Land Application Guidelines for the Organic Matter Recycling Regulation and the Soil Amendment Code of Practice

Best Management Practices

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Forward

This document provides guidance and best management practices to assist the user in complying with the requirements of the *Organic Matter Recycling Regulation* (OMRR) and the *Soil Amendment Code of Practice* (SACoP). These guidelines should be used in conjunction with the OMRR and the SACoP, supplementary literature and the knowledge and experience of a qualified professional.

This document is divided into chapters and further subdivided into sections. Several chapters and sections deal specifically with either the OMRR or the SACoP while others pertain to both. If a chapter or section applies only to one regulation, this is indicated in the title. References to other sources of information are provided at the end of some chapters.

For ease of reference a summary table, located immediately following the Table of Contents, provides direction to the relevant parts of the document based upon intended activity and appropriate regulations.

The term “residuals” is used throughout the document to encompass materials regulated by the OMRR and the SACoP (i.e. biosolids, pulp and paper residuals, fly ash, WTR, wood waste, waste lime, lime mud). “Organic matter” is used for residuals managed under the OMRR while “amendment” is used to distinguish residuals regulated under the SACoP. Organic matter is also used as a general term describing a soil parameter. “Retail grade organic matter” and “managed organic matter” are used as per the definitions provided in the OMRR.

This document was developed in consultation with Ministry of Environment staff to serve as a companion document to the OMRR (February, 2002) and the SACoP (June, 2007).

Intended Use

This guideline contains information on the sampling and analytical requirements for residuals and the receiving environment including soil and vegetation. The guideline reviews the sampling of all materials covered under the OMRR and the SACoP, and receiving soils and vegetation in relation to the land application of these residuals in BC. The guideline recommends sampling approaches and methodologies to ensure the land application of residuals meets the criteria set out in the OMRR and the SACoP.

This document is divided into 16 chapters, each of which covers a particular aspect of residuals management. Chapters 2 and 3 contain an overview and the requirements of the OMRR and the SACoP respectively. Chapter 4 addresses the OMRR and the SACoP in the context of other provincial regulations. Chapter 5 provides a brief introduction to the characteristics of the various residuals covered under the regulations. Chapters 6, 7, 8 and 9 address sampling and analysis of residuals to meet regulatory requirements. Chapter 12 covers sampling and analysis requirements for the receiving environment. Chapter 10 provides general best management practices for the use of residuals as a soil amendment or fertilizer. Chapter 11 outlines the requirements for a Land Application Plan (LAP). Chapters 13, 14 and 15 cover specific details related to residuals use in agriculture, silviculture and reclamation respectively. Chapter 16 contains a reference list and recommended reading.

These guidelines do not identify all the considerations that a qualified professional may encounter in managing residuals under the OMRR and the SACoP. This document is designed to provide guidance only, and should not be considered a definitive resource. As knowledge progresses with respect to the beneficial use of the various residuals covered by this guideline, management practices will change. As such, qualified professionals engaged in residuals recycling are required to keep informed of new developments. The qualified professional, through their seal on a LAP, bears the responsibility of ensuring that the use of residuals is in compliance with the regulations, and that the application adheres to the principle of beneficial use.

These guidelines assume that the qualified professional has a thorough understanding of residuals, soils, nutrient and trace element management and fertilization in general. A background reading and reference list is provided at the end of this document for further information. It is strongly suggested that individuals responsible for preparing and implementing a residual land application program be familiar with current research and literature and undertake ongoing professional development in this field.

Applicable chapters based on regulation framework and intent

End use objective	Chapters														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Organic Matter Recycling Regulation (OMRR) – biosolids, compost, biosolids growing medium															
Land application of biosolids for agriculture	✓	✓		✓	✓	✓	✓	✓		✓	✓	✓	✓		
Land application of biosolids for silviculture	✓	✓		✓	✓	✓	✓	✓		✓	✓	✓		✓	
Land application of biosolids for reclamation	✓	✓		✓	✓	✓	✓	✓		✓	✓	✓			✓
Land application of compost for agriculture	✓	✓		✓	✓	✓	✓	✓		✓	✓	✓	✓		
Land application of compost for silviculture	✓	✓		✓	✓	✓	✓	✓		✓	✓	✓		✓	
Land application of compost for reclamation	✓	✓		✓	✓	✓	✓	✓		✓	✓	✓			✓
Production of compost (Class A)	✓	✓		✓	✓	✓	✓	✓							
Production of biosolids growing medium	✓	✓		✓	✓	✓	✓	✓							
Soil Amendment Code of Practice (SACoP) – fly ash, pulp and paper residuals, lime residuals, WTR, wood residue															
Land application of soil amendments for agriculture	✓		✓	✓	✓	✓	✓		✓	✓	✓	✓	✓		
Land application of soil amendments for silviculture	✓		✓	✓	✓	✓	✓		✓	✓	✓	✓		✓	
Land application of soil amendments for reclamation	✓		✓	✓	✓	✓	✓		✓	✓	✓	✓			✓

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List of Abbreviations

General abbreviations used in this document:

ALC – Agricultural Land Commission
ALCA – *Agricultural Land Commission Act*
Aluminum – Al
ALR – Agricultural Land Reserve
ASP – Aerated static pile
B – Boron
BC – British Columbia
BGM – Biosolids growing medium
BMP – Best management practices
BOD – Biological oxygen demand
C – Carbon
Ca – Calcium
$CaCO_3$ – Calcium carbonate
CCE – Calcium carbonate equivalent
CEC – Cation exchange capacity
CH_4 – Methane
CI – Confidence interval
CKD – Cement kiln dust
C:N – Carbon to nitrogen ratio
CO_2 – Carbon dioxide
CSR – *Contaminated Sites Regulation*
EC – Electrical conductivity
EMA – *Environmental Management Act*
EPA – Environmental Protection Agency
Fe – Iron
ICP – Inductively coupled plasma
K – Potassium
K_2O – Potassium oxide
LAP – Land application plan
Mg – Magnesium
MHO – Medical Health Officer
MoE – Ministry of Environment
MPN – Most probable number
N – Nitrogen
N_2 – Nitrogen gas
N_2O – Nitrous oxide
NH_3 – Ammonia
NH_4^+ – Ammonium
NO_2^- – Nitrite
NO_3^- – Nitrate
OMRR – *Organic Matter Recycling Regulation*
P – Phosphorous
P_2O_5 – Phosphorus pentoxide
QA/QC – Quality assurance / Quality control
SACoP – *Soil Amendment Code of Practice*
S – Sulphur
TKN – Total Kjeldahl nitrogen
TOC – Total organic carbon
WTR – Water treatment residuals
WWTP – Wastewater treatment plant

Unit abbreviations used in this document:

°C – degrees Celsius

≤ – less than or equal to

≥ – greater than or equal to

cm – centimeters

dS – deciSiemens

dt – dry tonne

dw – dry weight

ha – hectares

kg – kilograms

km – kilometers

L – liters

m – meters

m^3 – cubic meters

mg – milligrams

mL – milliliters

mm – millimeters

n – number

ppm – parts per million

s – standard deviation

s^2 – variance

t – tonne

µg – micrograms

µg g^{-1} – µg/g

wt – wet tonne

ww – wet weight

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1 Introduction

This guideline outlines the regulatory requirements, best management practices (BMPs) and sampling and analysis requirements for beneficial reuse of residuals regulated under the *Organic Matter Recycling Regulation* (OMRR) and the *Soil Amendment Code of Practice* (SACoP). This BMP document replaces the *Best Management Guidelines for the Land Application of Managed Organic Matter in British Columbia* (2002) and the *Draft Guidelines for Sampling of Biosolids, Compost, Soil and Vegetation under the BC Organic Matter Recycling Regulation* (2002).

The OMRR was promulgated in February 2002 replacing the *Production and Use of Compost Regulation* and the draft 1983 *Guidelines for the Disposal of Domestic Sludge* under the *Waste Management Act*. The SACoP is in draft form at the time of writing.

The OMRR and the SACoP are designed to ensure that residuals are used in a manner protective of human health and the environment (Photograph 1). Under past permitting and approval processes, there existed a degree of uncertainty regarding the requirements for application of residuals, site management and environmental monitoring. This provided a challenge for residual recycling programs. The OMRR and the SACoP remove many of these uncertainties by providing clearly defined requirements for prudent residuals management.

Photograph 1: Applying biosolids to agricultural land

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This document provides BMPs for the land application of residuals as per the criteria set out in the OMRR and the SACoP. The BMPs are based on beneficial use of residuals which are most appropriately managed primarily as a nutrient source or soil conditioner, as opposed to disposal as a waste material.

This guideline covers the land application of managed organic matter regulated under the OMRR (Class A biosolids, Class B biosolids and Class B compost) and soil amendments regulated under the SACoP (fly ash, pulp and paper mill primary and secondary residuals, lime residuals, water treatment residuals (WTR) and wood waste) in BC.

The discharger must have a qualified professional prepare a Land Application Plan (LAP) when required by the OMRR and the SACoP. Under the SACoP, the discharger is the person who owns the application site. A residual producer who transports a residual to a site is not the discharger of the material unless they apply the residual to the site under contract to the land owner or is the site owner themselves. For example, if pulp and paper residuals are delivered to a site, the company who generates the residuals and delivers it to the application site is not the discharger unless they actually spread the material. Under the OMRR, the discharger can be an owner of a composting facility, an owner of a facility that produces managed organic matter for land application or the registered owner of the land where the managed organic matter is applied.

The OMRR and the SACoP charge a qualified professional with the responsibility of evaluating sites for residual use, accurately determining application rates and minimizing the opportunity for adverse impacts on human health and the environment. The term qualified professional, means an individual who:

- is registered in British Columbia (BC) with a professional organization, is acting under that organization's code of ethics, and is subject to disciplinary action by that organization, and
- through suitable education, experience, accreditation and knowledge, may reasonably be relied on to provide advice within their area of expertise, as it relates to the regulation, duty or function.

Professionals are responsible for the LAP that sets out the specific BMPs for each site, and for overseeing their implementation. A LAP addresses all aspects of residual land application, from the appropriate application rate to a post-application monitoring plan. This guideline is designed to assist professionals in sampling and analysis, in preparing LAPs and as a source of related information on the best management and use of residuals.

Municipalities, government agencies, universities and private companies throughout the province continue to conduct research into the use of biosolids and other residuals as fertilizers and soil amendments. It is the intent of this document to make this research, as well as knowledge gained elsewhere, available to interested stakeholders. As such, this document will be updated as knowledge and experience progresses in the beneficial reuse of residuals.

2 The BC Organic Matter Recycling Regulation

The OMRR was promulgated in 2002 under the authority of the *Environmental Management Act* (EMA) and the *Health Act*.

The following activities are regulated in BC under the OMRR:

- the production, distribution, sale, storage, use and land application of biosolids and compost; and,
- the construction and operation of composting facilities.

Approvals or permits from the BC Ministry of Environment (MoE) are required for organic materials and processes not covered by the OMRR, for biosolids that do not meet the pathogen or trace element limits required by the OMRR, and for the application of biosolids or compost to soils that contain elevated trace element concentrations exceeding the standards specified in the OMRR.

Residuals regulated under the OMRR are classified according to quality and process criteria as:

- Class A biosolids;
- Class B biosolids;
- Class A compost;
- Class B compost; or,
- biosolids growing medium (BGM).

Class A biosolids, Class B biosolids and Class B compost are considered managed organic matter. Class A compost and BGM are considered retail grade organic matter.

The OMRR provides management requirements specific to the classification of biosolids, compost and BGM. This guidance document provides additional information specific to each type of organic matter.

The OMRR as it applies to biosolids, compost and BGM is discussed in Sections 2.1 to 2.3 below.

2.1 OMRR and Biosolids

The OMRR defines biosolids as stabilized municipal sewage resulting from municipal wastewater or septage treatment that has been sufficiently treated to reduce pathogen densities, vector attraction and trace element concentrations. As such, the term biosolids in BC is restricted to certain municipal wastewater-based products. Biosolids must meet the following scheduled requirements stipulated in the OMRR:

- pathogen reduction processes outlined in Schedule 1;
- vector attraction reduction processes outlined in Schedule 2;
- pathogen reduction limits specified in Schedule 3;

- quality criteria outlined in Schedule 4;
- sampling and analysis protocols and frequencies provided in Schedule 5; and,
- record keeping practices specified in Schedule 6.

The OMRR provides for the beneficial use of biosolids that meet these specific quality criteria. Biosolids are classified in the OMRR as either Class A or Class B biosolids, depending on the extent to which these process and quality-based criteria are met. The class of biosolids achieved has implications for recycling options, final land use, site access, application methodology and monitoring requirements following biosolids application. Table 1 provides a summary of the requirements for Class A and B biosolids.

Table 1: OMRR criteria for Class A and Class B biosolids

OMRR Criteria	**Class A Biosolids**	**Class B Biosolids**
Process Criteria (Schedules 1, 2 and 3)		
Pathogen Reduction	√	√
Vector Attraction Reduction	√	√
Fecal Coliform (MPN g^{-1} dw)	< 1,000	< 2,000,000
Quality Criteria (Schedule 4; $\mu g\ g^{-1}$, dw)[a]		
Arsenic	75	75
Cadmium	20	20
Chromium	-	1,060
Cobalt	150	150
Copper	-	2,200
Lead	500	500
Mercury	5	15
Molybdenum	20	20
Nickel	180	180
Selenium	14	14
Zinc	1,850	1,850
Foreign Matter	≤ 1%[b]	≤ 1%[b]
Sampling and Analyses and Record Keeping (Schedules 5 and 6)		
Sampling and Analysis	Required	Required
Record Keeping	Required	Required

[a] Class A Limits for trace elements specified in *Trade Memorandum T-4-93 (September 1997), Standards for Metals in Fertilizers and Supplements*.

[b] Further requirement of no sharp foreign matter that can cause injury.

The land application of Class A biosolids in quantities greater than 5 cubic meters (m^3), Class B biosolids and Class B compost all require the completion of a LAP by a qualified professional. The requirements of a LAP are identified in Schedule 7 of the OMRR and discussed in Chapter 11 of this document. Pre-application soil analysis and calculations are required to ensure trace elements concentrations will not exceed concentration standards identified in Schedules 9 and 10 of the OMRR.

Notification must be given of a pending biosolids application under the requirements of the OMRR. At least 30 days before the intended land application, the generator must notify the

Waste Manager in the regional MoE office of the proposed application and provide a subset of information required in the preparation of the LAP identified in Schedule 13 of the OMRR. Under certain land use classifications the notification must also be provided to the Medical Health Officer (MHO) having jurisdiction over the area and to the Land Reserve Commission. Once received, the MoE and the MHO have 30 days to review the information on the proposed application and require the discharger to meet conditions, site-specific standards and management practices. The proposed application is considered acceptable if within the 30 day period:

- the MoE manager requests no further information; and,
- the MHO requests no further information and does not stop the application from proceeding.

In both of the above instances neither the MoE nor the MHO approves the application; the notification is sent as a referral for review and comment as required.

2.1.1 Class A Biosolids

Class A biosolids are the highest quality biosolids achievable under the OMRR. Class A biosolids contain lower fecal coliform densities (< 1,000 most probable number (MPN) g^{-1}) and lower trace element concentrations than Class B biosolids. Achieving stringent quality standards allows for more liberal distribution and use of Class A biosolids under the OMRR. The criteria for Class A biosolids are provided in Table 1. Refer to Section 3.4 for additional information on land application and distribution requirements.

Photograph 2: Aerial of the JAMES Pollution Control Centre

Fraser Valley Regional District

2.1.2 Class B Biosolids

Class B biosolids are subject to less stringent trace element and fecal coliform requirements (< 2,000,000 MPN g^{-1}) than Class A biosolids. As such, they are subject to more land application and distribution restrictions. The criteria for Class B biosolids are provided in Table 1. Refer to Section 3.4 for additional information on land application and distribution requirements.

2.2 OMRR and Compost

The OMRR replaces the former *Production and Use of Compost Regulation* (1993). Composting of most non-agricultural organic matter within BC is now regulated by the OMRR. Schedule 12 of the OMRR lists organic matter that is acceptable feedstock for composting. In addition to regulating the compost process and providing quality-based criteria, the OMRR also regulates the construction and operation of composting facilities and the distribution and land application of compost. As with biosolids, compost is also classified based on process and quality criteria.

Table 2 provides a summary of the requirements to produce Class A and B compost under the OMRR.

Table 2: OMRR requirements for Class A and Class B compost

OMRR Criteria	**Class A Compost**	**Class A Compost**	**Class B Compost**
	(Untreated and unprocessed wood residuals and yard waste)	(Incorporating Schedule 12 feedstock)	
Process Criteria (Schedules 1, 2 and 3)			
Pathogen Reduction	√	√	√
Vector Attraction Reduction	√	√	√
Fecal Coliform (MPN g^{-1} dw)	-	< 1,000	< 2,000,000
Quality Criteria (Schedule 4; $\mu g\ g^{-1}$ dw)			
Arsenic	13	13	75
Cadmium	3	3	20
Chromium	100	100	1,060
Cobalt	34	34	150
Copper	400	400	2,200
Lead	150	150	500
Mercury	2	2	15
Molybdenum	5	5	20
Nickel	62	62	180
Selenium	2	2	14
Zinc	500	500	1,850
Foreign Matter	≤ 1%[a]	≤ 1%[a]	≤ 1%[a]
Sampling and Analyses and Record Keeping (Schedules 5 and 6)			
Sampling and Analyses	Not required	Required	Required
Record Keeping	Not required	Required	Required

[a] Further requirement of no sharp foreign matter that can cause injury.

2.2.1 Class A Compost

Class A compost is divided into two categories:

- compost produced solely from untreated and unprocessed wood waste (hereinafter referred to as wood waste) and yard waste; and
- compost produced from another feedstock listed in Schedule 12 of the OMRR.

Compost produced solely from wood and yard waste must undergo suitable pathogen and vector attraction reduction processes and meet the quality criteria provided in Schedule 4, Column 1 to meet Class A requirements. Class A compost produced from feedstock other than wood and yard waste (i.e. feedstock listed in Schedule 12 of the OMRR) must also meet these requirements, but additionally must meet Schedule 3 pathogen reduction limits (< 1,000 MPN g^{-1} dry weight (dw) fecal coliform), and adhere to sampling, analysis and record-keeping requirements stipulated in Schedules 5 and 6 respectively. Biosolids may be used as a feedstock in the production of Class A compost provided that it does not exceed Class B biosolids quality criteria in Schedule 4.

Class A compost may be distributed without restriction and without a LAP.

2.2.2 Class B Compost

Class B compost must be produced from the approved feedstock listed in Schedule 12 of the OMRR. Class B compost must undergo suitable pathogen reduction and vector attraction reduction processes (Schedules 1 and 2) and meet the quality criteria provided in Schedule 4, Column 3. Additionally, Class B compost must not exceed Schedule 3 pathogen reduction limits (< 2,000,000 MPN g^{-1} dw fecal coliform), and adhere to sampling, analysis and record-keeping requirements stipulated in Schedules 5 and 6 respectively.

2.2.3 Compost Excluded from the OMRR

The OMRR does not regulate several types of composting operations. Small-scale backyard composting operations producing less than 20 m^3 of compost annually and demonstration gardens producing no more than 100 m^3 of compost annually are exempt from the OMRR. Compost facilities currently operating under a permit, approval or operational certificate are also exempt from regulation under the OMRR.

The OMRR does not apply to agricultural waste composting, which is defined as composting of agricultural waste in accordance with Part 5 of the Code of Agricultural Practice for Waste Management (under the Agricultural Waste Control Regulation). Agricultural waste compost is exempt from the OMRR if:

- the compost was produced on farm using only agricultural waste produced on that farm (even if the compost is subsequently removed from the farm and used elsewhere), or
- if the agricultural waste was produced elsewhere but is being composted for use on that farm only.

The OMRR does apply if the agricultural waste was produced elsewhere, composted on farm (with or without the addition of agricultural waste from that farm) and used off that farm.

If the composting operation is located on land in the Agricultural Land Reserve (ALR), the requirements of the *ALR Use, Subdivision and Procedure Regulation* (under the *Agricultural Land Commission Act* (ALCA)) must also be taken into consideration. The *ALR Use, Subdivision and Procedure Regulation* allows the production, storage and application of:

- compost from agricultural wastes produced on the farm for farm purposes in compliance with the Agricultural Waste Control Regulation;
- Class A compost in compliance with the OMRR if at least 50% of the compost produced is used on the farm.

The ALCA does not allow the production of Class B compost on land in the ALR. In order to produce Class B compost within the ALR, an application for a permit must be made to the Agricultural Land Commission (ALC). Those wishing to produce a Class B compost should contact the ALC early in the process to determine the likelihood that an application for permit would be successful.

Additional information on the Agricultural Waste Control Regulation and Code of Agricultural Practice for Waste Management can be found in Section 4.4. Additional information on the ALCA is provided in Section 4.5.

2.2.4 Construction, Operation & Expansion of Composting Facilities

Part 5 of the OMRR outlines the requirements for construction of new composting facilities and expansions to existing facilities. It also outlines the requirements for leachate management at composting operations. The OMRR requires that a qualified professional prepare plans and specifications for all new composting facilities (excluding those identified in Section 2.2.3) and for expansions to existing facilities that result in an increase of more than 10% of total production, or greater than 20,000 m^3 of product. Requirements for composting facility plans are contained in Part 5 of the OMRR.

If a new composting facility is proposed with a capacity greater than 20,000 t annually or if an expansion is proposed to an existing facility that results in an increase in capacity to more than 20,000 t of product annually an environmental impact study and report are required. Part 5 of the OMRR outlines the requirements of the environmental impact study.

Copies of all plans, specifications and environmental impact studies must be kept at the composting facility at all times and be available to the MoE Regional Waste Manager upon request.

Additional information on the OMRR requirements for composting facilities can be found in the compost facility requirements guideline: *How to Comply with Part 5 of the Organic Matter Recycling Regulation* (Forgie *et al*., 2004).

2.2.5 Notification

Plans and specifications for composting facilities and environmental impact study reports must be filed with the Regional Waste Manager at least 90 days before construction begins on a new facility or expansion of an existing facility. If the facility is located in the ALR or on forest reserve land, the ALC must also be notified of the planned development.

2.2.6 Leachate Management

Part 5, Division 3 of the OMRR outlines the requirements for leachate management at composting facilities. All stages of the composting process must either occur on an impermeable surface to prevent leachate from entering the soil on site, or occur under cover to prevent the formation of leachate from runoff. All leachate from the composting operation must be collected and either reused in the composting process or be treated and disposed of in an environmentally acceptable manner. If a qualified professional can demonstrate through an environmental impact study that leachate is not a concern on a site, then an impermeable surface or roofed area is not required.

2.2.7 Compost Feedstock and the OMRR

Schedule 12 of the OMRR provides a list of organic materials that can be composted under the regulation. Any materials not included in this list must be composted only under permit or approval from the MoE.

2.3 OMRR and Biosolids Growing Medium

BGM is classified as retail-grade organic matter and can be distributed without volume restriction. The OMRR requirements for BGM are summarized in Table 3.

Table 3: Summary of the OMRR requirements for biosolids growing medium

OMRR Criteria	Biosolids Growing Medium
Quality Criteria (Schedule 4; $\mu g\ g^{-1}$ dw)	
Arsenic	13
Cadmium	1.5
Chromium	100
Cobalt	34
Copper	150
Lead	150
Mercury	0.8
Molybdenum	5
Nickel	62
Selenium	2
Zinc	150
Foreign Matter	≤ 1% dw[a]
Sampling and Analyses and Record Keeping (Schedules 5 and 6)	
Sampling and Analysis	Required
Record Keeping	Required
Nutrient and Organic Matter Criteria (Schedule 11)	
Total Kjeldahl Nitrogen (TKN)	< 0.6%
Carbon to Nitrogen Ratio (C:N)	> 15:1
Organic Matter	≤ 15 %, dw

[a] Further requirement of no sharp foreign matter that can cause injury.

2.3.1 Biosolids Growing Medium Fabrication

BGM is a fabricated soil product derived from the combination of biosolids with other organic and inorganic feedstock materials (Photograph 3). BGM can be fabricated with Class A biosolids or Class B biosolids which meet the pathogen and vector attraction requirements for Class A biosolids in Schedules 1, 2 and 3 of the OMRR. Unlike Class A or Class B compost, which must be produced from the list of organic matter suitable for composting provided in Schedule 12, there are no OMRR criteria for the feedstock materials used to produce BGM aside from the biosolids requirements.

Photograph 3: Tub mixer used to combine feedstocks to achieve a BGM

2.4 OMRR and Managed Organic Matter Storage

The OMRR specifies requirements for the storage of managed organic matter. The regulation identifies facilities as either a storage site or storage facility – each with their own set of requirements. Depending on the time of year and local precipitation, the storage site can require covering (Photograph 4). The intent of the regulation is to minimize the need for managed organic matter storage and ensure that there is no escape of managed organic matter or adverse environmental impacts. Storage requirements are discussed further in Section 10.6.6.

Photograph 4: Covered storage for managed organic matter

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2.5 Land Application and Distribution

Retail-grade organic matter can be distributed without restriction, while managed organic matter is subject to land application and distribution criteria. Land application and distribution requirements for managed organic matter are summarized below.

Additional information on the land application of managed organic matter is provided in the following Chapters:

- Chapter 10 – General best management practices (BMPs)
- Chapter 11 – Developing a LAP
- Chapter 13 – Agricultural applications
- Chapter 14 – Silvicultural applications
- Chapter 15 – Land reclamation applications

2.5.1 Class A Biosolids

Class A biosolids can be sold, distributed and applied without a LAP providing that:

- $\leq 5\ m^3$ is applied per year per parcel of land;
- sealed bags for retail purposes are each $\leq 5\ m^3$ with no restrictions on the number of bags; or
- the volume of Class A biosolids is $\leq 5\ m^3$ per vehicle per day.

Class A biosolids may be distributed as a feedstock to composting or BGM fabrication facilities without volume restriction.

A LAP must be prepared if Class A biosolids are to be land applied, as a source of fertilizer or soil conditioning, in volumes > 5 m^3. Within the OMRR, the purposes of a LAP are discussed in Part 4 while Schedules 7 and 13 provide information on specific requirements of a LAP. Chapter 11 of this document provides guidance for the development of a LAP.

2.5.2 Class B Biosolids

A LAP is required for the land application of Class B biosolids regardless of volume. In addition, application of Class B biosolids must be conducted in accordance with land application methods outlined in Schedule 8 and soil substance standards provided in Schedules 9 and 10 or site-specific criteria approved by the Waste Manager.

Schedule 8 of the OMRR establishes management requirements for the application of Class B biosolids, including buffer distances for applications near water features, grazing and food crop restrictions, and signage requirements. Schedules 9 and 10 provide soil standards where managed organic matter has been applied.

Class B biosolids can be distributed to a composting facility without a volume restriction. Class B biosolids that meet Class A biosolids criteria specific to Schedules 1, 2 and 3 may be distributed as feedstock to a BGM facility without volume restrictions.

2.5.3 Class B Compost

A LAP is required for the land application of Class B compost. The application must adhere to the management requirements stipulated in Schedule 8 of the OMRR. Such requirements include buffer distances for applications near water features, grazing and food crop restrictions, and signage requirements.

2.6 References and Supporting Documentation

Forgie. D.J.L, L.W. Sasser and M.K. Neger. 2004. Compost Facility Requirements Guideline: How to Comply with Part 5 or the Organic Matter Recycling Regulation.

Province of British Columbia. 2002. Organic Matter Recycling Regulation. BC Reg. 18/2002. Queen’s Printer, Victoria, BC.

3 The BC Soil Amendments Code of Practice

The SACoP enables beneficial land application of soil amendments to augment soil structure, increase soil organic matter content and promote vegetation establishment. The application of soil amendments must not create or exacerbate a contaminated site.

The SACoP is authorized under the EMA. The SACoP simplifies the previous permitting and approval process by providing consistent, province-wide requirements for the land application of soil amendments.

The SACoP applies to the following residuals defined as soil amendments:

- fly ash derived from the burning of wood that has not been immersed in marine waters;
- residuals from the primary or secondary treatment of liquid waste produced after 1995 from a pulp or paper mill and domestic sewage if mixed with those residual solids;
- waste lime or waste lime mud;
- residuals from the treatment of water for domestic use or use in industrial processes; and,
- industrial residuals of wood that have not been treated with glue, paint, preservatives or other substances harmful to humans, animals or plants.

Soil amendments can be applied to land for beneficial purposes provided compliance with the quality and application criteria in the SACoP.

Photograph 5: Applying ash to agricultural land

SYLVIS

3.1 Soil Amendment Quality

Each of the five soil amendments regulated under the SACoP must meet the criteria for trace elements and foreign matter prior to land application. The amendment quality requirements are summarized in Table 4 below. These requirements are provided in Table 1 and Part 3 of the SACoP.

The trace element criteria for residuals regulated under the SACoP are identical to that of Class A biosolids with the addition of the Class B limits for copper and chromium.

Table 4: Soil amendment quality criteria

SACoP Criteria	**Soil Amendments**
Quality Criteria (Table 1; $\mu g\ g^{-1}$ dw)	
Arsenic	75
Cadmium	20
Chromium	1,060
Cobalt	150
Copper	2,200
Lead	500
Mercury	5
Molybdenum	20
Nickel	180
Selenium	14
Zinc	1,850
Foreign Matter (Part 3)	
Foreign Matter	≤ 1% dw[a]
Fecal Coliform (Part 3)	
Fecal Coliform[b]	< 1,000 MPN g^{-1} dw[c]

[a] Further requirement of no sharp foreign matter that can cause injury.

[b] Applies only to pulp and paper residuals containing domestic sewage.

[c] A fecal coliform concentration of ≥ 1,000 MPN g^{-1} dw does not prohibit application; rather, special management requirements apply.

3.2 Storage

Part 2 of the SACoP provides storage requirements for three of the five amendments governed under the regulation: fly ash, primary and secondary pulp and paper residuals, and WTR. These must be stored in a structure that prevents the escape of the amendment and is located at least 15 meters (m) from any watercourse and 30 m from any source of water used for domestic purposes. Vehicles or mobile equipment used to transport the amendment are not considered a structure. Examples of structures are reservoirs, lagoons, cisterns, gutters, tanks, and bermed areas.

Soil amendments can only be stored on a farm if all the amendment will be applied to that farm under a LAP. The SACoP allows temporary storage of soil amendments on a storage site without the need for a storage facility provided buffer distances and timelines are adhered to and the escape of the soil amendments is prevented. Soil amendments can be stored on a storage site for a maximum of nine months if the site is at least 30 m from any watercourse or source of water used for domestic purposes. If the distance is less than 30 m, the maximum storage period is two weeks.

Soil amendments must be covered from October 1 to March 31 if they are stored at a site on Vancouver Island, in the Greater Vancouver Regional District, in the Fraser Valley Regional

District or in other areas of the Province where the precipitation during that period exceeds 600 mm for the months October to March inclusive (Photograph 6).

Photograph 6: Residuals storage site in a high precipitation region

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Although the SACoP does not specify storage requirements for lime or wood residuals, it is recommended that the storage of these amendments be conducted to prevent the escape of the amendment and not cause adverse environmental impacts. It is further recommended that the storage area be located at least 30 m from any surface water or drinking water source.

3.3 Sampling and Analysis

Sampling and analysis are required to confirm that the soil amendments meet the quality requirements for land application. All soil amendments governed under the SACoP must meet the criteria for trace elements (provided in Table 1 of the SACoP) and foreign matter. Determination of fecal coliform concentration is required only for primary and secondary pulp and paper residuals containing domestic sewage. These requirements are summarized in Table 4 above.

Initial sampling and analysis are required for all soil amendments to confirm that the SACoP criteria are met. Regular monitoring is required only for fly ash and primary and secondary pulp and paper residuals (whether or not they contain domestic sewage). For these amendments, a sample must be collected by a qualified professional when:

- 1,000 dry tonnes (dt) of the soil amendments are produced;
- one year has passed since the facility started to produce the amendments; or,
- one year has passed since the last sampling and analysis.

The SACoP requires a qualified professional collect the samples. Additional details on sampling and analysis are provided in Chapters 6, 7, 8, 9 and 12.

3.4 Land Application and Distribution

A LAP authored by a qualified professional is required for the application of > 5 m^3 of amendment per site per year. A LAP is not required if the application rate does not exceed 5 m^3 of amendment per site per year although some restrictions apply if the amendment is primary or secondary pulp and paper residuals which contain domestic sewage. Application of primary or secondary pulp and paper residuals containing domestic sewage is restricted by the groundwater table and buffer zones. In addition, if the fecal coliform concentration is $\geq$ 1,000 MPN g^{-1} dw, planting and grazing restrictions apply and a sign is required.

The requirements of the SACoP do not apply to industrial wood residuals used for the activities prescribed in Section 3 (5 and 6) of the *Waste Discharge Regulation.* Refer to Chapter 4 for information on the SACoP in context with other provincial legislation.

The land application of soil amendments is discussed in detail in the following Chapters:

- Chapter 10 – General BMPs
- Chapter 11 – Developing a LAP
- Chapter 13 – Agricultural applications
- Chapter 14 – Silvicultural applications
- Chapter 15 – Land reclamation applications

3.5 References and Supporting Documentation

Province of British Columbia. 2007. Code of Practice for Soil Amendments. Ordered June 18, 2007.

4 Association with Provincial Regulations

Residuals applied under the OMRR and the SACoP may be subject to additional provincial regulatory requirements. These regulations include, but are not limited to:

- *Contaminated Sites Regulation (CSR)*
- *Waste Discharge Regulation*
- *Agricultural Waste Control Regulation*
- *Agricultural Land Commission Act (ALCA)*

The applicability of these regulations to residuals managed under the OMRR and the SACoP is discussed in Sections 4.2 to 4.5 below.

4.1 Co-application of OMRR and SACoP Residuals

Residuals regulated under the OMRR and the SACoP can be mixed and applied concurrently. In this instance the user must comply with both the OMRR and the SACoP - the more stringent regulatory requirements apply. Individual residuals must meet the quality requirements of the appropriate regulation. For example, if Class A biosolids are co-applied with primary pulp and paper residuals (which do not contain domestic sewage), the Class A biosolids must meet the OMRR Schedule 4 trace element criteria whereas the pulp and paper residuals must meet the SACoP Table 1 requirements for trace elements. Residuals cannot be combined for the purpose of dilution. Assuming > 5 m^3 of either residual is included in the mixture, a LAP would be required. The soil where the residuals are applied would be required to meet the OMRR Schedules 9 and 10 criteria and the SACoP requirement that the application of residuals does not create or exacerbate a contaminated site.

In instances where wood waste is used in the production of BGM, the SACoP is not intended to add additional requirements beyond the criteria given in the OMRR.

4.2 BC Contaminated Sites Regulation

Both the OMRR and the SACoP include references to the *CSR* (CSR; BC Reg. 375/96).

The OMRR specifies that a site is not a contaminated site with respect to a substance in the soil provided:

- the site has been used in accordance with the OMRR;
- the site has not been used for any commercial or industrial purpose or activity listed in Schedule 2 of the CSR; and,
- the site before the application of managed organic matter was not a contaminated site as defined by the same regulation.

The SACoP indicates that soil amendments must not be applied to an application site in a manner or amount as to create or exacerbate a contaminated site.

4.3 Waste Discharge Regulation

The *Waste Discharge Regulation* (WDR; BC Reg. 320/2004) is authorized under the EMA (EMA; July 2004). In lieu of permits or approvals the EMA allows for the development of codes of practice for industries, trades, businesses, operations and activities listed in Schedule 2 of the WDR. Codes of practice govern the discharge of waste from the prescribed industry or activity; the SACoP is the code of practice designed to regulate the land application of residuals for use as soil amendments.

Sections 6(2) and 6(3) of the EMA prohibit the introduction of waste into the environment. In this context, the WDR stipulates the industries, trades, businesses, operations and activities that require authorization to introduce waste, and that are exempt from the prohibition through compliance with a code of practice (*WDR Implementation Guide*, MoE, 2006).

The following operations, related to these Best Management Guidelines, are exempt from EMA Section 6 (2 and 3) and do not require authorization or compliance with a code of practice (note that compliance with other regulations or codes of practice may be required for activities not listed):

- The use of industrial wood residue for foundation material at constructions sites if applied under the direction of a professional engineer (WDR, Section 3(4)).
- The use of industrial wood residue as plant mulch or in residential gardens, as foundation material for animal bedding, and in sports areas (WDR, Section 3(5)).
- The use of industrial wood residue as a soil conditioner or ground cover in non-agricultural operations if < 100 m^3 per year is spread on a single property and it is applied in accordance with good agronomic practices (WDR, Section 3(6)).

The *WDR Implementation Guide* (MoE, 2006) indicates that use of industrial wood residue on sports areas includes ball diamonds, soccer pitches and riding or hiking trials; it does not include the placement of wood over large areas occasionally used for sports activities. Good agronomic practice, with respect to the application of wood residues, entails spreading the wood evenly over the site as a soil amendment and ensuring beneficial use with respect to the soil.

Industries, trades, businesses, operations and activities listed in Schedule 2 of the WDR and that operate under the appropriate code of practice are also exempt from Sections 6 (2 and 3) of the EMA with respect to introducing waste to the environment (i.e. an authorization to introduce waste is not required).

Regardless of the exemptions listed above, waste discharges must comply with EMA Section 6 (4). A person must not introduce waste into the environment in such a manner or quantity to cause pollution.

4.4 Agricultural Waste Control Regulation / Code of Agricultural Practice for Waste Management

The *Agricultural Waste Control Regulation* (AWCR; BC Reg. 131/92) falls under the authority of the EMA and the *Health Act*. The AWCR indicates that a person who carries out agricultural operations under the *Code of Agricultural Practice for Waste Management* (CoAPWM) is exempt from Sections 6 (2 and 3) of the EMA and therefore, does not require a permit or authorization to introduce wastes to the environment for the purposes of carrying out agricultural operations.

Part 7 of the CoAPWM pertains to the storage and use of wood waste, a residual also managed under the SACoP. The CoAPWM designates which activities wood waste can be used for, including application as a soil conditioner. The CoAPWM also provides storage requirements and delineates prohibited uses. Wood waste stored and used on a farm must be handled in a manner to prevent the escape of particulate matter, solid matter or leachate that causes pollution. Wood waste used on a farm must not be used:

- for landfill, and
- on sites within 30 m of any source of water used for domestic purposes with the exception of existing sites under use prior to April 1, 1992, provided that the use is not causing pollution.

The SACoP does not prohibit the application of wood waste within 30 m of domestic water sources although the CoAPWM does. Therefore, when applying wood waste to agricultural land it is important that the requirements of both the SACoP and the CoAPWM are taken into consideration and the most stringent criteria used.

4.5 Agricultural Land Commission Act

The *ALCA* (ALC, S.B.C. 2003) mandates that a person must not use agricultural land for non-farm use unless permitted by the Act, the regulations or an order of the commission. Soil amendments regulated under the SACoP are considered fill and their application is considered a non-farm use. In order to apply soil amendments to land within the ALR, an application for the placement of fill must be made under Section 20 of the ALCA. Applications should be submitted well in advance of the proposed application as processing time ranges from approximately 60 to 90 days. Both the ALC and the local government can veto the land application. Authorization by the ALC is not required for the placement of residuals regulated under the OMRR as the *ALR Use, Subdivision and Procedure Regulation* defines the following activities as farm use:

- application of compost and biosolids produced and applied in compliance with the OMRR; and,
- production, storage and application of Class A compost in compliance with the OMRR, if at least 50% of the compost is used on the farm.

The ALCA does not allow the production of Class B compost on land in the ALR. In order to produce Class B compost within the ALR, an application for a permit must be made to the ALC. Those wishing to produce a Class B compost should contact the ALC early in the process to determine the likelihood that an application for permit would be successful.

4.6 References and Supporting Documentation

Agricultural Land Commission. 2003 (Revised 2004). *Agricultural Land Commission Act*. S.B.C 2002. Burnaby, BC.

Ministry of Environment, Environmental Protection Division. 2006. Waste Discharge Regulation Implementation Guide. March 17, 2006.

Province of British Columbia. 1992. Agricultural Waste Control Regulation. BC Reg. 131/92 including amendments up to BC Reg. 321/2004. Queen's Printer. Victoria, BC.

Province of British Columbia. 2002. Agricultural Use, Subdivision and Procedure Regulation. BC Reg. 171/2002 including amendments up to BC Reg. 546/2004. Queen's Printer. Victoria, BC.

Province of British Columbia. 2004. Waste Discharge Regulation. BC Reg. 320/2004 including amendments up to BC Reg. 156/2005. Queen's Printer. Victoria, BC.

5 Properties of OMRR and SACoP Regulated Residuals

This Chapter provides information on the production and use of residuals regulated under the OMRR and the SACoP including substances which can affect the quality of the residuals.

5.1 Residuals Regulated by the OMRR

The following residuals are regulated by the OMRR:

- municipal biosolids that meet the Class A or Class B pathogen reduction processes and limits; vector attraction reduction processes and trace element limits in the OMRR;
- compost derived solely from organic matter listed in Schedule 12 of the OMRR and that meets the Class A or Class B compost pathogen reduction processes and limits; vector attraction reduction processes and trace element limits in the OMRR; and,
- BGM derived from Class A biosolids or Class B biosolids that meet Class A pathogen and vector attraction reduction requirements.

5.1.1 Biosolids

Biosolids are an organic residual derived from the treatment of municipal wastewater (Photograph 7). Biosolids refers to municipal sewage sludge that has been sufficiently treated through stabilization processes to reduce pathogen densities and vector attraction such that it meets the requirements of the OMRR.

Because of the high nutrient and organic matter content, biosolids can be beneficially applied to land as a fertilizer or soil conditioner.

5.1.1.1 Biosolids Production

The composition of influent wastewater and the type of treatment system used at a wastewater treatment plant (WWTP) can influence the nutrient and trace element content of the biosolids. Biosolids can be generated from anaerobic or aerobic treatment processes (Photograph 8). They can be dewatered following digestion, or lime stabilized. They can also be produced as a result of long-term storage of wastewater and sludge in a lagoon.

Photograph 7: Lime stabilized biosolids on the left compared to biosolids without lime

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The process of treating municipal wastewater involves preliminary, primary, secondary and occasionally, tertiary treatment of the wastewater with the goal of creating an effluent that is of a quality that can be discharged to ground or surface water. Preliminary wastewater treatment includes screening and grit removal to remove coarse solids that would interfere with equipment used during further treatment. Primary wastewater treatment involves gravity sedimentation to remove a significant portion of settleable solids and biological oxygen demand (BOD). The residue from primary treatment is called primary sludge. The primary-treated wastewater can then undergo secondary treatment where a microbial process is used to remove nutrients, trace metals and contaminants from the wastewater. The microbial biomass consumes or adheres to trace elements, pathogens and organic compounds from the wastewater, and then flocculates to form particles that will settle in sedimentation tanks. The settled material is termed secondary sludge.

Photograph 8: Aerobic digester at the Langley WWTP

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The material that settles out in the primary sedimentation and (if applicable) secondary biological flocculation processes is called sludge. Regardless of the treatment process employed (other than preliminary screening), WWTPs produce sludge. Sludge quantities and characteristics are a function of the untreated wastewater that enters a treatment plant as well as the treatment processes used at the plant. The quantity of sludge produced by a treatment plant depends on variables including influent wastewater characteristics (relative proportions of sanitary sewage, industrial wastes and storm water), and the type and level of treatment employed at the treatment plant.

In general, the more advanced the level of treatment, the greater the amount of sludge produced. Sludge handling and treatment processes alter the amount and characteristics of the sludge produced. Sludge handling processes are divided into six categories or levels of treatment. Sludge handling processes include: stabilization, dewatering, conditioning, drying, concentration, and beneficial use or disposal.

Sludge stabilization is necessary to eliminate nuisance conditions and reduce or eliminate pathogens. Volume (weight) reduction and methane (CH_4) gas or carbon dioxide (CO_2) production are stabilization functions. Stabilization processes include: anaerobic digestion, aerobic digestion, chemical stabilization, composting, heat treatment, disinfection, and lagooning.

Most sludge in BC undergoes either anaerobic or aerobic digestion, composting or lagooning. Anaerobic digestion is the most common method of sludge stabilization and involves the biological degradation of organic matter in the absence of free oxygen. This process results in the conversion of readily degradable organic matter into CO_2, CH_4, hydrogen sulphide and water, leaving a biologically stable residue. A considerable reduction in number of pathogenic bacteria occurs during digestion. Sludge from the sedimentation tank is pumped into a closed vessel called a digester. Within the digester the sludge is mixed, heated and held for 20-60 days. Mesophilic digesters operate in the 10-30 degrees Celsius (°C) range whereas thermophilic digesters operate at 38-60°C. Methane gas produced from these processes is often used to heat the digestion process. Aerobic digestion occurs in the presence of oxygen, and in the same temperature range as anaerobic digestion. Chemical stabilization is designed to create conditions that inhibit the growth of microorganisms and thus slow the degradation of organic matter and prevent odours. The most common form of chemical stabilization is to raise the pH of the sludge using lime or a similar material. Lagooning is also employed for pathogen reduction and dewatering (Photograph 9).

Photograph 9: Biosolids lagoon

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Once municipal sewage sludge has been sufficiently treated through stabilization processes to reduce pathogen densities and vector attraction such that it meets the requirements of the OMRR, it is termed biosolids, and can be beneficially recycled as a fertilizer or soil amendment.

Biosolids conditioning is a treatment process specifically designed to improve dewatering characteristics, should dewatering be required. Conditioning processes include: polymer addition, elutriation (a washing process), heat treatment and ash addition. Polymer addition thickens the biosolids and improves the production rate and solids capture. Solids concentration with polymer frequently precedes dewatering and/or stabilization processes. Thickening processes are commonly used when two types of biosolids from separate stabilization processes are combined for dewatering (Photograph 10). The methods used for concentration are physical processes and include gravity settling, dissolved air flotation and centrifugation.

Photograph 10: Solids thickening

SYLVIS

Dewatering is a biosolids handling process that removes sufficient water so that the biosolids transforms from a fluid state to a damp solid or dewatered cake. The most common dewatering devices are centrifuges, drying beds, lagoons, vacuum filters, pressure filters and belt filter presses. Biosolids drying is a thermal process whereby both volume and weight are reduced.

5.1.1.2 Biosolids as a Fertilizer and Soil Amendment

Two primary benefits of biosolids are their ability to improve soil fertility through the addition of nutrients, and soil physical properties through the addition of organic matter and organic C (e.g. Stehouwer, 2006). The addition of organic residuals can also increase the microbial activity in the amended soil (Rogers and Smith, 2007).

Biosolids contain all of the macro and micronutrients required by plants for normal growth. The essential macronutrients are nitrogen (N), phosphorus (P), potassium (K), sulphur (S), calcium (Ca) and magnesium (Mg); the micronutrients (or trace elements) include chloride, iron (Fe), boron (B), manganese, zinc, copper, molybdenum, nickel, selenium and cobalt. Applied to land, these organic sources of nutrients are considered a fertilizer source and must be managed accordingly. Biosolids are comparable to typical poultry manure in nutrient content (see Table 5). The concentration of each nutrient in biosolids varies with the treatment process used in generating the biosolids, and the source material entering the WWTP.

In general, biosolids produced from primary sludge have lower nutrient concentrations than from a combination of primary and secondary sludges. Two identical primary WWTPs, both using thermophilic digestion, but one with a shorter digestion period than another may produce biosolids with a similar concentration of N, but the forms and availability could differ. The processes governing the availability of nutrients in biosolids is described further in Section 10.3.

Table 5: Average nutrient comparison – biosolids and poultry manure

Organic Nutrient Source	Average concentration (%, dry matter basis)				
	Dry Matter	Total N	NH_3-N	Total P	Total K
Biosolids (dewatered)	25	4.3	0.86	2.3	0.2
Poultry layer manure[a]	41	4	1.1	3	2
Poultry broiler manure[a]	75	4.6	0.76	1.5	1.5

[a] Manure data adapted from *Environmental Guidelines for Poultry Producers, 2nd Ed.*, BCMAF 1997.

Relative to the nutrient requirement of most crops, N is the most abundant nutrient in biosolids. Typical biosolids contain N in several different forms, about 80% as organic N and 20% in inorganic forms (ammonium (NH_4^+), ammonia (NH_3) and nitrate (NO_3^-)).

Biosolids are also an excellent source of organic matter, the addition of which can improve the physical, chemical and biological properties of the soil. Research has demonstrated that organic C provided through the addition of biosolids improves soil aggregate stability and decreases bulk density (García-Orenes, *et al.*, 2005). Improvements to the physical characteristics of the soil can include: greater water holding capacity, improved aeration, reduced soil erosion, and easier root penetration.

Chemically, these materials can improve the cation exchange capacity (CEC) of the soil, the ability of the soil to hold positively charged nutrients such as K, Ca and Mg. The organic matter addition can increase microbial activity in the soil by providing soil microbes with both a short and long term nutrient source. On disturbed sites, biosolids can supply an innoculum of micro-organisms to assist in soil development and site rehabilitation.

5.1.2 Compost

Compost is not itself a residual as are the other materials discussed in this guideline, but is created from the composting of one or more different organic materials. It is a humus-like organic material that results from the controlled aerobic biodegradation of organic materials such as municipal biosolids, pulp and paper residuals, wood residues, manure, yard wastes and food wastes.

5.1.2.1 Compost Production

Composting is a controlled and managed process, delineating it from landfilling or stockpiling of organic residuals. When managed properly, composting produces sanitary, stable compost that can be utilized as a soil amendment or as feedstock in value-added products (Photograph 11).

Photograph 11: Turning a compost windrow

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Mixing feedstock to produce compost that optimizes important physicochemical properties is critical to successful composting. This is facilitated by starting with well-characterized feedstock of consistently high quality. The two parameters of primary interest to a composting facility in their initial compost mix are carbon-to-nitrogen ratio (C:N) and moisture content. A C:N of 30 is recommended to ensure the proper balance of nutrients to support microorganism populations within compost. A C:N exceeding 30 will result in a shortage of N which will inhibit microbial synthetic and reproductive functions and subsequent biodegradation of organic matter. Additionally, the consumption of excess C may lead to the immobilization of the already depleted pool of available N. A C:N of less than 30 results in a deficiency of C necessary for energy and growth, and excess N which may lead to the formation of organic acids, liberation of excess gaseous NH_3 and odour generation.

Moisture in compost is necessary to assist microorganisms in metabolic processes, and facilitate the transport of nutrients. Moisture also supports the movement of microbial populations, distributing them uniformly within compost. The recommended moisture content for aerobic composting is approximately 50-60%. At moisture contents below this range, microbial activity is inhibited and the rate of composting decreases. At levels above this range, water occupies pore space formerly occupied by air, and anaerobic conditions prevail, resulting in decreased degradation and increased organic acid and odour generation.

Upon mixing the organic materials to be composted, microbial population establishment and composting proceed rapidly. Diverse microbial populations colonize and are succeeded based on the changing conditions within the compost environment. As localized environments in compost vary, so too do the microbial populations that operate in these conditions.

Three primary groups of organisms are responsible for degradation activities in compost. They are bacteria, fungi, and actinomycetes.

The presence, composition and succession of these microorganism populations relates to changes in temperature during the composting process. Four primary temperature regimes occur during the composting process. Composting initiates in the mesophilic stage. This stage is characterized by temperatures below 40°C and the consumption of easily degradable organic C sources such as sugars, fats and hydrocarbons by mesophiles, predominantly bacteria. The initial mesophilic stage is short in duration, lasting only a matter of hours to 1-2 days. As the mesophilic stage progresses, the degradation of organic matter releases energy in the form of heat. The unique insulating property of compost allows the rapid warming of the compost to a point at which mesophilic degradation is inhibited. At this point, composting enters the thermophilic stage, and mesophiles are succeeded by thermophiles. Characterized by high-rate biological degradation at temperatures between 40-60°C, the thermophilic phase lasts from days to weeks. In addition to further degrading organic matter, the thermophilic stage proceeds at temperatures sufficient to destroy weed seeds, fly larvae, and human pathogens (Rynk, 1992). As the thermophilic stage ends, and the compost cools to below 40°C, mesophiles recolonize the compost in the cooling and curing phases. Mesophiles in these stages include bacteria, but also include fungi and actinomycetes that slowly degrade recalcitrant forms of organic matter including proteins, lignin, chitin and cellulose. The cooling stage continues until the compost does not reheat upon turning; the curing stage which follows it can last from weeks to months. Curing facilitates the formation of humus, the stable organic matter in compost that improves physical properties of amended soil. Curing also allows the recolonization of soil microorganisms as well as macroorganisms such as worms and insects.

Composting methods vary in their degrees of management and infrastructure requirements. In general, commercial or large scale composting is done by one of three different methods; static piles, windrows, and in-vessel composting.

The formation of static piles is the composting process requiring minimal infrastructure. In this process, compost is mixed and placed in piles on top of perforated pipes used to provide aeration. Static piles do not require turning during the composting process. Three types of aeration are used in static aerated piles. Passive aeration allows air to flow in through the perforated pipes as a result of ambient air movement and convective forces in the compost pile. Actively aerated static piles (ASP) are forcibly aerated by connecting a blower to the pipes placed within the compost. In some cases these blowers are integrated as part of an automated system and are activated based on changes in temperature and/or moisture within the compost pile. Positive forced aeration forces air up through the static pile, while negative forced aeration draws air down through the pile. Negative aeration allows for better control of odours in open-air static pile composting.

Windrow composting requires more management than static pile composting. In this process, compost is mixed and formed into long rows. A typical windrow may be 3-4 m wide, 2-3 m high, and as long as is required to process the required volume. Windrows are aerated by mechanical turning of the compost. Mechanical turning also allows the redistribution of heat and moisture, and decreases the density of the compost, temporarily enabling improved airflow. Several designs for windrow turners are used, including turners mounted on tractors that utilize a power take-off system, and larger turners that straddle the windrow.

In-vessel composting requires the most infrastructure of the three discussed composting processes. In this process, compost is placed within channels atop perforated flooring to allow for aeration. Mixing equipment on tracks above the channels turn the compost. Many in-vessel operations are covered or enclosed within a temporary or permanent building to provide a constant composting environment and facilitate odour management.

5.1.2.2 Compost as a Fertilizer and Soil Amendment

The quality of compost as a fertilizer or soil conditioner depends mainly on the nutrient content of the organic materials that make up the compost. Compost typically contains lower nutrient concentrations than biosolids or other similar residuals. The nutrients, particularly the N, are converted during composting from plant-available to less readily available organic forms. As compost is quite variable in composition, it is typically land applied as either a fertilizer or a soil conditioner, depending on the final C:N and nutrient content. It is also very desirable for use in landscaping and horticulture due to its soil-like properties and aesthetic qualities. A study conducted by Gale et al. (2006) concluded that the relative stability of compost generally precludes it from providing a significant source of plant available nitrogen. As such, the primary benefit of compost application lies in its ability to provide organic matter for the improvement of soil physical properties.

Compost can vary widely in quality depending on the organic materials that made up the original blend. Thus, characterizing compost feedstock is an important step in the composting process. Compost quality must be assessed prior to land application or other use to determine an appropriate application rate that will promote beneficial use and environmental protection.

5.1.3 Biosolids Growing Medium

Similar to compost, BGM is not a residual but rather is a product derived by mixing biosolids with various feedstock materials. The feedstock materials are selected to meet the final use objectives of the BGM.

5.1.3.1 Biosolids Growing Medium Production

Biosolids, a mineral feedstock and a C feedstock are normally used when fabricating a BGM. Mineral feedstock such as sand is used to increase porosity, provide structure and improve drainage. The C source functions to increase the C:N of the BGM. The ratio of feedstock ingredients must be carefully selected to ensure that the OMRR Schedule 11 requirements are met. The OMRR requirements for BGM are designed to be protective of human health and the environment; they are not intended to ensure soil fertility, aesthetics or structure or meet industry or landscape standards.

It is recommended that the intended use of the BGM be determined, and pilot scale mixing conducted prior to operational scale BGM fabrication. This will allow the opportunity to modify feedstock ratios and ensure that the physical, chemical and biological characteristics of the BGM are appropriate for the intended use.

In addition to the feedstock quality the manner in which the feedstock materials are mixed can impact the quality of the BGM. There are a variety of technologies which can be used to mix the feedstock materials such as horizontal auger tub mixers and bottom buckets (Photograph 12).

Photograph 12: A bottom bucket to fabricate BGM

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5.2 Residuals Regulated by the SACoP

The following residuals are regulated by the SACoP:

- fly ash derived from the burning of wood (except wood that has been immersed in marine waters);
- primary and secondary pulp and paper residuals produced after 1995 (including domestic sewage if mixed with the residuals);
- waste lime and waste lime mud;
- WTR; and,
- industrial wood residues that have not been treated with glue, paint, a preservative or other substance harmful to humans, animals or plants.

The chemical composition of typical residuals regulated by the SACoP are provided in Table 6 and compared to those residuals regulated under the OMRR. A summary of the sources, benefits, challenges and applications of the SACoP residuals is provided in Table 7.

