of Aerobic Compost in Ontario.

The average SAR and pH for each of the different sites were within the ranges specified by the MOE. The average C:N ratios for all of the sites were higher than both the MOE guidelines and the Trial 4 compost. This may suggest that the biosolids at these land application sites were still undergoing decomposition. Despite the higher C:N ratio, a thick vegetative cover was present over the entire area at site D(3). At sites I(1) and S(2), vegetation was patchy but exhibited signs of thick, healthy growth. The vegetation at sites G(0), B(1) and B(2) was still limited to sporadic small outcrops of grasses less than 5 cm in height. Areas B(1) and B(2) were graded in the early spring of 2004 which is thought to have caused the lack of established vegetation. These qualitative field

observations suggest that despite high C:N ratios, biosolids can support healthy plant growth, as little as one year after application.

The calcium and magnesium levels of the land applied biosolids were higher than those of the Trial 4 compost. With the exception of I(1), the magnesium levels were above the MOE's typical minimum levels. For calcium, sites G(0), B(1) and D(3) each had average concentrations above the MOE typical minimum of 3% dry weight.

The potassium and phosphorous levels of the land applied biosolids were below the MOE's typical minimum content and the Trial 4 compost levels. The nitrogen levels were above the MOE's typical minimum content with the exception of the G(0). The material at G(0) was applied only 3 months before sampling. Hence, this material was probably still largely composed of organic matter in the form of cellulose from the pulp and paper process and was undergoing further decomposition. As the organic material is decomposed, the organic carbon will be degraded to carbon dioxide and the percentage of nitrogen as a fraction of dry weight will increase (Brady & Weil, 1999). It is important to note, however, that the nitrogen content of soils and biosolids is dependent on other factors besides the age of the biosolids such as the presence of vegetation on the land application sites. Growing plants remove nitrogen from the soil solution as soon as it is released (Brady & Weil, 1999). The rate of this removal from soil is dependent on plant species.

7.3 Summary

Pore water sampling and analysis at the Goulais Landfill site indicated that heavy metals were either not detected or not significantly different from levels found in the baseline pore water samples collected from adjacent undisturbed areas. The water samples from the landfill had higher levels of the plant nutrients calcium, phosphorous and magnesium than those of the baseline samples. The results indicated that there were no negative effects on soil pore water quality based on the parameters tested.

Soil analysis conducted at Goulais in 2003 indicated that the levels of heavy metals in land applied biosolids were below environmental quality levels set by the CCME. The three areas sampled reflected biosolids applications in 1996, 1997 and 1998. There was

no significant difference found between the metal concentrations of the samples from the three areas with the exception of cobalt and nickel. The levels of these two metals decreased as the age of the biosolids decreased. There was no significant difference in the C:N ratio of the biosolids material collected from the three areas which would indicate that decomposition after five years has slowed and that the material has reached a level of stability. The average C:N ratio for each group was below 25 and comparable to typical compost C:N levels. The biosolids analyzed were low in the nutrients phosphorous, magnesium and potassium.

The soil sampling and analyses performed from other sites in 2004 indicated that the carbon to nitrogen ratio tended to decrease with the age of the applied material. The sites investigated had received biosolids at different times between 2001 and 2004. The heavy metal concentrations of the sampled material were below the regulatory limits for aerobic compost set by the MOE. Nutrient content was comparable to that of compost for calcium and magnesium, but slightly deficient for phosphorous and potassium.

The examination of the soil pore water from the Goulais Landfill and biosolids from a number of different sites indicated that the potential impact of heavy metals from the land application of the biosolids materials in various receiving environments is low. The comparison of the carbon to nitrogen ratio of biosolids of different ages illustrated that natural decomposition processes *in-situ* could effectively reduce the carbon to nitrogen ratio of the biosolids to a level indicative of a stable organic material. Levels of certain plant nutrients such as phosphorous and potassium appeared to be low in the biosolids material when compared to typical compost levels. Vegetation covers at sites with biosolids over two years in age appeared very thick and lush.

From these results, it would appear that land application and a stabilization period of three to five years should be sufficient to stabilize the biosolids to level at which they are well suited for use as an organic additive. Nutrient supplementation of potassium and phosphorous may be required to improve quality characteristics.

8 LEACHATE STUDY

One of the limitations to land application and re-use of pulp and paper mill biosolids is the fear of water contamination from nitrates and phosphates. After examining the results from the lysimeters study, a small scale leachate study was set up in order to assess the leachate from the fresh biosolids. This study was completed during the summer of 2004, the field season following the tomato plant study due to initial time constraints during the summer of 2003. The main objective of this study was to determine whether nitrate and/or phosphate leaching is an issue associated with St. Marys biosolids.

8.1 Methodology

False bottom pails identical to those used in the tomato plant study were filled with St. Marys biosolids (Group A) and a 50/50 mix by volume of St. Marys biosolids and wood yard waste (Group B) on July 21st, 2004. Group B was included in the study because this mix of material represents what is currently being land applied at reclamation sites by St. Marys Paper. The total volume of material in each pail was approximately 30 liters, which represented a depth of approximately 30 cm of material.

Three pails of each material mixture were set up for the experiment, as well as one additional pail used as a control for the purpose of comparison. The control consisted of an empty false bottom pail which collected natural precipitation. The pails were left in an open, unshaded area from mid-July to mid-September 2004. Every two weeks, duplicate samples were collected in clear plastic bottles from each pail. Five samples were collected from each pail over the course of the study.

The samples were analyzed for pH, nitrate, ammonia and phosphate immediately after collection. The nitrate, ammonia and phosphate were determined by colorimetry using a Palintest standard photometer. Reagents used during testing were Palintest PM163, PM152 and PM177 for nitrate, ammonia and phosphate, respectively. This is the method used for the determination of these analytes by the Ontario Ministry of the Environment Laboratory Services Branch. When necessary, samples were filtered prior to analysis.

Of the three analytes, only nitrate is regulated in drinking water, therefore nitrate levels in the samples were compared to Ontario drinking water guideline. Ammonia (NH_3) is commonly found in municipal and industrial wastewater effluent. It was examined because of its potential to oxidize to nitrate and its negative effect on aquatic ecosystem health, particularly its impact on fish. Phosphate (PO_4^{3-}) is the form of phosphorus readily available to plants. It is not regulated in drinking water or leachate, and is not normally associated with human health concerns. It is relevant, however, to eutrophication in lakes and rivers and, hence was also examined in the leachate

8.2 Results and discussion

The data collected during this study and are discussed in the following sections, and have been included in the appendix.

8.2.1 pH

As can be seen in Table 8-1, the average pH of the samples taken from groups A and B were 7.74 and 7.66, respectively. The variance of the pH in the both groups was small. The biosolids had a slight neutralizing effect on the mildly acidic rain water passing through the pails. The control, which consisted of collected rain water, had an average pH of 6.2. The pH of natural water is generally within the range of 6.5 to 8 ([http://www.cees.iupui.edu/Education/Workshops/Project Seam/water quality.htm](http://www.cees.iupui.edu/Education/Workshops/Project%20Seam/water%20quality.htm)). All of the pH readings for both groups fell within this range. Based on these results, there should be no environmental impacts related to the pH of the leachate.

Table 8-1 - Average leachate pH

	St. Marys biosolids	St. Marys biosolids & wood waste	
	Group A	Group B	Control or Base
Average	7.74	7.66	6.2
Range	7.19 - 8.04	7.43 - 8.01	4.52 - 7.5
Std. Dev.	0.23	0.18	1.3

8.2.2 Ammonia

The average ammonia levels for the collected leachate samples are shown in Figure 8-1. The water sample from the control collected on Sept. 8th had an ammonia level measured above 2.4 mg/L which does not appear in the figure because it was outside the y axis scale chosen to illustrate the differences in the data. For all dates, with the exception of the first sampling date, the control exhibited higher ammonia levels than the leachate collected from either group A or B. The variance in concentrations for Group A on Jul. 21st and 24th was high. Group B showed high variance on Jul. 24th and Sep. 8th. This variance could be caused by non-homogeneity in the biosolids material and wood waste mixture. From the nature of the wood waste, it would be expected that there would be a higher variance, in general, for all analytes tested for Group B. In the case of ammonia, however, looking only at standard deviation, groups A and B displayed almost the same magnitude in variance.

Figure 8-1 - Average leachate ammonia levels

According to the U.S. Geological Survey, in most natural surface waters, ammonia concentrations greater than 2 mg/L exceed the chronic exposure criteria for fish. Using this criterion, the ammonia levels in the leachate should, generally, not pose any issues for aquatic ecosystem health.

8.2.3 Nitrate

Figure 8-2 illustrates the average nitrate concentrations of Groups A and B, as well as the control. Group B consistently had higher nitrate levels than Group A and the control. The variability in Group B was also considerably larger than in the control and Group A.

Figure 8-2 - Average leachate nitrate concentration.

Both the U.S. EPA and Ontario have set their drinking water standard for nitrate at 45 mg/L. Regardless of the variance in the data collected, all of the samples collected were well below the regulatory drinking water limits for nitrates. This investigation's results are in line with conclusions made by Bockheim et al. (1988) during their field study which focused on nitrate leachate from a pine plantation amended with pulp and paper biosolids. The nitrate leaching is not expected to be a water quality issue associated with the use of St. Marys biosolids.

It is important to note however, that as the organic matter decomposes in the biosolids, ammonia will be produced which will be further oxidized by bacteria to nitrate. Another point worth mentioning is that in a natural setting, plant uptake of nitrogen in the form of nitrate can have a significant impact on the soil solution nitrate concentration. This study examined nitrate leaching in fresh biosolids under isolated conditions over a short span of time with respect to the decomposition of the organic matter within the biosolids. The

work done by Bockheim et al. (1988) does indicate that the level of nitrate leaching may change over time as the material decomposes. In that particular study, the biosolids were applied in August of 1984. Peaks in levels of ammonia and nitrate were not observed until the following summer. Due to the time constraints of this project, it was not possible to examine the effects of vegetative cover and biosolids decomposition on long-term nitrate leaching. This may be a topic of interest for future research.

8.2.4 Phosphate

The phosphate levels found in the leachate are shown in Figure 8-3. Group A exceeded Group B and the control on all occasions but one. For the August 8th set of samples, the average of the three Group B samples was higher than that of Group A. The variability in the results from the samples was quite significant for Group A on August 17th.

The phosphate was expressed as the concentration of phosphate (PO_4^{3-}) as phosphorous for the purpose of comparing the values to the U.S. EPA's guidelines for phosphate levels in streams. According to the United States Geological Survey, the U.S. EPA has suggested that:

- phosphate should not exceed 0.05 mg/L (as total P) in a stream at a point where it enters a lake or reservoir.
- phosphate should not exceed 0.1 mg/L in streams that do not discharge directly into lakes or reservoirs.

Total phosphate concentrations of non-polluted waters are usually less than 0.1 mg/ L as total P according to the Purdue University website (http://www.cees.iupui.edu/Education/Workshops/Project_Seam/water_quality.htm). The average value of the both Groups A and B exceed the EPA's stream guidelines. The control also exceeded the EPA limits on three of the five sampling dates. The levels of phosphate found in the leachate, however, were higher than natural occurring levels in oligotrophic waters (< 0.01 mg/L total P).

Leachate phosphate concentration

Figure 8-3 - Average leachate phosphate concentration.

Based on the results of this study, it is not possible to assess the risk of eutrophication of water bodies close to areas using biosolids. The extent of the risk associated with the phosphate and re-use of the material on land would depend on many factors including proximity of surface and groundwater sources, quality of those water bodies (e.g. BOD), amount of biosolids applied and amount of surface run-off. The results at this point only conclude that phosphate leaching should be identified as a relevant issue to monitor in the development of sustainable re-use strategies and perhaps investigated more closely in further research.

It is interesting to note the amount of phosphorous that was present in the biosolids indicated that the levels would be appropriate for plant growth, if not slightly below ideal levels. The total phosphorous of fresh St. Marys biosolids were found in Chapter 3 to be on average 0.17 % which is lower than the published values for compost, cow manure, Domtar's biosolids, and the MOE recommended value or good compost. Although total phosphorous includes contributions of forms other than phosphate, it would not be surprising if these other materials were associated with elevated leachate levels of phosphate as well.

8.3 Summary

From the results of this study, it could be concluded that the levels of ammonia and nitrate in the leachate from St. Marys biosolids and St. Marys biosolids and wood waste mixture are well below regulatory guidelines and limits. The risk of groundwater and/or surface water contamination from ammonia and nitrate leaching is low. The presence of phosphate in the leachate at levels above those found in natural waters would suggest that phosphate leaching should be considered in re-use strategy planning in order to minimize ecosystem impacts related to eutrophication.

9 CONCLUSIONS AND RECOMMENDATIONS

9.1 *Conclusions*

A review of historical data collected over the past five years indicated that the characteristics of the St. Mary's Paper biosolids were variable. Seasonal variation, fluctuations in pulp feedstock and wastewater treatment system modifications all contributed to this variance. Despite the variance in the nature of the biosolids, the research completed suggests that its constituents should not pose any significant issues for further development of the waste stream into a marketable product in the form of a soil amendment or topsoil alternative. The biosolids material from St. Marys Paper Ltd. was found to have low levels of heavy metals and toxic organic compounds, neutral pH and high levels of organic matter. The average C:N ratio of the material was found to be 65, which suggested that the material would require further stabilization prior to effective use as a growth medium or organic additive. This was confirmed by the results of the tomato plant growth study. Growth results suggested that nutrients, particularly nitrogen, were not initially readily available for vegetation within the biosolids matrix. Another contributing factor to the poor growth and nutrient deficiency of the tomatoes was the physical structure of the fresh biosolids upon drying. The surface became hard and tightly aggregated making it difficult for root penetration and provided poor soil water retention in comparison to commercial potting soil. Poor root growth would result in the lack of nutrient and water absorption for the plants.

The Jack Pine study suggested that fresh biosolids material was better suited as an organic amendment, as opposed to an alternative to potting soil. An increase in dry mass was observed when the 50-50 mix was used). The height of the plants grown in the 50% biosolids and 50% commercial potting soil were not significantly different from the height of plants grown in the control media, commercial potting soil. These results warrant further investigation and could lead to a unique prospect to reuse the biosolids as an organic additive within the pulp and paper industry.

Another beneficial re-use option which could be exercised by St. Marys Paper is in-vessel composting. Results from the composting experiment illustrated that it is possible

to produce high quality compost from the biosolids waste stream. In order to do so, operational parameters must be closely monitored and adjusted in order to establish an ideal composting environment. The dynamic nature of the feedstock requires a dynamic process. Nitrogen additions were required to achieve and maintain thermophilic temperatures during the fourth trial. Based on the current provincial regulations and the results from the final composting trial, this treatment process could lead to a regulatory reclassification of the biosolids from "waste" to a "product". This reclassification would allow unrestricted public use of the material and could lead to an opportunity for the development of a revenue-generating by-product stream for St. Mary's Paper Ltd.

A review of landfills previously covered with land applied biosolids revealed that, like composting, natural decomposition *in-situ* also lowered the carbon to nitrogen ratio of the biosolids and resulted in a more stable organic medium. This *in-situ* process appeared to take between three to five years. The C:N ratio of the biosolids sampled at a site covered with material varying from 5 to 7 years showed no significant difference between areas which had received material during different years or between areas receiving biosolids and the undisturbed land surrounding the landfill. This suggested that after five years, the C:N ratio of the land applied biosolids was no longer changing. The average C:N ratio over the entire site was 25 and was comparable to typical compost C:N levels. Biosolids sampled from more recently covered sites indicated that three years after application, the average C:N ratio was 34. Vegetation on the site was thriving and indicated that the biosolids were performing well as organic growth media. Based on the review of land application sites it would be possible in theory with time to stabilize the biosolids to levels similar to that achieved via composting through prolonged exposure to natural conditions. A large amount of land would be required to put such a process into practice as a method of generating a stable organic medium which could be harvested for resale.

Nutrient analysis of the biosolids from all land application sites investigated showed that the phosphorous and potassium levels were lower than that of organic additives such as compost. Metal analyses of soil samples from the land application sites confirmed that the levels of regulated heavy metals in the biosolids were below the regulatory limits for aerobic compost set by the MOE. The risk of negative environmental impact due to

heavy metal soil contamination associated with St. Marys biosolids land application would be negligible.

Pore water sampling and analysis at one land application site indicated that heavy metals were either not detected or not significantly different from levels found in the baseline pore water samples collected from adjacent undisturbed areas. As was found with the soil samples, the risk of negative environmental impact due to heavy metal contamination of water sources would also be negligible.

Further investigation into the biosolid's impact on water quality revealed that risks associated with ammonia and nitrate leaching from fresh St. Mary's biosolids were also very low. The levels of phosphate in the leachate from fresh biosolids were found to be at levels above those found in natural waters and could indicate that the material has a potential to generate leachate with elevated phosphate concentration. In contrast to this finding, elevated levels of total phosphorous were not found in the pore water samples collected from the land application sites.

St. Marys biosolids material represents a waste stream which is low in hazardous materials making it a good candidate for development into a valuable secondary resource. The biosolids show potential for re-use as an organic amendment to soil and also as a feedstock for in-vessel composting. Land applied biosolids exhibited good potential for use as an alternative organic growth media after decomposition under natural conditions. This finding could also be used to develop an avenue for re-use.

9.2 Recommendations

The following are recommendations and suggested future initiatives for research arising from this study:

- The metals analysis done at Carleton University on soil samples required acid digestion of ground samples. During further research, other options for extracting the metals from the soils should be investigated such as microwave digestion. The acid digestion method required many steps involving transferring samples

which introduced greater experimental error with each transfer. This method also took a considerable amount of time to complete (up to a week).

- The carbon to nitrogen ratio was used in this study to assess the stability of the biosolids material. In future work, oxygen uptake rate analysis could validate conclusions drawn from C:N ratio testing.
- Based on the appearance of mushrooms growing in the biosolids during the tomato plant studies, the development of the fresh biosolids as a growth media for mushrooms should be investigated.
- Further research into the use of the St. Marys material as an organic additive for seedling growth should be done in order to validate the results of this project. A study done during the growth season, with a variety of tree species and fertilizer treatments may reveal greater differences in the performance of the testing media and biosolids mixtures.
- A growth study comparing the performance of composted St. Marys biosolids to other materials such as previously land applied St. Marys biosolids and commercial compost may assist in determining which re-use strategy will generate a more effective product.
- Based on the thriving vegetation at land application sites, an investigation into the feasibility of using previously biosolids covered sites as areas to grow sod may prove to uncover a new re-use opportunity.
- Consecutive yearly testing from the same land application sites could provide greater insight to the changes in the biosolids quality over time. Results from a study of this nature would be useful in the development of a site used to naturally stabilize the biosolids material to create an organic growth medium.
- Soil testing done at the land application sites sampled illustrated the decomposition of the biosolids from the surface down to 15 cm. An examination of the relationship between decomposition and depth should be conducted.
- Phosphate leaching should be considered in re-use strategy planning in order to minimize ecosystem impacts related to eutrophication.
- It may be beneficial to record the composition of the fibre source to the mill in order to assist in the development of a consistent end product from the biosolids stream. For example, if composting is utilized as a re-use strategy, the initial compost feedstock composition may be altered depending on the characteristics of the wood moving through the mill and the nature of the biosolids the produced.

