STANDARDS AND GUIDELINES FOR THE LAND APPLICATION OF MECHANICAL PULP MILL SLUDGE TO AGRICULTURAL LAND

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Environmental Sciences Division
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SUMMARY

These standards and guidelines are intended for operations involving the land application of Mechanical Pulp (MP) mill sludge on agricultural land. General information on MP sludge is presented as well as the regulatory requirements for generators and recommended practices for end users.

The rationale for the land application of mechanical pulp mill sludge is that the material is a good soil amendment. This statement of benefit is based on the results of an Alberta research program that was initiated in 1991. The demonstrated benefits of sludge utilization on land are:

1. The sludge improves the nutrient status and physical properties of soil resulting in enhanced plant growth. Studies conducted by the Alberta Research Council and Alberta Agriculture to date have demonstrated significant increases in crop yields resulting from the nutrient content in the sludge and the improved water holding capacity and porosity of the soil from the organic content of the sludge. Refer to Section 4.0 for more information on studies conducted.

2. When applied at recommended rates and managed properly, MP sludge improves soil quality. The results of Alberta Research Council work were interpreted in the context of the Alberta soil quality criteria guidelines (ASAC, 1987).

3. Land application reduces the volume of sludge that is placed in landfills thereby extending landfill life and reducing the need for new landfill construction.

4. Land application reduces the volume of sludge that is disposed by incineration, thereby reducing air emissions.

These guidelines are designed to ensure protection of human health and the environment. The end user of the MP sludge is responsible for ensuring that the material is applied and stored in an environmentally responsible manner. The recommended practices contained within these guidelines are a means of ensuring that these objectives are met. If environmental issues arise, the end user may be denied further access to the sludge. Any adverse impact on the environment may be investigated by Alberta Environmental Protection.

These guidelines only cover land application of MP sludge to agricultural lands and do not apply to pasture lands or forested areas.
NOTE TO USERS

The following information on land application of MP sludge is provided as a general note to users:

1. MP sludge consists primarily of water, wood fibre, biomass, and residual process and wastewater treatment chemicals (mainly nutrients such as nitrogen and phosphorus). It represents a combination of the primary sludge and secondary sludge from the mechanical pulp mill’s wastewater treatment system.

2. Users are responsible for the quality and productivity of their land. To ensure quality and productivity are not compromised, areas proposed for land application should be characterized as specified in Table 4.1 prior to initial and any subsequent re-application. Please refer to Section 4.0 for more information.

3. Any method of spreading that results in an even application of sludge to soil may be used. Conventional tractor pulled manure spreaders and truck mounted spreaders which have an auger type flinger at the back to disperse the sludge are recommended. Following the contours of the land to minimize soil disturbance is also recommended.

4. Roto-tillers or tandem (double) discs are the most useful implements for incorporation in agricultural areas. Mouldboard plows are not recommended as they promote layering rather than mixing of the sludge. Incorporation within 72 hours of spreading is strongly recommended to minimize odours, ensure organic matter degradation, and allow maximum nutrient retention and availability.

5. Please refer to Section 2.0 and 3.0 for information on stockpiling, soil sampling recommendations, and land application rates. The specified application rates should not be exceeded as this could result in higher than optimum carbon and sodium levels in the soil.

6. As with the handling of other biological materials such as manure, good sanitary practices should be observed when handling and storing MP sludge.

7. If there are any conflicts between this guideline and the Environmental Protection and Enhancement Act or Regulations thereunder, then the Act or Regulations take precedence.

8. The generator and user must comply with all requirements of the Environmental Protection and Enhancement Act, its Regulations and approvals thereunder, and all other applicable laws.
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>SUMMARY</td>
<td>i</td>
</tr>
<tr>
<td>NOTE TO USERS</td>
<td>ii</td>
</tr>
<tr>
<td><strong>1.0 INTRODUCTION</strong></td>
<td>1</td>
</tr>
<tr>
<td>1.1 Background</td>
<td>1</td>
</tr>
<tr>
<td>1.2 Objectives</td>
<td>2</td>
</tr>
<tr>
<td>1.3 Environmental Protection and Enhancement Act Regulations</td>
<td>2</td>
</tr>
<tr>
<td><strong>2.0 REQUIREMENTS FOR GENERATORS</strong></td>
<td>4</td>
</tr>
<tr>
<td>2.1 Definitions</td>
<td>4</td>
</tr>
<tr>
<td>2.2 MP Sludge Assessment</td>
<td>6</td>
</tr>
<tr>
<td>2.3 Record Keeping</td>
<td>6</td>
</tr>
<tr>
<td>2.4 Reporting</td>
<td>7</td>
</tr>
<tr>
<td><strong>3.0 RECOMMENDED PRACTICES FOR USERS</strong></td>
<td>8</td>
</tr>
<tr>
<td>3.1 Receiving Soil and Area Suitability</td>
<td>8</td>
</tr>
<tr>
<td>3.2 Soil Suitability</td>
<td>9</td>
</tr>
<tr>
<td>3.3 Land Application Methods and Procedures</td>
<td>10</td>
</tr>
<tr>
<td><strong>4.0 TECHNICAL INFORMATION</strong></td>
<td>12</td>
</tr>
<tr>
<td>4.1 MP Sludge</td>
<td>12</td>
</tr>
<tr>
<td>4.2 Parameters of Interest</td>
<td>12</td>
</tr>
<tr>
<td>4.3 Land Application Practices</td>
<td>16</td>
</tr>
<tr>
<td><strong>5.0 SUMMARY OF RESEARCH STUDIES</strong></td>
<td>19</td>
</tr>
<tr>
<td>5.1 Background</td>
<td>19</td>
</tr>
<tr>
<td>5.2 Major Projects</td>
<td>20</td>
</tr>
<tr>
<td>5.3 Greenhouse Pot Trials</td>
<td>22</td>
</tr>
<tr>
<td>5.4 Column Leaching Experiment</td>
<td>23</td>
</tr>
<tr>
<td>5.5 Field Experiments</td>
<td>24</td>
</tr>
<tr>
<td>5.6 Winter Stockpiling</td>
<td>33</td>
</tr>
<tr>
<td>5.7 Summary</td>
<td>35</td>
</tr>
<tr>
<td><strong>6.0 RELATED REPORTS/PAPERS/PRESENTATIONS</strong></td>
<td>36</td>
</tr>
<tr>
<td>6.1 Project Reports</td>
<td>36</td>
</tr>
<tr>
<td>6.2 Conference Papers</td>
<td>38</td>
</tr>
</tbody>
</table>
LIST OF TABLES

TABLE 3.1 SOIL MONITORING ................................................................. 9
TABLE 3.2 MP SLUDGE APPLICATION SETBACK DISTANCES FROM RESIDENCES AND WATERCOURSES ................................................. 10
TABLE 3.3 MP SLUDGE APPLICATION REQUIREMENTS .......................... 11
TABLE 4.1 MP SLUDGE PROPERTIES .................................................... 15
TABLE 4.2 MP SLUDGE QUALITY REQUIRED FOR LAND APPLICATION .......... 16
TABLE 4.3 OPTIMUM RECEIVING SOIL PROPERTIES ............................ 17
TABLE 5.1 SELECTED CHEMICAL PROPERTIES (MEAN VALUES) FOR THE SOIL AND SOIL/SLUDGE MIXTURES PRIOR TO AND FOLLOWING SLUDGE APPLICATION ........................................................... 27

LIST OF FIGURES

FIGURE 5.1 TOTAL BROME YIELD VALUES (KG DRY WEIGHT) FOR THE SLAVE LAKE PULP CORPORATION PLOTS (1992-1997) AT SLAVE LAKE..... 26
FIGURE 5.2 TOTAL BROME YIELD VALUES (KG DRY WEIGHT) FOR THE CONVENTIONAL SLUDGE PLOTS (1993-1997) AT ALBERTA NEWSPRINT COMPANY ................................................................. 31
1.0 INTRODUCTION

1.1 Background

Three pulp mills in Alberta fall under the generic category of a Mechanical Pulp (MP) mill. They are as follows:

<table>
<thead>
<tr>
<th>Pulp mill</th>
<th>Location</th>
<th>Product</th>
<th>Average Sludge Production</th>
</tr>
</thead>
<tbody>
<tr>
<td>Millar Western Industries Ltd.</td>
<td>Whitecourt</td>
<td>Bleached CTMP</td>
<td>30-60 bone dry tonnes/day</td>
</tr>
<tr>
<td>Slave Lake Pulp</td>
<td>Slave Lake</td>
<td>Bleached CTMP</td>
<td>30-60 bone dry tonnes/day</td>
</tr>
<tr>
<td>Alberta Newsprint Co. Ltd.</td>
<td>Whitecourt</td>
<td>Newsprint (TMP)</td>
<td>30-60 bone dry tonnes/day</td>
</tr>
</tbody>
</table>

Pulping and pulp brightening are the two main stages of mechanical pulp processing. Alberta Newsprint produces its pulp by a process known as thermo-mechanical pulping (TMP) whereby wood chips are separated into fibres by a refiner. Millar and Slave Lake use a chemi-thermo-mechanical pulping (CTMP) process, which is the same as the TMP process, except wood chips are softened by pre-treatment in sodium sulphite and/or sodium hydroxide. In the second stage, brightening agents such as hydrogen peroxide and sodium hydrosulphite are used to whiten the pulp.