Table 6: Typical chemical composition of residuals regulated by the OMRR and the SACoP (various sources)

Residual[(a)]	**C:N**	**TKN**	**NH_4-N**	**Total P**	**Total K**	**pH**	**EC**
	ratio	%	mg kg^{-1}	mg kg^{-1}	mg kg^{-1}	pH units	dS m^{-1}
Biosolids	5-16	3.2-6.7	397-10,200	10,000-30,000	1,000-4,000	7-8	3-6
Compost	7-40	1-4.5	2,600[b]	8,000-10,000	5,000-10,000	7-8	2-15
Fly ash	96[b]	0.06-0.42	trace	1,800-14,000	10,300-41,300	8.9-13.5	16-50
Pulp and paper residuals – primary	111-478	0.08-0.4	37-122	580-1,000	120-800	6.4-7.6	0.19-0.7
Pulp and paper residuals – secondary	5-10	4.3-7.7	900-1,400[c]	7,700-12,000	2,000-6,000	6.6-7.9	3.9
Waste lime and lime mud	not available	0.2-0.3	trace	1,070-5,700	200-1,160	8.4-13	not available
WTR (Al or Fe-based)	16.5-26.3	0.73-0.94	31-58	2,790-4,360	790-1,200	5.25-6.25	0.31-0.58
Wood residues	150-1,313	0.04-0.23	trace	560[b]	1,310[b]	4.6[b]	3.09[b]

[a] References: Alberta Environment, 1999; Demeyer *et al.,* 2001; Edwards and Someshwar, 2000; Elliott *et al.,* 2002; Epstein, 2003; Gallimore *et al.,* 1999; Gaskin and Morris, 2004; Norrie and Fierro, 1998; Patterson *et al.,* 2004; Peters and Basta, 1996; Rynk, 1992.

[b] Range not available.

[c] Combined primary and secondary pulp and paper residuals.

Table 7: SACoP residuals summary matrix

Industrial Residual	Source	Benefits	Challenges	Applications
Primary pulp and paper residuals	• Sediment collected from settling of solids in primary pulp and paper wastewater treatment.	• Contains high level of organic matter which improves soil physical properties including soil aggregation and CEC. • High base cation concentrations in recovered clays beneficial to intensively managed / short rotation forests. • Can be used as weed suppression mulch. • Typically lower trace element concentrations.	• High C:N product liable to cause net immobilization of N following application. • Application used primarily as a soil amendment and not as a nutrient source.	• Primary and secondary pulp and paper residuals are usually combined prior to dewatering. • Combined pulp and paper residuals are used in mine reclamation; as a C and nutrient source in fabricated soils; landfill cover layers; composting feedstock; and as a fertilizer on agricultural sites. • Soil product development.
Secondary pulp and paper residuals	• Biological treatment of pulp and paper wastewater to remove suspended solids and reduce BOD.	• High N and P concentrations resulting from addition to facilitate biological process in secondary treatment.	• Low C:N content requires nutrient management. • Physical properties of bacterial biomass can be difficult to control. • Uncertainty in pathogen levels in non sanitary sewage mills.	
Wood ash	• Fly ash collected from incineration of wood waste.	• Serves as a liming substitute due to high concentrations of oxides and carbonates; can increase pH dependent CEC. • Provides a source of plant available base cations.	• Composition varies with type of wood incinerated and combustion technology. • Deficient in N and will require supplementation with N fertilizer if applied to mineral soils. • Can increase salinity and pH levels in soil and inhibit plant growth. • Can contain elevated concentrations of synthetic organic compounds.	• Land application as a liming agent, primarily on agricultural soils. • Ingredient in fabricated soils and soil products.
Wood waste	• Composed of bark and chips from sawmills and pulp and paper mills.	• Suitable as a bulking agent in composting due to high C:N. • Depending on composition, can be porous and absorptive.	• Variation in composition and cleanliness due to presence of sand and grit. Clean wood waste typically incinerated. • High C:N – mulch application. • Not useful as a fertilizer. • Leachate can have adverse environmental impacts.	• Used in composting and on slopes for erosion control and slope stabilization (particularly on sites heavily impacted by precipitation). • Vegetation competition suppression.
WTR	• WTR are residuals generated during the purification of drinking or industrial process water.	• Experimentally used to bind P in other high-P residuals. • Ca containing WTRs can be used as an alternative liming agent.	• Low concentrations of all nutrients except P which is primarily bound by aluminum (Al) and Fe making it poorly available to crops.	• Bind P on sites oversupplied with nutrients. • Land application as a liming agent (Ca – containing WTRs).

Adapted from SYLVIS, 2005

5.2.1 Fly Ash

5.2.1.1 Fly Ash Production

An interest in replacing fossil fuels with renewable biomass fuels has facilitated the investigation of wood waste use in energy production. The incineration of wood waste for heat or energy produces ash as a by-product at approximately 1% by weight (e.g. the incineration of 1,000 kg of wood waste produces 10 kg of ash). Two types of ash are formed in the combustion process. Bottom ash is the ash remaining in the incinerator following combustion. Fly ash (or precipitator ash) is suspended in and collected from the incinerator exhaust gas.

The SACoP enables the beneficial use of fly ash; however, bottom ash is not regulated under SACoP and the land application of this residual would require a permit or approval from the MoE. To be acceptable for management under the SACoP, the fly ash must be generated from clean wood waste that has not been in contact with sea water. Refuse derived fuel, waste tires, residue oils and other material may be used as additional fuel in power boilers to satisfy the industry's desire to improve energy efficiency. Fly ash from such processes also require a permit or approval from the MoE.

The most abundant nutrients in fly ash are K and Ca and, to a lesser extent, Mg, Al, Fe and P. The composition of fly ash is variable and depends on several factors including the type of wood incinerated, incineration technique and combustion temperature (Pitman, 2006). Generally, hardwood ash contains higher nutrient content that softwood (e.g. conifer) species, particularly P and K. Incineration temperatures ranging from 600-900°C are ideal for retaining nutrients. Source separation and the use of additives in the incineration of wood waste can also affect quality. In general, fly ash has a very high concentration of several macro and micro nutrients (excluding N which is lost during combustion) and low concentrations of trace elements of concern. The fly ash reflects the nutrient composition of wood waste incinerated. It also has a high pH (9-13.5) due to its high concentration of oxides and carbonates (Alberta Environment, 2002; Demeyer *et al.*, 2001).

Fly ash, as produced, has an extremely small particle size and is very dry making it susceptible to movement by wind. Typically, the ash is wetted during or immediately after precipitation for ease of handling and storage.

5.2.1.2 Fly Ash as a Fertilizer and Soil Amendment

Fly ash can be land applied as an alternative liming material or as a source of macro and micro nutrients for crop growth.

Fly ash is an excellent alternative liming material because it has a high pH and is similar to burned or hydrated lime in its reactivity in the soil. Because it is more similar to burned or hydrated lime than to pure calcium carbonate ($CaCO_3$), it acts to increase the soil pH more rapidly than limestone. Consequently fly ash is an excellent fertilizer source for agricultural land, reclamation sites or forested areas. Supplemental N may be required with fly ash application in the case of a soil N deficiency. The nutrients in fly ash are not present in the ideal proportions for vegetation growth; the relatively high concentrations of K and sodium can lead to soil imbalances if very high application rates are used. Section 10.4.3 contains more information on beneficial land application of fly ash.

5.2.2 Pulp and Paper Residuals

5.2.2.1 Primary and Secondary Pulp and Paper Residuals Production

The production of pulp for paper products generates a considerable volume of residuals. During pulping (Norrie and Fierro, 1998), virgin wood is broken down either mechanically or chemically to produce raw pulp. Mechanical pulping uses stone discs or refiners to physically grind the wood into pulp, while chemical pulping "cooks" chipped wood through the sequential addition of caustic reagents including sodium hydroxide and sodium sulphide to break down lignin while retaining cellulose and hemicellulose. Subsequent washing and bleaching of the pulp further add to the residual generated in the pulping process.

The main solid material produced from the effluent treatment process associated with a pulp mill is referred to as pulp and paper residuals. Treatment processes at pulp and paper mills typically yield two types of pulp and paper residuals: primary and secondary (Carpenter and Fernandez, 2000). Primary residual is obtained by the physical separation of wood fibres, clay, lime and ash (Bostan *et al.,* 2005) from the raw wastewater usually in clarifiers or lined ponds. Secondary residual is generated by settling the solids generated during the biological effluent treatment processes used to remove BOD and toxicity. To facilitate the secondary process, nutrients including N and P are added and the wastewater is oxygenated. The resulting primary and secondary residuals are contrasting in composition. The primary residual is composed of waste wood fibre and lime particles, and has a high C:N, while the secondary residual has a higher nutrient content and a lower C:N (Norrie and Fierro, 1998). Paper recycling residuals are typically similar to a primary residual.

At many mills, primary and secondary residuals are combined prior to dewatering, producing a residual that has a C:N ratio and nutrient content midway between the two materials (Photograph 13).

At some mills, domestic sewage from the mill is combined with pulp residuals for treatment. In such cases, the residuals may contain pathogens.

Photograph 13: Pulp and paper residuals stockpiled before application

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5.2.2.2 Pulp and Paper Mill Residuals as a Fertilizer and Soil Amendment

Primary pulp and paper residuals and paper recycling residuals, due to their high C:N, are an excellent soil amendment to increase soil organic matter. Secondary residuals should be land applied for their fertilizer value as they contain a substantial amount of all macro nutrients and are also a source of organic matter. Combined pulp and paper residuals (primary plus secondary) could be land applied either as a fertilizer source or as a soil conditioner, depending on the C:N and the nutrient content.

Section 10.4 contains additional information on the beneficial reuse of these residuals on land.

5.2.3 Lime-Based Residuals

5.2.3.1 Production of Lime Residuals

Lime-based residuals include materials such as lime mud and waste lime.

Lime mud is a by-product of the pulping of wood using the kraft chemical pulping process. During pulp production, a solution of sodium sulphide and sodium hydroxide is added as an aid in digestion of the wood chips, separating the desired cellulose fibers from lignin, and in the process it is turned into sodium carbonate. Calcium oxide (also known as caustic lime, quick lime or burned lime) is added to convert the sodium carbonate back to sodium hydroxide so it can be reused. During this process, $CaCO_3$ is formed. This residue is known as lime mud (Gaskin *et al.*, 2004; Mitchell, 2006).

Calcium carbonate is the major component of ground agricultural limestone, therefore lime mud is essentially limestone. However, lime mud consists primarily of ‘precipitated’ $CaCO_3$ with small amounts of magnesium carbonate and other trace elements and nutrients. The $CaCO_3$ making up lime mud is much more reactive than ground limestone because it has a very small particle size.

An initial step in the production of cement is the heating and mixing of limestone and siliceous materials (e.g. clay or shale). The exhaust from this process contains fine particulate known as cement kiln dust (CKD). The CKD is composed of unconsolidated starting materials and is typically recycled in the production process, or disposed of to landfill (Miller *et al.*, 2000).

Investigations into the beneficial use of CKD have identified its use as a liming agent. Although CKD generally has a lower neutralizing equivalent than $CaCO_3$, it has been found to increase pH at a rate faster than coarse limestone, due primarily to it fineness (Rodd *et al.*, 2004).

Ready mix concrete trucks are required to wash out their drums following delivery of a load of concrete (Envirochem Special Projects Inc., 1993). This washout process removes approximately 50 kg of residual concrete from a standard-sized concrete truck drum (Photograph 14). The resulting slurry is treated to recover the process water for reuse or safe discharge and to recover the sand, gravel and cement fines. The slurry typically undergoes one of two processes: processing in a mechanical solids reclaim system; or removal of sand, aggregate and cement fines in settling basins.

Photograph 14: Material washed out of concrete trucks

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Mechanical solids reclaim systems separate aggregate, sand and concrete/water slurry, enabling the reuse of the raw materials.

Settling basin systems can range from one primary settling pond, to a series of ponds allowing secondary and tertiary treatment of the washout slurry. Primary settling of the slurry results in the removal of sand, aggregate and some cement. Further treatment is facilitated by allowing the primary basin to overflow to a secondary basin(s) to remove cement fines. The recovered solids from settling basins have traditionally been used as construction fill or landfilled. However, the settling basin solids are currently being evaluated as a soil amendment, specifically as a potential alternative liming material.

An assessment of solids recovered from the primary treatment of slurry was conducted by SYLVIS in 2006. Analysis of the primary solids indicated a pH of approximately 11 and a $CaCO_3$ equivalent (CCE) of 25%. This CCE value is relatively low in comparison to other liming alternatives, including industrial wood ash (17-95%) (Demeyer, 2001) and lime mud (91-109%) (Edwards and Someshwar, 2000). A further challenge to beneficially recycling solids recovered from primary settling is that they are heterogeneous in composition and contain rocks up to 3 cm in diameter. The rocks may cause damage to application equipment and diminish the visual aesthetics of a soil to which the solids are applied.

Solids recovered from secondary treatment of washout slurry may be more amenable to beneficial recycling. The secondary solids would likely be more homogeneous and contain substantially fewer rocks. Evaluation of the secondary solids should be conducted to determine their beneficial properties.

5.2.3.2 Lime-Based Residuals as a Fertilizer and Soil Amendment

Lime based residuals are primarily sources of $CaCO_3$ and therefore find their preferred use as liming materials on sites that require an upward pH adjustment. Because of the very small particle size of the $CaCO_3$ particles, these residuals are much more reactive in the soil than ground agricultural lime and tend to raise the soil pH faster and higher than would a similar application of ground limestone.

These residuals also contain a small amount of nutrients and trace elements. However, at the application rates required to adjust the pH, the application of nutrients and trace elements would be insufficient to provide crop requirements on a deficient site.

Section 10.4.3 contains more information on the land application of lime based residuals.

5.2.4 Water Treatment Residuals

5.2.4.1 Production of Water Treatment Residuals

Water treatment residuals are materials generated during the purification of drinking or industrial process water.

Processes to remove turbidity, color, taste, inorganic ions and organic sediments from raw drinking water are necessary prior to distribution. The addition of flocculants such as alum or similar Al-based polymers in combination with calcium hydroxide to drinking water can achieve these removal objectives. Flocculants bind strongly to these constituents, forming insoluble species that precipitate from solution. These residuals are produced on a continuous basis, thus creating the need for a sustainable management strategy.

Drinking WTR are composed primarily of sediment, activated C, polymer and insoluble Al and Fe oxides and hydroxides. WTR typically contains high concentrations of Al, Fe and P, and low concentrations of other nutrients and trace elements. WTR can also have a significant amount of Ca. The pH of these WTR is typically below six due to the presence of Al and Fe (Gallimore, 1999).

Another common type of drinking WTR is generated during water softening where lime ($CaCO_3$) is added to remove hardness. These WTR consist of suspended solids and organic matter as well as significant amounts of $CaCO_3$ and magnesium hydroxide. These WTR are typically basic due to the presence of $CaCO_3$ (National Drinking Water Clearinghouse, 1998).

WTR as produced typically have a solids content of 1-2% and are managed as a liquid unless dewatered.

To meet regulatory discharge requirements, industrial, commercial and institutional wastewater dischargers often require the implementation of pre-treatment processes to reduce or eliminate substances prior to discharging to the wastewater collection system. Thus WTR are also formed during treatment of water other than raw drinking water. These residuals can have very different characteristics depending on the composition of the wastewater and the processes used to treat the water.

5.2.4.2 Water Treatment Residuals as a Fertilizer and Soil Amendment

Alum or Fe-containing WTR make relatively poor soil amendments and fertilizer sources. They contain low concentrations of all nutrients except P, which is primarily bound by Al and Fe making it less available to vegetation. The Al and Fe oxides and hydroxides bind soil P once the residual is land applied. If the receiving soil does not contain a sufficient P concentration, deficiencies can be induced by land applying these types of WTR.

Due to their propensity to bind P, these WTR have been used experimentally on sites that are oversupplied with this nutrient, and where there is risk of runoff or erosion of high P soil into surface water. These WTR have also been blended with other residuals such as biosolids to bind P before or during application (Elliott, 2002). Research into the use of these WTR to bind soil and residual P is ongoing.

Calcium-containing WTR typically have a very low concentration of all nutrients, including P. They typically have a relatively high pH (8-9) and can be used as an alternative liming material on sites that require pH adjustment. Calcium-containing WTR do not have the same propensity to bind P as do the Al and Fe containing WTR.

Section 10.4.1.2 contains more information on the use and land application of WTR.

5.2.5 Wood Residuals

5.2.5.1 Production of Wood Residuals

This type of residual can encompass waste wood generated by many different types of industrial operations including waste wood from mills, wood working plants, and similar sources (Photograph 15). The SACoP requires that it be uncontaminated with any substance that could be harmful to humans, animals or plants including but not limited to paint, glue or preservatives. Wood waste should also have a particle size that is suitable for its proposed use.

Photograph 15: Blackchips stockpiled in preparation for land application

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5.2.5.2 Wood Residuals as a Fertilizer and Soil Amendment

Wood waste has a very high C:N and low nutrient concentration. From a sustainability perspective, the use of wood waste promotes the long-term storage of fixed C, precluding its release into the atmospheric environment. It typically has a very low conductivity and a neutral pH. Wood waste can be used as a soil conditioning material to increase soil organic matter, as a mulching material or in horticultural applications.

Section 10.4.2 contains more information on land application of these residuals.

5.3 Substances Affecting Residual Quality

Substances affecting residual quality are typically divided into trace elements, pathogens and other constituents.

5.3.1 Trace Elements

Under the OMRR and the SACoP, the following 11 trace elements are considered potential pollutants when residuals are applied to land: arsenic, cadmium, chromium, cobalt, copper, lead, mercury, molybdenum, nickel, selenium and zinc. These trace elements (referred to as substances in the OMRR and the SACoP) must be monitored in both the residual and the soil before the residual is applied to land. Post-application monitoring is recommended to ensure that the residuals have been applied in an environmentally protective manner.

All residuals contain trace elements in varying concentrations. Biosolids typically contain the highest concentrations of trace elements of the residuals regulated under the OMRR and the SACoP.

Trace elements that are present in the soil at elevated concentrations can lead to various health and environmental concerns. Some trace elements, when present in excess amounts in the soil, can cause abnormal or stunted growth in plants and can bio-accumulate in plants that are then consumed by livestock or humans. For these reasons, the addition of these identified trace elements in residuals is limited to concentrations determined to be safe through research. Maximum allowable trace element concentrations in BC soils are based on those specified in the CSR.

Sources of trace elements in biosolids are primarily anthropogenic, with minor amounts occurring naturally from the weathering of rock. Anthropogenic sources include industrial/commercial and institutional wastewater sources, corrosion of pipes conveying source water, deposition from automobiles through exhaust and general wear (e.g. dust generated by brake use), as trace components or contaminants in fertilizers and pesticides, and non-point sources including runoff from rooftops, roadways and other impermeable surfaces that can collect and transport water

An example of a source of a trace element in biosolids is selenium in dandruff shampoo or mercury in dental amalgams. Industry, while under strict regulation as to what is acceptable material to discharge into municipal sewers, can contribute trace elements to the sewer system. The copper pipes that carry drinking water contribute most of the copper found in biosolids.

Trace elements in compost originate from the organic materials that comprise the compost feedstock, deposited through plant uptake, animal consumption in feed and subsequent excretion, atmospheric deposition, and if the compost contains biosolids, through the pathways by which trace elements enter the treatment system.

Sources of trace elements in the other residuals discussed in this guideline are primarily natural. Trace elements in fly ash, pulp residuals and wood waste originate from the raw material. Several trace elements in WTR are also naturally occurring. In general, the residuals regulated under the SACoP contain very low concentrations of trace elements relative to the concentrations found in biosolids.

Trace elements added to the soil in residuals such as biosolids are normally tightly adsorbed to soil and residual mineral and organic particles and are therefore unavailable for plant uptake or movement through soil to groundwater. At the typical residual application rates used for fertilization or soil conditioning, the application of trace elements is low and the soil capacity to adsorb them is adequate. Trace element solubility in the soil solution generally increases as soil pH decreases below pH 6.5; at low pH, trace elements become increasingly available for plant uptake. The trace elements can become more mobile in the soil system. The exception to this is molybdenum and selenium which are more soluble at higher pH. Residuals typically contain very small amounts of these trace elements; plant uptake of these elements of residual origin is therefore unlikely to be excessive.

Trace elements can enter surface water through wind or water erosion of soil. Trace elements generally do not move downward through the soil profile; rather, they appear to remain tightly bound to soil particles within the surface layer. The risk of movement of trace elements of residual origin into groundwater is minimal.

5.3.2 Pathogens

The presence of pathogens in residuals is typically limited to biosolids. An exception to this is pulp and paper residuals that have been mixed with domestic sewage at the mill.

Municipal wastewater and domestic sewage contain pathogens such as bacteria, viruses, protozoa and helminthes (parasitic worms). During the wastewater treatment process, pathogens are significantly reduced or destroyed by a combination of the following stabilization processes: high temperatures, chemical disinfectants, destruction of the microbial food source (volatile solids reduction) and desiccation (drying of biosolids). Following land application, any remaining pathogens are destroyed by heat, sunlight, drying, unfavourable pH and other microorganisms in the soil and on the soil surface.

Under the OMRR, biosolids and compost are divided into categories based partly on the level of pathogen reduction achieved; Class B biosolids and compost must have fecal coliform concentration < 2,000,000 MPN g^{-1} dw. In the application of Class B biosolids and Class B compost, public access restrictions at application sites and crop growing restrictions are designed to isolate the biosolids while final pathogen die-off occurs in the months following application. The SACoP includes a waiting period for the planting of food crops on sites that have been applied with pulp and paper residuals containing domestic sewage that have a fecal coliform concentration of ≥ 1,000 MPN g^{-1} dw.

5.3.3 Non-Regulated Substances

The OMRR and the SACoP regulate only trace elements and pathogens in the beneficial reuse and land application of residuals. Other constituents in residuals could be of interest when land applying residuals beneficially. The qualified professional must be aware of the current state of knowledge and act accordingly. Depending on the residual, these substances of interest can include:

- surfactants from detergent products, paints, pesticides, textiles and personal care products;
- synthetic and natural steroidal hormones;
- dioxins and furans;

- flame retardants (e.g. brominated diphenyl ethers); and,
- other volatile and semivolatile organic compounds.

None of these compounds are regulated by the OMRR or SACoP. To date, research has not demonstrated a risk to human health or the environment from the small amounts of these compounds present. Most of these compounds are degraded to some extent during the wastewater treatment process; the remainder are, in general, rapidly degraded in the soil following land application, or during composting. Plant uptake of these compounds has been demonstrated to be very low and not of concern for human health.

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6 Introduction to Sampling

Sampling and analysis are vital aspects of residuals management which extend throughout the process from assessing the quality of the residual for regulatory compliance through to assessment of the receiving environment, application rate determination and post-application monitoring. The resulting data is only as useful as the degree to which the sample represents the matrix.

Appropriate and effective sampling is essential to generating sound data on which regulatory compliance and decisions regarding future applications can be based. Sample collection should take into consideration the end use of the data, the regulatory requirements, the matrix being sampled, the parameters to be analyzed, due-diligence and any requirements for statistical analysis. For example, the number of samples collected impacts how the data can be interpreted. A minimum of three samples is required to calculate standard deviation and confidence interval (CI).

Quality assurance (QA) and quality control (QC) relates to a system designed to ensure that the product or service achieves standards of quality. There are two related components: quality control and quality assessment. Quality assurance includes documentation of procedures, identification of critical points within the data collection activities that require monitoring by quality control procedures, the level of quality achieved, problems encountered, and corrective actions undertaken. Quality assessment is to provide assurance that the quality control activities are being carried out effectively. It involves a continuing evaluation of performance of the data-producing systems and the quality of the data produced. QC is the overall system of activities that control the quality of a product (e.g. data) or service so that it meets the needs of users. The goal is to provide quality that is satisfactory, adequate, dependable and economical (CCME, 1993).

The premise of QA/QC is that data quality cannot only be documented, but can also be controlled through appropriate practices and procedures. Data that do not represent the population (the entire group of objects about which information is sought) have limited usefulness or may be ineffective in characterizing the residuals to be land-applied or the receiving environment. For example, the equipment used to collect the sample must not introduce the parameter of interest into the sample; a rusty shovel will introduce contamination in trace element analysis. With unreliable data the outcome could be an inappropriate application of residuals and a miscalculation of the effects on the receiving environment.

From the onset of the initial site visit, sample plan design and sample collection to the analysis, interpretation and evaluation of the data there needs to be clear documentation and definition of the degree of variation tolerated in the dataset. A complete QA program ensures that standard operating procedures exist for all essential aspects of a sampling program, including definition of the objectives; design of the sampling plan; preparation of sample containers and equipment; maintenance, calibration, and cleaning of field equipment; health and safety procedures; and chain-of-custody protocols.

The components of a QA/QC program are discussed in detail in several of the reference documents noted in Chapter 16. This Chapter provides an introduction to sampling applicable to the OMRR and the SACoP including a terse overview of sampling practices, sampling plans and types of samples.

6.1 Sampling Practices

Good sampling practices are essential to ensure data quality. The quality of the data produced can be affected by the equipment used, potential contamination and handling and storage of the samples.

6.1.1 Equipment

The equipment used depends on the physical consistency of the material to be sampled, the parameters of interest, age of the material (e.g. a crust often forms on aging residuals stockpiles) and other factors.

Sampling of a homogeneous stockpile of residuals can be accomplished with a shovel and trowel. If the stockpile is heterogeneous, a core sampler may be appropriate to determine variations in depth. Sampling of large heterogeneous stockpiles can require the use of earth moving equipment to access the interior of the pile.

Lagoon sampling can be accomplished using devices designed to capture material at depth such as a tube with a stopper on the end activated from the surface. There are a number of commercially available 'discrete-depth' sampling devices.

Soil samples can be collected using a variety of tools, including a soil sampling tube, a soil auger, a trowel or a shovel (Photograph 16). A sampling tube is small in diameter (2.5 cm) and is most appropriate for medium to fine-textured soils with low coarse fragment content on agricultural sites. Coarse-textured soils tend to have little cohesiveness, and may not remain in the sampling tube as it is removed from the soil. Sampling tubes will not penetrate rocky, untilled soils or retain soils that are very dry.

Photograph 16: Collection of a soil core

SYLVIS

A soil auger is more appropriate for soils with a moderate to high coarse fragment content. An auger is also more useful on dry soils, and on sites where the soil has never been tilled. The lack of cohesiveness in coarse-textured soils may be problematic with this type of sampling device. Several different types of soil augers are available.

For sites which are either very coarse textured or have a very high coarse fragment content, such as many forest and reclamation sites, the use of a trowel or small shovel may be more appropriate. When sampling with a trowel or shovel, it is important that the sample is collected evenly throughout the sampling depth to prevent sampling bias. The excavation of a small soil pit to 20-30 cm prior to sampling will allow for easier collection of a soil sample.

6.1.2 Contamination

As discussed previously, the goal in sample collection is to provide the laboratory with a sample that is characteristic of the existing conditions (i.e. the parameters of interest must not be affected by collection, storage and transport). Accordingly, all sampling equipment (including sample containers) must be in good condition, clean, and constructed of materials that will not interfere with analysis. For example, only sterilized equipment may contact a sample collected for fecal coliform analysis. Buckets for collecting soil samples must also be clean and free of fertilizer, manure, other organic matter, herbicides or other soil.

Similarly, the sample handling protocol must ensure the integrity of the sample. The sample must not be altered by the collection method. It is recommended that clean gloves are worn during sampling to avoid contamination. Avoid gloves coated with a powder.

Specialized equipment and sample container decontamination procedures involving a series of solvents may be required for certain parameters (e.g. trace organic sampling). Ideally, the laboratory will supply the sample containers and preservatives to ensure appropriate volumes and materials. The laboratory should also be able to provide specific direction on appropriate equipment decontamination procedures specific to their analytical methods. Consult with a professional knowledgeable in such sampling protocols.

6.1.3 Handling and Storage

The handling of samples following collection is important for accurate determination of various parameters, particularly fecal coliform and nutrients. Place the sample in a clean plastic or glass container and tightly seal. Zip lock bags will suffice for most solid samples (confirm with the laboratory) while liquid samples such as liquid biosolids will require wide-mouthed bottles. Sterilized sample jars or sterile Whirl–pak™ bags can be used for fecal coliform samples. The laboratory should provide the appropriate clean containers. Record sample information on the sample container. Pack samples adequately to ensure no leakage or breakage during shipping.

Samples should be transferred immediately to a cooler with frozen icepacks. The samples must be kept refrigerated or frozen (if appropriate) until being shipped to the laboratory. If samples are to be kept for an extended period of time, they must be frozen (except for bacteriological samples). Prior to freezing, confirm with the laboratory that freezing will not alter the parameter of interest. If the samples will be shipped to the laboratory within one day, they can be refrigerated. Samples should be shipped via courier or direct delivery to ensure they reach their destination within the required analyses timeline and without exposure to heat. Samples shipped outside of these guidelines will not yield data representative of the sampled material. Schedule your sampling events such that samples are not held for an extended period of time by the courier (e.g. over a weekend) on route to the laboratory. Contact the analytical laboratory to confirm when they are open for sample receipt. Most laboratories have specific requirements for sample collection and handling; additional information can be obtained from the laboratory.

Bacteriological samples should be refrigerated, not frozen. For bacteriological analysis there is a short holding time from the time the sample was taken until the time it must be analyzed. Thus, timing of sample collection and allowance for transportation is critical to ensure accurate representation of bacteriological indicators.

6.1.4 Sample Preparation

Sample preparation is important in residual analysis. The laboratory should have experience with organic residuals analyses. Where applicable, the laboratory should be certified or have the appropriate accreditation to complete the required analyses. In all cases, a strict QA/QC process should be followed and the results reported in conjunction with the sample analysis.

6.2 Representative Sampling

A representative sample defines the average characteristics of a material. In order to obtain a representative sample, several factors must be taken into consideration when designing a sampling plan including physical condition of the material to be sampled, volume of the sample required for analysis, composition of the material to be sampled and site-specific factors.

Under both the OMRR and the SACoP sampling of the residuals and soil are required. LAPs may require additional sampling of surface water, groundwater and vegetation.

6.2.1 Physical Condition

One of the most important factors is the physical condition of the material to be sampled and the limitations it may pose on sample collection. For example, a different sampling plan may be required for sampling a pulp and paper residual stockpile as opposed to a lagoon filled with material with much higher moisture content.

6.2.2 Volume

The volume of sample required for analysis is a function of the parameters of interest, the analysis technique and the characteristics of the media to be analyzed (for example, liquid versus solid residuals). The required sample volumes should be discussed with the laboratory prior to sample collection. In general, 500 g of sample on a dw basis is sufficient for trace element and nutrient analyses. An additional 100 g should be sufficient if fecal coliform analysis is required. Collecting a minimum of twice the volume required will allow for repeat or additional analysis. The extra sample can either be kept at the laboratory or by the sampler following accepted protocols for holding times and storage. The short holding time for bacteriological samples precludes storage.

The material must be adequately represented by the sample(s) therefore the volume of the material to be characterized affects the sampling plan. For example, the sampling plan for characterizing 10,000 m^3 of residuals will differ from that for 200 m^3 of residuals.

6.2.3 Importance of Sample Composition

Soil nutrient concentrations display temporal and spatial variability across the landscape. Residuals may have changing characteristics as a result of variations in process and feedstock materials. Thus, the sampling plan needs to reflect the variability and pattern of variability in the residuals. A discussion of appropriate sampling strategies is provided in Section 6.3.

6.2.4 Importance of Site-specific Factors

The person designing the sampling plan should be familiar with the site or facility, or arrange a pre-sampling site visit. If sampling residuals, familiarity with how the residuals are generated is recommended when designing the sampling plan. Site-specific factors which may affect design of the sampling plan include accessibility, handling, transitory events such as start-up and shut-down, climate and hazards.

6.3 Sampling Plans

A variety of sampling plans and types of samples are applicable to sampling of residuals and receiving environment soils.

When sampling it is useful to consider the population as composed of a number of separate units (e.g. the number of one litre samples in a biosolids lagoon; the number of spadefuls in an pile of wood residue, or the number of planter boxes of a soil product). The units are distinct from each other, and together their total number comprises the population (the entire material or area being investigated). The sampling plan designates which units of the population are included in the sample for measurement of the variables or characteristics of interest.

There are different types of sampling plans, usually classified as judgment, simple random, stratified random and systematic random sampling plans. A brief description of the various sampling plans is provided below. Typically, random or stratified random sampling plans are used for most residuals related sampling events. Recommendations regarding the number of samples to collect for each of the OMRR and SACoP requirements are presented in Chapter 8 and Chapter 9. Additional information on calculating the appropriate number of samples required is provided in Appendix 1.

6.3.1 Judgment Sampling Plan

Samples are selected such that they are representative of the population or entire substrate in the opinion of the sampler. In general, this is probably the most frequent type of sampling plan carried out but may result in biased samples.

The areas of the site an investigator may decide are typical of the site, have a higher probability of being selected for sampling than areas that look slightly different. The entire population will not be represented in the estimates provided by the sample. Under the terms of the OMRR and the SACoP when characterizing organic residuals or the receiving environment, sampling must be representative of the entire material or site. In addition, if any statistical analyses are to be performed, they assume a population that is adequately represented from the sample results.

Judgment sampling bias

An individual sampling a recently cultivated poplar plantation prior to application of residuals may inadvertently select soil samples only from between the tree rows. The samples may be more similar to one another than those within the tree row. Consequently the substrate within the tree row is not fairly represented and a bias is imparted.

6.3.2 Simple Random Sample

The basic characteristic of a simple random sample is that each unit has an equal probability of being selected. Methods of sample unit selection include listing each unit independently and using a random number generator or other similar methods to select sampling units.

Simple random sampling is appropriate for homogenous substrates, but it may not give a appropriate representation of variable substrates.

Selecting sample units

For a compost pile, project a 3-D grid throughout the pile with numbers assigned to each unit of the grid so that every spadeful of the compost in the pile has an equal probability of being selected. A random number generator can then be used to select the units for sample collection.

Twelve samples will be collected from a lagoon. The lagoon surface is delineated into a grid of 100 ‘squares’ and numbered consecutively. Using a random number generator, 12 units are selected for sampling. This method could result in evenly spaced samples across the lagoon surface or it could result in all 12 samples occurring at one end.

6.3.3 Stratified Random Sample

The stratified random sample is very similar to the simple random sample, but the substrate (residual, soil, plant population) is divided into subpopulations of some similar nature or condition in an attempt to ensure better coverage of the population. A simple random sample is then collected from within each subpopulation. Because organic materials, soils and site vegetation are heterogeneous rather than homogenous it is frequently useful to subdivide the volume or area to be sampled into relatively homogenous units for sampling.

Stratification enables statements to be made about each of the subpopulations (e.g. a soil series), and increases the precision of estimates for the entire population as all subpopulations are represented. Variability between samples from differing subpopulations is eliminated from the estimates of precision and only variability within the more homogenous subunits is present. Again, precision increases with a reduction in variation.

Sampling a subpopulation

Stratify the lagoon by depth into 3 layers. Collect random samples from each layer.

Stratify a compost pile by access to exterior air and drying conditions. Collect samples from the top exterior, bottom exterior, top interior and bottom interior of the compost pile.

6.3.4 Systematic Random Sample

Systematic sampling attempts to ensure representative coverage of the population is accomplished. The first sample point is assumed to be selected randomly and every sample point thereafter is collected at a specific interval.

The major limitation occurs when the population being sampled has a periodic trend and the sample occurrence matches this periodic trend (e.g. soil sampling across a system of small valleys and hills and sample collection only occurs on the hilltops). Perhaps the largest concern in systematic sampling would be the occurrence of an unrecognized pattern. Precision would potentially be lost and bias introduced without the individual performing the sampling being aware of the problem.

Sampling at specific intervals

Water treatment residuals collected every 60 seconds from a centrifuge after collection of the initial sample at a random time.

Samples collected from every 8th square from a randomly selected square in a lagoon which as been delineated into a grid of 100 squares.

6.4 Types of Samples

Within a sampling plan are the actual samples themselves. These are typically referred to as subsamples, point or batch samples and composite samples.

6.4.1 Subsamples

In sub-sampling, the sampling unit selected by one of the previous sampling plans described is divided into a number of smaller samples or subsamples. The characteristic under consideration is then measured on a randomly selected subsample from each unit. The primary advantage of sub-sampling is that it permits estimation of a characteristic of the larger sample without having to measure the characteristic in the entire volume of the material in the larger sample. The cost of the investigation may be reduced considerably.

Sub-sampling can be especially useful when collecting composite samples which are groups of individual samples, amalgamated and thoroughly mixed. Resulting sample volumes can be large, thus sub-sampling of the thoroughly mixed material facilitates laboratory analysis and reduces analytical costs. However, at each stage of sub-sampling, or 'multistage sampling' as it is sometimes identified, an additional component of variation is added and precision is lost.

Collecting a subsample

To determine the effect of a soil amendment application on soil organic matter in a specific land unit select a random sample of five 3 m x 3 m plots for sampling – a large quantity of soil to collect and analyze. To subsample collect three subsamples of the upper 15 cm of soil in which to measure soil organic matter. This establishes variability between subsamples within the same 3 m x 3 m square, and between squares. Despite the fact that variability is likely to increase by only sampling a small portion of the 3 m x 3 m squares, the reduced costs of analyzing and the ease of handling a smaller quantity of material often mitigate the loss in precision.

6.4.2 Point (Grab or Discrete) Samples and Batch Samples

Point samples (also referred to as discrete or grab samples) are single samples collected from one location. Batch sampling is characterized by a mass of material being collected from one location. Since this may result in a large quantity of material, the material may be homogenized and subsampled for analysis. Both point samples and batch samples provide characterization of single areas, but do not provide a representative sample for the volume of material being assessed. As such their primary usefulness lies in identification and characterization of anomalous conditions or areas.

When to collect a discrete sample

Within a land application unit of an old farm site which had been predominantly pasture there is an area which had previously had a stock pen located on it. A discrete sample of the soil from the stock pen area would be more useful than integrating that specific area into the general sampling plan of the remaining previously pasture areas.

6.4.3 Composite Samples

Composite samples are mixtures of numerous individual samples which adequately represent the population. Individual samples must be represented equally (i.e. same volume or mass) in order not to introduce bias, and each composite sample should be composed of the same number of individual samples. Measurement of the parameter of interest is then conducted on the composite sample. The primary benefit of collecting a composite sample or bulking samples is the reduction in laboratory costs. When comparing regulatory limits to analytical results, each composite sample represents one sample.

Composite samples and regulations

When sampling a pile of BGM, seven individual samples each having a volume of 250 mL are mixed to together to form a composite sample (sample 1). Another seven individual samples each having a volume of 250 mL are mixed together to form a second composite sample (sample 2). For regulatory purposes the total number of samples collected from the pile is two.

6.5 Sampling the Residuals

Most organic residuals are variable in composition; therefore, composite sampling (with the exception of fecal coliform analysis for pathogen reduction) is typically required to achieve a representative sample for analysis while retaining an affordable level of analytical costs.

Schedule 5 of the OMRR requires that sample collection and analyses be conducted for every 1,000 t dw organic matter or once per year, whichever occurs first. This is the minimum number of samples required. Additional samples are recommended for due diligence and increased data confidence.

Under the SACoP, fly ash and primary and secondary pulp and paper residuals must be sampled by a qualified professional when the earlier of:

- 1,000 t dw of soil amendments are produced at the facility, or
- one year has passed since the facility started to produce the soil amendments or one year has passed since the last sampling and analysis.

The SACoP does not stipulate the sampling frequency, or the requirement for a qualified professional to collect samples, for lime residuals, WTR or wood residue. Sample collection by a qualified professional is not a requirement for any of the residuals regulated under the OMRR.

A minimum of three composite samples, each consisting of seven equal volume subsamples, are recommended each time a sample is collected under the OMRR or the SACoP for parameters except fecal coliform.

Under the OMRR seven samples are required for fecal coliform analysis. Seven representative samples are recommended for pulp and paper residuals which contain domestic sewage.

Various sampling plans are effective; a systematic random or simple random sampling plan is suitable for residuals for which no identified pattern exists, for example from a continuous process or within a batch of a batch process. Stratified random sampling is suitable when an identifiable pattern or potential pattern exists.

Pre-application sampling of the receiving soil is necessary when a LAP is required. Should land application of organic residuals exceed an agronomic rate a post-application monitoring plan is also required. This plan may include vegetation and post-application soil sampling. Additional information on vegetation and pre and post–application soil sampling is provided in Chapter 12.

6.5.1 Sampling Solids

Sample collection methods for residuals vary based on the state of the residual and whether it is stockpiled or sampled as produced. Dewatered and solid residuals can be sampled as produced or from a stockpile. Dewatered residuals can include biosolids, compost, BGM, pulp and paper residuals and WTR. Solids include waste lime, lime mud, wood waste and fly ash.

When sampling residuals as they are produced, sample collection should be evenly spaced throughout the operating cycle, to mitigate variability and ensure representative samples. Three composite samples, each consisting of seven equal volume subsamples, are recommended for trace element analyses. A systematic random sample would be an appropriate sampling plan.

For example, ash samples collected from a conveyor at specific time intervals distributed over the operating period.

When discrete samples are required or for fecal coliform analyses, sample collection should be spread out over the cycle. Avoid collecting samples during periods when the residual generated may not be typical of the operation, for example during start-up.

Systematic random sampling of dewatered biosolids for trace elements

Background: A typical operating cycle for the centrifuge at a WWTP is seven hours (excluding start-up and shut-down). Three composite samples of seven subsamples each will be collected over 3 days and analyzed for total elements. A systematic random sampling plan will be used.

To determine the interval between subsamples divide the time dewatered biosolids are produced by the total number of subsamples to be collected. For example dewatered biosolids are produced for seven hours (420 minutes) and seven subsamples are required during that time:

420 minutesI7 subsamples = 60 minute intervals

Typical centrifuge operation begins at 8:00 am at which time the first subsample is collected. The sample should be placed in the container provided by the laboratory and stored at 4 ˚C (in the fridge or in a cooler). Using a systematic random sampling plan, the second subsample is collected 60 minutes later (9:00 am) and added to the same sample container as the first subsample. Sample collection continues every 60 minutes. After the seventh sample is collected (2:00 pm), composite sample #1 is complete. Refer to the timeline below.

The same process is completed for composite sample #2 (day 2) and sample #3 (day 3).

Timeline

8:00 am	subsample #1	Composite Sample #1
9:00	subsample #2	
10:00	subsample #3	
11:00	subsample #4	
12:00 pm	subsample #5	
1:00	subsample #6	
2:00	subsample #7	

When sampling from a stockpile, samples should be randomly distributed. If using a simple random sampling plan, envision the stockpile as a 3-D grid and sample randomly from the grid units. If using a stratified random sampling plan sample randomly within each strata.

A simple random sampling plan is appropriate for uniform stockpiles while a stratified random sampling plan is more appropriate for inconsistent residuals. For example, if a wood waste stockpile contains waste from various tree species which are not mixed together, a stratified random sampling plan could be used, with samples collected randomly within each strata. For some residuals, waste lime for example, it is recommended that sampling occurs as the stockpile of material is created. The stockpile can be challenging to sample after it is created.

Sampling BGM

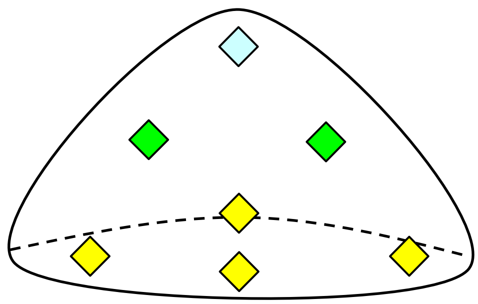
Collect 3 composite samples each composed of seven subsamples proportionally distributed throughout the stockpile and at a depth of at least 30 cm.

For example in a triangular pile (see diagram below) each composite sample would be composed of:

four subsamples collected from the bottom portion of the pile;

two subsamples collected from the middle portion of the pile; and,

one subsample collected from the top portion of the pile.



When sampling a stockpile, particularly if the residuals have been stockpiled for some time, avoid the upper layer of material. This layer could be contaminated from atmospheric deposition and other factors and will not be representative of the mass of material being assessed. Clear away material to the desired sampling depth with a clean spade or trowel and collect an uncontaminated sample. The sample depth should be at least 30 cm from the surface of the pile.

6.5.2 Sampling Liquids

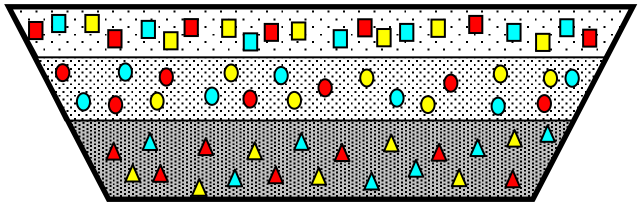
Stratified random sampling is suitable when an identifiable pattern or potential pattern exists, for instance, a biosolids lagoon that is known to consist of two or more vertical strata. For a stratified sampling process the samples or subsamples should all be located proportionally with the volume representation of the zones. Should three vertical strata exist, with each layer consisting of 33% of the volume, it is best to collect three composite samples (each consisting of seven subsamples) per layer. If a layer will be removed prior to use (e.g. the effluent is pumped off the top of the lagoon), sampling is not required for that strata; the samples collected should be reflective of the material to be used.

A minimum of three composite samples (each consisting of seven subsamples) is recommended per strata for trace element determination. If the lagoon is not stratified, a minimum of three composite samples (each consisting of seven subsamples) is recommended.

Sampling liquid residuals

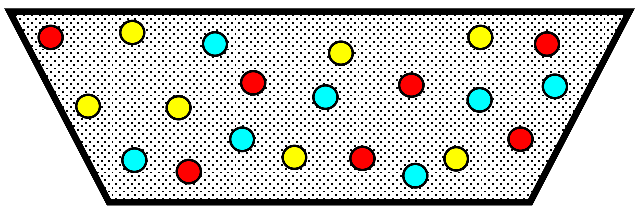
Where multiple strata exist

To adequately characterize the residual, it is recommended to sample each distinct stratum. For example, in a lagoon where three approximately equal volume strata exist, three composite samples of seven subsamples each would be collected per stratum.



Where one stratum exists

Three composite samples consisting of seven subsamples are recommended when sampling residuals from a lagoon with only one stratum.



6.6 Sampling Documentation

It is important to create and retain comprehensive records when sampling. Information should be recorded in a field notebook or on computer and duplicate copies made should the original be lost. The following information must be recorded as sampling is performed.

- Project and schedule: date, time and location of the sampling event, field names, access roads, latitude and longitude coordinates and location of permanent markers.
- Site conditions: weather during and before the sampling event and site conditions. Take photographs during sample collection and label these with identifying information for future reference.
- Sampling protocol: location of samples collected, sample pattern, collection depth, number of individual samples in each composite, size of individual samples, sampling equipment and containers, and any sampling difficulties encountered.
- Sample processing: description of any processing (e.g. soil sieving) performed on the sample.
- Storage of samples: in the field and prior to shipping to laboratory, whether duplicate samples have been retained.

- Transportation of samples to laboratory: method of transport, shipping container, date shipped, name of laboratory.
- Analyses: list of analyses requested and notes on any discussions with laboratory staff regarding the samples.

For each of the following sample matrices, additional considerations include:

- Residuals: information on the material being sampled including, the size of the pile or storage tank, age of the material, visual characteristics, odour, variation observed within the material, treatment or composting process utilized, composition of material, presence of foreign matter, and sampling protocol.
- Soil: soil conditions at time of sampling (depth to B horizon, depth to impermeable layer or bedrock, soil moisture, vegetation cover, surface stoniness, coarse fragment content), depth to groundwater, and site assessment (topography and slope of site, location of surface water features, location of houses, farms, roads, sensitive areas etc., livestock use of site, cropping and fertilization history).
- Vegetation: description of vegetation being sampled (plant species, height, ground cover, state of maturity, colour, density; portion of plant sampled), number of plants sampled for each composite, height sampled and rationale for the sampling plan.

At a minimum, samples should be labeled with the date, site identification, and sampler's initials or should be given a number that corresponds to a description kept with the field records. A chain of custody form must be completed for each set of samples collected. The form provides a method for tracking samples as they are transported to and analyzed by the laboratory. A chain of custody form must include the program or project identification, location of sample collection, depth, date and time of collection, and the name of the sampler. Chain of custody forms are usually provided by the laboratory that will be performing the analyses.

6.7 Health and Safety Protocols

Health and safety protocols have three basic elements: monitoring the health of field personnel, routine safety procedures; and, emergency procedures.

People working with residuals should be aware of the health considerations and utilize the necessary personal protective equipment as required including, but not limited to, physical barriers (gloves), respiratory protection (masks) and floatation devices (lifejackets). Provincial health and safety regulations and site-specific safety requirements must be observed. Emergency procedures must be established prior to transporting or sampling the residuals. These procedures could include: contact information for notification in the event of a spill, and location and contact information for emergency services.

Handle pathogen-containing residuals as you would any animal manure. Do not ingest these residuals or facilitate body entry. The primary method of reducing risk is limiting exposure. Specific actions that reduce exposure include:

- washing hands with soap and warm water after work and prior to eating, drinking or smoking;
- wearing waterproof gloves when contact is not preventable;
- keeping all cuts and wounds clean and bandaged; and,
- ensuring clothing and footwear is clean prior to leaving work.

If you come in contact with these materials, wash the area with soap and warm water. Contact your doctor should you ingest a pathogen-containing residual or if it enters your eye(s) or an open wound.

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7 Sampling Statistics

Sampling statistics can range in vigour from simplistic to complex. This chapter describes the minimum statistical requirements recommended to determine compliance with the OMRR and the SACoP. Additional information and detailed explanations are provided in Appendix 1. Topics include sample variation, precision, bias, and number determination.

7.1 Determining Compliance for Pathogen Reduction

Under the OMRR, fecal coliform is the only monitoring parameter for which the number of samples and the method for determining compliance are specified.

Neither the number of samples nor the method for determining compliance is specified in the SACoP. Fecal coliform determination under the SACoP is only required for residuals from the primary and secondary treatment of pulp and paper liquid waste if it contains domestic sewage. Fecal coliform determination is not required for other residuals defined as "soil amendments" under the SACoP or if pulp and paper residuals do not contain domestic sewage.

For Class A compost (not solely produced from yard waste and untreated and unprocessed wood waste) and Class A biosolids, the fecal coliform criterion is < 1,000 MPN g^{-1}. Seven representative samples must be collected and the concentration of fecal coliform must be < 1,000 MPN g^{-1} in all seven samples.

Under the SACoP, the fecal coliform concentration is not used to determine a class of material but rather mandate the requirement for additional management. If the concentration of fecal coliforms is > 1,000 MPN g^{-1} for primary and secondary pulp and paper residuals containing domestic sewage additional management is required.

Does the compost meet Class A criteria for pathogen reduction?

Using a simple random sampling plan, seven composite and representative samples are collected from a compost pile to determine if the compost meets the OMRR fecal coliform requirements for Class A compost (< 1,000 MPN g^{-1}, dw). The following results are reported:

Sample 1: 900 MPN g^{-1}, dw
Sample 2: 1,100 MPN g^{-1}, dw
Sample 3: 880 MPN g^{-1}, dw
Sample 4: 790 MPN g^{-1}, dw
Sample 5: 990 MPN g^{-1}, dw
Sample 6: 1,200 MPN g^{-1}, dw
Sample 7: 910 MPN g^{-1}, dw

This compost does not meet the Class A requirements as the fecal coliform concentration in Samples 2 and 6 exceed the OMRR criteria for Class A compost. For Class A compost the OMRR criteria must be met in all seven samples.

To determine if Class B biosolids or Class B compost are in compliance with the OMRR regulations for fecal coliform, seven discrete samples must be collected and analyzed. The data are used to calculate the geometric mean which is then compared to the OMRR criteria to determine compliance with the regulation.

The first step in calculating the geometric mean is to calculate the product of the data. The second step in calculating the geometric mean is to determine the 7^{th} root (because there are seven samples) of the product.

The method of fecal coliform sampling and analysis is not specified by the SACoP. It is recommended that seven representative samples be collected for consistency with the OMRR requirements for Class A biosolids and compost. To confirm the fecal coliform concentration is < 1,000 MPN g^{-1}, in a pulp and paper residual containing domestic sewage the concentration in all seven samples should be < 1,000 MPN g^{-1}, dw.

If additional accuracy and confidence are required refer to Appendix 1 for detailed information which can be used to determine the number of samples required for the desired statistical vigour.

Do the biosolids meet Class B criteria for pathogen reduction?

Seven discrete (grab) samples were collected, using a systematic random sampling plan, as the dewatered biosolids were being produced from the centrifuge. The following results were reported by the laboratory:

Sample 1: 1,500,000 MPN g^{-1}, dw
Sample 2: 1,600,000 MPN g^{-1}, dw
Sample 3: 1,700,000 MPN g^{-1}, dw
Sample 4: 1,800,000 MPN g^{-1}, dw
Sample 5: 1,900,000 MPN g^{-1}, dw
Sample 6: 2,000,000 MPN g^{-1}, dw
Sample 7: 2,100,000 MPN g^{-1}, dw

The OMRR criteria for fecal coliform in Class B biosolids is < 2,000,000 MPN g^{-1}, dw. The geometric mean is used to determine compliance. The calculation is shown below.

Start by calculating the product. Multiply the result of each of the samples.

$$\text{Product} = 1{,}500{,}000 \times 1{,}600{,}000 \times 1{,}700{,}000 \times 1{,}800{,}000 \times 1{,}900{,}000 \times 2{,}000{,}000 \times 2{,}100{,}000$$

$$= 5.86051 \times 10^{43}$$

Next take the 7^{th} root of the product (the 7^{th} root is used because there are seven samples)

$$= \sqrt[7]{5.86051 \times 10^{43}}$$

$$= 1{,}800{,}000 \text{ MPN } g^{-1}, \text{ dw}$$

As the geometric mean (1,800,000 MPN g^{-1}) is less than the OMRR criteria (2,000,000 MPN g^{-1}), the residual complies with the fecal coliform requirements for Class B biosolids.

7.2 Determining Compliance for Trace Elements

The OMRR and the SACoP do not specify the number of samples or method of determining compliance for trace elements.

It is recommended that a minimum of three composite samples each consisting of seven subsamples be collected per sampling event. For all residuals, the average concentration and the upper 95% CI should be less than or equal to criteria in the OMRR and the SACoP.

The following process is recommended for each trace element to determine compliance with the OMRR or the SACoP criteria:

1. Calculate the average.
2. If the average is greater than the regulatory limit, the trace element is considered to exceed the limit.
3. If the average is less than the regulatory criteria, determine the 95% CI.
4. If the upper CI is less than or equal to the regulatory criteria, the element is considered to meet the requirements.
5. If the upper CI is greater than the regulatory limit, the data do not comply with the requirements for the trace element. Additional samples may result in an upper CI which meets the regulatory requirements. Refer to Appendix 1 for information on estimating the number of samples required.

All the regulated trace element concentrations should be evaluated using this method.

For residuals managed under the OMRR, the class designation is assigned based on the lowest class acceptance. If all the trace element concentrations do not exceed the Class A criteria (i.e. the upper CI is less than or equal to the OMRR requirements) the material would be classified as Class A. However, if the concentration of one or more of the elements exceeds the Class A criteria but not the Class B criteria, the material would be classified as Class B.

For a soil amendment to be considered as compliant with the SACoP Table 1 criteria, the average concentration and upper CI for each of the 11 trace elements must not exceed the Table 1 requirements. If a substance (trace element) present in the soil amendment fails to meet the requirements, it cannot be applied under the SACoP.

Determining compliance with the OMRR trace element criteria

Three representative biosolids samples are collected to determine compliance with the OMRR trace element criteria. The following results are reported for mercury:

Sample 1: 4.6 $\mu g\ g^{-1}$ dw

Sample 2: 4.8 $\mu g\ g^{-1}$ dw

Sample 3: 8.6 $\mu g\ g^{-1}$ dw

The OMRR criteria for mercury is 5 $\mu g\ g^{-1}$ dw for Class A biosolids and 15 $\mu g\ g^{-1}$ dw for Class B biosolids. The calculation shown below is used to determine compliance.

Step 1: Calculate the mean (average)

$$\text{Mean } (\bar{x}) = (\text{result sample 1} + \text{result sample 2} + \text{result sample 3}) / \text{number of samples (n)}$$

$$= (4.6 + 4.8 + 8.6) / 3$$

$$= 6.0\ \mu g\ g^{-1}\ \text{dw}$$

The average is greater than the regulatory limit of 5 $\mu g\ g^{-1}$ dw for Class A biosolids.