- Further research is required into the effects of wood extractives such as phenol and p-cresol on vegetation at land application sites.
- The fate and degradation rate of wood extractives at land application sites would be useful for the pulp and paper industry as well as St. Marys Paper. The available research on this subject is limited.
- Before any of the re-use alternatives suggested in this study are adopted, a cost-benefit analysis should be undertaken to determine which strategy would present the greatest cost benefit.

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Appendix A

Experimental data

Ch. 3. Nutrient analysis data

Lab ID	L124056	L172399	L172409	L59635	L98459	L18961	L80963	Average	Range	DL	S
Parameter	Aug-03	May-04	May-04	Mar-02	Feb-03	Dec-00	Oct-02				
C:N Ratio %		61.3	68.7		63.8			64.6	61.3-68.7		3.7643
Inorganic Carbon %	0.64	1.17	0.99	0.15	0.34		0.29	0.60	0.15-1.17	0.01	0.411
Total Organic Carbon %	26	36	34	29.2	32.7		56.9	35.8	26-36	0.1	10.933
Total Carbon by Combustion %	26.6	37.1	35		33		57.2	37.8	26.6-57.2	0.1	11.545
Total Kjeldahl Nitrogen %	0.71	0.59	0.49		0.51		0.67	0.59	0.49-0.71	0.02	0.0963
Total Nitrogen %	0.63	0.58	0.59	0.55	0.51		0.82	0.61	0.51-0.82	0.01	0.1089
Chloride (Cl) mg/L	11	36	37	7	15		8	19	7-37	0.1-3	13.842
Nitrate+Nitrite-N mg/L	<0.2	0.7	0.9	0.4	0.3		0.2	0.5	<0.2-0.9	0.2	0.2915
SO4 and Cation in sat soil											
Calcium (Ca) mg/L	168	131	112	111	113		58.4	105.1	58.4-168	0.5-2	35.484
Potassium (K) mg/L	62	75	90	28	46		24	52.6	24-90	0-1	26.233
Magnesium (Mg) mg/L	77	146	137	29	32		16	72.0	16-146	0-2	57.108
Sodium (Na) mg/L	35	79	64	25	32		17	43.4	17-79	0-3	24.15
Sulphate (SO4) mg/L	49.6	85.5	133	53	61.9		30.4	72.8	30.4-133	0.2-6	36.169
Available Ammonium-N	44.7	42.3	56.1	40.2	31.8		1.9	34.5	1.9-56.1	0.2-0.5	18.533
Boron (B), Hot Water Ext.	6.6	9.6	6.3	7.4	11.3		0.4	7.0	0.4-11.3	0.1	3.7308
Available cations											
Sodium (Na)	460	1810	1800	440	410		490	990	370-1810	10	700.21
Potassium (K)	390	590	560	290	370	980	450	540	290-980	10	229.23
Calcium (Ca)	7830	22000	26400	4790	6390		9860	13888	4790-26400	20	9035
Magnesium (Mg)	710	1630	1460	360	480	1140	530	933.3333	360-1630	20	507.46
Boron (B)	7	29			16			23	7-29	5	11.06
Calcium (Ca)	14200	43300	48500		13300	12700		29450	12700-48500	100	17904
Sodium (Na)	200	700	600		400	300		500	200-700	100	207.36
Phosphorus, Total	1800	1830	1970	1270	1810		1460	1668	1270-1970	90	266.01
Sulfur (S)-Total	1600	1800	1500	1400	2100		2100	1780	1400-2100	100	301.66
Potassium (K)	560	1860	2010		1270			1713.333	560-2010	20	659.22

Notes:

- data point thrown out
- DL - detection limit
- S - standard deviation

Ch. 3. Metal analysis data

	L172409 May-04	L88459 Feb-03	L59635 Mar-02	L25087 Jan-01	L18991 Oct-00	L80963 Oct-02				
	mg/kg						Average	Range	DL	S
Aluminum (Al)	4700	2100					3400		0.01-200	
Arsenic (As)	0.7	0.8		2	1.7		0.65	0.8-<10	0.1-10	0.08
Barium (Ba)				396	196		296	196-396	0.5	141.42
Beryllium (Be)				<1	<1		<1		1	
Boron (B)	37						37	sv	5	
Cadmium (Cd)	2.3	1.8	0.8	1.2	1	0.6	1.3	0.6-2.3	0.5	0.63
Chromium (Cr)	8.9	6	18.3	32.1	17.8	6.8	14.65	6-32.1	0.5	10.00
Cobalt (Co)			3	3	15		3.75	<1-15	1	
Copper (Cu)	24	21	20	32	15	8	20	8-32	1-2	8.12
Lead (Pb)	6		12	12	10		7.5	<5-26	5	4.45
Magnesium (Mg)	3300	700			1140		1028	700-4000	5-100	1391.59
Manganese (Mn)				1170	646		908	646-2100	0.001	370.52
Mercury (Hg)				0.02	0.11		0.05	0.02-0.11	0.05-0.2	0.04
Molybdenum (Mo)							0.6	<1-1	1	
Nickel (Ni)	4	15	10	20	6	48	16.83	4-48	2	15.45
Selenium (Se)	0.2			0.6	0.7		0.59	<0.1-<2	0.1-2	0.40
Silicon (Si)		<1					<1	sv	0.1	
Silver (Ag)	<1						<1		1	
Strontium (Sr)				184	70		117	70-184	1	66.47
Thallium (Tl)				<1	<1				1	
Uranium (U)	<40	<40					<40		0.005-40	
Vanadium (V)				11	11		11		0.001	
Zinc (Zn)	280	170	190	154	91.7	60	157.62	60-280	0.003	77.55

Indicates value was below detectable limit and assigned a value of 0.5*detectable limit for analysis purposes

S - Standard deviation
DL - Detection limit

Ch. 3. Misc. characteristics

Lab ID	L80963	L18961	L124056	L172409	L69635	L98459					
Parameter	Oct-02	Dec-00	Aug-03	May-04	Mar-02	Feb-03	Average	Range	SD	Unit	DL
SAR	0.5		0.6		0.5	0.7	0.6	0.5-0.7	0.095743	SAR	0.1
pH in Saturated Paste	6.9		7	7.7	6.5	7.7	7.2	6.5-7.7	0.527257	pH	0.1
Conductivity Sat. Paste	0.7		1.9	2	0.9	0.9	1.3	0.7-2	0.618061	dS m-1	0.1
% Saturation	1030		380	400	667	500	595	380-1030	268.1805	%	1
% Moisture	68	74		71	70	70.9	51	68-74	2.166102	%	0.1
Loss on Ignition @ 550 C	74		51.7	54.9	51	62.1	58.7	51-74	9.59651	%	0
% Moisture			65.7	70.2		72	69.3	65.7-72	3.244996	%	0.5
Total Solids			351000	294000			322500	294000-35	40305.09	mg/kg wwt	10
Organic Matter	69		46	55	46	56	54	46-69	9.449868	%	1

Ch. 3. Organic compound data

Lab ID	L124056	L172409	L25087	L59635	L98459		CCME Soil quality guidelines		
	Aug-03	May-04	Jan-01	Mar-02	Feb-03	DL	Ag	Res/Park	Ind/Comm
Parameter									
Benzene		0.1	0.11			0.01	0.05	0.5	5
Carbon disulfide	0.03	0.2			0.12	0.01			
Dichloromethane	0.01	0.14				0.01	0.1	5	50
m-Cresol		0.9	1			0.5	0.1	1	10
o-Cresol		2.8	3.3			0.5	0.1	1	10
p-Cresol	1.1	4.4	3.6	0.6	2	0.5	0.1	1	10
Phenanthrene		0.7	8.6			0.5	0.1	5	50
Phenol	3.8	34	45	4.2	6.9	0.5	3.8	3.8	3.8
Naphthalene	0.8	2.9	17	0.5		0.5	0.1	0.6	22

Single detections in fresh biosolids - 2001 -2004

	Value	CCME Soil quality guidelines					
Parameter	pg/g	Agricultural	Residential/ Park	Industrial/ Commercial	Sample date	W.O#	DL
Total TEQ (ND=0)	0.287	4	4	4	5/21/2004	L172409	0.1
Total TEQ (ND=0.5DL)	1.12	4	4	4	"	L172409	0.1
23478 PeCDF	0.5		N/A		"	L172409	0.2
OCDD	7		N/A		"	L172409	6.2
12378 PeCDF	0.6		N/A		"	L172409	0.8
	mg/kg						
Benzo(a)anthracene or	1.9	0.1	1	10	1/26/2001	L25087	0.5
Bis(2-ethylhexyl)phthala	0.7		N/A		"	L25087	0.5
Diethylphthalate	6		N/A		"	L25087	2
Ethanol	60		N/A		"	L25087	3
Fluoranthene	8.5		N/A		"	L25087	0.5
Fluorene	0.8		N/A		"	L25087	0.5
m+p-Xylenes	0.08	0.1	1	17/20	"	L25087	0.01
Pyrene	6.8	0.1	10	100	"	L25087	0.5
Toluene	0.12	0.1	0.8	0.8	"	L25087	0.01
Acenaphthylene	6.3		N/A		"	L25087	0.5
Anthracene	1.3		N/A		"	L25087	0.5

Ch. 3. Undetected organics

Undetected organics from 2001 - 2004

7 different testing dates over past 4 years

1,1,1-Trichloroethane	Benzidine
1,1,2,2-Tetrachloroethane	Benzo(a)pyrene
1,1,2-Trichloroethane	Benzo(a)pyrene
1,1-Dichloroethane	Benzo(b or k)fluoranthene
1,1-Dichloroethene	Benzo(b or k)fluoranthene
1,2,3-Trichloropropane	Benzo(ghi)perylene
1,2,4-Trichlorobenzene	Bis(2-chloroethoxy)methane
1,2-Dibromoethane	Bis(2-chloroethyl)ether
1,2-Dichlorobenzene	Bis(2-chloroisopropyl)ether
1,2-Dichloroethane	Bromodichloromethane
1,2-Dichloropropane	Bromoform
1,3-Dichlorobenzene	Bromomethane
1,4-Dichlorobenzene	Butyl benzyl phthalate
123478 HxCDD	Carbon tetrachloride
123478 HxCDF	Chlorobenzene
1234789 HpCDF	Chloroethane
123678 HxCDD	Chloroform
123678 HxCDF	Chloromethane
12378 PeCDD	cis-1,3-Dichloropropene
123789 HxCDD	cis-1,4-Dichloro-2-butene
123789 HxCDF	Dibenzo(a,h)anthracene
1-Methylnaphthalene	Dibromochloromethane
2,3,4,6-Tetrachlorophenol	Dibromomethane
2,4,6-Trichlorophenol	Dichlorodifluoromethane
2,4-Dichlorophenol	Dichlorodifluoromethane
2,4-Dimethylphenol	Dimethylphthalate
2,4-Dinitrophenol	Di-n-butylphthalate
2,4-Dinitrotoluene	Di-n-octylphthalate
2,6-Dichlorophenol	Ethyl methacrylate
2,6-Dinitrotoluene	Ethylbenzene
234678 HxCDF	Hexachlorobenzene
2378 TeCDD	Hexachlorobutadiene
2378 TeCDF	Hexachlorocyclopentadiene
2-Butanone (MEK)	Hexachloroethane
2-Butanone (MEK)	Indeno(1,2,3-cd)pyrene
2-Chloroethylvinylether	Iodomethane
2-Chloronaphthalene	Isophorone
2-Chlorophenol	Nitrobenzene
2-Hexanone	N-Nitrosodi-n-propylamine
2-Methylnaphthalene	N-Nitrosodiphenylamine
2-Nitrophenol	o-Xylene
3,3'-Dichlorobenzidine	Pentachlorobenzene
4,6-Dinitro-2-methylphenol	Pentachlorophenol
4-Bromophenyl phenyl ether	Perylene
4-Chloro-3-methylphenol	Pyridine
4-Chlorophenyl phenyl ether	Styrene
4-Methyl-2-pentanone (MIBK)	Tetrachloroethylene
4-Nitrophenol	Total HxCDD
Acenaphthene	Total PCBs
Acetone	Total PCBs
Acrolein	Total PeCDD
Acrylonitrile	Total PeCDF
All Aroclors	Total TCDD
Aroclor 1016	trans-1,2-Dichloroethene
Aroclor 1221	trans-1,3-Dichloropropene
Aroclor 1232	trans-1,4-Dichloro-2-butene
Aroclor 1242	Trichloroethene
Aroclor 1248	Trichlorofluoromethane
Aroclor 1254	Vinyl acetate
Aroclor 1260	Vinyl chloride
Aroclor 1262	
Aroclor 1268	

Ch. 3. Toxicity equivalency factors

International Toxicity Equivalency Factors (I-TEF)

Compound	I-TEF
2,3,7,8-Tetrachlorodibenzo-p-dioxin	1
1,2,3,7,8-Pentachlorodibenzo-p-dioxin	0.5
1,2,3,4,7,8-Hexachlorodibenzo-p-dioxin	0.1
1,2,3,6,7,8-Hexachlorodibenzo-p-dioxin	0.1
1,2,3,7,8,9-Hexachlorodibenzo-p-dioxin	0.1
1,2,3,4,6,7,8-Heptachlorodibenzo-p-dioxin	0.01
1,2,3,4,6,7,8,9-Octachlorodibenzo-p-dioxin	0.001
2,3,7,8-Tetrachlorodibenzofuran	0.1
2,3,4,7,8-Pentachlorodibenzofuran	0.5
1,2,3,7,8-Pentachlorodibenzofuran	0.05
1,2,3,4,7,8-Hexachlorodibenzofuran	0.1
1,2,3,6,7,8-Hexachlorodibenzofuran	0.1
1,2,3,7,8,9-Hexachlorodibenzofuran	0.1
2,3,4,6,7,8-Hexachlorodibenzofuran	0.1
1,2,3,4,6,7,8-Heptachlorodibenzofuran	0.01
1,2,3,4,7,8,9-Heptachlorodibenzofuran	0.01
1,2,3,4,6,7,8,9-Octachlorodibenzofuran	0.001

Source:

<http://www.ene.gov.on.ca/cons/681e01.htm>

Ch. 4. - Tomato study plant growth data.

		16-Jul		11-Aug		29-Aug		25-Sep												
Pail	Contents	Ht	Ht	Ht	Ht	Ht	Ht	Toms	#	cm	cm	delta H	delta H	delta H	delta H	delta H	delta H	Total Growth	St. Dev.	Status
		cm	cm	cm	cm	cm	cm													
3	T		40	53	78	85	2	13	25	7	45									
4	T		31	34	63	68	6	3	29	5	37									
5	T		30	34	62	67	3	4	28	5	37									
8	T		28	42	71	72	8	14	29	1	44									f
9	T		31	46	78	70	7	15	32	-8	39									
10	T		33	38	78	63	6	5	40	-15	30	5.46	504							
13	TL		37	36	76	81	7	-1	40	5	44									f
14	TL		27	36	55	42	5	9	19	-13	15									
15	TL		36	43	46	47	1	7	3	1	11									
18	TL		29	40	61	59	2	11	21	-2	30									
19	TL		38	43	61	62	3	5	18	1	24									
20	TL		30	43	58	79	9	13	15	21	49	15.30	25 f							
23	B		35	27	25	32	1	-8	-2	7	-3									
24	B		36	30	25	21	1	-6	-5	-4	-15									
28	B		28	28	30	34		0	2	4	6									
29	B		41	35	41	44		-6	6	3	3									
30	B		23.5	6	10	17			4	7	-6.5	8.26	438 r							
33	BL		37	25	33	35		-12	8	2	-2									
35	BL		26	28	28	31	1	2	0	3	5									
39	BL		36	36.5	37.5	40		0.5	1	2.5	4									
40	BL		31	31	33	35		0	2	2	4	3.20	156							
43	W		33	38	39	27		5	1	-12	-6									
44	W		26	24	27	34		-2	3	7	8									
48	W		19	22	22	23		3	0	1	4									
49	W		35	29	37	36		-6	8	-1	1									

50	W	28	25	32	32	1	-3	7	0	4	5.21536	f
53	WL	42	43	58	49		1	15	-9	7		
54	WL	36	33	36	39	1	-3	3	3	3		f

		16-Jul	11-Aug	29-Aug	25-Sep							
Pail	Contents	Ht	Ht	Ht	Ht	Toms	11-Aug	29-Aug	25-Sep	Total Growth		
		cm	cm	cm	cm	#	delta H	delta H	delta H	delta H	St. Dev.	Status
59	WL	36	36	36	36		0	0	0	0		
60	WL	38	38	38	40		0	0	2	2	2.94392	
63	ML	32	35	47	50	2	3	12	3	18		
66	ML	41	46	45	46		5	-1	1	5		
76	ML	41	43	47	42		2	4	-5	1		
70	ML	29	28	33	36	1	-1	5	3	7	7.27438	

Status legend	
f	flower
	dead
r	regrowth after snapping off
t	tomato

Average chg in height and width over time between measurments

	11-Aug	29-Aug	25-Sep	Av total ht chg Jul16- Sep25	St. Dev.	Deaths	Av total wdth chg Jul16- Sep25	Std. Dev
T	9.00	30.50	-0.83	38.67	5.47	0.00	55.50	6.47
TL	7.33	19.33	2.17	28.83	15.30	0.00	31.00	13.25
B	-4.40	-0.17	2.67	-3.10	8.26	1.00	-5.25	8.41
BL	-2.38	2.75	2.38	2.75	3.20	2.00	0.25	3.95
W	-0.50	3.67	-6.33	2.20	5.22	1.00	-2.60	3.44
WL	6307.83	6374.67	6368.00	3.00	2.94	2.00	-0.75	6.40
ML	2.25	5.00	0.50	7.75	7.27	0.00	3.75	8.85

% plants bearing fruit

T	6	100.00
TL	6	100.00
B	2	33.33
BL	1	16.67
W	1	16.67
WL	1	16.67
ML	2	33.33

Ch. 4. - Tomato study plant growth data cont'd.

Pail	Contents	16-Jul			11-Aug		29-Aug	25-Sep	
		Width cm	Leaf #	Status	Width cm	Leaf #	Width cm	Width cm	
3	T	20	6		44	120	61	77	57
4	T	23	3 t		37	92	100	86	63
5	T	22	3 t		43	63	92	78	56
8	T	21	5		63	118	83	67	46
9	T	18	3		60	163	70	68	50
10	T	23	3 t		36	81	68	84	61
13	TL	22	2		68	160	81	61	39
14	TL	19	4 2t		20	60	39	46	27
15	TL	24	3 t		29	81	36	32	8
18	TL	25	4		63	153	67	70	45
19	TL	26	5		52	147	58	65	39
20	TL	22	5		58	116	66	50	28
23	B	27	4 f		25	22	21	10	-17
24	B	24	4 f		21.5	19	16	12	-12
25		16	4 t		14	12	1	8	-8
28	B	13	5		15	20	17	16.5	3.5
29	B	23	4		19.5	20	23	22	-1
30	B	13	5		6	7	7	16	3
33	BL	23	18		22	24	18	20	-3
35	BL	16	5		12.5	20	16	18	2
39	BL	20	7		21	35	19	17	-3
40	BL	17	4		13	13	15	22	5
43	W	20	12		13	12	23	12	-8
44	W	15	6		10.5	35	16	15	0
48	W	12	15		16	22	15	12	0
49	W	23	7		19	21	25	22	-1
50	W	19	4		20	21	22	15	-4
53	WL	20	23		22	37	21	20	0
54	WL	15	5		27	30	26	23	8
59	WL	20	4		17	21	19	14	-6
60	WL	18	4		17	22	19	13	-5
63	ML	20	4		24	40	26	36	16
66	ML	20	5		19	39	14	21	1
76	ML	21	6		17.5	37	16	16	-5
70	ML	13	4		18.5	30	19	16	3

	Avg total width chg Jul 16- Sep25	Std. Dev
T	55.5	6.473021
TF	31	13.25142
B	-5.25	8.412788
BF	0.25	3.947573
W	-2.6	3.435113
WF	-0.75	6.396614
M	3.75	8.845903

█ - plant died

Ch. 4 - Tomato study - mushroom observations.

