



**Ontario Forest  
Industries Association**

## **TECHNICAL ANNEX**

# **GUIDELINES FOR THE UTILIZATION OF PULP AND PAPER MILL BIOSOLIDS IN SILVICULTURE AND LAND RECLAMATION**

Prepared for:

**ONTARIO FOREST  
INDUSTRIES ASSOCIATION**

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**WATER AND EARTH  
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In Association with:

**DR. THOMAS E. BATES  
and  
LAFLEUR DE LA CAPITALE INC.**



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September, 1999

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## **1.0 INTRODUCTION**

The purpose of this document is to provide the technical support and rationale to the guidelines outlined in the accompanying document, entitled *Guidelines for the Utilization of Pulp and Paper Mill Biosolids in Silviculture and Land Reclamation*. (Working Draft dated February 1999). Considerable research effort has been directed to the utilization of pulp and paper mill biosolids (PPMB) and other potentially beneficial residues in the areas of forestry and land reclamation. It is the goal of this document to highlight some of that research and experience, and to identify the issues of importance, both from a forest productivity point of view and areas of potential environmental concern.

### **1.1 PPMB Overview**

For the purposes of this technical support document and the accompanying guidelines, the scope of PPMB materials is limited to the following residues from mill wastewater treatment systems and de-inking processes:

- Solid residues from primary wastewater treatment (primary clarifier fibre);
- Solids from secondary treatment processes;
- Combined primary and secondary biosolid residues; and
- Biosolids from de-inking processes.

A brief description of each of these materials is provided below.

#### **Primary Treatment Biosolids:**

These are solid residues derived from the primary treatment of pulp and paper mill wastewaters using physical and chemical sedimentation processes. Primary biosolids are produced from sedimentation in primary clarifiers or large settling basins; flocculants may be added to promote settling of the solids. In some mills (eg., some board mills) the primary solids are recycled directly back into the manufacturing process (Reid, 1997).

When they are dewatered, these materials have a solids content of approximately 20 – 45%, with the solids consisting of roughly 85% wood fibres, 10% calcium carbonate, and 5% inorganic clay and ash particles (dry weight basis). Other trace components may include pigments and ink solids, soil, grit and miscellaneous inorganic solids.

Primary biosolids have a low nutrient content and a high C:N ratio, and consequently are of limited value as fertilizers. However, these materials have a high organic content and are of value in supplying organic matter to soils, and as a mulch for moisture retention, weed control and erosion prevention.

### **Secondary Treatment Biosolids:**

Secondary pulp and paper mill biosolids are produced from the sedimentation of biologically treated wastewater, and are composed primarily of microbial biomass, with minor components of other inorganic and organic solids. With few exceptions, secondary treatment systems at Ontario pulp and paper mills use aerobic microbiologic processes. Micro-organisms in the secondary treatment process use the organics in the wastewater as food, increasing the microbial mass. Nitrogen and phosphorus added as nutrients to biological systems treating pulp and paper mill wastewaters tend to be retained by the biomass and are therefore components of these biosolids (NCASI, 1993)

Secondary biosolids have a much lower solids content than primary biosolids because they are composed of biological cells, which contain water inside the cells. The materials are very difficult to dewater since the cell walls must be broken to release the water and raise the solids content. For practical purposes, secondary biosolids behave as a liquid and must be combined with primary biosolids to be dewatered and land applied as solid materials.

Secondary biosolids generally have a higher metals content than primary materials due to the uptake of metals by the biomass, and as a result of concentration effects due to the lower solids content (NCASI, 1984a. Other characteristics of the secondary biosolids, such as the solids content and chemical composition (eg., concentrations of parameters such as sulphate, sodium, chloride, etc.) are dependent on the feedstock, the pulping and manufacturing processes of the mill (for example, mechanical or thermomechanical vs. chemical pulping), and paper-recycling operations.

**Combined Biosolids:**

Combined biosolids consist of a mixture of primary and secondary biosolids, which are blended to allow dewatering of the secondary materials. The properties of the combined biosolids vary considerably, and will reflect the properties of the primary and secondary biosolids based on the mixture ratio, which may range anywhere from 5% to 75% secondary biosolids (NCASI, 1993).