Step 2: Calculate the variance

$$\text{Variance } (s^2) = \frac{\text{sum of (observation – mean)}^2}{\text{Number of samples – 1}}$$

$$= \frac{(4.6-6.0)^2+(4.8-6.0)^2+(8.6-6.0)^2}{3 - 1}$$

$$= 5.1\ \mu g\ g^{-1}\ \text{dw}$$

Step 3: Calculate the standard deviation using the variance calculated in Step 2.

$$\text{Standard deviation (s)} = \sqrt{\text{variance}}$$

$$= \sqrt{5.1}$$

$$= 2.3\ \mu g\ g^{-1}\ \text{dw}$$

Step 4: Calculate the upper CI. Note: the t value ($t_{.05}$) for a 95% confidence level and 3 samples is 4.303.

$$\text{Upper CI } \mathrm{CI} = \bar{x} \pm t_{\alpha/2} \frac{s}{\sqrt{n}}$$

$$= 6.0 + (4.303)(2.3/\sqrt{3})$$

$$= 6.0 + 5.7\ \mu g\ g^{-1}\ \text{dw}$$

(Note: subtracting 5.7 would give the lower CI)

$$= 12\ \mu g\ g^{-1}\ \text{dw}$$

Since the upper CI is greater than the Class A OMRR limit of 5 but below the Class B OMRR limit of 15 $\mu g\ g^{-1}$ dw, the biosolids are Class B with respect to mercury.

7.3 Determining Compliance for Foreign Matter

The OMRR and the SACoP specify the following foreign matter criteria:

- the concentration must be ≤ 1% dw; and,

- there must be no sharp foreign matter in a size and shape that can cause injury.

These criteria apply to retail-grade and managed organic matter regulated under the OMRR and soil amendments regulated under the SACoP.

It is recommended that three composite samples, each consisting of seven subsamples be collected and a 95% CI used to determine compliance. The average foreign matter concentration and the upper 95% CI should be < 1% in order to meet the OMRR and SACoP requirements.

7.4 Determining Compliance for Nutrients, Organic Matter and C:N

The OMRR requires nutrient evaluation during the preparation of a LAP for managed organic matter; however, no criteria are provided with respect to minimum or maximum concentrations. Numerical nutrient criteria are provided in the OMRR for retail-grade organic matter: BGM and Class A compost.

Three composite samples, each consisting of seven subsamples should be collected. The sample mean and 95% CI should be calculated to determine compliance. To meet the Schedule 11 criteria for BGM:

- the sample mean and upper 95% CI should be < 0.6% for TKN;
- the sample mean and upper 95% CI should be ≤ 15% for organic matter; and,
- the sample mean and lower 95% CI should be > 15:1 for C:N.

The C:N is required when determining vector attraction reduction for Class A compost under Schedule 2 of the OMRR. To determine if the C:N ratio is ≥ 15:1 and ≤ 35:1, it is recommended to collect a minimum of three composite samples each consisting of seven subsamples. These data and the upper and lower CIs will be used to determine compliance. The compost is compliant if the lower CI is ≥ 15 and the upper CI is ≤ 35.

When completing a LAP, the SACoP requires measurement of the TKN, NH_3 plus NH_4^+, NO_3^--N, and plant available P and K in the soil amendments to be applied. The SACoP does not specify nutrient or organic matter concentrations as regulatory limits.

7.5 References and Supporting Documentation

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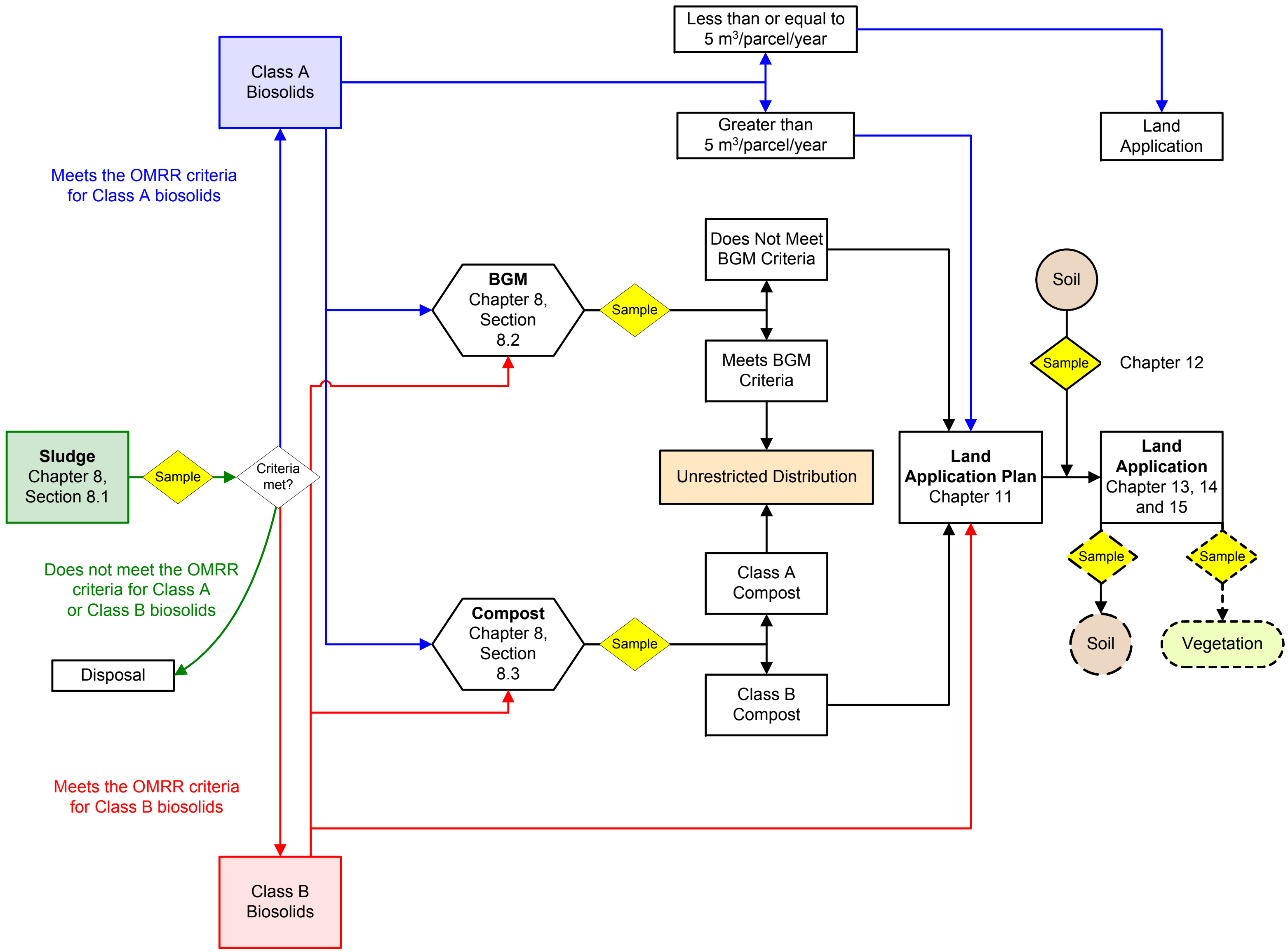
8 Sampling and Analysis for the OMRR

The OMRR requires sampling at several stages to determine compliance. Figure 1 illustrates the required and recommended sampling for residuals managed under the OMRR. Initial sampling and analysis are completed to determine material quality with respect to the OMRR criteria: Class A or B biosolids. Further sampling is completed to confirm process and quality criteria in the production of compost and BGM. Required parameters and recommended methods of determining compliance with the OMRR are discussed in the sections below and summarized in Table 8 located at the end of this Chapter.

Figure 1: OMRR Sampling Flow Chart



8.1 Biosolids

Sampling is required to determine whether the OMRR biosolids criteria are met and to determine the class of the material. Treated sludge may be designated as Class A or Class B biosolids depending on the degree to which it meets pathogen reduction processes, vector attraction reduction, pathogen reduction limits and quality criteria, as provided in the OMRR.

Schedule 5 of the OMRR requires that sample collection and analyses be completed at least every 1,000 t dw organic matter or once per year, whichever occurs first. This is the minimum number of samples required. Additional samples may be recommended for regulatory compliance using the recommended CI criteria. Initially it is recommended that samples be collected on a monthly basis to establish a database of residual quality.

To classify the material it must be analyzed for trace elements (Schedule 4 of the OMRR), fecal coliform and foreign matter. For designation as either Class A or Class B biosolids the material must meet all the OMRR requirements for the given class.

Additional monitoring may be required to confirm vector attraction reduction depending on the reduction process used.

8.1.1 Trace Elements

Schedule 4 of the OMRR stipulates that Class A biosolids must meet the trace element (substance) limits as set out for chemical fertilizers in *Trade Memorandum T-4-93 (September 1997), Standards for Metals in Fertilizers and Supplements*. At the time of writing, the memorandum included the trace elements and associated limits presented in Table 8. As the OMRR links Class A biosolids to Federal fertilizer quality standards the qualified professional is advised to consult the *Fertilizers Act* to ensure the concentrations presented in Table 8 are current.

The OMRR does not require Class A biosolids be analyzed for chromium and copper; however, these analyses are required for the calculation of projected post-application soil trace element concentrations in the application of Class A biosolids.

Class B biosolids must meet the 11 trace elements limits listed in Schedule 4 of the OMRR which are identical to those for Class A biosolids except for mercury, chromium and copper. Specifically, Class B biosolids must contain no more than 15 $\mu g\ g^{-1}$ mercury, 1,060 $\mu g\ g^{-1}$ chromium and 2,200 $\mu g\ g^{-1}$ copper.

Managed and retail-grade organic matter are analyzed for total elemental content. The sample should be analyzed using standard methods as outlined in the *BC Environmental Laboratory Standards Manual* or equivalent. Ensure sample detection limits are requested that will facilitate comparison with the appropriate OMRR standards and trace element predictions. For example, if the laboratory detection limit of selenium is 3 $\mu g\ g^{-1}$, obtaining a result from the laboratory stating that the concentration is less than the detection limit does not provide sufficient information as the OMRR limit is 2 $\mu g\ g^{-1}$. For trace elements such as selenium and mercury, different analytical techniques are often required to obtain the appropriate detection limits.

The treated sludge complies with the OMRR requirements for Class A biosolids if the average and upper 95% CI indicate that the concentration of each trace element does not exceed the limits as set out for chemical fertilizers in *Trade Memorandum T-4-93 (September 1997), Standards for Metals in Fertilizers and Supplements*.

The treated sludge complies with the OMRR requirements for Class B biosolids if the average and upper 95% CI indicates that the concentration of each trace element does not exceed the limits listed in Schedule 4 of the OMRR.

8.1.2 Pathogen Reduction - Fecal Coliform

Class A biosolids must meet pathogen limits as specified in Schedule 3 of the OMRR. The material must contain a fecal coliform count of less than 1,000 MPN g^{-1} dw. To meet the Class A pathogen designation, all seven representative samples must have a fecal coliform count of less than 1,000 MPN g^{-1} dw.

For Class B biosolids, the geometric mean of the seven discrete fecal coliform samples must be less than 2,000,000 MPN g^{-1} dw as outlined in Schedule 3 of the OMRR.

Organic matter is analyzed for fecal coliform concentrations as an indicator of relative numbers of general pathogens present. Fecal coliforms are the indicator of choice as they are closely associated with fecal contamination, are relatively easy to identify and enumerate, and are usually present in large numbers when fecal contamination is present. The method used for enumerating fecal coliform is the multiple-tube fermentation technique or MPN technique. To meet the requirements of the OMRR, samples of organic matter should be analyzed for fecal coliform content measured as MPN g^{-1} dw. Consult the laboratory for the sample volume required to conduct the fecal coliform analysis. Typically, the laboratory will provide sterilized sampling containers.

Samples should be collected at the end of the treatment process after the pathogen reduction process has been completed to confirm that the pathogen reduction process was successful. For example, when the alkaline stabilization method is used for pathogen reduction samples should be collected after the required high pH period. For mechanically dewatered sludge, samples can be collected from the centrifuge or belt press. For naturally dewatered biosolids or liquid biosolids, samples can be collected from the drying bed or lagoon (storage area) respectively. If the results indicate Class A fecal coliform criteria are met, the biosolids should be re-sampled as close as possible to the time the biosolids will be used or land applied. Alternatively if Class A quality is predicted based on previous data, a single sampling event can be completed as close as possible to the time the biosolids will be used or land applied.

Challenges to fecal coliform determination in biosolids exist as reactivation and re-growth can occur and false positives have been detected, resulting in incorrect or misleading data. False positive bacteria include *Klebsiella*, *Enterobacte*r and *Citrobacter* species (Doyle and Erikson, 2006).

8.1.3 Foreign Matter

Class A and Class B biosolids must contain ≤ 1 % foreign matter and no sharp foreign matter that can cause injury (Photograph 17). The size of the foreign matter sample depends on the amount and type of foreign matter present. The sample collected for foreign matter analysis should represent the quality of the material produced. The amount of sample collected can be determined based on visual observation. If the foreign matter is fairly small in size, or there is no visible foreign matter, a smaller sample size of approximately one liter (L) should be sufficient. Should large pieces of foreign matter be evident a larger sample size, for example a 20 L pail may be required. Three samples should be collected each consisting of seven equal volume grab samples.

According to the recommendations for determining compliance, the sludge complies with the OMRR requirements for Class A or Class B biosolids if the average foreign matter content and upper 95% CI is ≤ 1 % dw and there is no sharp foreign matter in a size or shape that can cause injury.

Photograph 17: Foreign matter on a residuals lagoon

SYLVIS

8.2 Biosolids Growing Medium

OMRR compliant BGM is a retail-grade biosolids product which can be distributed with no volume restriction. Sampling of the BGM is required to determine compliance with the OMRR.

There also exist provincial guidelines for soil and amendment quality that do not relate to the OMRR, but can affect the use of the soil products in reference to product quality. An example is the *BC Landscape Standard* developed by the BC Society of Landscape Architects and the BC Landscape and Nursery Association.

Under the OMRR, Class A or Class B biosolids that meet Class A pathogen and vector attraction reduction requirements (as specified in the OMRR Schedules 1, 2 and 3) can be used as a component of a BGM (refer to the OMRR Division 4 and Schedule 11).

BGM must meet the OMRR requirements of Schedule 4 (Column 2) and Schedule 11: trace elements, foreign matter, sharp foreign matter, TKN, C:N and organic matter (Table 8).

Sampling and analysis must be completed at least every 1,000 t dw of BGM or once per year, whichever occurs first. For due diligence and increased confidence in product quality, additional samples are recommended. A minimum of three composite samples, each comprised of seven subsamples, should be collected monthly or per batch, whichever occurs first. A batch of BGM is composed of the same feedstock materials in the same ratio.

8.2.1 Trace Elements

The biosolids used in the creation of BGM must not exceed Class B trace element concentrations (Schedule 4 Column 3 of the OMRR). BGM itself must not exceed the appropriate trace element limits from Column 2 of Schedule 4 of the OMRR.

The OMRR and the SACoP reference the BC Laboratory Manual for the Analysis of Water, Wastewater, Sediment, Biological Materials and Discrete Ambient Air Samples (last amended in 2005), which describes the Strong Acid Leachable Metals (SALM) in soil method. The SALM method dictates that only the fraction of the sample passing through a 10 mesh (2 mm) sieve is analyzed with the rationale that particles greater than 10 mesh are not soil. This may have implications for fabricated soils such as BGM where wood waste is used as a feedstock ingredient. BGM may need to be ground prior to analysis to account for the metals contained in the wood. Contact the analytical laboratory to discuss sample preparation procedures prior to submitting the samples.

It is recommended that BGM is compliant if the sample mean and upper 95% CI for each element does not exceed the concentrations provided in Schedule 4, Column 2 of the OMRR.

8.2.2 Pathogen Reduction - Fecal Coliform

BGM must be derived from biosolids that meet Class A pathogen limits. Determination of the pathogen concentration in the BGM is not required.

8.2.3 Foreign Matter

BGM must contain ≤ 1% foreign matter and no sharp foreign matter in a size or shape that can cause injury.

The amount of sample collected can be determined based on visual observation. If the foreign matter is small in size, or there is no visible foreign matter, a sample size of approximately 1 L should be sufficient. Should large pieces of foreign matter be evident a larger sample size, for example 20 L may be required. Three samples should be collected each consisting of seven equal volume grab samples.

BGM is compliant for foreign matter if the average foreign matter content and upper 95% CI is ≤ 1% dw and it contains no sharp foreign matter in a size or shape that can cause injury.

8.2.4 Total Kjeldahl Nitrogen, Carbon to Nitrogen Ratio and Organic Matter

It is recommend that three composite samples, each consisting of seven subsamples should be collected to determine the TKN, C:N and organic matter concentration.

The BGM complies with the OMRR requirements for TKN if the average TKN concentration and upper 95% CI is < 0.6% by weight (Schedule 11).

It is recommended that the C:N be reported as the ratio of total organic carbon (TOC) to organic N (TKN – NH_3) as this ratio is more applicable to predicting environmental impact due to the following:

- the concentration of organic C in the soil influences the rate of N immobilization; and,

- organic N provides an indication of the N mineralization potential.

Total organic carbon and NH_3 analysis may need to be requested separately as analytical laboratories may report C:N differently. Confirm with the laboratory prior to submitting the samples.

It is recommended that the BGM is compliant for C:N if the mean and lower 95% CI is > 15:1.

Although loss on ignition is sometimes used as a measure of organic matter, it is not recommended for specific matrices; if lime stabilized biosolids are used to produce the BGM the $CaCO_3$ can decompose and be released as CO_2 during the ignition process leading to an erroneously high organic matter content.

It is recommended that the BGM is compliant for organic matter if the mean concentration and upper 95% CI is $\leq$ 15% dw (Schedule 11).

8.3 Sampling Compost

Sampling is required to determine if the compost meets the OMRR criteria for Class A or B compost.

Schedule 5 of the OMRR stipulates that all the required analyses for Class A and Class B compost must be carried out at intervals of at least 1,000 t dw of organic matter (compost in this case), or once per year, whichever occurs first. This is the minimum number of samples required.

A minimum of three composite samples (each consisting of seven subsamples) is recommended per batch. ASP or windrow is considered a batch.

Samples collected should demonstrate that the composting process was effective and the compost to be applied or distributed meets the OMRR criteria. It is recommended that samples for regulatory purposes should be collected as close as possible to the time the compost is applied or distributed (i.e. after screening, if applicable, and curing). Refer to Section 6.5 for information on sample collection procedures. The exception is Class B compost which can be sampled for fecal coliform determination once the pathogen reduction process is complete.

Additional sample collection may be beneficial for process monitoring.

Although not required by the OMRR, monitoring of the feedstock materials in addition to the biosolids (as required) will allow the compost generator to design compost mixtures to meet the OMRR requirements.

8.3.1 Pathogen Reduction - Fecal Coliform

For Class A compost the OMRR requires each of the seven samples analyzed for pathogen determination have fecal coliform densities < 1,000 MPN g^{-1} dw. If compost is made solely from yard waste or untreated and unprocessed wood residuals, sampling requirements for pathogen reduction limits do not apply.

The OMRR requires that the geometric mean of the seven samples collected for Class B compost pathogen determination must be < 2,000,000 MPN g^{-1} dw (Schedule 3).

The compost is Class A if the concentration of fecal coliform in all seven samples is < 1,000 MPN g^{-1} dw.

The compost is Class B if the geometric mean of seven discrete samples is < 2,000,000 MPN g^{-1} dw.

8.3.2 Trace Elements

Class A compost must not exceed the trace element concentrations listed in Schedule 4 of the OMRR. Allowable trace element limits are substantially lower than for Class A and B biosolids. Biosolids used as feedstock for the production of Class A compost must not exceed the trace element limits established for Class B biosolids (Schedule 4 of the OMRR).

Biosolids used in the production of Class B compost and Class B compost itself must be analyzed for trace element content and must not exceed the trace element limits identified in Column 3 of Schedule 4 of the OMRR.

It is recommended that compost is compliant with the OMRR Class A trace elements if the upper 95% CI indicates that the concentration of each trace element does not exceed the limits as set out in Schedule 4, Column 1 of the OMRR.

It is recommended that compost is compliant with the OMRR Class B trace elements if the upper 95% CI indicates that the concentration of each trace element does not exceed the limits as set out in Schedule 4, Column 3 of the OMRR.

8.3.3 Foreign Matter

Class A and Class B compost must contain ≤ 1% foreign matter and no sharp foreign matter in a size or shape that can cause injury.

The amount of sample collected can be determined based on visual observation. If the foreign matter is fairly small in size, or there is no visible foreign matter, a sample size of approximately 1 L should be sufficient. Should large pieces of foreign matter be evident a larger sample size, for example a 20 L pail may be required. It is recommended that three composite samples be collected, each consisting of seven equal volume grab samples.

The compost complies with the OMRR requirements for foreign matter if the mean foreign matter content of the sample and the upper 95% CI is ≤ 1% (dw) and there is no sharp foreign matter in a size or shape that can cause injury.

8.3.4 Carbon to Nitrogen Ratio

Determination of the C:N is required for Class A compost.

It is recommended that three composite samples, consisting of seven subsamples, be collected for determination of the C:N. Samples should be collected after screening to reflect the material that will be land applied.

It is recommended that the C:N be reported as the ratio of TOC to organic N (TKN minus NH_3) as this ratio is more applicable to predicting environmental impact due to the following:

- the concentration of organic C in the soil influences the rate of N immobilization; and,

- the organic N concentration provides an indication of the N mineralization potential.

TOC, TKN and NH_3 analysis may need to be requested separately as analytical laboratories may vary in the method of reporting C:N. Confirm with the laboratory prior to submitting the samples.

It is recommended that the Class A compost is compliant for C:N if the lower 95% CI is ≥ 15:1 and the upper 95% CI is ≤ 35:1.

Table 8: Summary of sampling requirements and recommendations for OMRR residuals and products

Sampling Guidance	Class A Biosolids	Class B Biosolids	Class A Compost	Class B Compost	Biosolids Growing Medium	Decision Rule (Compliance Achieved)
Parameters						
Trace elements ($\mu g\ g^{-1}$)	Trade Memorandum[a]	OMRR Schedule 4	OMRR Schedule 4	OMRR Schedule 4	OMRR Schedule 4 and 11	Sample mean and 95% UCI ≤ criteria for each trace element
Arsenic	75	75	13	75	13	
Cadmium	20	20	3	20	1.5	
Chromium	Not required	1,060	100	1,060	100	
Cobalt	150	150	34	150	34	
Copper	Not required	2,200	400	2,200	150	
Lead	500	500	150	500	150	
Mercury	5	15	2	15	0.8	
Molybdenum	20	20	5	20	5	
Nickel	180	180	62	180	62	
Selenium	14	14	2	14	2	
Zinc	1,850	1,850	500	1,850	150	
Fecal coliform (MPN g^{-1} dw)	< 1,000	< 2,000,000	< 1,000	< 2,000,000	Not required	*Class A biosolids and compost*: concentration in each of seven samples < criteria *Class B biosolids and compost*: geometric mean of seven samples < criteria
Foreign Matter (%)	≤ 1 dw, no sharp foreign matter that can cause injury					Sample mean and 95% UCI ≤ criteria
(%, dw)	Not required	Not required	Not required	Not required	< 0.6	Sample mean and 95% UCI < criteria
C:N	Not required	Not required	≥ 15:1 & ≤ 35:1	Not required	> 15:1	Sample mean and 95% LCI > criteria
Organic Matter (%, dw)	Not required	Not required	Not required	Not required	≤ 15	Sample mean and 95% UCI ≤ criteria
Sampling Plan	Systematic random, simple random, stratified random	Systematic random, simple random, stratified random	Systematic random, simple random, stratified random	Systematic random, simple random, stratified random	Simple random	-
Type of Sample	Composite	Composite, seven discrete samples for fecal coliform	Composite	Composite, seven discrete samples for fecal coliform	Composite	-
Number of Samples (minimum)	3 (each composed of seven subsamples)	3 (each composed of seven subsamples)	3 (each composed of seven subsamples)	3 (each composed of seven subsamples)	3 (each composed of seven subsamples)	-

[a] *Trade Memorandum T-4-93 (September 1997), Standards for Metals in Fertilizers and Supplements*

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9 Sampling and Analysis for the SACoP

9.1 Introduction

Prior to land application, all residuals managed under the SACoP must be sampled and analyzed for trace elements and foreign matter. Soil amendments cannot be applied to land if the trace element concentration or foreign matter content exceeds the criteria provided in Part 3 of the SACoP. Fecal coliform analysis is required only for pulp and paper residuals that contain domestic sewage if mixed with these residuals. This chapter provides supporting information on sampling and analysis to assess amendment quality for land application.

Fly ash and primary and secondary pulp and paper residuals must be sampled by a qualified professional when the earlier of:

- 1,000 t dw of soil amendments are produced at the facility, or
- one year has passed since the facility started to produce the soil amendments or one year has passed since the last sampling and analysis.

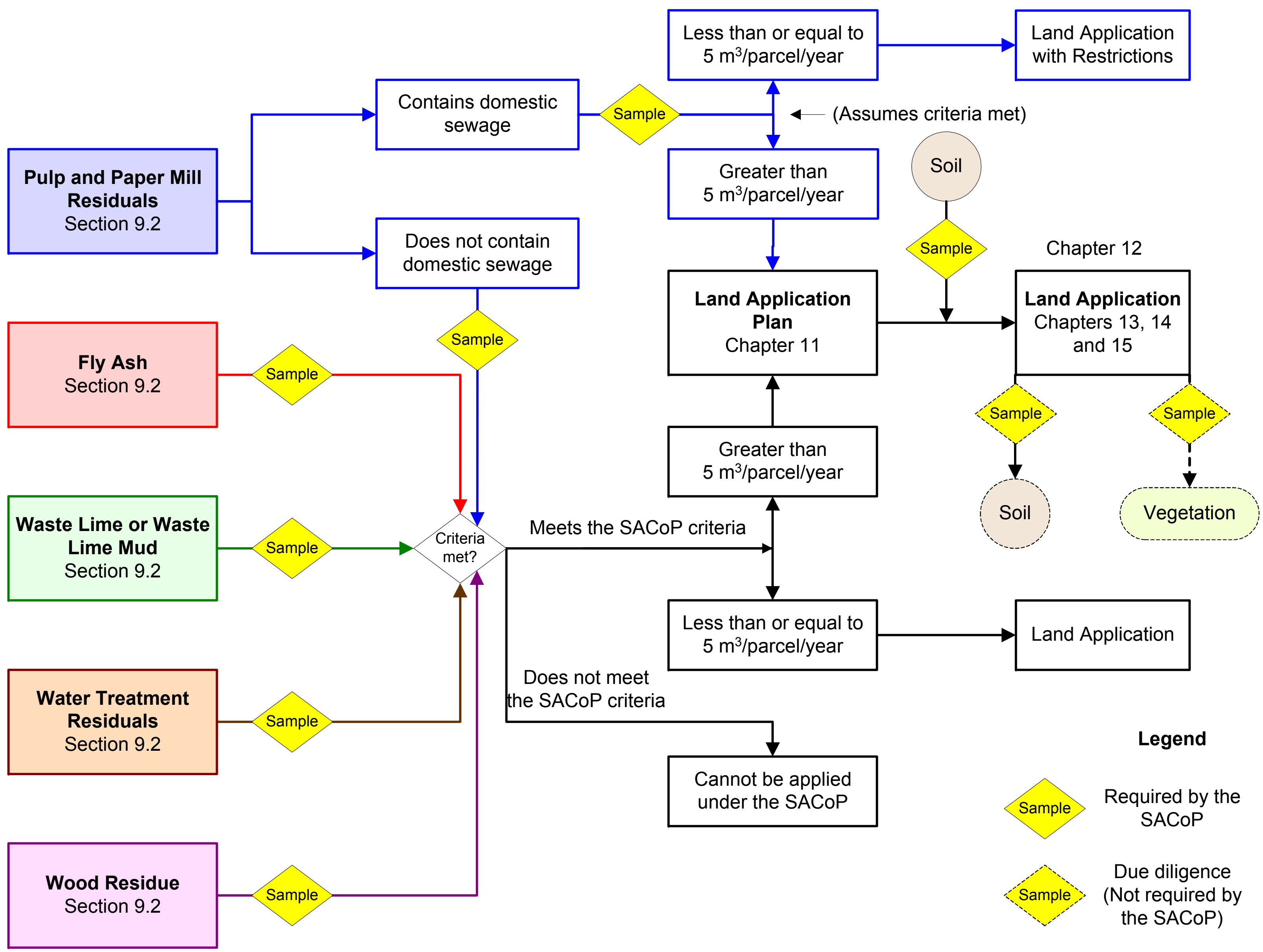
More frequent sampling and analysis may be required by the director. The SACoP does not stipulate the sampling frequency, or the requirement for a qualified professional to collect samples for waste lime or waste lime mud, WTR or wood residue. Sample collection by a qualified professional is not a requirement for any of the residuals regulated under the OMRR.

As a minimum it is recommended that these materials be sampled at least every 1,000 t dw or once per year. For all soil amendments, three composite samples, each consisting of seven subsamples, should be collected per sampling event.

Additional analysis is required for amendment use under a LAP; these parameters include moisture, TKN, plant available P and K; NH_3 plus NH_4^+; and NO_3^--N. Pre-application sampling of the receiving soil is necessary in the preparation of a LAP. Should amendment application exceed an agronomic rate a post-application monitoring plan is also required. This plan may include vegetation and post-application soil sampling. Sampling and analysis for a LAP are discussed in Chapter 12.

Figure 2 illustrates the sampling requirements for residuals managed under the SACoP. Sampling requirements for each of the soil amendments and methods of determining compliance with the SACoP are discussed in further detail in the sections below and summarized in Table 9.

Figure 2: SACoP Sampling Flow Chart



9.2 Soil Amendments

Aside from fecal coliform enumeration which must be measured in pulp and paper residuals containing domestic sewage, the analytical parameters required by the SACoP are identical for all the SACoP soil amendments. These parameters are summarized below.

9.2.1 Trace Elements

The concentration of trace elements in the soil amendments must not exceed the criteria given in Table 1 of the SACoP and summarized in Table 9.

It is recommended that soil amendments comply with the SACoP trace elements requirements if the mean and upper 95% CI indicates that the concentration of each element does not exceed the limits as set out in Table 1 of the SACoP.

9.2.2 Pathogen Reduction - Fecal Coliform

Pulp and paper residuals containing domestic sewage and having a fecal coliform density of $\geq$ 1,000 MPN g^{-1} dw are subject to additional management methods under the SACoP.

Pulp and paper residuals are analyzed for fecal coliform concentration as an indicator of relative numbers of general pathogens present. Fecal coliform are used as they are closely associated with fecal contamination, are relatively easy to identify and enumerate, and are usually present in large numbers when fecal contamination is present. The method used for enumerating fecal coliform is the multiple-tube fermentation technique or MPN technique. Consult the laboratory for the sample volume required. Typically, the laboratory will provide sterilized sampling containers.

Unlike the OMRR, neither the number of fecal coliform samples that should be collected nor the method of determining compliance is specified in the SACoP. Seven representative samples are recommended to assess the pathogen reduction through fecal coliform analysis.

Challenges with false positive results of fecal coliform contamination have been identified including the presence of false positive bacteria in pulp and paper effluent. False positive bacteria include *Klebsiella*, *Enterobacter* and *Citrobacter* species (Doyle and Erikson, 2006).

Fecal coliform concentration in SACoP residuals does not preclude use, but does necessitate additional management requirements to ensure protection of human health and the environment. It is recommended to avoid the additional management requirements, the fecal coliform density should be less than 1,000 MPN g^{-1} dw in all seven representative samples.

9.2.3 Foreign Matter - All Soil Amendments

Soil amendments must contain $\leq$ 1% foreign matter and no sharp foreign matter in a size or shape that can cause injury.

The amount of sample collected can be determined based on visual observation. If the foreign matter is small in size, or there is no visible foreign matter, a smaller size of approximately 1 L should be sufficient. Should large pieces of foreign matter be evident a larger sample size, for example 20 L may be required. Three samples should be collected each consisting of seven equal volume grab samples.

It is recommended that the soil amendment is compliant with respect to foreign matter if the mean and upper 95% CI is ≤ 1% dw and there is no sharp foreign matter in a size or shape that can cause injury.

Table 9: Summary of sampling requirements and recommendations for residuals regulated under the SACoP

Sampling Guidance	Fly Ash	Primary and Secondary Pulp and Paper Residuals	Lime Residuals (Waste Lime or Lime Mud)	WTR	Wood Residuals	Decision Rule (Compliance Achieved)
Parameters						
Trace elements ($\mu g\ g^{-1}$)	SACoP Table 1	SACoP Table 1	SACoP Table 1	SACoP Table 1	SACoP Table 1	Sample mean and 95% UCI ≤ criteria for each trace element
Arsenic	75	75	75	75	75	
Cadmium	20	20	20	20	20	
Chromium	1,060	1,060	1,060	1,060	1,060	
Cobalt	150	150	150	150	150	
Copper	2,200	2,200	2,200	2,200	2,200	
Lead	500	500	500	500	500	
Mercury	5	5	5	5	5	
Molybdenum	20	20	20	20	20	
Nickel	180	180	180	180	180	
Selenium	14	14	14	14	14	
Zinc	1,850	1,850	1,850	1,850	1,850	
Fecal coliform (MPN g^{-1} dw)	Not required	< 1,000 (if contains domestic sewage, otherwise not required)	Not required	Not required	Not required	Sample mean and 95% UCI < criteria
Foreign Matter (%)	≤ 1 dw, no sharp foreign matter that can cause injury					Sample mean and 95% UCI ≤ criteria
Sampling Plan	Systematic random, simple random	Simple random, stratified random, systematic random	Systematic random, simple random	Systematic random, simple random	Systematic random, simple random, stratified random	-
Type of Sample	Composite	Composite, seven representative samples for fecal coliform	Composite	Composite	Composite	-
Number of Samples (minimum)	3 (each composed of seven subsamples)	3 (each composed of seven subsamples)	3 (each composed of seven subsamples)	3 (each composed of seven subsamples)	3 (each composed of seven subsamples)	-

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10 Considerations for the Use of Residuals for Fertilization or Soil Amendment

This chapter provides information on the proximal factors to consider in designing a land application program for residuals regulated under the OMRR and the SACoP. It includes information on the determination of application rates, on-site nutrient management, calculation of trace element addition rates, soil quality considerations, site selection and management, and post-application monitoring. Information specific to sampling and analysis for land application is provided in Chapter 12. Specific information on application of residuals to agricultural, silvicultural, and reclamation sites is included in Chapters 13, 14 and 15 respectively.

This chapter provides general information on the various residuals regulated under the OMRR and the SACoP. It does not provide detailed information about the potential variability in the characteristics of each residual. Residuals are produced by many different processes and can be variable in quality and thus in their impact on an application site. The decision to apply a residual to land must be made with thorough knowledge of its characteristics, the characteristics of the proposed application site and whether the application will be beneficial to the site. The onus is on the qualified professional to remain current about residual quality and the proposed application site to ensure that the application is beneficial to soil and vegetation on site, while being protective of human health and the environment.

10.1 Public Information and Community Considerations

Public notification, other than the posting of signs for certain residuals, is not required by the OMRR and or the SACoP. The general public may be not familiar with the various types of residuals that are suitable fertilizers or soil amendments and may have questions regarding applications on their land or on adjacent property. In order to educate, increase awareness and minimize concerns of nearby property owners and communities, it is prudent to inform stakeholders that an application will be occurring in an area, and to provide some background information on the residual. For small-scale applications, it may be sufficient to notify neighbours of when, where and how the residual is to be applied in their area, either personally or by letter. Where large-scale, ongoing applications will be occurring, it is suggested that one or several open houses be held to inform, answer questions, address concerns, and reassure stakeholders that the residual will be land applied in a manner that is protective of human health and the environment (Photograph 18). Explaining the pre-treatment of the residual, crop harvest waiting periods and access restrictions may be useful.

If neighbours and affiliated stakeholders are not informed at the beginning of a land application planning process, significant delays in the project can result while questions and concerns are addressed. For ongoing residuals application programs, it is recommended that a communications and consultation plan be developed and implemented.

Photograph 18: Stakeholder tour held to inform them of planned residuals applications

SYLVIS

10.2 Site Selection

The suitability of a site for residual application is influenced by several factors, including climate, soil properties, depth to groundwater table, and topography and slope of the site. These factors are discussed in this section, which also includes site assessment recommendations.

10.2.1 Permitted Watersheds

Class B biosolids and Class B compost cannot be land applied in a watershed that is used as a permitted water supply under the *Safe Drinking Water Regulation*, BC Reg 230/92. The SACoP does not contain a similar prohibition.

10.2.2 Climate

Climate influences the time of year during which residuals may be applied to a particular site. Soils in wet, coastal climates usually have a high groundwater table throughout the late fall, winter and spring, limiting application of residuals to the dry summer period. Snow cover and/or frozen soils limit application in the interior. Runoff during spring snowmelt is a concern more so in the interior.

Climate will also influence site access. Wet soils and snowpack may limit access to sites on the coast and in the interior to the dry, summer season. Seasonal watercourses or high water levels may also influence site access.

Application limitations due to climate are discussed in Section 10.6.2.

10.2.3 Soil Properties

Soil properties can have a major influence on the suitability of a site for application of a residual. The ease with which added water and/or nutrients can enter into (infiltration) and move through the soil profile (permeability and internal drainage) will determine how quickly the constituent will be absorbed and dispersed within the soil. The actual volume of soil is important for a determination of the assimilatory capacity of the soil (how much added liquid and nutrients the soil can accept), and knowledge of the soil's ability to hold nutrients (CEC) within the soil profile is important in the site assessment.

The ability of a soil to withstand the impact of heavy equipment will determine not only if the residual application is warranted, but also the application timing. Careful consideration of soil properties will provide the qualified professional with adequate information to make a decision about the suitability of a site's soil for residual application. It is the responsibility of the qualified professional to determine the limitations of any potential sites for residual application.

10.2.3.1 Soil Infiltration

Infiltration is defined as the rate at which water or nutrients enters the soil. It is influenced by soil texture, pore size, structure, and organic matter content.

Large pore size allows for easy entry of added water and/or nutrients through the soil surface. An assessment of soil texture is important. Coarse-textured soils with abundant large soil pores have a more rapid infiltration rate than fine-textured soils that have a predominance of smaller sized pores. However, fine textured soils with good soil structure will have a component of larger soil pores between the structured soil aggregates. Organic matter is an important component in soil structure development, thereby enhancing soil infiltration rate.

Soils that are vegetated with perennial species usually have an abundance of roots which create root channels and promote soil structure development. These soils often have a suitable infiltration rate.

In soils where the surface structure has been disturbed or damaged, for example, by trafficking under wet soil conditions, the surface pores may become clogged, resulting in a sealing of the soil surface. This process, which is referred to as “puddling”, impairs the infiltration rate of added water and/or nutrients through the soil surface. The creation of a surface seal increases the potential for surface runoff and surface soil erosion. Runoff and/or surface soil erosion may result in transport of nutrients and pollutants to surface water.

The effect of puddling is not limited to the movement of water and nutrients. Air must be able to exchange between the soil and the atmosphere. Reductions in air exchange can result in large anaerobic soil pockets forming, which can result in root dieback. Soils that have been “puddled” may have limitations for residuals application unless they can be cultivated prior to the application.

Soils with high moisture content (i.e. a high groundwater table) can also have a reduced infiltration rate.

During a field inspection, the qualified professional should note any signs of “puddled” soils. These soils are often found in depressional areas where deposition of finer soil particles has occurred. Examination of the top few centimetres (cm) of a puddled soil will show a horizontal settling pattern in the soil particles.

Any evidence of surface soil erosion should also be noted, as indicated by the presence of water flow features such as rivulents or rills (small gullies) on the soil surface. Sites where surface soil erosion has occurred may indicate an impaired soil infiltration rate and therefore may have limitations for application of residuals.

10.2.3.2 Soil Permeability and Internal Soil Drainage

Soil permeability is the rate at which water moves through the soil; internal soil drainage is the ability of water to leave the column. Both of these soil characteristics are influenced by soil texture, pore size, structure, homogeneity of the soil pore structure between different soil horizons, and presence of restricting layers in the soil.

As with soil infiltrability, soil permeability and internal soil drainage are most rapid in coarse-textured soils and well-structured, fine-textured soils that have a component of large soil pores. Poorly structured, fine-textured soils tend to hold water within the smaller soil pores for longer periods of time, creating anaerobic soil conditions which reduce the soil microbial population and inhibit decomposition of any added soil organic matter. Release of nutrients is also reduced, and losses of N through denitrification may occur. Poorly drained soils have limitations for application of residuals.

By contrast, soils which are very rapidly pervious and drained (i.e. coarse-textured (sandy) soils with little or no organic matter), or soils with a high coarse fragment content (common in mine reclamation situations), may be prone to leaching losses if excess quantities of water and/or nutrients are applied. This is of particular concern with application of high nutrient residuals where leaching losses could lead to adverse impacts to groundwater.

Although high coarse fragment content in coarse-textured soils may increase the potential for leaching of nutrients, moderate coarse fragment content may improve the permeability and internal drainage of fine-textured soils. By providing pore space and preferred pathways for movement of soil water and nutrients, some of the limitations on fine-textured soils may be reduced.

Soils most suitable for application of high nutrient residuals are those with a medium texture with moderate to good permeability and internal soil drainage, or those with an adequate component of soil organic matter. Coarse-textured soils with a high component of organic matter have a higher capacity to hold added water and nutrients; well structured, fine-textured soils, particularly those with a moderate component of coarse fragments will have better soil permeability and drainage, and have less limitation for application of high nutrient residuals. Coarse textured soils can benefit from the addition of high organic matter residuals.

Application of residuals on soils that have permeability and internal soil drainage limitations may be possible under certain management conditions which may include application during the dry, summer season, or the use of dried or composted residuals rather than those with a higher moisture content.

Soils with permeability or drainage limitations may also have fewer limitations if the site is vegetated by perennial grasses and/or shrubs. The ability of plants to take up excess water and nutrients at the appropriate time of year may reduce certain site limitations.

The presence of restricting layers within a soil profile will reduce both the perviousness and internal drainage of a soil. Discontinuities in soil texture may temporarily impede water and nutrient flow through the soil profile. An example of a restricting layer is the presence of a poorly structured and slowly draining clay loam horizon underlying a well structured silty clay loam soil. Water will tend to accumulate in the upper silty clay loam horizon while it flows more slowly through the lower clay loam horizon. If surface runoff or soil erosion is a concern, application of liquid residuals should be restricted.

Soils which contain a “plough-layer”, found in many agricultural soils where frequent trafficking by heavy agricultural machinery creates a compacted layer approximately 20 cm below the soil surface, will also have impeded soil permeability and internal soil drainage. Depending upon the degree of compaction, impedance of water flow by this plough-layer may again be temporary; however, the presence of this layer must also be considered in the assessment for site suitability.

More serious impedances to soil drainage occur with the presence of cemented layers. Soils with cemented layers are often not suitable for crop production, and may be found in grassland or forested soils. The cementing agents vary depending upon soil texture and site conditions; however, the cemented layers are usually quite impermeable to water and/or nutrient flow. Additions of excess water can lead to an accumulation of water and excess nutrients in the soil layers above the impermeable layer. This could potentially lead to surface runoff, surface soil erosion or subsurface leaching losses.

Depending upon the proximity of the proposed application to surface water, application of a liquid residual may be acceptable on sites where soils have restricted or cemented layers. Special management considerations would be required and may include application during a certain time period (i.e. dry, summer season) or the use of dried or composted residuals rather than liquid residuals.

Compaction of soils will reduce permeability and internal soil drainage. Fine-textured soils, particularly those with poor soil structure, are most prone to compaction. Compaction usually occurs when heavy equipment is operated under wet soil conditions, resulting in destruction of the soil structure and a reduction in the soil pore size (i.e. the larger soil pores between the soil aggregates are crushed). A reduction of these larger pores will inhibit water, oxygen, and nutrient flow through the soil. Depending upon the soil moisture conditions, this destruction of soil structure may lead to the creation of anaerobic soil conditions, and reduced microbial activity and decomposition of added soil organic matter.

Compacted soils will have limitations for application of liquid residuals, unless the soil can feasibly be decompacted by cultivation or with the use of excavators as in forest soils.

The possible occurrence of restricting or cemented layers in a particular soil type may be determined through soil survey or surficial geology reports, or by examination of the soil where it has been exposed in ditches, dugouts, or in other excavations. However, prior to examining the soils in these locales, it is best to refresh the soil face (i.e. remove materials that may have sloughed down from above) in order to obtain the best view of the soil profile. Soils tend to ravel down slope and colours change with exposure to the atmosphere.

The best approach for assessing soils on a particular site is to excavate one or more soil pits in each different soil type. A soil pit excavated to a depth of 100 cm will assist the qualified professional in determining soil characteristics which cannot otherwise be determined by evaluation of the soil surface.

Excavation of soil pits will allow the qualified professional to gain information about the soil texture, structure, the presence or absence of any restricted or cemented layers, and the inferred internal drainage of the soil. During the process of excavation of a pit, the qualified professional will soon note any presence of restricting or compacted layers.

Soil drainage may be inferred by soil color. Dull gray or bluish colors in subsurface soil horizons indicate reduced or anaerobic (poorly drained) soil conditions, usually resulting from permanent water saturation. Soils with these dull coloured horizons are referred to as “gleyed” soils, and will have limitations for application of liquid residuals.

Soils with evidence of bright orange or red blotches (“mottles”) in the subsurface soil horizons indicate conditions of periodic inundation (i.e. a seasonally high water table). The lower horizons of these soils are commonly dry during the summer months. Therefore, soils with mottling in the subsurface horizons will have limitations for liquid residuals application during the time of year when the groundwater table is high. However, application during the dry summer period may be acceptable. In this scenario, an alternative to the use of residuals with a high moisture content would be the use of solid or composted residuals.

Although compaction of soils is more often a result of mismanagement than an inherent soil property, the occurrence of compacted soils should be considered in the soil assessment since it has implications for the application of liquid residuals. Evidence of soil compaction may be found where there are signs of rutting or crushing of the soil surface, or where areas of the soil surface have been disturbed, such as during logging. Examination of the surface soil horizons will indicate a crushing of the soil structure, and a reduction in the soil pore space.

10.2.3.3 Soil Depth and Volume

Soil depth will influence the ability of the soil to accept an applied volume of liquid residual, and the ease with which the liquid is either dispersed or stored within the soil profile. Soils that are deep and relatively permeable will have a greater capacity to hold and disperse added water, soil nutrients, and potential contaminants. Soils that are shallow to bedrock or compacted parent materials, those with impermeable layers within the soil profile, or those with high coarse fragment content will have less soil volume available for uptake of applied water and nutrients. The potential exists in these shallow or volume-limited soils for surface runoff, surface soil erosion, and/or subsurface leaching losses to occur.

The application of a solid or composted residual may be more appropriate for these sites than the use of a liquid residual. Although shallow soils have limited volume, they are often sites that would benefit from an application of a residual.

Soil volume is determined by depth to bedrock and impermeable layers, including cemented layers and compacted soil parent materials. It does not, however, include depth to restrictive layers such as plough-pans or textural discontinuities.

During the field assessment, the qualified professional should observe the proximity of the soil surface to either bedrock or compacted soil parent materials such as glacial till. Examination of the subsurface soil layers in ditches or soil pits will provide the qualified professional with information about soil depth.

A determination of coarse fragment content is also important. A high coarse fragment content will limit the available soil volume; a moderate coarse fragment content in fine textured soils may improve soil permeability and drainage. For information on determining coarse fragment content of soil, refer to Luttmerding *et al* (1990).

The qualified professional should be aware that shallow soils have less capacity to accept and disperse added water and excess soil nutrients than deep, permeable soils.

10.2.3.4 Capacity of the Soil to Hold Excess Nutrients

The capacity of a soil to hold excess available soil nutrients is dependent upon the clay and organic matter component in the soil (CEC). Coarse textured (sandy) soils with low organic matter content have little ability to hold soil nutrients; clay textured soils or soils with high organic matter content have a greater ability to retain nutrients within the soil profile.

Soils with high organic matter content also have a greater ability to bind trace elements. Organic matter tends to form complexes with these elements, preventing them from becoming available or mobile in the soil.

A determination of the soil texture, either by hand-texturing or through the collection of a composite sample and laboratory analysis, will provide the qualified professional with information about the clay component of the soil.

Soil organic matter content can usually be discerned by the color of the soil. Soils with surface horizons which are either dark brown or black in color usually have relatively high organic matter content. Soils that are light brown, grey, or yellow in color are usually lacking in soil organic matter.

However, in soils where dark colors extend down through the soil profile, and where these dark layers are underlain by soil horizons which are dull grey or bluish in color, the soil may be poorly drained. The groundwater table may also be situated within one meter of the soil surface. These poorly drained soils have limitations for application of liquid residuals.

10.2.3.5 Trafficability

The ability of a soil to withstand the ground pressure and weight of heavy equipment (i.e. soil strength) will influence the timing for a residual application.

Soil texture, structure and soil water content are the primary factors influencing soil trafficability. Soils which are coarse (sandy) textured, with a medium to low soil water content will have the greatest soil strength. Poorly structured, fine-textured soils with a moderate to high soil water content generally have the lowest soil strength, and are the most susceptible to soil compaction. Fine-textured soils with a strong soil structure will have moderate soil strength providing the soil water content is not too high.

Assessment of soil texture, structure, and soil water content is crucial in determining soil strength and trafficability. Timing of application will be limited to the dry, summer period for fine-textured soils, particularly those with a high soil moisture content. Coarse-textured soils may have more flexibility for timing of application, depending upon the component of finer soil particles, and the soil water content.

A determination of soil texture through hand-texturing or laboratory analysis will provide the qualified professional with information about the proportion of sand, silt and clay in the soil (Soil Classification Working Group, 1998).

Examination of the soil profile will allow the qualified professional to obtain information about soil structure and depth to the groundwater table. Good soil structure is identified by the presence of soil “aggregates” or “peds” with an abundance of larger soil pores between these aggregates. The presence of soil fauna or earthworms will also indicate soil organic matter content and soil structure development.

10.2.3.6 Other Soil Considerations

Areas of the BC Interior have alkaline soils which are identified by a white deposit on the soil surface. The evaporation of soil moisture from a shallow water table brings soluble salts to the surface; these are left as a white precipitate as the water evaporates. These alkaline soils are usually very poorly drained and are in general unsuitable for application of residuals because of limitations for crop growth.

10.2.4 Depth to Groundwater

The OMRR states that biosolids or biosolids compost with Class B pathogen concentrations must not be applied to land where the groundwater table is within 1 meter of the soil surface at the time of application. The SACoP requires that pulp and paper residuals containing domestic sewage adhere to the same requirement. For many areas of the province, this will restrict the application of these residuals to the dry summer season. Coastal areas often have elevated groundwater tables beginning in late fall, and continuing until late spring. Areas of the interior may be less restricted in the late fall unless frost or snowfall provides a limitation. However, many soils of the interior are fine-textured and hold moisture within the soil profile for longer periods of time.

During field assessments of the soil, the qualified professional should obtain information about the level of the groundwater table. This may be ascertained by water level in ditches, or by excavation of soil pits to the 1 m depth. A periodic high water table can also be inferred by soil color. Dull gray or bluish colors in subsurface soil horizons indicate reduced or anaerobic (poorly drained) soil conditions, usually resulting from permanent water saturation. Soils with evidence of bright orange or red blotches (“mottles”) in the subsurface soil horizons indicate conditions of periodic inundation (i.e. a seasonally high water table).

10.2.5 Slope, Aspect and Topography

Sites which are sloping or which have variation in topography pose limitations for application of residuals. Sloping land increases the potential for surface runoff, surface soil erosion, and subsurface leaching losses, which could lead to adverse surface or groundwater impacts.

Certain soil properties may reduce the risk of surface or groundwater pollution on sloping sites. Soils with moderate to rapid infiltrability, permeability, and internal soil drainage, such as coarse-textured or well structured medium textured soils will readily absorb added water and soil nutrients, reducing the risk for surface runoff or soil erosion. By contrast, soils which have been puddled or compacted present a greater risk where they are situated on sloping sites.

Impaired permeability from restricting layers may also result in increased potential for surface runoff or subsurface leaching losses on sloping sites. The accumulation of excess soil water may result in oversaturation of the soil above the restricting layer. The excess water may then be prone to surface runoff and/or subsurface leaching losses.

As discussed previously, deep, permeable soils have the potential to absorb and disperse a large amount of added water and soil nutrients without a great risk of groundwater pollution. This generally also applies to deep soils located on sloping sites. However, shallow soils with impermeable subsurface soil layers or those with high coarse fragment content are at greater risk of leaching losses and possible groundwater contamination when they are situated on sloping sites. Where oversaturation of the shallow soil volume occurs, the risk increases for this excess water to flow down slope on the soil surface or subsurface along the impermeable layer. This overland subsurface water could potentially lead to pollution of surface and/or groundwater.

Slope configuration is an important factor in the assessment of sloping sites. Sites with irregular topography and slope breaks over relatively short distances are less of a concern than sites where the slopes are long and uniform. Sites that slope directly toward bodies of surface water are also a concern. Any surface runoff following a residual application could potentially cause pollution of the water body.

Aspect is an important component of runoff. The potential for runoff from south facing slopes is high during spring snow melt in areas where snowfall accumulation occurs.

Residuals may be applied to sloping sites provided that any potential for overland flow, surface soil erosion, and subsurface leaching loss is minimal. Generally sites with broken and irregular topography are more suitable than sites where the slopes are long and uniform. Avoid sites which slope directly towards surface bodies of water, and select sites where the soils have good infiltration, permeability, and internal soil drainage, such as coarse to medium textured soils. Sites that are vegetated, particularly with perennial grasses and shrubs, have reduced potential for overland flow, and an increased ability to utilize water and nutrients soon after residuals application.

The potential for surface runoff and subsurface leaching loss increases with increasing slope angle and length. Runoff potential is higher from south and west aspect slopes during spring snow melt. The qualified professional must carefully assess site slope and topography, soil texture and permeability, aspect and climate and make a professional judgment of site suitability based on these factors. Where residuals are to be applied to a slope, it may be appropriate to increase the buffer distance from surface water to reduce the potential for runoff to enter the watercourse.

10.2.6 Potentially Sensitive Sites

Active floodplains and riparian areas are sensitive sites due to the potential for these sites to flood or to have elevated groundwater tables. As such, they have limitations for application of residuals. The exception might be higher terraces where the potential for flooding is low and the site is supporting species such as poplar which have a high nutrient and water requirement.

These alluvial sites are often very productive, and any vegetation occupying the site would efficiently utilize any water and nutrients provided by residual applications.

Other sites that might be considered to be sensitive are those most prone to compaction. Fine-textured soils are most easily compacted, depending upon the structure of the soil and the soil water content. Timing of application is the most important consideration on these sites.

Sites that contain threatened or endangered species are also considered to be sensitive sites. Habitat and land use issues should be considered in site evaluations where appropriate.

10.3 Nutrient Management – General Information

In the application of residuals for fertilization value, the concentration of plant macro and micro nutrients in the soil and in the residual should be considered. The quality, form and availability of nutrients in the residual and soil are determinants in application rate calculations.

10.3.1 Nitrogen

Nitrogen is one of the most important nutrients for plant growth. It is usually the rate-limiting nutrient in plant systems; it is the soil nutrient required in the largest amount by most vegetation and typically in shortest supply in soil. Most native soils contain only small amounts of plant-available N. Crop requirements for N and other nutrients beyond that provided by the soil are met by the addition of chemical fertilizers or organic amendments. Residuals including biosolids, secondary pulp and paper residuals and some composts are an excellent source of fertilizer N.

10.3.1.1 Soil Nitrogen Forms

Nitrogen in the soil exists as a result of the special ability of a small group of bacteria to “fix” atmospheric N, and transform it into organic and inorganic N. The largest pool of soil N is organic, consisting mainly of C-based compounds such as proteins that are not available to plants until soil microbes degrade and convert them to inorganic forms of N. The main inorganic or mineral forms of N in soil are NO_3^- and NH_4^+; these are plant-available when the residual is applied.

The soil’s microbial population is constantly transforming the N pool in the soil. Microbes decompose soil organic matter (including plant residues and organic amendments) and in the process convert organic N to inorganic N (in the form of NH_4^+), a process called mineralization. Nitrification is the process whereby another population of microbes converts NH_4^+ to NO_3^-. These two processes produce most of the pool of plant-available N in the soil.

Under various conditions, additional transformations and losses of N can occur. Immobilization is the reverse process of mineralization and occurs when the microbial population converts inorganic forms of N to organic N. This process occurs when a N deficient site is fertilized; the soil microbes consume the added N, depleting the soil supply for a period of time. On adequately fertilized sites, immobilization following fertilization will not normally occur. However, on forested sites, agricultural sites with an inadequate supply of N, or on a site where high C organic amendments have recently been added, N immobilization is likely to occur.

Leaching of NO_3^- can occur when heavy rains saturate the soil, and water moves down and through the soil profile, as occurs in coastal areas of BC during late fall and winter. Nitrate is soluble in the soil solution and moves readily with soil water. If N in excess of vegetation requirements is applied to a site in areas of high rainfall, heavy rains can mobilize NO_3^- not assimilated by vegetation and soil organisms down through the soil beyond the root zone, and potentially into groundwater sources. Excess NO_3^- leaching below the root zone is an indication of an excess application rate of high N residuals. In drier areas of BC, annual precipitation is low such that NO_3^- leaching does not generally occur except on agricultural sites that are over-irrigated. Normal irrigation will move NO_3^- down in the soil profile but not beyond the vegetation rooting depth. The leaching of NO_3^- does not occur alone. As a negatively charged ion, NO_3^- can bond with a positively charged ion, often K. This process is called cation stripping. It can concurrently move cations out of the rooting zone and down through the solum.