Wastewater generated from the processing of pulp is directed to a wastewater treatment system. Sludge proposed to be used for land application originates from the primary and secondary portions of the wastewater treatment system. MP sludge is essentially a combination of primary and secondary sludge that is composed mainly of water, wood fibre, biomass, and residual process and wastewater treatment chemicals. Currently, this sludge is disposed through incineration or landfilling.

Land treatment of MP sludge is the planned and controlled application of the sludge into the soil surface. The intent of land treatment is the use of the soil-plant system to degrade, immobilize, and assimilate waste constituents. The Alberta regulatory expectation of land treatment is maintenance, and preferably enhancement of the quality of the soil-plant system with minimal risk to human health and the environment. Current and on-going research has shown that MP sludge, when applied to agricultural areas, results in increased plant growth and is a good soil amendment as a result of the nitrogen, phosphorus, and organic matter content of the sludge. The research confirms land application as a feasible, alternate disposal method to landfiling or incineration of MP sludge. Please refer to Sections 4.0 and 5.0 for more information on MP sludge and a summary of the research information compiled and used in the development of these standards and guidelines.
Alberta Environmental Protection endorses options for waste disposal that result in the best use of the material while protecting human health and the environment. The land application of MP sludge benefits the user by enhancing soil quality, benefits the generator by saving landfill space, and is regulated by the department to protect public interests.

To ensure land application is environmentally acceptable and the land is suitable to receive MP sludge, users or generators should conduct sludge, soil, and site assessments. Elements of the work include:

1. routine sludge monitoring to assess sludge quality, and
2. assessment of site and soil characteristics which could impact the land application of the sludge.

These standards and guidelines represent the compilation of extensive research work that has been performed regarding the environmental effects and fate of the land application of MP sludge in an agricultural setting. The requirements presented outline the best management practices for land application of MP sludge.

1.2 Objectives

These standards and guidelines describe environmental controls for the land application of Mechanical Pulp (MP) mill sludge to agricultural land with a view to:

1. ensuring land application is conducted in a manner that protects human health and the environment, and
2. guiding generators and users of MP sludge by outlining the basis for application reviews and approval requirements pursuant to the Environmental Protection and Enhancement Act (EPEA).

The information provided is an integration of technical and regulatory information, and applies only to land application of MP sludge on agricultural lands.

1.3 Environmental Protection and Enhancement Act Regulations

In accordance with the Activities Designation Regulation (211/96), an EPEA approval is required for the construction, operation, and reclamation of the following activities related to wood products:

a) a pulp and paper manufacturing plant, and
b) a pulp manufacturing plant.
Mechanical pulp mills fall under one of the above activities depending on the extent of pulp processing. Wastes generated, as a result of the subject activities, must be disposed in accordance with approval requirements. Generators must apply for approval, to Alberta Environmental Protection, for the disposal of MP sludge by means of land application. An approval application must be prepared in accordance with the Approvals and Registrations Procedure Regulation (113/93 and 216/96).

Generators who have obtained formal approval will then be required to meet the conditions of their operating approval and Section 2.0 of these standards and guidelines. Persons responsible must also comply with all requirements of the Environmental Protection and Enhancement Act and associated regulations, and all other applicable laws. Any inconsistencies between the contents of these standards and guidelines and an approval shall be resolved in favour of the approval. If inconsistencies exist between these standards and guidelines and EPEA or Regulations thereunder, then the Act or Regulation takes precedence.

As a means of monitoring the disposal of sludge by land application, generators are required to maintain records for submission to Alberta Environmental Protection. This information is used to assess compliance with the requirements of these standards and guidelines.
2.0 REQUIREMENTS FOR GENERATORS

Generators of MP sludge that obtain approval for disposal of the material by land application will be required to meet the conditions of their approval and requirements in this section.

2.1 Definitions

The following terms are defined to ensure clarity for the purposes of these standards and guidelines:

a) "agricultural land" means land cultivated and used for the growth of cereal crops, oil seed, pulse, forages, and sod, but does not include permanent pasture land;

b) "biological treatment" means the use of natural biological processes for the breakdown of organic matter in wastewater;

c) "Department" means the Department of Environmental Protection;

d) "Director" means, subject to Section 40 of EPEA, a person designated by the Minister of Environmental Protection as a Director for the purposes of the Environmental Protection and Enhancement Act;

e) "EPEA" means the Environmental Protection and Enhancement Act;

f) "generator" means the corporate entity or individual that produces the MP sludge;

g) "incorporation" means the mixing of MP sludge into the soil resulting in a uniform soil and sludge mixture;

h) "initial application" means the first sludge application on an area of agricultural land;

i) "land application" means a waste management practice where MP sludge is surface spread and incorporated into the soil;

j) "Mechanical Pulp (MP) mill" means a plant that manufactures pulp principally by mechanical action to break down wood chips into pulp;

k) "MP sludge" means the primary or secondary sludge or a combination thereof, removed from the wastewater treatment system of a Mechanical Pulp mill;
l) "organic soil" means a soil which contains 17% or more of organic carbon by weight and which has a depth of 0.4 metres or more of unconsolidated organic material;

m) "primary sludge" means solids removed from the wastewater before biological treatment;

n) "re-application" means any subsequent application after the initial application;

o) "saline/sodic soil" means a soil containing exchangeable sodium and/or other soluble cations in sufficient quantity to interfere with the growth of most crops;

p) "secondary sludge" means solids removed from the wastewater after biological treatment;

q) "soil" means unconsolidated mineral or organic surficial materials, which can have, or are being altered by weathering, biological processes, or human activity;

r) "stockpiling" means the storage of MP sludge for a period longer than 30 days;

s) "user" means the corporate entity or individual who applies the MP sludge to agricultural land;

t) "water course" means
  i) the bed and shore of a river, stream, lake, creek, lagoon, swamp, marsh or other natural body of water, or
  ii) a canal, ditch, reservoir, or other man-made surface feature,

whether it contains or conveys water continuously or intermittently; and

u) "year" means calendar year.
2.2 MP Sludge Assessment

2.2.1 MP sludge used for land application is to consist only of primary or secondary sludge, or a combination thereof, from the wastewater treatment system of the generator and is not to be mixed with more than a combined, 5% by weight, of any other non-hazardous substance.

2.2.2. Unless otherwise specified in an individual EPEA approval, monitoring of MP sludge physical and chemical properties includes the following:

a) The generator must characterize the following MP sludges for all parameters listed in Table 4.1:
   i) MP sludge not initially characterized, or
   ii) MP sludge that has been altered due to process modifications requiring an approval.

b) The generator must obtain written authorization from the Director for land application of the sludges outlined in 2.2.2 (a) that do not meet the criteria in Table 4.2.

c) MP Sludge that has been initially characterized and approved for land application must be analyzed by the generator for the following parameters once every four months, if the sludge is being spread on land:
   i) pH,
   ii) SAR,
   iii) Soluble ions sodium, calcium, magnesium,
   iv) Total Organic Carbon,
   v) Trace metals (Cd, Cr, Cu, Ni, Pb, Zn),
   vi) Total Nitrogen, and
   vii) Electrical Conductivity (EC).

d) The generator must have a best management practices plan in place that ensures that each load of MP sludge destined for land application is of the same consistent and acceptable quality as approved under Section 2.2.2(b).

2.3 Record Keeping

2.3.1 Generators that distribute MP sludge for the purposes of land application are to document and retain the following information for a minimum of 10 years:

a) Name, address, and phone number of the land owner, company, or individual using the MP sludge.

b) Legal land description of all areas of MP sludge application.
c) Quantity of MP sludge issued to each user.

d) Confirmation that the user has received information on the proper soil characteristics, soil sampling recommendations, and application and handling as outlined in these standards and guidelines.

e) Confirmation from the end user that the sludge has been spread and incorporated.