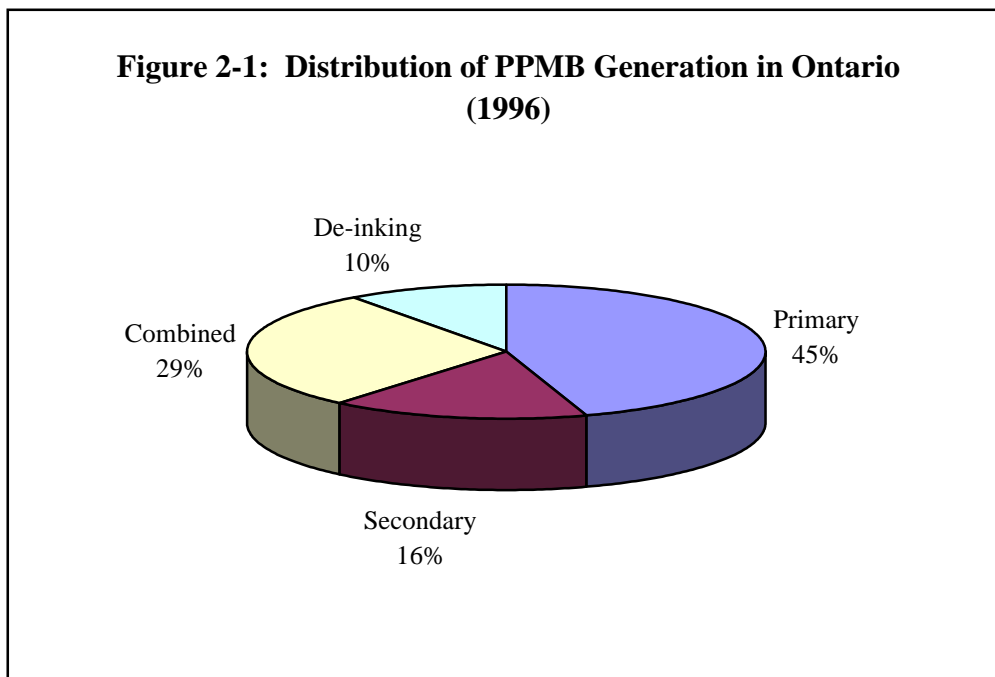
Combined biosolids can be dewatered to 30% to 50% total solids, depending on the mixture ratio. These materials are valuable for supplying macro- and micro-nutrients to plants, and organic matter to soils. The C:N ratio of these materials may range from under 30:1 to greater than 100:1, again depending on the ratio of primary to secondary biosolids.

**Solid De-inking Residues:**

This category refers to the primary, secondary or combined biosolids that are generated at de-inking mills that manufacture paper products from recycled de-inked fibre (RDF) feedstock. Newsprint and waste fine papers can be re-pulped and de-inked, and then processed to produce tissue, newsprint and other paper products. The nature of the de-inking biosolids will largely depend on the wastewater treatment process used at the mill; however, they will generally be composed of paper fibre, microbial cells (if secondary treatment is used), carbonate and clay fillers, and some inorganic materials (ink residues, ash, etc.). The de-inking residues can be expected to have similar characteristics and beneficial uses as other PPMB's.

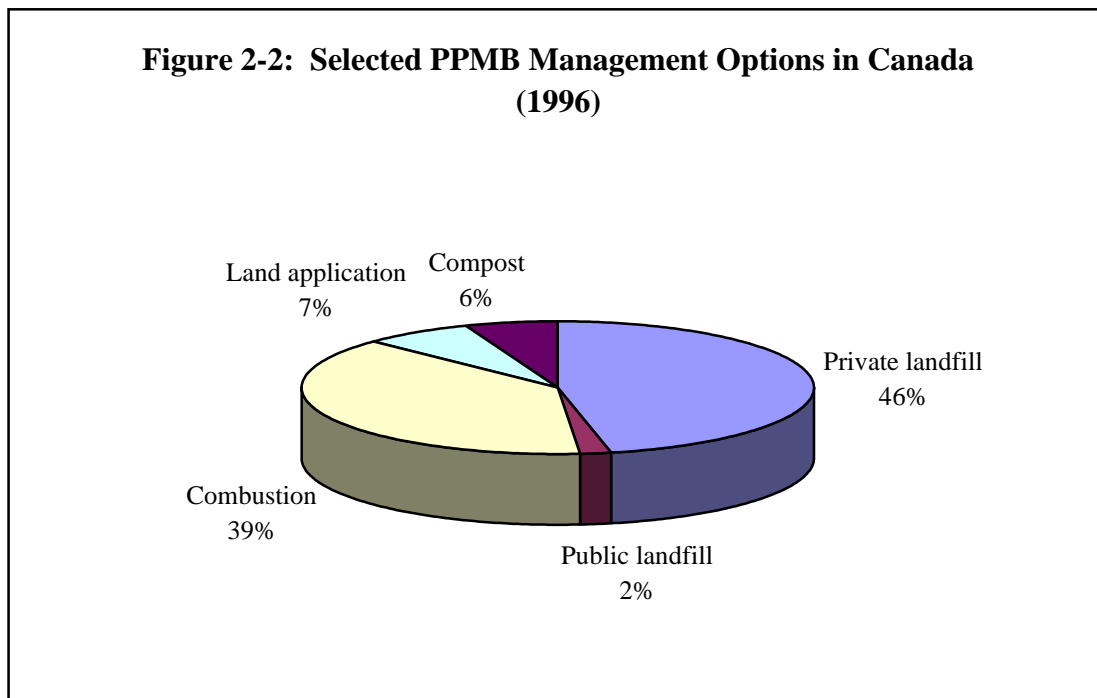
## **1.2 PPMB GENERATION AND MANAGEMENT IN ONTARIO**

Pulp and paper mills in Ontario generate approximately 350,000 dry tonnes of PPMB annually, which represents 20% of the estimated annual PPMB generation of 1.7 million dry tonnes in Canada (Reid, 1997). From information collected by the Pulp and Paper Research Institute of Canada in January 1996 (Reid, 1997), representing seven Ontario mills (including chemical pulping, newsprint, de-inking operations, board, and multi-product mills), the distribution of the types of biosolids generated was as illustrated below in Figure 1-1.



This distribution is expected to change as more mills implement secondary wastewater treatment processes to meet stringent effluent criteria.

The majority of PPMB generated in Ontario are disposed at landfills (primarily privately-owned, with a small percentage sent to public sites), or by combustion as fuel in boilers at the mill sites. A small proportion of the biosolids are land applied; however, the percentage of land application appears to be increasing from year to year as the practice becomes more widely accepted. Recent data from 55 Canadian forestry product mills (Reid, 1997) indicate the distribution of selected management options for biosolids as shown below in Figure 1-2.