Under anaerobic conditions in the soil and provided there is a C source, certain bacteria will reduce NO_3^- to nitrogen gas (N_2) which is emitted to the atmosphere. This process is called denitrification and can result in the loss of significant amounts of N from a soil. Depending on conditions, denitrification can also lead to the emission of nitrous oxide (N_2O), a potent greenhouse gas.

10.3.1.2 Forms of Nitrogen in Residuals

Biosolids contain N in several forms. As in soil, the largest pool is organic N, consisting of proteins and amino acids which are rapidly degraded in the soil, and more resistant N compounds which decompose very slowly and become part of the soil's pool of organic matter. Biosolids also contain some inorganic N as NO_3^-, NH_4^+ and NH_3. On average, anaerobically digested biosolids contain 20% of their total N as NH_4^+, and less than 1% as NO_3^-. Once in the soil, the NH_4^+ and NH_3 move freely from one form to the other depending on soil pH. At neutral pH, the proportion of NH_4^+ to NH_3 is 100:1. The NH_3 fraction is volatile. If biosolids are surface applied without incorporation, much of the NH_4^+/NH_3 can be lost to the air in a process called volatilization.

The inorganic N in biosolids is available for plant uptake in the year of biosolids application. As well, a predictable amount of the organic N pool will be mineralized during the year of application and the first several years after biosolids application. The fraction that becomes available in years 2 and 3 following application is known as the residual N.

The amount of N in stabilized compost is significantly lower than in biosolids, and typically almost all is in the organic form with a small component cycling between mineral forms (NH_3 and NO_3^-) and organic forms.

Nitrogen in secondary and combined pulp and paper residuals is largely in the organic form, with less than 10% existing in inorganic forms when the residuals are produced. The quantity and forms of N are dependant upon the process and relative proportions of primary to secondary residuals as a blend.

Other than primary and secondary pulp residuals, SACoP regulated residuals contain very little N; these include WTR, fly ash, waste lime and lime mud and wood residues.

10.3.2 Phosphorus

10.3.2.1 Soil Phosphorus Forms

Phosphorus exists in the soil in both organic and inorganic forms and is found bound to many different compounds within the soil. Phosphorus is present in the soil solution as dissolved P and bound to or within soil particles as particulate P.

Dissolved P, the P that is found in the soil solution, is defined as the fraction smaller than 45 micrometers. Both organic and inorganic forms of dissolved P are present in the soil solution; this is the fraction vegetation assimilates. The typical assimilation form of P is orthophosphate which is part of the dissolved inorganic fraction. Orthophosphate (ortho-P) is found in two forms in the soil, primary and secondary; the amounts of each of these two forms of orthophosphate are in equilibrium in the soil. When the soil pH is lower than 7.2, primary orthophosphate (H_2PO_4) is more abundant. Secondary orthophosphate (HPO_4) dominates when pH is higher than 7.2. Primary orthophosphate is taken up by plants much more readily than the secondary form.

Particulate P is defined as the fraction of soil P that is larger than 45 micrometers in size. This fraction is found as mineral P (complexed with other minerals), adsorbed to soil material and within organic matter. There is wide variability within this fraction of P as to the binding strength within or to soil particles. That P that is easily dissolved into the soil solution is termed labile-P while the more recalcitrant P is termed non-labile and is very resistant to degradation. The labile-P fraction is the fraction that replenishes the soil solution P as plant assimilation occurs, while the non-labile fraction is slowly degraded over time. Organic non-labile-P is mineralized slowly over time by microbes in a process similar to the mineralization of organic N.

Phosphorus added to soil in chemical fertilizer or residuals can become tightly bound or fixed to soil particles and become part of the non-labile fraction of soil P. Significant research is focused on determining the factors controlling P transformations.

Laboratory analysis of soil for plant-available P typically quantifies all of the ortho-P and a portion of the labile-P in the sample.

Phosphorus is normally very tightly bound and immobile in the soil and thus does not have the same potential to leach as N. Phosphorus can move by overland flow; runoff from an application site or erosion of soil containing a high concentration of P into surface water can lead to the degradation of surface water quality. Phosphorus can also move with soil water through soil macropores, cracks and worm holes into tile drains and ditches that drain into surface water sources. Higher soil concentrations of plant-available P are strongly correlated with the amount of P in tile drain water or eroded soil.

10.3.2.2 Forms of Phosphorus in Residuals

The forms and availability of P in biosolids is understood in greater detail than for other residuals. Because information on other residuals is incomplete, it is recommended that each residual be analyzed for total and plant-available P, and this information used to estimate the P availability and soil additions at a given application rate.

Phosphorus is found in biosolids in both organic and inorganic forms. The proportions of each vary with wastewater characteristics and the biosolids treatment process. Phosphorus in biosolids is present primarily in the particulate fraction. Inorganic P is relatively insoluble and therefore poorly available for plant uptake.

Approximately 40% of biosolids P will be plant-available in the year of application unless ferrous chloride or alum has been used in the treatment plant, in which case availability of P will be reduced. Analysis of the biosolids for plant-available P will give an indication of the availability of P in the year of application. The Quebec MoE (Hebert, 2004) suggests using the following equation to estimate P availability from biosolids in the year of application:

$$\%\ \text{available P} = 70 - (\text{Al}_{total} + 0.5\ \text{Fe}_{total}\ (\text{mg kg}^{-1}) - 20{,}000)/2000$$

When biosolids are applied to meet the N requirement of the vegetation on site, P in excess of vegetation requirements is typically applied. After several applications of biosolids or other organic amendment, the soil concentration of plant-available P can increase beyond the concentration considered adequate for plant growth.

10.3.3 Other Nutrients and Soil Quality Parameters

10.3.3.1 Potassium

Biosolids, when applied to meet vegetation N requirements, contain insufficient K to meet most vegetation requirements. If the application site has received regular nutrient additions as fertilizer or manure, the soil may have adequate K and this will address any short-term K deficiencies in the soil. If the soil concentration is inadequate supplemental K fertilizer may be required.

Fly ash contains a substantial amount of K and when applied to make a pH adjustment to a site, may over supply the soil. The qualified professional should exercise care in applying fly ash on forage production sites with an elevated background soil concentration of K.

Potassium concentrations in compost and residuals regulated under the SACoP vary depending on the feedstock used in the process; laboratory analysis is recommended to determine existing concentrations and to predict the K concentration in the soil after residual application.

10.3.3.2 Sulphur

Soil in much of the Southern Interior and Central BC is deficient in S. As a result, trees, forages and other crops grown in these areas are commonly deficient in S. Sulphur deficiencies can lead to reduced yield or crop failure, depending on the severity of the deficiency. Sulphur is required for normal growth and development of all vegetation and is normally added as part of a blended fertilizer when fertilizing agricultural land throughout these areas of the province. Most residuals contain a significant amount of S and can help to correct a soil deficiency of this nutrient. Laboratory analysis is recommended to assess the concentration in the residual and to predict soil status after residual application.

10.3.3.3 Copper

Copper is naturally deficient in soil throughout much of Central and Southern Interior of BC. This soil deficiency produces copper-deficient forages that do not provide the minimum required copper concentration for normal growth and development of ruminant animals. Normally, cattle are fed copper-containing trace mineral supplements to supplement shortages in the feed. The supplement provides the required 10 ppm of copper in the diet.

Most BC biosolids contain a significant amount of copper, ranging from 500 to 2,000 ppm. When used as a fertilizer for forage crops, biosolids can eliminate forage deficiencies of this mineral. Cattle fed biosolids-amended forages can safely be fed a copper-containing mineral supplement; the combination of higher forage copper plus the mineral mix copper is typically below their safe upper limit for copper intake (100 ppm in the total ration).

Sheep are much more susceptible to copper toxicity than cattle; chronic toxicity can be induced if sheep are fed forage containing as little as 15 ppm copper for an extended period of time. If biosolids or other residuals containing high concentrations of copper (> 1,500 ppm) are applied to pasture or forage crops that are to be fed to sheep, the copper content of the forage should be monitored, particularly in the year of application. Monitoring is particularly important if such residuals are applied to sites that are already well supplied with copper.

The other residuals regulated by the OMRR and the SACoP do not contain copper at the relatively high concentrations found in biosolids; livestock health is unlikely to be affected with applications of other residuals.

10.3.3.4 Boron

Boron is an essential plant micronutrient that is found at fairly high concentrations in fly ash. Boron has a narrow range in the soil between deficiency and toxicity to vegetation; a background soil concentration of 1 ppm is required for normal growth of most vegetation. At 3 ppm toxicity to sensitive vegetation can occur.

Boron deficiencies are common in the Interior of BC and can lead to crop growth reduction. Many residuals contain sufficient B to eliminate deficiencies on low B sites but not sufficient to over supply the soil.

Applications of wood fly ash to raise pH 1 or 2 pH units can add a substantial amount of B to the site, depending on the B concentration of the wood ash. It is recommended that proposed receiving sites be assessed for B concentration (measured as hot water soluble B) before residual application and that wood ash be used cautiously on sites with a high background concentration of B or where B-sensitive vegetation is to be grown.

10.3.3.5 Sodium and Sodium Adsorption Ratio

Many of the residuals regulated by the OMRR and the SACoP contain substantial amounts of sodium relative to their concentrations of the major soil cations, Ca and Mg. If these residuals are applied at high rates or repeatedly to a site, the ratio of sodium can increase in the soil relative to Ca and Mg which can lead to deterioration of soil structure. On sites that have an elevated sodium concentration or high sodium adsorption ratio, high sodium residuals should be used with caution. Soil sodium should be monitored on receiving sites to ensure that it does not increase to a level of concern.

10.3.3.6 Conductivity and pH

OMRR requires that the pH and conductivity (an estimate of salinity) of biosolids and compost and of the receiving site be assessed. The SACoP requires measurement of the pH and conductivity of the soil amendments and the receiving site.

Neither regulation prescribes limits for these parameters in amendments or on application sites. It is the responsibility of the qualified professional to ensure that the pH and conductivity of proposed application sites are within the acceptable range for the vegetation to be grown on the site, and that application of the residual will not result in impairment of site productivity.

Typically soil pH can be modified, thus pH is not a reason to exclude a site. In some cases an application of biosolids or compost can help to increase and buffer a low pH soil. High conductivity on a site should be assessed and considered as it can indicate over-application of organic amendments in the past or other soil salinity problems. Crop failure is a serious concern on very high electrical conductivity (EC) sites unless a salt tolerant crop is chosen.

Biosolids, biosolids compost as well as pulp and paper residuals typically have a relatively high salt content. If applied at agronomic rates they are unlikely to elevate soil salinity. Non-agronomic application rates of these amendments, particularly on dryland sites where rainfall or irrigation are insufficient to move salts down through the soil, can lead to increased soil salinity.

10.4 Application Rate Determination

Both the OMRR and the SACoP require that regulated residuals are land applied to provide a defendable benefit to soil and vegetation on-site while minimizing the potential for adverse environmental impacts. Information on how the application rate was determined must be contained in the LAP. Determining the appropriate application rate of a residual for the selected site is one of the most important steps in developing a land application program. If the selected application rate exceeds the annual crop nutrient or soil conditioning requirement for the site, the LAP must contain requirements for monitoring soil and vegetation quality changes as a result of the application. The LAP can also include requirements to monitor surface or groundwater quality.

The types of residuals regulated by the OMRR and the SACoP vary considerably in their characteristics and use as fertilizers and soil amendments. In general, high nutrient residuals are applied as a fertilizer to meet the nutrient requirements of the vegetation on site, liming materials are applied to adjust pH on site to the desired level, and low nutrient, high organic matter residuals are applied to increase soil organic matter content and improve soil physical properties. This section discusses the characteristics of each residual as a determining factor in the appropriate use of the residual and the rate at which it should be applied. For more information on the individual residual characteristics refer to relevant sections of Chapter 5.

High nutrient residuals typically include biosolids, secondary pulp and paper residuals, some combined pulp and paper residuals and certain types of compost. These residuals are normally land applied as a fertilizer source with the intent of meeting vegetation requirements for one or more nutrients. As N is normally the rate-limiting nutrient for crop growth, and is the nutrient that is most likely to cause environmental damage if over-applied, application of these residuals is typically based on providing the crop's N requirement for a single growing season. On most sites, a N based application rate is appropriate.

Under certain circumstances the application rate of a high nutrient residual can be based on a multi-year N requirement. This is discussed in the applicable sections of Chapters 10, 11 and 12.

On sensitive sites that have an elevated soil concentration of plant-available P due to repeated long-term application of manure or other organic amendments, it is suggested that a P-based application rate be considered when land-applying nutrient-rich residuals.

Water treatment residuals are classified as high nutrient residuals because most WTRs contain a significant amount of P and moderate amounts of other nutrients. However, because WTRs also contain P-binding alum and ferric chloride, special considerations are necessary for their application. Some types of WTR contain a high concentration of Ca; these residuals may have use as alternative liming materials if their pH and acid neutralizing value are acceptable. Section 10.4.3 contains information on alternative liming materials.

Liming materials include waste lime, waste lime mud and fly ash. These residuals are normally land-applied to sites that have an acidic soil reaction and require liming to elevate the pH into the target range for the vegetation. Information on developing application rates for these residuals is found in section 10.4.3. Fly ash can also be considered a fertilizing residual because of its high nutrient content.

High C:N, low nutrient residuals include several of the residuals regulated by the OMRR and the SACoP which do not fall into the three broad categories above (e.g. some compost, industrial residues of wood, primary pulp and paper residuals and some combined pulp and paper residuals). Their preferred end use is to increase soil organic matter or to be used as surface mulch depending on the objectives of the land application program. These residuals can be mixed with high nutrient residuals to modify the C:N and create a soil amendment composed of two types of residuals. Section 10.4.2 provides information on developing application rates for these residuals. Compost application rates can be determined on a nutrient basis or on other decision criteria depending on the objective (e.g. increasing soil organic matter or providing a surface mulch). Depending on the feedstock from which they are made, compost can be either nutrient-rich fertilizing materials or high C:N soil amending residuals.

10.4.1 High Nutrient Residuals

10.4.1.1 Nitrogen Based Application Rates

Most applications of the high nutrient residuals regulated by the OMRR and the SACoP (biosolids, secondary and combined pulp and paper residuals and some high nutrient compost) should be N-based, balancing the N requirement of the target vegetation with the amount of N available from the residual. Compost and combined pulp and paper residuals with a C:N of less than 20:1 should be considered high nutrient residuals and applied at an agronomic N rate.

Lime-stabilized biosolids should be managed both on their nutrient content and on their liming value. Section 10.4.3 provides a discussion of application rates based on liming value. WTR should be land applied based on their P concentration and the characteristics of the site unless they are high Ca WTR in which case they may be used as an alternative liming material or used in combination with other residuals. Sections 10.4.1.2 and 10.4.3 provide information on application rates of these residuals.

When determining a N based application rate, the objective is to meet the vegetation's requirement for N for the growing season in which the residual is land-applied. This is termed the agronomic application rate, and is most applicable to agricultural applications but can also be relevant to forestland fertilization and some reclamation applications. At this application rate, the vegetation is expected to utilize most of the applied N, leaving minimal residual N in the soil after the growing season. Minimal residual NO_3^--N reduces the potential for N movement into groundwater or surface water.

To calculate an agronomic application rate based on N, the following four factors must be considered:

Agronomic N Requirement for Target Vegetation

The agronomic rate of N is the amount of N required by the target crop to achieve its expected growth and yield during the cropping season. Nitrogen requirements of crops can be found in fertilizer and crop production guidebooks. Soil data can also be used to estimate crop N requirements, although in high precipitation areas of BC, soil N is often a poor predictor of available N.

The Amount of N Available From the Residual

Most residuals contain N in both inorganic and organic forms. All of the inorganic N in the residual will be available for crop growth in the year of application (less any volatilization, leaching or immobilization). A portion of the organic fraction will mineralize in the year of application. The sum of the inorganic fraction plus the mineralized organic N is the amount of N that will be available to the crop in the year of application.

Cowley *et al.* (1999) conducted a study to evaluate N mineralization rates from different organic residuals. They concluded that N mineralization rate was positively correlated with initial organic N and increased as the stability of the residual decreased (i.e. increased decomposition rate). As such, manures were observed to have the highest mineralization rate, followed by biosolids and composts.

Table 10 lists estimated first year organic N mineralization rates for fresh biosolids. Between 10 and 40% of the organic N will mineralize in the year of application, depending primarily on climate and growing season moisture. First year mineralization rates do not differ significantly between aerobic and anaerobic biosolids, or between biosolids that have been dewatered, air-dried or heat-dried. Lagoon stored or composted biosolids mineralize significantly less N than fresh biosolids, on average 10% of the organic N in the year of application. Mineralization of N from lime-stabilized biosolids is typically at the high end of the range provided in Table 10. Typically a further 10% of the organic N will mineralize in the year following application and 5% in year 3. The remaining organic N will become part of the soil organic matter.

Nitrogen mineralization rates from pulp and paper residuals have been investigated, although less information is available for these residuals than for biosolids. Wang *et al*. (2003) conducted an incubation study comparing N mineralization rates in biosolids and pulp and paper residuals. Over a 26 week incubation period, they measured N mineralization rates of 15%. In comparison, the maximum N mineralization rate in biosolids was 32%. Mineralization rates in pulp and paper residuals may be comparatively lower than in biosolids because lignin and polyphenol in the pulp and paper residuals may inhibit N mineralization. Also, as pulp and paper residuals (i.e. primary and combined) generally has a higher C:N, a net immobilization of N may occur as soil microbes assimilate mineral N from their environment for energy and growth (Janssen, 1996).

Table 10: Estimated first year biosolids nitrogen mineralization rates for BC environments

Location	Mineralization rate (% of initial organic N)
South Coastal region – irrigated or dryland	20-40
Southern Interior – dryland	20-30
Southern Interior – irrigated	20-40
Central Interior and Peace – dryland	10-20
Central Interior and Peace – irrigated	20-30

Note: these values apply to anaerobic and aerobically-digested biosolids, in liquid, dewatered, or dried form. Composted or lagoon stored biosolids will mineralize 10% of organic N in the year of application; mineralization rate of N from lime-stabilized biosolids will be at the high end of the above ranges.

The Loss of N from Residual before Vegetation Uptake

A significant amount of the NH_3 in residuals can be lost during land application depending on the type of site (e.g. forest vs. agricultural), the application method used (surface applied vs. incorporated), whether the residual is liquid or dewatered, and the temperature and wind speed following application. Losses are greatest from residuals surface-applied to agricultural land and not incorporated, ranging from 40 to 80%. Losses in agricultural systems can be minimized by injecting the residual or incorporating with tillage within 2 days of application. Losses in traditional forested sites tend to be low (5-25%) due to minimal solar radiation and wind at soil level, and low pH of the forest floor. Losses in reclamation applications can be high (80-90%). Application rates must be adjusted to account for the loss of NH_3 during application.

A loss of NH_3 is a loss of N to the plants and soil; incorporation to conserve NH_3 is recommended where possible.

Up to 100 kg N ha^{-1} can be immobilized on susceptible sites following residual application (see Section 10.3.1 for further discussion). Forested sites, recently cleared sites with a high C:N and low fertility agricultural sites may experience immobilization of N. On such sites, the application rate must be increased to account for the temporary immobilization of N. Appropriate sections of Chapters 13 and 14 discuss N immobilization in more detail. A small amount of the immobilized N will become available in subsequent years, but this will not significantly affect future N availability.

Nitrogen Available to the Target Vegetation from Other Sources

Nitrogen available to the target from other sources must be considered in the application rate determination. If the site has received regular nutrient additions in previous years, soil residual N will provide a portion of the vegetation's requirement. A cover crop or green manure crop that will be tilled into the site prior to residual application will contribute N during the growing season. Extra fertilizer N must also be considered. The application rate must be reduced to account for these extra sources of N.

For some crops, providing all of the crop's N requirements through the residual application may not be a good management objective. Some crops may require more plant-available N early in the growing season than the residual can provide. A small application of N fertilizer in the early season can supply the required plant available N.

All of these factors must be considered when determining the appropriate application rate. The application rate is site-specific; more detailed information on calculating application rates incorporating these factors is provided in Chapters 13, 14 and 15.

10.4.1.2 Phosphorus-Based Application Rates

Phosphorus-based application rates are not common in residuals management but there are scenarios where they are appropriate: when the proposed application site has an elevated soil P concentration and is considered sensitive; and, in the land application of high P WTR. Site-specific P based application rates are discussed below. Water treatment residuals are discussed at the end of this section.

On sensitive sites with an elevated soil concentration of plant-available P, it is suggested that a P-based application rate be considered. Many jurisdictions in North America and Europe have instituted or are moving towards P-based application rates of manure and organic residuals on sensitive sites with elevated soil P.

Sensitive sites are those which are located in an area of the province with sensitive fresh water systems such as the Shuswap-Okanagan region. Other factors which deem a site 'sensitive' include whether the site slopes towards a water course where surface runoff or erosion might occur, or whether the site is tile-drained such that drainage water containing P could move into ditches and into surface water. Sites that have a plant-available P concentration of greater than 80 mg kg^{-1} of soil (dry basis; Bray P1 analysis) should be considered to have elevated soil P; on such sites the management goal should be to apply only as much P as the crop can utilize. An application rate based on supplying the P requirement will normally reduce the typical application of the residual by at least 50%. Sites receiving a P-based application of residuals may require supplemental N fertilization.

When calculating an application rate based on P, it is necessary to understand the concentration of plant-available P in the soil. Normally, the Kelowna extract or Bray P1 analytical method should be used. If the laboratory test indicates that the site's plant-available P is high or very high, or if the soil concentration is greater than 80 mg kg^{-1} of soil, the soil is oversupplied. The anticipated crop uptake of P is also required. Most agricultural crops require in the range of 20 to 60 kg of P per hectare (ha) in a given growing season. The concentration of P in the residual to be applied is required. The application rate should be based on the amount of plant-available P in the managed organic matter. Section 10.3.2.2 provides information on calculating the amount of plant-available P in the residual.

Most drinking WTR contain a relatively low concentration of conventional fertilizer nutrients but also have a very low C:N and a low pH, thus they should be land applied based on nutrient content and availability of nutrients. They contain a relatively low concentration of N and usually a relatively high concentration of total P of which all but a very small fraction is tightly bound to the alum and ferric chloride added during water treatment. Alum and ferric chloride WTRs typically have a low pH, in the range of pH 5 to 6 while high Ca WTRs have a higher pH, in the range of pH 7 to 9. Alum and ferric chloride WTRs can have an acidifying effect on the soil pH of an application site; sites with a neutral or higher pH should be chosen for application of these residuals. If the WTR application rate is excessive, a large portion of soil P can be bound and made unavailable by excess alum and ferric chloride after land application, inducing a P deficiency in the soil.

Water treatment residuals have been used experimentally to bind excess P in high P soils where there is concern about runoff or erosion of P-containing soil into surface water. It has been demonstrated that the application of WTR binds excess soil P and reduces the amount of P moving into water sources although as yet there is insufficient information available to recommend an application rate. There are unanswered questions about long term soil fertility and other issues. Similarly, biosolids and WTR have been blended experimentally to bind the P in the biosolids and reduce addition of available P through biosolids application, and mitigate odour generation in biosolids treatment.

High Ca WTR may be considered alternative liming materials if the pH and acid neutralizing value are sufficiently high to raise soil pH without oversupplying other constituents. Section 10.4.3 provides additional information on land application of alternative liming materials.

10.4.2 Application Rates of High C:N Residuals

The following high C:N residuals are regulated by the OMRR and the SACoP, provided that they meet the trace element limits found in Schedule 4 of the OMRR or Table 1 of the SACoP and other applicable limits:

- wood waste (industrial residue of wood that has not been treated with glue, paint, a preservative or another substance harmful to humans, animals or plants);
- primary and combined pulp and paper residuals (residuals from primary and secondary treatment of liquid waste produced after 1995 from a pulp or paper mill and domestic sewage if mixed with those residual solids); and,
- biosolids and other compost with a high C:N (higher than 20:1).

High C:N residuals are considered soil conditioners rather than sources of nutrients, and as such are used to increase soil organic matter content and to improve soil physical characteristics such as water holding capacity, structure and nutrient holding capacity. Application rates of soil conditioners are typically higher than rates of high nutrient residuals. However, application rates must be set with an agronomic objective such as a defined improvement in soil properties, and with knowledge of the amounts of C and nutrients that are being applied to the soil in the residual.

Wood wastes typically have a high C:N (> 100:1) and will be land applied as a soil conditioner. Because they are typically very low in all nutrients, the receiving site may require fertilization to avoid nutrient deficiencies in soil and on-site vegetation.

Primary pulp and paper residuals have a high C:N (111-478:1), being composed primarily of waste wood fibre. The application rate is based upon use as a soil conditioner. Combined pulp and paper residuals typically have a C:N of 28-32:1. The C:N of combined residuals can vary and must be assessed before application to determine the appropriate application rate based on nutrient content or as a source of soil organic matter.

Pulp and paper residuals can also contain a substantial amount of sodium and have an elevated conductivity. The application rate should consider the sodium concentration of the residuals and receiving soil, and conductivity of each. On sites with elevated conductivity or sodium, application rates should not exacerbate site conditions.

Pulp and paper mill residuals typically have low concentrations of trace elements.

Paper recycling residuals are typically a high C:N residual resulting from primary treatment at recycling paper mills.

Compost can have varying C:N, depending on the feedstocks used in their production. Typically they are within the ‘high C:N’ range (greater than 30:1) and should be land applied based on their soil conditioning properties and on their nutrient content. Compost should be assessed before application to land; if the C:N is less than 20:1, the compost should be land applied as a nutrient source. If the C:N is greater than 30:1, the compost can be land applied as a soil conditioner to increase soil organic matter. Compost can also contain a high concentration of salts which can impact growth of vegetation on site; the application rate may need to be reduced if salts are a concern. Compost contains trace elements; these must be assessed in the compost and in receiving soil before application and may limit application of the compost.

10.4.2.1 Managing High C:N Residuals

There are several factors to consider in the use of high C:N residuals. These include:

- C:N;
- concentration of available N in the residual;
- available K and P concentration in the soil;
- conductivity of the residual and the soil;
- vegetation establishment;
- proportion of rapidly degradable and slowly degradable C;
- contribution to the organic matter content of the soil;
- trace elements and other contaminants; and,
- application depth and incorporation.

C:N

Residuals with a C:N above 20:1 are generally considered soil conditioners rather than nutrient sources. However, residuals with an intermediate C:N of 20-50:1 contain a significant amount of nutrients relative to their C content and should be land applied based on meeting a soil conditioning goal with consideration to the amount of available nutrients in the residual, particularly N. Care should be taken to avoid an excess application of nutrients, particularly N. For residuals with a high C:N (greater than 50:1), application rates can be based solely on meeting a soil conditioning objective.

Concentration of available N in residual

Residuals vary in concentration of organic and inorganic (available) N. The amount of available N in the residual is the sum of NH_4^+ plus NH_3 and NO_3^-. If a residual has a low N concentration, it will provide a minor amount of N to growing vegetation. There will be a low potential for excess soil N after vegetation growth ceases in fall.

Available P and K in the soil

If the receiving soil contains elevated concentrations of P and K, care should be taken to ensure that the amounts of these nutrients applied in a soil amendment do not exacerbate the concentration.

Conductivity of the residual and the soil

Compost and high C:N residuals can have a high conductivity due to the salt content of the feedstock. At high application rates ensure that soil conductivity will not increase to a level that adversely impacts vegetation growth.

Vegetation establishment

Sites that receive an application of a high C:N material alone will be N deficient for a period of time following application as the soil microorganisms immobilize most available N in the process of digesting the available C. If vegetation is to be established on the site immediately following application, establishment may be delayed and yields may be reduced unless a source of N is provided.

Proportion of rapidly degradable and slowly degradable C

Carbon compounds vary in the rate at which they degrade in the soil. Highly lignified C compounds such as are found in woody materials degrade very slowly in the soil while non-lignified C (e.g. straw, green wastes) degrade rapidly. The decomposition rate of high lignified materials will increase if particle size is reduced, increasing surface area for utilization by microorganisms. Composts contain almost no rapidly decomposable C; it is consumed during the composting process. Decomposition of C and release of N from composted materials will be slow as compared to non-composted raw materials.

Contribution to the organic matter content of the soil

Materials with a large proportion of slowly degradable C will contribute a larger proportion to the soil organic matter than materials with mostly rapidly degradable C. One year after application, approximately 30% of the C from most highly degradable residuals will remain in the soil to contribute to the pool of soil organic matter; the remainder is lost as CO_2 during decomposition. By comparison, 50 to 70% of C from woody, lignified residuals may remain after one year in the soil. When the goal is to increase the organic matter content of the soil, the application rate should be based on the target organic matter remaining in the soil after one year of decomposition.

Trace elements and other contaminants

Application of trace elements in the residual must be monitored as per the requirements in the OMRR and the SACoP. At very high application rates of a soil conditioner, trace element content may be a limiting factor.

Application depth and incorporation

The maximum acceptable depth of soil conditioning material is dependent upon several factors. These factors include: the ease with which the material can be tilled in to the soil, the degree of alteration of the physical soil characteristics and the degree to which the application alters the soil temperature (surface applications). The acceptable depth will be dependent also on the texture, particle size and moisture content of the residual applied, and the proportion of rapidly to slowly degradable C. A general rule for soil conditioning materials to be incorporated is to limit the depth of application to that which can be turned under by available tillage equipment. A depth of 5-15 cm of material is acceptable. For surface applications, the applied material should not insulate the soil surface such that soil warming is inhibited, nor should it reduce aeration of the soil which may lead to soil sealing, reduced oxygen exchange and adverse impacts on soil biota and vegetation.

If the amendment volume cannot be applied at one time, it should be applied in several applications or ‘lifts’ with sufficient time between applications to allow decomposition of a portion of the organic matter. This time period will depend primarily on the material’s particle size and proportion of rapidly degradable C, and on the availability of sufficient nutrients in the soil to encourage decomposition by microbes. It will vary from several months to years. Residuals with a large particle size and a small proportion of rapidly degradable C applied to a site with low fertility will decompose slowly. Reapplication of residuals may only be possible after one year or more. On a fertile site, material with a small particle size and a large proportion of rapidly degradable C, such as chopped straw, will decompose very rapidly, enabling reapplication within a few months.

10.4.2.2 Application Rate Determination for High C:N Residuals

Factors discussed previously are used to determine the upper limit for application rate of a soil amendment. For example, the upper limit may be determined by the nutrient content of the soil or of the proposed amendment, or the concentration of a single trace element. Several other factors require consideration. The volume of soil amendment applied should not significantly alter soil temperature. This is of particular concern with surface applied amendments. The application rate of soil amendment must not adversely alter the seedbed such that seed germination is impaired.

In consideration of these factors, the maximum application rate should be based on the optimal soil organic matter content. One approach for determining the optimal organic matter content of a soil is to assess the organic matter content of a reference native soil or a productive agricultural soil on a similar site nearby. The final organic matter content of the amended soil should not exceed that of the reference soil by more than 50%. Larger increases in soil organic matter content may lead to crop growth reduction and soil nutrient imbalances. To substantially increase the organic matter concentration in a soil, applications should be completed in several lifts over more than one growing season, or through the combined application of low and high C:N residuals.

The preferred method for determining an application rate of a high C:N residual is to increase the soil organic matter to a predetermined optimal concentration.

In the following example, an application rate for sawdust (C:N = 442:1) as a soil conditioner is calculated. With this high C:N, the maximum application rate is not based on the nutrient content of the residual but rather on increasing the soil organic matter content to 4% from the current 2%. In determining the application rate, the residual volume required to increase the organic matter content is based on a 50% loss of C in the year of application. The final application rate of material is high and will require application in several lifts. Due to microbial immobilization of N, the site will be severely deficient in N for several years following amendment unless supplementary N is added. The calculation steps are shown on the following page.

Description	Calculation	Result
1. Determine the organic matter contribution from the residual one year after application, assuming that 50% will be lost during the first year.	Predicted organic matter contribution from sawdust: 900 kg tonne $(t)^{-1}$ x 50% loss in year 1 = 450 kg t^{-1}	450 kg per t organic matter from sawdust
2. Determine the existing soil organic matter content in the top 15 cm of the soil.	Soil organic matter content = 2% (from laboratory data) or 0.02 kg per kg soil	
3. Estimate bulk density based on soil texture.	Soil bulk density = 1,500 kg m^{-3} (estimated based on soil texture)	
4. Use soil volume in plough layer or top 15 cm (0.15 m) of soil.	Soil volume = 1,500 m^3 ha^{-1} (10,000 m^2 ha^{-1} x 0.15 m)	
5. Convert soil OM from percent to t ha^{-1}.	0.02 kg organic matter per 1 kg soil x 1,500 kg soil m^{-3} x 1,500 m^{-3} soil ha^{-1} = 45,000 kg ha^{-1} or 45 t ha^{-1} organic matter in the soil	45 t ha^{-1} – existing soil organic matter content
6. Calculate the organic matter required to increase soil organic matter to desired concentration (dry basis).	Desired organic matter content = 4% or 0.04 kg per kg of soil Double soil organic matter content (to increase concentration from 2 to 4%): add 45 t ha^{-1} organic matter	45 t ha^{-1} – organic matter required to achieve desired final soil organic matter content
7. Calculate the application rate of sawdust required on 'as-is' basis	45 t of organic matter required, each t of sawdust contributes 450 kg of organic matter to soil. Sawdust DM = 40%	100 dt of sawdust per ha (dry basis) **250 t of sawdust required per ha on as-is basis**

10.4.2.3 Combining Low and High C:N Residuals

Combining a low and high C:N residual can mitigate some of the challenges encountered with using high C:N residuals. High C residuals provide organic matter to the soil but insufficient nutrients to support a crop on site. High nutrient residuals are applied to land in relatively low amounts to avoid supplying the soil with excess nutrients. Combining the two types of residuals provides the soil with a large application of organic matter without concurrent nutrient deficiencies. For example, biosolids (C:N approximately 10:1) could be combined with primary pulp and paper residuals (C:N >70:1). The application rate of the combined residuals is determined based on achieving a target organic matter and C:N in the amended soil. To determine the application rate, the qualified professional employs a series of simultaneous equations using the C, N, organic matter, bulk density and other characteristics of the high nutrient and high C:N residuals.

10.4.3 Application Rates of Liming Materials

The following liming materials are regulated by the OMRR and the SACoP (provided that they meet the trace element limits found in Schedule 4 of the OMRR or Table 1 of the SACoP and other applicable limits):

- waste lime and waste lime mud;
- fly ash derived from the burning of wood, other than wood that has been immersed in marine waters;
- lime-stabilized biosolids; and,
- high Ca WTR (if pH and acid neutralizing value are sufficient to be an effective liming agent).

All of these residuals typically have a very high pH and are therefore effective alternative liming materials. They can be used to replace lime on sites that require liming to raise the soil pH. Refer to Chapter 5 for information on the characteristics of these residuals.

Application rates of liming materials are normally calculated with the objective of a pH adjustment. Sites should have a demonstrated requirement for liming and typically have a pH below 6.5 (for most agricultural soils), unless it can be demonstrated that a site with a neutral or basic pH requires liming to meet the pH requirement of the vegetation.

The application rate of the residual is based on the lime requirement of the site and the acid neutralizing equivalency (or value) of the residual. The acid neutralizing value of the residual, or calcium carbonate equivalent (CCE), is a measure of how effectively the residual can neutralize acidity in the soil relative to pure $CaCO_3$. Calcium carbonate is the standard liming material and has a reference CCE of 100%. Residuals (such as lime stabilized biosolids, fly ash) that can be used as a lime substitute typically have acid neutralizing values ranging from 55 to 100%.

The following example demonstrates a fly ash application rate calculation to raise soil pH from 5.0 to 6.5:

1. Determine the lime requirement for the receiving site (in t ha^{-1} of pure $CaCO_3$). Request the determination of lime requirements for the receiving site when laboratory analyzes a soil sample for pH (normally completed by agricultural labs, based on adjusting pH up to 6.5). The qualified professional should confirm with the laboratory the lime requirement soil pH endpoint.
2. Determine the acid neutralizing value (or %CCE) and moisture content of the residual. Request %CCE and moisture content on a sample of residual that is to be land applied.
3. Calculate the application rate by adjusting the lime requirement for the %CCE and the moisture content of the residual, in t ha^{-1}.
4. For liming residuals that contain nutrients (fly ash, lime-stabilized biosolids) ensure that the proposed application rate does not provide excess nutrients.

5. Ensure that post-application soil trace element concentration will not exceed applicable regulatory limits.

Description	Calculation
1. Determine lime requirement of receiving site	Background pH of proposed receiving site: 5.0 desired final pH of receiving site: 6.5 lime requirement (to raise pH to 6.5): 3 t ha^{-1} of pure $CaCO_3$ (from laboratory report)
2. Acid neutralizing value or % CCE of fly ash	%CCE = 55% (from laboratory data) Moisture content = 40% (from laboratory data)
3. Calculate amount of ash required to adjust pH (t ha^{-1}, dry basis)	3 t ha^{-1} of $CaCO_3$/55% CCE = 5.5 dts per ha of fly ash
4. Convert to 'as-is' t ha^{-1}	5.5 dt ha^{-1}/60% dry matter in ash = 9.2 'as-is' t of fly ash per ha.
5. At proposed application rate, assess predicted soil concentrations of nutrients and trace elements to ensure none will be in excess following application; if so, reduce application rate.	See Section 10.5 for information on predicting post-application trace element soil concentration.

Lime-based residuals (e.g. waste lime and lime mud) typically have an acid neutralizing value similar to pure $CaCO_3$. They may also contain significant concentrations of nutrients, in particular P. Care should be taken when determining an application rate of these residuals that the soil does not become overloaded with P or other nutrients.

Fly ash typically has an acid neutralizing value (or %CCE) of 55 to 65%, but can be higher depending on the degree of combustion. Fly ash also contains a substantial amount of nutrients except N, and typically has high concentrations of K, Mg, S, sodium, B and zinc. It is an excellent fertilizer provided that these nutrients are limiting in the soil. As there is little N in the fly ash, supplemental N is typically required.

Lime-stabilized biosolids are biosolids to which lime has been added to raise the pH to a minimum of 12 as a pathogen destruction process. Lime stabilization is one of the pathogen destruction processes in OMRR to produce Class A biosolids. The resulting residual is typically a high nutrient material with a pH of 12. This residual should be land applied as a high nutrient residual, based on meeting the crop's agronomic N or P requirement (see Section 10.4.1 above). However, the application will raise the pH of the soil so the selected site should be amenable to a pH increase. The best use for this type of residual is on a site that requires liming and is nutrient deficient. Determine the application rate on both a nutrient and a lime basis.

High Ca WTR are generated when lime is added as a softener to drinking water. The residual consists mainly of $CaCO_3$, and is a useful liming material. The residual should be assessed for pH and acid neutralizing value and for concentrations of other nutrients. If the pH and acid neutralizing value are only moderately high, the application rate required to raise the pH to the desired level may be such that the soil is oversupplied with other nutrients such as P.

10.5 Managing Trace Elements

10.5.1 Residual Trace Element Limits

Both the OMRR and the SACoP require that the same 11 trace elements (referred to as substances) be monitored in the residuals, and in the receiving soil. These trace elements are: arsenic, cadmium, chromium, copper, cobalt, lead, mercury, molybdenum, nickel, selenium and zinc. Concentration limits for these trace elements in residuals, provided in Schedule 4 of the OMRR and Table 1 of the SACoP, are reproduced here in Table 8 and Table 9. If the concentration of any of the 11 trace elements in the residual exceeds the allowable limits as specified in the OMRR or the SACoP, the residual cannot be land applied except through the MoE permit and approval process. Chapters 8 and 9 provide information on residual and soil sampling.

10.5.2 Soil Background Trace Element Assessment

The background soil concentration of the same 11 trace elements must be determined by soil sampling at each planned residual application site prior to application. These data, coupled with the trace element data for the residual, are used to predict the post-application soil trace element concentrations. The sections below provide information on site suitability based upon soil trace element concentrations.

For residuals regulated under the OMRR, Schedules 9 and 10 of the OMRR outline maximum allowable soil trace element concentrations for various site uses following the application of managed organic matter. Schedule 9 contains generic soil standards for cobalt, molybdenum, nickel and selenium on agricultural, urban park, residential, commercial and industrial land. Schedule 10 contains matrix soil standards for arsenic, cadmium, chromium, copper, lead, mercury and zinc on the same five types of application site. Schedule 10 incorporates several site-specific factors related to human health and environmental protection that represent expected exposure pathways. Therefore, in determining the soil standard for trace elements, the final land use and the most limiting exposure pathway applicable to the site are considered. For OMRR-regulated residuals, soil trace element data is assessed to ensure that none of the 11 regulated trace elements exceeds allowable soil maximum concentrations provided in Schedules 9 and 10 of the OMRR. In cases where a trace element in the soil of the proposed application area exceeds the applicable soil standard, the qualified professional may elect to determine site-specific standards based on Protocol 2 of the CSR, as allowed by the OMRR. However, at the time of writing, this provision has never been employed. Sites where one or more soil trace element concentrations exceed the OMRR soil standards are typically managed under an approval or permit from the MoE.

Application sites typically have soil trace element concentrations below the OMRR limits. It is recommended that application of residuals not occur on sites where any one of the trace element concentrations is within 75% of the appropriate soil concentration for the land use. It is also recommended that application of a residual not increase the soil concentration of any of the 11 trace elements beyond 75% of the appropriate soil standard. This margin is recommended to allow for variability in on-site application of residual, in sampling and in lab analysis.

For residuals regulated under the SACoP, soil amendments must not be applied to an application site in such a manner or amount as to create or exacerbate a contaminated site. Under the SACoP, a site which has a soil concentration of one or more trace elements that exceed the CSR standard can be used for residual application provided that the application of that residual does not increase the soil concentration of those trace elements.

10.5.3 Residual Sampling Requirements

All residuals regulated under the OMRR are required to be routinely sampled and analyzed for the required trace elements, nutrients and other quality parameters; Chapter 8 contains sampling information.

Of the residuals regulated under the SACoP, only fly ash and pulp and paper residuals must be routinely sample for the required trace elements, nutrients and quality parameters. Sampling of these residuals must be completed by a qualified professional. The other residuals (WTR, wood residues, lime-based residuals) do not require routine sampling and analysis. However, all residuals that are to be land applied under a LAP require sampling and analysis for the required parameters prior to application; analytical data must be included in the LAP. Chapter 9 provides more information on sampling and analytical requirements related to the SACoP.

10.5.4 Estimated Post-application Soil Trace Element Concentrations

For application of all residuals regulated under the OMRR and the SACoP where a LAP is required (all applications of Class B biosolids and compost, and all applications of Class A biosolids and SACoP soil amendments in excess of 5 m^3 of residual), prior to land application, the post-application soil concentration of all 11 identified trace elements must be estimated to ensure that final trace element concentrations do not exceed allowable soil limits. To predict post-application soil concentrations the following data are required: the application rate of residual, soil bulk density and both the soil and residual pre-application trace element data. Refer to Chapter 12 for soil sampling and analysis procedures.

The generator often has current trace element data for the residual. If this information is not available, is dated, or there is concern over the consistency of the product, samples of the material to be land applied should be collected and analyzed (Chapter 8 and 9 provide protocols for sampling and analysis). Recall that for fly ash and pulp and paper residuals regulated under the SACoP a qualified professional is required to collect the samples. Residuals can be complex materials to analyze, and sample preparation as well as analytical procedures will significantly impact data quality. It is prudent to discuss sample preparation and analysis methodology with the laboratory, and to ensure that the lab has obtained the appropriate accreditation to perform the analyses. It is recommended that the qualified professional validate residuals quality data provided by the generator through independent sampling.

The steps in calculating trace element additions from the residual are outlined below with copper is used as an example. The sample LAPs included in Appendix 2 contain complete sets of trace element data.

Soil bulk density (dw per volume of soil, usually expressed as kg m^{-3}) is required for calculating final soil trace element concentrations. The bulk density of BC soils ranges from 1,000 to 2,000 kg m^{-3}; coarse textured (sandy) soils normally have a bulk density in the lower half of the range while fine-textured soils (i.e. more clay) are in the middle of the range. Compacted, fine-textured soils can have a bulk density as high as 2,000 kg m^{-3}. Bulk density can also be obtained from the receiving soil conducted in the laboratory. For an accurate bulk density determination, the sample must be collected using the proper sampling technique. Refer to a soil sampling and analysis reference text for more information.

The bulk density should be obtained from the depth of soil into which the residual is to be incorporated. Depth of incorporation will affect final trace element concentrations in the amended soil.

Data required for trace element addition rate determination for application of biosolids to agricultural land:

Biosolids copper content: 650 ppm or mg kg^{-1}

Biosolids application rate: 10 dry t ha^{-1} or 10,000 kg ha^{-1}

Bulk density of furrow slice (top 0-15 cm of soil): 1,300 kg m^{-3} of soil

Background soil copper concentration: 32 mg kg^{-1}

Step 1. Convert biosolids trace element data from ppm (mg kg^{-1}) to kg ha^{-1} to be applied.

650 mg kg^{-1} copper x 10,000 kg ha^{-1} (appl. rate) = 6.5 kg ha^{-1} from biosolids

Step 2. Convert background soil trace element data from soil ppm to kg ha^{-1}.

Calculate volume and weight of top 15 cm of soil per ha (1 ha furrow slice)

Volume = 0.15 m x 10,000 m^2 = 1,500 m^3 ha^{-1} furrow slice

Weight = 1500 m^3 ha^{-1} x 1,300 kg m^{-3} = 1.95 x 10^6 kg ha^{-1}

Convert soil copper from ppm to kg ha^{-1}

32 mg kg^{-1}x (1.95 x 10^6 kg ha^{-1}) = 62.4 x 10^6 mg ha^{-1} or 62.4 kg ha^{-1} background soil copper concentration (shortcut method: multiply 32 x 1.95)

Step 3. Add biosolids copper to the soil background copper concentration.

6.5 + 62.4 = 68.9 kg ha^{-1} total soil copper post-application

Step 4. Convert kg ha^{-1} soil copper back to concentration (ppm) basis.

68.9 kg ha^{-1} / 1.95 = 36 ppm or mg kg^{-1}

The post-application soil concentration of copper is estimated to be 36 ppm. This value is then compared with the OMRR soil matrix table for copper (Schedule 10) to ensure that the final concentration does not exceed the allowable maximum, which in this application, for agricultural soils is 150 ppm (for residuals regulated under the SACoP, refer to the appropriate CSR Schedule as discussed above).

This calculation is repeated for all 11 trace elements. If any projected trace element concentration exceed allowable limits, the application rate must be reduced or application at the site should not be conducted. Some sites, as a result of previous management or natural trace element concentration of the soil, may have high background concentrations of certain trace elements. Pre-application soil testing and estimation of post-application soil trace element concentrations will identify these sites.

The sample calculation assumes that there is no significant change in the bulk density of the soil following application. For some applications the bulk density will change; however, with agronomic application rates the change is usually not significant.

The calculation of estimated soil trace element concentrations uses a series of assumptions about the depth of incorporation into the soil, soil bulk density and cumulative trace element additions. The qualified professional should recognize these assumptions and use accurate values in calculating these estimates. Should any of the trace element estimates approach the concentrations as defined in the regulations, it is suggested that post-application sampling be conducted. It is recommended that estimated post-application trace element concentrations remain below 75% of the appropriate regulatory limit. This is reviewed in Section 10.5.2.

10.6 Site Management

Site management of residuals includes: restrictions on unincorporated applications; climate and season of application; buffers from roads, dwellings and water sources; signage and access restrictions; land use criteria; and on-site storage of residuals.

10.6.1 Unincorporated (Surface) Applications of Residuals

Residuals are either surface applied or incorporated, depending on the site and application objective. The OMRR restricts the surface application of biosolids and biosolids-compost containing fecal coliform where limited or no treatment for vector attraction reduction has been completed at the WWTP. The OMRR requires that Class B biosolids and compost meet pathogen reduction processes in Schedule 1 and vector attraction reduction processes in Schedule 2 to be of a quality acceptable for surface application. If the biosolids or compost does not meet these criteria, they are to be incorporated by tillage or the biosolids injected at the application site unless it can be demonstrated by the qualified professional in the LAP that a surface application will be protective of human health.

The SACoP does not restrict surface applications but requires that a LAP for fecal coliform-containing residuals provide information regarding on-site management practices specific to pathogen management. This LAP requires a discussion of management methods or processes to reduce or prevent the transmission of pathogens by vectors.

10.6.2 Climate and Season of Application

Timing of application is critical to ensuring that the residual does not cause pollution from leachate or runoff into surface water or groundwater. BC can be divided into three general climatic types that mandate different seasonal application strategies. This section discusses these climatic differences and how they affect residuals application; Chapters 13, 14 and 15 contain detailed information on specific seasonal requirements.

10.6.2.1 Lower Fraser Valley and Southern Vancouver Island

In South Coastal BC, the preferred seasons for residual applications are spring and summer (April through August). Residuals can be applied to bare land that will be seeded or to existing vegetation that is actively growing and can benefit from the nutrients or soil conditioning properties provided by the residual.

Application of residuals between November and March is typically not recommended. Annual rainfall is high and can be intense during this period. During this time, plant growth typically is slow and only small amounts of nutrients are required by plants. The potential for leaching of residual soil NO_3^- into groundwater is high during this time. As well there is danger of flooding in low lying areas which can lead to surface runoff. Heavy precipitation events can result in surface runoff on sloping areas. In addition, soils are typically saturated, limiting access to equipment associated with residuals application.

Special consideration is required for fall applications on agricultural sites (September and October). If high nutrient residuals are applied to bare land without vegetation, there is greater potential for NO_3^- leaching once fall rains begin. The exception is residuals applications to forested sites. On sites that have actively growing vegetation, the vegetation will utilize added nutrients, but as plant growth slows, residual NO_3^- leaching and surface runoff can occur. Fall and winter (September through March) applications of residuals in these areas of BC should be limited to low application rates on well-drained sites with well-established vegetation that can immediately use the nutrients available from the application.

10.6.2.2 Northern, Central and Southern Interior of BC

In the Northern, Central and Southern Interior of BC, the preferred seasons for application of residuals are spring and early summer. The low annual precipitation and frozen soils during the winter period result in less restrictive fall and winter applications. The predominant consideration in the drier areas of the province is surface runoff during spring snowmelt. In areas where it is possible to access a frozen or snow covered site to spread a residual, it is critical that no runoff occurs during snowmelt. Applications on frozen or snow-covered ground should only be contemplated on flat sites. Buffers from watercourses should be increased. Leaching of NO_3^- is less of a concern as the soils freeze and residual soil NO_3^- from the previous fall will still be available for plant growth the following spring.

10.6.2.3 Interior Wet Belt (Salmon Arm, Areas of West Kootenays)

The interior wet belt experiences higher annual precipitation, particularly as snowfall than in other areas of the interior. Consequently, the qualified professional should give consideration to applying residuals in fall and winter to ensure that surface runoff does not occur during spring snowmelt. Fall application is not recommended due to occasionally heavy fall rain events.

10.6.3 Buffers from Roads, Dwellings and Water Sources

Buffer zones are required when land applying Class B biosolids, Class B compost and pulp and paper residuals containing domestic sewage. The minimum required buffer zones are listed in Table 11 below and are found in Schedule 8 of the OMRR and in Part 3 Section 7(2) of the SACoP.

These zones provide a buffer between the application area and potentially sensitive environments. In addition, buffers from property lines improve the aesthetics of residuals applications, and limit public exposure to pathogen-containing residuals and odours following application.

Although buffers are not required for the application of Class A biosolids, Class A compost, BGM or residuals regulated under the SACoP aside from pulp and paper residuals containing domestic sewage, the application must not result in adverse environmental impacts as per the EMA. It is recommended that the same buffer distances be considered as warranted by site conditions including the proximity to sensitive environments. Although OMRR Class A residuals and SACoP residuals that do not contain domestic sewage pose minimal risk from a human health perspective, the potential for nutrient impacts to surface water or groundwater are the same. These residuals should be applied according to BMPs for chemical fertilizers.

Table 11: Buffers required for Class B biosolids, Class B compost and pulp and paper residuals containing domestic sewage

Feature	**Distance (m)**
Potable water sources – wells	30
Irrigation wells	30
Lakes, rivers, streams	30
On-site dwellings	30
Off-property occupied dwellings	30
Boundaries of property zoned residential or recreational	30
Major arterial roads and highways	20
Minor public roads	10

10.6.3.1 Buffers to Surface Water

The minimum buffer distance from major surface water sources is 30 m. It is advised that buffers be used for other types of water bodies such as ephemeral (seasonal) streams and ditches based on the potential for adverse impacts. Buffers may need to be increased:

- on sites with slopes;

- on sites with bare soil which provides little filtering of runoff as compared to sites with good vegetative cover;
- where residuals are surface applied and not incorporated; and
- on sites with subsurface lateral flow along compacted or cemented horizons.

Ultimately, the appropriate buffer will be protective of water quality by ensuring that none of the residual or runoff enters surface water bodies.

10.6.3.2 Buffers to Groundwater

Groundwater buffers are designed to protect groundwater as well as domestic and irrigation water wells. When residuals are applied at agronomic rates at the appropriate time of year, and when buffers are observed, the potential for groundwater contamination is minimized. However, as with surface water, buffers may need to be increased in special circumstances.

10.6.3.3 Property and Road Buffers

Under the OMRR, buffers from farm dwellings, neighbouring properties and roads and required for the application of Class B biosolids and Class B compost. Under the SACoP, the application of pulp and paper residuals containing domestic sewage requires property buffers. A 30 m buffer is required from property boundaries and on-site dwellings. There must be a 20 m buffer zone from major roads and highways, and 10 m from minor public roads. No buffer is required when residuals are applied next to logging roads; however, when odour or aesthetics may be a concern, a buffer is recommended. Again, these buffer requirements should be considered to be minimum standards; on sites where application of residuals may impact neighbouring properties, buffers may be increased. Although neither the OMRR nor the SACoP specify buffers for other regulated residuals, public perception and risk of odour should be given consideration in the decision to recommend buffers for property and roads in the LAP.

10.6.4 Signage and Access Restriction

Under the OMRR, Class B biosolids and Class B compost application sites require signage that identifies the site as having received residuals (Photograph 19 and Photograph 20).

Where applicable under the OMRR, signs must state that residuals derived from a WWTP have been applied to the site and that animal grazing on the site must be restricted for 60 days and outline the 18 and 38-month food for human consumption restrictions. The signs must also provide a contact person and telephone number for further information. Schedule 8 of OMRR outlines this information.

Under the SACoP, signage of application sites is only required following application of pulp and paper residuals containing domestic sewage. Signage is not required at sites that have received any other residual regulated under the SACoP or if the site has received pulp and paper residuals without domestic sewage. When required under the SACoP, the sign must be a minimum of 1 m^2 in size. Signage must be posted on each road or path to the land application site, and must be in place for 38 months following application.

When required under the SACoP, signage must contain information on the fecal coliform density of the residual, contact information, a description of the application site, and details about required livestock and human food harvest restrictions. Section 7(4) of the SACoP outlines this information.

Class B biosolids and Class B compost application sites as well as domestic sewage-containing pulp or paper mill residual application sites should have restricted public access or use; sites should be fenced and gated. Where possible on forested sites, it is advised that access to the site be restricted by gates or road closures. More often, signs are posted at key entry points into the application area.

Photograph 19: Typical signage for a biosolids application site

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10.6.5 Criteria for Land Use

The OMRR and the SACoP both contain food harvest restrictions for some residuals. Under the OMRR, Class B biosolids and Class B compost with a fecal coliform concentration $\geq$ 1,000 MPN g^{-1} or that have not been processed to reduce vector attraction can only be applied if food crops for human consumption are not grown for 18 months for crops with harvested parts above the surface and for 38 months for crops with harvested parts below the land surface. The SACoP stipulates the same harvest restrictions following the application of pulp and paper residuals containing domestic sewage with a fecal coliform density $\geq$ 1,000 MPN g^{-1} of total solids (dw). Under the OMRR, domestic livestock grazing on a Class B biosolids-amended site is restricted for 60 days following application. The SACoP does not stipulate livestock feed harvest or grazing restrictions; however, a 60 day grazing restriction is recommended when pulp and paper residuals containing domestic sewage are applied if the fecal coliform concentration is $\geq$ 1,000 MPN g^{-1}. Livestock feed crop suitability is covered in more detail in Chapter 13.

10.6.6 On-Site Storage of Residuals

Under the OMRR, all biosolids and Class B compost land applied under a LAP must adhere to the on-site storage requirements in the regulation.

Under the SACoP, on-site storage requirements are only stipulated for fly ash, pulp and paper mill residuals and WTR. While there are no on-site storage requirements for wood residues, waste lime or lime mud, these materials can be stockpiled on-site prior to use. It is recommended that the on-site storage requirements apply to both OMRR and SACoP residuals.