11-Aug-03

Pails containing mushrooms

* All pails contain some amount of St. Mary's biosolids

Pail #
23
24
25
28
29
30
38
39
43
44
48
53
54
55
58
59
60

Total = 17

Total pails in study
with St. Mary's
biosolids =

24

% of total pails

70.8

Ch. 4. -Tomato study - C:N data.

Media	ID	Wgt (mg)	%N	%C	%S	C:N	Avg C:N
Potting Soil	1	3.200	0.53	36.02	1.11	67.50	
Potting Soil	2	3.067	0.56	40.67	0.98	73.17	70.34
Biosolids & Fill	3	3.511	0.77	32.62	0.77	42.35	
Biosolids & Fill	4	3.472	0.60	28.83	0.70	48.24	45.29
Biosolids & Wood Waste	5	4.120	0.65	32.25	0.61	49.86	
Biosolids & Wood Waste	6	3.650	0.70	32.08	0.62	45.62	47.74
Biosolids, Wood Waste & Fill	7	3.530	0.32	19.42	0.88	60.53	
Biosolids, Wood Waste & Fill	8	3.000	0.18	11.26	0.18	61.55	61.04
Biosolids	9	3.110	0.68	38.67	0.63	56.87	
Biosolids	10	3.070	0.70	37.39	0.67	53.21	55.04
Topsoil & Fill	11	3.060	0.33	23.01	0.42	68.90	
Topsoil & Fill	12	3.339	0.16	8.87	0.83	55.39	62.15
Municipal biosolids	13	4.500	2.78	26.30	1.01	9.46	
Municipal biosolids	14	3.540	2.43	27.86	0.89	11.47	10.46

	Phosphorous		Carbon			
Media	mg/kg	%	%	Avg C:P	Avg C:N	St.Dev
T	516.46	0.05	38.34	742.45	70.34	4.01
TL	255.27	0.03	15.94	624.56	62.15	4.17
B	1097.72	0.11	38.03	346.44	55.04	3.00
BL	144.82	0.01	30.72	2121.52	45.29	0.72
W	581.66	0.06	32.17	553.04	47.74	9.55
WL	572.26	0.06	15.34	267.98	61.04	2.59
ML	7897.71	0.79	27.10	34.31	10.46	1.42

	%C	Avg
T	36.02	
T	40.67	38.34
BL	32.62	
BL	28.83	30.72
W	32.25	
W	32.08	32.17
WL	19.42	
WL	11.26	15.34
B	37.39	
B	38.67	38.03
TL	23.01	
TL	8.87	15.94
ML	27.89	
ML	26.30	27.10

Ch. 4. -- ICP Media sample weights.

First run

	all weights in grams			
	glass	glass+ sample	glass+dry sample	DrySample/25mL
1B	30.095	31.0536	30.77264	0.67764
2A	30.647	31.709	31.382	0.735
3B	30.3297	31.6494	31.6035	1.2738
5B	29.4821	30.4015	30.8135	1.3314
6G	99.47	100.701	100.195	0.725
7A	29.3892	31.6109	31.4343	2.0451
7B	29.8632	31.9855	31.9259	2.0627
8B	30.8348	31.7393	31.5329	0.6981
9B	30.3393	31.3111	30.961	0.6217
10A	30.7556	31.9316	31.3875	0.6319
11A	30.0346	31.2049	31.174	1.1394
10B	29.727	30.8245	30.3628	0.6358
12A	50.3701	51.6265	51.5702	1.2001
12B	50.458	50.6998	51.6462	1.1882
13A	29.2164	30.8418	30.5068	1.2904
13B	30.224	31.8012	31.5709	1.3469

Second run

	glass	glass + dry sample	DrySample/25mL
1	99.536	100.421	0.885
2	99.593	100.4242	0.8312
3	101.115	102.2887	1.1737
4	99.189	101.747	2.558
5	101.3539	102.415	1.0611
6	98.5104	99.8607	1.3503
7	101.229	102.906	1.677
9	101.162	101.806	0.644
10	100.954	101.5798	0.6258
11	99.1438	101.4271	2.2833
12	99.2796	100.3664	1.0868
13	100.8903	101.85	0.9597

below detection limit (DL)

DL ppm	0.0031	0.0042	0.0018	0.0072	0.0189	0.0048	0.051	0.039	0.0222										
As	B	Cd	Co	Cr	Cu	Fe	Mg	perm in soil	perm in soil										
mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg										
perm in soil	perm in soil	perm in soil	perm in soil	perm in soil	perm in soil	perm in soil	perm in soil	perm in soil	perm in soil										
min	min	min	min	min	min	min	min	min	min										
1B	0.878	27.106	0.187	6.884	0.154	5.678	0.418	15.410	0.555	20.472	85.130	3140.678	249.500	9204.740	2.551	94.113			
2A	0.735	29.400	0.455	15.486	0.151	0.455	0.455	15.486	0.194	6.805	77.160	2624.680	226.400	7709.680	2.407	81.871			
11	1.719	45.578	0.868	19.003	0.868	19.003	0.868	19.003	0.448	8.790	307.500	8748.972	225.500	4847.780	7.160	277.725			
12A	1.200	48.004	1.023	21.352	0.290	0.639	1.023	21.352	0.448	8.790	293.200	8107.824	241.300	5026.664	7.765	161.775			
12B	1.168	47.528	0.868	19.003	0.868	19.003	0.868	19.003	0.448	8.790	347.900	7319.096	246.800	5192.728	11.030	232.074			
9B	0.622	24.968	0.298	10.294	0.007	0.298	0.3313	0.878	27.272	0.409	18.431	39.860	1807.688	26.420	1062.410	23.750	955.043		
10	0.632	25.276	0.008	0.313	0.081	3.220	0.733	29.007	0.742	29.180	28.648	56.290	2227.014	35.390	1396.186	30.500	1188.975		
10B	0.636	25.432	0.011	0.417	0.082	3.212	0.814	32.007	0.742	29.180	58.580	2303.387	38.660	1520.132	34.580	1360.698			
5B	1.274	50.943	0.258	10.294	0.007	0.258	0.3313	0.878	27.272	0.409	18.431	39.860	1807.688	26.420	1062.410	23.750	955.043		
5B	1.351	53.258	0.417	7.826	0.258	10.294	0.007	0.258	0.3313	0.878	27.272	0.409	18.431	39.860	1807.688	26.420	1062.410		
6B	0.725	29.000	0.733	25.256	0.733	18.307	0.002	0.083	0.127	0.390	0.946	32.634	0.381	20.024	79.330	2735.517	72.870	2512.759	
7A	2.063	61.800	0.838	11.461	0.118	8.171	0.391	12.050	0.258	10.294	1.881	20.550	1.147	14.022	425.900	5204.158	353.000	4321.516	
7B	2.063	62.508	0.323	3.917	0.082	6.025	0.258	10.294	0.007	0.258	0.3313	0.878	27.272	0.409	18.431	39.860	1807.688	26.420	1062.410
8B	0.598	21.974	0.631	22.604	0.433	15.517	0.158	5.640	0.258	10.294	0.391	12.050	1.147	14.022	425.900	5204.158	353.000	4321.516	
13A	1.290	51.616	0.184	3.171	0.116	2.251	0.458	6.878	1.287	24.547	12.140	235.196	144.100	8603.921	144.700	2803.394	35.840	694.356	
13B	1.347	53.876	0.329	6.114	1.178	21.865	0.258	10.294	0.007	0.258	0.3313	0.878	27.272	0.409	18.431	39.860	1807.688	26.420	1062.410
SECOND RUN																			
1	0.845	35.400	0.051	2.347	13.910	392.838	0.051	0.051	0.845	28.910	14.343	128.400	358.191	303.500	8573.448	2.979	84.150		
2	0.831	33.248	0.054	2.498	78.840	2371.571	0.054	0.054	0.831	28.910	14.343	128.400	358.191	303.500	8573.448	2.979	84.150		
3	1.174	48.848	0.038	1.770	12.190	259.849	0.038	0.038	1.174	12.190	12.190	12.190	12.190	12.190	12.190	12.190	12.190		
4	2.558	102.320	0.018	0.812	32.960	315.285	0.018	0.018	2.558	32.960	32.960	32.960	32.960	32.960	32.960	32.960	32.960		
5	1.081	42.444	0.017	1.958	15.308	390.478	0.017	0.017	1.081	15.308	15.308	15.308	15.308	15.308	15.308	15.308	15.308		
6	1.350	54.012	0.030	1.539	12.960	239.947	0.030	0.030	1.350	12.960	12.960	12.960	12.960	12.960	12.960	12.960	12.960		
7	1.877	67.060	0.027	1.259	23.960	352.713	0.027	0.027	1.877	23.960	23.960	23.960	23.960	23.960	23.960	23.960	23.960		
8	0.644	25.760	0.055	3.226	8.752	419.255	0.055	0.055	0.644	8.752	8.752	8.752	8.752	8.752	8.752	8.752	8.752		
9	0.626	25.022	0.010	3.320	8.752	348.632	0.010	0.010	0.626	8.752	8.752	8.752	8.752	8.752	8.752	8.752	8.752		
10	0.626	25.022	0.010	3.320	8.752	348.632	0.010	0.010	0.626	8.752	8.752	8.752	8.752	8.752	8.752	8.752	8.752		

Media	ID	DL ppm	0.0195		0.0111		0.0244		0.1347		0.0198		0.2348		0.0438		0.183		0.1875	
			mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
FIRST RUN																				
T	1B	0.678	27.106		0.344	12.673		0.440	16.225	1.485	54.786		56.220	2074.110	12.610	485.218	18.690	898.904	106.900	3943.834
T	2A	0.735	29.400		0.317	10.772		0.408	13.874	1.068	37.007		15.540	1872.109	18.360	624.480	26.220	891.337	103.700	3527.211
T	11	1.139	45.576		0.593	13.700		0.502	11.019	1.175	25.761		115.400	2532.034	10.370	227.532	18.960	437.950	84.170	1845.005
TL	12A	1.200	48.004		0.635	13.218		0.529	11.005	1.103	27.184		55.820	1158.855	11.770	245.168	21.300	443.713	80.160	1669.961
TL	12B	1.188	47.528		0.617	12.973		0.511	8.637	1.429	30.096		121.000	2545.869	13.930	263.889	23.090	485.619	92.480	1946.011
B	9B	0.622	24.868		0.231	9.265		0.773	31.068	2.727	109.659		109.300	4395.207	26.340	1139.617	5.518	221.982	22.710	913.222
B	10	0.632	25.278		0.287	11.754		0.760	30.078	3.581	140.885		44.210	1738.381	37.050	1465.817	7.228	266.035	35.050	1388.691
B	10B	0.636	25.435		0.285	11.222		0.818	32.178	3.951	155.345		123.100	4840.359	44.210	1738.381	8.194	322.193	38.980	1532.761
BL	3B	1.274	50.982		0.696	13.656		0.809	15.874	2.600	51.028		134.600	2639.739	17.723	73.089	27.190	533.640	87.820	1723.563
WL	5B	1.331	53.256		0.69	13.267		0.843	14.618	2.959	79.589		174.300	2148.237	12.160	228.107	23.430	439.950	117.100	2168.813
WL	6B	0.725	29.006		0.413	14.255		0.887	30.369	3.758	129.588		138.100	4798.552	39.020	1345.517	10.890	375.577	47.220	1628.278
WL	7A	2.045	81.600		1.010	12.347		1.360	18.670	5.248	64.156		130.200	2030.562	27.220	332.783	51.410	628.484	133.500	1632.029
WL	7B	2.083	82.506		1.525	16.483		1.501	15.011	3.280	39.754		152.800	1851.942	17.310	209.798	53.780	651.937	146.400	1774.373
WL	8B	0.698	27.824		0.379	13.355		0.859	30.781	3.660	131.070		126.100	1851.942	36.210	1298.734	15.610	559.017	52.010	1662.556
WL	13A	1.561	51.616		0.829	16.059		0.879	18.975	68.320	1323.621		135.000	2815.468	574.600	9776.038	24.410	480.665	88.550	1662.553
WL	13B	1.347	53.678		0.749	13.899		0.824	15.263	47.160	875.343		128.100	2378.178	324.300	6019.376	24.480	454.377	87.700	1627.812
SECOND RUN																				
T	1	0.865	35.400		0.652	24.059		0.312	8.616	2.327	65.734		111.400	3146.893	12.430	351.130	23.740	670.921	112.700	3183.616
T	2	0.831	33.248		0.895	29.021		0.314	9.429	6.686	198.087		120.800	3433.301	20.780	925.000	38.610	1167.285	134.100	4033.325
BL	3	1.174	48.948		1.480	31.524		29.010	617.918	66.610	1206.802		68.680	1249.893	7.186	152.637	3.534	75.275	10.930	232.811
WL	4	2.586	102.320		0.906	10.702		0.502	4.905	4.983	42.934		110.700	1081.900	21.360	208.757	16.480	181.068	48.850	487.197
WL	5	1.061	42.444		0.868	15.729		0.468	10.768	5.098	120.135		109.500	2578.870	17.790	419.141	5.603	132.069	19.060	449.162
WL	6	1.350	54.012		0.405	6.611		1.691	27.805	25.860	552.840		106.300	1968.081	18.000	333.259	5.740	106.273	19.940	369.177
WL	7	1.677	67.000		2.171	32.364		0.687	10.236	8.262	138.074		108.400	1630.848	30.170	449.781	16.130	240.459	39.930	595.259
B	9	0.644	25.760		0.063	3.187		1.664	56.832	133.300	6174.689		83.980	3260.093	16.020	821.084	3.848	148.378	13.910	539.884
B	10	0.626	25.032		0.027	1.063		1.560	38.390	1533.637	66.480	2696.200		80.000	522.983	3.860	523.693	11.260	449.824	

Ch. 4. -- ICP Media samples - average concentration.

Below detection limit (<DL)
thrown out
<DL & assigned 0.5*DL
Standard deviation

As	B	Cd	Co	Cr	Cu	Fe	Mg	Mn	Mo	Ni	Pb	Se	Zn	Ca	P	Na	K
327.9379	20.8096	14.24284	3581.921	8573.445	84.15354												
2371.571	7.741819	33.77647	18.39509	4243.864	9444.177	138.0835											
6.88	5.68	15.41	20.47	3140.68	8204.74	84.11											
11.84	5.12	15.47	6.61	2624.49	7700.68	81.87											
2.68	693.51	0.06	4.86	22.89	14.93	3397.74	8730.76	98.56									
0.32	1131.71	0.01	3.24	9.05	6.12	686.60	778.77	26.23									
259.849	1.597512	48.03187	5.103519	1630.953	455.6105	141.7952											
315.2854	2.040657	17.9828	6.300821	2231.099	921.2275	210.2228											
6.75	21.49	13.39	7204.62	4714.24	497.03												
1.40	192.36	0.03	3.46	29.17	8.27	3690.96	2030.36	281.36									
0.52	167.07	0.01	2.86	18.43	4.48	3068.16	2335.34	185.64									
360.475	0.398748	2.0851	20.73556	9.268693	1304.778	828.5568	581.4438										
239.9467	0.029823	1.284157	17.84233	6.691106	927.7568	984.4775	305.3025										
7.83	3.50	11.64	7.81	1737.64	5128.08	45.72											
16.31	4.39	32.53	20.02	2735.32	2512.76	1127.59											
1.69	156.14	0.13	2.82	20.71	10.95	1676.42	2288.64	465.01									
0.24	173.62	0.18	1.39	8.81	6.14	779.76	2066.95	444.81									
3.92	8.77	4.76	20.55	14.02	5203.90	4321.30	715.74										
15.52	5.64	32.78	12.45	7743.49	4872.25	560.31											
352.7132	3.95551	48.10518	8.818818	3144.007	1517.591	390.4283											
2.27	84.26	0.03	6.46	32.66	13.96	5203.71	3928.71	730.61									
2.33	172.42	0.02	1.96	12.10	4.11	1908.18	1532.62	374.39									
10.29	10.29	0.30	3.22	27.27	16.43	1607.69	1062.41	955.04									
11.55	3.31	29.07	26.65	2227.01	1388.19	1188.87											
18.84	3.21	32.01	28.18	2303.40	1520.13	1360.10											
419.2547	2.135093	65.95487	13.68789	2451.568	598.9565	549.3012	3.187112	18.5132									
349.6325	0.387504	2.341004	51.93353	10.52523	2044.593	745.0463	487.7156	1.05284	26.71307								
7.11	161.91	0.29	2.84	41.28	19.29	2128.65	1062.16	908.32	1.08	18.09							
8.53	204.65	0.19	0.56	16.98	8.19	327.89	402.40	354.30	1.21	8.37							

Average

As	B	Cd	Co	Cr	Cu	Fe	Mg	Mn	Mo	Ni	Pb	Se	Zn	Ca	P	Na	K
2.68	695.81	0.06	4.86	22.89	14.93	3397.74	8730.76	98.56									
11.77	0.78 <0.04	0.05	6.65	19.83	9.90	8724.90	5055.72	190.52	<0.41	0.63	19.13	0.76	12.09	88.90	2681.60	516.46	856.96
7.11	161.81	0.28	2.84	41.25	19.28	2128.65	1062.15	908.22	1.08	18.09	0.5	0.83	10.22	31.01	2078.85	255.27	455.83
1.40	192.36	0.03	3.46	29.17	8.27	3690.96	2030.36	281.35	0.33	18.63	0.40	0.15	10.36	46.98	1857.18	144.82	256.66
7.58	156.14	0.13	2.82	20.71	10.95	1676.42	2288.54	465.01	0.46	11.96	0.56	0.17	18.90	207.29	2872.68	581.66	263.44
2.27	94.26	0.03	5.48	32.66	13.96	5203.73	3928.71	730.51	0.37	19.19	0.44	0.44	18.47	93.26	1837.78	572.26	519.97
1.97	3.11 <0.03	0.01	6.40	23.21	183.74	8352.00	2632.06	598.31	<0.38	14.98	<0.44		17.13	1069.48	2497.32	7897.71	467.52

Standard Deviation

As	B	Cd	Co	Cr	Cu	Fe	Mg	Mn	Mo	Ni	Pb	Se	Zn	Ca	P	Na	K
0.32	1131.71	0.01	3.24	9.05	6.12	686.50	778.77	26.23									
0.046012	1.245212	0.001082	0.548162	1.320101	0.225458	698.3371	125.0334	38.86286	0.011601	0.133026	0.013801	0.001	1.3113	5.759973	795.8452	33.9216	26.13289
6.53	204.65	0.15	0.56	16.98	8.19	327.89	402.40	354.30	1.21	8.37	0.01	0.01	14.78	699.43	1005.95	525.47	77.43
0.52	167.07	0.01	2.86	18.43	4.48	3068.16	2335.34	185.64	0.12	11.27	0.15	0.17	11.94	5.72	855.06	68.18	243.68
11.79	173.52	0.18	1.39	8.81	6.14	779.76	2066.95	464.01	0.15	3.66	0.17	0.15	11.94	235.01	1308.06	515.16	189.01
2.33	172.42	0.02	1.95	12.10	4.11	1908.18	1532.62	374.39	0.22	9.18	0.27	0.18	8.70	48.81	200.18	482.82	190.47
1.697256	1.216133	0.001034	0.398995	1.696198	58.63527	356.2884	181.9653	135.8309	0.011206	1.527628	0.013447	2.603718	316.6786	167.0836	2556.36	18.58656	62.04247

Ch. 4. - Water quality standards

	CCME Water quality guidelines					
	Community		Aquatic life		Agriculture	
	MOE LQC mg/l	MAC mg/L	AO mg/L	Freshwater mg/L	Irrigation mg/L	Livestock mg/L
As	2.5	0.025		0.005	0.1	0.025
Ba	100					
B	500				0.5-6	5
Cd	0.5	0.005		0.000017	0.0051	0.08
Co					0.05	1
Cr	5	0.05				
Cu		0	≤ 1	0.002-0.004	0.2-1	0.5-5
Fe			≤ 0.3	0.3		
Mg						
Mn			0.05		0.2	
Mo		0		0	0	0
Ni		0		0.025-0.15	0.2	1
Pb	5	0.01		0.001-0.007	0.2	0.1
Se	1	0.01		0.001	0.02-0.05	0.05
Zn		0	≤ 5	0.03	1-5	50
Ca		0		0	0	1000

Note:

MOE LQC - Ministry of Environment of Ontario Leachate Quality Criteria

MAC - Maximum allowable concentration

AO - aesthetic objective

EPA DWTR - EPA Drinking water standards.