The data for Canada are believed to be fairly representative of Ontario conditions, except that the amounts of PPMB being land applied may be higher, and the proportion being combusted may be smaller than the national average.

In the United States, it is estimated that about 12% of the pulp and paper mill biosolids is land-applied, while approximately 46% is landfilled (Vance, 1997).

The reliance on landfilling as the predominant means of biosolids management reflects a continued perception of biosolids as unwanted residues that require disposal, rather than materials with intrinsic value to forestry and agricultural production. Certainly, the economics of land application versus landfill disposal play a critical role in the selection of residue management options. However, it has been demonstrated that land applications of biosolids to forests and land reclamation sites can be economically viable and environmentally sustainable when managed responsibly.

### **1.3 HISTORY OF PPMB UTILIZATION IN ONTARIO**

The use of PPMB in agricultural land applications in Ontario was first established in the Niagara region in the early 1980's (Bellamy et al., 1990), where it was recognized that the material was a rich source of organic matter that could be used as a substitute for animal manure. In other jurisdictions, the beneficial use of PPMB for agricultural and non-agricultural purposes is also well established (eg., Bockheim et al, 1988; Morris and Nutter, 1997; NCASI, 1983; Vance, 1997).

Approvals from the MOE for organic soil conditioning sites involving the agricultural usage of PPMB have now become fairly routine, due in large part to the positive documented crop response to the applications (Bellamy et al., 1995; Curnoe and Dow, 1996). Specific guidelines for the use of PPMB in agricultural land applications are currently in preparation in Ontario, as well as in other jurisdictions in Canada (Alberta Environmental Protection, 1998; MOE, 1998; AIFQ/MEF, 1997). The development of these guidelines reflects the growing interest in the use of PPMB as a valuable resource for soil improvement and crop management.

Since the late 1980's, non-agricultural land applications of PPMB have been developed in Ontario. These have included silviculture sites, nursery pot trials, and land reclamation projects (Chong, 1996; Domtar, 1998; WESA, 1998). This growth in experience as well as considerable experience in other jurisdictions in the use of PPMB and municipal wastewater treatment biosolids has led to the development of safe management practices for these non-agricultural land application programs (eg., GVRD, 1998; Leonard and McKinney, 1997; Sopper, 1993).

## **2.0 OPPORTUNITIES FOR BENEFICIAL UTILIZATION OF PPMB**

It has been demonstrated that, when properly managed, applications of PPMB to forest soils and land reclamation sites can provide benefits through accelerated biomass production and improvements to soil quality, without adverse effects to the environment. In fact, in many situations there is a potential for net positive environmental effects, through a reduction in soil erosion, enhanced moisture retention, and a reduced reliance on organic chemical herbicides and inorganic fertilizers.

Pulp and paper mill biosolids are rich in organic matter and contain moderate levels of nutrients suitable for fertilization. The physical and chemical properties of PPMB largely depend on the nature of the pulping and paper-making or recycling processes, the wastewater treatment processes, as well as the material feedstock used at the mill. Typical ranges of the relevant physical and chemical characteristics of the PPMB categories are presented in Table 2-1. Note that individual mills may produce PPMB of differing characteristics to the ranges shown in the table. A discussion of the importance of the various characteristics of PPMB is presented below in Section 2.1.

**Table 2-1: Typical Ranges of Physical and Chemical Properties of PPMB**

Parameter	Units	PPMB Category	
		Primary	Combined
Total solids	% (wet basis)	20 – 57	24-55
Volatile solids	%	33 – 85	30-87
pH	---	7.1 - 8.0	6.2 – 8.8
Organic carbon	%	16 – 40	14 – 41
C:N ratio	---	100:1 – 850:1	16:1 – 250:1
Total nitrogen	mg/kg	400 – 6900	1000 – 25000
Ammonia	mg/kg	5 – 300	10 – 1500
Nitrate	mg/kg	---	<1 – 20
Phosphorus (total)	mg/kg	140 – 1000	200 – 2500
Potassium	mg/kg	120 –2600	15 – 2000
Calcium	%	0.5 – 12	0.1 – 8
Magnesium	mg/kg	200 – 3500	400 – 2600
Sulphate	mg/kg	800 – 3000	150 – 4000
Aluminum	mg/kg	1000 – 10000	1000 – 5000
Arsenic	mg/kg	<0.005 - <10	<0.1 – 3
Boron	mg/kg	---	5 – 15
Cadmium	mg/kg	0.003 – 1.6	<0.2 – 2
Chromium	mg/kg	1.9 – 34	<1 – 20
Cobalt	mg/kg	<1 – 3	<0.6 – 5
Copper	mg/kg	7.5 – 55	<5 – 300
Lead	mg/kg	<0.01 – 30	<1 – 30
Manganese	mg/kg	55 – 1400	---
Mercury	mg/kg	<0.001 – 0.2	<0.001 – 0.2
Molybdenum	mg/kg	0.5 - <2	<0.5 – 5
Nickel	mg/kg	2.5 – 20	<1 – 15
Selenium	mg/kg	<0.005 - <5	<0.005 - <1
Zinc	mg/kg	15 – 50	<10 - 450

Notes:

1. All units expressed on dry weight basis except where noted.
2. Organic carbon contents estimated as 47% of volatile solids.
3. Information gathered from Bellamy et al., 1995; MOE, 1998; Alberta Environmental Protection, 1998; NCASI, 1984b and Domtar, 1998.