2.4 Reporting

The generator must provide to the Director by March 31 of each year the information outlined in Sections 2.0 compiled for the previous year.
3.0 RECOMMENDED PRACTICES FOR USERS

The use of MP sludges as a soil amendment has been demonstrated to be beneficial in enhancing soil quality and productivity and not harmful to the environment provided certain conditions and practices are followed. This section outlines those recommended practices that users of the MP sludge should follow to maintain soil quality/productivity as well as preventing any negative environmental impact.

3.1 Receiving Soil and Area Suitability

The following is a recommended procedure for the collection and analysis of soil samples to ensure suitability for MP sludge application.

3.1.1 Areas proposed for initial and re-application of MP sludge should be characterized by the user as follows:

a) Area soil samples should be taken as follows:

Six to ten random sampling locations are selected around the perimeter of a circle approximately centered on a land unit no greater than 16 ha in area.

16ha Area

A total of 3 samples should be taken from each land unit as follows:

i) One composite sample from the 0-15 cm depth at 6-10 random locations along circle;
   ii) one discrete 15-50 cm depth sample from one location along circle; and
   iii) one discrete 50-90 cm depth sample from one location along circle.

For land units of irregular shapes, an ellipse may be more suitable than a circle; however, the basic elements and objectives of the sampling scheme described should be maintained.
b) All soil samples should be analyzed for the parameters listed in Table 3.1:

**TABLE 3.1 Soil Monitoring**

<table>
<thead>
<tr>
<th>INITIAL APPLICATION</th>
<th>RE-APPLICATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. pH(^1), EC(^2), SAR,</td>
<td>1. pH(^1), EC(^2), SAR,</td>
</tr>
<tr>
<td>2. Soil texture(^3)</td>
<td>2. C:N ratio(^4)</td>
</tr>
<tr>
<td>4. Soluble ions sodium, calcium, magnesium.</td>
<td></td>
</tr>
</tbody>
</table>

\(^1\) pH using the CaCl\(_2\) method.
\(^2\) Electrical Conductivity (EC) using the saturated paste method.
\(^3\) Particle size (percent sand, silt, clay) by the hydrometer method.
\(^4\) C:N ratio = TOC:TN. The C:N ratio is used as a means of determining if accumulations of organic carbon are occurring over time. Total nitrogen, which includes both mineral and organic nitrogen should be expressed on a dry weight basis and can be calculated using total kjeldahl nitrogen and nitrate-N.

c) Collection, analysis of samples, and reporting should be conducted as described in the following documents:


### 3.2 Soil Suitability

Research has demonstrated that the application of MP sludge will have a benefit to most agricultural lands. Section 3.2.1 describes the conditions that are not suitable for land application of MP sludge. Application of MP sludge to lands with these criteria can lead to lower soil quality and productivity. To prevent this from occurring, it is recommended that the user undertake the soil testing outlined in Section 3.1.1 prior to considering application of MP sludge.
3.2.1 The user should not apply MP sludge under the following conditions:

a) to organic soil,
b) to soil with a C:N ratio greater than 40:1,
c) to soil which has an EC greater than 6 dS/m,
d) to soil which has a SAR greater than 8,
e) to soil in low lying areas that have saturated soil conditions for more than six consecutive weeks.

3.3 Land Application Methods and Procedures

It has been demonstrated that the land application of MP sludge has a positive impact on the environment and soil quality/productivity if the following recommended practices are followed. Failure to follow these procedures may result in an adverse effect to the environment and result in government enforcement action and access to additional MP sludge being denied.

3.3.1 MP sludge should not be applied to an area where the slope exceeds 15%.

3.3.2 MP sludge should not be applied within the setback distances listed in Table 3.2.

TABLE 3.2 MP Sludge Application Setback Distances from Residences and Watercourses

<table>
<thead>
<tr>
<th>Slope of Land</th>
<th>Recommended Distance from Residence or Watercourse</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 to 3%</td>
<td>15 metres</td>
</tr>
<tr>
<td>3 to 9%</td>
<td>30 metres</td>
</tr>
<tr>
<td>9 to 15%</td>
<td>50 metres</td>
</tr>
</tbody>
</table>

3.3.3 MP sludge should not be applied in an area where the seasonally high watertable is within 1.5 metres of the soil surface.

3.3.4 MP sludge land applications should not exceed an application rate of 50 tonnes/ha (dry weight basis) and should be conducted in accordance with Table 3.3.
### TABLE 3.3 MP Sludge Application Requirements

<table>
<thead>
<tr>
<th>Application Rate¹ (tonnes/ha dry weight basis)</th>
<th>Application Frequency</th>
<th>Recommended Receiving Soil Monitoring²</th>
</tr>
</thead>
<tbody>
<tr>
<td>40-50</td>
<td>Initial and every four years</td>
<td>Initial and every four years for re-application</td>
</tr>
<tr>
<td>25-39</td>
<td>Initial and every two years</td>
<td>Initial and every two years for re-application</td>
</tr>
<tr>
<td>&lt;25</td>
<td>Initial and every two years</td>
<td>Initial and every four years</td>
</tr>
</tbody>
</table>

¹ Refer to Section 5.0 for studies on application rates. (ha = hectare)
² See Section 3.1.1 for initial and re-application monitoring requirements

3.3.5 MP sludge should be spread in a manner that results in uniform application.

3.3.6 Whenever possible, the user should incorporate MP sludge into the soil within 72 hours after it is spread.

3.3.7 MP sludge should not be spread on frozen soil unless it can be incorporated within 72 hours after spreading.

3.3.8 For the incorporation of MP sludge, the user must comply with any local Municipal government requirement for incorporation that is less than 72 hours.

3.3.9 The user should follow the requirements below when stockpiling MP sludge for a period greater than 30 days:

a) The MP sludge should be stockpiled in a manner that prevents contamination of any surface watercourses and groundwater.

b) The stockpile should not be located on land having a slope greater than 9%.

c) Stockpiles should not be established within 60 metres of watercourses or residences.

d) Not more than a quantity sufficient for one application of MP sludge should be stored at a designated application area at any time.

e) Stockpiling should be done in a manner that prevents odours from becoming a nuisance.
4.0 TECHNICAL INFORMATION

4.1 MP Sludge

MP Sludge Assessment and Properties

Generators who apply for approval to dispose of MP sludge by land application are required to characterize the sludge to assess its suitability in a land application program. The information is submitted to Alberta Environmental Protection in support of a land application proposal. Sludges not previously approved or sludge that has been altered due to plant process changes must be re-characterized and receive written authorization from the Department prior to use in a land application program.

Mechanical pulp mills use primary and secondary processes for treatment of wastewater generated from pulp processing operations. Primary sludge is produced by the primary wastewater treatment system of a pulp mill and usually consists of a gravity clarifier or sedimentation basin. Secondary sludge is produced by the biological treatment system and involves the removal of organic materials from the wastewater. Samples were analyzed to determine the variability in physical and chemical properties of the MP sludge produced by the Alberta mechanical pulp mills. Values for selected properties of MP sludge are provided in Table 4.1. The data represent statistical values for analyses conducted between 1992 and 1997. Table 4.2 outlines the sludge quality required for land application to agricultural lands. Sludges with properties outside the parameters listed in Table 4.2 should not be land applied without prior written authorization from the Director.

4.2 Parameters of Interest

pH

pH is one of the most commonly measured characteristics of soil because of its influence on the availability of nutrients and possible toxicity problems. The pH(CaCl₂) value is much less variable than pH(H₂O) due to the use of a higher salt (CaCl₂) solution in the analysis, and is a more useful measurement for comparing pH values across time. pH(CaCl₂) is valuable in assessing land for repeated sludge application and to assess the period of time over which sludge-borne constituents affect soil pH.
Nitrogen

Plant available and total nitrogen values indicate the potential of sludge to provide nitrogen. The sludge could supply 48 to 143 mg of plant available nitrogen per kg of sludge and a total of 8 to 44 kg nitrogen per tonne when applied to soil. Because of the organic nature of the sludge, the majority of the nitrogen exists as organic nitrogen and becomes available on a “slow release” basis.