Ch. 5. - Jack pine height and dry mass data

All heights measured on Jan 15, 2004, all heights in cm

Block	Pos	1	2	3	4	5
		100% Bio	75% Bio	50% Bio	25% Bio	0% Bio (Control)
1	1		3.9	9.5	4.9	6.05
	2	3.2	4.5	6.6	4.2	6.5
	3	3.4		7.2	5.7	5.8
	4	3.4	4.2	6.6	4.9	6.1
2	1	4	5.2	5.2	4.4	
	2	3	2.3	6.2	4.2	5
	3	5.7	5.6	5.2	3.7	5.6
	4	3.4	5.5	5.4	5.3	7.1
3	1	4.3	4.2	5.2	4.2	6.2
	2	3.6	3.3	5	5.5	5.6
	3	3.3	4.1	5.7	4.3	5.7
	4	3.5	4.3	5.2	3.7	6.1
4	1			4.8	4.2	7.6
	2		4.3	6.4	5.2	6.8
	3	2.7	3.5	5.8	4.5	4.4
	4	3	3.2	6.9	3.5	
Avg		3.663846	4.164286	6.05625	4.625	6.039285714
St. Dev		0.772027	0.934474	1.179248	0.661816	0.81857723
Dead		3	2	0	0	2

	ID	All masses in grams		
		Tops	Roots	Total
0%Bio	1.3	0.073	0.083	0.156
	2.1	0.045	0.055	0.1
	3.4	0.062	0.058	0.12
	4.2	0.051	0.049	0.1
	1.1	0.047	0.066	0.113
	1.2	0.041	0.035	0.076
	2.3	0.056	0.04	0.096
	1.4	0.09	0.126	0.216
	Avg	0.058125	0.064	0.122125
	St. Dev.	0.016462	0.029199	0.044460064
25%Bio	1.1	0.0308	0.1059	0.1367
	1.2	0.1578	0.1203	0.2781
	1.3	0.0705	0.1283	0.1988
	1.4	0.038	0.0723	0.1103
	2.1	0.07	0.058	0.128
	2.4	0.068	0.069	0.137
	3.3	0.068	0.068	0.136
	4.2	0.058	0.067	0.135
	Avg	0.071388	0.0861	0.1574875
	St. Dev.	0.038296	0.027535	0.054992894
50%Bio	1.1	0.1	0.1	0.2
	1.2	0.067	0.1	0.167
	1.3	0.08	0.074	0.154
	1.4	0.1	0.1	0.2
	2.3	0.085	0.098	0.183
	4.1	0.097	0.085	0.182
	3.1	0.2	0.1	0.3
	3.4	0.09	0.078	0.168
	Avg	0.102375	0.091875	0.19425
	St. Dev.	0.041019	0.01109	0.045634417
75%Bio	2.2	0.069	0.068	0.137
	2.2	0.068	0.068	0.136
	3.4	0.069	0.072	0.141
	4.2	0.069	0.054	0.123
	1.1	0.0381	0.0874	0.1255
	1.2	0.0535	0.0215	0.075
	1.3	0.0125	0.0873	0.0998
	1.4	0.055	0.0597	0.1147
	Avg	0.054263	0.064738	0.119
	St. Dev.	0.020166	0.021067	0.02229151
100%Bio	1.1	0.032	0.078	0.11
	1.3	0.058	0.084	0.142
	2.2	0.028	0.054	0.082
	3.1	0.019	0.042	0.061
	4.1	0.065	0.065	0.13
	4.2	0.01	0.03	0.04
	4.3	0.005	0.065	0.07
	4.4	0.054	0.093	0.147
	Avg	0.033876	0.063876	0.09776
	St. Dev.	0.022737	0.02131	0.040138154

Dry Mass Summary

Average	All masses in grams		
	Tops	Roots	Total
0%Bio	0.058125	0.064	0.122125
25%Bio	0.071388	0.0861	0.157488
50%Bio	0.102375	0.091875	0.19425
75%Bio	0.054263	0.064738	0.119
100%Bio	0.033876	0.063876	0.09776

St. Dev	Tops	Roots	Total
0%Bio	0.016462	0.029199	0.04446
25%Bio	0.038296	0.027535	0.054993
50%Bio	0.041019	0.01109	0.045634
75%Bio	0.020166	0.021067	0.022292
100%Bio	0.022737	0.02131	0.040138

Ch. 5. - Jack pine height and dry mass ANOVA summary

ANOVA - Dry Weights

	F	p
Comparison between:		
50-100 Roots	28.474	0.001
50-100 Tops	16.840	0.005
50-100 Total	17.083	0.001
50-25 Tops	2.439	0.141
50-25 Roots	0.303	0.591
50-25 Total	2.117	0.168
All groups Total	8.201	0.001
All groups Roots	0.208	0.507
All groups Total	8.201	0.001
75-25 Tops	1.252	0.282
75-25 Roots	3.037	0.103
75-25 Total	3.365	0.088
25,75, 50 tops	4.014	0.033
25,75, 50 roots	6.064	0.008
25,75, 50 totals	3.702	0.042
75-100 Tops	3.600	0.079
75-100 Roots	0.007	0.936
75-100 Total	1.714	0.212
0-100 Roots	0.000	0.992
0-100 Total	1.325	0.269
0-75 Tops	0.176	0.681
0-75 Roots	0.003	0.955
0-75 Total	0.032	0.861
0-25 tops	0.810	0.383
0-25 roots	2.426	0.142
0-25 total	2.000	0.179

ANOVA Plant Height

	F	p
Comparison between:		
25% Bio & 50%	20.516	0.000
75% Bio & 50%	23.233	0.000
50-100	43.292	0.000
100,75, 25	5.438	0.008

- p>0.05

Ch. 5.- Jack pine greenhouse layout.

Biosolids Growth Study - Jack Pine Project
Greenhouse Layout - NRT219

Window													
	5.1.3	1.1.1	1.1.3	5.2.1	5.2.3	4.2.1	4.2.3	4.3.1	4.3.3	3.4.1	3.4.3		
5.1.2	5.1.4	1.1.2	1.1.4	5.2.2	5.2.4	4.2.2	4.2.4	4.3.2	4.3.4	3.4.2	3.4.4		
2.1.1	2.1.3	3.1.1	3.1.3	1.2.1	1.2.3	2.3.1	2.3.3	5.3.1	5.3.3	4.4.1	4.4.3	2.4.1	2.4.3
2.1.2	2.1.4	3.1.2	3.1.4	1.2.2	1.2.4	2.3.2	2.3.4	5.3.2	5.3.4	4.4.2	4.4.4	2.4.2	2.4.4
4.1.1	4.1.3	2.2.1	2.2.3	3.2.1	3.2.3	1.3.1	1.3.3	3.3.1	3.3.3	5.4.1	5.4.3	1.4.1	1.4.3
4.1.2	4.1.4	2.2.2	2.2.4	3.2.2	3.2.4	1.3.2	1.3.4	3.3.2	3.3.4	5.4.2	5.4.4	1.4.2	1.4.4

First digit - media group

Second digit - block number

Third digit - position within block

Group 5 (Control - 0% Bio)

1st block

position 1

Ch. 6. - Compost Temperature and pH data

	Date	pH 1	pH 2	Amb T	T1	T2	T3
1		7.5	7.67	26	34	35	35
2		8.32	8.62	17.1	32	31.7	29.8
3		7.56	7.5	22	29.3	29.4	29.4
4		7.37	7.54	17.3	23.9	23.9	23.9
7		7.4	7.44	17.4	22.1	20.8	23.5
8				10.9			
9		7.25	7.44	21.9	22.8	22.6	22.8
10		Restart					
11	18-Jun	8.53	8.64	17	41	41.3	41.1
14	21-Jun	7.9	8.51	18.2	37.4	37.7	37
15	22-Jun			17.3	36.1	36.2	35.8
16	23-Jun	8.61	8.49	14	36	36	36
17	24-Jun			10	32.1	32.1	32
18	25-Jun	8.73	8.73	17.2	32.2	32.4	32.6
21	28-Jun	7.84	8.69	17.7	34.3	34.1	34.4
	29-Jun			19.2	36.2	36.2	36.2
	30-Jun	8.45	8.62	27.4	36.6	36.6	36.3
	1-Jul	8.46	8.66	19.5	35.9	36.9	36.5
	2-Jul			23.5	25.5		
	28-Jul	5.35	5.32	21	40.9	40.4	
	30-Jul	5.65	5.56	25.5	42.5	42.8	42.7
	31-Jul	5.95	5.94	19	43	43	43
	1-Aug			19.7			
	2-Aug			21.7			
	3-Aug	6.32	6.31	23.2	38.1	38.2	37
	4-Aug			16.2	36.9	36.8	36.6
	5-Aug	6.58	6.54	19	35	35	35
	6-Aug	6.71	6.69	18.8	33	31.5	31
	7-Aug	6.75	6.76	19.5	31.5	32	32.5
	8-Aug			19.2			
	9-Aug			17.6			
	10-Aug			17.8	35.5	34.5	34.8
	11-Aug			16	30.3	30.8	29.6
	12-Aug			16.5	23.6	24	27
	13-Aug			20.2	24	27	25
	14-Aug			21.4	26.2	24.8	24.1
	15-Aug			24.7	23.9	24.5	25.3
	16-Aug	6.9	6.93	24.9	37.4	37.3	36.9
	17-Aug			21.7			
	18-Aug			23.3			
	19-Aug	7.06	7.06	18.8	28.2	28.6	28.8
	20-Aug	7.5	7.57	15.8	29.7	29.9	29.8
	21-Aug			12.8			
	22-Aug			12.9			
	23-Aug	8.18	8.2	18.2	35.9	35.5	35.1
	24-Aug			17	29.1	29.2	29.1
	25-Aug	9.11	9.11	22	34.4	34.8	
	26-Aug			22	38.5		

Date	pH 1	pH 2	Amb T	T1	T2	T3	
27-Aug	9.06	9.05	20	41.7	41.6	41.4	
28-Aug			14.7				
29-Aug			15				
30-Aug	8.97		15	39			
31-Aug	8.57		16	37			
1-Sep	8.18		21	30.1	30.3	30.3	
2-Sep	8.14		21.5	42.5	42.2	42.4	
3-Sep			26.5	45.1	45.1	45	
4-Sep	8.59		18.1	49.1	49.4	49.3	
5-Sep	8.75		27.8	51.2	52.4	52.7	
6-Sep			19.9	46.9	47.1	47	
7-Sep	8.53		18	46.4	46.3	46.2	
8-Sep	8.28		18	34.5	33.5	34	
9-Sep	8.49		18.6	39.1	39.2	39.2	
10-Sep	8.37		22.9	39.5	39.7	39.1	
11-Sep			16.7	39.5	39.1	39.8	
12-Sep	8.29		18	40.5	40.5	40.5	
13-Sep	8.23		22.4	40.2	40.5	40.3	
14-Sep	8.22		24	41	41.5	41.4	
15-Sep			23.6	43.4	43.3	42.1	
16-Sep	8.31		17.6	31	32	32	
17-Sep	8.34		10.4	33.4	33.5	34.1	
18-Sep			13.7				
19-Sep	8.29		16				
20-Sep	8.32		18	39.7	40.4	40.4	
21-Sep	8.27		15.8	40.1	40.8	41	
22-Sep			17				
23-Sep			18.1				

Ch. 6. - Compost Moisture content data

Date		Empty	Full	Dry	Unit	MC %
Chips	4	0.0112	0.1212	0.0825	kg	35.182
	5	0.0114	0.1161	0.0753	kg	38.968
	6	0.0112	0.1278	0.0833	kg	38.165
Bio	7	0.0114	0.1996	0.066	kg	70.988
	8	0.0114	0.1858	0.0615	kg	71.273
	9	0.0114	0.2148	0.0684	kg	71.976
Compost						
7-Jun	A	2.202	27.858	10.057	g	69.383
	B	2.241	25.149	9.364	g	68.906
8-Jun	1	0.0114	0.23	0.0985	kg	60.156
	2	0.0112	0.2613	0.1061	kg	62.055
	3	0.0114	0.2305	0.0935	kg	62.529
9-Jun	G	4.251	116.63	39.111	g	68.580
	H	4.265	117.516	33.366	g	74.304
	I	4.266	100.248	39.667	g	63.117
	1	2.235	24.711	9.385	g	68.188
	2	2.193	40.033	14.03	g	68.718
	3	2.194	37.295	13.255	g	68.488
10-Jun	1	2.229	32.579	11.447	g	69.628
	2	2.2	31.864	11.166	g	69.775
	3	2.193	34.858	12.085	g	69.717
	J	4.26	111.914	38.097	g	68.569
	K	4.289	101.022	34.445	g	68.826
	L	4.221	117.164	39.193	g	69.036
11-Jun	D	4.267	91.195	31.552	g	68.612
	E	4.225	120.216	41.3	g	68.036
	F	4.253	100.529	34.708	g	68.367
14-Jun	1	2.235	44.077	15.656	g	67.925
	2	2.193	39.777	14.482	g	67.303
	3	2.195	34.832	12.875	g	67.276
	M	4.226	114.149	40.17	g	67.301
	N	4.205	109.057	38.428	g	67.361
	O	4.193	119.204	41.484	g	67.576
16-Jun	1	2.256	33.619	11.767	g	69.674
	2	2.207	27.89	10.308	g	68.458
	3	2.22	34.089	12.313	g	68.330
	H	4.278	97.763	33.33	g	68.923
	I	4.279	102.619	34.568	g	69.200
	J	4.276	111.384	37.243	g	69.221
(new section - all weights in grams - from this point onwards units are omitted)						
17-Jun	Y	2.199	17.354	9.175		53.969
	X	2.194	21.138	7.588		71.527
	Z	2.187	19.584	8.294		64.896
	Q	4.192	80.072	32.664		62.478
	R	4.202	54.41	28.69		51.227
	S	4.226	72.076	22.233		73.461
18-Jun	a	2.197	28.322	12.128		61.987

Date		Empty	Full	Dry	Unit	MC %
	b	2.24	25.581	10.931		62.765
	c	2.2	25.906	11.202		62.026
	p	4.221	67.646	27.435		63.399
	d	4.257	72.878	29.826		62.739
	m	4.216	74.56	29.945		63.424
21-Jun	X	2.198	29.697	12.573		62.271
	Y	2.194	29.317	12.636		61.501
	Z	2.187	26.741	11.675		61.359
	F	4.241	87.294	35.906		61.874
	N	4.194	90.725	37.361		61.670
	E	4.214	88.593	36.651		61.558
23-Jun	X	2.198	23.041	10.302		61.119
	Y	2.194	21.7	9.84		60.802
	Z	2.187	23.072	10.328		61.020
	A	4.209	86.064	36.477		60.579
	B	4.238	78.43	33.957		59.943
	C	4.181	75.86	32.704		60.207
25-Jun	X	2.199	24.092	10.647		61.412
	Y	2.194	24.028	11.996		55.107
	Z	2.187	27.544	10.621		66.739
	N	4.193	81.409	34.232		61.097
	E	4.217	73.521	31.55		60.561
	F	4.242	70.729	30.174		60.997
28-Jun	A	68.018	120.214	88.851		60.087
	B	72.296	120.292	91.449		60.095
	C	72.177	118.374	90.726		59.848
	D	67.743	116.896	87.618		59.565
	E	63.213	120.746	86.567		59.408
	F	69.617	116.93	88.982		59.070
30-Jun	A	68.021	112.358	86.673		57.931
	B	72.304	121.934	93.087		58.124
	C	72.18	117.555	91.178		58.131
	A	2.201	19.448	9.3		58.839
	B	2.243	24.337	11.312		58.953
	C	2.202	26.65	12.242		58.933
2-Jul	A	2.2	22.943	10.938		57.875
	B	2.242	21.723	10.378		58.236
	C	2.2	23.143	11.016		57.905
	D	67.744	107.317	84.741		57.049
	E	63.215	108.833	82.685		57.319
	F	69.616	121.317	91.802		57.088
Total	C	72.17	121.211	90.386		62.856
	F	69.614	116.36	87.022		62.760
	H	82.122	119.314	95.614		63.723
29-Jul	7	4.205	83.512	36.146		59.725
	2	4.285	89.151	38.594		59.573
	3	4.207	97.317	41.885		59.534
30-Jul	P	4.213	63.714	28.58		59.048
	12	4.29	63.861	28.741		58.955
	11	4.246	63.602	28.271		59.524
31-Jul	E	4.215	91.407	40.948		57.871

Date		Empty	Full	Dry	Unit	MC %
	F	4.242	93.302	40.296		59.517
	Q	4.299	81.503	36.167		58.770
3-Aug	X	2.199	28.995	13.664		57.214
	Y	2.196	37.71	17.361		57.299
	Z	2.188	35.037	16.243		57.213
	M	4.214	83.282	38.59		56.523
	A	4.209	121.68	55.289		56.517
	C	4.178	84.262	39.201		56.267
5-Aug	2	4.294	82.105	39.239		55.090
	3	4.282	80.743	38.497		55.252
	11	4.247	73.879	35.329		55.362
6-Aug	M	4.23	61.297	30.331		54.263
	A	4.241	60.448	30.061		54.063
	C	4.188	62.083	30.788		54.055
9-Aug	P	4.234	70.655	34.85		53.906
	F	4.25	69.928	34.885		53.356
	7	4.208	67.793	33.986		53.168
16-Aug	M	4.227	62.468	33.675		49.438
	11	4.255	61.05	33.29		48.878
	A	4.233	63.655	34.678		48.765
19-Aug	P	4.214	42.742	24.812		46.538
	F	4.245	38.147	22.309		46.717
	7	4.191	49.79	28.471		46.753
20-Aug	B	4.248	59.804	32.804		48.600
	1	4.256	51.914	28.848		48.399
	T	4.18	72.275	39.233		48.523
23-Aug	Q	4.311	46.904	27.165		46.343
	12	4.294	60.379	34.47		46.196
	E	4.317	48.935	28.311		46.223
25-Aug	F	4.242	72.534	37.475		51.337
	T	4.181	73.532	37.749		51.597
	P	4.212	59.722	31.324		51.158
27-Aug	B	4.24	65.364	34.873		49.884
	1	4.254	69.686	37.15		49.725
	7	4.192	69.095	36.634		50.015
30-Aug	12	4.289	61.891	34.781		47.064
	E	4.249	67.167	37.656		46.904
	Q	4.316	68.532	38.112		47.371
31-Aug	7	0.0147	0.248	0.1388	kg	46.807
	8	0.0148	0.2471	0.1387	kg	46.664
	9	0.0147	0.1692	0.0963	kg	47.184
Trial 4						
1-Sep	L	2.217	27.58	7.83		77.869
	U	2.185	16.729	11.945		
	A	4.214	70.889	29.766		61.677
	M	4.217	62.457	20.633		71.813
	11	4.246	65.154	27.612		61.637
2-Sep	12	4.289	115.4	48.093		55.897
	E	4.249	131.1	53.292		65.947
	Q	4.316	114.1	47.445		60.715
3-Sep	P	4.214	72.154	31.336		60.079