## **2.1 BENEFICIAL CHARACTERISTICS OF PPMB**

The important characteristics of PPMB related to their application in forestry and land reclamation projects are described below. Also described are the elements and compounds that are potentially found in PPMB and that need to be monitored to ensure that they do not cause adverse effects on the environment.

### **pH (a measure of acidity or alkalinity)**

The pH of materials applied to bare soils is not critical unless application rates are very high. The pH of materials applied to established crops should be in the range of 6.0 to 8.5 to prevent damage to the crop.

Application of materials relatively high in metals are restricted to soils with pH values of 6.0 or above because most metals are markedly more soluble and plant available in acid soils. Most forested sites in Ontario are acid and materials low in metal content are suitable for application to acid soils.

### **Organic Matter**

Organic matter is best estimated from organic carbon content. Almost all mineral soils in Ontario would be improved by increasing the organic matter content. Organic matter in soils helps to cement the porous groups of soil particles (aggregates) together making them more resistant to dispersion by raindrops, running water or cultivation. By reducing dispersion, organic matter makes soils more resistant to erosion and easier to penetrate by plant roots, water and air. Better water penetration makes soils more drought resistant as does the deeper root penetration in porous soils. Organic matter in soils also increases the storage capacity for plant nutrients. Materials high in organic carbon are therefore of great benefit for soil application.

### **Nitrogen**

Nitrogen is an expensive plant nutrient to which all plants except legumes and a few other species such as alders have a continuing requirement. Nitrogen in forest systems is generally inadequate for maximum productivity, since land of higher productivity is most often used for agricultural uses (Henry, 1997). Similarly, mineral soils remaining at surface following

aggregate extraction are generally low in nitrogen and of negligible productivity without fertilization and development of organic matter. The plant available nitrogen in PPMB is therefore of considerable value for tree production and land reclamation.

Most of the nitrogen in PPMB is initially found in the organic form, but when land applied, the nitrogen can have a dynamic nature, cycling between various forms of available and immobilized N, as illustrated schematically on Figure 2-3. Accurate predictions of the additions of plant available N (mineralization) and losses (plant uptake, volatilization, leaching, etc.) are very difficult, as are the determinations of the nitrogen storage capacity of the soil. However, it has been demonstrated that nitrogen loadings that exceed the assimilative capacity of the soil system (including the vegetation requirements) can result in nitrate leaching (Bockheim et al, 1988; Brockway and Urie, 1983; Cole, 1997), which can lead to groundwater pollution.

Nitrogen dynamics in forest systems are of added complexity as compared to agricultural land applications in that: i) the crops are perennial with changing N-requirements as the trees mature, ii) the understory must also be considered as a nitrogen sink, iii) there is a continuing recycling of nutrients through decaying leaves, litter fall, branches, etc., and iv) there is no annual harvest of the crop (ie., removal of nitrogen from the system) (Henry, 1997).