Under the OMRR and the SACoP, residuals can be stockpiled at the application site for up to two weeks prior to land application with no restrictions as to the location of the pile, providing that the residual is be managed in such a way as to prevent movement of material from the pile. Residuals can be stockpiled on-site for up to nine months prior to being applied to the site provided that the pile is sited at least 30 m from any surface water or well, and that the material is managed to prevent the escape of material from the pile. It is recommended that this minimum buffer be adhered to for short-term stockpiling of residuals. For this type of on-site storage, an impermeable surface is not required provided that there is no escape of material from the pile as runoff or leachate.

For liquid residuals or for storage of any residual for longer than nine months, the residual must be stored in a permanent structure designed to prevent escape of the residual by leaching or runoff of material. For solid or dewatered residuals, a bermed area may be sufficient. For liquid residuals, a leak-proof container or reservoir is required. Storage facilities of this type must be situated at least 15 m from watercourses and 30 m from wells.

In the GVRD, FVRD and any other area of the Province for which the precipitation from October to March inclusive exceeds 600 mm, residuals stored on-site must be covered to prevent rain contacting the residual between October and March inclusive if not stored in a storage facility with an impermeable bottom where leachate can be collected.

On-site storage requirements are provided in Part 2 of the SACoP and Division 1 of the OMRR.

Photograph 20: Signage posted on an earth berm surrounding a covered biosolids stockpile

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10.7 Application Logistics and Techniques

The primary objective of all residuals applications is to apply the residual where desired, at the correct rate, with minimal negative site impacts and as uniformly, efficiently and economically as possible. The wide range of physical properties of different residuals requires an equally broad range of management and handling methods to efficiently apply these materials.

Factors to consider when selecting the most efficient application technology are characteristics of the residual, the terrain and site conditions anticipated at the time of application, the application rate, treatment objectives, off-site impacts, and availability of equipment. Equipment availability and short-term cost savings frequently prevent better technologies from being used. The benefits of a better application method include more uniform application, lower maintenance costs and reduced odour during and after application.

10.7.1 Site Condition Challenges

Site conditions may govern the choice of application technology. Residual applications can be on forest, landfill, mine, range or cultivated farm land. Site conditions can range from undulating forest and range sites, to extremely rocky and rugged mine sites, with slopes ranging from flat to very steep (angle of repose). The varying conditions require a wide variety of different application technologies. Site factors to consider when choosing an application technology are: site access, ability of equipment to traverse the site, traction during wet weather, soil compaction, vegetation type and susceptibility to damage, application rate and uniformity, ease of tillage, and odour sensitivity.

10.7.1.1 Agriculture

Cultivated agricultural sites are generally accessible with conventional farm equipment. Uncultivated sites such as rangeland are often located on rough and varied terrain. Conventional agricultural equipment and tillage methods may have limited application on these types of sites due to steep slopes or roughness of the terrain. Cultivated farmland is amenable to almost any application method, but conventional manure spreading equipment is most commonly used. For specific information on residuals application on agricultural sites, refer to Chapter 13.

10.7.1.2 Silviculture

Silvicultural applications are typically subdivided into plantation and natural forestry. Plantation forestry implies trees grown in rows on flat to gently rolling terrain where equipment can traverse between the rows. Natural forestry implies randomly planted trees and can include much more difficult terrain and steep slopes. For specific information on residuals application on forested sites, refer to Chapter 14.

10.7.1.3 Reclamation

Reclamation applications occur on a variety of different types of sites. Mine site conditions can range from very fine tailings to very coarse waste rock dumps, with slopes from flat to angle of repose. Other reclamation sites such as gravel pits, quarries, landfills, slides and erosion channels also present varied terrain and access challenges. A common element on reclamation sites is exposed and often loose mineral materials containing a high percentage of coarse fragments (large rocks). Steep slopes, limited access, rugged terrain and loose soils present the greatest application challenges. For specific information on application of residuals on reclamation sites, refer to Chapter 15.

10.7.2 Application Technologies

There are many application technologies to assess in matching the material handling characteristics of the residual to the challenges presented by a particular site and set of project objectives. The following discussion presents some options for applications of liquid and solid biosolids. Although most of the residuals regulated by the SACoP have not yet been used on a large scale in land application programs in BC, the techniques for land applying biosolids will apply to residuals with similar characteristics.

10.7.2.1 Liquid and Slurried Residuals

Residuals are often handled as a liquid or slurry which has many advantages, the most important one being eliminating the cost of dewatering. Communities with relatively small volumes or short hauling distances can handle biosolids in liquid form. Liquid application of trucked or re-watered biosolids has also been used with success to overcome challenging site conditions in forestry and reclamation. Handling biosolids in liquid form allows the use of simple, proven technologies, but increases the cost of hauling and the risk of spills. A wide variety of technologies are available for applying liquid biosolids that are discussed below under the headings of spraying, spreading, and injection systems.

Other residuals that may be handled as a liquid or slurry are primary and secondary pulp and paper residuals and WTR; however, these residuals are usually dewatered prior to use.

One of the simplest and most adaptable methods used to apply a liquid residual is to spray it on with a high-pressure nozzle. Depending on the pressure available, residuals can be sprayed 30-60 m, allowing large areas to be covered quickly, even over difficult terrain. Application rates are easily controlled for quantity and uniformity, but are limited to frequent light applications because of leaching and run-off concerns. Other limitations of spray application are visual impact, vegetation fouling and odours.

A variety of spray application equipment is available, ranging from hose and nozzle systems to vehicle mounted spray tankers. For small-scale and research applications in a rugged forestry setting, hand-held fire hoses work effectively. Larger gun and hose-reel systems adapted from agricultural irrigation equipment are commonly used for farm applications. The use of a hose-reel in a forestry setting is less effective due to pressure loses in the hose and excessive wear and damage from moving the hose through the forest. For hose systems, the solids concentration should generally be less than 10%, and should be reduced further as the hose increases in length.

Self-propelled tanker systems come in a variety of shapes and sizes, ranging from on-highway trucks to off-road vehicles (Photograph 21). Use of highway trucks on farmland is limited by poor traction during wet weather and soil compaction concerns. Vacuum/pressure tankers with remote monitors can effectively apply liquid residuals on rugged terrain, but require an extensive road or trail system and support equipment to apply large volumes.

Photograph 21: Self-propelled liquid tanker being used to fertilize a slope

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Another method of applying liquid residuals is by surface spreading using a tanker towed behind a tractor (Photograph 22). Spray bars or splash plates are commonly used to achieve an even distribution of the material. For slurries too thick for spray bars and splash plates, there are rear-discharge and side-cast manure spreaders designed for sloppy materials. Surface spreading reduces over-spray, aerosol formation, and odours that can occur with high pressure spray type applicators. However, this application technology has a limited ability to traverse uneven sites.

Liquid residuals can be applied directly onto the soil surface below the vegetation. One such system is the sleigh foot applicator. The sleigh foot parts the grass sward and deposits the liquid residuals onto the soil surface at the soil/air interface, with minimal disturbance of the soil, roots, or grass. The applied residual is nearly invisible following application and odours are greatly reduced. However, this application method can only be used on cultivated agricultural sites or sites with similar conditions.

Photograph 22: Tractor towed liquid tanker being used to fertilize a row of poplar trees

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Another popular method of applying liquid residuals is sub-surface injection. The primary advantages of this method are reduced odour, vector attraction reduction, run-off prevention, and improved N utilization by reducing NH_3 volatilization. Injection systems are available in a variety of configurations ranging from a tractor-mounted - hose fed system, to a self-propelled vacuum/pressure tanker injection system. Injection shanks can be welded to the back of ripper teeth for very heavy soils. All of these systems involve cutting a slot in the soil and injecting the residual under pressure directly into the soil below the surface. Injection systems vary in the size and strength of the shank, depth of injection, and amount of surface and sub-surface soil disturbance and root damage they cause. Sub-surface injection with conventional equipment is limited to cultivated soils with few rocks.

Where a liquid application is desired using dewatered biosolids or other residuals, a re-watering step is required. For smaller projects either a tarp lined pit or a half buried container can be used as a mixing basin. A tractor-powered manure agitator can be used to re-slurry the residual. For larger projects, some jurisdictions have used a re-watering plant that is capable of mixing and storing large amounts of re-watered slurry. The re-watering of dewatered residuals is not as common as dewatered application technologies have been developed.

10.7.2.2 Dewatered Biosolids

For larger biosolids generators, the high cost of hauling and applying large volumes of liquid residuals justifies dewatering. Dewatered biosolids are semi-solid and can have very different physical properties depending on the type of treatment processes and dewatering methods used to produce them. Primary sludges tend to be granular while biological sludges can be gelatinous and difficult to dewater. Lagoon or land-stored biosolids tend to become more friable with age.

The degree of treatment (primary, secondary or tertiary) and the solids content of the dewatered biosolids have the greatest impact on the handling characteristics. While solids content is not always a good indicator of form or characteristics, typically at solids concentrations less than 25%, biosolids become increasingly plastic, sticky, and may tend to flow. As solid concentration increases above 25%, dewatered biosolids become increasingly granular and friable. Treatment plant characteristics will also affect biosolids handling characteristics. Primary biosolids at 25% solids will have properties distinctly different from secondary biosolids with the same solids content. Polymer can reduce the viscosity of the biosolids due to the capture of additional fines and the residual polymer itself. Basing an application system on the solids content of a specific biosolids without evaluating the application technology could result in unforeseen challenges.

The stickiness, viscosity, and texture of the dewatered biosolids are the key factors to consider when determining the type of application equipment best suited to a particular biosolids. Subtle differences in physical properties can make a significant difference in how well application equipment will work with a particular biosolids.

The method of handling the biosolids following dewatering can also affect the characteristics of the final product. Positive displacement pumps and to a lesser extent long screw conveyors will shear the dewatered biosolids, breaking down any internal structure, and making the biosolids more plastic. Minimizing the amount of shear or vibration imparted to the biosolids during handling can maintain its viscosity and help avoid shifting loads. Dewatering systems can affect odour generation as well as impact physical application.

10.7.2.3 Other Non-liquid Residuals

Biosolids compost is moist but not wet, very friable and easy to handle with conventional manure spreading equipment.

Dry ash can be very dusty and often water must be added before it can be transported and land applied. Often water is added after the ash is precipitated. Ash that has been wetted can be easily spread with manure spreaders, lime trucks or fertilizer spreaders. Excess water can result in the ash caking and becoming difficult to spread evenly. Optimum wetting of ash for dust control appears to be in the range of 25 to 35% moisture. Lumps may form following wetting of ash; these should be screened out prior to loading ash into the application equipment to avoid internal damage to equipment during spreading. Ash lumps are normally quite soft and will break apart if crushed with a loader bucket or similar piece of equipment. Note that fly ash typically has a high pH; the caustic nature of these residuals can cause deterioration of residuals handling equipment.

Wood residues must be ground to a uniform, relatively small particle size to be spread with conventional solid manure spreading equipment. Care must be taken to ensure that there are no rocks in the wood waste as they can damage the internal mechanisms of spreading equipment.

Primary pulp and paper mill residuals are typically dewatered to 12 to 25%. They are fibrous, friable and typically simple to apply using similar technologies to that of dewatered biosolids. Secondary pulp and paper residuals are gelatinous, typically sticky and somewhat massive. Usually, pulp and paper mills will mix primary and secondary residuals together prior to dewatering. The mixture tends to be 18 to 22% solids and typically resembles anaerobically digested dewatered biosolids (Photograph 23).

Photograph 23: Spreading pulp and paper residuals with a dozer

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Lime mud as produced has a moisture content of 40 to 50% which is quite wet for application with solid manure application equipment, but too dry for liquid application equipment. Challenges to uniform application of lime mud exist. Some companies have blended ash with lime mud to dry the lime so that it can more easily be spread with conventional equipment.

Lime residuals from cement and concrete fabrication can be highly variable, contain significant coarse fragment content – typically rocks and/or gravel – and may prove difficult to apply in a uniform method as a solid. Grinding or crushing may be required prior to application. Liquid or semi-solid residuals can be spray applied.

As with liquid application technologies, dewatered residuals application methods and equipment have been adapted from agricultural waste handling equipment.

Manure spreaders are most commonly used to apply non-liquid residuals (Photograph 24). They come in a wide variety of shapes and sizes and differ in their configuration and internal mechanisms. These variations can make a difference in how well a spreader will perform with a given biosolids or other residuals on a particular site. Generally, manure spreaders can be categorized as rear-discharge or side-discharge, and can be pulled with a tractor, or self-propelled on a truck or off-road equipment chassis.

The essential elements of the spreading unit are a box or hopper, a means of conveying the product to the discharge point, and a mechanism to discharge and uniformly distribute the product onto the soil surface. Spreader boxes are usually well designed with steep sides to prevent material hanging up or “bridging”. Farm spreaders typically have one of three types of internal conveyors; chain driven flights, screw conveyors, or a push-out mechanism, while some custom-built spreaders have walking floors. Floor chain, push-out, and walking floor style spreaders typically have a rear lift gate that prevents material from falling out during loading and transport.

All of these conveying systems work reasonably well on level ground with fairly solid residuals. Floor chain and walking floor systems are less effective when spreading on slopes, particularly down slope, and with sloppy material. With higher solids content residuals, material can slough into the beaters unevenly, particularly when applying to uneven ground or on a slope, resulting in an uneven application. A partially open rear gate can alleviate this problem with floor chain and push-out spreaders, but will back up most walking floor systems. Push-out systems without a sliding floor or lid will tend to mound the residual and spill it over the sides, particularly if the material exhibits plastic flow. Screw conveyors provide the most consistent delivery of residual to the discharge point regardless of consistency, site slope or bumps. Screw conveyors typically require about five times the energy used by walking floor and floor chain systems, are prone to “bridge” and are more expensive.

The discharge mechanisms for ejecting and distributing the residual onto the ground typically involve spinning paddles or hammers designed to shred or break up the material into fine particles and distribute them as uniformly as possible in a fan to the side or rear of the spreader. Side-cast spreaders typically have a smaller ejector that spins at a higher speed and spreads the residual over a width of 10 to 20 m, much wider than most rear-discharge units, and are particularly well suited to lower application rates.

The most common distributor for rear-discharge spreaders is one or more horizontal shafts with angled paddles, although spreaders with vertical shaft paddles, and horizontal spinners like those of sand and fertilizer spreaders have been used. Distributors for rear-discharge spreaders typically turn more slowly and spread in a short, narrow (3 to 5 m wide) fan behind the spreader. The resulting spread pattern is much coarser and less uniform than that of a side-cast spreader. Most of these spreaders have a tendency to cast more material to the sides and leave the centre almost bare, resulting in a striping effect. The spreading pattern may be the result of the slower speed and design of the typical horizontal beater. These beaters generally handle debris well, and rear-discharge spreaders typically have a higher throughput and can spread faster than side-cast spreaders.

Photograph 24: Rear-discharge manure spreader

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10.7.3 Calibration of Application Rate in the Field

Application rates of residuals are calculated on a dw basis, and must be converted to the ‘as-produced’ weight using the moisture (or solids) content of the residual. Terms such as “bulk” or wet tonnes (wt) are used to describe the amount of ‘as-produced’ material. Determining application rates on a dry matter basis removes the variability associated with moisture content.

Ensuring an accurate application rate is important, and is usually accomplished with liquid residuals by converting the residual from a weight (i.e. bulk tonnes) to a volume (m^3) basis, and by determining the volume of the applicator vehicle and the area covered by one full tank or load of liquid residual. Verifying application rates with solid residuals may be accomplished through a variety of methods. To use the tarp system to calculate the application rate, the desired residual application rate is converted from bulk tonnes per ha to kg per m^2 (Photograph 25). To calibrate the application equipment, tarps with a standard area are placed in the path of the spreading equipment. After one pass of the spreading equipment, the tarps are weighed, and the actual application rate determined. The operator can then adjust the speed of travel or rate of discharge accordingly on the next pass. Application equipment with built-in scales can use the weight applied per unit area to validate application rates.

Photograph 25: Tarp used to determine a residual application rate

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10.8 Post-Application Monitoring

The OMRR does not require post-application monitoring of residual application sites. If the application rate of residual used on the site exceeds the agronomic rate for the site, a post-application monitoring plan must be included in the LAP. The agronomic rate is defined as the application rate that provides the desired fertilizer nutrient concentrations or soil conditioner levels to establish or sustain the intended vegetation or crops on the land and minimize the potential for adverse environmental impacts.

Under the SACoP, post-application monitoring of residual application sites is not required. If the proposed application rate of residual exceeds the annual soil conditioning or crop nutrient requirements for the site, a post-application monitoring plan must be included in the LAP. The plan must include a description of a process for monitoring the composition of the soil on land after soil amendments have been applied and a statement of the potential changes in the soil and vegetation quality this will cause.

Although not required by OMRR or the SACoP, post-application site monitoring can provide due diligence in assessing if there are any adverse environmental impacts following a residual application. The post-application monitoring protocol depends on which parameters are of concern; residual impact on soil, groundwater, surface water and plant tissues can all be examined. The information in this section identifies: the benefits of post-application monitoring, parameters that can be monitored and the information gained from monitoring. Refer to Chapter 12 for additional information on post-application monitoring.

10.8.1 Post-Application Monitoring Plan Requirements

The requirement for a post-application monitoring plan is essentially the same under both regulations. If the proposed residual application rate exceeds the agronomic nutrient requirement of the vegetation on a site (based on fertilizer nutrient concentrations or soil conditioning levels), a post-application monitoring plan for the site must be included in the LAP. The post-application monitoring plan must assess the risk of changes in soil and vegetation quality resulting from residual application. The parameters that should be included in the monitoring plan should be based on the characteristics of the residual that are most likely to adversely impact the soil and vegetation on the site. These might include: post-growing season soil NO_3^- concentration, NO_3^- concentration of forage, post-application trace element concentrations in soil and vegetation, soil pH and conductivity and soil and vegetation macro and micro nutrients. The monitoring plan is not required to address changes to surface or groundwater quality; it is assumed that the application will not impact water quality. Water monitoring can be conducted as due diligence, or may be indicated under site-specific conditions. Monitoring parameters are discussed in further detail in the sections that follow. As well, Chapters 13, 14 and 15 discuss monitoring requirements specific to different types of applications.

10.8.2 Optional Post-Application Monitoring

Although there is no requirement for post-application site monitoring if agronomic application rates are used, in some cases it is advisable. Sampling of soil, vegetation and water can provide information on the positive and potential negative impacts of the residual on the environment.

10.8.2.1 Soil Nitrate Concentration

For agricultural and some reclamation applications of high nutrient residuals, the post-application concentration of NO_3^- in the soil can be monitored in the fall after vegetation growth has slowed or stopped. Fall soil NO_3^- concentration is an indication of how accurately the crop N requirements were met with the N added in the residual and other sources. High fall soil NO_3^- concentrations indicate excess available N while low fall soil NO_3^- concentrations indicate additions that match the N requirements. In high rainfall areas of the province, NO_3^- will leach out of the crop's rooting zone with fall rains. To measure NO_3^- concentration accurately in these areas, sampling must be completed in the window between when crop growth slows (or crop is harvested) and fall rains begin, usually late September. If this window is missed, deep soil sampling will be required to characterize the residual soil NO_3^-. In low precipitation areas where soils are frozen through the winter, NO_3^- may remain in the soil profile throughout the winter and be available for crop growth the following spring.

Soil NO_3^- concentration is not normally a good indicator of appropriate application rate on forested sites where N dynamics are different.

10.8.2.2 Vegetation Protein and Nitrate Concentration

Residuals can have an impact on the quality of forages. In the year of application of a high N residual such as biosolids or secondary pulp and paper residuals, vegetation will have substantially more protein than in previous or following years, especially if fertilization of the site has been minimal prior to residual application. The resulting forage is of high quality for grazing animals. Under certain circumstances, the forage may contain an elevated concentration of NO_3^- concentration that is a livestock health concern.

In the presence of an abundant soil supply of NO_3^-, forage will accumulate NO_3^- in concentrations much higher than normal, as high as 2,500 – 3,500 ppm NO_3^- compared to a normal forage containing less than 500 ppm NO_3^-. Many environmental factors determine how much NO_3^- forages will accumulate, but soil concentration of NO_3^- is the most important determinant. On well-fertilized sites receiving high nutrient residuals, or when the application rate is above the recommended agronomic rate, high NO_3^- forage may occur. High NO_3^- forage is toxic to livestock; causing death at very high concentrations and reduced productivity at slightly elevated concentrations. If there is any concern that site vegetation has an elevated NO_3^- concentration, it should be sampled and analyzed by a lab familiar with agricultural analyses. Vegetation should be tested before livestock are put onto the site to graze, or when the site is harvested for forage production. Chapter 13 contains a further discussion of forage quality and foliar nutrient concentrations.

10.8.2.3 Other Soil Macro and Micronutrients

The various residuals regulated under the OMRR and the SACoP have highly variable concentrations of macro and micro nutrients. Fly ash contains a significant amount of K, sodium, S and B; WTR contain a significant amount of P but can bind soil P; and pulp mill residuals contain a high concentration of sodium. It is advisable to conduct post-application soil sampling on receiving sites where there is uncertainty regarding nutrient imbalances in soil or vegetation caused by the residual, taking particular note of the parameters of concern in the applied residual. This is particularly recommended when land applying an unfamiliar residual for the first time.

10.8.2.4 Soil pH and Conductivity

The residuals regulated under the SACoP are highly variable in pH and conductivity. It is prudent to conduct post-application monitoring of soil to assess the impacts on site pH and conductivity particularly when land applying an unfamiliar residual for the first time. Where impacts are significant, it is advisable to monitor the site for more than one year.

10.8.2.5 Soil Trace Element Concentration

Monitoring soil for trace elements following a residual application is not normally required as part of a LAP unless the application rate exceeds the crop's agronomic requirement as discussed above. If residual applications are made on an agronomic basis, the amount of any one trace element added to the soil will normally be small relative to the soil's background concentration of that trace element. As well, variability in sampling and analysis usually obscures small changes in total soil trace element concentration. If a non-agronomic application rate has been used and trace element monitoring is recommended, the application site should be re-sampled using the same methodology as the pre-application testing, and the post-application concentrations of all 11 required trace elements must be compared to the pre-application concentrations to ensure that none exceed allowable limits.

10.8.2.6 Groundwater and Surface Water Monitoring

Residuals applied at the agronomic rate should not affect groundwater quality. In the land application of residuals, particularly those containing high concentrations of nutrients, the contaminant of concern in groundwater is normally NO_3^-. If there is a concern about potential contamination, groundwater should be tested for NO_3^--N. However, unless pre-application sampling of groundwater (Photograph 26) has been conducted, it will be difficult to determine if contamination was the result of pre-application activities (such as manure application or domestic sewage) or of residual application.

Soil NO_3^- monitoring in and beneath the crop root zone can determine if NO_3^- leaching is occurring and potentially affecting groundwater quality. If the ground is too rocky for soil sampling, suction lysimeters can be used to monitor water quality. However, the use of suction lysimeters and the analysis of data obtained from them are much more difficult than soil sampling; a discussion of the methodology is beyond the scope of these guidelines.

Photograph 26: Sampling groundwater at a residual land application site

SYLVIS

Buffer zones between residual application areas and watercourses are intended to prevent the contamination of surface water from runoff. Surface water can however, be monitored. Acquiring accurate data when sampling surface water is difficult, as is it often subject to daily and seasonal variation. Identifying and understanding the analytical requirements and the background or upstream water quality parameters is important. It is recommended that a professional knowledgeable about water sampling be consulted if surface water contamination is a concern. Contaminants of concern with surface runoff or erosion from residual application sites are typically N and P.

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11 Developing a Land Application Plan

This chapter outlines the requirements of a LAP for residuals applications under the OMRR and the SACoP, and identifies the relevant areas of these Guidelines that provide more information on specific aspects of the LAP. Sample LAPs for different types of applications are contained in Appendix 2. These LAPs serve as examples only; LAPs will differ with each application site and residual applied.

The primary role of the LAP is to ensure that residuals are land applied for their fertilizing or soil conditioning properties and that the application will not lead to degradation of the environment, or impair any designated future use of the land to which the residuals are applied. This includes protection of soil quality, surface and ground water, air quality and the quality of the vegetation grown as a result of the application. The LAP ensures that trace element additions to the soil are within allowable limits, and appropriate residuals and site management practices are implemented to protect human health. Information required in the LAP can be divided into several sections: preliminary information, determining the appropriate application rate of the residual, calculating the soil concentration of trace elements following application, ensuring that public health requirements are met, outlining any special management concerns and outlining required post-application monitoring. These topics are discussed in this chapter with reference to other chapters of the document where more information can be found.

11.1 Best Management Practices for Minimum Loss, Minimum Risk LAP

Successful land application of residuals is based on a comprehensive understanding of the site, the residual to be applied and the expected response of the environment to this application. The following is a list of BMPs to minimize risk to health and the environment:

- Ensure storage facilities are maintained in a manner that prevent the escape of residuals and observe buffer distances when locating the facility.
- Notify neighbours of the residual application in their area prior to application.
- Select application sites that will benefit from the constituents in the residual and pose minimal risk to the environment.
- Utilize an application rate that matches the site's requirement for nutrients or soil conditioning.
- Balance inputs of other nutrients where possible.
- Ensure that the application does not negatively impact the site's pH or conductivity.
- Ensure that post-application trace element concentrations in the soil do not exceed allowable limits.
- Inject or immediately incorporate the residual where recommended.
- Apply only during the recommended times of the year.
- Observe minimum buffers; increase if site conditions warrant.

- Observe the depth to groundwater requirement.
- Avoid residual application on days with inclement weather.
- Avoid sites with slope or soil concerns that make application inadvisable.
- Avoid sites in close proximity to heavily populated areas or recreational areas.
- Avoid sites in close proximity to environmentally sensitive areas.
- Observe regulated post-application food crop waiting periods and BMPs related to livestock grazing.
- Provide and maintain required signage and access restrictions for 38 months after application where appropriate for Class B biosolids, Class B compost and domestic sewage-containing pulp and paper residuals applications.
- Design and implement a post-application monitoring plan that will address environmental concerns.

11.2 Land Application of Small Volumes

Under the OMRR, a LAP is required for any application to land of Class B biosolids or Class B compost, and applications of greater than 5 m^3 of Class A biosolids. Class A biosolids can be distributed in volumes less than 5 m^3 without a LAP. Class A compost and BGM can be distributed with no volume restriction.

Under the SACoP, any application to land of a regulated soil amendment in a volume greater than 5 m^3 requires a LAP. Residuals regulated under the SACoP can be land applied without a LAP provided that no more than 5 m^3 of the residual is applied to a site in a one year period. There is no restriction on the distribution of volumes less than 5 m^3 of pulp and paper residuals containing domestic sewage regardless of fecal coliform content of the residual; however, the application must adhere to depth to groundwater and crop restrictions as well as buffer and signage requirements as outlined in Section 7 of the SACoP.

Although there is no LAP requirement for volumes less than 5 m^3, an LAP is recommended when any volume of pulp and paper residuals containing ≥ 1,000 MPN g^{-1} dw fecal coliform are applied. As a minimum generators and end users should keep records of where the material was land applied, and the fecal coliform concentration of the material.

11.3 Responsibilities of the Qualified Professional

Under both the OMRR and the SACoP, a qualified professional must prepare and sign each LAP, and during or following land application of the residual, must conduct a site visit to confirm that the application was completed to the specifications of the LAP. The qualified professional must provide written certification to the discharger following the post-application site visit. Under the SACoP the qualified professional is required to complete the sampling of fly ash and pulp and paper residuals.

11.4 Notification of Application

Depending on the type of residual and application site, several regulatory authorities may require notification of a planned residual application, including the Regional Waste Manager of the MoE, the MHO appointed under the *Health Act* and the Provincial ALC. Notification requirements are outlined in the following sections.

For both the OMRR and the SACoP, the MoE Regional Waste Manager has 30 days to respond to the proposed application with a request for additional information. The MHO has the authority to veto the LAP or to impose conditions on the application within the 30 day notification period. The application can proceed if there is no communication from either of these parties 30 days after the notification period, or 30 days after receipt of additional information if requested. The ALC has no authority under the OMRR or the SACoP to either request further information or veto a proposed application. The ALC can veto applications of soil amendments (residuals regulated under the SACoP) under the ALCA.

The LAP must be provided to the registered owner of the land prior to the residual application.

11.4.1 OMRR Notification Requirements

At least 30 days before the intended application of managed organic matter the MoE Regional Waste Manager must be notified of the proposed application by submitting Schedule 13 in the OMRR. Most of the information required for Schedule 13 should be contained in the LAP. Within 30 days of receiving the Schedule 13 notification, the Regional Manager may request additional information and within 30 days of receiving the information may impose site-specific standards or management practices.

Should the proposed application be on agricultural land or in a watershed permitted as a water supply, the appropriate MHO must also be provided with the information from Schedule 13 and given 30 days notice of the proposed application. If the proposed application is to occur within the ALR, the BC Land Commission must be notified.

When notification of the MHO is required, the MHO can within 30 days of receiving notification:

- stop the land application from proceeding; or
- impose conditions for land application.

The timeline can be modified if there is agreement between the discharger, the manager and, if applicable, the MHO.

A copy of the LAP signed by the qualified professional must be kept at the facility or kept by the registered owner of the land application site for 36 months after the application of soil amendments under the LAP. Upon request the LAP must be made available to a MoE manager, or an inspector or officer under the *ALCA*.

11.4.2 SACoP Notification Requirements

All proposed applications to land of residuals regulated under the SACoP in volumes greater than 5 m^3 require notification of the Regional Waste Manager or appropriate MoE Director. Schedule 1 of the SACoP is submitted as notification. If the proposed application is onto land with an agricultural use, as defined in the CSR, or in a watershed (defined as a watershed from which water flows into a drinking water source, and intended to apply to both surface and groundwater), notification must be provided to the MHO in whose jurisdiction the application site is located. If the land is within the ALR, notification must also be submitted to the ALC. Notification must be supplied at least 30 days before the proposed application. Under the ALCA, an application must be made to the ALC to apply residuals regulated under the SACoP within the ALR.

For applications under the SACoP, the Regional Manager or Director can request changes to the planned application or additional information on the application in the form of site-specific standards or additional management information. If the Director requests additional information regarding a proposed application, that application cannot proceed until at least 30 days after the additional information has been provided to the Director and the MHO. Within this time:

- the director may require the discharger to comply with site-specific standards or management practices; and,
- the MHO may provide written directions prohibiting the land application of soil amendments to the application site or, impose conditions on the land application.

The time limits can be modified if agreed by the Director, discharger and the MHO as applicable.

The discharger must keep a copy of the LAP and certifications by the qualified professional for 36 months after the application of soil amendments under the LAP. These must be made available for inspection by an officer and, on request, provided to a director or an official under the ALCA.

11.5 Duration of Land Application Plan

For both the OMRR and the SACoP a separate LAP is required for each distinct geographic site where a residual is to be applied; each LAP is current for a one year period from the time of writing. For many applications of residuals, a LAP can be produced for the application of one type of residual at one site to be completed within one year. In this case, at the end of one year, the application has been completed and the LAP expires. Applications to agricultural sites are often initiated and completed within one calendar year.

On certain sites, the application of the residual is planned to occur over several years on different areas of a site. Often, the site operator requires flexibility in timing of application of the residual. In any one year, the size of area that receives the residual may depend on weather or other factors out of the control of the operator. For example, the landowner may plan to apply the residual to three areas of the site during the year the LAP is written, but because of unforeseen factors, delay the application until the next calendar year, or apply the residual to only one of three planned application areas. Residual applications at reclamation sites often require this type of LAP. For this type of ongoing application, one LAP can be written to cover the entire proposed application area, and include all soil analytical data for the site so that the site operator has the flexibility to proceed with applications to the site as is convenient. However, the LAP must be updated annually for the areas of the site that have not yet received the residual. As discussed below, each time a LAP is updated, notification as required must be undertaken and depending on site conditions, residuals and soil may require reassessment.

A site is defined as a field or group of fields, or an area that is to receive residuals over a period of time such as a reclamation site or a forested area of defined size. The LAP should cover one application of the residual over the whole area, whether that application occurs at one time or over a period of time.

Each LAP is a separate entity. Notification requirements to MoE and, if required, to the MHO and ALC must be completed with each update of the LAP. If site conditions do not change from year to year, soil sampling for trace elements may not be required each time a LAP is updated; the qualified professional must use discretion in making this decision or may request guidance from the Regional Director. It is advisable to update residual quality data, application rates and trace element addition data annually.

11.6 The Site, Discharger and Qualified Professional

Under both OMRR and the SACoP, a LAP must contain:

- the full name and address of the facilities where the residual is produced;
- the local contact for the discharger and their address and phone number;
- the name and address of the person preparing the LAP (their professional designation is also recommended);
- the name of the registered owner of the land on which the land application will take place;
- the street address and legal description of the land application site;
- the location and boundaries of the land application site (a map or plan of suitable scale is required);
- the intended dates for land application during the year;
- written authorization from the registered owner of the land where the proposed application is to occur (or agent); and,
- the signature and stamp of the qualified professional.

Additional information required for applications under the SACoP includes:

- The latitude and longitude of the proposed application site and a description of the boundaries of the application site.
- The street address and legal description of each storage facility and storage site where the residual will be stored prior to application, and a map or plan showing these locations.

11.7 Residual Characteristics

Information requirements pertaining to residuals applied under the OMRR and the SACoP are discussed below.

When preparing a LAP under the OMRR, the following information is required about the biosolids or compost:

- fecal coliform as MPN per gram dw (see Schedules 1, 3 and 5 of the OMRR);
- a physical description of the constituents, including foreign matter;
- vector attraction reduction process or management method (see Schedule 2 of the OMRR);
- moisture content plus total nitrogen (TKN), NH_3 plus NH_4^+, NO_3^-, plant available P and plant available K, all expressed in $\mu g\ g^{-1}$ dw;
- pH and EC; and,
- concentrations of the 11 required trace elements expressed in $\mu g\ g^{-1}$ dw (see Schedule 4 of the OMRR).

Under the SACoP, the LAP requires the following residual information:

- moisture content as a percentage, TKN, NH_3 plus NH_4^+, NO_3^--N, plant available P and plant available K, all expressed as $\mu g\ g^{-1}$dw;
- concentrations of the 11 required trace elements in $\mu g\ g^{-1}$ dw (Table 1 of the SACoP);
- pH and EC;
- a physical description of the material, including foreign matter; and,
- for soil amendments that contain domestic sewage, the fecal coliform in MPN g^{-1} (dw).

The SACoP does not require the analysis of residuals for other parameters besides the required 11 trace elements, and basic nutrient and quality data. The onus is on the qualified professional to request additional analyses of the residual if other parameters appear to be of concern. The residuals must be applied in a manner that does not create or exacerbate a contaminated site. It is the responsibility of the qualified professional to determine additional residual-specific parameters for analysis in addition to the SACoP requirements.

11.8 The Receiving Site/Soil

Under both the OMRR and the SACoP, the following information about the receiving site is required:

- concentrations of the 11 required trace elements and predicted post amendment soil concentrations of the same trace elements (required trace elements listed in Table 1 of the SACoP and Schedule 4 of the OMRR);

- EC and pH of the soil; and,
- calculation of soil conditioner or crop nutrient requirements for the site.

For residuals managed under the OMRR, information on the site's slope and aspect, soil type and depth, climate, vegetation, and surface and groundwater location is not required to be included in the LAP but is recommended for inclusion. If any site factors are of concern for the residual application, these should be included along with management methods to address these site challenges.

For residuals managed under the SACoP, the LAP is required to contain information on any conditions specific to the proposed application site that may limit the site's suitability for residual application. The SACoP lists gradient, drainage issues and type of groundcover as site conditions that may affect the suitability of a site for residual application. The SACoP suggests other factors be considered. The LAP must contain site management methods used to address any specific site challenges.

The LAP should contain general site information used to assess and support the suitability of the site for residual application. The general site assessment should include information about the: soil type and texture, soil depth and presence of horizons. Annual rainfall, temperature data and other relevant climate data should be included. Site vegetation should be described, including the biogeoclimatic zone and subzone where appropriate. The location of the closest surface water sources and wells should be identified. The risk of flooding and high groundwater table should be assessed. Land use on adjacent properties should be noted. Chapter 10 and relevant sections of Chapters 13, 14 and 15 contain site and soil information that can assist in site assessment.

11.9 Residual Application Rate Determination

Residuals application to land must be completed with a defined goal in mind such as soil conditioning or fertilization. The LAP must state the proposed application rate of the residual for the site and year, and provide a rationale for this rate in terms of a demonstrated requirement at the site for soil conditioning or provision of nutrients; there must be a demonstrable benefit to the soil and/or vegetation on site from the application. By establishing the objective of the application, it is also possible to measure the degree to which this objective has been accomplished in any post-application monitoring.

Chapter 10 provides general information on developing application rates for the various types of residuals based on their characteristics and beneficial reuse on land; Chapters 13, 14 and 15 provide information on the land application of residuals specific to agriculture, silviculture and reclamation applications of residuals.

Chapters 8 and 9 contain information on sampling protocols for the various residuals covered by the regulations and Chapter 12 contains information on sampling protocols for receiving sites.

11.10 Trace Element Addition

Both the OMRR and the SACoP specify trace element limits for residuals. If any of the 11 trace elements exceed the limits as set out in the regulations, the residual cannot be land applied under these regulations. Schedule 4 of the OMRR and Table 1 of the SACoP contain trace element limits for residuals.

The LAP must identify the concentrations of the 11 trace elements in the residual and at the application site prior to residual application. The OMRR and SACoP require that the LAP provides the predicted post-application soil concentration of all 11 trace elements. The OMRR requires that every LAP contain a description of the methodology that would be used to measure the soil concentration of trace elements post-application if this were required. The SACoP requires this only if the proposed application rate exceeds the agronomic rate for the site.

The OMRR also contains receiving site soil standards for the 11 monitored trace elements. If the background soil has one or more trace elements that exceed the appropriate standard for that element, the site cannot be used for residuals application under OMRR unless site-specific standards are approved. Schedules 9 and 10 of the OMRR contain soil standards for managed organic matter application sites.

The SACoP references the soil standards found in Schedules 4 and 5 of the CSR. When soil amendments are applied to land under the SACoP, the application must not either create or exacerbate a contaminated site. If the background soil on a proposed application site contains an elevated concentration of one or more trace elements, the site can be used for residual application provided that the application does not cause an increase in the background soil concentration of the trace elements that are in excess of the appropriate soil standards.

Section 10.5 provides additional information on trace elements, determining trace element additions and predicting soil concentrations. Necessary information about the residual and soil at the receiving site is as follows:

- concentration in the residual of the 11 identified trace elements;
- concentration in the receiving soil of same 11 trace elements; and,
- bulk density of the receiving soil.

Refer to Chapters 8, 9 and 12 for information on sampling residuals and soil, and on interpretation of analytical data.

11.11 On-site Storage Requirements

Under the SACoP, the LAP is required to contain the street address and legal description of each storage facility and storage site where soil amendments will be stockpiled prior to application, and a map or plan showing the locations of the storages. The LAP must also contain a description of any site conditions that may adversely impact the storage of the residual on site prior to land application. It must contain a description of management methods that will be used to prevent leachate generation at storage sites and facilities. The onus is on the qualified professional to ensure that storage facilities or sites adhere to SACoP requirements for buffers and leachate control and do not cause environmental damage.

Section 10.6.5 covers BMPs for the on-site storage requirements for residuals.

Under the OMRR, the LAP must provide information on storage and leachate management requirements for the residual at the application site. The onus is on the qualified professional to ensure that on-site storage adheres to these requirements. It is recommended that the LAP contains the same information pertaining to on-site storage as is required by the SACoP.

11.12 Public Health and Water Quality Requirements

11.12.1 Class B Biosolids and Class B Compost Application in Permitted Watersheds

Under the OMRR, Class B biosolids and Class B compost cannot be applied in watersheds that are permitted for supply of drinking water as defined under the *Safe Drinking Water Regulation*, BC Reg 230/92. Under both the OMRR and the SACoP, notification of the MHO is required for applications of managed organic matter or soil amendments in watersheds, and the MHO can veto or impose restrictions on the application. Refer to Part 3 Divisions 3 and 5 in the OMRR, and Part 3 (9) in the SACoP for further information.

11.12.2 Application Buffers

The LAP should contain information on buffers required for the proposed application. Section 10.6.3 discusses buffer distances required by the OMRR and the SACoP. As well, Chapters 13, 14 and 15 provide specific information on buffers required with different types of application sites. Ensure that buffers are adequate to protect surface water and groundwater, and areas bordering the residual application site. The buffer distances in the OMRR and the SACoP should be considered minimum distances; specific conditions at each application site will dictate whether these are sufficient for environmental protection. The LAP should contain a map of the application areas and clearly defined buffers.

11.12.3 Crop Planting and Livestock Grazing Restrictions

A LAP should contain information about required food crop and livestock grazing restrictions following residual application to the site. Food crop and grazing restrictions are required on sites that have received Class B biosolids, Class B compost and pulp and paper residuals containing domestic sewage if the fecal coliform concentration is ≥ 1,000 MPN g^{-1}.

11.12.4 Signage and Access Restriction

Signage is required, under the OMRR and the SACoP, at sites that receive Class B biosolids, Class B compost and pulp and paper residuals containing domestic sewage if the fecal coliform content of the residual is greater than or equal to 1,000 MPN g^{-1} (dw). The LAP should contain information on the signage required and the information required to be on the sign. Signage information is contained in Section 10.6.4.

Sites that receive Class B biosolids or compost with fecal coliform concentrations greater than or equal to 1,000 MPN per gram of total solids or that receive unprocessed Class B biosolids have restricted public access. The LAP should also contain information on the management methods to meet these requirements.

11.13 Application Method and Timing

Application method and timing information must be included in the LAP. The LAP should describe the method of application and the equipment to be used, including whether the residual is to be incorporated and the estimated time between application and incorporation. The LAP should also discuss the timing of residual application, any seasonal considerations with the application and include any special management methods required to meet seasonal application requirements (e.g. high water table, snow covered ground).

11.14 Previous Applications

The LAP should reference any previous residual additions to the site which were completed under the OMRR, the SACoP or an approval or permit, including permit or approval number and dates. Previous monitoring results will be useful for assessing soil quality and providing supporting information for the current application.

11.15 Special Management Considerations

Both the OMRR and the SACoP require the qualified professional to outline any special management methods that will be required to address specific site conditions and any residual application challenges at the proposed application site, and to include this information in the LAP. The onus is on the professional producing the LAP to identify any special management concerns at the proposed residual application site (beyond adhering to the required buffers and using the appropriate application rate of biosolids), and to develop a plan that adequately addresses those concerns. Special management conditions may include, but are not limited to, site gradient and proximity to surface water, appropriate time of year for application, specific application equipment required, site sensitivity due to proximity of neighbours, odour mitigation, and dust control.

Under the SACoP, the LAP must outline any site challenges (as determined by the qualified professional) and the management methods that will be undertaken at the site to address the challenges. The LAP must also outline management methods that will be used to prevent the transmission of pathogens by vectors. For applications of residuals that contain fecal coliform concentrations $\geq$ 1,000 MPN g^{-1} total solids, the LAP must outline methods that will be used on site to prevent the spread of disease.

Under the OMRR, the LAP must outline any site challenges, and the proposed management methods to mitigate the identified challenges. It must also contain procedures to manage application of Class B biosolids that do not meet the Class A fecal coliform standard or that have not been processed to reduce vector attraction, or application of Class B compost that does not meet maturity requirements. Section 10.6.1 outlines suggested on-site management of these residuals.

Sections 10.2 and 10.6 and relevant Sections of Chapters 13, 14 and 15 discuss site selection and management.

11.16 Special Class B Biosolids Requirements

Biosolids require vector attraction reduction requirements as identified in Schedule 2 of the OMRR. If vector attraction reduction has not been achieved, biosolids can only be land applied by injection into the soil or incorporation within six hours of application unless it can be demonstrated that the risk of pathogen transmission by vectors is minimal. Refer to Section 10.6.1 for more information on application of biosolids that do not meet vector attraction reduction requirements.

11.17 Post-Application Monitoring

The regulation and code require that a post-application monitoring plan be developed and included in the LAP if the residual application rate exceeds the annual crop nutrient or soil conditioning requirement. The monitoring plan must address potential changes in soil and vegetation quality as the result of the residual application. Section 10.8 and Chapter 12 discuss post-application monitoring of soil, vegetation and surface and groundwater on and adjacent to a residual application site. Chapters 13, 14 and 15 cover specific monitoring requirements for different types of application.

While not required when the proposed application rate meets the crop nutrient or soil conditioning requirement, a post-application monitoring plan is recommended for all applications. This monitoring plan may include an assessment of the degree to which the application achieved the LAP objective, as well as the framework for an environmental monitoring program. A review of Section 10.8 and the appropriate subsections of Chapters 13, 14 and 15 will assist in identifying scenarios where monitoring is the most appropriate. Post-application monitoring is often useful to validate increases in productivity or soil/plant nutrient status and used to refine subsequent application rates.

12 Sampling and Analysis for Land Application

Under the OMRR and the SACoP sampling is required to ensure that the residuals meet the regulatory criteria for use. These sampling requirements are discussed in Chapters 8 and 9.

12.1 Sampling Residuals Prior to Use or Distribution

Assuming the quality criteria have been established, additional sampling and analysis is recommended prior to land application if the residuals have been stored. Application rate determinant parameters change during storage. For example, if the land application is based on a N application rate, the N concentration should be confirmed as close as possible to the time of application. If the residuals are being applied as a liming agent, the pH of the residuals should be confirmed.

For retail grade organic matter (i.e. Class A compost and BGM), parameters which could impact human health or the environment should be reassessed prior to distribution or application in public areas. For example, the fecal coliform concentration of Class A compost should be measured just prior to distribution. Although not required under the OMRR, it is also recommended that the fecal coliform concentration of BGM be analyzed. Seven representative samples of the BGM and Class A compost should be collected and the fecal coliform concentration should be less than or equal to 1,000 MPN g^{-1} in all seven samples.

12.2 Receiving Environment – Soil Analytical Requirements

Both the OMRR and the SACoP require receiving environment sampling whenever a LAP is mandated. Pre-application soil samples must be collected to determine background or existing site conditions, the application rate and the predicted post-application trace element concentration.

12.2.1 Receiving Site Analytical Requirements

The soil of the site selected to receive managed organic matter or soil amendment must be sampled and analyzed for the following parameters:

- Trace elements: arsenic, cadmium, cobalt, chromium, copper, lead, mercury, molybdenum, nickel, selenium and zinc
- Soil quality parameters: pH and EC
- Nutrients: although not explicitly required by the OMRR or the SACoP, the receiving soil should also be analyzed for the major crop nutrients to assess the nutrient status of the site and calculate the application rate. In most situations, plant-available N, P and K are sufficient.

The above information must be included in the LAP. Additional soil quality parameters, although not required, are recommended for residuals being applied to improve the quality of the soil: organic matter, C:N ratio, bulk density, and texture. Bulk density is required for post amendment soil trace element predictions.

The initial and post-application soil concentration of the 11 trace elements listed above must not exceed the soil standards provided in Schedules 9 and 10 of the OMRR for the applicable land use. Under the SACoP, the trace elements concentrations after application must not create or exacerbate a contaminated site.

12.3 Pre-Application Soil Sampling Methodology

When collecting soil samples for establishing baseline conditions on a proposed application site, the goal is to collect a sample that accurately represents the soil of the land area that is to receive the residual. For most application sites, collection of composite soil samples from each defined sampling area to a depth of 15 cm is adequate to characterize the application area. The same sampling protocol can be used to collect samples for both trace element and nutrient determination. Several factors to consider in ensuring that representative samples are collected are outlined in the sections below.

12.3.1 Sample Collection Schedule

Soil data are required to be included in the LAP, requiring samples to be collected at least one month before the LAP is submitted. Although it is not always possible, there are preferred times of year for collecting soil samples, especially for determination of plant-available nutrients. In coastal areas of the province, the preferred time for soil sample collection for nutrient determination is in spring when the soil is warming and as crop growth begins. In the interior, either spring or fall sampling is appropriate. In general, summer is not the preferred time to collect samples for nutrient determination. For trace element determination, sample collection time is not as critical. If a site is re-sampled for post-application monitoring or for re-application, sampling should occur at the same time of year as the initial sampling.

12.3.2 Defining the Sampling Area

Depending on the size, topography, previous or present land use and soil type, the site may be sampled as one area or subdivided into smaller areas for soil sampling. Sites that are up to 10 ha in size and that are fairly uniform in topography, soil type and present or previous land use can be sampled as a whole (e.g. fields or reclaimed areas). Sites that are variable in topography, soil type or management history should be subdivided into smaller units and sampled individually (e.g. forested areas, some reclamation sites, large fields). Sites larger than 10 ha in size should be subdivided into smaller areas for sampling; however, if the area is very uniform, soil type does not vary significantly, and management history has been similar over the whole area, larger sites can be sampled as a whole (e.g. very uniform fields, mine tailings or waste rock piles). The qualified professional must use their judgment in defining sampling areas and in understanding the concepts of variation as it affects precision, accuracy and regulatory compliance. If an application area is subdivided into smaller parcels for soil sampling, this should be recorded on a map (using GPS), and all future sampling should be completed in this configuration.

12.3.3 Sampling Pattern

There are many sampling patterns that have been developed to ensure that a representative sample is collected from each sampling area. The simplest and most effective for routine soil sampling is random sampling in a ‘zigzag’ pattern over the sampling area. On square or oblong sites, visually divide the area in half. Walk in a zig-zag pattern up one side of the site and down the other side collecting samples. In non-symmetrical sampling areas, collect samples randomly in zig-zag fashion from all parts of the sampling area. Avoid areas that may skew the representative nature of the sample due to contamination or land use such as dead spots, manure deposits and wet areas - unless the residual will be applied to these areas. If the residual is to be applied to these types of areas, a stratified random sampling plan may be appropriate if the areas make up a significant portion of the total application area. If the areas do not, a point sample might best characterize these areas.

If there is concern that a proposed application site may have been contaminated due to previous land use, an alternative soil sampling pattern should be used to identify areas of the site that are affected. Consult a contaminated sites sampling reference and a qualified professional familiar with this type of sampling.

12.3.4 Sampling Depth

The standard depth for soil sampling is 0-15 cm; most nutrients and trace elements will remain within this top layer of soil following application. On most agricultural and reclamation sites, this is the appropriate depth from which to collect samples. If the residuals are to be incorporated, soil samples should be collected from the zone of incorporation.

Where there are concerns about movement of soil nutrients or trace elements to a greater soil depth, incremental sampling of the top 60 cm of soil may be necessary (i.e. 0-15 cm, 15-30 cm and 30-60 cm). If leaching of NO_3^--N is a concern, incremental sampling will be required.

On some sites (e.g. undisturbed forested sites), particularly where there are distinct differences between the horizons, it may be more appropriate to sample soils by horizon. This is especially important where sampling of the lower soil horizons is contemplated. For example, where the soil consists of a surface “A” horizon which is high in organic matter, extends to a depth of 23 cm, and is overlying a “Bm” horizon with low organic matter content, it would be more appropriate to sample the individual horizons separately.

Soil samples collected from sites in perennial grass or legumes typically have a layer of decaying organic matter on top of the soil. The surface layer should be removed before the sample is placed in the collection container, retaining only the fine roots that extend into the soil. When sampling newly worked bare soil, press down firmly on the soil before sampling to mimic the settled soil depth; if this is not done, only the top 10 cm of real soil depth will be sampled as ploughing and disking temporarily expand the surficial soil volume.

12.3.5 Sampling Intensity

One composite sample of soil should be collected from each defined sampling area of the proposed application site. For small sampling areas (3 ha or less), the composite should consist of a minimum of ten subsamples. For large sampling areas, the composite should consist of a minimum of 25 subsamples. In general, a minimum of four subsamples should be collected from each ha of sampling area.

12.3.6 Preparation of Composite Samples

All soil subsamples from a sampling area should be collected in a clean plastic bucket or bag. When all subsamples have been collected from within a sampling area, the soil material should be mixed well in the bucket or similar container. Rocks should be removed and lumps of clay and other soil material should be broken up thoroughly. Subsamples for laboratory analysis should be placed in clean labelled plastic bags or containers; a minimum of 500 g of material is normally required for laboratory analysis. Confirm with the laboratory prior to collecting the samples to ensure sufficient sample volume is collected and appropriate handling requirements are followed.

12.3.7 Re-sampling Sites to be Reapplied with Residuals

On some sites, re-sampling of the site for background trace element concentration prior to the next application must be done carefully. On sites with fine textured soils that have a significant amount of clay, the residuals may not mix completely into the soil following application. When the soil is re-sampled prior to a subsequent application of residuals, highly variable and incorrect trace element values can occur as there may exist localized areas of unincorporated residuals. On this type of site it is recommended that several additional steps be taken to ensure that accurate trace element data is obtained from the site. These are as follows:

- Collect three composite samples from each sampling area, each comprised of at least seven subsamples collected from the entire sampling area. Using this method, an average value for each sampling area can be calculated.
- Mix each sample very well before sub-sampling, breaking up lumps of clay thoroughly.
- Request the laboratory dry and grind the entire sample then to take a subsample of the dried and ground sample for trace element determination. Typically the laboratory collects a small sample of the material submitted which is dried, ground and analyzed for trace elements.

Alternatively, soil sampling can be undertaken using the standard protocol and if highly variable trace element data results, the site can be re-sampled using this more rigorous protocol.

12.4 Analytical Methods

12.4.1 Trace Elements

The OMRR and the SACoP require background soil concentrations of 11 trace elements to be included in the LAP. The soil samples collected must be analyzed for ‘strong acid digestible’ or 'strong acid soluble' trace element concentration. The standard method of analysis for determining the soil concentration of trace elements is to digest the sample in a concentrated acid solution, such as nitric and hydrochloric acid, which destroys the organic matter and releases trace elements into the acid solution.

Trace element analysis is often completed using inductively-coupled plasma spectrophotometry (ICP) or similar analytical system. Trace element data is normally reported in ppm or mg per kg of dry soil. The ICP can provide data for many different trace elements, including all of the required OMRR and SACoP trace elements except mercury. Mercury is determined using a separate analysis and must be requested specifically. Arsenic and selenium may require graphite furnace atomic adsorption methods to meet regulatory-specific detection limits although more frequently these are completed using ICP Mass Spectrometry (ICPMS). It is important not to confuse elemental concentrations of P and K that may be provided as part of a total element ICP analysis with that of plant available nutrient concentrations.

In general, analytical, environmental and soil laboratories are equipped and have the expertise to perform these analyses. An accredited laboratory should be chosen, and subsequent analyses should be performed by the same laboratory to avoid between-laboratory variability.

12.4.2 Nutrients

Although not specifically required soil samples should also be analyzed for NH_4^+-N, NO_3^--N and plant available P and K which are required for application rate determination and site assessment.

The determination of additional constituents are also valuable in determining the condition of the soil. The organic matter content of the soil is useful in predicting the ability of the soil to retain and release nutrients for plant uptake over the growing season. Agricultural soils with a high concentration of organic matter (greater than 5%) typically release significant amounts of nutrients, particularly N, over the growing season. Soil S, Ca, Mg and sodium concentrations are also useful in identifying sites where application of residuals may not be appropriate due to previous oversupply of nutrients to the site, or where an application may help to correct a nutrient deficiency.

These analytical procedures are most commonly performed by agricultural and soil laboratories (although some analytical laboratories can perform them), and are usually included as part of a soil fertility package with fertilizer recommendations. Soil nutrient data are normally provided in ppm or mg per kg of dry soil and occasionally in kg per ha. Nitrogen constituents (and NH_4^+) should be determined on a wet basis; if the sample is dried before analysis, a significant amount of NH_3 will be lost. Ensure that the laboratory reports the percent moisture or percent solids so that the application rate can be converted from a dry basis to an as-produced basis. Depending on the laboratory and the area of the province in which the samples are taken, analytical methods may vary. For more detailed information about analytical methods, discuss the required analytical techniques with laboratory staff prior to undertaking the sampling and analysis.

12.4.2.1 Ammonium-nitrogen

Ammonium-N is typically determined colorimetrically following extraction with an acid solution. This determination is often not included in standard soil fertility packages, and may have to be requested specifically if it is desired. Normally, soils have only a very small amount of NH_4^+-N as this form of N is transient between organic N and NO_3^-. However, if a site has recently been amended (or the previous fall in interior areas) with residual containing a substantial amount of NH_4^+, the soil concentration of NH_4^+-N may be quite high. This NH_4^+ should be considered plant-available for the upcoming growing season.

12.4.2.2 Nitrate and Nitrite-Nitrogen

Nitrate and nitrite (NO_2^-)-N is the standard laboratory determination for plant-available N. Both NO_2^- and NO_3^- concentrations are quantified in the standard laboratory test, in which NO_3^- and NO_2^- ions are extracted in an acid solution and typically measured using a NO_3^- electrode or colorimetrically. Normally, soils contain significantly less NO_2^- than NO_3^- as biological activity quickly converts NO_2^- to NO_3^- in the soil. This test does not measure NH_4^+-N or organic N, both of which can contribute substantially to plant-available N over the growing season.