Carbon

Total carbon analyses measure organic carbon (biomass, plant and soil organic matter) plus inorganic carbon content (carbonates, bicarbonates). Because MP sludge is highly organic, the total carbon values approximate organic carbon content. The ratio of total organic carbon to total nitrogen (C:N ratio) is an indication of the level of organic matter decomposition in soil. It narrows with increasing decomposition. A range of 10:1 to 25:1 occurs for most surface soils. When sludge is incorporated into surface soils, a C:N range of 15:1 to 30:1 should be targeted.

Saturated Paste Extract Properties

Saturated paste extract properties provide a measure of the contents of the soil solution which are the most mobile and available in the soil. These measurements indicate the salinity status of the soil, or in this case the sludge, and its probable effect on soil structure and water movement. Saturation percentage is used as an indicator of soil water-holding properties. The relatively high values of 400 to 1200% reported indicate the water holding capability of the sludge is comparable to peat.

Electrical Conductivity

Electrical conductivity (EC) is a measure of salinity or the salt concentration of solutions. In the context of Alberta soil quality criteria guidelines (ASAC 1987), an EC of $\leq 2$ dS/m indicates there is no limitation to the ability of a soil to support plant growth. Values in the range of 4 to 6 dS/m are considered to result in slight to moderate limitations.

Sodium Adsorption Ratio (SAR)

Sodium adsorption ratio is an indirect measurement of the sodium hazard and is calculated using the values of water-soluble calcium, magnesium, and sodium obtained from analysis of the saturated paste extract. High SAR is particularly damaging in shrinking/swelling clays such as montmorillonite. High sodium can deteriorate soil structure and result in soil management problems such as cultivation, permeability, and root penetration. According to the Alberta soil quality
criteria guidelines, an SAR of <4 indicates there is no limitation on plant growth. Values of SAR between 4 and 8 indicate slight to moderate limitations.

**Total Elemental Content**

Total elemental content represents the maximum levels of heavy metals in the soil or sludge and is used as an indication of a worse case scenario in assessing the potential for heavy metal and other trace element contamination. Available information indicates that MP sludge does not pose a risk to soil in terms of heavy metal or trace element contamination.

**Organics**

Organic component analyses conducted indicate that volatile organic components are non-detectable with the exception of trace levels of phthalate in some samples. Phenolic compounds, polycyclic aromatic hydrocarbons, and pesticides were not detected.

Analytical work confirms that most organic compounds present in the sludge are of plant origin. Analyses show the presence of C$_{14}$, C$_{16}$ and C$_{18}$ fatty acids, plant sterols, dicarboxylic acid, and alcohols which occur in the trees used for pulp and newsprint manufacture.

**Chlorine Compounds**

Chlorine based compounds are not used in the mechanical pulp mill processes thereby precluding the generation of chlorinated dioxins and furans. Trace levels of dioxins and furans have been detected in de-ink process sludge from the recycled component (newspapers, magazines, used paper products). An assessment of these levels indicated negligible loading of dioxin and furans to land relative to the Alberta Tier I Criteria for Contaminated Soil Assessment and Remediation (March 1994). The Alberta Tier I Criteria are remediation targets for soil contaminants that do not result in land use restrictions.
### TABLE 4.1 MP Sludge Properties

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Range*</th>
<th>Mean*</th>
<th>Standard Deviation*</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH(H₂O)</td>
<td>5.3 - 9.6</td>
<td>7.4</td>
<td>1.6</td>
</tr>
<tr>
<td>pH(CaCl₂)</td>
<td>5.1 - 9.4</td>
<td>7.1</td>
<td>1.7</td>
</tr>
<tr>
<td>Total N (%)</td>
<td>0.80 - 4.4</td>
<td>2.0</td>
<td>1.1</td>
</tr>
<tr>
<td>Total C (%)</td>
<td>36.0 - 55.4</td>
<td>45.7</td>
<td>5.4</td>
</tr>
<tr>
<td>C:N Ratio (TOC:TN)</td>
<td>10:1 – 68:1</td>
<td>31.0</td>
<td>19.0</td>
</tr>
<tr>
<td>CaCO₃ Equivalent (%)</td>
<td>0 - 4.8</td>
<td>2.1</td>
<td>1.7</td>
</tr>
<tr>
<td>CEC (cmol(+)/kg)</td>
<td>22 – 85</td>
<td>44.5</td>
<td>21.3</td>
</tr>
<tr>
<td>Plant Available Phosphorus (mg/kg)</td>
<td>61 – 500</td>
<td>202</td>
<td>176</td>
</tr>
<tr>
<td>Plant Available Nitrogen</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nitrate &amp; Nitrite – N (mg/kg)</td>
<td>11 – 21</td>
<td>15.3</td>
<td>4.1</td>
</tr>
<tr>
<td>Ammonium – N (mg/kg)</td>
<td>37 – 122</td>
<td>74.0</td>
<td>34.0</td>
</tr>
<tr>
<td><strong>Saturated Paste Properties</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Saturation (%)</td>
<td>488 – 1200</td>
<td>892</td>
<td>281</td>
</tr>
<tr>
<td>EC (dS/m)</td>
<td>0.5 - 6.13</td>
<td>2.2</td>
<td>2.0</td>
</tr>
<tr>
<td>SAR</td>
<td>1 – 50</td>
<td>19.0</td>
<td>20.8</td>
</tr>
<tr>
<td>Cl (mg/L)</td>
<td>25 – 258</td>
<td>115</td>
<td>91.0</td>
</tr>
<tr>
<td>NH₄-N (mg/L)</td>
<td>7 – 297</td>
<td>73.9</td>
<td>98.0</td>
</tr>
<tr>
<td>NO₃-N (mg/L)</td>
<td>&lt;0.01 - 5.9</td>
<td>1.4</td>
<td>2.1</td>
</tr>
<tr>
<td>NO₂-N (mg/L)</td>
<td>0.1 - 1.3</td>
<td>0.3</td>
<td>0.4</td>
</tr>
<tr>
<td>Ca (mg/L)</td>
<td>28 – 152</td>
<td>90.0</td>
<td>37.0</td>
</tr>
<tr>
<td>Mg (mg/L)</td>
<td>6 – 37</td>
<td>21.6</td>
<td>9.3</td>
</tr>
<tr>
<td>Na (mg/L)</td>
<td>60 – 1640</td>
<td>508</td>
<td>670</td>
</tr>
<tr>
<td><strong>Total Elemental Content (mg/kg)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Al</td>
<td>545 – 5500</td>
<td>3193</td>
<td>1557</td>
</tr>
<tr>
<td>Ca</td>
<td>4080 – 12800</td>
<td>8023</td>
<td>3017</td>
</tr>
<tr>
<td>Cd</td>
<td>0.3 - 1.38</td>
<td>1.1</td>
<td>0.5</td>
</tr>
<tr>
<td>Cr</td>
<td>2.5 - 14.7</td>
<td>10.5</td>
<td>8.8</td>
</tr>
<tr>
<td>Cu</td>
<td>1.6 - 37.0</td>
<td>17.5</td>
<td>11.1</td>
</tr>
<tr>
<td>K</td>
<td>650 – 5290</td>
<td>2678</td>
<td>1729</td>
</tr>
<tr>
<td>Na</td>
<td>858 – 18000</td>
<td>7799</td>
<td>6329</td>
</tr>
<tr>
<td>Ni</td>
<td>4.3 - 16.0</td>
<td>8.3</td>
<td>6.2</td>
</tr>
<tr>
<td>P</td>
<td>1528 – 7950</td>
<td>4117</td>
<td>1974</td>
</tr>
<tr>
<td>Pb</td>
<td>&lt;1.5 - 7.06</td>
<td>3.1</td>
<td>2.4</td>
</tr>
<tr>
<td>Zn</td>
<td>22.0 – 114</td>
<td>64.4</td>
<td>32.9</td>
</tr>
</tbody>
</table>

*Data provided in several project reports including Macyk and Faught (1997), Macyk and Faught (1996), Macyk and Pojasok (1996), Macyk and Pojasok (1995), and Macyk and Thacker (1991). The statistical values represent data for 32 samples.
TABLE 4.2 MP Sludge Quality Required for Land Application

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Maximum Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon:Nitrogen</td>
<td>75:1</td>
</tr>
<tr>
<td>Sodium Adsorption Ratio</td>
<td>50</td>
</tr>
<tr>
<td>Trace Elements</td>
<td>Maximum Concentration mg/kg dry weight¹</td>
</tr>
<tr>
<td>Cadmium (Cd)</td>
<td>3</td>
</tr>
<tr>
<td>Chromium (Cr)</td>
<td>210</td>
</tr>
<tr>
<td>Copper (Cu)</td>
<td>100</td>
</tr>
<tr>
<td>Nickel (Ni)</td>
<td>62</td>
</tr>
<tr>
<td>Lead (Pb)</td>
<td>150</td>
</tr>
<tr>
<td>Zinc (Zn)</td>
<td>500</td>
</tr>
</tbody>
</table>

¹These values represent the maximum concentration of the trace elements that can be present in a Class A compost.