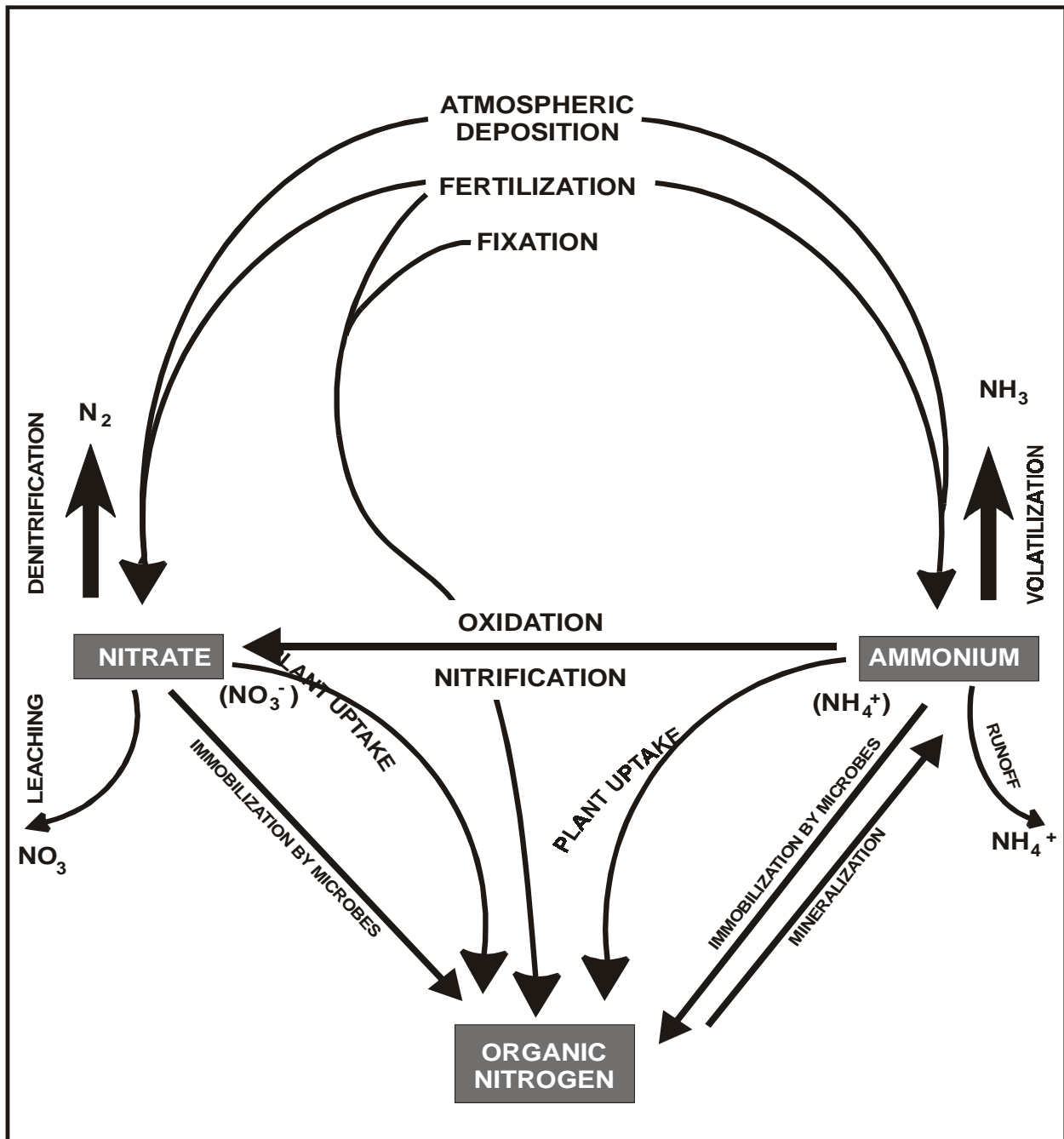


FIGURE: 2-1  
**THE NITROGEN CYCLE: INPUTS, TRANSFORMATIONS AND LOSSES**  
 (AFTER HENRY, 1997)

**C:N Ratio** (organic carbon to total nitrogen)

As materials with low C:N ratios break down in the soil they release plant available nitrogen. Materials with high C:N ratios (usually above 30:1) such as most primary PPMBs rob the soil of nitrogen during early stages of decomposition depleting supplies for plant growth. The C:N ratio is therefore a very useful tool for estimating plant available nitrogen.

**Phosphorus**

Phosphorus is a plant nutrient which is low in most Ontario soils unless they have had a long history of fertilization. Established trees are more able than most annual crops to obtain phosphorus from the soil because of the mycorrhizal fungi associated with their roots. Phosphorus is not very water soluble in soils but can wash off the surface, mostly on soil particles during soil erosion, to pollute surface waters. Primary PPMBs are usually low in phosphorus but secondary and combined PPMBs can contain appreciable amounts and have value as sources of phosphorus.

**Potassium**

Potassium is an important plant nutrient but the content is low in most paper wastes. It is rarely of concern as a water pollutant.

**Calcium**

Calcium is a plant nutrient which is not deficient for plant growth in Ontario except in acid soils. Calcium in the form of lime is commonly used to neutralize soil acidity and is therefore of benefit on acid soils. It is rarely a water pollutant. Calcium is present in PPMBs.

**Magnesium**

Magnesium is a plant nutrient which can be deficient for plant growth in acid or very sandy Ontario soils. It is present in significant concentrations in some PPMBs. Magnesium in PPMBs is not likely to be of concern as a pollutant.

## **2.2 ELEMENTS OF POTENTIAL ENVIRONMENTAL CONCERN**

### **Arsenic**

Arsenic is not required by plants or animals but at higher concentrations can be toxic to both. Once in the soil it can remain there for a very long time. In PPMBs it is not likely to be at concentrations of concern.

### **Boron**

Boron is a “micronutrient” (required by plants but in quite small amounts). The range of concentrations between deficient and toxic to plants is quite small. For plant growth, amounts of boron which are safe to apply in the short term are lower than any element in this list, except molybdenum. It is therefore imperative that boron content of any material for application to land be tested occasionally. Boron does leach from soils, so long term accumulations are less critical than for most heavy metals. There is little concern of boron toxicity to animals or aquatic organisms from soil application; however, the province has established an interim maximum acceptable concentration of 5 mg/L for boron in drinking water samples.

### **Copper, Zinc & Nickel**

These are micronutrients and also heavy metals. Some Ontario soils are deficient in zinc for some crops, particularly in soils high in plant available phosphorus. Copper can be deficient on organic soils. Nickel has not been found to be deficient in Ontario soils. Zinc and nickel are more soluble and plant available in acid soils. At high concentrations all three can be toxic to plants and animals and aquatic organisms. Once in the soil they can remain there for hundreds of years. Concentrations in PPMBs are usually low.

### **Molybdenum**

The comments about copper, zinc and nickel apply to molybdenum except that it is less soluble and plant available in acid soils. It also can leach out of soils much more readily. Molybdenum requirements of plants are very small. It should be monitored in PPMBs. It should be recognised that the method detection limits for molybdenum used by some laboratories are not sufficiently low for their data to be useful in terms of plant requirements.

### **Cadmium and Mercury**

These heavy metals are not required by plants but can be taken up by them and are toxic to both plants and animals. Once in the soil they can also remain there for hundreds of years. Cadmium is more soluble and plant available in acid soils. Cadmium and mercury concentrations are usually low in PPMBs.

### **Lead and Chromium**

These two heavy metals differ from cadmium and mercury chiefly in that they are not readily taken up from soil by most plants unless the soils are acid. Lead can be ingested by grazing animals and small children by eating soil. Concentrations in PPMBs can be expected to be low relative to potentially toxic concentrations.