Date		Empty	Full	Dry	Unit	MC %
	B	4.24	85	36.239		60.378
	T	4.183	81.401	34.977		60.121
	U	2.189	26.553	11.802		60.54
	L	2.223	25.575	11.428		60.54
4-Sep	F	4.242	118.815	50.988		59.200
	1	4.258	114.82	49.566		59.020
	7	4.194	118.347	50.69		59.269
5-Sep	C	4.186	108.611	47.229		58.781
	2	4.301	98.561	43.144		58.792
	3	4.284	83.602	36.745		59.075
7-Sep	A	4.252	109.034	48.155		58.101
	11	4.254	117.592	51.582		58.242
	M	4.228	109.116	48.148		58.127
8-Sep	U	2.19	24.879	11.671		58.213
	M	2.216	27.527	12.782		58.255
	P	4.22	74.586	33.823		57.930
	B	4.242	82.621	37.327		57.788
	T	4.186	81.469	38.895		55.038
9-Sep	12	4.281	108.831	49.151		57.083
	E	4.228	115.696	52.07		57.080
	Q	4.304	108.659	49.075		57.097
	M	2.216	22.019	10.533		58.001
	U	2.19	23.8	11.263		58.015
10-Sep	1	4.289	95.634	43.868		56.671
	7	4.199	103.025	46.75		56.944
	F	4.245	90.535	41.57		56.745
13-Sep	M	2.217	18.903	9.471		56.526
	U	2.193	21.572	10.606		56.587
15-Sep	A	4.252	95.295	44.206		56.115
	B	4.242	103.24	47.297		56.509
17-Sep	2	4.301	89.43	41.923		55.806
	3	4.284	94.205	43.874		55.972
19-Sep	B	4.242	100.002	47.691		54.627
	T	4.186	94.285	44.773		54.953
21-Sep	P	4.22	101.32	47.801		55.117
	Q	4.304	83.447	40.107		54.762

Ch.6. - Compost Bulk density (BD) data

Trial 1	Empty (kg)	Vol (L)	Full (kg)	Sample wgt (kg)	BD kg/L	Avg BD kg/L
Start						
1	0.2145	2.8	2.2195	2.0050	0.7161	
2	0.2145	2.8	2.3155	2.1010	0.7504	
3	0.2145	2.8	2.2115	1.9970	0.7132	0.7265
End						
1	0.2134	2.8	2.2976	2.0842	0.7444	
2	0.2138	2.75	2.1645	1.9507	0.7093	
3	0.2138	2.7	2.1000	1.8862	0.6986	0.7174

Trial 2	Empty (kg)	Vol (L)	Full (kg)	Sample wgt (kg)	BD kg/L	Avg BD kg/L
Start						
1	0.215	2.8	1.8590	1.6440	0.5871	
2	0.215	2.75	1.8342	1.6192	0.5888	
3	0.215	2.8	1.8900	1.6750	0.5982	0.5914
End						
1	0.214	2.7	1.7667	1.5527	0.5751	
2	0.214	2.7	1.7013	1.4873	0.5509	
3	0.214	2.7	1.7143	1.5003	0.5557	0.5605

Trial 3	Empty (kg)	Vol (L)	Full (kg)	Sample wgt (kg)	BD kg/L	Avg BD kg/L
Start						
1	0.2156	2.3	2.0011	1.7855	0.7763	
2	0.2156	2.3	2.0701	1.8545	0.8063	
3	0.2156	2.3	2.0803	1.8647	0.8107	0.7978
End						
1	0.185	2.7	2.0438	1.8588	0.6884	
2	0.185	2.7	2.0512	1.8662	0.6912	
3	0.185	2.7	2.0509	1.8659	0.6911	0.6902

Trial 4	Empty (kg)	Vol (L)	Full (kg)	Sample wgt (kg)	BD kg/L	Avg BD kg/L
Start						
1	0.2154	2.6	1.8674	1.6520	0.6354	
2	0.2154	2.5	1.8110	1.5956	0.6382	
3	0.2154	2.55	1.8392	1.6238	0.6368	0.6368
End						
1	0.2144	2.5	1.7132	1.4988	0.5995	
2	0.2144	2.5	1.7756	1.5612	0.6245	
3	0.2144	2.5	1.7491	1.5347	0.6139	0.6126

Trial	Mixing ratio			Volume (m ³)			Total Volume (m ³)
	Biosolids	WChps	Sawdust	Bio	WChps	Sawdust	
1	6	2		2.4	0.8	0	3.2
2	2	1	1	0.8	0.4	0.4	1.5
3	4	2	1	1.6	0.8	0.4	2.8
4	3	1	1	1.2	0.4	0.4	2

Vol. of loader bucket	0.4 m ³
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Ch.6. - Compost Experiment Journal

Date	Notes
7-Jun	Trial 1 started - mixing 15 min on, 60 min off
8-Jun	Rain
10-Jun	Thought moisture a bit high - left lids slightly ajar Material seems to collect at motor end. Tried to push it over, but not really effective. Some pockets around edges look as if they are not being mixed.
17-Jun	Emptied composter and refilled with sawdust and wood chips, bio to cut moisture 2:1 ratio of bio to sawdust plus and additional scoop of woodchips (2B:1WC:1S) Turn 15:60
23-Jun	Added 20L of water to composter
2-Jul	Emptied composter
28-Jul	refilled - ratio - 2 woodchips, 4 bio, 1 sawdust Added 21L of phos acid
5-Aug	Motor has failed - belt broke and fixed within a 2 hours
16-Aug	White mould on top of dead areas in corner, consistency loosening up, looks less clumpy
19-Aug	Added 1/3 of pail of Nutrite and 40L of water
23-Aug	Added 20 kg of Nutrite and 60L of water, scrapped sides
24-Aug	Smelled strongly of ammonia
25-Aug	REALLY bad ammonia, like needed respirator and goggles
27-Aug	Steaming
30-Aug	Still smelly & steaming
1-Sep	Turned old trial material over, smell has somewhat dissipated. New batch ratio 3 bio:1 WC:1 sawdust. Added 12.5 kg VAN 3:45:1 Chicken manure.
2-Sep	Steaming
4-Sep	Smelled slightly of ammonia, steamy
7-Sep	Motor failure - chain break sometime in last 24 hrs
8-Sep	Motor fixed in am. Added 9.7 kg of AN
10-Sep	Added 16L of water
23-Sep	Major motor failure - chain break, spring arm break, belt break - trial aborted.

Ch. 6. - Compost Trial summary

Trial 1

Date	Day	MC (%)	pH	Amb Temp (C)	Temp (C)	C:N	%N	%C	%H	%S
	1	69.14	7.50	27.8	28.0					
	2	61.58	7.59	26	34.7	69.60	0.60	41.68	3.27	0.18
9-Jun	3	68.63	8.47	17.1	31.2					
	4	69.26	7.53	22	29.4	66.47	0.60	39.67	3.37	0.25
	5	68.34	7.46	17.3	23.9	63.48	0.63	40.24	3.06	0.21
14-Jun	8	67.46	7.42	17.4	22.1					
	10	68.97	7.35	21.9	22.7	65.10	0.64	41.63	3.07	0.27
Selected for C:N testing						60.83	0.63	38.50	2.57	0.40
						231.46	0.20	46.85	7.29	0.12

Trial 2

Date	Day	MC (%)	pH	Amb Temp (C)	Temp (C)	C:N	%N	%C	%H	%S
	1	62.93	8.50	13.8	15.0	94.01	0.40	37.35	3.97	0.13
	2	62.49	8.59		41.1	108.72	0.36	38.46	4.53	0.17
19-Jun	3			15	40.3					
20-Jun	4			19	38.7					
21-Jun	5	61.71	8.21	18.2	37.4					
22-Jun	6	61.70		17.3	36.0					
	7	60.61	8.55	14	36.0	107.18	0.37	39.07	4.50	0.26
24-Jun	8	60.24		10	32.1					
	9	60.99	8.73	17.2	32.4	110.79	0.35	38.75	4.73	0.12
28-Jun	12	59.68	8.27	17.7	34.3					
	13	59.35		19.2	36.2	115.22	0.34	38.85	4.73	0.12
30-Jun	14	58.49	8.54	27.4	36.5					
	16	57.58	8.56	19.5	36.4	106.02	0.34	35.81	4.13	0.23
Selected for C:N testing						64.20	0.50	31.96	3.18	0.32

Trial 3

Date	Day	MC (%)	pH	Amb Temp (C)	Temp (C)	C:N	%N	%C	%H	%S
	1	59.61	5.34	21	40.7	61.79	0.48	29.92	3.01	0.26
	2	59.18	5.61	25.5	42.7	58.56	0.51	29.79	2.86	0.27
	3	59.18	5.95	19	43.0	66.25	0.46	30.22	3.10	0.25
	6	56.44	6.32	23.2	37.8	66.33	0.52	34.77	3.85	0.21
5-Aug	8	55.23	6.56	19	35.0					
6-Aug	9	54.13	6.70	18.8	31.8					
9-Aug	12	53.48	6.84	17.6	34.0					
10-Aug	13			17.8	34.9					
11-Aug	14			16	30.2					
12-Aug	15			16.5	24.9					
13-Aug	16			20.2	25.3					
14-Aug	17			21.4	25.0					
15-Aug	18			24.7	24.6					
	19	49.03	6.92	24.9		67.60	0.50	33.45	3.66	0.22
	22	46.67	7.06	18.8	28.5	62.24	0.54	33.75	3.74	0.25
20-Aug	23	48.51	7.54	15.8	29.8					
23-Aug	26	46.25	8.19	18.2						
	28	51.36	9.11	22	34.6	35.98	0.84	30.24	3.19	0.32
	30	49.87	9.06	20	41.6	31.75	1.09	34.68	3.97	0.25
30-Aug	33	47.11	8.97	15	39.0					
	34	46.88	8.18	16	37.0	29.43	1.01	29.69	3.24	0.42
Selected for C:N testing										

Trial 4

Date	Day	MC (%)	pH	Amb Temp (C)	Temp (C)	C:N	%N	%C	%H	%S
	1		8.18	21	30.2	30.35	33.08	4.36	0.23	1.08
2-Sep	2	60.85	8.14	21.5	42.4					
3-Sep	3	60.34		26.5	45.1					
	4	59.16	8.59	18.1	49.3	28.37	32.91	4.61	0.22	1.16
5-Sep	5	58.88	8.75	27.8	52.1					
6-Sep	6			19.9	47.0					
7-Sep	7	58.16	8.53	18	46.3					
	8	57.46	8.28	18	34.0	26.56	30.40	4.08	0.26	1.14
9-Sep	9	57.46	8.49	18.6	39.2					
10-Sep	10	56.78	8.37	22.9	39.4					
	11	59.02		16.7	39.5	26.92	28.42	3.92	0.26	1.06
12-Sep	12		8.29	18	40.5					
13-Sep	13	56.56	8.23	22.4	40.4					
14-Sep	14		8.22	24	41.3					
15-Sep	15	56.31		23.6	42.9					
16-Sep	16		8.31	17.6	31.7					
17-Sep	17	55.89	8.34	10.4	33.7					
18-Sep	18			13.7						
19-Sep	19	54.79	8.28	16						
20-Sep	20		8.32	18	40.2					
	21	54.94	8.27	15.8	40.6	21.49	24.68	3.00	0.19	1.15
Selected for C:N testing										
Value thought to be skewed by incomplete mixing										

Ch.7 - Field Study - Goulais lysimeter data

All values in parts per million

Lysimeter	July 13	24	Ca	Cu	Fe	K	Mg	Na	P	Zn
DL (ppm)	0.2948	0.0048	0.051	0.1875	0.038	0.183	0.0438	0.0198		
G(7)	28.8413	0.0095	0.0985	10.0085	3.8027	3.4004	0.9227	0.0824		
Sample 1.1 - N	31.5345	0.0193	0.1105	2.9274	6.9454	3.8286	0.8751	0.0798		
Sample 1.2 - N	42.2807	0.0143	0.1280	18.5970	7.7184	3.6099	1.7811	0.0821		
G(6)	20.4307	0.0077	< 0.051	25.5317	4.2275	3.3850	2.2591	0.3314		
Sample 2.2 - N	12.3184	0.0098	0.1290	2.8871	2.0436	2.6028	1.3495	0.0768		
Sample 2.3 - N	34.7294	0.0096	0.0702	2.2867	6.4402	2.7804	2.1385	0.0444		
G(5)	39.0857	0.0223	0.3028	1.9109	5.5893	2.6459	2.2600	0.1350		
Sample 3.2 - N	30.0749	0.0087	0.1073	8.4850	3.4911	2.1549	2.0139	0.0978		
Sample 3.1 - N	21.4720	0.0081	0.1157	7.4822	4.0279	2.8840	1.0782	0.0875		
Baseline	1.7243	0.0082	0.0797	1.8402	0.4193	4.8084	0.0492	0.1049		
Sample Base-1N	0.8733	0.0060	< 0.051	2.1321	0.2470	4.0115	0.0624	0.0387		
Sample Base-2N	1.7214	0.0051	< 0.051	1.0321	0.5181	3.8644	< 0.0438	0.0801		
Sample Base-3N										

ANOVA between G(7), G(6) and G(5) samples

	F	P	P < 0.05
Ca	0.79	0.494	N
Cu	0.84	0.558	N
Fe	1.53	0.290	N
K	0.23	0.798	N
Mg	1.00	0.421	N
Na	3.33	0.106	N
P	1.86	0.267	N
Zn	0.53	0.611	N

ANOVA results between all Goulais samples and the Baseline samples

	F	P	P < 0.05	Significant difference found for :
Cu	3.456799	0.092628	Y	Ca
Fe	2.817827	0.12416	Y	Mg
K	2.282218	0.186544	Y	Na
P				P
Zn	0.452084	0.603031	Y	

All lysimeter samples

Average	28.419	4.920	3.100	1.609	0.111	0.012	8.904
Std. Dev	9.919	1.855	0.606	0.814	0.048	0.009	8.203
Max	42.281	7.718	3.886	2.280	0.331	0.022	25.532
Min	12.318	2.044	2.155	0.875	0.044	0.008	1.911
Baseline							
Average	1.420	0.394	4.181	0.055	0.075	0.008	1.401
Std. Dev	0.525	0.136	0.597	0.058	0.033	0.001	0.551
Max	1.724	0.518	4.808	0.092	0.105	0.006	2.132
Min	0.813	0.247	3.864	0.022	0.040	0.005	1.032
Goulais includes all G(7), G(6), G(5) samples							

SAR Calculation

	Na	Ca	Mg	Na	Ca	Mg	SAR
Avg	3.1	29.4	4.9	3.901767	45.68847	3.218149	0.79
Goulais							
Base	4.2	1.4	0.4	5.235983	2.203825	0.257821	4.72

Atomic weights:

Na	22.99
Ca	40.08
Mg	24.32

Sample SAR calculation:

$$SAR = \frac{Na}{(Ca + Mg)^{0.5}}$$

where

SAR = sodium absorption ratio
 = sodium concentration (meq/L)
 = calcium concentration (meq/L)
 = magnesium concentration (meq/L)

$$\begin{aligned} \text{Meq Na} &= (1/3.1) \text{ mg/L} / (22.99) = 0.13 \\ \text{Meq Ca} &= (2/29.4) \text{ mg/L} / (40.08) = 0.73 \\ \text{Meq Mg} &= (2/4.9) \text{ mg/L} / (24.32) = 0.2 \\ \text{SAR} &= (0.13) / (0.73 + 0.2)^{0.5} = 0.2 \end{aligned}$$

Ch. 7 - Field Study - GoulaisLysimeter pH

Sampled on July 13

ID	pH	Avg
1.1	6.38	
1.2	6.55	
1.4	6.57	6.5
2.2	5.95	
2.3	5.4	
2.4	6.58	5.98
3.2	6.04	
3.1	6.24	
3.3	6.37	
Base 1	4.71	
Base 2	5.34	
Base 3	4.47	4.84

ANOVA results

Comparison	F	p
G(7)&G(6), Base	17.84899	0.003913
G(7), G(6), G(5)	1.595265	0.278248
G(5), Base	24.7704	0.007614
G(6), Base	7.040506	0.05678

Ch. 7 - Field Study - Goulais C:N Ratio

Site ID	Sample ID	Weight (mg)	%N	%C	%H	%S	C:N
Baseline	Base 1	4.100	0.071	1.517	N/A	0.278	21.510
	Base 2	3.527	0.098	2.633	N/A	0.276	26.843
	Base 3	3.439				0.274	19.84
G(7)	1.1	3.523	0.504	11.475	N/A	0.320	22.785
	1.2	3.818	0.475	13.882	N/A	0.433	29.244
	1.4	3.117	0.661	15.804	N/A	0.554	23.901
	1.3	3.259	0.904	18.986	N/A	0.617	20.993
G(6)	2.1	3.272	1.006	18.564	N/A	0.690	18.448
	2.2	3.975	0.781	18.274	N/A	0.915	23.389
	2.3	3.077	0.872	20.700	N/A	0.852	23.735
	2.4	4.029	0.886	21.861	N/A	0.555	24.682
G(5)	3.1	2.031	0.880	22.113	2.991	0.462	25.125
	3.2	2.088	0.883	19.167	2.497	0.345	21.698
	3.3	2.012	0.817	20.258	2.731	0.394	24.796
	3.4	2.246	0.918	20.640	2.873	0.190	22.484

	Avg %N	S
G(7)	0.636	0.196837
G(6)	0.886	0.092412
G(5)	0.875	0.04207
	Avg C:N	S
G(7)	24.231	3.550709
G(6)	22.564	2.797481
G(5)	23.526	1.693171
Baseline	22.731	3.657765

ANOVA between G(7), G(6) and G(5)

SUMMARY

Groups	Count	Sum	Average	Variance
Column 1	4	96.9225	24.23062	12.6075353
Column 2	4	90.25418	22.56354	7.82589767
Column 3	4	94.10339	23.52585	2.866827352

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Grp	5.602522	2	2.801261	0.360673367	0.706842	4.256492
Within Grp	69.90078	9	7.766753			
Total	75.5033	11				

ANOVA between G(7), G(6), G(5) and Baseline

SUMMARY

Groups	Count	Sum	Average	Variance
Column 1	4	96.9225	24.23062	12.6075353
Column 2	4	90.25418	22.56354	7.82589767
Column 3	4	94.10339	23.52585	2.866827352
Column 4	3	68.19311	22.73104	13.3792454