4.3 Land Application Practices

Receiving Soil and Area Suitability

Soil types that may most benefit from MP sludge application are those that are either low in organic matter, fine textured (clayey) soil, or coarse textured (sandy) soil. However, receiving soil with these properties require increased technical expertise to assess requirements and potential consequences of sludge addition. For example, MP sludge, which has high water absorption/retention properties, when applied at high application rates to poorly drained and fine-textured soil, may result in excessive soil moisture levels. Sandy textured soil permits rapid leaching of soluble salts and nutrients introduced through sludge addition or generated during sludge degradation. Clayey soil is subject to erosion. MP sludge application rates or frequency of additions in excess of what is outlined in these standards and guidelines may degrade groundwater because of leaching, and contaminate surface water runoff.

Section 3.1 outlines the assessment that must be conducted to demonstrate the suitability of an area for land application. Soil sample collection increases with increase in slope to account for the larger surface area with slope and potential increase in soil variability.
The available nutrients in MP sludge may not be sufficient to meet crop requirements. The user should undertake routine soil fertility testing to assess crop nutrient requirements. Plant available nitrogen, phosphorus, and potassium may need to be adjusted to meet these requirements.

Land Application Restrictions

Proper site selection is needed to ensure effective sludge application and to protect surface water, groundwater, and other vectors that may adversely impact human health and the environment. Category 1 in Table 4.3 outlines receiving soil properties for which MP sludge application is suitable. Soil characteristics in Category 2 pose recognized agronomic limitations and require a more careful assessment of application rates and frequency to ensure soil is not adversely impacted.

Application rates and frequencies, outlined in Table 3.3, are intended to ensure that receiving soil properties return approximately to the steady-state soil conditions that existed prior to sludge addition. Soil monitoring results should be compared with values provided in Table 4.3 to justify re-application on the same area.

### TABLE 4.3 Optimum Receiving Soil Properties

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Acceptable Areas for Application</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Category 1</td>
</tr>
<tr>
<td>pH(CaCl₂)</td>
<td>6.5 - 7.5</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>SAR</td>
<td>&lt;4</td>
</tr>
<tr>
<td>Electrical Conductivity¹ (dS/m)</td>
<td>&lt;2</td>
</tr>
<tr>
<td>C:N ratio</td>
<td>10 – 25 : 1</td>
</tr>
<tr>
<td>Texture¹²</td>
<td>CL, SiCL, SiL, Si, SiC, L, SCL, SC, SL</td>
</tr>
</tbody>
</table>

**Category 1:** Receiving soil properties for which MP sludge application is suitable

**Category 2:** Receiving soil properties that pose agronomic limitations and require a more careful assessment of application rates and frequency to ensure soil is not adversely impacted

¹ Electrical Conductivity (EC) using the saturated paste method.
² Particle size (percent sand, silt, clay) by the hydrometer method.
C - Clay, Si - Silt, L - Loam, S - Sand, H – Heavy
Incorporation of MP sludge into the soil is necessary to:

a) minimize odours,
b) improve soil workability,
c) maximize benefit of moisture contained in the sludge,
d) maximize nutrient retention and availability, and
e) ensure organic matter turnover.

Stockpiling may be necessary to hold MP sludge at a user site until conditions are suitable for sludge application. Crop production and frozen soil are major limitations to land availability and stockpiling for six to eight months of storage may be necessary.
5.0 SUMMARY OF RESEARCH STUDIES

The rationale for the utilization of mechanical pulp mill sludge is that the sludge is a good soil amendment and that land application is not just a technique for sludge disposal. This statement of benefit is based on the results of a research program that was initiated in 1991. The demonstrated benefits of sludge utilization on land are:

1. The sludge improves the nutrient status and physical properties of soil resulting in enhanced plant growth. It is also beneficial in reclaiming disturbed areas.

2. When applied at recommended rates and managed properly, the sludge does not have a deleterious effect on soil quality. The results of the work are being interpreted in the context of the soil quality criteria guidelines utilized in Alberta (ASAC, 1987).

3. Land application reduces the volume of sludge that is placed in landfills thereby reducing the need for landfill construction.

4. Land application reduces the volume of sludge that is disposed of by incineration resulting in reduced air emissions.

5.1 Background

Land application research involving a cooperative effort of industry, provincial and federal funding agencies, and the Alberta Research Council began in June 1991. The objective of this research is to provide industry personnel, government regulators and the general public with data that promote a reasoned and clear understanding of the implications/benefits of mechanical pulp mill sludge land application on agricultural and forest land, and provides a basis for developing operating guidelines for land application activities. To meet the objectives, a series of activities were undertaken as follows:

a) review of the literature,
b) sludge characterization,
c) greenhouse pot experiments,
d) growth chamber experiments,
e) column leaching experiments,
f) field land application trials,
g) operational land application, and
h) assessment of the impact of winter stockpiling.
5.2 Major Projects

Each of the components of the sludge utilization work or projects had a number of objectives including activities specific to pulp mill sludge characterization and assessment of the impact of land application. The projects were initiated sequentially and each had its own set of specific objectives. However, the activities for each project were designed to result in an overall complementary program beginning with the characterization phase followed by bench scale laboratory assessments, field trials, and finally implementation of land application at the operational scale.

Although the bench scale decomposition work, greenhouse pot trials, and column leaching studies involved soils obtained in the forest setting, the results are relevant to agriculture as similar soils are being farmed throughout northcentral and northern Alberta.

5.2.1 Characterization Work

The characterization work related to the sludges and receiving soils involved an intensive analytical program including chemical and physical properties:

- pH (H₂O and CaCl₂)
- Total Carbon (%)
- Organic Carbon (%)
- CaCO₃ Equivalents (%)
- ANC (Acid Neutralizing Capacity) (%)
- Total Nitrogen (%)
- Carbon:Nitrogen Ratio
- CEC (Cation Exchange Capacity) (cmol/kg) and exchangeable Na, K, Ca, and Mg
- Plant Available N and P (mg/kg)
- Particle Size Distribution
- Saturated paste extract properties:
  - Saturation (%)
  - EC (Electrical Conductivity) (dS/m)
  - SAR (Sodium Adsorption Ratio)
  - Soluble ions
- DTPA plant available (extractable) metals,
- Total metals, and
- Organic component analyses:
  - GC-MS (Gas Chromatography-Mass Spectroscopy)
- Dioxins and Furans
Characterization data for the sludges are contained in a number of the reports that are listed in Section 6.

5.2.2 Sludge Decomposition Work

The experimental design for the sludge decomposition work included:

1. Three sludges (Alberta Newsprint Company, Millar-Western Pulp Ltd., and Slave Lake Pulp Corporation),
2. Two forest soils (medium- and coarse-textured),
3. Six application rates and frequencies (0, 2.5, 5, 10, 2.5 + 2.5, and 5+5 cm),
4. Three incubation temperatures (5, 15 and 25 °C),
5. Six sampling times (0, 1, 3, 6, 12, and 24 weeks), and
6. Three replicates.

Note that 1 cm of sludge is equivalent to 10 bone dry t/ha.

Carbon dioxide evolved and oxygen consumed were measured weekly and soil carbon and nitrogen were measured for each sampling event. Soil pH, cation exchange capacity, and oil and grease content were determined on samples from the first and last sampling events. Biological assay (Microtox™) and GC-MS of the oil and grease extracts were determined on composite samples from the first and last sampling events. The results obtained indicated that:

- Rates of degradation (24 weeks incubation) varied with sludge source and ranged from 10 to 40% of added sludge and increased with temperature. Degradation rates were about two fold greater for the 15°C compared to the 5°C treatments.
- Single applications showed the same rate of degradation as double or split applications of the same total amount of sludge added.
- Soil pH and oil and grease content increased with sludge addition rate. The increase depended on sludge rate, type, and incubation temperature.
- GC-MS analysis of the oil and grease fractions from the three sludges showed the presence of fatty acids, plant sterols and phthalate. Sludge incubation (24 weeks) led to a significant decrease in the above organic compounds for all sludges.
- The half-lives for the applied sludge carbon at 15°C and the 10 cm application rate for sludge from the three mills ranged from 1.1 to 3.9 years for the fine-textured soils and 1.2 to 2.8 years for the coarse-textured soils.
- The half-lives for the 2.5 cm and 5 cm sludge rates were similar to the 10 cm values. The 15°C incubation temperature treatment is the most relevant as field measurement of mean soil temperature during the May to October period inclusive resulted in a value of 13.5°C. Assuming six months of about
15°C per year, the half-lives of applied sludge carbon for the 10 cm application rate would range from 2.2 to 7.8 years for the fine-textured soils and 2.4 to 5.6 years for the coarse-textured soils.