### **Manganese**

Manganese is a micronutrient and also required by animals. In acid Ontario soils it can be toxic to plants, even where no manganese has been applied, and in neutral to alkaline soils under dry conditions it can occasionally be quite deficient. Manganese is not of concern in products for land application when application is restricted to soils with pH values of 6.0 or greater. However where PPMB products are applied to acid soils with pH values of 5.4 or less, the manganese content should be considered.

### **Aluminum**

Aluminum is not required by plants or animals and is present in appreciable concentrations in soils. It is not of concern in materials added to soils with pH values above 5.4. However, aluminum toxicity does occur in acid soils with pH values of 5.4 or less due to solubility of soil aluminum. Aluminum leaching out of acid soils can be toxic to aquatic organisms.

### **Sodium**

Sodium is not required by plants. If the concentration is high in soils or in materials applied to soils, relative to the calcium and magnesium content, it can disperse the soil clay and organic matter impeding water, air and root penetration. This can cause severe soil damage which is very difficult to reverse. Sodium concentrations are of potential concern in some PPMBs, and should be monitored.

### **Trace Organic Compounds**

Sources of trace organic chemical compounds in PPMB include background concentrations naturally occurring in the wood fibre and waste paper feedstock, the derivation of organic compounds during the manufacturing process, and compounds that are indirectly related due to general industrial processes (fuels and combustion emissions, solvents, lubricants, plasticizers, etc.). Categories of trace organic compounds that are found in PPMB include the following:

- Extractable organics in wood and wood fibre;
- Volatile organic compounds;
- Polycyclic aromatic hydrocarbons;
- Chlorinated byproducts of chemical bleaching;
- Polychlorinated biphenyls;
- Other compounds (phthalates, phenolics, organo-chlorine herbicides)

The use of chlorine-based bleaching agents has reduced significantly in recent years, with a corresponding reduction in the levels of chlorinated hydrocarbons found in pulp mill effluents and biosolids. Chlorine-based bleaching compounds are not used in mechanical pulping processes.

Polychlorinated biphenyls (PCB's) were once used as a carrier in carbonless papers; however, this practice was stopped in the 1970's. Paper containing PCB's may periodically appear as a raw material at secondary fibre mills and de-inking operations (NCASI, 1984a).

The limited data available from Ontario pulp and paper mills and other jurisdictions indicate that trace organic compounds in PPMB are not detectable to various detection limits of less than 1 parts per million or are occasionally detected at very low concentrations in the order of parts per million or less (MOE, 1998).

In PPMB samples that have been tested, the concentrations of trace organic compounds were sufficiently low that they are not expected to be of environmental concern.

### **3.0 FOREST PRODUCTIVITY ISSUES**

#### **3.1 SOIL BUILDING**

Biosolids can enhance the soils physical, biological and chemical properties. When added to reasonably well-drained soils, biosolids can promote root growth by improving soil tilth, enhancing moisture retention, and by encouraging soil organisms such as earthworms that aerate and enrich the soil. All of these benefits combined, can result in higher yields and faster growth rates for agricultural and forestry crops. Well drained sandy soils will benefit most from the incorporation of biosolids primarily due to the fact that they will enhance their moisture holding capacity.

The application of biosolids to compacted and poorly drained soils, however, can impede the transfer of carbon dioxide and oxygen between the soil surface and underground soil layers. This can have an adverse effect on plant root systems which results in a slower growth rate. As well, trees growing under these conditions will be stressed, thus making them more susceptible to insects and diseases. Under these conditions, it will be necessary to relieve the soil compaction through tillage during the site preparation. Drainage problems must be alleviated through grading or ditching prior to any soil building efforts. If drainage continues to be a problem, tree species tolerant of wet conditions such as silver maple can be considered as a crop.

The application of secondary biosolids, which are much smaller in particle size than the primary biosolids, tend to blend with the soil easier making it more resistant to dewatering. The larger particle size associated with primary materials, when mixed with soil will take longer to break down and can have a negative impact by allowing too much air penetration as well as robbing the soil of nitrogen during decomposition. The larger particles of primary material tends to be of more benefit when applied to the soil surface as a mulch.

#### **3.2 FERTILIZATION**

The use of biosolids has one main advantage over inorganic or chemical fertilizers in that they contribute to the overall physical properties of the soil. The actual amounts of the nutrients, nitrogen, phosphorus and potassium, found in PPMB, are relatively low. The organic material, however, will increase the bacterial count in the soil, thus making the desired nutrients more readily available to the plant roots.

Soils high in sand content do not hold nutrients or moisture as well as a clay or loam-based soil. Therefore, they will benefit from the addition of organic matter. At the other extreme clay soils tend to be dense and need organic matter to increase porosity. Given the high C:N ratio associated with primary PPMB, it may be necessary to augment their application in some situations with the addition of a high nitrogen fertilizer.

In plantations it may frequently be more efficient to use the PPMB material as a mulch between the rows and break it down mechanically by discing or tilling. Each year, a new material can be spread over the older mulch.

### **3.3 WEED CONTROL**

The application of PPMB to the soil surface in the form of a mulch can be an excellent form of organic weed control. Controlling weeds is critical during the early years of a tree crop, particularly for species such as hybrid poplar. Stand growth and yield can be significantly improved by controlling weed growth during the establishment years of a plantation. Weeds compete with the young trees for moisture, soil nutrients and sunlight. Uncontrolled herbaceous materials, such as grasses, also provide habitat for rodents such as meadow voles. These creatures can cause a high mortality on tree plantations during the winter months by feeding on the bark of the young trees below the snow surface.