In coastal areas of the province, soil NO_3^- concentrations in spring will be very low as winter rainfall moves residual NO_3^- into the subsoil or the NO_3^- is lost to the atmosphere through denitrification. In interior areas, substantial amounts of NO_3^- may be present in the soil in spring, although this NO_3^- may be found below the 15 cm depth as spring snow melt transports NO_3^- down the soil profile. Sampling to 30 cm in interior sites that are thought to have high N fertility is recommended. Because of wide variations in soil NO_3^--N concentration and crop N requirements over a growing season, it is not possible to make general statements regarding ideal NO_3^- concentrations in the soil for crop production. As such, the qualified professional should use their judgment when interpreting soil reports.

12.4.2.3 Plant-available Phosphorus

The standard laboratory analyses used to determine plant-available P in BC are the Bray P1 and the Kelowna extract. The Bray P1 extract is a weak solution of hydrochloric acid and ammonium fluoride, and is most suitable for acidic soils such as are found in high rainfall areas of the province. The Kelowna extract is a modified Bray P1 and is suitable for both non-acidic interior soils and acidic coastal soils. These analyses are designed to extract the portion of the total P in a soil sample that is plant-available at the time of soil sampling and the portion that will become available within the growing season. Both extract all of the ‘ortho-P’ or soluble (dissolved) P in the sample and a portion of the active (labile) P that will supply P over the growing season. By contrast, the ‘total P’ determination extracts all of the P in a sample. The plant-available P as determined by Bray P1 and Kelowna extracts is only a small portion of the total P in a soil as most of the P is tightly bound in organic and inorganic compounds. Plant available P exceeding 80 ppm in the top 15 cm of soil is typically considered sufficient to meet crop requirements for at least one growing season. Soils with soil test P exceeding 150-200 ppm P should be considered over-supplied and typically do not require P additions.

12.4.2.4 Plant available potassium

In BC, two different standard extractants are commonly used for determination of plant-available K, the Kelowna extractant (acetic acid and ammonium fluoride) and ammonium acetate. The NH_4^+ in the extractant displaces other cations (K, Mg, Ca) from the soil's exchange complex and plant-available cations are determined in solution. As with P, these methods extract that portion of the total soil K that is considered to be crop-available in the current growing season. Soils with plant-available K exceeding 400 ppm in the top 15 cm of soil are typically considered over-supplied and do not require added K for at least two growing seasons.

12.4.3 Other Parameters

The OMRR and the SACoP require that background soil samples be analyzed for pH and EC.

12.4.3.1 Soil pH

Soil pH is a measure of the acidity of the soil. It is measured from a suspension of soil and distilled water using a pH meter. Normally, pH determination using a 1:2 soil:water mixture is acceptable for most determinations; most BC and Alberta soil and environmental labs use this pH determination. A $CaCl_2$ extract can also be used to determine pH. This method may be less dependant on the soil:liquid ratio and more reflective of the field pH. It is also more stable for soil which has been air-dried and stored up to one year.

Agricultural soils produce optimally in the pH range of 6.0 to 7.0, depending on the soil type, and are limed to maintain the pH within the optimum range for the geographic area and soil type. Forest soils typically have a low (acidic) soil pH, but trees are well adapted to growing under acidic conditions. Some agricultural soils (for example, cranberry fields) also have low pH.

12.4.3.2 Electrical conductivity

Electrical conductivity is a measure of the total salt content of the soil and is normally reported as deciSiemens per meter (dS m^{-1}). For soils with a low (normal) conductivity, EC should be determined using the 1:2 soil:water method. However, if the soil's EC is expected to be greater than 2 dS m^{-1}, the 'saturated paste' method should be requested from the laboratory. If lab data shows that the soil's EC is greater than 2 dS m^{-1} using the 1:2 soil:water method, the analysis should be repeated using the saturated paste method. The 1:2 soil:water method is accurate for soils with a low EC but this extract loses accuracy as the EC increases. The saturated paste method is more time consuming and typically more expensive to perform in the laboratory but is more accurate for higher conductivity soils.

Soil with an E.C. below 2 dS m^{-1} is non-saline, between 2 and 4 dS m^{-1} is weakly saline and greater than 4 dS m^{-1} is moderately to very saline. Crop growth may be inhibited at EC levels greater than 4-8 dS m^{-1}, depending on the crop to be grown on the site. Soils with an EC greater than 1 dS m^{-1} are encountered primarily in the southern interior of the province where annual evapotranspiration exceeds precipitation, and soil salts are not washed out of the root zone periodically as in coastal areas. Residuals such as biosolids contain a substantial amount of salts which can contribute to soil salinity. Soils with an EC greater than 4 dS m^{-1} should be monitored following the application of residuals to ensure that EC does not continue to rise. If the EC continues to increase applications should cease until the EC returns to within the acceptable range.

12.4.4 Post-Application Sampling

The OMRR stipulates that if the application rate of managed organic matter used on a site is higher than the agronomic rate for the site, a post-application monitoring plan should be included with the LAP for the site. The plan must include methods to monitor the post-application soil concentration of the 11 trace elements identified in the OMRR.

A LAP completed under the SACoP requires (if the application rate exceeds the soil conditioning or crop nutrient requirements) a plan for monitoring the composition of the soil after the soil amendment has been applied and a statement of the potential changes in the soil and vegetation quality this will cause.

For both the OMRR and the SACoP the post-application soil concentrations of trace elements should be determined by re-sampling the site using the same methodology as previous sampling was completed (i.e. same sampling areas, depth and intensity). Sample at the same time of year as when the pre-application sampling was conducted. Post-application soil samples should be sent to the same laboratory and analyzed using the same techniques.

Although post-application soil monitoring for agronomic applications is not required under the OMRR or the SACoP it is recommended for due diligence purposes to confirm that the application of residuals does not have a negative impact on the receiving environment.

For managed organic matter applied under the OMRR, the concentration of trace elements in the soil after application should not exceed the criteria given in Schedule 9 and 10 of the OMRR.

The SACoP does not identify specific limits for soil constituents post-application. It states that soil amendments must not be applied to an application site in such a manner or amount as to create or exacerbate a contaminated site. Post-application sampling is recommended to confirm that constituents are within the appropriate regulatory requirements.

Under some circumstances it is useful to monitor the soil concentration of plant-available N following an application of high nutrient residuals. It is useful to assess the soil's plant available N concentration in the fall after the growing season is finished. If the application rate of the residual was high for the site and crop, the soil concentration of available N will be high in the fall when crop growth has stopped. This information can be used to modify an application rate for the following year, or to gather information for future applications.

Sampling to monitor for residual NO_3^- is done at three depths in the soil. Collect soil samples using the methodology described in Section 12.3 above with the following differences. On most agricultural sites, collect samples in late fall, after crop harvest or when plant growth has slowed, but before heavy fall rain or snow occurs, or the soil freezes. Collect samples from the 0-15 cm, 15-30 cm and 30-45 or 60 cm depths (depending on difficulty of sampling). Collect samples in three containers, and composite as described above to make three separate depth samples for each sampling area. These samples are then analyzed for NO_3^--N and NH_4^+-N. A fall soil plant-available N concentration of greater than 100 kg ha^{-1} is considered high. If the soil profile contains greater than 100 kg ha^{-1} of NO_3^- plus NH_4^+ and the residual application rate was based on N, the application rate during the previous growing season was not agronomic.

12.5 Receiving Environment – Vegetation

Schedule 7 of the OMRR requires a post-application monitoring plan for applications where the agronomic application rate is exceeded. This plan may include vegetation monitoring. The OMRR does not specify either analyses required or sampling frequency. This is the responsibility of the qualified professional.

The SACoP requires that the LAP include a statement of potential changes in vegetation quality that will be caused by application rates that exceed the annual crop nutrient requirements.

The following section is a terse overview of vegetation sampling of agricultural, tree and shrub crops. Additional information sources are highly recommended if the qualified professional identifies that the post-application monitoring plan requires vegetation monitoring, or vegetation monitoring is being conducted for research purposes. Consult an expert in the field or refer to the literature. A list of relevant references is provided in Section 12.6.

When residuals are applied at non-agronomic rates, several considerations relating to the vegetation quality exist. The soil concentration of plant-available nutrients can be high and this can result in vegetation with high concentrations of certain nutrients. In terms of agricultural crops typically the main concern is elevated plant NO_3^--N. Elevated plant NO_3^--N can result in livestock health problems if the affected forage is fed as a high percentage of the ration. High soil concentrations of plant-available trace elements from an application of organic matter can result in changes in trace element concentrations and the ratios of those concentrations, leading to forage or grazing land that may cause livestock health problems.

When residuals are used to fertilize trees and tree crops, foliar analysis is useful prior to application to determine the nutritional status of the tree and potential response to fertilization. Post-application foliar monitoring in conjunction with growth measurements are typically used to assess the success of the fertilization program.

12.5.1 Sampling Methodology

The following sampling protocol is recommended if there is concern about the quality of the vegetation as feed for livestock. As with soil sampling, the goal of vegetation sampling is to collect representative samples from the selected area of concern. The samples collected must represent the variability in the sampling site.

12.5.1.1 Agricultural Crops or Seeded Reclamation Sites

Samples should be collected at the time of harvest or as close to harvest as possible so that the samples represent the material that the livestock will be eating. If the amended area is planted to a forage crop, samples should be collected at the time of each harvest through the growing season following application. If the site is to be grazed, samples should be collected just before the land is grazed.

In agricultural production systems, sample the part of the plant that the livestock will be consuming. If samples are being collected from a field of perennial forage, silage corn or cereal to be harvested as green feed, sample the whole plant at the height the harvesting equipment would cut. If samples are to be collected from grazing land, sample at the height that livestock would normally graze. Large plants (e.g. silage corn) should be chopped and subsampled for analysis. Smaller plants (e.g. forage grass and legumes, cereals, pasture or grazing land) can be harvested and submitted to the laboratory whole or chopped before being submitted.

It is also acceptable to sample while forage is being harvested. If crop material is to become silage, sampling of chopped material is much easier than field sampling. Collect a grab sample of known volume from each load of silage as it is put into storage (one sample per load or 10 samples per field, whichever is smaller). If forage is to be put up as hay, field sampling pre-harvest is easier than sampling hay in the windrow or in the bale.

Ensure the vegetation sample is free from contaminants that may occur as a result of deposition of road dust. Samples should be representative of field conditions and collected without bias or systematic contamination.

If field sampling, samples must be collected from the entire area where residuals were applied. With soil sampling it is relatively straightforward to collect many samples from throughout a sampling area. With vegetation sampling the task is more difficult. Generally fewer subsamples are collected to make up the composite sample for analysis. Samples should be collected from throughout the area to ensure areas are adequately represented. The choice of a suitable sampling plan (as discussed in Section 6.3) and collection of an appropriate number of samples will ensure adequate representation of the population.

One method is to conduct a simple random sample plan. Divide the sampling area into a grid on paper, and assign numbers to each square on the grid. Randomly select several of the squares to sample. Five to ten randomly chosen sites should be sampled in a sampling area, depending on the size of the site. From each randomly selected sampling area, collect a grab sample of material (making sure that each subsample is the same size) or sample a standard area such as 0.5 m^2. Combine these to create one composite sample per sampling area from all samples collected. Typically at least 0.5 kg of the sample is required for analysis.

If a more intensive assessment is required, the number of samples required to reach a specific confidence level in your results can be determined. Consult statistical reference materials for more detail and refer to Appendix 1 for additional information. Ensure that the areas sampled for foliar constituents are delineated such that pre or post-application soil sampling results can be of use in interpreting foliar constituent concentration.

12.5.1.2 Tree and Shrub Crops

Plant nutritional status is frequently reflected to a larger degree in the leaves than in other plant organs. Thus foliage is frequently used for tissue analysis and assessment of plant response to fertilization.

There are two basic types of tree foliar response to fertilization: increases in leaf size and nutrient content of determinate species; and increases in leaf size, nutrient content and leaf number in indeterminate species. Determinant trees are those which, when they set bud in the fall prior to the dormant season, have a specific number of pre-formed foliar buds. Thus, with any fertilization the following season, nutrients may be used to increase leaf size and nutrient content, but not leaf number. Many conifers are determinant species. Indeterminate species also have preformed buds but are also capable of producing buds that grow and expand within the same growing season. Thus, with fertilization, nutrients may be used by the tree to increase leaf number as well as leaf size and nutrient content. Many deciduous trees fall into this category. Sampling foliage in a post-application monitoring plan must take the form of growth into consideration.

Sample Collection Schedule and Materials Collected

Foliar nutrient concentrations vary with season, tree age, foliar age, leaf position in the crown, recent seed production, fungal disease or insect damage, drought, flooding and soil factors other than fertility. Many of these factors cannot be measured, but their effects on variability can be controlled by standardizing the tissue sampled, and time of year sampling is conducted.

For conifers, sampling in the dormant season is generally recommended with the use of dominant or co-dominant trees, collection from the upper third of the crown, the current year's foliage, and avoiding damaged trees or those with heavy cone crops. In addition, if samples from several sites are being collected for comparative purposes all samples should be collected within a short period and should be material of comparative age and sun exposure.

In general, N, P, K, and S concentrations in foliage of deciduous trees show a maximum in the summer followed by a decline as the growing season progresses. Other elements may be elevated early in the spring then decline; gradually increase over the growing season; or gradually decrease over the growing season. To evaluate fertilization response to the application of residuals on deciduous trees, it is recommended that foliar samples be collected at optimum growing conditions before the onset of re-translocation of elements from the leaves back into the trees (which occurs in the autumn, prior to leaf fall). Thus, depending on the location within the province and the elevation of the site, sample collection periods may range from mid July to the end of August.

As with sampling of coniferous trees, samples of deciduous trees are collected from the upper third of the crown of undamaged trees. In terms of age of leaves to collect, one method is to collect leaves which have recently matured. On the terminal (leader) this condition might be found seven or eight leaves down. On a lateral branch it might be four to six leaves from the tip. In addition, if samples from several sites are being collected for comparative purposes all samples should be collected within a short period and should be material of comparative age and sun exposure. It should be noted that if leaves are collected from the terminal, all leaves should be collected from terminals as they may have substantially higher nutrient concentrations than leaves collected from lateral branches.

The best approach is to standardize the collection schedule and the material collected. In this manner a database of information can be accumulated for comparisons within and between sites.

Samples should be collected from the entire application area. If the site and tree growth on the site are relatively uniform, a simple random sampling plan will be adequate. If there are differences a stratified random sample plan or a systematic random sample plan may be more appropriate. For a basic index of tree nutritional response to application of residuals, collect a composite sample of 8 to 10 subsamples. If the application area is quite large consider increasing the number of samples collected. Confirm the required volume of material for analysis with the analytical laboratory.

If a more intensive assessment is required, the number of samples required to increase statistical vigour can be estimated. Consult statistical reference materials or a qualified professional for more detail.

12.6 References and Supporting Documentation

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13 Considerations for Agricultural Applications

This chapter outlines BMPs for the environmentally safe and beneficial application to agricultural land of residuals regulated under the OMRR and the SACoP. It addresses the determination of application rates, site selection and management, appropriate application timing and post-application site monitoring. A sample LAP is provided in Appendix 2. Detailed background information on land application in general can be found in Chapter 10. The information provided in this chapter builds upon the foundation provided in Chapter 10.

Biosolids, regulated under the OMRR, have become a widely accepted soil amendment for use on agricultural sites over the past two decades. Throughout BC and the rest of Canada there are many active agricultural land application programs using biosolids as a fertilizer for forage grass, feed grains and silage corn (Photograph 27). Ongoing research programs, particularly in the Pacific Northwest, continually add to the knowledge base about application of biosolids to agricultural land.

Composting provides a management method for on-farm residuals to reduce the volume and mass of residuals that must be handled. The use of compost, particularly those composed of composted green waste and manure, is of interest in the rapidly growing organic sector of agriculture. In addition to its well-demonstrated use as a soil amendment, compost use has also been investigated in suppressing soil-borne plant diseases that can negatively impact some agricultural crops.

The soil amending materials regulated by the SACoP have been used primarily on small scale applications and have not yet been brought into widespread use on agricultural land in BC. Large ongoing programs are common elsewhere in Canada and throughout the Pacific Northwest. Our understanding of their use on agricultural land in BC is growing as they become more widely used; future editions of this document will contain additional information as it becomes available.

Photograph 27: Silage corn fertilized with biosolids

SYLVIS

13.1 Objectives

In agricultural applications, residuals are used to provide nutrients for plant growth, or some other demonstrable benefit to the crop on site such as pH adjustment and improvement of soil physical properties. Residuals must be land applied with the same careful management practices that are required when using manures and fertilizers. Application of residuals at excessive rates, at the inappropriate time or incorrect location can lead to poor crop performance, degradation of soil and/or degradation of water quality.

13.2 Notification

Part 4, Division 2 (Section 22) of OMRR and Section 9 of the SACoP provide information on notification requirements for application of regulated residuals.

Under OMRR, all applications of managed organic matter in volumes greater than 5 m^3 require notification of the Regional Waste Manager of the MoE. Under the SACoP, all applications of soil amendments in volumes greater than 5 m^3 require notification provided to the Regional Waste Manager of the MoE. Under both regulations, applications of residuals on agricultural land or in a drinking water supply area (applies to both surface and groundwater drinking water sources) require notification provided to the appropriate MHO. Applications on land in the ALR require notification provided to the ALC. It is recommended that local government with jurisdiction in the area in which the application is to occur also be informed.

13.3 Site Selection and Management

13.3.1 Soil and Site Suitability Guidelines for Agricultural Sites

Factors most likely to influence site selection for agricultural applications include soil texture and structure as they relate to soil infiltration, permeability, internal soil drainage, and trafficability. Sites with coarse to medium-textured soils and with adequate organic matter content are ideal for residual application. These soils usually have good infiltrability, permeability, and internal soil drainage. For more information on soil management on agricultural sites, consult the various soil management handbooks available from the BC Ministry of Agriculture and Lands.

13.3.1.1 Depth to Groundwater Table

Soil drainage is an important factor in site trafficability. Soils with an elevated groundwater table, particularly finer-textured soils, will have reduced ability to withstand the weight of heavy farm machinery. The OMRR requires that Class B biosolids and compost must not be applied to land where the groundwater table is within one meter of the soil surface at the time of application. Similarly, the SACoP requires that applications of pulp and paper residuals containing domestic sewage must adhere to the same depth to groundwater restriction. Where groundwater depth is of concern, residuals applications should be conducted to coincide with low water table levels.

Coastal sites usually have elevated groundwater tables beginning in late fall and continuing through winter and into late spring. Interior sites may be less restricted in late fall, depending upon frost and snowfall.

As an indication of the depth to groundwater, the qualified professional should observe the agricultural fields for the presence of standing water or assess the water level in drainage ditches. If no visual indicators are present, digging or core sampling to a depth of one meter is recommended. A periodic high water table can also be inferred by soil color. Dull gray or bluish colors in subsurface soil horizons indicate reduced or anaerobic (poorly drained) soil conditions, usually resulting from permanent water saturation. Soils with evidence of bright orange or red blotches (“mottles”) in the subsurface soil horizons indicate conditions of periodic inundation.

13.3.1.2 Soil Depth and Permeability

Soil depth or volume and the presence/absence of restricting or impermeable layers will also influence suitability of a site for residuals application. Soils that are shallow, have a high coarse fragment content, and either restricting or impermeable soil layers have less soil volume available to absorb and disperse added water and soil nutrients. These soils may also have a greater potential for surface runoff, surface soil erosion, or subsurface leaching losses.

Agricultural soils that have been puddled or compacted should be avoided as potential sites for residuals application due to their reduced soil infiltration, permeability, and internal soil drainage. Where cultivation of the site is possible prior to application these limitations may be reduced. Soils which have been puddled or compacted usually have fine soil textures and often the soil structure has been destroyed. Cultivation of sites that have been puddled or compacted may be limited by soil water content or depth to groundwater table.

13.3.1.3 Artificial Drainage and Nutrient Loss to Surface Water

Artificial tile drainage is often installed on agricultural lands to control soil water content, and to lower the level of the groundwater table. By lowering the level of the groundwater table and controlling the soil water content, the trafficability of the site is improved earlier in the season, allowing for a greater period of access to the site. Artificial drainage also allows earlier soil warming, better aeration and improved conditions for the growth of plant roots.

Because subsurface tile drains flow into open ditches which may then flow into bodies of surface water, care must be taken with the application of liquid residuals, particularly high nutrient residuals, where the potential exists for movement of liquid through the soil and into drains. Liquid residuals can move directly through the soil and into tile drains by way of soil cracks and macropores. On annually cropped fields, where the soil has not been tilled since the previous spring, liquid residuals can flow through soil pores and directly into drains within a short time following application. Annually cropped land that is tile drained should be disked prior to residual application to break up soil macropores and reduce the potential of direct movement into drains.

Phosphorus is undesirable in freshwater lake systems because it causes eutrophication, which depletes oxygen in fresh water. Phosphorus is relatively immobile in soil and does not leach in a similar manner as NO_3^-. Substantial amounts of P can, however, move into tile drains and into surface water under certain soil conditions. Small soil particles can move through the soil macropores, cracks and worm holes into tile drains following irrigation or rain. As the concentration of P in the soil increases, the amount of P moving into the drainage system adhered to soil particles increases. This problem is exacerbated on annually cropped land where the soil is left bare over winter, allowing development of worm hole networks and on clay soils where deep cracks form during dry weather. It is recommended that tile drained fields with an elevated concentration of P be avoided for application of high nutrient residuals, or that a P-based application rate be used on the site. For more information, consult the *BC Agricultural Drainage Manual*, available from the BC Ministry of Agriculture and Lands.

13.3.1.4 Irrigation

Irrigation of agricultural crops provides water to the crop during periods of soil moisture deficit. It is critical for crop production through much of the interior of the province, and for short periods in summer in the south coastal region. Irrigation should replenish the soil water in the top 60 cm of soil. If fields are over-irrigated, there is a serious potential for leaching of NO_3^- from the root zone throughout the growing season. Irrigation systems must be rotated around the field frequently enough to avoid over-watering the soil thereby reducing the potential for NO_3^- leaching below the root zone.

Over-irrigation can also cause surface sealing of the soil, which reduces the infiltration rate of water into the soil. The creation of a surface seal increases the potential for surface runoff and the risk of surface soil erosion. For more information, consult the *BC Sprinkler Irrigation Manual*, available from the BC Ministry of Agriculture and Lands.

13.3.1.5 Slope, Aspect and Topography

A discussion on slope, aspect and topography is presented in Section 10.2.5. The potential for surface runoff, surface soil erosion, and subsurface leaching losses increases on sloping sites. Soils situated on a slope which have been puddled or compacted, have a shallow soil volume, or have restricting or impermeable layers close to the soil surface have the greatest limitations for residuals application.

The risk of surface runoff and surface soil erosion increases as the slope angle and length increases. The potential for runoff is greater on sites with fine textured soils that have a slower infiltration rate as compared to coarse-textured soils. Site aspect also has an important influence on the potential for surface runoff on sites that experience significant snow accumulation in winter. Snow covered south facing slopes can melt quickly under warm, sunny conditions in early spring, leading to significant surface runoff.

Slope angle and uniformity also influence site suitability. Sites with long, uniform slopes have greater limitations than sites where the topography is broken and irregular. Sloping sites situated directly above a body of surface water have greater management challenges than sites sloping away from surface water.

Sloping sites that are vegetated have a greater ability to absorb and utilize applied water and nutrients than sites with bare soils. The potential for surface runoff or subsurface leaching losses is reduced on sloping sites that are vegetated.

Sloping sites may be utilized for application of residuals if management practices minimize surface soil erosion and reduce the potential for pollution of water sources. The risk of surface runoff and soil erosion increases as the slope angle and length increases. Runoff potential is greater on south facing slopes during snowmelt. Fine-textured soils absorb water more slowly than coarse-textured soils, and thus may have an increased risk of runoff and should be avoided. Avoid sites where a combination of these factors will increase the risk of surface runoff. The selection of sites with short irregular slopes that slope away from surface bodies of water, the selection of vegetated sites, or adoption of soil conservation practices on sloping sites with bare soil will reduce suitability limitations on sloping sites.

Soil conservation practices include the utilization of cross-slope or contour farming, where cultivation occurs across the slope, rather than directly down slope which may encourage rill erosion. The use of diversion terraces, or low ridges constructed at intervals across a slope will reduce the velocity of any surface runoff, trapping water and soil particles, and allowing more time for water movement into the soil. Creation of a vegetated spillway for any additional surface runoff will allow water to be removed from the slope without causing excessive surface soil erosion. The incorporation of crop residues on soils will also increase surface roughness and soil infiltrability, reducing the risk of surface runoff.

13.3.2 Buffers, Required Signage, Access Restrictions, and Site Access

For information on buffers, required signage, access restrictions and site access, refer to Section 10.6.3.

13.3.3 On-Site Storage

Section 10.6.6 discusses on-site storage requirements in detail. Refer to Part 4, Division 1 of the OMRR (Section 16) and Part 2 of the SACoP for on-site storage requirements. On-site storage requirements apply to Class A and Class B biosolids, Class B compost, fly ash, pulp and paper residuals and WTR only; there are no storage requirements for Class A compost, lime wastes or wood residues. It is recommended that these residual stockpiles be managed using the same requirements.

Residuals stockpiled at a site for a period of time before they are land applied must be managed to prevent runoff or leaching of contaminants from the stockpile. Buffers from watercourses must be observed in all areas of the province. In the areas of the province specified by the OMRR and the SACoP, managed organic matter and soil amendments must be covered from October 1 to March 31 to prevent leaching and runoff.

13.3.4 Crop Suitability and Growing Restrictions

There are grazing and growing or planting restrictions after application of residuals with a fecal coliform concentration of ≥ 1,000 MPN g^{-1} dw. The purpose of these restrictions is to prevent the direct ingestion of the residual by domestic animals and to allow time for pathogen reduction. After application of the residual to the soil, sunlight, lack of moisture, heat and other environmental factors facilitate pathogen mortality.

Domestic animal grazing is restricted for 60 days on sites that have received Class B biosolids or Class B compost with fecal coliform concentrations ≥ 1,000 MPN g^{-1} dw. Restricted animal grazing is recommended for 60 days for sites that have received pulp and paper residuals containing domestic sewage with a fecal coliform concentration ≥ 1,000 MPN g^{-1} dw. It is also recommended that harvesting of feed crops be restricted for 60 days.

On sites that have received Class B biosolids or compost, crops for human consumption with the edible portion located above ground cannot be grown for 18 months. If the harvested parts are located below ground, the crop cannot be grown for 38 months.

Planting restrictions pertain to pulp and paper residuals containing domestic sewage with a fecal coliform concentration ≥ 1,000 MPN g^{-1} dw. For sites applied with these residuals, the land owner must not allow the planting of food crops for 18 months if only the parts growing above the surface of the land are harvested or for 38 months if the parts growing below the surface are harvested for human consumption.

Due to the length of the growing or planting restriction period, residuals with a fecal coliform concentration ≥ 1,000 MPN g^{-1} dw are not suitable for use on land used to grow crops for human consumption. Livestock feed crops are suited for applications of these residuals provided that the recommended 60 day harvesting restriction is observed. The following section identifies management considerations for application to various feed crops.

There are no growing, planting or grazing restrictions for applications of Class A biosolids or for soil amendments that do not contain domestic sewage.

13.3.4.1 Forage Stands (grass or grass-legume) - Dryland or Irrigated, up to 40% Legumes

Fertilization of forage stands is a good agricultural use for high nutrient residuals such as biosolids and secondary pulp and paper residuals. Forage stands offer flexibility for timing of application. They require a substantial amount of N during a cropping season, and can make use of the gradually released N from these residuals in particular. Residuals can be applied to forage land when a field is ploughed and re-seeded in spring (or fall in dry parts of the province) provided there will be a 60-day period before the first cut is removed. They can be applied to existing forage stands provided that grazing and cropping are restricted for 60 days. In areas where the first cut of forage is taken off in late June or early July, early spring applications to existing stands are appropriate. When the first cut is removed in early or mid-May, spring applications may not allow for a sufficient waiting period. In dry areas of the province, fall applications on existing grass stands are acceptable providing there is minimal potential of runoff during spring snow melt. Fecal coliform containing residuals cannot be used as a fertilizer top-up between cuts as the inter-cropping period is too short.

Refer to Sections 13.4.1 and 13.4.2 for a discussion of application rates to use when renovating forage stands.

Applying residuals to existing grass swards requires special consideration. Residuals should be applied immediately following harvest. The application must not physically smother the grass stand; the stand can be irrigated following the application to wash the material off the grass and assist in moving nutrients into the soil.

Annual dry matter yield from a forage stand can vary from 1 t ha^{-1} from an older stand on a dryland site to 18-20 t ha^{-1} from an irrigated, intensively managed forage stand. Forage protein content can vary from a low of 8% to a high of 25%. Variations in yield and crop protein content can have a significant impact on the crop’s N requirement. Should yield and protein data be available, these values can be used to calculate the crop’s N requirement rather than average values provided in Table 12.

13.3.4.2 Pure Legume Stands and Mixed Alfalfa Legume Stands with > 40% Legumes

Alfalfa and other legume stands are not well suited for application of high N residuals (legume-grass mix stands containing up to 40% legumes are acceptable). The N-fixing capability of the legumes reduces the N requirement from fertilizer. If legume stands are fertilized regularly, they do not fix atmospheric N, and once heavy fertilization of a legume stand begins, fertilization is typically required for the life of the stand. A one-time application of biosolids or other high N residual will not provide sufficient nutrients for the lifetime of the stand, requiring the producer to continue to apply chemical fertilizer and not receive the benefits of the stand’s N-fixing capability. Legumes require a substantial amount of K that is not supplied in large quantities by biosolids (other residuals contain more of this nutrient); supplemental K fertilization may be required.

13.3.4.3 Silage Corn

Silage corn for livestock feed is a standard crop on most dairy farms in BC and is also suitable for biosolids or other high N residual. The long growing season of corn fits well within the recommended 60 day cropping restriction. The residual can be applied and tilled in prior to seeding and will provide most of the fertilizer nutrients needed by the silage corn during the growing season. The crop may require additional N fertilizer during the early rapid growth period and the residual may not be able to supply enough available N to meet the crop's needs during this time. This additional fertilizer N must be considered when determining the residual application rate.

The annual dry matter yield of a crop of silage corn can vary from under 5 t ha^{-1} to as high as 20 t ha^{-1}. The crude protein content of silage corn can vary from 4 to 20%. As with forages, a more accurate crop N requirement can be determined from historical crop yield and protein data than from average values such as are given in Table 12.

13.3.4.4 Cereal Forages

Cereals grown as 'green feed' for livestock feed are harvested whole before the grain matures. Oats and barley are the most common grains grown for this purpose, and they are either ensiled or dried and baled for winter livestock feed. Cereal forages can make excellent use of the nutrients in biosolids and other high nutrient residuals. As with silage corn, cereal crops may require supplementary N to meet crop requirements early in the growing season. This additional N must be accounted for in the residual application rate.

Typical dry matter yields of a single cut cereal crop for livestock green feed ranges from less than 2 t ha^{-1} to 12-14 t ha^{-1}. Crop crude protein content will range from 5 to 18%.

13.3.4.5 Grain (for livestock feed) and Grass Seed Crops

Grain and grass seed crops (provided the grain is grown as livestock feed) are well suited for application of harvest-restricted residuals (but cannot be used on sites where grain for human consumption will be grown within 18 months). As with silage corn, grain and grass seed crops may need supplemental N fertilizer early in the growing season to provide the concentration of available N the crop requires, and this will reduce the allowable application rate of the residual.

13.3.4.6 Rangeland

Refer to Section 13.7 for a complete discussion on the use of residuals on dryland range.

13.3.4.7 Other Crops

Other crops suitable for residuals with fecal coliform concentrations which are $\geq$ 1,000 MPN g^{-1} dw, include turf, ornamental plants and fibre crops. To minimize public contact with the residuals, a 60 day restriction period is recommended prior to distribution.

13.3.5 Vector Attraction Management for Class B Biosolids, Pulp and Paper Residuals with Domestic Sewage

Under OMRR, Class B biosolids must undergo a vector attraction reduction process at the treatment plant. If biosolids have not met this requirement, they must be managed on-site to reduce vector attraction. On most agricultural sites, the appropriate management method is to inject or incorporate the biosolids into the soil, or an alternate management method that accomplishes the same level of vector attraction reduction. Injection of biosolids is the preferred management method however, if biosolids are surface applied, they should be incorporated within 1 hour of application. The OMRR requires incorporation within 6 hours of application.

The SACoP requires that pulp and paper residuals that have been mixed with domestic sewage, and have a fecal coliform concentration $\geq$ 1,000 MPN g^{-1}, be managed on site to prevent the spread of disease and pathogens by vectors. The LAP must set out the specific management methods that will achieve this goal. On most agricultural sites, these residuals should be incorporated into the soil on site by tillage or injection. On remote and inaccessible sites, surface application without incorporation may be acceptable. The qualified professional must assess the site and determine the appropriate management method.

13.4 Application Rates of Residuals on Agricultural Land

Both the OMRR and the SACoP require that applications of residuals to land be made on an agronomic basis to provide a pre-determined concentration of nutrients to the crop, to meet defined soil conditioning goals or to provide benefit to the soil or vegetation on site. The types of organic matter regulated by the OMRR and the SACoP vary considerably in their characteristics and therefore in the basis for their application to agricultural land.

The various residuals regulated by the OMRR and the SACoP can be divided into three broad categories for application rate determination:

- high nutrient residuals which are applied to meet the N or P requirement of the crop on site including: biosolids, secondary pulp and paper residuals, some mixed pulp and paper residuals, WTR, and some types of compost;
- liming materials which are normally land applied to sites that require liming to bring the pH into the desirable range for crop production including: fly ash, lime residuals and lime-stabilized biosolids; and,
- high organic matter residuals that contain low concentrations of nutrients and have a high C:N including: wood wastes, primary pulp and paper residuals, paper recycling residuals, and some types of compost.

Generic information on developing application rates for each of these residuals is found in Chapter 10. Chapter 5 discusses the characteristics of each of the residuals and Chapter 10 discusses application rate determination for each type of residual; the information contained in those chapters will be required when developing agronomic application rates for agricultural applications and should be read before reading this chapter. This chapter contains supplemental information specific to applying these residuals to agricultural land, building upon the information provided in Chapters 5 and 10.

13.4.1 Nitrogen Based Application Rates of High Nutrient Residuals

Nitrogen is normally the rate-limiting nutrient for crop growth, and is the nutrient that is most likely to result in an adverse environmental impact when over-applied to soil. Applications of high nutrient residuals are normally based on providing the crop's N requirement for a single growing season. Under certain circumstances, such as when the soil P concentration on a site is elevated due to previous nutrient additions, the application rate may be based on providing the crop's P requirement. Section 10.4.1.2 provides an example of sites where a P-based application rate is advisable. In dry areas of the province, it is acceptable to provide the crop's N requirement for two growing seasons. Section 13.4.2 provides information on multi-year N application rates.

The following subsections outline the information needed, and steps required in calculating an application rate based on the various different nutrient management goals for the site. Refer to Chapter 10 for detailed background information and Section 13.4.8 for sample calculations.

13.4.1.1 Determining the Crop's Agronomic Nitrogen Requirement

An agronomic N application rate provides the crop's N requirement for one growing year. The agronomic N application rate is a function of the type of crop, its expected yield, the climate and growing season length, water availability to the crop during the growing season and the amount of available N in the soil. Table 12 lists the agronomic N requirements for forages, silage corn and cereals.

The crop's N requirement is based on:

- crop type - grass and grass-legume forage stands, silage corn or cereals cut as forage;
- expected yield - a combination of climate, water availability (irrigated crops have a higher yield), age of stand, and management;
- region of the province - Coastal and Southern Interior forage crops generally have a higher yield and protein content than those grown in the Central Interior or Peace regions; and,
- site fertility - sites with poor fertility will require more N to meet crop yield objectives because the soil will contain little residual N and there may be some immobilization of N following application of biosolids or other residuals.

For agricultural crops not listed in Table 12, information can be found in fertilizer guides or from a soil test fertilizer recommendation. If a more comprehensive method of determining the crop's N requirement is desired, or for more detailed information than is contained in this chapter, refer to the references provided in Section 13.9.

The crop's N requirement will depend partly on the past fertility of the site. The site's fertility must be assessed as high, low or very low before the crop's N requirement can be determined. To determine the N requirement of a crop to be grown on a high fertility site, refer to the values in Column 3 of Table 12. Requirements for crops to be grown on low and very low fertility sites are provided in Columns 4 and 5; assessment of low fertility sites is discussed below. The crop information required can be obtained from the producer.

13.4.1.2 Crop Nitrogen Requirement on High Fertility Sites

Fields that have been applied with manure annually and/or have received agronomic applications of fertilizer over many years will have high fertility. These soils contain a large pool of organic N as the result of previous nutrient applications; mineralization of the organic N pool provides a significant amount of N during the growing season. However, it is difficult to accurately predict how much N will be released from the soil's pool of organic N during a growing season. Therefore, it is assumed that a high fertility soil will mineralize approximately 20% of the N required by a crop, and that the remaining required N must be applied in fertilizer sources (fertilizer N, manure, residual). The crop N requirement values for high fertility sites in Table 12 are based on providing 100% of the N that will be taken up by a crop, even though the soil on a fertile site is expected to contribute a portion of the crop's requirement. This application rate adjustment is necessary as N assimilation by the crop is never 100% efficient, not all of the plant-available N in the soil (or that added in nutrient additions) will be utilized by the crop. The 20% applied in excess of actual crop uptake represents the crop's inefficiency of N utilization. If a cover crop or sward is turned under, it will mineralize additional N which must be considered separately. This is discussed below.

Most intensively managed fields in the South Coastal and Okanagan-Shuswap regions of BC will have high fertility, and can be assumed to provide the 20% of crop N as in Column 3 of Table 12. A site fertility assessment should be made before determining the crop's N requirement; sites with lower fertility will require additional N to compensate for the soil's inability to contribute a portion of the crop's requirements, and for immobilization of N.

13.4.1.3 Crop Nitrogen Requirement on Low and Very Low Fertility Sites

Sites that have received very little nutrient additions (chemical fertilizer or manure) in the years before proposed residual application, or that have poor fertility for other reasons will contribute a very small amount of the N required by the crop. Sites may be so N deficient that a significant amount of the added N becomes immobilized, resulting in a N deficient crop after fertilization. On these sites, the crop N requirement must be increased to account for N immobilization and to provide the additional N that is otherwise assumed to come from residual soil N. If the N requirement is not adjusted, crop yields may be significantly reduced.

A low fertility site is one that has received infrequent manure applications (e.g. every two years or less) and that has received only average chemical fertilizer application. On such a site, nutrient additions in chemical fertilizer or manure will have been sufficient to meet crop requirements, but not allow any build-up in the soil of nutrients. On this type of site, use the crop N requirement values listed in Column 4 of Table 12.

A very low fertility site is one that has received only very small, infrequent applications of manure and small amounts of chemical fertilizer yearly (35 kg ha^{-1} of N or less). On these sites, historical nutrient additions will have been lower than crop requirements, allowing for a minimal organic N pool in the soil. Sites that have been recently cleared from forest or brush and minimally fertilized will have very low fertility. Sites that once received regular nutrient additions but that have been cropped for several years without the addition of nutrients may have very low fertility. Fields in alfalfa or another legume that is N-fixing cannot be considered to have very low fertility. On a site assessed as having very low fertility, use the crop N requirement values found in Column 5 of Table 12. Once a site has been amended with N (as in Column 5), it is assumed to be a fertile site. It should not require amendment unless several years of cropping occur on the site without adequate nutrient addition.

Table 12: Nitrogen requirements of perennial forages, silage corn and cereals for the Central and Southern Interior of BC and Coastal BC

Column 1	Column 2	Column 3	Column 4	Column 5
Expected yield of crop	Expected yield of crop	High (normal) fertility site	Low fertility site	Very low fertility site
t ha^{-1} (D.M.)	t $acre^{-1}$ (D.M.)	N required (kg ha^{-1})	N required (kg ha^{-1})	N required (kg ha^{-1})

Grass and Grass-legume mix stands for hay or silage production (up to 40% legumes)

A. Coastal and Southern Interior of BC (dry matter yield)
(ave. protein content = 16%)

4	1.8	100	150	200
6	2.7	155	205	255
8	3.6	205	255	305
10	4.5	260	310	360
12	5.4	310	360	410
16	7.2	410	460	510

B. Central Interior and Peace (dry matter yield)
(ave. protein content = 12%)

4	1.8	80	130	180
6	2.7	115	165	215
8	3.6	150	200	250
10	4.5	190	240	290
12	5.4	230	280	330

Silage corn - whole province (dry matter yield)
(ave. protein content = 8%)

10	4.5	130	180	230
15	7	190	240	290
20	9	260	310	360

Cereals – 1 cut, whole crop cut for forage (dry matter yield)
(ave. protein content = 11%)

4	1.8	70	120	170
6	2.7	110	160	210
8	3.6	140	190	240
10	4.5	180	230	280
12	5.4	210	260	310

Adapted from 'Environmental Guidelines for Poultry Producers, 2nd Edition' BCMAF, 1997

Notes:

- Crop N requirement values in column 3 assume the field has been regularly supplied with nutrient additions in manure or fertilizer; 20% of crop's N requirement assumed to come from soil organic N. If site has never or infrequently received nutrient additions, see Section 13.4.1.3 and use the values in Columns 4 and 5.
- If the crop protein level is significantly different than the values given above, recalculate N requirement using correct protein level (crop protein = crop N level x 6.25).
- Crop N requirement values assume no volatilization losses of NH_3. If volatilization losses are expected, use values from Table 12 and increase application rate accordingly.

13.4.1.4 Accounting for Other Sources of Nitrogen

Other sources of N available to the crop must be considered when determining a residual application rate. Crop N requirements provided in Table 12 assume that the site has been fertilized frequently and adequately; the amount of residual N that previous amendments will contribute to the crop has been factored into the crop N requirement. Therefore it is not necessary to consider the N contribution from previous manure or residual applications or previous fertilization.

A recently ploughed-down legume or green manure crop will contribute some N to the crop. Nitrogen addition from these crops is normally between 35 and 110 kg ha^{-1} yr^{-1}, depending on whether a grass or legume cover crop was grown and the yield of the crop. A value in the middle of the range is appropriate if specific information on the ploughed-down crop is not available.

In the Interior, an application of liquid or solid manure made to the site since the previous year's crop was taken off (such as a fall manure application) will contribute substantial N to the following year's crop and this contribution must be subtracted from the residual N requirement.

If fertilizer N is to be used during the cropping season, this must be subtracted from the total N requirement to be supplied by the residual. For example, a small amount of fertilizer N may be applied as a side-dress for silage corn when the crop is in its rapid growth stage.

13.4.1.5 Nitrogen Available to the Crop from the Residual

Analyzing the residual for total N (), NH_4^+, NO_3^- and total solids will provide the required information to determine the amount of N available from an application of the residual. The inorganic fraction (the NH_4^+ and NO_3^-) will potentially be available for crop growth in the year of application. A portion of the organic fraction (total N less NH_4^+ and NO_3^-) will be mineralized to available N in the year of application. The sum of the inorganic fraction plus the mineralized organic N is the amount of N that will be available from the residual in the year of application. Values are normally expressed as kg per dt.

The fraction of organic nitrogen that will mineralize in the year of residual application will vary with the type of residual to be applied, application method, climate and rainfall (including irrigation). Table 10 contains estimated mineralization rates of the organic fraction of biosolids N in the year of application for varying cropping and climatic conditions throughout BC. Organic N will mineralize 10 to 40% in the year of application, depending primarily on climate and growing season moisture. First year mineralization rates do not differ significantly between aerobic and anaerobic biosolids, or between biosolids that have been dewatered, air-dried or heat-dried. Lagoon stored or composted biosolids mineralize significantly less N than fresh biosolids. Mineralization of N from lime-stabilized biosolids is typically at the high end of the ranges provided.

In the two years following application, N will continue to be released from biosolids but at a much slower rate. It is estimated that in the year following application, 10% of the remaining organic N will be mineralized and in the third year, 5% of the remaining organic N will be released. The remaining organic N will become part of the pool of soil organic matter.

Specific information on the mineralization of N from other high nutrient residuals is not available. It is assumed that mineralization of N in other residuals is similar to or slightly less than from biosolids.

13.4.1.6 Volatilization Losses of Nitrogen from Residuals during Land Application

Much of the NH_4^+ from residuals can be lost during land application depending on the moisture content of the material, whether the residual is incorporated into the soil, and temperature and wind speed on the days following application. Table 13 can be used to estimate NH_3 volatilization losses during and following residual application. This data is from studies on biosolids but is expected to be relevant to similar high nutrient residuals.

Table 13: Estimated ammonia volatilization losses from biosolids applied to agricultural land

Application method	**Volatilization rate (% of NH_3 loss)**	
	Liquid	Dewatered
Incorporation by tillage		
0-2 days to incorporation	20	40
3-6 days to incorporation	30	50
> 6 days to incorporation	40	60
Injected	5	5
Composted or drying bed biosolids	5	5

Adapted from *Managing Nitrogen from Biosolids*. Henry *et al.,* 1999.

13.4.2 Application Rates Based on Multi-Year Nitrogen Additions

For most applications of residuals, the appropriate application rate provides the crop's N requirement in the year of residual application. However, in certain cropping situations it is acceptable to exceed the one-year agronomic application rate. In the Interior of BC where annual precipitation is low and soils are frozen for the winter months, there is little potential for leaching loss of NO_3^- during or after the growing season. Although the potential for leaching exists under irrigated fields, normal irrigation will replenish the moisture in the top 60 cm of soil only and thus will not transport NO_3^- out of the root zone. Much of the residual soil NO_3^- will be available for crop growth the following spring.

In dry areas of the province, it is acceptable to use an application rate of residual equivalent to up to two years N requirement for the crop when renovating forage fields. For agricultural applications, it is not acceptable to apply more than a two year requirement for N. This practice allows the producer to provide the crop's nutrient needs for two years following seeding, and till the residual into the soil at the time of seeding where the nutrients are fully accessible to the growing crop. In subsequent years until the field is reworked, chemical fertilizer can be surface applied to meet crop nutrient requirements.

In the year a field is reseeded, the forage yield will be significantly lower than during the following three or four years. A typical yield of forage grass or grass:legume mix in the Interior is 4-8 t ha^{-1} (dw) in the establishment year and 6 to 12 t ha^{-1} (dw) in the years following, depending on whether or not the field is irrigated, and on the level of fertilization. When calculating an application rate based on a two-year N requirement, the lower N requirement during the establishment year should be considered. The producer can estimate the expected yield for the forage stand in the establishment year and years following.

When the residual application rate is based on a two-year N requirement, the following approach is recommended:

- Forage should be tested for NO_3^- at harvest if forage NO_3^- is suspected to be elevated. The forage may accumulate a high concentration of NO_3^- in the year of residual application, with excess NO_3^- in the soil.
- Caution should be used if high rates of irrigation are used. Ensure that irrigation on site is not excessive. If this is not possible, do not use a two-year application rate. There will be excess NO_3^- in the soil profile through the growing season from the increased application rate that may move down into groundwater if the site is over-irrigated.
- Two-year application rates should not be used if the proposed site is on a river or stream floodplain where seasonal flooding or high water table may occur.
- Coarse-textured soils (sandy, high percentage of coarse fragments) will be more susceptible to leaching losses than fine-textured soils, facilitating NO_3^- movement. This is a consideration in conjunction with irrigation.

If the forage is over-seeded with a cereal cover crop in the year of planting, the excess available N during the first growing season may cause the cereal to grow excessively tall and to lodge before it can be harvested.

13.4.3 When to Use Phosphorus Based Application Rates

When applying high P residuals on sensitive sites with an elevated background soil concentration of plant-available P, a P-based application rate should be considered. See Section 10.4.1.2 and the discussion below. In addition, application rates of Al and Fe-containing WTR should be partially P based as they contain a significant amount of P and can bind soil available P. Section 10.4.1.2 provides more information on application rates of these residuals.

When a residual such as biosolids is applied to meet the N requirement of a crop, P may be applied at twice the amount required by the crop. Because P is immobile in the soil and crop requirements are low relative to requirements for N, the soil concentration of P can become excessive if amendments are regularly applied to a site (e.g. frequent applications of manure). On sites that have an elevated soil concentration of P and that are considered sensitive (i.e. there is risk of transport of P from the site into surface water), it is recommended that a P based residual application rate be used. In this case, only as much P as the crop is expected to use in the current growing season should be applied to the site. The soil P concentration should not continue to increase. This will result in an application rate of residual of less than half of what would be applied to meet the N requirement. Sensitive sites with an elevated soil concentration of P should be avoided as residual application sites in the context of soil P concentrations because the appropriate application rate may be so low that there will be little benefit to the crop in terms of other nutrients, particularly N.

Refer to Section 10.4.1.2 for information on developing an application rate based on meeting the P requirement of the crop on site. Refer also to Section 10.3.2 for a discussion of the forms of P in soil and residuals. Section 13.3.1.3 provides a discussion of P movement into surface water through tile drains.

13.4.4 Use of Liming Amendments on Agricultural Land

Fly ash contains a substantial amount of all macro and micro nutrients except N; care should be taken to ensure that the application of ash does not oversupply the soil with nutrients or induce a nutrient imbalance. Sites already oversupplied with nutrients, particularly K and B, should be used with caution as an excess of these nutrients can negatively impact vegetation quality and livestock health.

Refer to Section 10.4.3 for information on developing an application rate for an alternative liming material and for specific information on managing the various liming materials regulated under the OMRR and SACoP.

13.4.5 Use of High C:N Residuals on Agricultural Land

Refer to Section 10.4.2 for general information on high C:N residuals and how to develop application rates for such materials.

13.4.6 Balancing Soil and Residual Phosphorus and Potassium Additions

Residual and receiving soil concentrations of plant available P and K should be assessed when determining an application rate. Receiving soils can have an excess or deficiency of these nutrients. In most cases, biosolids contain insufficient K to meet crop requirements, and supplementary fertilizer will be required unless soil reserves are adequate. Other residuals such as wood ash contain a substantial amount of K, and consideration is required to avoid excess additions to the soil.

Some sites, due to long term addition of organic amendments and fertilizer, may have elevated soil concentrations of plant available P and K. Such sites are identified through soil sampling prior to the residual application. Request the laboratory perform plant-available P and K soil analyses. This data will be provided in mg per kg and the soil concentration typically rated as low, medium, high or excess. Sites with crop available P and K in the high to excess range have sufficient soil reserves to meet crop requirements for at least one growing season.

A fertilizer recommendation for P and K for the crop to be grown on the site should be requested with the soil analysis, and considered in determining whether supplemental fertilizer will be required in addition to the nutrients provided by the residual. The amount of P and K that will be applied in the residual should be determined and compared with the fertilizer recommendation for these nutrients.

In general, most of the K in residuals is plant available, however, an analysis of plant-available K will give a more accurate determination of availability. The fertilizer recommendation will assist in determining if supplemental K fertilizer is required to assure normal crop yield. Sites with long-term nutrient additions may have an elevated soil K concentration sufficient to make up the shortfall in the application for one or two growing seasons.

Fertilizer recommendations are given in phosphorus pentoxide (P_2O_5) and potassium oxide (K_2O) equivalents. Residual laboratory data is given in elemental concentrations of N, P and K. To convert P_2O_5 to elemental P, multiply by 0.44 and to convert K_2O to elemental K, multiply by 0.83.

13.4.7 Soil pH and EC

It is important that applications of high nutrient residuals such as biosolids, secondary pulp and paper residuals and WTR be made to agricultural soils within the pH range of 6 to 7.5, particularly if the residual has elevated concentrations of aluminium and/or Fe. Solubility of some trace elements increases as soil pH decreases, particularly below pH 5. Low pH soils should be amended with lime to bring their pH into the acceptable range for the production of agricultural crops before being amended with these residuals.

The optimal use of liming residuals is to increase the soil pH. A residual which has a high pH and contains a significant amount of nutrients, should be applied to a low pH site which is also nutrient deficient.

Avoid sites with an elevated EC.

13.4.8 Sample Calculations for Nitrogen-based Application Rate of Biosolids

The following is a six step sample calculation for the determination of a N based biosolids application rate.

Step 1 Gather information on the biosolids and the crop

Biosolids information

Type	**Anaerobically digested, dewatered**	
Nutrient concentrations	Percent	kg $tonne^{-1}$ (dry)
Total Kjeldahl N (TKN)	4.3	43
NH_4^+-N	0.86	8.6
NO_3-N	0.08	0.8
Organic N (TKN – NH_4^+-N)	3.44	34.4
Application method	Surface applied	Disked in 2 days later

Crop information

Type	Forage grass, irrigated
Area of province	Southern interior
Expected yield	8 t ha^{-1}
Site fertility	Low
Crop N requirement	255 kg ha^{-1} available N
Supplemental fertilizer N used?	No
Green manure ploughdown?	No

Step 2 Determine crop's N requirement from Table 12 or fertilizer guidelines, less N additions from supplemental fertilizer N or green manure ploughdown.

Crop N requirement	255 kg ha^{-1} available N from biosolids
Less other N additions	0
Total required available N from biosolids	255 kg ha^{-1}

Step 3 Calculate the amount of available N per dt of biosolids

Use the kg $tonne^{-1}$ data for Organic N, NH_4^+-N and NO_3-N from Step 1	Organic N = 34.4 kg $tonne^{-1}$ NH_4^+-N = 8.6 kg $tonne^{-1}$ NO_3-N = 0.8 kg $tonne^{-1}$
A. Mineralized organic N = kg $tonne^{-1}$ x mineralization rate (Table 10)	Available organic N = 34.4 kg $tonne^{-1}$ x .3 (30% min. rate) = 10.3 kg $tonne^{-1}$
B. Available NH_4^+-N = kg $tonne^{-1}$ x fraction not volatilized (Table 13)	Available NH_4^+-N = 8.6 kg $tonne^{-1}$ x 0.6 (40% volatilization loss) (100% - 40% = 60%) = 4.3 kg $tonne^{-1}$
C. Available NO_3-N = kg $tonne^{-1}$	Available NO_3-N = 0.8 kg $tonne^{-1}$
Total available N in biosolids = A + B + C above	Total available N in biosolids = 10.3 + 4.3 + 0.8 = 15.4 kg $tonne^{-1}$

Step 4 Calculate application rate of biosolids

Crop N requirement (kg ha^{-1})	From step 2: crop N requirement = 255 kg ha^{-1}
Available N in biosolids (kg $tonne^{-1}$)	From step 3: available N in biosolids = 15.4 kg $tonne^{-1}$
Application rate of biosolids (tonnes ha^{-1}) Correct to 'as-produced' basis with biosolids moisture content	Appl. rate = 255/15.4 = 17 t ha^{-1} (dry)

Step 5 Calculate the application rate of P and K and compare with soil test values

Step 6 Calculate trace element additions. See Section 10.5 for information on calculating trace element additions and projected trace element soil concentrations.

13.5 Application Technology

Biosolids, liquid and dewatered, are applied to agricultural land using many different types of equipment adapted from that used for manure application. Additional information on application equipment and methods is provided in Section 10.7.2.

Regardless of whether the residual to be spread is liquid or dewatered, the most environmentally sound method of application is to inject the residual (liquids only) or surface apply the residual (liquid or solid) followed immediately by incorporation by disking or plough down of grass sward. Both of these techniques maximize the recovery of nutrients, minimize odours and vector transmission concerns and minimize the potential of runoff into surface water.

13.5.1 Vacuum Tanker with Splash Plate

Compared to alternative methods, this method of application can result in increased odours (and potential vector attraction) and loss of NH_3. If spreading residuals using this method, avoid spreading on windy days, and monitor buffer areas carefully to ensure that spray drift remains within the application area.

13.5.2 Injector

Odours, vector attraction and nutrient loss are minimized with this application equipment. However, the injector can only be used on well-cultivated agricultural land where rocks and other hazards are not present.

13.5.3 Sleigh Foot

With this type of applicator, the residual can be deposited beneath an existing forage stand, reducing smothering and contamination of the stand. This method reduces odours and spray drift, and conserves nutrients by placing the material directly on the soil surface. Although not widely available in BC, this technology is appropriate for both manure and residual applications.

13.6 Seasonal Considerations in Timing of Residual Application

Seasonal considerations in the timing of residual applications are particularly applicable to high nutrient residuals (e.g. biosolids, pulp and paper residuals, high nutrient compost) as they have a high N content and are organic-source fertilizers. However, there are seasonal issues with the application of all of the residuals regulated under the OMRR and the SACoP, and the relevant portion of these guidelines also should be considered by a qualified professional when land applying such residuals.

A general discussion on climate and seasonal considerations for land application of residuals is provided in Section 10.6.2. Specific seasonal recommendations by month for agricultural applications are included in the following section. These are adapted from *Environmental Guidelines for Poultry Producers in BC* (Van Kleeck, 1997).