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Grp	6.808849	3	2.269616	0.258286433	0.853911	3.587431
Within Grp	96.65927	11	8.787207			
Total	103.4681	14				

Ch. 7 - Field Study - Goulais Metals and Cations Data

All values in mg/kg dry wgt

0.5 * DL

Sample ID	Ca	Co	Cu	Fe	K	Mg	Mn	Na	Ni	P	Zn
Base 1	1448.33	5.57	4.71	9566.63	1338.93	3002.54	193.68	379.45	11.96	73.14	29.63
Base 2	789.32	1.85	3.28	3040.28	294.60	505.27	290.76	73.82	7.45	64.21	47.65
Base 3	2284.09	14.32	12.99	16992.55	1967.12	6337.13	337.13	947.61	48.16	238.27	57.19
Average	1507.25	7.25	6.99	9866.49	1200.22	3281.65	273.86	466.96	22.52	125.21	44.82
S	749.12	6.40	5.24	6980.96	844.85	2926.93	73.21	443.42	22.32	98.02	14.00

111A	2224.81	4.24	18.27	7023.61	1265.38	3737.94	1347.19	315.26	23.48	1283.34	37.40
111A	2148.32	8.22	28.45	9487.86	2121.72	5872.96	842.70	601.76	47.14	1709.34	106.37
112A	3090.54	6.75	27.37	7895.63	1660.38	5956.18	1083.38	517.75	23.28	1805.96	107.44
113A	3670.74	4.21	23.72	6303.08	1726.00	4543.34	966.84	605.88	40.40	1932.81	114.31
121A	3998.11	7.58	35.14	12887.30	1467.33	5956.57	1465.63	417.06	37.88	1386.48	180.76
122A	3289.84	6.45	35.45	12479.18	1247.64	5505.27	1791.50	374.24	63.35	1438.92	161.99
123A	3463.75	7.96	41.16	14301.04	1725.95	7048.89	1983.97	515.47	65.01	1751.07	211.27
131A	2617.19	8.81	35.51	12061.04	2132.68	5153.64	1287.89	516.81	32.30	1686.48	185.56
132A	2807.43	8.18	34.40	13555.03	1494.08	7274.19	1544.08	506.10	30.07	1458.20	156.54
133A	2492.81	7.82	29.02	8935.47	1762.84	5904.23	731.81	346.49	91.00	1344.23	147.76
141A	2868.54			11024.78	1403.19	4040.32	1223.44	333.05		1337.88	163.19
142A	2212.97	6.50		12482.14	1062.95	4721.92	1920.43	235.75	54.98	1386.98	134.00
143A	3391.00	7.44	35.09	15412.34	1420.99	6281.81	2495.96	335.93	30.80	1316.03	149.11
Avg	2944.31	7.01	31.24	11063.73	1676.24	5538.02	1437.29	432.43	44.97	1626.98	142.75
S	596.60	1.48	6.63	2886.61	320.76	1070.40	605.36	118.35	20.34	219.14	44.32

211A	3917.20	5.87	36.23	7943.21	2450.64	5557.32	2026.80	596.60	22.70	2643.31	147.37
212A	2565.37	8.68	28.76	3637.08	1213.75	1984.94	747.23	222.66	135.42	2373.22	76.86
213A	2592.23	5.86	29.46	6358.69	1598.20	3851.78	1291.44	520.07	29.19	2927.43	125.85
221A	3638.89	23.85	6586.80	2024.01	5652.22	1777.44	477.73	25.58	1841.57	102.03	
222A	2958.52	4.33	21.20	4348.92	1555.99	3972.57	747.89	428.20	42.65	1333.95	88.84
223A	3134.56	4.96	24.55	4422.39	2811.54	4471.27	966.72	658.58	28.82	1854.60	93.12
231A	3006.44	17.97	3817.17	962.22	2413.47	531.65	129.43	15.53	916.22	77.23	
232A	3384.06	8.95	34.89	10751.61	1300.34	5013.32	1639.77	431.65	119.71	1305.21	264.63
232A	3358.44		35.35	11678.96	1331.59	4949.28	1501.43	352.75		1289.32	289.22
233A	2064.76	7.80	27.58	8668.88	1798.94	3723.08	623.20	293.08	27.51	1321.34	124.66
241A	2412.14	1.52	6.87	1234.14	365.28	818.96	239.86	62.78	21.83	357.14	45.48
242A	3182.84	6.54	25.18	8614.11	1980.68	4871.97	937.56	450.36	28.48	1636.12	441.15
Avg	3017.95	4.97	25.97	6505.16	1616.10	3940.01	1086.92	385.32	43.17	1649.95	166.38
S	635.15	3.19	8.32	3137.00	660.36	1602.07	654.93	180.85	43.14	731.67	116.33

311A	16200	1.96	24.6		749	2740	1150	97	6.5	1470	108
312A	37600	2.81	23.2		948	4450	1420	178	10.1	1630	112
313A	13100	4.22	23.1		773	4380	676	145	12.7	1130	84
321A	22400	3.08	29.2		876	3830	1360	161	8	1280	104
322A	18500	3.2	26		731	3160	1070	113	6.7	1300	102
323A	19600	3.78	34		820	3760	1020	108	9.1	1320	139
341A	14000	3.76	23.2		1150	3870	785	257	11.3	1180	78
342A	15600	2.41	25.3		796	2930	676	102	8.2	1510	110
Avg	19626.00	3.16	26.08		856.38	3640.00	1019.63	145.13	9.33	1352.60	104.63
S	7875.96	0.76	3.79		138.44	638.26	289.66	64.03	1.98	170.69	18.59

Ch. 7 - Field Study - ANOVA - Goulais Metals and Cations Data

ANOVA between G(7), G(6) and G(5)

	F	p
B	10.6207	0.0003
Ca	57.0345	0.0000
Co	7.9003	0.0019
Cu	2.1017	0.1411
Fe	14.3274	0.0010
K	8.0981	0.0015
Mg	8.5880	0.0011
Mn	2.4426	0.1040
Na	12.0822	0.0002
Ni	4.3476	0.0227
P	0.9559	0.3959
Zn	1.1367	0.3343

ANOVA between G(7), G(6), G(5) & Baseline

	F	p
B	7.5111	0.0006
Ca	42.4648	0.0000
Co	3.9544	0.0173
Cu	10.3065	0.0001
Fe	5.4110	0.0112
K	4.8559	0.0068
Mg	5.0612	0.0056
Mn	5.3673	0.0042
Na	5.4259	0.0039
Ni	3.1574	0.0391
P	9.3229	0.0001
Zn	2.2741	0.0988

Ch. 7 - Field Study - Land application sites C:N ratio

Site ID	Sample ID	%N	%C	C:N
B(1)	B1.1	0.53	35.57	67.40
	B1.2	0.54	36.07	66.33
	B1.3	0.53	34.43	65.39
	B2.1	0.75	36.55	48.99
	B2.2	0.76	35.24	46.54
	B2.3	0.67	33.00	49.11
	B3.1	0.63	37.18	59.05
	B3.2	0.58	38.76	66.65
	B3.3	0.62	36.69	58.94
D(3)	D1.1	0.69	23.18	33.66
	D1.2	0.81	25.94	31.94
	D1.3	0.58	17.18	29.80
	D2.1	0.75	25.42	33.95
	D2.2	0.75	28.81	38.65
	D2.3	0.76	28.84	38.08
	D3.1	0.73	20.82	28.69
	D3.2	0.65	26.05	40.26
	D3.3	0.86	28.35	33.11
G(0)	G1.1	0.53	35.12	66.12
	G1.2	0.54	34.58	64.06
	G1.3	0.56	33.95	60.17
	G2.1	0.62	36.25	58.69
	G2.2	0.58	33.51	57.68
	G2.3	0.50	38.81	77.61
	G3.1	0.49	31.50	64.55
	G3.2	0.61	38.40	59.84
	G3.3	0.58	35.70	61.61
I(1)	I1.1	0.64	27.15	42.36
	I1.2	0.71	27.84	38.98
	I1.3	0.64	34.87	54.40
	I2.1	0.85	30.20	35.47
	I2.2	0.73	28.84	36.59
	I2.3	0.73	24.68	34.04
	I3.1	0.68	27.27	39.93
	I3.2	0.43	12.93	29.79
	I3.3	0.66	28.02	42.65
B(2)	OB1.1	0.71	33.12	46.71
	OB1.2	0.68	37.96	55.77
	OB1.3	0.85	37.03	56.97
	OB2.1	0.59	31.84	54.15
	OB2.2	0.65	32.02	49.52
	OB2.3	0.60	25.32	42.04
	OB3.1	0.68	30.56	44.75
	OB3.2	0.74	35.82	48.51
	OB3.3	0.70	33.37	47.95
S(2)	S1.1	0.83	29.73	35.77
	S1.2	0.77	26.84	34.88
	S1.3	0.84	35.14	41.61
	S2.1	1.01	29.10	28.87
	S2.2	0.97	26.40	27.17
	S2.3	0.92	29.79	32.38
	S3.1	0.72	34.37	47.61
	S3.2	0.81	28.81	36.97
	S3.3	0.85	30.89	36.15

C:N	
B(1)	B(2)
67.40	46.71
66.33	55.77
65.39	56.97
48.99	54.15
46.54	49.52
49.11	42.04
59.05	44.75
66.65	48.51
58.94	47.95

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
Column 1	9	528.3913	58.71015	72.01932
Column 2	9	446.3733	49.59704	25.7733

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	373.719332	1	373.7193	7.6431	0.013813	4.493998
Within Groups	782.340889	16	48.89631			
Total	1156.06022	17				

	Year/Site ID	Avg	S
Goulais	2004 G(0)	63.37036	6.043831
Batchewana	2003 B(1)	58.71015	8.486419
Iron Brige	2003 I(1)	39.35631	6.974411
Batchewana	2002 B(2)	49.59704	5.076741
Sowerby	2002 S(2)	35.71108	6.222254
Devils Lake	2001 D(3)	34.23726	3.999218

Ch. 7 - Field Study - Land application sites data from Envirotest Laboratories

	Sample ID									Avg	S	Max	Min	Unit	DL
B(1)	B.1.1	B.1.2	B.1.3	B.2.1	B.2.2	B.2.3	B.3.1	B.3.2	B.3.3						
Calcium (Ca)	91	101	95	87	99	100	99	104	89	96.11111	5.90433	104	87	mg/L	2
Potassium (K)	52	59	52	112	128	125	80	71	88	85.22222	30.12797	128	52	mg/L	1
Magnesium (Mg)	24	18	16	101	131	133	60	56	59	66.44444	45.67579	133	16	mg/L	1
Sodium (Na)	13	13	11	68	80	87	46	39	53	45.55556	29.19808	87	11	mg/L	1
SAR	0.3	0.3	0.3	1.2	1.2	1.3	0.9	0.8	1.1	0.82222	0.420648	1.3	0.3	SAR	0.1
% Saturation	400	380	420	324	280	265	330	263	595	381.8889	104.7753	595	263	%	1
pH in Saturated Paste	7.5	7.7	7.5	7.9	7.6	7.6	7.6	7.7	7.7	7.64444	0.123603	7.9	7.5	pH	0.1
Conductivity Sat. Paste	0.7	0.6	0.6	1.4	1.6	1.7	1.1	1	1.1	1.08889	0.413658	1.7	0.6	dS m-1	0.1
Mercury (Hg)-Total	0.04	0.035	0.033	0.027	0.032	0.032	0.028	0.029	0.031	0.031889	0.003951	0.04	0.027	mg/kg	0.005
Silver (Ag)-Total	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	0			mg/kg	1
Aluminum (Al)-Total	3610	4800	3950	4380	3980	4330	2750	2850	3400	3783.333	695.5933	4800	2750	mg/kg	3
Arsenic (As)-Total	2.5	2.59	2.57	1.08	1.02	1.59	0.83	0.77	0.91	1.54	0.795566	2.59	0.77	mg/kg	0.03
Boron (B)-Total	17.8	18.8	17	30.6	26	26.1	20.1	19.6	21.7	21.96667	4.597554	30.6	17	mg/kg	0.6
Barium (Ba)-Total	311	324	291	455	393	398	378	352	390	385.7778	51.23909	455	291	mg/kg	0.04
Beryllium (Be)-Total	0.21	0.43	0.28	0.41	0.3	0.46	0.18	0.15	0.14	0.284444	0.124209	0.46	0.14	mg/kg	0.06
Bismuth (Bi)-Total	0.04	0.03	0.03	0.09	0.04	0.03	0.03	0.03	0.03	0.038889	0.01965	0.09	0.03	mg/kg	0.02
Calcium (Ca)-Total	23000	34200	28000	48400	47400	45400	35800	34400	37200	37088.89	8672.434	48400	23000	mg/kg	7
Cadmium (Cd)-Total	1.55	1.5	1.42	1.98	1.88	1.8	1.78	1.67	2	1.731111	0.209251	2	1.42	mg/kg	0.02
Cobalt (Co)-Total	1.29	1.34	1.21	2.18	1.78	2.61	1.42	1.64	1.56	1.67	0.460462	2.61	1.21	mg/kg	0.01
Chromium (Cr)-Total	9.3	16.7	8.9	12.4	9.5	10.9	7.7	10.2	8.8	10.48889	2.693253	16.7	7.7	mg/kg	0.1
Copper (Cu)-Total	25.1	21.5	19.5	21.9	22.5	22.1	18.5	18.5	19.5	21.01111	2.188661	25.1	18.5	mg/kg	0.2
Iron (Fe)-Total	2650	3430	2520	3800	3190	4200	2780	2950	3050	3174.444	551.5231	4200	2520	mg/kg	6
Potassium (K)-Total	1550	2040	1470	1980	1580	1760	1230	1120	1420	1572.222	311.4794	2040	1120	mg/kg	7
Magnesium (Mg)-Total	2400	3930	3250	6360	4820	6620	2610	2820	3050	3884.444	1599.165	6620	2400	mg/kg	2
Manganese (Mn)-Total	1840	2190	1870	2240	2250	2240	2120	2120	2250	2124.444	161.3313	2250	1840	mg/kg	0.03
Molybdenum (Mo)-Total	0.69	0.75	0.65	0.89	0.76	0.95	0.82	0.68	0.73	0.768889	0.10018	0.95	0.65	mg/kg	0.02
Sodium (Na)-Total	382	568	340	677	514	589	414	386	529	488.7778	113.8494	677	340	mg/kg	2
Nickel (Ni)-Total	4.4	5.2	4.8	7.8	5.5	7.1	4.9	4.7	6	5.6	1.161895	7.8	4.4	mg/kg	0.2
Lead (Pb)-Total	16.4	13.2	14.6	8.32	7.76	9.61	5.81	5.3	6.23	9.692222	4.082869	16.4	5.3	mg/kg	0.05
Selenium (Se)-Total	0.2	0.3	0.2	0.4	0.3	0.4	0.2	0.2	0.2	0.266667	0.086603	0.4	0.2	mg/kg	0.1
Tin (Sn)-Total	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	0	0	0	mg/kg	4
Strontium (Sr)-Total	106	129	113	182	152	161	140	131	146	140	23.64318	182	106	mg/kg	0.02
Titanium (Ti)-Total	137	162	141	173	122	185	90	115	123	138.6667	30.26962	185	90	mg/kg	0.03
Thallium (Tl)-Total	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	0	0	0	mg/kg	0.2
Uranium (U)-Total	0.512	0.629	0.582	0.977	0.892	0.967	0.582	0.537	0.572	0.694444	0.192286	0.977	0.512	mg/kg	0.006
Vanadium (V)-Total	8.07	10.1	7.91	11.9	10.3	13.1	8.8	12.7	11	10.43111	1.919319	13.1	7.91	mg/kg	0.06
Zinc (Zn)-Total	155	138	140	221	201	203	177	167	183	176.1111	28.91991	221	138	mg/kg	2
Phosphorus, Total	1270	1280	1120	2020	1910	1790	1550	1360	1520	1535.556	312.1342	2020	1120	mg/kg	90
Boron (B), Hot Water Ext.		8		6.3					8.2	7.5	1.044031	8.2	6.3	mg/kg	0.1

D(3)	Sample ID															DL
	D1.1	D1.2	D1.3	D2.1	D2.2	D2.3	D3.1	D3.2	D3.3	D.Avg	S	Max	Min	Unit		
Calcium (Ca)	147	218	205	264	212	199	182	214	121	195.7778	41.83234	264	0	121 mg/L	2	
Potassium (K)	18	11	10	21	20	16	47	48	40	25.68667	15.10794	48	0	10 mg/L	1	
Magnesium (Mg)	19	51	56	43	34	34	29	34	19	35.22222	12.84307	56	0	19 mg/L	1	
Sodium (Na)	2	3	7	8	7	261	5	9	7	34.33333	85.03088	261	0	2 mg/L	1	
SAR	<0.1	0.1	0.1	0.1	0.1	4.5	0.1	0.1	0.2	0.8625	1.550979	4.5	0	0.1 SAR	0.1	
% Saturation	230	180	176	200	224	233	260	193	190	209.5556	28.43462	260	0	176 %	1	
pH in Saturated Paste	7.4	7.8	7.5	7.7	7.3	7.4	7.6	7.9	7.3	7.544444	0.218581	7.9	0	7.3 pH	0.1	
Conductivity Sat. Paste	0.7	1	1	1.3	1.1	2.1	1	1.1	0.7	1.111111	0.416667	2.1	0	0.7 dS m-1	0.1	
Mercury (Hg) Total	0.038	0.026	0.031	0.044	0.036	0.038	0.05	0.044	0.043	0.038778	0.007563	0.05	0	0.025 mg/kg	0.005	
Silver (Ag) Total	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	0	0	0	0 mg/kg	1	
Aluminum (Al) Total	7030	8310	7290	9060	7450	5950	5340	6780	5380	6955.556	1261.914	9060	0	5340 mg/kg	3	
Arsenic (As) Total	1.24	1.33	1.39	1.51	3.27	1.54	1.51	1.79	5	2.064444	1.280457	5	0	1.24 mg/kg	0.03	
Boron (B) Total	15.3	14.2	14.8	20.9	13.3	14.3	8.7	12.9	11.5	13.98889	3.280794	20.9	0	8.7 mg/kg	0.6	
Beryllium (Be) Total	263	223	232	398	232	245	175	203	239	246.2222	62.26311	398	0	175 mg/kg	0.04	
Bismuth (Bi) Total	0.71	1.03	0.91	1.15	0.91	0.53	0.48	0.92	0.48	0.791111	0.249772	1.15	0	0.48 mg/kg	0.06	
Bismuth (Bi) Total	0.11	0.05	0.05	0.08	0.05	0.05	0.05	0.05	0.06	0.062222	0.022236	0.11	0	0.05 mg/kg	0.02	
Calcium (Ca) Total	36400	45700	41300	51600	45500	31700	25300	37900	25200	37844.44	9209.792	51600	0	25200 mg/kg	7	
Cadmium (Cd) Total	0.91	0.68	0.78	0.91	0.74	0.91	0.68	0.81	0.99	0.821111	0.115374	0.99	0	0.68 mg/kg	0.02	
Cobalt (Co) Total	2.94	3.04	2.73	3.05	2.82	2.91	2.18	2.29	2.34	2.7	0.339706	3.05	0	2.18 mg/kg	0.01	
Chromium (Cr) Total	30.2	19.6	16.5	15.9	65.6	10.9	17.5	21.7	15.5	23.71111	16.5864	65.6	0	10.9 mg/kg	0.1	
Copper (Cu) Total	22.1	23.7	21	23.6	21.4	20.2	20.2	35.8	28.8	24.08889	5.132116	35.8	0	20.2 mg/kg	0.2	
Iron (Fe) Total	7720	8960	6830	6740	13700	5280	6420	6700	5710	7562.222	2538.468	13700	0	5280 mg/kg	6	
Potassium (K) Total	1230	1250	1040	2750	1210	1210	1090	1280	1360	1380	522.5179	2750	0	1040 mg/kg	7	
Magnesium (Mg) Total	5610	7830	6830	9760	7510	3970	4060	6280	3300	6127.778	2112.864	9760	0	3300 mg/kg	2	
Manganese (Mn) Total	2550	2080	1480	1890	3000	1160	1510	1860	1300	1870	601.5189	3000	0	1160 mg/kg	0.03	
Molybdenum (Mo) Total	2.33	1.3	1.29	1.64	1.62	1.05	1.33	1.57	1.48	1.512222	0.360963	2.33	0	1.05 mg/kg	0.02	
Sodium (Na) Total	301	487	354	1250	433	357	282	341	275	453.3333	306.6663	1250	0	275 mg/kg	2	
Nickel (Ni) Total	10.6	11.3	10.8	11.1	10	8.7	11.2	12.3	14.1	11.22222	1.491457	14.1	0	8.7 mg/kg	0.2	
Lead (Pb) Total	11.1	11.1	10.6	11.3	10.3	9.73	15.1	16.1	19.1	12.71444	3.247095	19.1	0	9.73 mg/kg	0.05	
Selenium (Se) Total	0.4	0.5	0.5	0.5	0.5	0.3	0.3	0.6	0.4	0.444444	0.101379	0.6	0	0.3 mg/kg	0.1	
Tin (Sn) Total	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	0	0	0	0 mg/kg	4	
Strontium (Sr) Total	118	131	131	210	117	117	81.6	110	95.8	123.4889	36.0809	210	0	81.6 mg/kg	0.02	
Titanium (Ti) Total	289	330	285	335	323	252	245	271	230	284.4444	38.55552	335	0	230 mg/kg	0.03	
Thallium (Tl) Total	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	0.222369	1.46	0	0 mg/kg	0.2	
Uranium (U) Total	1.15	1.25	1.34	1.46	1.23	0.852	0.87	1.1	0.861	1.123667	0.222369	1.46	0	0.852 mg/kg	0.006	
Vanadium (V) Total	20.8	26.7	17.9	17.9	41.8	18.5	18.5	18.9	17.2	21.4	8.468028	41.8	0	12.9 mg/kg	0.06	
Zinc (Zn) Total	94	74	97	104	86	101	74	91	106	91.88889	11.91055	106	0	74 mg/kg	2	
Phosphorous - Total	1380	1090	1120	1290	1280	1580	1050	1270	1330	1263.333	164.0122	1580	0	1050 mg/kg	90	
Boron (B) - Hot Water Ext.		5.7		5.7					7.1	6.186667	0.80829	7.1	0	5.7 mg/kg	0.1	