As a plantation develops, its canopy will eventually become dense enough to shade out the sunlight to the soil surface between the rows. Depending on the species, this may take 3 to 5 years. The low sunlight reaching the plantation floor, creates an environment where competing vegetation will not be able to grow and flourish. Recent research in Ontario has demonstrated the effectiveness of primary PPMB as a weed control for the early establishment period of a plantation (Lo et al., 1998).

The first step in weed control within a tree plantation starts with site preparation. Preparation can be undertaken a number ways depending on such factors as budgets, equipment access to plantation sites and availability of equipment. Site preparation and ongoing weed control may consist of mechanical, chemical and manual cultivation, or a combination of all three. Studies in Ontario have been completed that demonstrate typical approaches for weed control using primary PPMB and other site management techniques (Bols, 1996).

### **3.4 WATER RETENTION**

Biosolids either applied on the soil as a mulch or mixed into the soil as an amendment will increase the soil's moisture holding capacity. A mulch can be applied at any time during the year, however, early autumn or spring are good times because the soil is moist and warm. If applied over a frozen, or snow covered soil, the mulch will act as an insulating blanket. This will slow down the warming of the soil in the spring, which can impact on the trees by retarding leaf formation. This does not seem to have any lasting effects on plants in southern regions.

However, in northern regions where the growing season is short to begin with, delayed warming of the soil due to an added layer of mulch, on an annual basis, could reduce plant growth.

When used as a mulch, the biosolids shade the soil surface, thus lowering its temperature and offering protection from drying winds. Mulches also reduce weed growth which competes with crops for moisture and nutrients. Mulches are especially useful in conditions, such as forest plantations, where it is either impossible or extremely costly to provide irrigation. Mulched trees tend to be healthier and exhibit faster growth than trees growing under the same conditions without a mulch layer. As the mulch decomposes, it provides added nutrients to the soil below.

Coarse bark when used as a mulch between plantation rows, will also provide an added advantage by cushioning or disbursing the weight of heavy maintenance equipment, such as tractors, thus reducing soil compaction. Heavily compacted soils have difficulty in absorbing and facilitating the exchange of gases between the soil and air.

Biosolids, when mixed with soil in the form of an organic amendment, acts as a soil conditioner which modifies the soil properties and enhances plant growth. Organic matter has the ability to hold large amounts of water which can be easily absorbed by plant roots. Organic matter can prevent soil caking and increase soil porosity and aeration. As well, organic particles in the soil hold nutrient ions loosely on their surfaces making them more easily absorbed by roots.

### **3.5 EROSION CONTROL**

Soil erosion can occur in two ways; wind blowing away soil particles and water flowing across the soil surface transporting soil particles as it flows. Once the cover material on a tree plantation site has been removed or buried, soil erosion can take place.

Other factors that influence soil erosion within a plantation are such things as soil type, topography and exposure. Light sandy soils with a low organic content tend to be drier and more susceptible to erosion by wind. Exposed soil on a slope, will be more easily eroded by spring runoff and summer rains. An exposed field on an open landscape, will be more susceptible to wind erosion than a plot surrounded by forest.

Drifting or erosion of soil removes the finer particles, which are more easily transported, and can contain up to twice as much nitrogen, organic matter, phosphorous and other nutrients as the larger grained material left behind.

By applying PPMB to an exposed soil in the form of a cover or mulch, the risk of erosion by wind or water will be greatly reduced if not eliminated. Primary and secondary materials will provide similar protection to an exposed soil. The heavier, larger particle sizes associated with primary PPMB products will provide better protection on slopes than the smaller secondary materials. Pulp and paper mill biosolids that are applied to harvested forest areas or land reclamation sites, and incorporated into the soil, will also promote the colonization of native plant species by providing a more substantial rooting medium. As these native plants become established, and their root systems spread, they too will contribute to the prevention of soil erosion.

### **4.0 POTENTIAL ENVIRONMENTAL ISSUES**

As with the use of any fertilization technique or soil amendment practice, there is a potential risk to the environment arising from the poorly managed use of PPMB, or from the application on inappropriate sites. These risks can be managed to within acceptable limits by adhering to the guidelines and operational practices outlined in the accompanying document. A description of the main environmental issues, and how the environmental risk has been addressed in the development of the guidelines, is presented in this section.

#### **4.1 GROUNDWATER IMPACTS**

The source of potential groundwater impacts from PPMB applications is the soluble constituents in the biosolids. These parameters, such as chloride and nitrogen, can readily dissolve in water infiltrating through the biosolids and be transported to the water table. A balance must be achieved between the amount of the particular element or compound available for dissolution and leaching versus the amount that can be taken up or stored in the plant/soil system.

For most PPMB situations in forestry and land reclamation projects, the primary factor that controls the application rate with respect to potential groundwater impacts will be the nitrogen content of the biosolids. The application rates specified in the guidelines are designed to provide appropriate controls on the amount and rate of nitrogen release to that which can be accommodated by the plant/soil system. Once a better understanding of the nitrogen dynamics in Ontario's forest soils is developed, the application rates for various tree species and soil types may be more finely tuned.