5.3 Greenhouse Pot Trials

Greenhouse pot trials utilizing conventional and de-ink sludges from the operations of Alberta Newsprint Company were completed during the period of June 1992 to March 1994. The objective of these trials was to determine the impact of addition of different rates of both conventional and de-ink sludge on soils and plants. The results of this work were intended to provide a preliminary assessment of potential application rates for land application in the field.

The bulk sludge and soil samples were air-dried, ground and homogenized. The sludges each represented a composite of material collected over a 10 day period. The bulk soil sample represented a medium-textured Luvisolic soil collected at the forest cut-block field experiment site.

Sludge application rates included the equivalent of 0 cm, 2.5 cm (25 t/ha), 5 cm (50 t/ha), 10 cm (100 t/ha) and 20 cm (200 t/ha). Sludge quantities were based on the wet bulk density of the sludge, a soil incorporation depth of 17 cm, soil density of 1.3 g/cm$^3$ and a soil weight of 2100 g.

Fertilizer additions were based on plant available N and P with a target application rate of 150 mg N/pot and 170 mg P/pot utilizing solutions of ammonium nitrate and ammonium phosphate (monobasic). Calculations regarding the additions were based on the amount of sludge added and the respective amount of nutrients contained therein. As a result, the control received the largest fertilizer addition.

For the grass treatments a total of 130 brome grass seeds were placed in each pot. The pine and spruce seedlings utilized were selected on the basis of uniform height and visual health. Moisture content was maintained at or near 80% of field capacity by watering on a pot weight basis three times per week.

Observations were recorded once a week and photographs taken at two-week intervals. The grass was harvested 1 cm above the surface of the growth medium and fresh weight determined. The material was then washed in a dilute metal free detergent solution, rinsed three times in distilled water, dried at 70°C for 24 hours and the dry weights recorded.

Four harvests, each occurring after about a 90 day growth period, were completed for each of the conventional and de-ink sludge experiments. Fresh and dry weights of the brome grass were determined for each of the treatments for the four harvests associated with each of the two experiments.
The yield data indicated that the sludge amended treatments had consistently higher yields than the control for the four consecutive harvests. Elemental analysis of the grass tissue indicated that there were minor differences in total elemental content in the grass grown in the sludge amended treatments and the control treatments. The de-ink sludge amended treatments resulted in slightly higher boron, sodium and chloride values in the tissue for some of the harvests.

The pine and spruce growth after two years in the greenhouse indicated that the sludge amended pots resulted in more growth than the control pots. The trends were similar for both species with the 10 cm sludge application resulting in the most growth. In addition to the height growth differences the sludge amended treatments resulted in trees with larger root volumes, thicker stems and a darker green and more vigorous appearance than the trees in the control pots.

In summary, it was apparent that the conventional and de-ink sludge had a positive impact on the growth of brome grass, pine and spruce and this impact was related to more than the nutrient addition associated with the sludge. This was evident from the fact that the control pots had received the highest rate of fertilizer addition with decreasing amounts as sludge addition increased for the amended treatments.

5.4 Column Leaching Experiment

The column leaching experiment was undertaken to determine the potential for leaching of any deleterious compounds that might occur as a result of land application or during stockpiling or temporary storage.

The experimental variables included two methods of sludge application (mixing and top loading), two water addition regimes (one and two times the long-term average annual precipitation for the Whitecourt region), four rates of sludge addition (0, 2.5, 5 and 10 cm for mixing and 0, 25, 50 and 90 cm for top loadings) and four sampling times (30, 90, 180 and 360 days) following implementation. The results indicated that:

- Sludge amendment resulted in decreased soil pH, and increases in electrical conductivity (EC) and soluble ions in the saturated paste extract during the initial stages of the experiment. The values for these parameters declined with cumulative water additions during the leaching process.

- Total carbon content, cation exchange capacity and total trace metal levels were not significantly affected by sludge amendment rate and water addition amount. There was little movement of trace metals in the columns.
5.5 Field Experiments

Field experiments were undertaken to assess the impact of sludge application on soil quality and plant growth and to provide the basis for development of recommendations regarding environmentally acceptable rates of sludge addition. This work was used to verify and confirm the results of the sludge decomposition work, greenhouse pot trials, and column leaching studies.

Four controlled field experiments were established including one at the Slave Lake Pulp Corporation mill site and three experiments in the Mayerthorpe, Whitecourt, and Fox Creek areas involving sludge from the operations of Alberta Newsprint Company.

5.5.1 Slave Lake Pulp Corporation Mill Site Study

Materials and Methods

Individual plots each 6 m x 12 m were established in an area where the mill site soil was comprised of a mixture of LFH, A, Ae, and upper B horizons of the Luvisolic soils present. Baseline soil sampling was conducted in 15 cm increments to 105 cm in each of the plots.

Sludge was spread on the plots on June 9 and 10, and incorporated on June 10, 1992. The treatments included a control (0 cm) and layers of 1 cm, 3 cm, and 5 cm as well as 5 cm per year (multiple) application treatment and combination of 5 cm sludge and 0.5 cm wood ash. Each treatment was replicated three times and the plots were tilled to a depth of 15 cm.

Brome grass was hand broadcast at the rate of 90 kg/ha and fertilizer was hand broadcast at the rate of 36 kg/ha N and 16 kg/ha P on each of the plots. The plots were then lightly raked to incorporate the seed and fertilizer.

Samples were collected from the 0 to 15 cm and 15 to 30 cm depth intervals following sludge incorporation. In the fall of 1993 and 1994 each of the plots were again sampled in 15 cm intervals to a depth of 105 cm to determine what changes had occurred relative to the baseline and post-application characteristics.

Tissue samples were collected from the plots at the time of the first harvests in each of 1992, 1993, and 1994. One harvest was completed in 1992 (August), two in 1993, 1994, 1995, and 1996 (June and August) and one in June of 1997. The entire plots were harvested with a lawnmower. The grass removed was weighed immediately at the site and subsamples were returned to the laboratory to determine moisture content and ultimate dry weight.
The soil and soil/sludge samples were analyzed to determine pH, carbon (total, organic, inorganic), total nitrogen, cation exchange capacity and extractable cations, saturated paste extract properties, DTPA extractable elements, total elements, calcium carbonate equivalent, and particle size distribution on all pre-incorporation soil samples.

Results

Sludge application had a beneficial effect on grass yield as demonstrated in Figure 5.1 which provides data for the total yield generated from the harvests conducted annually. For each treatment a total yield was compiled based on the annual yields realized from 1992 to 1997 inclusive. Yield increases were in proportion to sludge application rate and the effects were most evident in 1993 and 1994. Increases were still evident in 1995 and 1996 and it should be noted that alsike clover had invaded the control plots due to the declining grass cover resulting in artificially higher yields for the control plots.

The pH of the surface soil (0 to 15 cm) was slightly alkaline prior to sludge application. Following sludge application and incorporation, the soil pH increased in all of the sludge amended treatments (Table 4.1). The largest increase occurred in the 5 cm sludge + ash treatment with an average pH change of 0.7. By the fall of 1995 soil pH was back to baseline values for all treatments except the 5 cm sludge + ash and 5 cm sludge/yr. The 1996 values were slightly lower than the values reported for 1995.