13.6.1 Coastal and Vancouver Island Regions

13.6.1.1 February and March

If the land is subject to flooding and/or runoff, residuals should not be applied if there is the potential of runoff entering watercourses. If runoff is not a concern, up to approximately 30% of the annual nutrient requirement can be applied to established grass stands or over-wintering cover crops. Residuals should not be applied to any other land, particularly bare land. Residuals should not be applied to frozen or snow-covered land if there is a danger of runoff during spring thaw.

If applying residuals with a fecal coliform concentration ≥ 1,000 MPN g^{-1}, applications to perennial forage crops should occur as early as possible within this time period due to the required grazing restrictions and recommended harvest restrictions.

13.6.1.2 April and May

These months are preferred for residuals application. The application rate must meet crop N requirements, and the restrictions given in the OMRR and the SACoP for residuals containing a fecal coliform concentration of ≥ 1,000 MPN g^{-1} if applicable.

13.6.1.3 June to August

Residuals application during these months poses little environmental risk. For harvest-restricted residuals, application must be carefully coordinated with the existing cropping schedule to comply with the restrictions given in the OMRR and the SACoP for residuals containing a fecal coliform concentration of ≥ 1,000 MPN g^{-1} if applicable.

13.6.1.4 September and October

Actively growing forage stands that are well drained and not subject to flooding can receive residuals during these months; no more than 25% of the crop's annual N requirement should be applied to grass stands. High nutrient residuals can be applied to cover cropped land, provided that the cover crop was well established before September 1. The cover crop will utilize the nutrients contained in the residual. The application rate on cover cropped land must reflect the low N requirement of a cover crop late in the fall. Residuals should not be spread on bare land during these months as soil and climate conditions are ideal for nutrient movement.

13.6.1.5 November to January

Residuals should not be applied during these months. With the onset of winter, crop growth slows so there is very little requirement for nutrients. Extremely high rainfall in this region results in wet soils and access difficulties. High rainfall also causes flooding and increases the potential for runoff into watercourses. All of these factors combine to make this the least desirable time of year on the south coast to apply most residuals.

13.6.2 Northern, Central and Southern Interior of BC

13.6.2.1 April, May and June

These months are preferred for residuals application. There are no crop restrictions except that the application rate must meet crop N requirements, and the restrictions given in the OMRR and the SACoP for residuals containing a fecal coliform concentration of $\geq$ 1,000 MPN g^{-1} if applicable.

13.6.2.2 June to August

Residuals application during these months poses little environmental risk. If applicable, the restrictions given in the OMRR and the SACoP for residuals containing a fecal coliform concentration of $\geq$ 1,000 MPN g^{-1} must be adhered to. This may limit the use on established crops.

13.6.2.3 September and October

Frozen soils and low winter precipitation in the Interior of BC limit winter loss of NO_3^- due to leaching. Residual application to all agricultural land during these months is acceptable as most of the nutrients will be available for the crop the following spring. Avoid wet areas and areas close to watercourses where spring flooding or runoff during snowmelt may occur.

13.6.2.4 November to March

There is a high risk of contaminated runoff during spring snowmelt from residuals applied to frozen or snow-covered ground. In most cases, residual application should not be considered when the ground is snow-covered. If field access is possible, application should only be considered on fields where there is no danger of runoff occurring during snowmelt. Frozen or snow-covered fields that receive residuals should be level or have a shallow slope, be distant from water courses, have medium textured soils, have a northern exposure and be well covered with vegetation. Ensure seasonal watercourses are protected by adequate buffers.

Snowmelt occurs up to one month earlier in the southern interior than in North Central BC. In more southerly areas of the interior, late February and March may be acceptable months for application of a residual provided that snowmelt is complete and that the soil is dry enough to support vehicle traffic without damage. Professional judgment must be used in determining the acceptability of application during these months.

Due to the recommended 60 day crop harvest restriction for residuals containing a fecal coliform concentration of $\geq$ 1,000 MPN g^{-1}, applications to perennial forage crops should occur as early as possible in spring, provided that there is no danger of flooding or surface runoff.

13.6.3 Interior Wet Belt (Salmon Arm and Areas of the West Kootenays)

Consideration should be given when spreading residuals on frozen or snow-covered ground. The heavy winter snowpack in these areas can result in higher risk of runoff into adjacent watercourses with spring snowmelt. Seasonal watercourses must be adequately protected with buffers.

13.7 High Nitrogen Residuals - Application to Grassland Range

Biosolids have been routinely applied to BC grasslands for fertilization since biosolids application programs began in the province, and have been shown to increase productivity of the rangeland. The following discussion provides recommendations for applying biosolids to BC grasslands to enhance range production and minimize the risk of range degradation. To date, other residuals have not been used extensively to fertilize rangelands; of those regulated under the SACoP, secondary pulp and paper residuals may also be a suitable fertilizer source for rangeland.

In BC, rangeland application of biosolids occurs on the natural grasslands found throughout parts of the Southern Interior, Cariboo and Chilcotin. These grasslands are used for cattle grazing in early spring before higher elevation grazing in forested areas is available, and again in some instances in fall before livestock return to the home ranch. They also provide an important winter food source for bighorn sheep, deer and elk. The grassland ecosystems are fragile; they exist in a very arid climate, with hot summers and cold winters. Vegetation is adapted to these extreme conditions. Natural vegetation consists of bunchgrasses (a variety of mostly perennial grasses) and forbs.

Biosolids application on rangelands will increase the yield, digestibility and protein content of forage. A one-time application of biosolids can provide benefits in terms of increased yields for as long as five years due to an increased supply of nutrients, and improved soil water holding capacity. Biosolids are surface applied on rangeland without incorporation unless the site is being renovated for weed control and to re-establish vegetation cover. Leaching of nutrients in this ecosystem is minimal as annual precipitation is low. However, the potential for surface runoff during spring snowmelt is a concern, as is the establishment of undesirable species on the range site. Managed organic matter is most often applied to degraded rangeland to improve the re-growth and establishment of native vegetation.

13.7.1 Site Selection

With overgrazing and the introduction of non-native species, the vegetation on many of the bunchgrass ranges has changed. Knapweed (*Centaurea* sp.) and other noxious weeds are serious problems at many sites, and sagebrush and annual grasses at some sites dominate perennial bunchgrasses.

Site selection for residuals application on grassland range is important. Applications to sites in poor condition due to an invasion of non-native species such as knapweed (*Centaurea* sp.) will encourage weed growth. Application to these sites is not recommended. Sites in poor condition due to overgrazing with only a slight weed infestation may benefit from residuals application in terms of improved range quality; the residuals may provide a competitive advantage to grasses and forbs. Alternatively, on similar sites, application may exacerbate weed infestation. Preferred sites are in fair to good condition, without a weed problem. Degraded range areas that are to be renovated and reseeded with a non-native grass such as crested wheat grass (*Agropyron cristatum*) are excellent candidates for application; the seeded species will effectively compete with the weeds, and the residuals can be tilled into the soil. Sites in excellent natural condition should not receive residuals unless it can be demonstrated that there is a significant benefit to the land and vegetation.

Topography will largely determine where biosolids can be applied. Access will be limited to relatively level, easily accessible sites. Required buffers from surface and groundwater, and from roads and neighbouring property must be observed. Signage and access restriction requirements must be adhered to. Rangeland that has received Class B biosolids must not be grazed for 60 days following application.

13.7.2 Application Rates

Nitrogen application rates on dry grassland range in Southern BC are not based on the agronomic application rate basis. Nitrogen removal from the site during grazing by cattle is very low - under 50 kg N ha^{-1} per year. Bunchgrass range in excellent condition yields 580 to 1,300 kg per ha of forage dry matter per season and at an average protein content of 12%, only 25 kg per ha of N is harvested during grazing. Most of the N is returned to the site in feces and urine. There is the potential for fertilized range to produce higher yields than from the unfertilized range discussed previously, however yield ultimately is limited by available soil moisture once adequate N has been provided. Thus it is unlikely that N removal from the site will approach 100 kg N ha^{-1} per year.

Application rates on range must be made on the basis of providing a long-term source of nutrients to the grassland with minimal risk of environmental damage due to grass smothering, or runoff of residuals constituents. This reduces the environmental degradation that would occur with annual fertilization. Based on current knowledge, the maximum application rate of biosolids on grassland range sites in Southern BC is an application made no more frequently than every 5 years, providing 200-250 kg of available N in the year of application.

13.7.3 Application Timing

October, November and December are the preferred months for rangeland application, with the later fall months preferred. Cold air and soil lowers microbial activity and reduces volatilization losses of N. Late fall applications will depend on the presence of snow. Snowmelt the following spring will move nutrients, especially N, into the soil. Spring applications can have the effect of smothering vegetation, and unless sufficient rain falls during the spring, nutrients may not move into the soil where they can be accessed by plant roots.

13.8 Post-application Monitoring of Residual Application Sites

If a residual is applied to a site at the agronomic rate there is no requirement in the OMRR or the SACoP to provide a post-application monitoring plan in the LAP or to implement post-application monitoring of the site. However, if the proposed application rate of residual exceeds the agronomic rate, a post-application monitoring plan for the site must be included in the LAP.

It must address any potential changes in soil and vegetation quality as the result of the application.

Although there is no requirement for site monitoring if agronomic application rates are used, it is advisable. Sampling of soil, vegetation and water can provide information on post-application soil, vegetation and water resource qualities. The following section discusses some parameters specific to agricultural applications.

13.8.1 Monitoring Soil Nitrate

The soil NO_3^- concentration in the fall can indicate how closely the crop's N requirements were met. The concentration of NO_3^- in the soil of the receiving site can be monitored in the fall after crop growth has slowed or stopped. A high fall soil NO_3^- concentration indicates that there was excess plant-available N during the growing season while the opposite situation indicates that the crop's needs were closely met or that there was insufficient N available. In high rainfall areas of the province, NO_3^- can leach out of the root zone, and eventually into groundwater with fall and winter rains. In dry areas of the province where soils are frozen in winter, NO_3^- will remain in the soil profile throughout the winter and be available for crop uptake the following spring. In these areas, high soil NO_3^- in fall is not a serious concern but should be considered when making N application recommendations for the following season.

To measure residual NO_3^- accurately, sampling must be done in the window between the time crop growth slows and fall rains begin, usually late September in South Coastal BC. If this sampling window is missed, residual NO_3^- may have moved down in the soil profile and deep sampling will be required to correctly characterize the soil NO_3^- concentration.

Fall soil NO_3^--N of 100 kg per ha or more is considered high; if soil samples taken during the critical fall period contain a NO_3^- concentration higher than 100 kg per ha NO_3^--N (top 15 cm of soil), it is likely that the application rate of residual was too high.

13.8.2 Monitoring Soil Trace Element Concentrations

Monitoring soil for trace elements following residual application is not usually required. If residual applications are made on an agronomic basis, the amount of any one trace element added to the soil will be small relative to the soil's background concentration of that trace element. As well, variability in sampling and analysis can obscure small changes in total soil concentrations.

If it is necessary to monitor soil trace element concentrations post-application, this should be done by re-sampling the field using the same methodology and analyses as with the pre-application sampling.

13.8.3 Monitoring Vegetation Quality

13.8.3.1 Crop Protein

The application of high nutrient residuals to established grass and grass-legume forage stands can improve forage quality. In the year of residual application, forage will have substantially higher protein than in previous or following years, especially if fertilization of the site has been minimal prior to residual application. Crop protein level in the year of residual application may increase from as low as 8-10% to as high as 16- 18% crude protein. An analysis of the forage will indicate the protein level. This high quality forage should be utilized by the producer and fed accordingly. Animals in late pregnancy or in lactation make best use of the extra protein in the forage. Alternatively, it can be fed to supplement feed of marginal quality. Forage protein level will decline in years two and three, but still remain elevated above the concentration prior to residual application.

13.8.3.2 Crop Nitrate Concentration

A detriment of improved forage quality following high nutrient residual application is the potential that the forage contains an elevated NO_3^- concentration. Silage corn and cereal 'green feed' can also be affected. In the presence of an abundant soil supply of NO_3^-, forage will accumulate elevated concentrations of NO_3^-. Many environmental factors determine the quantity of NO_3^- forage will accumulate, with soil concentration being the most important. On well-fertilized sites receiving high nutrient residuals, or when the application rate is above the recommended agronomic rate, high NO_3^- forage may occur. Elevated NO_3^- in feed can cause livestock death at very high concentrations and reduce productivity at slightly elevated concentrations.

If biosolids or other high N residuals are applied to high fertility sites (sites that have received fertilizer, manure or other high nutrient residuals frequently), forage produced in the year of application should be routinely analyzed for NO_3^-. To convert NO_3^--N to the NO_3^- ion form, multiply value by 4. All forages containing less than 1,700 ppm NO_3^--N (0.17%) are safe for livestock. Conserved forages (hay or silage) with greater than 1,700 ppm NO_3^--N are potentially toxic. Hay poses a greater risk than silage; the ensiling process reduces NO_3^- concentrations by over 50%. High-risk forages could be ensiled. Forage fed as green feed (forage that is cut and fed immediately) that contains greater than 3,400 ppm NO_3^--N (0.34%) is potentially toxic. Grazing land containing 4,500 ppm NO_3^--N (0.45%) can be toxic to cattle. For a more complete discussion of NO_3^- in forages, consult *Advanced Forage Management* (Bittman *et al.,* 1999).

13.8.3.3 Forage Copper Content

Crops may have slightly elevated concentrations of some trace elements following residual application as a result of the addition of trace elements in the residual. Normally, trace element concentrations will not be elevated sufficiently to negatively impact the health of livestock consuming the vegetation.

An exception to this is copper and biosolids; biosolids containing high concentrations of copper (>1,500 ppm) can result in forage that contains an elevated concentration of copper in the year of biosolids application only. In subsequent years vegetation copper typically returns to pre-residual concentrations. The other residuals regulated by the OMRR and the SACoP typically do not contain such high concentrations of copper and elevated foliar concentrations are not anticipated.

Copper toxicity in sheep (not cattle) can occur when forage, containing as little as 15 ppm copper, is fed for an extended period of time. Forage sampling and testing for copper can determine if concentrations are sufficiently elevated to be of concern, or suspect forage can be supplemented with other low copper containing forage to minimize any potential problems. Elevated forage copper is not a concern for cattle; their tolerance level is 100 ppm in the ration.

13.8.4 Groundwater Quality

Residuals applied at an agronomic rate should not affect groundwater quality. If there is concern that surface runoff has entered a well near the application site, the well can be tested for parameters of concern including fecal coliform or NO_3^-. Unless pre-application sampling of well water or groundwater has been completed it is difficult to determine if contamination occurred prior to residual application (such as from manure application or leaking of domestic sewage) or the result of the application. If groundwater contamination is a concern, sample water for parameters prior to residual application to establish pre-application water quality. Note that the concentration of certain parameters in groundwater can fluctuate throughout the year. Sampling of groundwater should be completed immediately before and shortly after residual application

Deep soil sampling for soil NO_3^- can be conducted on sites where there is the potential for NO_3^- from a residual application entering groundwater. Soil samples should be collected from below the root zone – to as deep as 1-2 m in several depths to determine soil NO_3^- concentration and movement.

13.8.5 Surface Water Quality

Buffer zones between residual application areas and watercourses are designed to prevent the contamination of surface water from runoff. However, surface water can be monitored if there are unique concerns regarding water quality. Obtaining accurate data when sampling surface water is difficult, and a monitoring plan that also assesses water quality upstream from the application site is required. Contaminants of concern with surface runoff are typically NH_4^+-N, pathogens and P. It is beyond the scope of these guidelines to outline procedures for monitoring surface water quality; a qualified professional with expertise in this area should be consulted.

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14 Considerations for Silvicultural Applications

This chapter outlines BMPs for the environmentally safe and beneficial application of OMRR and SACoP regulated residuals to forest sites. It addresses calculation of application rates, site selection and management, appropriate application timing, and post-application site monitoring. An example LAP is found in Appendix 2. Detailed background information on land application of these residuals can be found in Chapter 10; the information provided in this chapter builds upon the foundation provided in Chapter 10.

Biosolids, regulated under the OMRR, have become a widely accepted soil amendment for use on forested sites in BC. Municipalities have been applying biosolids to forestland for over 25 years. The Greater Vancouver Regional District, City of Prince George, District of Campbell River, Regional District of Nanaimo, Resort Municipality of Whistler and City of Vernon have all applied biosolids as a forest fertilizer. Municipalities throughout the province have been able to promote the growth of trees due to extensive biosolids forest fertilization research conducted in local forest ecosystems in the Pacific Northwest.

A lack of plant essential nutrients, especially N, limits the productivity of many BC forest ecosystems. The application of inorganic fertilizer is common in intensively managed plantations, and many communities throughout the Pacific Northwest use biosolids as a source of nutrients.

While soil amending materials have been used in silvicultural applications elsewhere in Canada the residuals regulated by the SACoP have been, to date, used on a limited basis on forest land in BC. There is an opportunity to enhance forest productivity through the application of pulp and paper residuals, fly ash, lime-based residuals and clean wood residuals.

For the purposes of this document, silvicultural applications refers to the use of residuals as a fertilizer to existing natural stands or ‘to be established’ plantations where the previous land use has been forestry. The use of residuals in forestry-related reclamation activities – including road and landing reclamation, or to minimize sediment transport occurring from erosion events is addressed in Chapter 15. This chapter reviews silvicultural-specific considerations in the beneficial use of residuals. This includes applications to traditional forests (this excludes short rotation plantations and Christmas tree plantations), short rotation intensive culture of fast growing trees (hybrid poplar and related species), and Christmas tree plantations.

14.1 Silvicultural Objectives

As with the beneficial use of residuals in any application, identifying the objective the land manager endeavours to achieve is paramount in both the best management of the residual and that of the forest ecosystem. Residuals and soil amendments are typically applied to forest plantations to increase the growth of the trees present or to be planted, and/or to increase the growth of the understory vegetation. Biosolids have been applied to forestland to increase the growth and nutrition of understory species in the improvement of animal habitat, or to negate objectionable visual quality concerns. For the most part, however, biosolids are applied to accelerate and sustain the growth response of the tree species being fertilized, minimizing potential adverse effects on other forestland values. Residuals have varying beneficial uses including provision of nutrients, provision of organic matter, pH adjustment, and mulch for competition control for tree establishment.

Irrespective of land ownership, the application of a residual to forest land must be made with consideration given to not only the objectives of the application, but also the effects of the application on other forestland values. These values include recreation (e.g. hunting, hiking, biking etc.), landscape aesthetic considerations, other non-traditional uses (e.g. trapping, food gathering, shrub and flower gathering), wildlife considerations, biodiversity and possible historical or religious significance. In determining the objective of a forestland application the qualified professional must give consideration to the potential effects on other uses and the values associated with these uses. Many of these resource values will be identified in the *BC Forest Practices Code* framework.

14.2 The OMRR and SACoP and Associated Forestry Regulations

Forest fertilization with residuals is regulated by the OMRR and the SACoP, and all forestland applications must adhere to these regulations. These include substance and pathogen limits, the preparation of management plans, and the buffer distances to watercourses and access roads. Note that under the OMRR, application buffer distances exclude logging roads for biosolids which meet Class B pathogen reduction limits; this allows for biosolids applications contiguous from the edge of the roadway into the stand.

The OMRR requires that Class B biosolids be applied only to land areas with restricted public access and use. With forest fertilization this is accomplished through the use of signs at all major access points into the stand. The sign text must relay the information as described in the regulation. The SACoP requires signage for the land application of pulp and paper residuals containing domestic sewage if the concentration of fecal coliforms is $\geq$ 1,000 MPN g^{-1}.

The use of managed organic matter and soil amendments as a forest fertilizer, just like inorganic fertilizer, is guided by the *Forest Practices Code* and associated guidebooks. Directly applicable is the *Forest Fertilization Guidebook*, and while this guidebook does refer to the use of biosolids, it makes reference to OMRR and subsequent supporting information in providing guidance. The majority of this guidebook is relevant to the application of managed organic matter and soil amendments, it is important to note that the stand selection criteria along with application and calibration techniques were developed based on the aerial application of inorganic fertilizers. Application rates for managed organic matter and soil amendments will be different than those identified in the Guidebook due to the nature of the residuals. The qualified professional must use judgment in interpreting and using this guidebook for forest fertilization.

The *Community Watershed Guidebook* provides professionals with information on appropriate activities within a community watershed, including forest fertilization. While the guidebook allows for the use of inorganic fertilizers, the qualified professional should be aware that the guidebook has specified that biosolids *should not* be applied in a community watershed. While with appropriate management the use of biosolids as a forest fertilizer will not have any adverse environmental impact on water quality, currently the use of biosolids as fertilizers in community watersheds is not permitted. The OMRR also specifies that Class B biosolids must not be land applied in a watershed used as a permitted water supply under the Safe Drinking Water Regulation. There is no similar restriction for Class B Compost or Class A biosolids.

14.3 Characteristics of Residuals and Their Beneficial Use in Forest Applications

Both the OMRR and the SACoP require that applications of residuals to land be made on an agronomic basis – that is, to provide a pre-determined concentration of nutrients to the vegetation on site, to meet defined soil conditioning goals or to provide some other justifiable benefit to the soil or vegetation on site, such as a pH adjustment. The types of residuals regulated by the OMRR and the SACoP vary considerably in their characteristics, therefore in their basis for application to forest sites. The residuals covered by these regulations can be broadly categorized into three types:

- High nutrient residuals which are applied to meet the nutrient requirements of the vegetation on site (biosolids, combined pulp and paper residuals, secondary pulp and paper residuals, fly ash).
- Liming residuals which are normally land applied to sites that require liming to adjust soil reaction (fly ash, waste lime and lime mud).
- High organic matter residuals that contain low concentrations of plant essential macronutrients, that often have a high C:N, and that are normally land applied for their soil conditioning properties (wood wastes, primary pulp and paper residuals, some compost and some combined pulp and paper residuals).

Of these three categories of residuals, the first group is most appropriate for forest applications because the primary goal in forest amendment is to provide nutrients to improve growth of vegetation on site. Liming materials and high organic matter residuals have limited use in silvicultural applications except as noted later in the chapter. The following Section discusses high nutrient residuals which can be used for forest fertilization; liming and soil conditioning residuals are discussed in Chapter 10.

14.4 Forest Response – High Nutrient Residuals

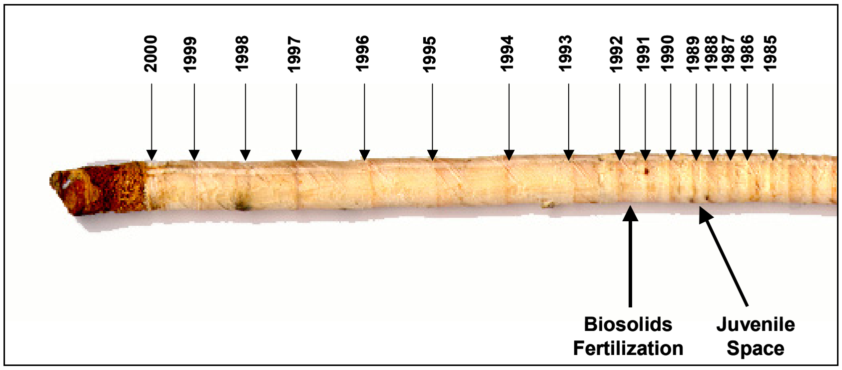
The following section is based on research into tree response to fertilization with biosolids; the stand response to application of other high nutrient residuals will be similar.

Tree species respond to the application of residuals by increasing photosynthetic efficiency and by increasing leaf area. Increased foliage production and expansion of the live crown occurs.

During the year of fertilization, tree growth response is typically limited to an increase in the existing foliage photosynthetic efficiency. In determinant species needle number is determined and primordia set in the bud based on growing conditions present in the previous year (the growth response of indeterminate species may include leaf number). As such, in the first year following fertilization the number of needles does not increase, only the size of these pre-determined needles. In the second year, significant increases in foliage mass typically occur as a result of increased needle number, size of those needles and number of shoots or branches (many biosolids fertilized determinant tree species respond in the second year with increased auxiliary bud expression).

To achieve the maximum response from residual fertilization, the tree crown requires area to increase in size. Without the opportunity to increase foliar biomass, the growth response will be limited to that achieved only by the increase in photosynthetic efficiency.

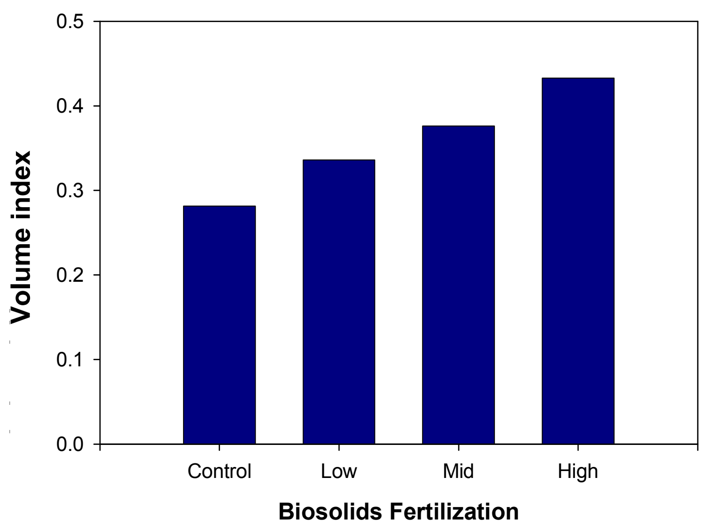
Figure 3: Growth response following a single biosolids application



Malaspina University College

Trees fertilized with high nutrient residuals at the appropriate application rates generally respond with increased growth rates for five to eight years following application (Figure 3 and Figure 4). Information on the growth response of specific tree species to biosolids fertilization may be found in the literature or from BC Ministry of Forests and Range offices that have implemented biosolids forest fertilization and growth response monitoring programs; tree response to fertilization with other high nutrient residuals is expected to be similar.

Figure 4: Volume increase versus biosolids application rate



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Biosolids application rate for a second growth stand near Prince George (Control = 0 dt ha^{-1}, Low = 18 – 20 dt ha^{-1}, Mid = 39 through 47 dt ha^{-1}, High = 103 dt ha^{-1}).

14.5 Stand Selection Criteria

The following evaluation criteria are based upon the primary objective of increasing forest production to meet timber supply objectives. Residual forest fertilization activities designed to ameliorate visual quality concerns, or modify wildlife habitat will differ in the stand (site) selection criteria and appropriate application rate.

Candidate stands for fertilization are identified based on meeting forest level planning objectives, and are evaluated first according to their biological suitability, and second by the operational feasibility.

14.5.1 Biological Criteria

Biological criteria are used to assess the candidate stand's acceptability for residual fertilization. These criteria are found in the following four sub-sections.

14.5.1.1 Autecological Characteristics and Stand Health

Douglas fir (*Pseudotsuga menziesii* (Franco)) traditionally shows consistent and significant growth response to biosolids fertilization. Western hemlock (*Tsuga heterophylla* (Raf.)) shows erratic growth responses. Sitka spruce (*Picea sitchensis* (Bong.)), Western red cedar (*Thuja plicata* (Donn)), Lodgepole pine (*Pinus contorta* (Dougl.)) and White spruce (*Picea glauca* (Moench)) have shown an increase in growth response to biosolids fertilization. It is expected that tree response to fertilization with other residuals will be similar.

Trees with short narrow crowns, short chlorotic and sparse foliage often indicates competitive stress and foliage nutrient deficiencies. Soil and foliar nutrient analysis will assist in the determination of a nutrient limitation. The qualified professional is referred to ancillary texts and references for the diagnosis of pre-fertilization nutrient imbalances.

As with inorganic fertilizers, residual fertilization may increase or decrease the candidate stand's susceptibility to insect, disease and wildlife damage. In contrast to inorganic fertilization, biosolids fertilization of Sitka spruce has resulted in a significant decrease in the incidence of weevil attack (*Pissodes strobi* (Peck)) attack. Increasing foliar tree nutrition typically makes foliage more palatable for animals, and can result in increased herbivory – depending on stand age and species.

14.5.1.2 Age and Size

Fertilization may be used to reduce the effects of uneven age class distribution in forest level planning.

In coastal Douglas fir there is no clear relationship between age and response following fertilization provided there is sufficient room for crown expansion and the crown is in good health. Because the volume increment of a stand declines with increasing age, carrying the cost of fertilization through to rotation must be given consideration. Older stands approaching rotation that have sufficient room for crown expansion will result in the greatest economic returns.

As with inorganic fertilization, the response to application of residuals in older unmanaged stands, even in combination with thinning treatments, is uncertain, however recent research has shown significant increases in growth following fertilization. The qualified professional should understand the results of fertilization trials and operational inorganic programs prior to initiating a fertilization program using residuals. A small screening trial initiated the year prior to proposed operational applications can provide useful background information.

Fertilization of young stands with residuals to meet free-growing objectives and adjacency requirements is possible, however, as with inorganic fertilization of young stands, the trees should be "free to grow" and well above the competing vegetation (Photograph 28). Additional vegetation management activities may be required. As application rates are related to nutrient requirement of the vegetation and trees, the low nutrient demand of recently planted trees, in combination with the naturally occurring nutrient flush occurring after harvest may negate the benefits of application.

In plantation forests, where trees are row planted and typically undergo intensive management, residuals can be applied in conjunction with site preparation activities. In these situations the use of residuals is similar in nature to agricultural applications, although the potential for N immobilization in recently cleared and previously non-fertilized stands can be significant. Often high nutrient residuals can be combined with high C residuals to concurrently achieve soil amendment and tree fertilization objectives.

Photograph 28: Fertilization of a poplar plantation

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14.5.1.3 Stand Density

Tree response to fertilization is related to the opportunity for crown expansion. Residual fertilization conducted in conjunction with spacing allows for easier access and will result in optimum growth potential. Candidate stands should have a favourable dominant and co-dominant espacement. Fertilization should be delayed following spacing if the height of the live crown is insufficient to utilize the applied nutrients (i.e. in conjunction with pruning – see below), if the height to diameter ratio of the trees will result in increased risk of top breakage (i.e. increased foliar biomass on a thinner than sufficient bole), or immediately following pruning.

Pruning of the trees will result in a significant volume of “green manure” applied to the forest floor, supplementing the nutrients applied from the residual (if applied). Fine slash will make manual applications of residual difficult, and will prevent it from reaching the soil. Residual fertilization at the time of spacing, followed by an application the year before pruning is recommended (assuming the trees have an acceptable height to diameter ratio). The amount of foliar biomass reflects the nutrient demand and utilization of the applied nutrients. Fertilization of trees with insufficient live crown or large height to diameter ratios with either inorganic or organic fertilizers should be avoided.

14.5.1.4 Hygrotope and Trophotope

The moisture and nutrient regimes of the candidate stand’s soils will affect the tree responses to residual fertilization. Very xeric sites should be avoided, as a lack of moisture will limit tree response. Typically soils on these sites are thin and the operational logistics of application difficult. Applications to subhygric and hygric sites should be considered with respect to the impact of a possible excess of soil moisture and proximity to surface or groundwater resources.

While stand selection criteria rank drier sites lower for inorganic fertilization, these stands should be considered more suitable as candidate stands for residual fertilization and the use of soil amendments. This will add nutrients and organic matter, which can also increase the soil moisture holding capacity. While the application of residuals to very xeric sites should be avoided, sites drier than those typically excluded for inorganic fertilization should be given consideration for residual fertilization.

14.5.2 Operational Criteria

Operational criteria in candidate stand evaluation relate to the logistics and feasibility of application as well as to environmental protection and minimizing the potential for adverse impacts.

14.5.2.1 Climate

The climate of the area, as it relates to quantity, frequency and intensity of precipitation events, duration of snow cover and /or frozen ground, and mean and extreme temperatures should be considered in an operational assessment. The impact of climate in the determination of residual application rates is discussed further in Section 10.6.2.

14.5.2.2 Form of Residual

The form of residual proposed for forest fertilization or soil amendment affects operational site evaluation criteria and is related to moisture content. The use of a liquid residual (1-15% solids) will require the transportation of large amounts of water, and it would be sprayed onto the stand. De-watered residuals (as a semi-solid with 16-45% solids), ash and lime materials, are typically flung or distributed through the stand with modified manure spreaders. Residual form affects the application method, but also stand and site response. A liquid has a larger potential for off-site movement on steep slopes as compared to de-watered applications. Compost applications are typically completed with trucks and excavators or by bark blowers that can blow the compost through hoses and onto the application area. Blowers work well with low density and relatively dry residuals.

14.5.2.3 Size, Location, Access and Storage

The candidate stand must be of a size that warrants the mobilization of application equipment. As with any forest management activity, the scale of the activity will relate to the cost, and operational feasibility.

The residual must be transported from the generator to the application site, and the proximity of the WWTP to the candidate stand, condition of the roads, and sensitivity of the transportation corridor can affect the suitability of the stand for fertilization.

The layout and road access through the candidate stand will also affect its suitability. In contrast to inorganic fertilization, where applications are typically made from the air, residual applications occur from the ground. The mass of residual per unit N is much higher than inorganic fertilizer, and the economics of aerial application make residual fertilization a ground-based initiative. Transportation and use of residuals in liquid form will result in more transportation weight per unit nutrient, and will affect access roads and trafficability.

The location of the stand with respect to adjacent land uses is another consideration. Forest fertilization with biosolids or pulp and paper residuals will result in a musty odour (not unlike wet peat moss) that will remain over and around the stand for several days to a week following application. Typical wind patterns and proximity of the stand to residential or recreational facilities should be given consideration in suitability assessment.

Refer to Section 10.6.6 for information on the storage of residuals.

14.5.2.4 Aspect, Topography, and Slope

The topographical characteristics of the land as well as the slope characteristics will affect the operational ability to apply residual, as well as the potential for off-site movement. The moisture content of the material proposed for use will affect the operational suitability of a given stand. Steep uniform slopes with few micro-topographical discontinuities are not suitable for residuals with high moisture contents, as the potential for off-site movement is high. Residual moisture content, season of application, slope of the landscape, woody debris, understory vegetation and forest floor characteristics all affect the potential for off-site movement.

Slope aspect will affect residual drying on the surface through the amount of incoming solar radiation. Aspect will also affect the length of time the area is under snow or the ground is frozen.

Candidate stands for residual fertilization that are growing on gullied slopes with several to many water courses are difficult to buffer, and these sites increase the risk of possible water-related impacts.

14.5.2.5 Soils

Soil suitability is related to texture, parent material and depth. Organic soils, or lacustrine soils high in clay warrant special consideration. Shallow soils (i.e. xeric ridge-tops with significant rock outcrops) should be avoided. Coarse textured, deep soils are preferred, but not required.

If application is to occur from skid trails located through the stand attention should be given to the amount of soil disturbance and possible root damage to the trees. The permeability and hydraulic conductivity of the soil should be considered with the application of liquid residuals. Slow infiltration of liquid on a fine textured soil can result in soil sealing and a decrease in the movement of oxygen to the tree roots – both undesirable conditions that can adversely affect the health of the stand.

See Section 10.2.3 for a general discussion of soil properties as they influence site selection and management.

14.5.2.6 Understory Vegetation

The amount and type of understory vegetation present in the candidate stand will affect ground based application techniques (i.e. the application of liquid residual distributed over the stand by hose and nozzle). Understory vegetation will also assist in minimizing the potential for off-site movement. While the understory vegetation present in a recently harvested stand may not indicate inherent site fertility, it is the existing vegetation on the site that will utilize the nutrients added. Fertilization of the stand will also result in the fertilization of the understory, and may result in significant competition problems for young stands or stands approaching canopy closure. Competition for moisture and light, and the opportunity for snow press are possible.

Stand fertilization can increase the palatability of understory vegetation to wildlife, and has been used by land managers to promote wildlife habitat. The response of understory vegetation to residual fertilization has been used to improve visual quality in transportation corridors, and stabilize slopes and minimize surface erosion into watercourses.

While the understory vegetation will compete with the trees for the applied nutrients, this “loss” is not permanent. Applications at canopy closure will result in the shading out of some of the understory vegetation and a mineralization of this organic matter – re-introducing it into the existing pool of nutrients.

Understory vegetation can efficiently compete for moisture as well as nutrients, and growth phenology should be taken into account in assessing the relative response of both trees and understory vegetation to fertilization.

Understory vegetation will also influence the ability to deliver the residual to the forest floor. The intent is to apply the residual to the soil. Dense understory or significant woody debris can impair the delivery of the residual to the soil.

14.5.2.7 Water Resources

Class B biosolids, Class B compost and pulp and paper residuals containing domestic sewage must not be applied to surface water bodies, and a 30 m buffer must be maintained around any fisheries lake, fishery stream, or open water body that flows into a fishery stream. Buffer distances for all fertilizer applications are described in detail in the appropriate *Forest Practices Code* guidebook. In the use of Class B biosolids and Class B compost as defined in the OMRR, and pulp and paper residuals containing domestic sewage as defined in the SACoP, the buffer distances required under these regulations will exceed those required under current forest practices guidelines.

Candidate stands that have a number of fisheries streams or surface water bodies will require buffers, and these buffers will significantly increase with residuals requiring buffers under the OMRR and the SACoP. Significant stand area in buffer negates the usefulness of the residual as a forest fertilizer.

The qualified professional should assess the site for overland flow and off-site movement, as well as subsurface lateral flow if the soils are thin; slopes are steep and parent material impervious.

Class B biosolids, Class B compost and pulp and paper residuals containing domestic sewage cannot be applied to forestland where the groundwater is within one meter of the soil surface at the time of application.

14.5.2.8 Other Resource Use

In planning for the fertilization of forest stands with a residual, operational considerations must also be given to other land uses. This can include, for example, crown range. Access and use of the stand by other users must be taken into consideration when identifying potential application areas and coordinating the timing of application for those areas. In keeping with the previous example of cattle grazing use the application of Class B biosolids and compost, and pulp and paper residuals containing domestic sewage will require domestic animal grazing restrictions. Residual application is to be completed in cooperation with the grazing leaseholder.

In the application of Class B biosolids and Class B compost the OMRR requires that signs be posted for 38 months after the most recent application on each road or path through or to the application site; the same requirement exists in the SACoP for applications of pulp and paper residuals containing fecal coliform in excess of Class A limits. Forested sites with intensive public use (e.g. hiking or mountain bike trails) may not be ideal stands for fertilization with these residuals from an operational and public perception basis. Conversely, biosolids has been applied in high use and multi-stakeholder interest forests as a demonstration and education opportunity. In these situations interpretive trails and signs explaining the activities and anticipated results often accompany the applications.

14.6 Determining Application Rates of Nitrogen-Containing Residuals

The following residuals regulated by the OMRR and the SACoP contain N and thus should be land applied based on balancing the on-site vegetation's N requirements and the N contained in the residual:

- Biosolids
- Secondary and combined (primary and secondary) pulp and paper residuals
- Most compost

All other residuals regulated by the SACoP typically contain either very little or no N and therefore must be applied to land based on meeting other site requirements. See Chapter 7 for information on deriving application rates of these residuals.

Once candidate stands have been assessed and the qualified professional is confident that residual fertilization is biologically suitable and operationally feasible, the application rate is calculated with the objective of supplying enough available (mineral) N to match the agronomic requirements of the trees – an agronomic N application rate.

Typically the objective in forest fertilization is to apply the amount of residual to provide the N requirement of the trees for that year. Over-application of the residual, not unlike inorganic fertilizers, can result in foliar nutrient imbalances and changes in growth form (i.e. increased branching per node, stem and branch “speed” wobble), and adverse environmental impacts including NO_3^- leaching.

In addition to N, high nutrient residuals contain significant (and variable) amounts of P, Ca, Mg, S and trace elements (i.e. B) that can mitigate existing limitations to forest productivity. Only in special situations are forest fertilization applications not based on removing a N limitation to productivity. It is important for the qualified professional to consider that other nutrients will be applied concomitant with N and account for these additions.

The N in biosolids, secondary pulp and paper residuals and compost is different than the N in inorganic fertilizer; inorganic N is 100% available for trees, understory vegetation and soil biota to assimilate and utilize. The majority of N in the residuals is in an organic form, and must be mineralized prior to becoming available to most plants. As such, while inorganic fertilizer forest fertilization rates may be 200-400 kg total N ha^{-1} (as the total N is most often all mineral or available N in inorganic fertilizers), biosolids application rates on a total basis may be 2,500 kg total N ha^{-1} (as only a portion of the total N is available or mineral N).

The organic nature of the N in the residuals, and its mineralization over time, results in a continuous but diminishing supply of N to the trees. Nitrogen in secondary and combined pulp and paper residuals is largely in the organic form, with less than 10% existing in inorganic forms when the material is produced. The amount of N in stabilized compost is significantly lower than in biosolids, and typically almost all is in the organic form with a small component cycling between mineral forms (NH_3 and NO_3^-) and organic forms.

Most of the other residuals regulated by the SACoP contain very little N; these include WTR, fly ash, waste lime and lime mud and wood residues.

The pH of biosolids, compost and pulp and paper residuals is typically neutral or slightly alkaline, however biosolids treated with lime will have a very high pH. Water treatment residuals typically have a pH below neutral while fly ash is alkaline. High pH residuals will affect soil N dynamics and can increase the mineralization rate of forest floor organic matter in stands with a low soil reaction. The extent of this increased nutrient availability must be considered when applying high pH residuals.

14.6.1 Agronomic Application Rates

Extensive research has been conducted in the Pacific Northwest on the use of biosolids as a slow release organic forest fertilizer, and based on this research a model has been developed to determine appropriate agronomic application rates. This model is in use throughout the Pacific Northwest in the determination of biosolids, pulp and paper residuals and compost forestland fertilization application rates.

This model incorporates characteristics of the residual, stand characteristics and the N transformation pathways that determine the form and availability of biosolids. These characteristics and transformation rates are discussed separately below.

Although developed based on biosolids research, the model has been used to determine application rates for pulp and paper residuals, compost and other N containing residuals.

14.6.1.1 Nitrogen Form

The forms of N in the residual and their importance are discussed in Section 10.3.1. The concentrations of NH_3 plus NH_4^+, NO_3^- plus NO_2^- and organic N are required.

14.6.1.2 Tree Uptake

As the objective of most forest fertilization programs is to increase the growth rate of the trees, knowing tree N requirement is important. The amount of N a tree species requires is dependent upon its age, size, foliar biomass and general health. Stand stocking is another important consideration. Typically, N demand will increase with increasing age until canopy closure when the requirement will diminish. The ability of a forest stand to respond to fertilization with residuals depends on both the rate of supply and the ability of the species to increase its growth rate. An established hybrid poplar stand may assimilate as much as 300 kg N ha yr^{-1}, a young Douglas fir stand, 125 kg N ha yr^{-1}, and an older Douglas fir stand 50 kg N ha yr^{-1}. For the purposes of residuals application rate determination, tree uptake is net N required, adjusted for N cycled through litter fall and decomposition.

14.6.1.3 Understory Vegetation

While the N present in the residuals may be intended for the trees, there is significant competition for the N between the trees, soil microorganisms and the understory vegetation (Table 14). Nitrogen uptake rates for understory vegetation range from 100 kg N ha yr^{-1} in a young Douglas fir stand, to over 300 kg N ha yr^{-1} in a hybrid poplar stand at canopy closure. If control of competing vegetation is planned the understory N uptake estimate should be modified. As with tree uptake, for the purposes of residuals application rate determination understory uptake is net N, adjusted for N supplied through understory litter fall and decomposition.

Table 14: Estimated nitrogen uptake by trees and understory vegetation

Trees/Vegetation	Estimated N Requirement (kg ha^{-1} yr^{-1})
Trees:	
Hybrid poplar at canopy closure (short rotation)	300
Hybrid poplar 1 year old (short rotation)	50
Douglas fir at canopy closure	125
Douglas fir following spacing and pruning	75
Douglas fir commercial thinning	50
Lodgepole pine at canopy closure	75
Understory:	
Coastal Douglas fir (*Gaultheria* / *Mahonia* site) at canopy closure	50
Coastal Douglas fir prior to canopy closure (herbaceous)	100
Coastal hybrid poplar at canopy closure (grasses and herbaceous)	150
Coastal hybrid poplar prior to canopy closure (grasses and herbaceous)	300

The estimated annual N requirements in Table 14 are approximations only. Nitrogen uptake rates will depend on species, stocking (site occupation), stand condition, age, foliar biomass and soil moisture regime. Subsequent stand management activities (i.e. competition control) will affect N requirements. Local BC Ministry of Forests and Range professionals should be able to provide estimates of N uptake rates from previous inorganic fertilization programs, if completed in their region.

14.6.1.4 Immobilization

Nitrogen deficient microorganisms will utilize the mineral N supplied by the residual that is not assimilated by the trees and understory vegetation. In N immobilization, mineral or inorganic N is transformed into organic N in soil microbial biomass – the reverse of mineralization. The N in the microbial biomass will eventually be mineralized and re-released, or retained in stable organic matter compounds. Immobilization rates vary, depending on whether the site has been previously fertilized, soil organic matter composition (C:N, soil C forms) moisture and temperature. Immobilization rates can be higher on poor sites where nutrient cycling and decomposition are slowed by low temperatures and extremes in moisture. Mor type forest floors are typical of these sites. Higher productivity sites will have lower rates of immobilization. The time duration between fertilizations will affect the immobilization of N in subsequent fertilization events. Nitrogen immobilization rates range from 0 to as much as 1,000 kg N ha^{-1} yr^{-1}. Typical immobilization rates for a medium to poor productivity coastal Douglas fir site are 175 kg N ha^{-1} yr^{-1}.

14.6.1.5 Mineralization

In the first year following forest fertilization with residuals the mineral, or inorganic forms of N will be made available for assimilation by the plants and soil biota. The mineral N present in the residual will be supplemented by the addition of NH_3/NH_4^+ through mineralization. Mineralization rates are dependent upon the characteristics of the residual itself, and the environment (moisture and temperature) in which they are applied. Extremes of moisture and temperature will limit mineralization. Residual treatment processes have a significant effect on mineralization rates. Actual mineralization rates can be determined by a simple mineralization experiment. As this N transformation pathway is a key factor in the determination of an appropriate application rate, it is important for the qualified professional to have a good estimate or actual mineralization rates. Mineralization rates of biosolids are found in Table 10.

14.6.1.6 Volatilization

Immediately following application NH_3 present in the residual can volatilize into the atmosphere. This is a strictly physical process and depends on the initial NH_3/NH_4^+ concentration, the moisture content, the temperature and wind speed and whether the residual was surface applied or incorporated. Ammonia losses can range from 10% in low temperatures and wind speeds where the residuals are immediately incorporated to as much as 100% with the surface application of dewatered biosolids to an open, warm and windy poplar plantation. Table 15 contains estimates of NH_3 volatilization losses from forested sites.

Table 15: Ammonia volatilization ranges

Volatilization	**Estimated Loss (%)**
Traditional Forests:	
Open stand, summer surface application, moist soils	30-60
Closed stand, summer surface application, moist soils	10-30
Short Rotation Hybrid Poplar:	
Open Stand, summer surface application, moist soils	50-90
Open stand, summer incorporated, moist soils	15-25
Closed stand, winter surface application, wet soils	10-25

14.6.1.7 Denitrification

Mineral N as NH_3 will undergo nitrification to NO_3^--N in aerobic environments. As another form of mineral N, NO_3^- can be assimilated by plants and soil microbes, leach out of the soil profile, or denitrify. The process of denitrification occurs when there is the presence of NO_3^-, an anaerobic environment, available C and adequate temperature. Denitrification results in the loss of NO_3^--N as N_2 or N_2O. Denitrification losses are typically low – about 10%, unless special situations are encountered, or the professional is creating conditions to promote denitrification losses.

14.7 Calculating the Application Rate for Nitrogen-containing Residuals

The application rate should be calculated from a N budget developed from the above transformations. Two examples are provided on the following pages (Table 16 and Table 17). These examples can be used to calculate the application rate of other N-containing materials such as pulp and paper residuals and compost.

The first example (Table 16) is for a three-year-old hybrid poplar plantation growing in the Fraser River Valley. The anaerobically digested biosolids from a local WWTP are applied to the plantation between the rows of trees and remain on the surface. The application occurs in the spring. The biosolids N characteristics and N transformation assumptions are provided. Based on previous research the biosolids mineralization rate, NH_3/NH_4^+ volatilization rate and denitrification rates are known. Uptake of N by the hybrid poplar and understory and immobilization by the soil are provided from local research or from the literature.

First the initial NH_3/NH_4^+ concentrations are calculated (dt basis), and losses and gains attributed to volatilization and mineralization accounted for. Denitrification occurs on this net total NH_3/NH_4^+ concentration. Note that while most biosolids do not contain significant concentrations of NO_3^--N, under certain conditions and digestion processes NO_3^- can be present. This NO_3^- concentration would need to be added to the mineral N pool, and denitrified as per local research or literature references. As NO_3^- does not volatilize, the transformation pathways for volatilization and mineralization are not applied to NO_3^- present in the biosolids.

The N required is then compared to the N present in a dt of biosolids and the application rate calculated. The application rate can then be specified in wet or bulk tonnes, from which the applications are verified, or to kilograms (kg) of N ha^{-1} required.

Note that in the first example the amount of total N recommended is 2,500 kg N ha^{-1}, which intrinsically seems very high as compared to inorganic fertilization rates. This N application rate accounts for not only the mineral or inorganic N additions, but also the organic additions. In typical biosolids the organic N component is upwards of 80% of the total N present in the biosolids. From the example provided, only 30% of this organic N pool will be available for assimilation in the first year.

With most high N organic residuals, excluding compost, the remaining organic N will mineralize at a significantly lower rate in subsequent years. While this rate will be low (1-5%), application rate calculations for repeated applications need to account for residual soil N and reduced soil immobilization and understory uptake. Methods for determining residual N and adjusting for its concentration are found in references specific to managing residuals N. It is this sustained but diminishing release of N from the biosolids that results in a prolonged growth response typical in biosolids fertilized plantations.

In the second example (Table 17) the biosolids used in the previous example are to be used in the fertilization of a mature coastal Douglas fir forest following a thinning treatment. The biosolids will be surface applied during the fall, with relatively little understory present. Note that in this example the application rates are significantly lower as a result of changes in the tree and understory N requirements and N transformations.

Table 16: Example calculation of biosolids agronomic application rate for poplar fertilization

Criteria	Units	Value		Calculation	Comments
Biosolids N					
Initial NH_3/NH_4^+	%	1		n/a	Obtained from biosolids analysis
Initial NO_3^-/NO_2^-	%	0		n/a	Obtained from biosolids analysis
Organic N	%	4		n/a	Obtained from biosolids analysis
Solids	%	25		n/a	Obtained from biosolids analysis
N Transformations					
Mineralization Rate	%	30		n/a	From mineralization study or literature
Volatilization Losses	%	75		n/a	Actual values or estimate
Denitrification Losses	%	10		n/a	Actual values or estimate
N Uptake/Storage					
Tree Uptake	kg N ha^{-1} yr^{-1}	300		n/a	Professional knowledge or literature
Understory Uptake	kg N ha^{-1} yr^{-1}	150		n/a	Professional knowledge or literature
Soil Immobilization	kg N ha^{-1} yr^{-1}	200		n/a	Professional knowledge or literature
Available N required	kg N ha^{-1}		650		Sum of N uptake and storage
N Transformations					
Initial NH_3/NH_4^+	kg dt^{-1}	10		(1/100)*1000 kg dt^{-1}	Calculate initial concentration per tonne
Volatilization Losses	kg dt^{-1}	-7.5		(75/100)*10 kg dt^{-1}	Calculate volatile N losses
Mineralization Additions	kg dt^{-1}	12		(4/100)*(30/100)*1000 kg dt^{-1}	Calculate mineral additions
NH_3/NH_4^+ Total:	kg dt^{-1}		14.5		Sum of NH_3/NH_4^+ transformations
Denitrification Losses	kg dt^{-1}	1.5		(10/100)*14.5 kg dt^{-1}	Calculate volatile N losses
Net Available N	kg dt^{-1}		13		Calculate net N available/tonne applied
Application Rate	dt ha^{-1}		50	650/13	Tonnes required to meet N needs
Application Rate	wt ha^{-1}		200	50/(25/100)	Convert dt to wt
Application Rate	kg ha^{-1}		2500	50*(1+0+4)*10	Application rate by N content

Table 17: Example calculation of biosolids agronomic application rate for forest fertilization

Criteria	**Units**	**Value**		**Calculation**	**Comments**
Biosolids N					
Initial NH_3/NH_4^+	%	1		n/a	Obtained from biosolids analysis
Initial NO_3^-/NO_2^-	%	0		n/a	Obtained from biosolids analysis
Organic N	%	4		n/a	Obtained from biosolids analysis
Solids	%	25		n/a	Obtained from biosolids analysis
N Transformations					
Mineralization Rate	%	30		n/a	From mineralization study or literature
Volatilization Losses	%	20		n/a	Actual values or estimate
Denitrification Losses	%	10		n/a	Actual values or estimate
N Uptake/Storage					
Tree Uptake	kg N ha^{-1} yr^{-1}	50		n/a	Professional knowledge or literature
Understory Uptake	kg N ha^{-1} yr^{-1}	50		n/a	Professional knowledge or literature
Soil Immobilization	kg N ha^{-1} yr^{-1}	200		n/a	Professional knowledge or literature
Available N required	kg N ha^{-1}		300		Sum of N uptake and storage
N Transformations					
Initial NH_3/NH_4^+	kg dt^{-1}	10		(1/100)*1000 kg dt^{-1}	Calculate initial concentration per tonne
Volatilization Losses	kg dt^{-1}	-2		(20/100)*10 kg dt^{-1}	Calculate volatile N losses
Mineralization Additions	kg dt^{-1}	12		(4/100)*(30/100)*1000 kg dt^{-1}	Calculate mineral additions
NH_3/NH_4^+ Total	kg dt^{-1}		20		Sum of NH_3/NH_4^+ transformations
Denitrification Losses	kg dt^{-1}	2		(10/100)*20 kg dt^{-1}	Calculate volatile N losses
Net Available N	kg dt^{-1}		18		Calculate net N available per tonne applied
Application Rate	dt ha^{-1}		16.7	300/18	Tonnes required to meet N needs
Application Rate	wt ha^{-1}		66.8	16.7/(25/100)	Convert dt to wt with % solids
Application Rate	kg ha^{-1}		835	16.7*(1+0+4)*10	Application rate by N content

14.8 Application Rates for other Residuals

Chapter 10 contains an extensive discussion on developing application rates for residuals that are not sources of N. Refer to that chapter for information on the general use of these residuals.

Fly ash is an excellent source of nutrients (except N) and while it is normally used as an alternative liming material, in Scandinavia, New Zealand and the Southern United States it has been used as a forest fertilizer to replace nutrients removed during forest harvesting. It is applied to the forest floor following harvesting at rates designed to replace the nutrients lost during harvesting. The high pH of the ash can increase soil pH, effectively increasing decomposition and mineralization rates, thus increasing N and other nutrient availability. Although low to no N is applied in the residual, the residual increases the availability of existing nutrients immobilized or cycled slowly in the forest floor. In short rotation forests, high C amendments have been used effectively as mulch, temporarily suppressing understory vegetation growth. Nitrogen immobilization can occur following application and supplemental fertilization may be required.

14.9 Co-Application of Biosolids and Other High Nitrogen Residuals with Organic Residuals

The determination of agronomic application rates requires that there be a N demand through the uptake of the trees and understory vegetation. With forest fertilization at the time of planting when tree and understory N requirements are minimal, high N residuals can still be applied based on the N demand of the trees. However the application rate will be low, and may not be economically feasible. From an operational logistics perspective there is an advantage to being able to apply a residual such as biosolids prior to planting (ease of access, ability to traverse the site). Based on an understanding of soil immobilization and C:N ratios it is possible to co-apply high N residuals with high C organic residuals. This approach uses soil immobilization to temporarily store and release applied N over time, as the trees' requirement for N increases with increasing age. The approach is called the C:N/organic matter approach or balanced soil amendment approach.

Many high C residuals can be used in this approach, however the OMRR allows for the application of certain high C materials within the definition of managed organic matter –they must be untreated or unprocessed. The application of clean wood waste and primary pulp and paper residuals, both high organic matter residuals, is regulated under the SACoP. When co-complying organic residuals governed under the OMRR and the SACoP, the most restrictive requirements apply.

14.9.1 Application Rate Determination

In this approach the goal is to achieve a productive soil through changing the organic matter content and the nutrient status of the rooting zone of the soil. Typically a soil that has a stable organic matter content of 5% is usually considered productive. This amount of organic matter normally gives the soil desirable chemical, biological and physical properties. A productive soil also needs to have nutrients in balance, particularly C and N. Humus generally has a C:N around 15:1.

14.9.1.1 Target Organic Matter Content

The C compounds added to soil (either biosolids or other organic matter) do not have the same stability as humus and as such will decompose in the soil within a short time span following application. Depending upon the type of residuals applied, generally 50% will decompose in the first one to two years in the soil; if the objective is to have 5% organic matter, then a target application rate should be about 10%. Some organics will decompose much faster, like straw, and some much slower, like wood with significant lignin, so a 50% decomposition rate is only an estimate. If the high N residual alone were added to the soil to achieve 10% organic matter, it would be well in excess of an agronomic rate and would result in NO_3^- leaching if additional management practices were not used. Compost is a stabilized organic matter, and decomposition rates will be considerably slower.