G10	Sample ID														Unit	DL
	G1.1	G1.2	G1.3	G2.1	G2.2	G2.3	G3.1	G3.2	G3.3	G Avg	S	Max	Min			
Calcium (Ca)	78	78	100	100	119	72	114	194	102	98	106,111	36,77,106	194	0	72 mg/L	2
Potassium (K)	67	72	115	115	118	63	152	206	101	112	111,778	45,58,996	206	0	63 mg/L	1
Magnesium (Mg)	63	69	102	121	121	73	128	249	82	105	109,555	55,60,151	245	0	63 mg/L	1
Sodium (Na)	24	42	60	49	28	79	123	123	53	57	57,222	29,75,842	123	0	24 mg/L	1
SAR	0.5	0.8	0.8	1	0.8	0.6	1.2	1.4	0.9	0.9	0.9	0.27,838	1.4	0.5	0.5 SAR	0.1
% Saturation	364	351	293	288	288	273	285	285	270	285	300,444	33,52,852	364	270	%	1
pH in Saturated Paste	7.7	7.8	7.9	7.8	7.8	7.8	8	8	8.1	8	7.88,889	0.12,993	8.1	7.7	pH	0.1
Conductivity Sat. Paste	0.9	1	1.3	1.3	1.5	1.6	1.5	1.4	1.3	1.4	1.32,222	0.23,333	1.6	0.9	dS m ⁻¹	0.1
Mercury (Hg)-Total	0.024	0.026	0.031	0.031	0.025	0.018	0.022	0.023	0.024	0.025	0.024,222	0.003,456	0.031	0.018	mg/kg	0.005
Silver (Ag)-Total	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	0	0	mg/kg	1
Aluminum (Al)-Total	4430	4280	3760	4550	4550	4830	4560	5140	4950	4430	454,778	405,024	5140	3760	mg/kg	3
Arsenic (As)-Total	0.87	0.91	0.82	0.82	2.1	0.96	0.88	0.86	0.78	0.8	0.98,778	0.41,703	2.1	0.78	mg/kg	0.03
Boron (B)-Total	18.8	18.6	18.4	19.4	25.1	22.4	22.4	18.9	21.1	20.3	20,333	2,22,486	25.1	18.4	mg/kg	0.6
Barium (Ba)-Total	334	348	338	328	328	355	372	313	361	354	348,222	22,48,71	385	313	mg/kg	0.04
Beryllium (Be)-Total	0.4	0.37	0.33	0.33	0.42	0.53	0.44	0.79	0.66	0.5	0.48,333	0.14,824	0.79	0.33	mg/kg	0.06
Bismuth (Bi)-Total	0.02	0.03	0.03	0.03	0.07	0.04	0.03	0.03	0.02	0.02	0.03,222	0.01,563	0.07	0.02	mg/kg	0.02
Calcium (Ca)-Total	44700	44000	41600	46500	47100	48500	48500	45500	52100	48800	465,444	306,802	52100	41600	mg/kg	7
Cadmium (Cd)-Total	1.77	1.87	1.99	1.73	1.94	1.94	1.94	1.61	1.78	1.75	1.80,889	0.10,709	1.94	1.61	mg/kg	0.02
Cobalt (Co)-Total	1.7	2.36	1.6	1.95	1.98	1.6	1.6	1.72	1.74	1.67	1.81,222	0.24,314	2.35	1.6	mg/kg	0.01
Chromium (Cr)-Total	11.5	12.3	7.7	12	14.5	8.4	8.4	8.4	9.3	8	10,233	2,40,312	14.5	7.7	mg/kg	0.1
Copper (Cu)-Total	17.1	19.6	18.7	38.2	22.1	19	18.2	18.2	18.4	18.3	21,068	6,57,038	38.2	17.1	mg/kg	0.2
Iron (Fe)-Total	3500	3350	2860	7240	4130	3020	3020	3300	3260	3280	377,556	134,625	7240	2860	mg/kg	6
Potassium (K)-Total	1650	1920	1580	1930	1910	1850	1740	1740	1770	1710	178,778	130,745	1960	1580	mg/kg	7
Magnesium (Mg)-Total	5330	4950	4470	5730	6280	5520	5520	7150	6820	5830	578,444	85,730	7150	4470	mg/kg	2
Manganese (Mn)-Total	2060	1780	1730	2230	2030	2060	2060	1610	1940	1860	192,889	19,977	2230	1610	mg/kg	0.03
Molybdenum (Mo)-Total	0.72	1.37	0.59	1.42	0.78	0.56	0.56	0.66	0.61	0.59	0.81,111	0.33,846	1.42	0.56	mg/kg	0.02
Sodium (Na)-Total	452	571	431	523	561	548	548	533	531	514	540,444	84,90,784	661	431	mg/kg	2
Nickel (Ni)-Total	5.3	10.5	5.4	6.7	6	4.9	5.4	5.4	5.4	5.1	6,077	1,74,196	10.5	4.9	mg/kg	0.2
Lead (Pb)-Total	8.19	8.07	8.06	6.56	8.51	7.16	7.16	7.33	6.9	7.43	7,645	56,077	8.51	6.56	mg/kg	0.05
Selenium (Se)-Total	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.4	0.3	0.3	0.31,111	0.03,333	0.4	0.3	mg/kg	0.1
Tin (Sn)-Total	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	0	0	mg/kg	4
Silicon (Si)-Total	142	143	136	136	138	160	150	144	156	149	146,444	8,00,173	160	136	mg/kg	0.02
Titanium (Ti)-Total	162	154	152	152	152	190	159	174	167	154	163,778	12,04,967	190	152	mg/kg	0.03
Thallium (Tl)-Total	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	0	0	mg/kg	0.2
Uranium (U)-Total	0.719	0.688	0.739	0.733	0.851	0.851	0.778	0.872	0.913	0.784	0.78,722	0.07,803	0.913	0.688	mg/kg	0.006
Vanadium (V)-Total	11.1	9.1	8.51	13.7	12.9	8.55	9	9	9.12	8.51	10,05,444	2,01,276	13.7	8.51	mg/kg	0.06
Zinc (Zn)-Total	203	215	216	190	218	213	213	187	206	200	205,333	11,35,782	218	187	mg/kg	2
Phosphorus, Total	1650	1660	1790	1880	1960	1960	2130	1640	1740	1920	181,889	16,714	2130	1640	mg/kg	90
Boron (B)-Hot Water Ext.	7.5				10					9.7	9,06,667	1,36,504	10	7.5	mg/kg	0.1

I(1)	Sample ID									Avg	S	Max	Min	Unit	DL
	I1.1	I1.2	I1.3	I2.1	I2.2	I2.3	I3.1	I3.2	I3.3	I Avg					
Calcium (Ca)	159	180	207	155	155	206	159	144	168	170.3333	22.73763	207	144	mg/L	2
Potassium (K)	23	38	51	49	32	28	30	30	30	34.55556	9.593111	51	23	mg/L	1
Magnesium (Mg)	24	19	33	33	21	30	36	34	41	30.11111	7.321961	41	19	mg/L	1
Sodium (Na)	10	10	14	22	14	13	7	4	8	11.33333	5.220153	22	4	mg/L	1
SAR	0.2	0.2	0.2	0.4	0.3	0.2	0.1	0.1	0.1	0.2	0.1	0.4	0.1	SAR	0.1
% Saturation	260	270	280	263	256	173	223	125	233	231.4444	51.33009	280	125	%	1
pH in Saturated Paste	7.2	7.5	7.4	7.3	7.7	8.1	7.4	7.7	7.5	7.533333	0.269258	8.1	7.2	pH	0.1
Conductivity Sat. Paste	0.8	0.9	1	1	0.8	0.9	0.9	0.8	0.9	0.888889	0.078174	1	0.8	dS m-1	0.1
Mercury (Hg)-Total	0.034	0.048	0.036	0.411	0.04	0.04	0.04	0.037	0.042	0.080889	0.123856	0.411	0.034	mg/kg	0.005
Silver (Ag)-Total	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	0			mg/kg	1
Aluminum (Al)-Total	3320	3760	3210	3700	3850	6580	5000	4800	5850	4452.222	1179.775	6580	3210	mg/kg	3
Arsenic (As)-Total	1.45	1.65	1.77	1.65	2.27	1.35	1.17	1.24	1.05	1.511111	0.37311	2.27	1.05	mg/kg	0.03
Boron (B)-Total	14.3	15.5	15.2	24.7	27.4	37.7	22.2	10.2	19.9	20.78889	8.375626	37.7	10.2	mg/kg	0.6
Barium (Ba)-Total	309	317	311	348	387	549	264	118	226	314.3333	117.4798	549	118	mg/kg	0.04
Beryllium (Be)-Total	0.13	0.19	0.14	0.23	0.15	0.35	0.49	0.35	0.71	0.304444	0.194622	0.71	0.13	mg/kg	0.06
Bismuth (Bi)-Total	0.04	0.04	0.04	0.04	0.04	0.04	0.09	0.06	0.05	0.048889	0.016915	0.09	0.04	mg/kg	0.02
Calcium (Ca)-Total	21600	24100	24000	29600	27600	49700	27500	13700	29300	27455.56	9679.503	49700	13700	mg/kg	7
Cadmium (Cd)-Total	1.5	1.47	1.55	1.61	1.54	1.42	0.96	0.58	0.9	1.281111	0.369169	1.61	0.58	mg/kg	0.02
Cobalt (Co)-Total	1.29	1.35	1.27	1.35	1.62	2.48	1.88	4.33	2.14	1.967778	0.98173	4.33	1.27	mg/kg	0.01
Chromium (Cr)-Total	9.1	9.6	9.1	10.2	12.4	13.6	9.7	11.3	9.3	10.47778	1.610728	13.6	9.1	mg/kg	0.1
Copper (Cu)-Total	21.6	22	21.6	23.7	22	39.5	18.1	21.3	17.9	23.07778	6.437348	39.5	17.9	mg/kg	0.2
Iron (Fe)-Total	2300	2560	2210	2310	2830	4200	4570	7710	4680	3707.778	1810.233	7710	2210	mg/kg	6
Potassium (K)-Total	1140	1260	1250	1380	1450	3640	1530	634	1240	1502.667	841.4713	3640	634	mg/kg	7
Magnesium (Mg)-Total	1300	1740	1350	1800	1540	3560	3540	3380	4910	2568.889	1298.879	4910	1300	mg/kg	2
Manganese (Mn)-Total	1510	1630	1410	1600	1450	2150	1320	685	1520	1475	379.391	2150	685	mg/kg	0.03
Molybdenum (Mo)-Total	0.8	0.87	0.73	0.78	0.9	1.4	0.92	0.83	0.72	0.883333	0.205973	1.4	0.72	mg/kg	0.02
Sodium (Na)-Total	283	423	359	397	451	1340	404	156	329	460.2222	341.6983	1340	156	mg/kg	2
Nickel (Ni)-Total	4.7	5	4.4	5	6.1	10.8	6.1	9.8	6.4	6.477778	2.287344	10.8	4.4	mg/kg	0.2
Lead (Pb)-Total	11.5	8.75	9.59	8.52	10	7.96	10.4	16.4	7.64	10.08444	2.668286	16.4	7.64	mg/kg	0.05
Selenium (Se)-Total	0.2	0.2	0.2	0.3	0.3	0.3	0.4	0.3	0.4	0.288889	0.078174	0.4	0.2	mg/kg	0.1
Tin (Sn)-Total	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	0			mg/kg	4
Strontium (Sr)-Total	102	119	121	134	145	225	119	50.9	103	124.3222	46.19074	225	50.9	mg/kg	0.02
Titanium (Ti)-Total	118	134	114	106	127	198	229	283	266	175	69.91602	283	106	mg/kg	0.03
Thallium (Tl)-Total	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	0			mg/kg	0.2
Uranium (U)-Total	0.802	0.91	0.819	0.9	0.712	0.831	1.05	0.6	0.897	0.835667	0.128272	1.05	0.6	mg/kg	0.006
Vanadium (V)-Total	8.74	9.23	8.4	8.59	9.7	12.4	12	15.2	12.6	10.76222	2.375651	15.2	8.4	mg/kg	0.06
Zinc (Zn)-Total	154	150	155	176	173	159	100	145	94	145.1111	29.09658	176	94	mg/kg	2
Phosphorus, Total	1770	1770	1640	1960	1900	1980	1150	750	1030	1550	454.2576	1980	750	mg/kg	90
Boron (B), Hot Water Ext.	7.2			5.7					5.5	6.133333	0.929157	7.2	5.5	mg/kg	0.1

	Sample ID									Avg	S	Max	Min	Unit	DL
	OB1.1	OB1.2	OB1.3	OB2.1	OB2.2	OB2.3	OB3.1	OB3.2	OB3.3	OB Avg					
Calcium (Ca)	103	104	99	135	106	128	89	76	88	103.1111	18.79125	135	76	mg/L	2
Potassium (K)	99	99	90	102	88	88	80	92	77	90.55556	8.545629	102	77	mg/L	1
Magnesium (Mg)	61	57	58	78	64	71	56	47	57	61	9.082951	78	47	mg/L	1
Sodium (Na)	55	50	62	47	42	43	45	30	35	45.44444	9.709674	62	30	mg/L	1
SAR	1.1	1	1.2	0.8	0.8	0.8	0.9	0.7	0.7	0.888889	0.176383	1.2	0.7	SAR	0.1
% Saturation	250	240	250	218	243	195	270	335	305	256.2222	42.57281	335	195	%	1
pH in Saturated Paste	7.9	7.7	8.2	7.6	7.5	7.6	7.6	7.5	7.4	7.666667	0.244949	8.2	7.4	pH	0.1
Conductivity Sat. Paste	1.2	1.2	1.2	1.4	1.2	1.3	1.1	1	1.1	1.188889	0.116667	1.4	1	dS m-1	0.1
Mercury (Hg)-Total	0.033	0.037	0.024	0.038	0.041	0.047	0.046	0.046	0.054	0.040667	0.008888	0.054	0.024	mg/kg	0.005
Silver (Ag)-Total	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	0			mg/kg	1
Aluminum (Al)-Total	4450	4750	4380	5550	4980	4730	4520	4060	4590	4667.778	420.4099	5550	4060	mg/kg	3
Arsenic (As)-Total	3.16	3.49	1.82	2.72	2.98	3.29	2.96	4.26	4.58	3.251111	0.816937	4.58	1.82	mg/kg	0.03
Boron (B)-Total	21	22.1	24.9	15.3	14.7	16.6	17.2	19.2	20.1	19.01111	3.389883	24.9	14.7	mg/kg	0.6
Barium (Ba)-Total	328	356	374	226	235	258	279	292	341	296.7778	53.65813	374	226	mg/kg	0.04
Beryllium (Be)-Total	0.26	0.29	0.29	0.57	0.38	0.32	0.32	0.24	0.3	0.33	0.098362	0.57	0.24	mg/kg	0.06
Bismuth (Bi)-Total	0.05	0.04	0.03	0.04	0.03	0.05	0.1	0.05	0.06	0.05	0.021213	0.1	0.03	mg/kg	0.02
Calcium (Ca)-Total	28400	30700	36200	25400	23900	22400	25000	23100	28600	27077.78	4406.466	36200	22400	mg/kg	7
Cadmium (Cd)-Total	1.5	1.54	1.55	0.91	0.98	1.17	1.19	1.36	1.61	1.324444	0.252444	1.61	0.98	mg/kg	0.02
Cobalt (Co)-Total	2.92	2.58	2.71	3.22	2.57	3.03	2.66	2.47	2.23	2.71	0.30282	3.22	2.23	mg/kg	0.01
Chromium (Cr)-Total	12.9	14.9	15.7	20.6	13.8	15.7	13.8	15.2	15.1	15.3	2.204541	20.6	12.9	mg/kg	0.1
Copper (Cu)-Total	27.2	23.4	22.6	19.3	22.1	30	21.7	25.2	29.2	24.52222	3.63276	30	19.3	mg/kg	0.2
Iron (Fe)-Total	4800	4480	5280	5620	6160	5700	4650	4970	4320	5108.889	821.2778	6160	4320	mg/kg	6
Potassium (K)-Total	1320	1500	1270	1180	1340	1270	1300	1390	1500	1341.111	106.7057	1500	1180	mg/kg	7
Magnesium (Mg)-Total	3520	3540	5420	4890	3990	4430	3760	3000	3300	3983.333	789.0342	5420	3000	mg/kg	2
Manganese (Mn)-Total	1660	1780	1970	1500	1180	1290	1350	1240	1510	1497.778	264.9423	1970	1180	mg/kg	0.03
Molybdenum (Mo)-Total	0.78	0.74	0.9	0.85	0.87	0.93	0.73	1.23	0.91	0.882222	0.149731	1.23	0.73	mg/kg	0.02
Sodium (Na)-Total	408	409	510	367	469	372	364	355	399	405.8889	52.30785	510	355	mg/kg	2
Nickel (Ni)-Total	9.3	8.3	9.1	10.2	8.7	9.3	8.6	7.5	7.3	8.7	0.91515	10.2	7.3	mg/kg	0.2
Lead (Pb)-Total	12.6	15.1	9.51	11.3	11.5	14.9	13.5	15.5	19	13.65667	2.83106	19	9.51	mg/kg	0.05
Selenium (Se)-Total	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.3	0.233333	0.05	0.3	0.2	mg/kg	0.1
Tin (Sn)-Total	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	0			mg/kg	4
Strontium (Sr)-Total	113	123	139	82.9	85.6	92.3	99.6	99.1	117	105.7222	18.61899	139	82.9	mg/kg	0.02
Titanium (Ti)-Total	220	210	202	228	233	266	228	236	190	223.6667	22	266	190	mg/kg	0.03
Thallium (Tl)-Total	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	0			mg/kg	0.2
Uranium (U)-Total	0.719	0.741	0.63	0.793	0.781	0.783	0.716	0.767	0.946	0.764	0.084733	0.946	0.63	mg/kg	0.006
Vanadium (V)-Total	13.9	13.8	14	15.4	12.4	15.1	13	12.6	13.3	13.72222	1.03293	15.4	12.4	mg/kg	0.06
Zinc (Zn)-Total	180	171	165	120	118	134	141	161	183	152.5556	24.9455	183	118	mg/kg	2
Phosphorus, Total	1550	1590	1370	1210	1340	1320	1410	1490	1450	1414.444	119.5842	1590	1210	mg/kg	90
Boron (B), Hot Water Ext.		5.6		5			5.7			5.433333	0.378594	5.7	5	mg/kg	0.1