The organic carbon content of the plot soils was relatively high due to the presence of stripped "topsoil" materials which tended to mask some of the effects of sludge addition. The variability associated with organic carbon and the C/N ratio is demonstrated by the values reported for the control plots (Table 5.1). In general the C/N ratios reported in the fall of 1995 and 1996 were similar to baseline values.
FIGURE 5.1. Total Brome Yield Values (kg dry weight) for the Slave Lake Pulp Corporation Plots (1992 - 1997) at Slave Lake
### 4.0 SUMMARY OF RESEARCH STUDIES

**TABLE 5.1. Selected Chemical Properties (Mean Values) for the Soil and Soil/Sludge Mixtures Prior to and Following Sludge Application**

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
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</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Pre</td>
<td>Post</td>
<td>Pre</td>
<td>Post</td>
<td>Pre</td>
<td>Post</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td>0-15</td>
<td>7.5</td>
<td>7.2</td>
<td>7.4</td>
<td>7.3</td>
<td>7.5</td>
<td>7.2</td>
<td>17</td>
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<tr>
<td></td>
<td>15-30</td>
<td>7.6</td>
<td>7.0</td>
<td>7.4</td>
<td>7.5</td>
<td>-</td>
<td>-</td>
<td>15</td>
<td>16</td>
</tr>
<tr>
<td>3 cm Sludge</td>
<td>0-15</td>
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<tr>
<td></td>
<td>15-30</td>
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<td>7.6</td>
<td>7.4</td>
<td>7.5</td>
<td>-</td>
<td>-</td>
<td>17</td>
<td>13</td>
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<tr>
<td>5 cm Sludge</td>
<td>0-15</td>
<td>7.5</td>
<td>7.8</td>
<td>7.7</td>
<td>7.6</td>
<td>7.6</td>
<td>7.3</td>
<td>17</td>
<td>15</td>
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<tr>
<td></td>
<td>15-30</td>
<td>7.6</td>
<td>7.8</td>
<td>7.7</td>
<td>7.6</td>
<td>-</td>
<td>-</td>
<td>14</td>
<td>15</td>
</tr>
<tr>
<td>5 cm Sludge + Ash</td>
<td>0-15</td>
<td>7.5</td>
<td>8.2</td>
<td>8.2</td>
<td>8.1</td>
<td>8.1</td>
<td>7.8</td>
<td>14</td>
<td>18</td>
</tr>
<tr>
<td></td>
<td>15-30</td>
<td>7.5</td>
<td>8.2</td>
<td>7.8</td>
<td>7.9</td>
<td>-</td>
<td>-</td>
<td>15</td>
<td>16</td>
</tr>
<tr>
<td>5 cm Sludge/yr</td>
<td>0-15</td>
<td>7.4</td>
<td>7.8</td>
<td>7.7</td>
<td>7.9</td>
<td>7.9</td>
<td>7.3</td>
<td>18</td>
<td>14</td>
</tr>
<tr>
<td></td>
<td>15-30</td>
<td>7.4</td>
<td>7.9</td>
<td>7.7</td>
<td>7.9</td>
<td>-</td>
<td>-</td>
<td>17</td>
<td>15</td>
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## TABLE 5.1. (CONTINUED)  
Selected Chemical Properties (Mean Values) for the Soil And Soil/Sludge Mixtures Prior to and Following Sludge Application

<table>
<thead>
<tr>
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</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>0-15</td>
<td>3</td>
<td>2</td>
<td>3</td>
<td>2</td>
<td>4</td>
<td>1</td>
<td>125</td>
<td>109</td>
<td>95</td>
<td></td>
</tr>
<tr>
<td></td>
<td>15-30</td>
<td>3</td>
<td>2</td>
<td>3</td>
<td>3</td>
<td>-</td>
<td>-</td>
<td>115</td>
<td>107</td>
<td>95</td>
<td></td>
</tr>
<tr>
<td>3 cm Sludge</td>
<td>0-15</td>
<td>2</td>
<td>7</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>90</td>
<td>294</td>
<td>168</td>
<td></td>
</tr>
<tr>
<td></td>
<td>15-30</td>
<td>2</td>
<td>7</td>
<td>4</td>
<td>4</td>
<td>-</td>
<td>-</td>
<td>65</td>
<td>290</td>
<td>166</td>
<td></td>
</tr>
<tr>
<td>5 cm Sludge</td>
<td>0-15</td>
<td>3</td>
<td>11</td>
<td>7</td>
<td>4</td>
<td>3</td>
<td>1</td>
<td>99</td>
<td>460</td>
<td>265</td>
<td></td>
</tr>
<tr>
<td></td>
<td>15-30</td>
<td>2</td>
<td>10</td>
<td>5</td>
<td>5</td>
<td>-</td>
<td>-</td>
<td>91</td>
<td>419</td>
<td>185</td>
<td></td>
</tr>
<tr>
<td>5 cm Sludge + Ash</td>
<td>0-15</td>
<td>2</td>
<td>11</td>
<td>5</td>
<td>3</td>
<td>3</td>
<td>1</td>
<td>92</td>
<td>545</td>
<td>237</td>
<td></td>
</tr>
<tr>
<td></td>
<td>15-30</td>
<td>2</td>
<td>10</td>
<td>6</td>
<td>6</td>
<td>-</td>
<td>-</td>
<td>70</td>
<td>458</td>
<td>259</td>
<td></td>
</tr>
<tr>
<td>5 cm Sludge/yr</td>
<td>0-15</td>
<td>3</td>
<td>12</td>
<td>10</td>
<td>9</td>
<td>4</td>
<td>4</td>
<td>140</td>
<td>569</td>
<td>461</td>
<td></td>
</tr>
<tr>
<td></td>
<td>15-30</td>
<td>2</td>
<td>11</td>
<td>7</td>
<td>8</td>
<td>-</td>
<td>-</td>
<td>94</td>
<td>450</td>
<td>288</td>
<td></td>
</tr>
</tbody>
</table>
Sodium adsorption ratios (SAR) ranged from 2 to 3 prior to sludge application and increased to 11 or 12 for the highest application rate treatments. By 1995 the values for all treatments were back down to baseline levels for the 0 to 15 cm depth interval a further decline in SAR levels occurred in 1996. Sodium levels were also down to or near baseline levels by the fall of 1996.

DTPA extractable data collected after sludge application showed that only a few plant available elements including phosphorus, potassium and sodium were present in higher concentrations than found in control plots or prior to sludge application. Total elemental analysis data indicated that most elements were present in lower concentrations in the ash and sludge than the receiving soils.

The plant tissue from the various treatments generally had normal or below normal elemental concentrations when compared to published values for brome grass, grasses, or plants in general. The sludge and ash had little impact on tissue concentrations of most elements, but where they did have an impact it was generally favourable in raising below normal levels to normal or sufficient levels. Overall the effect of the application of sludge and ash on the elemental content of brome grass tissue occurred mainly in the first and second growing seasons.

Recommendations

Based on the results of this study it is recommended that a 5 cm application rate of the Slave Lake Pulp Corporation sludge be considered for operational land application in the area. Furthermore, applications of 3 cm of sludge every two to three years or 5 cm of sludge every three to four years should be environmentally acceptable provided that the area is supporting annual cereal crops, forage, or pasture.

5.5.2 Alberta Newsprint Company Agricultural Plot Area

Materials and Methods

The agricultural field plot experiment was established near Mayerthorpe, Alberta on soils representative of the area. The variables included two sludges (conventional and de-ink), six application rates (0 cm, 1 cm, 3 cm, 5 cm, 10 cm and a 5 cm/yr multiple application), one crop (brome grass) and three replicates. The sludges were spread and incorporated on May 6 and 7, 1993. The fertilization strategy of equalizing the nutrient level in all treatments was used as previously described for the greenhouse experiment.
About one week after the sludge was applied and incorporated, samples of the soil/sludge mixtures were collected to determine post-application characteristics of the surface soils. In addition, soil samples to depths ranging from 105 cm in some treatments to 3 m in the remainder was completed in the fall of 1993, 1994, 1995, 1996 and 1997. Analyses for parameters listed previously were completed.

Plot harvests according to the procedure described previously were completed in September 1993, June and August 1994, 1995, 1996 and 1997. Plant tissue was collected for analysis at the time of the first harvest completed in each of the first three years.

Results

Grass yields increased with increased sludge application rate. Figure 5.2 provides a cumulative mean total treatment yield for the harvests conducted from 1993 to 1996 inclusive. The data indicate that for the five growing seasons, the 10 cm sludge rate resulted in double the yield of the control. It should also be noted that in the past three growing seasons the control plots have had a significant invasion of alsike clover and alfalfa which has inflated the yield values for these plots.

There was no significant change in soil pH resulting from the additions of conventional or de-ink sludge to the agricultural soil. The addition of 5 cm and 10 cm of sludge resulted in minor increases in C/N ratio (from 15 to 18) however the values were back to baseline within two to three years.

Electrical conductivity (EC) levels in the zone of incorporation increased by a maximum of 1.5 dS/m following sludge application and were back down to pre-application levels by the fall of 1994. The increases in EC were attributed primarily to the fertilizers that were applied. The maximum sodium adsorption ratio (SAR) value following sludge application was 1 which occurred in the 10 cm de-ink sludge treatment.