The metal contents in PPMB are much lower than for most sewage biosolids and leaching of soluble metals from most PPMB is not expected to present environmental concerns, even at the higher rates of application. Recent research examining the fate of metals in forestry applications of municipal sewage biosolids at very high rates (450 tonnes/ha) 15 years previously, concluded that the elements were still strongly retained in the upper 20 cm of soil horizon. It was further concluded that the metals would remain strongly bound in the soil unless there was a substantial loss in the retention mechanisms such as cation exchange and organic binding (Harrison et al., 1997).

The guidelines restrict the metals content in the PPMB for all but low rates of application to the long-term provincial targets for biosolid applications on agricultural land. This is intended to remove the potential for leaching and groundwater impacts in these situations.

The levels of trace organic compounds are very low in PPMB, and are not expected to pose any environmental concerns from applications to forestry sites and land reclamation projects.

Separation distances from the PPMB application areas to water supply wells will serve to further reduce the potential for groundwater impacts by allowing for a sufficiently long groundwater flow path from the application sites.

## **4.2 SURFACE WATER IMPACTS**

Potential adverse effects to surface water can arise from the movement of solid particles and soluble materials in runoff to surface watercourses. There is considerably less risk of this occurring at non disturbed forestry sites as compared to cultivated fields because of the abundance of ground vegetation which limits the amount and rates of runoff. The use of primary PPMB as an erosion control measure can have the effect of reducing the potential for runoff in surface water.

Separation distances from surface watercourses are specified in the guidelines to provide protection against surface water impacts. The separation distances reflect the various land slopes and the different PPMB to be used in different forestry and land reclamation situations.

The guidelines also provide a recommended limit for the level of extractable phosphorus in soils that are to receive PPMB. The purpose of this limit is to control the amount of soluble phosphorus in the shallow soil system, which could potentially enter the surface water environment and provide nutrients for nuisance aquatic plant growth.

## **4.3 POTENTIAL IMPACTS TO SOIL**

The primary environmental issue related to soils is the potential for accumulation of metals. As noted above, the metals content in most PPMBs is at such low levels that accumulations in soil are not expected to be of concern. The guidelines place restrictions on the maximum concentrations of metals that should be in biosolids and soils for application sites. These restrictions are particularly important for acid forest soils with a pH less than 6.0, where the metals tend to be more soluble, and for very high application rates.

In the guidelines, an allowable annual sodium loading for PPMB applications is also provided to prevent damage to soil structure and impairment to root development. Sodium loadings from PPMB are not expected to be of concern since most of the soluble sodium will

have been removed from the biosolids during dewatering. Nevertheless, analyses of soluble sodium, magnesium and calcium should be completed regularly on PPMB to monitor the levels of exchangeable cations in the materials.

#### **4.4 ODOUR CONTROL**

Odours can be generated during PPMB application activities, such as loading and unloading, storage pile movement, forwarding and spreading. Odours are generally most prevalent with secondary and combined biosolids since these are biologically active materials. The odours are the result of anaerobic decomposition of organic material in the biosolids, and are caused by the following classes of compounds (O'Connor et al., 1997):

- volatile fatty acids
- sulphur-based and nitrogen-based compounds
- phenolics, ketones and other organic compounds

The primary management approach to mitigate nuisance impacts from the odours is to provide a reasonable separation between the source of the odours and any sensitive receptors, such as individual residences and residential areas. Timing of applications to avoid high winds toward sensitive areas may also be required in rare cases.

The recommended separation distances outlined in the guidelines to mitigate odour impacts from PPMB are consistent with those used in Ontario for other biosolids with a similar potential for odour generation.

#### **5.0 ISSUES RECOMMENDED FOR FURTHER REVIEW**

As the base of information grows with respect to the utilization of PPMB in silviculture and land reclamation projects in Ontario, the guidelines should evolve to reflect the increased scientific knowledge. The following issues are recommended for further study to provide more research and documentation on the beneficial use of PPMB to silviculture and land reclamation:

1. The long-term impacts (or lack thereof) to groundwater quality around high application rate land reclamation sites involving the use of low C:N ratio, high nitrogen PPMB in Ontario need to be confirmed. Studies should be undertaken to monitor the concentrations of nitrate in the groundwater surrounding land reclamation sites over a period of several years following the initial applications of PPMB.

2. The fate of applied nitrogen in forest ecosystems amended with PPMB in Ontario needs further study. Such topics as the mineralization rates, immobilization, volatilization losses, plant uptake, and the effects of litter fall and decaying vegetation, are worthy of further research.
3. Better quantification of the sustainable rates of nitrogen application based on measured tree growth response is warranted. Tree growth response to fertilizer applications at various rates and covering several tree species and soil types would provide useful information as to the long-term rates of application that provide benefits to silviculture sites.
4. Further study is suggested on optimizing the application rates and materials used for mulches at silviculture sites. In particular, the blending or co-usage of high and low C:N ratio materials in order to avoid nitrogen deficiencies, while still providing acceptable levels of weed control, is worthy of further consideration. Similarly, the need to add supplemental nitrogen fertilizer to the mulch applications, and whether low C:N ratio PPMB can be used for this purpose, should be studied.
5. Public awareness and acceptance of the benefits of PPMB utilization should be promoted. The importance of promoting PPMB applications as the responsible use of a valuable resource to soil and crops, rather than a waste disposal technique, is critical to the overall success of this initiative. Properly managed sites and controlled demonstration plots can assist in the promotion of PPMB usage to silviculture and land reclamation sites.

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