S(2)	Sample ID												Unit	Min	Max	S	Avg	DL
	S1.1	S1.2	S1.3	S2.1	S2.2	S2.3	S3.1	S3.2	S3.3	S Avg	S	Avg						
Calcium (Ca)	178	153		191	169	230	165	179	164	187	179.5556	22.37248	230	153	mg/L			2
Potassium (K)	49	45		50	56	47	52	35	19	33	42.88889	1.69877	56	19	mg/L			1
Magnesium (Mg)	34	36		29	50	57	39	30	35	41	39	9.219544	57	29	mg/L			1
Sodium (Na)	8	9		3	13	14	9	2	7	10	8.333333	4	14	2	mg/L			1
SAR	0.1	0.2	<0.1	0.2	0.2	0.2	0.2	<0.1	0.1	0.2	0.171429	0.048795	0.2	0.1	SAR			0.1
% Saturation	215	230		243	260	248	255	240	250	235	245.1111	19.7259	285	215	%			1
pH in Saturated Paste	7.2	7.2		7.3	7.2	7.3	7.2	7.5	7.2	7.4	7.277778	0.109291	7.5	7.2	pH			0.1
Conductivity Sat. Paste	1	0.9		1	1.1	1.3	1	0.9	0.8	1	1	0.141421	1.3	0.8	dS m ⁻¹			0.1
Mercury (Hg)-Total	0.05	0.051		0.057	0.059	0.051	0.06	0.051	0.05	0.052	0.054556	0.004613	0.061	0.05	mg/kg			0.005
Silver (Ag)-Total	<1	<1		<1	<1	<1	<1	<1	<1	<1	<1	0	0		mg/kg			1
Aluminum (Al)-Total	4690	5740		4240	4330	4620	4230	3850	4610	4650	4557.778	519.1045	5740	3850	mg/kg			3
Arsenic (As)-Total	1.9	2		1.97	2.2	2.88	2.46	2.25	1.9	2.41	2.22	0.327796	2.89	1.9	mg/kg			0.03
Boron (B)-Total	13.6	20.7		17.1	15.7	17.6	16.5	18	15.6	17.7	16.94444	1.967937	20.7	13.6	mg/kg			0.6
Barium (Ba)-Total	185	216		234	198	238	217	225	190	238	215.6687	20.41446	238	185	mg/kg			0.04
Beryllium (Be)-Total	0.39	0.64		0.4	0.54	0.46	0.44	0.39	0.5	0.6	0.484444	0.092481	0.64	0.39	mg/kg			0.06
Bismuth (Bi)-Total	0.04	0.03		0.03	0.03	0.04	0.04	0.07	0.04	0.04	0.04	0.012247	0.07	0.03	mg/kg			0.02
Calcium (Ca)-Total	21100	30900		26900	26400	27800	24800	26200	27000	29100	26888.89	2739.728	30900	21100	mg/kg			7
Cadmium (Cd)-Total	0.78	0.84		1.01	0.78	0.94	0.96	0.99	0.84	1.02	0.905556	0.096451	1.02	0.78	mg/kg			0.02
Cobalt (Co)-Total	2.24	1.82		2.21	1.33	1.54	1.46	1.12	1.5	1.37	1.621111	0.38979	2.24	1.12	mg/kg			0.01
Chromium (Cr)-Total	10.2	8.6		8.3	8.3	9.5	10.4	8.5	10.9	8.9	9.288889	0.994289	10.9	8.3	mg/kg			0.1
Copper (Cu)-Total	21.1	17.7		19.3	22.5	31.7	21.3	19.2	18.5	19	21.14444	4.241495	31.7	17.7	mg/kg			0.2
Iron (Fe)-Total	4680	5150		3230	3280	5220	3610	2510	3710	2980	3816.667	971.5966	5220	2510	mg/kg			6
Potassium (K)-Total	1070	1240		1130	1110	1470	1210	1040	974	1240	1164.889	146.4927	1470	974	mg/kg			7
Magnesium (Mg)-Total	3240	4370		3010	3970	3540	4040	2980	3590	4720	3762.222	608.1484	4720	2980	mg/kg			2
Manganese (Mn)-Total	1190	1520		1390	1250	1470	1350	1380	1380	1500	1381.111	109.5952	1520	1190	mg/kg			0.03
Molybdenum (Mo)-Total	0.8	0.62		0.63	0.71	0.96	0.76	0.89	0.67	0.7	0.748889	0.116237	0.96	0.62	mg/kg			0.02
Sodium (Na)-Total	202	272		207	218	338	245	236	239	300	251.2222	45.18788	339	202	mg/kg			2
Nickel (Ni)-Total	7.2	5.2		6.1	5.5	7.2	6.4	5	6.1	5.3	6	0.824621	7.2	5	mg/kg			0.2
Lead (Pb)-Total	7.97	6.99		9	8.61	9.3	10.2	8.29	8.76	10.6	8.88	1.098818	10.6	6.99	mg/kg			0.05
Selenium (Se)-Total	0.2	0.4		0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.05	0.4	0.2	mg/kg			0.1
Tin (Sn)-Total	<4	<4		<4	<4	<4	<4	<4	<4	<4	<4	0	0		mg/kg			4
Strontium (Sr)-Total	78.8	119		107	96.1	109	103	104	91.2	113	102.3444	12.13272	119	78.8	mg/kg			0.02
Titanium (Ti)-Total	195	209		152	164	155	166	130	184	163	168.6667	23.91652	209	130	mg/kg			0.03
Thallium (Tl)-Total	<0.2	<0.2		<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	0	0		mg/kg			0.2
Uranium (U)-Total	0.709	1.63		0.787	0.799	0.865	0.918	0.727	0.827	0.832	0.899333	0.281464	1.63	0.709	mg/kg			0.006
Vanadium (V)-Total	11.5	9.19		8.21	8.7	8.25	9.33	7.28	9.44	8.69	8.954444	1.167316	11.5	7.28	mg/kg			0.06
Zinc (Zn)-Total	77	76		97	87	103	105	106	95	108	94.88889	12.28255	108	76	mg/kg			2
Phosphorus, Total	1190	1330		1330	1190	1350	1130	1300	1250	1290	1266.667	77.13624	1350	1130	mg/kg			90
Boron (B)-Hot Water Ext.	4.4			5.8					4.4		4.868667	0.80929	5.8	4.4	mg/kg			0.1

Ch. 8 - Leachate data

21-Jul

	NO3(mg/L)	PO4(mg/L)	NH3(mg/L)	pH
A1	0.84	6.6	0.072	7.91
A2	1.04	6.1	0.144	8.04
A3	1.12	5.3	0.312	8.01
B1	1.84	4.7	0.192	7.91
B2	5.4	5.4	0.264	7.84
B3	4.44	3.3	0.12	7.84
Control	0.16	0.34	0	7.26

8-Aug

	NO3(mg/L)	PO4(mg/L)	NH3(mg/L)	pH
A1	0.84	0.8	0	7.73
A2	0.28	1.92	0.024	7.54
A3	0.48	1.08	0.048	7.79
B1	1.8	3.6	0.024	7.47
B2	2.56	3.8	0.096	7.7
B3	1.24	2.9	0.096	7.63
Control	0.08	0.26	0.096	7.5

17-Aug

	NO3(mg/L)	PO4(mg/L)	NH3(mg/L)	pH
A1	1.28	3.8	0.12	7.65
A2	0.88	0.58	0.12	7.61
A3	1.12	6.2	0.096	7.56
B1	3.44	0.5	0.048	7.53
B2	2.2	0.72	0.096	7.47
B3	1.52	2.3	0.024	7.49
Control	0.2	0.16	0.144	6.06

24-Aug

	NO3(mg/L)	PO4(mg/L)	NH3(mg/L)	pH
A1	1.88	4	0.384	7.91
A2	0.64	4.5	0.072	7.98
A3	0.28	3.4	0.072	7.19
B1	4.48	1.54	0.024	8.01
B2	1.64	2.3	0.192	7.43
B3	2.72	1.52	0	7.55
Control	1.24	0	0.216	5.42

8-Sep

	NO3(mg/L)	PO4(mg/L)	NH3(mg/L)	pH
A1	0.76	3.8	0.048	7.74
A2	1.12	4.3	0.144	7.89
A3	1.4	4.8	0.072	7.59
B1	5.2	2.6	0.264	7.71
B2	6	3.5	0.384	7.6
B3	1.84	2.9	0.12	7.71
Control	0.04	0	>2.4	4.52

Average conc.

NO3	A (mg/L)	B (mg/L)	Control (mg/L)
21-Jul	1.00	3.89	0.16
8-Aug	0.53	1.87	0.08
17-Aug	1.09	2.39	0.20
24-Aug	0.93	2.95	1.24
8-Sep	1.09	4.35	0.04

St. Dev (S)

21-Jul	0.14	1.84
8-Aug	0.28	0.66
17-Aug	0.20	0.97
24-Aug	0.84	1.43
8-Sep	0.32	2.21
Sum of S	1.79	7.12

Average conc.

PO4	A (mg/L)	B (mg/L)	Control (mg/L)
21-Jul	6.00	4.47	0.34
8-Aug	1.27	3.43	0.26
17-Aug	3.53	1.17	0.16
24-Aug	3.97	1.79	0.00
8-Sep	4.30	3.00	0.00

St. Dev (S)

21-Jul	0.66	1.07
8-Aug	0.58	0.47
17-Aug	2.82	0.88
24-Aug	0.55	0.44
8-Sep	0.50	0.46
Sum of S	5.11	3.43

Average conc.

NH3	A (mg/L)	B (mg/L)	Control (mg/L)
21-Jul	0.18	0.19	0.00
8-Aug	0.02	0.07	0.10
17-Aug	0.11	0.06	0.14
24-Aug	0.18	0.07	0.22
8-Sep	0.09	0.26	>2.4

St. Dev (S)

21-Jul	0.12	0.07
8-Aug	0.02	0.04
17-Aug	0.01	0.04
24-Aug	0.18	0.10
8-Sep	0.05	0.13
Sum of S	0.39	0.39

Ch. 8 - Leachate pH data

Measured pH over course of study

	Measured pH over course of study	
	A	B
	7.91	7.91
	8.04	7.84
	8.01	7.84
	7.73	7.47
	7.54	7.7
	7.79	7.63
	7.65	7.53
	7.61	7.47
	7.56	7.49
	7.91	8.01
	7.98	7.43
	7.19	7.55
	7.74	7.71
	7.89	7.6
	7.59	7.71
Avg	7.74	7.66
Std. Dev.	0.23	0.18

	St. Mary's biosolids	St. Mary's biosolids & wood waste	
	Group A	Group B	Control
Average	7.74	7.66	6.2
Range	7.19 - 8.04	7.43 - 8.01	4.52 - 7.5
Std. Dev.	0.23	0.18	1.3

Ch. 8 - - Leachate NH3 & NO3 data

21-Jul	NO3(mg/L)	NH3(mg/L)	mol of N as NH3/L	additional NO3(mg/L)	Total NO3(mg/L)
A1	0.84	0.07	4.24E-06	0.26	1.10
A2	1.04	0.14	8.47E-06	0.53	1.57
A3	1.12	0.31	1.84E-05	1.14	2.26
B1	1.84	0.19	1.13E-05	0.70	2.54
B2	5.40	0.26	1.55E-05	0.96	6.36
B3	4.44	0.12	7.06E-06	0.44	4.88
Control	0.16	0.00	0.00E+00	0.00	0.16

8-Aug	NO3(mg/L)	NH3(mg/L)	mol of N as NH3/L	additional NO3(mg/L)	Total NO3(mg/L)
A1	0.84	0.00	0.00E+00	0.00	0.84
A2	0.28	0.02	1.41E-06	0.09	0.37
A3	0.48	0.05	2.82E-06	0.18	0.66
B1	1.80	0.02	1.41E-06	0.09	1.89
B2	2.56	0.10	5.65E-06	0.35	2.91
B3	1.24	0.10	5.65E-06	0.35	1.59
Control	0.08	0.10	5.65E-06	0.35	0.43

17-Aug	NO3(mg/L)	NH3(mg/L)	mol of N as NH3/L	additional NO3(mg/L)	Total NO3(mg/L)
A1	1.28	0.12	7.06E-06	0.44	1.72
A2	0.88	0.12	7.06E-06	0.44	1.32
A3	1.12	0.10	5.65E-06	0.35	1.47
B1	3.44	0.05	2.82E-06	0.18	3.62
B2	2.20	0.10	5.65E-06	0.35	2.55
B3	1.52	0.02	1.41E-06	0.09	1.61
Control	0.20	0.14	8.47E-06	0.53	0.73

24-Aug	NO3(mg/L)	NH3(mg/L)	mol of N as NH3/L	additional NO3(mg/L)	Total NO3(mg/L)
A1	1.88	0.38	2.26E-05	1.40	3.28
A2	0.64	0.07	4.24E-06	0.26	0.90
A3	0.28	0.07	4.24E-06	0.26	0.54
B1	4.48	0.02	1.41E-06	0.09	4.57
B2	1.64	0.19	1.13E-05	0.70	2.34
B3	2.72	0.00	0.00E+00	0.00	2.72
Control	1.24	0.22	1.27E-05	0.79	2.03

8-Sep	NO3(mg/L)	NH3(mg/L)	mol of N as NH3/L	additional NO3(mg/L)	Total NO3(mg/L)
A1	0.76	0.05	2.82E-06	0.18	0.94
A2	1.12	0.14	8.47E-06	0.53	1.65
A3	1.40	0.07	4.24E-06	0.26	1.66
B1	5.20	0.26	1.55E-05	0.96	6.16
B2	6.00	0.38	2.26E-05	1.40	7.40
B3	1.84	0.12	7.06E-06	0.44	2.28
Control	0.04	>2.4	>0.00014	>8.75	>8.79

Average conc.

NO3	A (mg/L)	B (mg/L)	Control (mg/L)
21-Jul	1.64	4.91	0.16
8-Aug	0.62	2.13	0.43
17-Aug	1.50	3.50	0.73
24-Aug	1.58	3.21	2.03
8-Sep	1.41	5.28	>8.79

St. Dev (S)

21-Jul	0.24	2.07
8-Aug	0.20	0.69
17-Aug	0.20	1.83
24-Aug	1.49	1.19
8-Sep	0.42	2.67

Sample calculation - additional NO3 from oxidation of NH3:

Nitrogen - 14 g/mol

NO3 - 1(14) + 3(16) = 62 g/mol

NH3 - 1(14) + 3(1) = 17 g/mol

[NH3] = 0.07 mg/L

mol of N as

NH3/L = 0.07mg/L / 1000 mg/g / 17 g/mol
= 4.24E-06

add'n

NO3(mg/L) = 4.24E-06 * 62g/mol * 1000mg/g
= 0.26 mg/L

Ch. 8 - Leachate phosphate data

21-Jul

	PO4(mg/L)	PO4 mg/L as P
A1	6.6	2.59
A2	6.1	2.39
A3	5.3	2.08
B1	4.7	1.84
B2	5.4	2.12
B3	3.3	1.29
B3 rep	3.3	1.29
TAP	0.34	0.13

8-Aug

	PO4(mg/L)	PO4 mg/L as P
A1	0.8	0.31
A2	1.92	0.75
A3	1.08	0.42
B1	3.6	1.41
B2	3.8	1.49
B3	2.9	1.14
B2 rep	3.9	1.53
Base	0.26	0.10

17-Aug

	PO4(mg/L)	PO4 mg/L as P
A1	3.8	1.49
A2	0.58	0.23
A3	6.2	2.43
B1	0.5	0.20
B2	0.72	0.28
B3	2.3	0.90
Base	0.16	0.06
Rep	3.3	1.29

24-Aug

	PO4(mg/L)	PO4 mg/L as P
A1	4	1.57
A2	4.5	1.77
A3	3.4	1.33
B1	1.54	0.60
B2	2.3	0.90
B3	1.52	0.60
Base	0	0.00
Rep A1	4.06	1.59

8-Sep

	PO4(mg/L)	PO4 mg/L as P
A1	3.8	1.49
A2	4.3	1.69
A3	4.8	1.88
B1	2.6	1.02
B2	3.5	1.37
B3	2.9	1.14
Base	0	0.00
Rep	0	0.00

Average Phosphate Concentration as Phosphorous

Average Phosphate Concentration as Phosphorus			
	Average		
	A	B	Control
Date	mg/L		
21-Jul	2.35	1.75	0.34
8-Aug	0.50	1.35	0.26
17-Aug	1.38	0.46	0.16
24-Aug	1.56	0.70	0.00
8-Sep	1.69	1.18	0.00

Standard Deviation

Date	A	B
	mg/L	
21-Jul	0.26	0.42
8-Aug	0.23	0.19
17-Aug	1.11	0.39
24-Aug	0.22	0.17
8-Sep	0.20	0.18

Sample conversion of [PO4] to [PO4] as P

Phosphorous - 31 mg/mmol

Oxygen - 16 mg/mmol

$$\text{PO}_4 \text{ (mg/mmol)} = (31 \times 1) + (16 \times 3) \\ = 79 \text{ mg/mol}$$

$$[\text{PO}_4] = 6.6 \text{ mg/L} \\ = 6.6 \text{ mg/L} / (79 \text{ mg/mmol}) \times (31 \text{ mg/mmol}) \\ = 2.59 \text{ mg/L as P}$$