DTPA extractable element data showed that only a few elements were present in higher concentrations than in the control plots or prior to sludge application. Total elemental analysis data indicated that most elements were present in lower concentrations in the sludges than in the receiving soils. Sludge application had little effect on the elemental content of the brome grass tissue.
FIGURE 5.2. Total Brome Yield Values (kg dry weight) for the Conventional Sludge Plots (1993 - 1997) at Alberta Newsprint Company
5.5.3 Operational Land Application

Extending the research to the operational scale allowed for some evaluation of the effect of sludge addition on a wider range of soil types (sandy, gravelly, clayey) and different crops including cereal grains and canola. It also allowed for an evaluation of the effectiveness of operational land application including uniformity of application over large areas and efficiency of various types of equipment for incorporation.

Slave Lake Pulp Corporation

In 1993, Slave Lake Pulp Corporation (SLPC) implemented an operational sludge land application program with co-operating farmers in the Smith-Hondo area. SLPC organized the delivery and spreading of the sludge and land owners incorporated it with conventional farm implements.

Prior to sludge application in 1993, soil samples were collected to the 3 m depth at one location per 5 ha of sludge amended land to define the baseline properties. In the fall of 1994 and 1995, soil samples were collected from the 0 to 15 cm and 15 to 30 cm depths in the sludge amended fields. The sampling protocol included preparation of a composite sample based on four sub-samples for each 10 ha of land.

The samples collected in 1993, 1994 and 1995 were analyzed to determine pH, total nitrogen, total carbon, total organic carbon, plant available phosphate, electrical conductivity (EC), nitrates, nitrites, NH$_4$-N, soluble ions (Ca, Na, K, Mg, S) and sodium adsorption ratio (SAR) by calculation.

The sludge application had a measurable effect on pH levels in 3 of the 13 fields sampled. For several farms the 1995 values were similar to the baseline values and most of the differences reported were relatively small and could be attributed to sampling variability.

Total nitrogen, organic carbon and available phosphate increased as a result of sludge addition. By 1995 total nitrogen content decreased to values similar to baseline levels. The C/N ratios in 1995 were only slightly higher than baseline values.

Electrical conductivity levels increased slightly as a result of sludge addition with a maximum increase of 1.22 dS/m in one field while increases of less than 0.1 dS/m occurred in five of the fields. The 1995 levels had decreased to near baseline values in all but one field.
The values reported for nitrates and nitrites suggested that groundwater contamination should not be a problem. Increases in sodium adsorption ratio (SAR) due to sludge application ranged from 0.2 to 2.1. In 1995, twelve of the fourteen fields sampled had SAR values that remained the same or decreased from 1994 levels.

The application of sludge had very little to no effect on soil suitability ratings. In both 1994 and 1995 soil suitability ratings either remained the same or improved compared to the ratings for the baseline condition. Some improved ratings occurred due to changes in pH. Although EC and SAR values were generally higher in 1994 than in 1993 for most of the soils analyzed, these increases were not large enough to change the suitability ratings based on these criteria.

Overall, the land application program has demonstrated that the sludge is a useful soil amendment and that multiple applications could be considered for the fields included in the program.

**Alberta Newsprint Company**

Alberta Newsprint Company initiated an operational land application program in the fall of 1993. Baseline sampling was completed at various locations at the millsite in 1993 and 1994. Baseline sampling was completed at two farms in 1994, eight farms in 1995, and five farms in 1996. Sampling requirements changed during the three year period with sampling in 1993, 1994 and 1995 being done to the 3 m depth and in 1996 to the 1 m depth. Sludge was applied at rates of 25 dry t/ha on the agricultural fields and 60 dry t/ha at the millsite locations.

Post-application sampling at the initial two farms was completed in the fall of 1994, 1995 and 1996 following the original protocol of sampling to 3 m with one core or site per 5 ha of land receiving sludge.

Crop yields increased as a result of the sludge application and the sampling and analytical work completed to date indicate that any changes in parameters such as pH, C/N ratio, EC, soluble Na and SAR were not significant in terms of impacting soil quality.

### 5.6 Winter Stockpiling

Stockpiling of MP sludge in farm fields during the winter increases the availability of sludge to farmers for spring application. Fall applications are impacted by haying and harvest activities, while spring transportation of sludge from the mill to the farm fields is limited by road bans and reduced access to fields due to wet soil conditions. Winter stockpiling provides a supply of sludge that the farmer can apply when field conditions are suitable.
Two issues have been raised in regard to the impact of stockpiling. The first relates to the impact on soil quality due to runoff and leaching in the vicinity of the stockpile. The second relates to the quality, primarily nutrient status, of the sludge after remaining in a stockpile for several months.

In the spring of 1996, the Alberta Research Council (ARC) undertook some monitoring activities to assess the impact of stockpiling on three farms that had received sludge from Alberta Newsprint Company (Macyk et al. 1996). The results of this work indicated that any impact due to sludge stockpiling at the three farms occurred beneath and immediately adjacent to the stockpiles and to a distance of about 5 m from the stockpiles. In addition, the Alberta Research Council organized and interpreted analytical data that had been generated by Millar Western Pulp (Whitecourt) Ltd., in a study of stockpiling on one of their farms (Macyk and Faught 1996d).

In the fall of 1996, the ARC initiated additional work to evaluate soil quality and sludge quality relative to winter stockpiling (Macyk et al. 1997). The work with Millar Western involved baseline sampling in two quarter sections of land prior to stockpiling. In the spring of 1997, sampling was conducted beneath the stockpile and at distances of 0, 5 m, and 10 m from the edge of the stockpile. A total of 17 different transects were sampled. In addition the sludge was sampled to evaluate any changes in quality with time. Preliminary interpretation of the analytical data indicates that any detectable change occurred primarily in the 0 to 15 cm soil depth interval beneath the pile and to a maximum distance of about 5 m from the edge of the pile. The changes noted were minor with increases in NO$_2$-N from baseline values that ranged from <0.1 m/L to 13 mg/L to post stockpiling values of <0.1 mg/L to 18.3 mg/L. There were no measurable changes in the NO$_3$-N values.

The work with Alberta Newsprint Company also involved activities related to evaluating potential changes in sludge quality and soil quality. A large sludge stockpile was established on a high point in the landscape with a slope of about 2.5% to the northeast. Baseline sampling of the field was completed in 1995 (Macyk and Faught 1996b) and initial assessments related to winter stockpiling were completed in the spring of 1996 (Macyk et al. 1996). Soil sampling beneath and adjacent to the stockpile, and sampling of the sludge were completed in early May, 1997. The data for these samples are not available at this time.
In addition, temperature sensors were installed at the 30 cm, 50 cm, and 115 cm (15 cm below sludge in soil) in a 1 m high sludge pile and at the 0 cm (surface), 15 cm, 30 cm, 50 cm, 100 cm, and 200 cm (interface of sludge and soil surface) in a 2 m high pile. This was done to get an assessment of the temperature regimes in the pile and to determine the potential for decomposition to occur during the storage period. The data indicated that the soil did not freeze below the sludge pile. The temperature at 15 cm below the soil surface in the 1 m pile declined from a mean monthly value of about 35 °C in November 1996 to about 18 °C in April 1997. At the sludge/soil interface of the 2 m pile the temperature declined from 38 °C in November 1996 to 32 °C in April 1997. The mean monthly temperature at the 1 m depth in the 2 m pile declined from 58 °C in November 1996 to 47 °C in April 1997. Average monthly air temperatures of -11 °C to -17 °C and daily minimums below -30 °C were reported during the November to April period.

Based on the results of the work completed to date and the preliminary results related to the 1997 field program, it is apparent that winter stockpiling does not have a negative impact on soil quality and sludge quality. Any changes that have been noted occur beneath and immediately adjacent to the stockpile.

5.7 Summary

The research and operational work completed to date has demonstrated that mechanical pulp mill sludge is a good soil amendment. An overview of the scope of the research program and some of the results were provided. For specific information regarding any of the projects the reader is referred to the list of reports and conference papers provided in Section 6.0.
6.0 RELATED REPORTS/PAPERS/PRESENTATIONS

This section provides a listing of the reports and conference papers/presentations that have been generated since the inception of the sludge utilization program that was initiated in 1991.

It was stated previously that the results of the research work were interpreted in the context of the soil quality criteria guidelines utilized in Alberta. The reference for these guidelines is:


6.1 Project Reports


6.2 Conference Papers