14.9.1.2 Target C:N

As a second criteria, the excess N added from biosolids or other residual must be immobilized by excess C added as high C material (i.e. primary pulp and paper residuals, wood chips, paper fines, straw) that will be released later as decomposition continues. Generally, when the amount of C in a soil is 30 times the amount of N, it is thought that N mineralization is balanced with N immobilization. As the newly-amended organics decompose, some of the C will be lost as CO_2, decreasing the mass, but the N will remain and be utilized by the microbes - thus the C:N decreases with time. Account for this change when deciding upon an initial C:N of the amendment. Potentially, if fresh C-rich materials are used, a beginning C:N of 30-40:1 is appropriate. If a stable C source is used, then the appropriate beginning mixture should be 20-30:1.

The application rates and ratios of the two amendments (the high N residual and a C source) can be determined using these two objectives: a beginning organic matter concentration in the soil, and a C:N that depends upon the nature of the high C material.

14.9.2 Calculations Using the C:N and Organic Matter Approach

There are three main steps to calculating application rates using this approach. The first is the analysis of all the soil and amendment components, and the second and third are performing calculations. Design values for depth of incorporation and initial target soil organic matter content are required. Determining the correct ratios of biosolids and C source involves solving a series of simultaneous equations. From these sets of equations the correct application rate ratios are calculated. These calculations are beyond the scope of this document and the reader is referred to supporting documents or a qualified professional.

14.9.3 Considerations

The C:N of some organic residuals may already be below the target C:N; i.e. one high in newly-cut grass. Such a material will not work in this approach, as it would not classify as a high C material.

Once organic matter is mixed into the soil, decomposition occurs. As the concentrations change with decomposition the target for both organic N and C:N are higher than the amendment. A number of different high C materials can be used. Each of these has different characteristics of nutrient content and decomposition and each of these must be studied before beginning a major application program using this approach. In a high C residual there exist numerous forms of C, some of which are readily available in the form of starches and simple sugars. Others are more stable, and decompose very slowly. As such, materials with comparable total C concentrations may have vastly differing decomposition and immobilization rates. The same is true for the forms and availability of N in the high N residuals used in this approach. The N may exist in several different mineral forms, or as organic N, again in several forms with varying decomposition/mineralization rates.

As discussed previously, the OMRR specifies the organic materials that can be composted, but not co-applied. As such, the co-application of a high N residual and a high C amendment will require a permit or approval from the MoE if the amendment is not regulated under the SACoP. If the amendment is regulated under the SACoP, the most restrictive criteria of the two regulations applies when completing a LAP.

14.10 Tracking Trace Element Concentrations

Both the OMRR and the SACoP require that the preparation of the LAP must include residual sampling prior to application to determine trace element concentrations, soil sampling to determine the background trace element concentrations and a calculation to determine the predicted trace element concentrations post-application. Section 10.5 contains sample calculations for determining trace element addition rates. As these soil samples must be analyzed for the trace element concentrations required by the OMRR and SACoP, the qualified professional should consider using the pre-application soil sampling to also determine the fertility status of the soil and use this information in determining appropriate application rates.

14.11 Application Timing

The timing of application in a forest fertilization program is not as critical as with other uses (e.g. agricultural applications) and usually relates more to transportation and application logistics. Timing of application should be considered in conjunction with the phenology of the trees to be fertilized (and response) and climate.

14.11.1 Seasonality

Forest fertilization activities should not occur over snow, on frozen ground, or during intense rainfall events where off-site movement is possible. Depending on the form of residual applied (liquid or semi-solid) and the application method, it may be advisable to avoid applications to juvenile stands during spring candling (bud burst and growth). Mechanical damage resulting from certain types of application could adversely affect tree form.

In coastal environments consideration should be given to the quantity, frequency and intensity of rainfall events in conjunction with liquid residual applications to forest stands.

Season of application, as it relates to the climate, will affect the N transformations in the calculation of an application rate. Denitrification losses will be low without anaerobic (water saturated) soil conditions. Ammonia losses from surface applied residuals will be lower in cooler spring and fall applications.

14.11.2 Rotation

Residual fertilization can increase the merchantable yield and value of the tree species fertilized, reducing rotation age by accelerating the rate of stand development. The largest response to fertilization is gained through the coordination of spacing, pruning and thinning activities with residual fertilization. The applications are generally easier at these events as they relate to stand access and the ease with which the residual can be applied through the stand.

14.12 Special Considerations – Short Rotation Plantations

Short rotation culture of trees for timber is a combination of agriculture and forestry (Photograph 29). In this system, trees (usually hybrid poplar) are planted in rows in ploughed or prepared sites. The trees grow very rapidly with appropriate management, resulting in a harvestable tree in 12 to 18 years. Extensive plantations of hybrid poplar exist in the Fraser Valley, on Vancouver Island and up the West Coast of BC. Small plantations of irrigated poplars occur in the interior.

Control of competing vegetation is extremely important from the first years of plantation establishment through to canopy closure. Residual fertilization will result in a significant increase in the understory vegetation, and this vegetation will compete with the trees for nutrients, but more importantly, water. Residual fertilization of hybrid poplar trees prior to, or just following canopy closure should ensure adequate vegetation control is practiced. Often, residuals are applied and incorporated, resulting in a concurrent short-term control of vegetation and a conservation of biosolids-applied N.

Soils and root systems under hybrid poplar stands are susceptible to disturbance and damage from heavy application equipment. The time of year and type of equipment used can address these situations. They are often located on floodplains adjacent to surface water bodies and may require special site-specific considerations. Short rotation poplar plantations are ideal for the co-application of high N residuals and high C residuals prior to planting, and in ongoing silvicultural activities including fertilization and vegetation management.

Photograph 29: Poplar plantation amended with biosolids, pulp and paper residuals and lime mud

SYLVIS

14.13 Special Considerations – Christmas Tree Plantations

Residuals have been used in the fertilization of Christmas tree plantations (or farms). One of the benefits observed in the fertilization of trees with biosolids is an increase in the "branchiness" of the trees – auxiliary buds will develop into branches resulting in a dense canopy and increased foliar biomass (Photograph 30).

To minimize exposure to pathogens, residuals containing a fecal coliform concentration of $\geq$ 1,000 MPN g^{-1} should not be applied to Christmas tree plantations within 60 days of harvest for sale to the public.

Photograph 30: Increased needle growth resulting from biosolids forest fertilization

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14.14 Applications and Equipment

Application technology for residual forest fertilization has evolved significantly over the past 25 years. Efficient, and thus economical, forest fertilization programs involve the transportation of the residuals to localized staging areas throughout the stand to be fertilized. Forestry machinery designed for stand access (forwarders and skidders) have been modified with the addition of large side or rear discharge manure spreaders that "fling" dewatered biosolids over, through or under the stand. See Section 10.7 for a complete discussion of application technologies.

For most stands, to achieve uniform coverage over the site, off-road application vehicles are required (Photograph 31). Reducing the block area to intensively managed roadside corridors, and fertilizing only those areas that can be applied from existing roadways greatly reduces the cost associated with a specialized vehicle, as similar manure spreading technology can be mounted on a much less expensive vehicle.

Photograph 31: Aero-spread box mounted on a Rottne forwarder for forestry applications

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The ability to apply biosolids low in solids (i.e. not dewatered or “liquid” biosolids) is a common practice in smaller municipalities and towns where the cost of dewatering biosolids is higher than the cost associated with the transportation and/or application of the biosolids as a liquid. The transportation of liquid biosolids is expensive relative to the nutrient content (recall that the application rates are calculated on a dry basis, regardless of the solids content) and forestland application sites need to be relatively close to the biosolids generator to be cost effective.

Forest fertilization with liquid applications involves the use of tanker trucks to transport the biosolids to the application area, where it is often off loaded into storage tanks. Again, specially designed applicator vehicles that spray liquid biosolids are used to distribute biosolids through the stand. Smaller communities can use tanker trailers and roll off tanks to leave liquid biosolids at the application site where it can be distributed via pump and by hand held hose to the forest floor. This type of equipment would also be suitable for applying other liquid residuals.

Consideration should be given to the hydraulic loading associated with liquid applications. It is common to apply the residual in several “lifts”, allowing the water and residual to migrate into the forest floor and soil between applications.

14.15 Management and Monitoring

Residual storage requirements have been discussed in previous sections and the reader is referred to these sections (Section 10.6.6). Buffer distances to surface water, roads, buildings, wells, and property boundaries have been discussed in Section 10.6.3.

Prior to residual fertilization the block boundaries, water bodies, buffer zones and similar considerations should be clearly marked on aerial photography. Dividing the block into application compartments, with residual volumes (delineated into applicator vehicle “loads” or similar units of bulk measure) clearly indicated will assist in even application and easier project management. All application personnel should be familiar with the block and application compartments, and have a listing of project management and emergency contacts.

A contingency plan should be developed in the case of residual fertilization to non-designated areas, including surface water bodies. This contingency plan should specify the appropriate procedures to follow. In the event of residual entry into a water body a water quality monitoring plan should be identified.

Land application plans must be completed as required in the OMRR and the SACoP. The OMRR and the SACoP place responsibility on the qualified professional to ensure no adverse environmental impacts occur as a result of an application. Should a post-application monitoring program be deemed necessary, it is imperative that the objective of any monitoring program be clearly defined. Extensive research has been conducted on the effects of biosolids forest fertilization, and the qualified professional should be aware of this research, and the results of past biosolids forest fertilization monitoring programs in developing a site-specific monitoring program. The qualified professional should have a solid understanding of any existing or previous monitoring ongoing on and adjacent to the biosolids fertilized stand(s). If other residuals are applied to a forested site, the qualified professional should ensure that they have a good understanding of the possible impacts of the application on the site.

Monitoring programs should be designed to answer a specific question, not generate data. In assessing whether a monitoring program is required the qualified professional should consider potential for the “worst case scenario” to occur. If necessary, a monitoring program should first verify that the event has happened, then assess impact. For example, when a qualified professional prepares a LAP to apply biosolids to a stand of Douglas fir that is sloping towards a fisheries stream. While the topography is not so steep as to preclude the site from biosolids fertilization, there is concern that biosolids, applied as a liquid, may move off-site if the application were to occur in or immediately prior to an intense rainfall event. The qualified professional may increase the required 30m buffer, and identify a monitoring plan in the event of this occurring. The qualified professional should think through the possible impacts. The monitoring program may first require a visual inspection of the buffer boundaries following the first significant rainfall event. If off-site movement is observed, a program of sampling the surface water above and below may be initiated – again looking for parameters indicative of possible impacts.

Monitoring programs specific to environmental protection should be delineated from those designed for other purposes. While not directly related to the OMRR or the SACoP, these monitoring programs may be conducted to assess the success in achieving fertilization objectives. This may include post-application empirical growth measurements, and/or foliar nutrient analysis and vector interpretation. They may be designed to assess nutrient utilization, or to refine application rates. Foliar nutrient concentration prior to application may often be compared to concentrations post-application.

14.16 References and Supporting Documentation

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15 Considerations for Land Reclamation Applications

Often the substrate remaining following disturbance from mining, logging or other industrial applications has little resemblance to a productive soil. Disturbed soils are frequently severely nutrient deficient, devoid of organic matter, soil biota and nutrient cycling activities, lack adequate moisture holding abilities and are often located in extreme climatic environments. Application of organic matter provides an inoculation of micro-organisms, as well as an organic substrate from which to initiate nutrient cycling, soil development and the establishment of a plant and animal community.

The utilization of residuals in disturbed lands rehabilitation may include a diverse series of activities:

- re-vegetation of completed or to be completed mining operations;
- establishment of vegetation on landfill covers;
- returning forestry roads and landings back to productive forest; and,
- specialized restoration activities related to the minimization of erosion or ecosystem modification.

The BMPs in the use of residuals as amendments in disturbed land reclamation are very site-specific. The climate, soil or soil substrate characteristics, residual characteristics and ultimate land use objectives must all be considered. A sample LAP for reclamation purposes is provided in Appendix Two.

15.1 Reclamation Objectives

The objective in the reclamation of disturbed land is typically to restore and maintain the soil productivity to a level that will support a self-sustaining community of plants and animals. In accomplishing this objective, several equally important objectives may be achieved; reducing erosion, ensuring terrain stability, and improving visual quality. The goals of a reclamation program are sometimes “restoration” directed, but more often involve site and soil rehabilitation in accordance with a subsequent land use or reclamation plan.

Residuals should only be used in reclamation programs that are carefully planned and managed. The goals and objectives in using residuals for reclamation programs should be clearly defined and quantifiable.

15.1.1 Definitions

Numerous terms, including deactivation, restoration, and rehabilitation are used in reference to the reclamation of disturbed lands, often interchangeably. The term deactivation is commonly used in reference to roadways and forestry landings. Deactivation of roadways and landings provides maintenance free pathways for surface water, seepage and overland flow to prevent soil erosion and surface ponding of water. Deactivation activities do not address the site or soil productivity. Restoration, especially ecological restoration, is subject to various definitions, but usually implies the practice of re-establishing the historic plant and animal communities of a given area or region and the renewal and maintenance of the ecosystem.

Often there is a cultural element present in this definition. The term rehabilitation is used when the objective is not necessarily the establishment of historical communities of plants and animals, but other land uses as defined in a rehabilitation plan or proposal. Site rehabilitation activities ensure that natural drainage patterns are restored and the potential for erosion is minimized. Soil rehabilitation implies the re-establishment of soil productivity to a level capable of sustaining the production of vegetation – whether the objective is tree growth, range or intensive agriculture. Residuals can be used in reclamation activities that include deactivation, restoration and both site and soil rehabilitation.

Residuals are often used in the remediation of sites that have elevated concentrations of trace elements or specific constituents. In this application the specific properties of the residuals are used to reduce the availability of elevated pollutants, allowing for the establishment of vegetation. The use of residuals in site remediation are beyond the scope of this document and the reader is referred to qualified professionals in this field.

15.2 Other Regulations Pertaining to Reclamation

The reclamation of forestry roads, landings, compacted logging trails, and small gravel and rock pits is regulated under the *Forest and Range Practices Act*. Residuals are used as soil amendments in forestry-related reclamation activities and additional information can be found in *Forest Practices Code* guidebooks.

The use of residuals in mine reclamation in BC must adhere to the regulations related to mine management and closure under the BC *Mines Act*. This Act requires that every owner, agent and mine manager institute and carry out a program of environmental protection and reclamation, and with a few pre-legislation exclusions, requires that the land surface be reclaimed to an acceptable level that considers previous and potential future use. The Act requires that the level of land productivity to be achieved on the reclaimed areas be equal to or greater to that which existed prior to the mining, unless evidence can be provided which demonstrates the impracticality of doing so. Part 10 of the *BC Health, Safety and Reclamation Code* specifically governs reclamation activities for mining activities. The land must be re-vegetated to a self-sustaining state using appropriate plant species. The Code also requires that the growth medium satisfy the land use, productivity and water quality objectives as set out in a closure plan. The act requires that mine roads, tailings, and waste dumps be reclaimed, and that the owner, agent or mine manager undertake a monitoring program to demonstrate that the reclamation objectives of land use, productivity, water quality and stability are achieved. This Act specifically requires that vegetation established on mine sites be monitored. This is discussed in context with the use of residuals in mine reclamation in Section 15.12 below.

15.3 Reclamation - Ecological Context

Pedogenesis (the development of soils) occurs through the interaction of five factors – climate, organisms, topography, parent material and time. Time allows for weathering of the parent material and the leaching of soil constituents down through the developing soil profile. The parent material will affect soil texture, structure, nutrition and exchange capacity. Topography affects water movement and erosion processes. Climate affects soil and air temperature, moisture status, wind and solar radiation. The biotic factor includes soil organisms, vegetation, and animals – including humans.

In most mine reclamation activities, there is insufficient overburden to adequately cover the re-contoured site. Typically the quality of this overburden does not resemble the previously existing soil - having been mixed and stored, sometimes for many years, prior to being replaced. Therefore the biotic component of the soil is often compromised, and the productivity of the soil limited. Mine waste rock dumps, tailings and berms typically lack organic matter. Pedogenesis on these sites may be promoted with the addition of organic matter; the microbial community present in organic matter initiates nutrient cycling. Pioneering vegetation established on these sites contributes organic matter, and further soil development. Pedogenesis continues over time, with the soil increasing in C and N, and developing characteristics related to the factors influencing its development.

Initially the establishment of vegetation is limited to species with unique abilities – usually N fixers. The lichens, shrubs and trees that host the bacteria capable of fixing N have the competitive advantage of growing in environments where N is limited. With the addition of organic matter and nutrients, a successional sequence of events occurs both in the development of a soil and establishment of a community of vegetation. Adding organic material to waste rock dumps and tailings does not "make" a soil. The added organic matter, along with the parent material provide the "working capital" on which pedogenesis occurs.

The reclamation and site rehabilitation of forestry roads and landings can be easier than that of mine reclamation; often the soil has not been removed but has been compacted, or aggregate material added to its surface. Decompaction of roads and landings, along with the replacement of forest floor is practiced.

15.4 Site Selection Criteria

The site selection criteria for residuals use in the reclamation of disturbed land are dependent on the reclamation objectives, climate, substrate present and operational criteria related to the logistics of application. These criteria affect not only the suitability of the disturbed site for biosolids amendment, but also the degree of rehabilitation achieved.

15.4.1 Physical Site Characteristics

Land topography, aspect, slope angle and length, and drainage all affect a disturbed site's suitability for residuals use. Mine reclamation typically occurs on large tiered flat benches, surrounded by steep (angle of repose) slopes. These slopes can be very long, and the benches very high. Application to the bench-tops can be completed relatively easily, however the slopes pose a greater challenge. The aspect of the slope will determine the incidence of solar radiation, substrate temperature, snow retention and ultimately the species adapted to survive and grow in these conditions. Drainage must be considered from the perspective of the availability of moisture through the growing season, but also from the proximity of surface and groundwater resources to the candidate application area.

Slope, angle and substrate quality will affect stability of the slope both pre- and post-application. The qualified professional must consider stability issues both in assessing the site for suitability, but also the stability of that site following the application of residuals and the re-establishment of vegetation. Surface applications to steep slopes of loose granular substrate can create a shear face. The establishment of vegetation and the weight associated with the increased water holding capacity of the forming soil can result in slope instability and mass movement. If the slope is inherently unstable residuals should not be applied. Tailings ponds provide different physical site challenges, including access, floatation, and erosion. The application of residuals to these areas may require unique technology depending on the water content and size of the deposit. Residuals have been used successfully to stabilize tailings dams and facilitate water management.

15.4.2 Climate

Climate affects site access, application logistics and the length of the growing season. The quantity, seasonality and intensity of precipitation events are important considerations as far as water and possible constituent movement through coarse textured waste rock and tailings piles are concerned. For example, movement through a berm of washed sand in a coastal environment will be very different from the same application to a high elevation dry interior site.

Temperature and moisture are key determinants in the regulation of mineralization rates. Extremes in soil water content or temperature can result in a reduction in mineralization rates (if the extremes are not variable) or an increase in mineralization rates (repeated cycles of temperature and moisture fluctuations).

The re-contoured topography pre- and post-mining activity is often considerably different, and this difference will have an affect on local weather patterns. Wind corridors, extreme soil substrate temperature and radiation frost pockets can pose a significant challenge in the establishment of vegetation. Reliance on the closest weather station (if not located at the disturbed site) often does not provide reliable data.

15.4.3 Existing Substrate

The existing substrate (such as fine textured tailings, very coarse waste rock dumps, arrest berms and road and landing base) again affects application logistics and vegetation establishment success. The existing substrate (parent material) will affect stability and trafficability over the disturbed site, as well as the feasibility of residuals incorporation. The texture, porosity, hydraulic conductivity and exchange capacity will affect nutrient retention and constituent movement.

Mineral mine disturbed sites may have elevated concentrations of trace elements in the soil substrate, related to the ore content or trace elements and chemicals used to extract the mineral of interest. It is important for the qualified professional to know these background concentrations, and the effect that rehabilitation with residuals will have on their fate and availability. For example, dry interior sites may experience salt build-up following the application of certain residuals.

In the rehabilitation of compacted landings the addition of significant organic matter in the form of branches and bark will affect the net available N following the application of a N-containing residual. This additional C input will reduce the short term N availability. Decompaction should ensure that a hardpan layer does not remain under the rehabilitated road or landing, restricting root penetration and limiting water movement through the soil profile.

15.4.4 Existing Vegetation

In most reclamation programs there exists no vegetation, and the primary objective often is to establish such a community. Often the vegetation composition on previously “reclaimed” portions of a mine site may contain species that are less desirable, or even introduced noxious weeds. Nutrient applications to these developing soils are likely to result in the fertilization of these weeds – an undesirable objective. Professional judgment should be used in evaluating the acceptability of these areas for application. It may be advantageous to incorporate and begin anew, remembering that a seed bank will still be present. Depending on the species and its characteristics, it may be possible to use the change in site productivity and competitive advantage of new vegetation to exclude undesirable species.

15.4.5 Size, Location and Access

The economic feasibility of residuals applications to disturbed soils is affected by: the size of the disturbed area, site access and proximity to affected stakeholders and the generator of the residuals to be applied. Transportation can be a significant cost associated with the use of residuals in rehabilitation initiatives, as large mineral mines are often located away from urban and industrial centers. Conversely, many aggregate mines are located near or within urban environments.

15.4.6 Residuals Form

The form of the residuals to be applied (either liquid, dewatered semi-solids or solids) will determine the application method and can affect site suitability in relation to slope stability and off-site movement. Hydraulic loading of the site in both coastal and interior environs should be considered in relation to the ability of the site to accept the application and the possibility of residuals constituent movement. Residuals can be combined with sand to create reclamation mixes to facilitate slope applications (Photograph 32).

Photograph 32: Excavator casting a pulp and paper residual and sand mix over a slope

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15.4.7 Water Resources

The location and proximity of surface water and groundwater resources are important in assessing the suitability of a candidate disturbed site. Proximity and sensitivity of groundwater to the application areas should be considered. Special attention must be given to steep slopes immediately adjacent to surface water bodies. An understanding of the quantity, quality and fate of water moving above and through the disturbed site is useful, and recommended. All buffer distances to surface water bodies should be maintained as per the OMRR and the SACoP.

When using Class B biosolids in the rehabilitation of forestry roads and landings, 30 m buffers are required on each side of culverts to be pulled at deactivation.

Watercourses should be restored to prevent water ponding, or movement traveling down reclaimed roadways. Certain mining activities can result in the creation of artificial water bodies – which can include tailing ponds. Depending on the nature of these water bodies buffer distances can vary.

15.5 Preparing Areas for Reclamation

If possible, the qualified professional should work closely with the land or mine manager in the preparation of the area for reclamation. Discontinuities in slopes, berms and piles will create topographical micro sites allowing for increased diversity. The opportunity to contour the site to minimize wind corridors and desiccation, creating aspect variations and slope discontinuities (terraces or “plantable spots”) can assist in the application logistics and subsequent vegetation establishment.

If available, overburden should be applied to the site in conjunction with residuals application. Overburden will introduce a seed bank, microbial diversity and organic matter to facilitate nutrient cycling. Many mines, however, do not have sufficient overburden to cover the disturbed areas, and as a result residuals applications are made directly to the new soil parent material. In the progressive reclamation of active mines, understanding the mine plan will assist the qualified professional in managing the logistics of residuals stockpiles, access points and transportation.

15.6 Determining Application Rates

Residual application rates can be determined on an agronomic basis – provided there is vegetation previously established, or on a non-agronomic basis, designed to provide non-N based requirements.

15.6.1 Agronomic Fertilization Applications

Fertilization of existing vegetation, established initially through a reclamation program can be based upon the fertility of the developing soil and the requirements of the vegetation. Biosolids, secondary and combined pulp and paper residuals and some compost can be used as a nutrient source. Application rates can be determined based on the N dynamics model discussed in Chapter 14. Immobilization of N in the amended substrate, depending on the type of residual applied, in previously fertilized or coarse textured (i.e. waste rock based) developing soils will be low. The agronomic application calculations must take this into consideration. Sites that have been hydroseeded or fertilized previously may have elevated concentrations of P or other plant macro nutrients. This is another consideration in the determination of an agronomic application rate.

15.6.2 Non-agronomic Applications

Predominantly, residuals applications for reclamation functions are conducted on a non-agronomic basis as there is no vegetation or established soil system. Residuals are applied to enhance soil development. Often residuals mixtures are used to provide the organic matter and nutrient capital to initiate vegetation establishment and nutrient cycling.

15.6.2.1 Target C:N

The C:N of the residuals affects the conversion, or mineralization, of nutrients (i.e. N, P, S) from an organic form to an inorganic form which is available for use by vegetation. With a C:N greater than 25:1 there is an immobilization of N where micro-organisms remove and incorporate plant available N (DETR, 1999).

High nutrient residuals (biosolids, secondary pulp mill residuals, some compost and some combined pulp and paper residuals) can be co-applied with a high C amendment (wood waste, primary pulp and paper residuals, some compost and some combined pulp and paper residuals) to temporarily immobilize excess plant available N and regulate its release over time.

This method is described in further detail in Chapter 14, in relation to biosolids forest fertilization at time of planting. This technique can be applied equally to mine reclamation activities as much as road and landing site rehabilitation. The basis for this type of application rate determination can be found in Section 14.7.

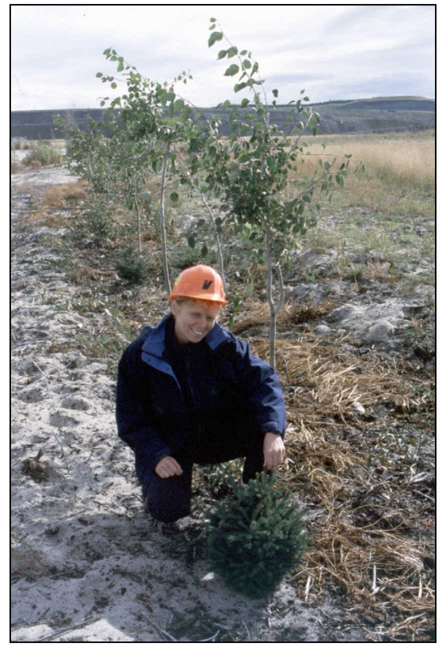
The nutrient availability from these mixtures is not additive when applied together, and mixtures should be evaluated together in the determination of an appropriate application rate. Agronomic application rates of these mixtures should be determined based on the mixed amendment. If the target C:N and organic matter approach is used, the organic residuals must meet the requirements of this method as outlined in Chapter 14. Qualified professionals should understand the mineralization and nutrient dynamics of these mixtures in prior to calculating an application rate.

15.6.2.2 Deep Row Applications

On the eastern seaboard where much gravel mining has occurred over the past century, a method has been developed that uses residuals applications to grow trees and add diversity and structure to reclaimed gravel pit ecosystems (Photograph 33).

Residual application to aggregate mines are typically completed through the uniform surface application, followed by incorporation, or in some circumstances the mixing of residuals with sand and surface distribution of this reclamation mix. The deep row technique involves the application of high nutrient residuals into deep rows. This method is suitable for solid and semi-solids residuals; it is not suitable for liquid residuals.

Photograph 33: Poplar tree established in a deep row system in BC



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Using an excavator, a series of trenches are dug into the substrate parallel to each other at 2.5 to 3 m spacing. Residuals are applied in the trench and covered and slightly mounded with the material excavated from the trench itself. In a large-scale operational program, an excavator digs and simultaneously fills adjacent rows following residuals application. In the early spring, trees are planted down the deep rows over the residuals.

Extensive monitoring has shown that with properly designed systems, no excess N moves down below the deep row. By covering the deep row residuals with additional gravel or overburden the mineralization rate of the residual is significantly reduced through the creation of an anaerobic environment. Through the introduction of oxygen from the tree roots the residual mineralizes, releasing N to the tree roots. This forms a feed-back system whereby the degree of mineralization is regulated by the root penetration and growth of the tree, matching N release to the needs of the trees. The residual serves as a nutrient and moisture reserve.

This method is useful in the establishment of trees, without concurrent establishment of understory vegetation. As residuals are applied only in the rows, the trees growing in the rows have a competitive advantage in rooting into the residuals. To minimize the competition for moisture, the area is not normally seeded

In calculating the appropriate application rates for a deep row system, it is vital that the qualified professional have a sound understanding of the factors controlling mineralization and the mineralization rate of the material to be applied.

This deep row method has had several applications; to grow large areas of trees on suitable mine topography, on mine perimeters to provide a visually pleasing buffer of trees (improving the visual landscape aesthetics) and in small areas to provide structural diversity in the creation of cover, habitat and shade over the reclaimed area. The deep row method minimizes odour potential and can be used with Class B managed organic matter that does not meet vector attraction reduction or pathogen reduction requirements.

Monitoring these types of applications can prove difficult. While the collection of pre-application soil samples is possible, the location and objective in post soil sampling is questionable. Please refer to Chapter 12 for additional information. Application rates for the deep row system are calculated based upon the agronomic calculation provided in Section 14.7.

15.6.2.3 Target Organic Matter

The majority of disturbed soils or soil forming materials– especially following mine activities – are deficient in organic matter; a requirement to initiate and sustain nutrient cycling and pedogenesis. The addition of organic matter to the soil forming materials can decrease the bulk density reducing settlement and recompaction (Moffat and Boswell, 1997 in DETR, 1999). A lower bulk density leads to increased porosity and water holding capacity allowing additional water retention to support vegetation establishment. Increased organic matter may improve hydraulic conductivity if applied to soil forming materials that are prone to clogging (i.e. clay) or forming a surface crust (DETR, 1999). As the organic matter is converted to humus and litter is accumulated, the addition of organic matter may also serve to increase the CEC of the soil (Sopper, 1993 in DETR, 1999).

The agronomic nutrient application rate of residuals on disturbed sites may provide less organic matter than is required to develop a productive soil. Calculation of a non-agronomic biosolids application rate is typically based on achieving a target concentration of organic matter in the developing soil. Excess N and the potential for NO_3^- leaching are expected.

An experienced qualified professional should complete the determination of a non-agronomic biosolids application rate. The establishment and monitoring of rate trials is suggested in refining application rates. Assessing vegetation development and the sustainability of that vegetation following non-agronomic biosolids applications should allow for an evaluation of the effect and efficacy of these treatments.

Non-agronomic application rates must be determined based on a beneficial use objective, and the means to achieve that objective must be clearly defined. Application rates calculated on the basis of increasing the developing soil trace element concentrations to near the regulated maximum is not beneficial use, and is not an authorized activity under the OMRR or the SACoP, nor a BMP.

A reclamation LAP which identifies a non-agronomic application rate, should include additional site evaluation criteria and monitoring. These are further defined in Section 15.15.

15.6.2.4 Target pH adjustment

Acidifying effects can be seen due to the weathering of some soil forming materials, such as china clay sand, crushed sandstone and coal shale and the application of inorganic fertilizers such as ammonium sulphate (DETR, 1999). Acid rock drainage mitigation can require the application of lime-based residuals. Lime materials can be added to modify the soil properties and maintain the soil pH within a range that is optimum for plant growth. Waste lime, waste lime mud, fly ash, lime stabilized biosolids and high Ca WTR can be used as liming materials. Lime mud has been used experimentally with pyritic mine tailings to decrease acid generation and acid mine drainage. The results however indicated that low pH conditions persisted in the tailings although alkaline conditions were observed at the interface of the lime mud and tailings (Catalan and Kumari, 2005 in SYLVIS, 2005).

An example of an application rate calculation based on pH adjustment is given in Chapter 10. When determining an application rate based on pH adjustment for residuals that also contain nutrients (fly ash, lime stabilized biosolids), the nutrient application rate should also be considered.

15.7 Trace Elements

Where completing a LAP under either the OMRR or the SACoP, pre-application soil samples must be collected and the final post-application soil concentrations estimated. This may be a difficult undertaking, and is further discussed in Section 15.15 below. Mineral mines and mine processing activities can result in elevated concentrations of trace elements in the tailings, dams, and often in waste rock dumps as well. With these elevated concentrations, it is important that the final land use objectives be clearly defined to ensure these objectives do not conflict with the existing “soil” quality, or the quality following application of the residual(s).

On mineral sites the concentration of specific trace elements in the soil may preclude the application of residuals under the OMRR due to the post-application soil concentrations limits (Schedules 9 and 10). Residual applications in these cases may require a permit or approval from the MoE. Under the SACoP, the application must not create or exacerbate an existing contaminated site. In many mineral mines the application of residuals may result in a dilution of background elements elevated as a result of mining activity.

15.8 Site Restrictions

The OMRR requires restricted site access in the application of Class B biosolids, and while active mines are restricted to public access, orphaned mines and forestry road and landing rehabilitation sites must be signed at appropriate access points. The SACoP requires signage to be posted at each point of access after the application of primary or secondary pulp and paper residuals containing domestic sewage having a fecal coliform density of greater than or equal to 1,000 MPN per gram total solids.

15.9 Residuals Storage on Disturbed Sites

Both the OMRR and the SACoP give storage requirements for residuals to be applied under a LAP. The SACoP requirements do not apply to the storage of lime or wood residue. Additional information on the specific storage requirements is given in Section 10.6.5.

For due diligence purposes a site assessment should be completed before the establishment of a large or long-term stockpile area. The assessment should address the sensitivity of the surrounding environment, including the potential for NO_3^- leaching, surface run-off and stability. Stockpiles should not be located in a floodplain. Climate, and the amount, intensity and seasonality of precipitation must be considered when assessing a stockpile location. The potential for N movement from stockpiles in the cold, dry interior will differ substantially from coastal environs. Substrate texture onto which the stockpiles are placed will affect the permeability/porosity of the soil and affect the potential for movement.

Characteristics of the residuals may change with storage; the qualified professional should ensure a representative sample is obtained of the product immediately prior to its use in the determination of trace element concentrations pre-application and in the determination of appropriate application rates. This is further discussed in Chapter 12.

15.10 Application Methods

Equipment used in the application of residuals to disturbed soils is similar in nature to that used in other applications, and these methods are discussed in greater detail in Chapter 10.7.2. Mine sites requiring rehabilitation are generally hard on equipment, consisting of exposed, steep, coarse textured long slopes and fine particle silt and sand in tailings ponds. Mineral mine tailings ponds can develop clay lenses which retain water in the form of “slimes” at depth. These “slimes” can pose a hazard for application equipment.

Where appropriate, the incorporation of the residual into the soil substrate will increase the effectiveness of the amendment in vegetation establishment. Incorporation is difficult in coarse textured waste rock dumps, however specialized harrows have been designed and used successfully. Surface application is common on waste rock dumps.

Several different application methods have been used in the application of biosolids to disturbed soils in BC, and these are further described below. Similar application methods could be used for the application of other residuals.

15.10.1 Slope Re-Contouring and Blending

Reclamation of steep side slopes has always presented a reclamation challenge. The steep grade precludes the use of conventional agricultural equipment for applying a soil amendment directly to the slope face. In order to facilitate direct materials placement, extensive re-contouring is required (Photograph 34). One approach to slope reclamation is to pull back the top or crest of the slope (approximately 1 m) decreasing the height / incline of the slope. Using a small wide track bulldozer the slope angle is gradually decreased to a grade that enables a dozer to traverse the slope face. A reclamation mixture is blended at the top of the slope, utilizing the excess material from the cut back and appropriate residuals. This reclamation mixture is then evenly distributed down the slope.

Photograph 34: Dozer contouring a steep slope in preparation for residual application

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The re-contouring, although labour and equipment intensive, achieves a uniform application and increases slope stability thus minimizing potential erosion. By blending the residual with the native mine spoils prior to slope placement a good seedbed is created and the potential for odours may be minimized. In addition, the re-graded slope can enable direct drill seeding, decreasing the seeding rate and potential seed loss. Once re-vegetated, the slope has a natural rolling hill appearance, improving the aesthetics of the overall site. Re-grading may also extend the toe of the slope. If the slope is encroaching on a perimeter boundary, this application technique may not be feasible.

15.10.2 Gravity Placement – End Dumping

Conventional reclamation on mine sites involved dumping overburden/soil over the slope crest. Haul trucks transport the soil material to the slope's edge and dump the material, letting the effects of gravity place the soil on the slope face. The advantages of using this method are related to the economics of application. The trucks are often available on site and the application is simple.

However, an application of this type is highly irregular and susceptible to erosion. Because one is relying on gravity to place the soil material on the slope face, the material often concentrates at the crest of the slope leaving the bottom portion of the slope, often up to 1/3 of the entire length bare. In addition, incorporation into the native material is extremely difficult because it has little or no adhering qualities, thus the newly placed reclamation mix is susceptible to mass wasting.

Spreading systems have been engineered to overcome some of the aforementioned difficulties. Where the crest and toe of the slope is accessible a chain may be placed between two pieces of equipment and dragged over the slope, mixing the residuals with the existing substrate. If only the crest of the slope is accessible a swivel or large weight may be placed at the end of the chain while dragged over the applied slope.

As access to the slopes is not possible, seeding is difficult and can be expensive as seed application options can be limited to hydro seeding or aerial seeding.

15.10.3 Specialize Spreaders

On short slopes, where site conditions preclude equipment to traverse the slope face, high powered side cast spreaders can cast material over 30 m horizontally, with an angle of trajectory that enables the material to carry over 20 m vertically with minimal spillage. A deflector plate controls the angle of trajectory and prevents spillage. The application distance is controlled by the vehicle’s RPM and speed of the flights. For the most effective application, material should be applied from both the crest and base of the slope.

With the application from both the crest and base, uniform coverage is achieved over the entire slope face. While stability problems are reduced, the logistics of seeding remain as above.

15.10.4 Hydro-Seeder/Liquid Spray Applications

Liquid residuals may be applied by a hydroseeder to small disturbed areas. The slurry is applied evenly to the designated area in lifts or coats, and allowed a period for air-drying between lifts to avoid “runs” or a flow of the liquid mixture on or off the slope. Extensive site management is required during the liquid spray application to control the number of lifts or make other adjustments to the application method as required to achieve a controlled, even application with no slumping. Maximizing slurry solids content is desirable to minimize water application. A supply of water is subsequently required on the application site for rewatered applications. Distance of travel to the water source will affect the overall application costs. It is necessary that the slopes be accessible from both the top and the bottom, facilitating spray application both up-slope and down-slope.

Hydro-seeding units are extremely sensitive to debris such as rocks or branches. As a result, caution should be exercised in materials handling to ensure that the residuals are not contaminated with rocks or other debris, typically introduced at the stockpile site.

15.10.5 Conventional Agricultural Equipment

This application method involves the use of regular agricultural tractors and manure spreaders, both rear and side discharge. The equipment simply discharges as the equipment traverses the application site. As with hydro seeding, this agricultural equipment is generally available. A rear discharge spreader is extremely limited to angle of incline, and is generally useable only on relatively flat areas. A side discharge unit however has a broader range of use as it can achieve a discharge pattern over 6 m horizontally. Its capabilities are limited to that of the tractor and length and incline of the slope. For steep side slopes that are relatively short, up to 8 m, the side cast spreader can easily achieve a uniform application over the slope face by casting from both the top and bottom of the slope.

Of the various types of application equipment described above, the use of conventional agricultural spreaders is typically the lowest cost option. In addition, if the tractors are able to traverse the slope while discharging, the site would also facilitate direct seeding, either broadcast or drill seeding. The suitability of this method is highly dependent on the inclination of the application area and length of slope.

15.11 Application Timing

Timing the application of residuals in the rehabilitation of disturbed sites is related to site access, climate and growing season. Applications should typically not be made to frozen ground, or on snow where there exists the potential for surface run-off. On some sites access may be limited by floatation (especially on tailings or sedimentation ponds) and applications may be performed while the tailings are frozen. Ensuring protection of water resources is paramount.

15.12 Vegetation Establishment

The qualified professional needs to consider the timing of residuals application in conjunction with the establishment of vegetation.

For example, when applying high N residuals the NH_3/NH_4^+ concentration can act to inhibit seed germination if seeded in conjunction with, or immediately following residuals application. As mines are often located in environments of extreme climate, attention should be given to the actual growing season, which is often very short and related to adequate moisture and temperature.

The choice of species for vegetation establishment depends on the expected soil fertility and climatic conditions. Nitrogen fixing species do not retain their competitive advantage over other species following application of high N residuals, and it is typical to observe few N fixing plants growing the first year following application and seeding. While N-fixing plants may not occupy a large percentage of the vegetative cover in the first few years after nutrient application, they will assist in sustaining subsequent growth.

Distribution of seed can be accomplished from the air, or on the ground. Seed drills can be used on amended tailings.

The establishment of trees and shrubs requires special considerations with respect to competition from previously established vegetation, available root zone (modified through incorporation), herbivory and desiccation from wind and solar radiation.

15.13 Special Considerations – Mineral Mines

The availability of trace elements present in mine tailings and waste rock dumps can be affected by pH and substrate chemistry (i.e. high pyrite concentrations which may generate acidic drainage). The qualified professional should understand the site's trace element content and availability, and the effect of residuals applications and vegetation establishment on trace element availability and acid drainage. Excess soil trace elements may affect foliar chemistry and impact grazing animal health.

15.14 Special Considerations – Forest Roads and Landings

High nutrient residuals, applied alone or in combination with a high C residuals, can be incorporated into roads and landings in conjunction with deactivation and de-compaction activities. As with forest fertilization, appropriate buffer distances must be maintained to surface water bodies. As culverts are removed in most road deactivation, the location of all culverts is usually marked and biosolids-free buffers established to each side.

Typically forestry roads and landings are rehabilitated with the objective of growing trees. In the Interior of BC it is recommended that trees not be planted into the biosolids amended area immediately after application. With the addition and incorporation of the residuals there will be a significant increase in water holding capacity, and the freeze-thaw activity following the first winter has been observed to damage tree roots and heave plugs.

For the future establishment of conifers, grass and herb species chosen for forestry road and landing reclamation should be low growing, so as to not shade, or snow press subsequent seedlings.

15.15 Management and Monitoring

Project management guidelines for residuals use in reclamation are similar to other uses. Application areas, water bodies, buffer zones and similar considerations should be marked on maps or aerial photography. A list of project management and emergency contacts should be made available to all the all parties involved, and a contingency plan should be developed in the case of accidental biosolids applications to non-designated areas.

When developing a LAP under either the OMRR or the SACoP it is required that a monitoring program be formulated that addresses changes in soil and vegetation quality where residuals application rates exceed agronomic application rates.

In addition to the requirements of the OMRR and the SACoP, it is suggested that the site evaluation for a non-agronomic biosolids application include:

- Why the proposed amendment application is preferred to other options
- An estimate of the total and excess nutrients expected following the application
- Identification of the most-probable adverse human health or environmental impact
- A description of the monitoring plan to assess the environmental impact
- A description of the management technologies that will be employed to minimize adverse environmental impact

Monitoring the effects following residuals use in reclamation can be designed to assess first whether the most probable adverse environmental effect has occurred, then, if it has occurred, the extent and impact of its effect.

The BC *Mines Act* requires monitoring programs; water, soil and vegetation sampling programs may be ongoing or completed. The qualified professional should be familiar with these programs and their results prior to designing a residuals-related post-application sampling program.

15.15.1 Soil Monitoring

Pre-application soil monitoring is required under OMRR and the SACoP in the development of a LAP and determining background fertility and trace element concentrations. Non-agronomic application rates require the formulation of a post-application soil monitoring program.

Pre and post soil analysis should include total trace elements and available nutrients, pH, EC, and organic matter concentration. Representative samples should be collected from the rooting zone or zone of incorporation. Non-agronomic application rates may warrant further sampling to assess the depth and extent of N movement where potential contamination is a concern. This can be completed by taking replicate soil samples at depth. See Chapter 12 for a discussion of sampling for NO_3^- determination.

Obtaining representative soil samples from replaced overburden, tailings, and forestry roads and landings is relatively simple compared to sampling waste rock dumps, where there is a high coarse fragment content and a lack of substantial amounts of fines. Pre-application analysis of the developing soil will provide insight into the fertility and trace element content of the fines (and of the coarse parent material). Post-application soil sampling on these sites typically results in nutrient and trace element concentrations similar to that of the residuals applied, as little weathering of the soil parent material has occurred. Care must be taken when scaling these concentrations up to an area basis by multiplying the concentrations by the percentage of fines in the zone of incorporation. The usefulness of post-application soil sampling in these situations is limited, and if completed, the results must be carefully interpreted.

Post-application sampling is recommended for additions of residuals designed to modify the pH of the soil to confirm that the pH is within the desired range and significant changes have not occurred.

When using the deep row technique, soil sampling post-application should be taken immediately below the row to assess residuals constituent movement.

15.15.2 Water Monitoring

Surface water monitoring should identify if there are any existing water quality concerns, and the parameters to be analyzed determined from this assessment; in conjunction with the type of residuals applied. Surface water monitoring should be conducted only as part of a program designed to quantify the impact of a most probable adverse environmental impact. If surface run-off from steep slopes into a stream is that event, evidence of movement should be confirmed then sampling should be conducted both upstream and downstream of the application area. Samples should be compared with an appropriate control, or historical data. Surface water chemistry often changes through the seasons. Chloride and NO_3^- are good indicator compounds for high N residuals. Caffeine can be used as an indicator for municipal biosolids.

Mining involves explosives, and most explosives are N based. Explosive residue can be found on waste rock and in settling dust following detonation. In the development of a surface water monitoring plan, current and future mining activities should be considered.

Groundwater sampling can be conducted through wells in situations where excess constituents from the residuals are suspected to be moving down through the developing soil profile. A good understanding of the hydrogeological layout and water movement through the disturbed site is important prior to initiating a groundwater sampling program.

15.15.3 Foliage Monitoring

Monitoring of foliage quality is a required activity under the *Health Safety and Reclamation Code for Mines* in BC, and should be conducted on reclamation programs where vegetation is to be established on soil parent material with little to no initial organic matter. Under the OMRR, non-agronomic application rates require the development of a post-application vegetation sampling program. The SACoP requires documentation of the potential changes in the vegetation quality that will be caused by a non-agronmic application.

Imbalances in nutrient ratios are possible on disturbed sites such as incorrect copper:molybdenum ratio in vegetation which can result in molybdenosis in ruminant animals. Non-agronomic applications that produce excess soil NO_3^- may result in luxury consumption of N by vegetation and possible health impacts for grazing animals. Chapter 12 contains more information on monitoring vegetation. As with soil analysis, foliar nutrient analysis should be conducted at the same time in the vegetation's development to facilitate appropriate comparisons and the analysis should include plant essential nutrients and trace elements. Note that the uptake of trace elements may vary significantly by species, plant maturity, sampling location and time of sampling (within the day).

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Appendix One – Statistical Definitions, Formulas and Examples

Definitions

The following is a list of definitions used when discussing statistics:

Population: a set of units or group of objects fitting a defined objective, for example, all soil in the 30 cm layer of 1 ha of land; the total amount of fly ash produced by a co-generation plant in 1 year (or 10 years etc.). It is often useful to envision the population as if it were composed of discrete units, such as all the soil in the 30 cm layer of one ha of land as composed of some number of spadefuls of soil. Thus, one spadeful is one unit of the entire population, and the population is all of the spadefuls of soil in the defined area. A measure of a nutrient concentration in one spadeful of soil would be an observation of the population.

Parameter: a numerical descriptive measure of some attribute of a population, which is calculated from all observations in a population, for example, the mean zinc concentration of all fly ash produced by a co-generation plant over a 10 year period.

Sample: a subset of units of the population, for example, 10 spadefuls from the 30 cm layer of the one hectare land unit in the example above.

Sample statistic: a numerical descriptive measure of some attribute of a sample, which is calculated from the observations in a sample, for example, the mean zinc concentration derived from 10 samples of fly ash from a co-generation plant.

Variable: a characteristic or property of an individual population unit, for example, zinc concentration, bulk density. The name variable is derived from the fact that any particular characteristic will vary among the units in a population. For instance, the zinc concentration in each spadeful of soil will vary from spadeful to spadeful.

Due Diligence Sampling

The purpose of this Appendix is to provide guidance for determining a suggested number of samples and sampling method to characterize the materials with a specified level of confidence.

Statistical Analysis Overview

Definitions of the terminology used in the following Section can be found in the Definitions Section at the start of this Appendix. There are two terms worth emphasizing. The word ‘parameter’ always refers to a population quantity and ‘statistic’ always refers to a sample quantity. Parameter refers to some measure of all possible units in a population. Statistic refers to some measure of a subset of units in a population. A sample statistic is used as an estimate of the population parameter.

For example, if the zinc concentration in fly ash was measured continually, and the mean concentration was 3.4 $\mu g\ g^{-1}$, the parameter for all of the material would be known to be 3.4 $\mu g\ g^{-1}$. However, continuous measurements are impractical so the zinc concentration in a subset of the population (a sample) is measured, the mean is calculated and used to draw inferences about all the fly ash produced within that time period. In statistical texts the symbols denoting the two types of quantities differ. Population parameters are typically denoted with

Greek lettering and sample statistics with Arabic lettering. For example, μ and x both represent the mean of a sample.

The word ‘sample’ can be confusing as statistically it refers to a subset of a population (for example, 5, 10 or more units from a population). It can also refer to the actual physical unit collected (for example, a soil sample). For example, a sample may consist of 10 soil samples. The only method of distinguishing between the meanings is the context in which it is used.

Understanding measurements, sample variation, precision and bias is important in assessing the confidence level of your results. First, measurements are discussed.

Measurements

Measurements are a quantification of some attribute or variable of the material being land applied or of the receiving environment. For instance, the moisture content of the biosolids is a quantitative measurement of one variable describing the physical characteristics of the biosolids. Typically, due to the quantities of material involved, measurements cannot be made on the entire quantity or population of the material being characterized, thus, samples are collected to support inferences regarding the entire population. For example, biosolids samples collected monthly over a 1 year period for pathogens, trace elements and nutrients would be used to make inferences about the characteristics of all of the biosolids produced at the treatment plant during that period. In a LAP, the purpose of quantitative assessments of both the material to be land applied and the receiving environment is to support predictions regarding the effect of the material being applied on the receiving environment. The information ultimately leads to the decision as to whether the application of the material should proceed on that site.

Depending on the attribute involved, the ‘reliability’ of the measurement may be of greater or lesser importance. In general, an inference based on a small sample size (for example, 5 samples) will be less reliable than one based on a larger sample size (for example, 30 samples). For example, if the measurement is of one of the trace elements listed in Schedule 4 of the OMRR or in Table 1 of the SACoP, which can limit the land application of residuals, the reliability of the measurement may be of greater importance than that of the cation exchange capacity, which may be used to characterize the receiving environment soils.

Using statistical methods, a confidence interval (CI) may be placed around the statistic of interest (for instance, sample mean) such that some percentage of the time the population parameter would be found within that interval. Consider the statement: 95% of the time the mean mercury (Hg) concentration of biosolids from a WWTP will fall within the interval of 2.8 to 4.6 μg g^{-1}, versus the statement, 99% of the time the average Hg concentration in biosolids from the same WWTP will fall within the interval of 2.4 to 5.0 μg g^{-1}. By varying the interval we influence the ‘reliability’ of the estimate. Derivation of the interval is a function of the variability of the material or site being characterized and the number of samples collected.

Sample Variation

When working with residuals and soils, variability of the material is inherent to the system. It is important to understand the degree of variability of a material in order to make valid interpretations based on sample measurements. For example, consider the nitrogen concentrations of 3 samples of a secondary pulp and paper mill residuals collected at 2-week intervals. If the material is highly uniform, sample values of 4.5, 4.3 and 3.9% nitrogen may indicate a significant difference in quality of the residuals between the sample periods. If the material is quite variable, each of the values may fall well within the established confidence limits. In simplest terms, understanding the variability of a material means understanding and defining a 'normal' range for specific characteristics of that material.

> Sampling provides a 'point estimate' of a true value of a defined population, the population parameter. A departure from the true value is attributed to measurement error, sampling error and total error. Total error is the sum of measurement error and sampling error.

Measurement error is variability between measurements for the same variable on the same sample. It can be referred to as the error caused by the failure of the observed measurements to be the 'true' value for the unit. There are two types of measurement error. The first is the error innate to the measurement process and is a limitation of the equipment or process. It is also referred to as reproducibility or the ability to get the same result time after time. An illustration of this point would be to take 10 successive weights of a mass of biosolids. If the scale of measurement is fine enough (e.g. 0.001 g), 10 slightly different weights will result. As this first process is random these errors tend to cancel each other out as the sample size increases. Also, the coarser the measurement unit, the less this factor contributes to total error. For example, 8.001, 8.004, and 8.010 g will all be 8 g when measuring to the nearest gram. The second type of measurement error results in a bias (consistent over or underestimation) such as ignoring the 'tare' weight of a truck going over a scale. Consequently, load weights will always be overestimated by the truck weight and a biased estimate will result.

Sampling error is the variability between samples. For example, if our goal is to determine the effect of a residual application on soil nitrogen content, we cannot collect all possible 15 cm soil cores from the land area and analyze each for nitrogen. Instead, we collect samples from the area to estimate the fertilization effect. The method of sampling is reproducible but samples differ from each other despite the apparent uniformity of the area. The sampling error is that which results from sampling only a few units in a population rather than the entire population.

As mentioned above, total error is the combination of these two sources of variability. Typically, in biological situations the variability between samples contributes substantially more to total variability than measurement error.

Two usual measures of variability are sample variance and sample standard deviation. These measures capture the variation of observations. Variance is calculated based on the difference between the individual observations and the mean of the observations, while standard deviation is the square root of the variance. For example, if nitrogen concentrations of 5 biosolids samples were 4.20, 4.50, 3.90, 4.60 and 4.50%, the mean would be 4.34%. The differences between each observation and the mean would be: -0.14, 0.16, -0.44, 0.26 and 0.16. Variance (s^2) is calculated from the sum of these differences squared, as follows:

$$s^2 = \frac{\text{sum of (observation – mean)}^2}{\text{number of observations – 1}}$$

Thus, for the example above,

$$s^2 = \frac{(4.2-4.34)^2+(4.5-4.34)^2+(3.9-4.34)^2+(4.6-4.34)^2+(4.5-4.34)^2}{5 - 1}$$

$$s^2 = \frac{(-0.14)^2+(0.16)^2+(-0.44)^2+(0.26)^2+(0.16)^2}{5 – 1}$$

$$s^2 = 0.332/4$$

$$s^2 = 0.083$$

In statistical texts the formula might be presented as follows:

$$s^2 = \frac{\sum (x_i - \overline{x})^2}{n-1}$$

This formula can be tedious so the following working formula is more frequently used for calculations.

$$s^2 = \frac{\text{(sum of the squares of the sample measurements)} - \dfrac{\text{(sum of sample measurements)}^2}{\text{number of observations}}}{\text{number of observations - 1}}$$

$$s^2 = \frac{(4.2^2+4.5^2+3.9^2+4.6^2+4.5^2) - [(4.2+4.5+3.9+4.6+4.5)^2/5]}{5-1}$$

$$s^2 = 0.332/4$$

$$s^2 = 0.083$$

In statistical texts, the formula might be presented as follows:

$$s^2 = \frac{\sum x_i^{\,2} - (\sum \overline{x})^2 / n}{n-1}$$

Standard deviation (s) is the square root of s^2 and is 0.29%.

The sampling plan may require modifications of this basic formula.

When coupled with the characteristics of the distribution, inferences regarding the population can be made. For example, if the distribution of nitrogen concentration in several samples follows a ‘normal curve’ (bell shaped and symmetrical as in Figure 1), 68% of all the observations would be found within 1 standard deviation of the mean (4.34% ± 0.29%) and 95% of the observations would be found within 2 standard deviations of the mean (4.34% ±

0.58%). For a sample size of 5, this type of range calculation fails to contribute much information as 68% or 95% of 5 (in terms of whole numbers) is minor, but for a sample size of 30 it can be very valuable to know how tight the distribution is, as this indicates precision.

Sample Precision

Precision is the spread or variability of the observations (measurements from several samples) around a measure of central tendency such as the mean. If we assume that Figure 1 represents the nitrogen concentrations from 30 samples of each of two different compost sources, diagram "b" represents a more precise distribution than diagram "a". In other words, the various measurements resulting from the 30 samples are generally closer to the average nitrogen concentration in diagram "b" than the measurements in diagram "a". Diagram "b" may be said to represent a less variable material than diagram "a" (providing the units are identical).

Precision is inversely related to the variability among samples. In other words, the higher the variability among samples the less precise the measurements; and the less variable the sample the greater the precision of the measurements. Typically, within the same material, precision increases and variability decreases as the number of samples collected increases. The distribution constructed from a sample size of 10 from one compost source would likely be more variable than the one constructed from 30 samples from the same compost source.

Actual measures of variability include variance, standard deviation, and standard error of the mean among others. Estimates of the variability of residuals are important in calculating the numbers of samples required to reach a specific confidence level.

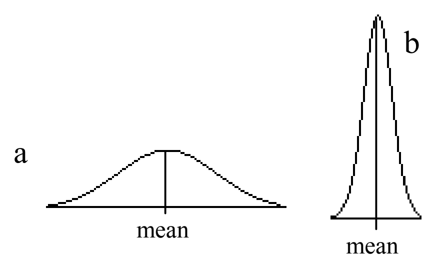


Figure 1: Example of two different frequency distributions.

Sample Bias

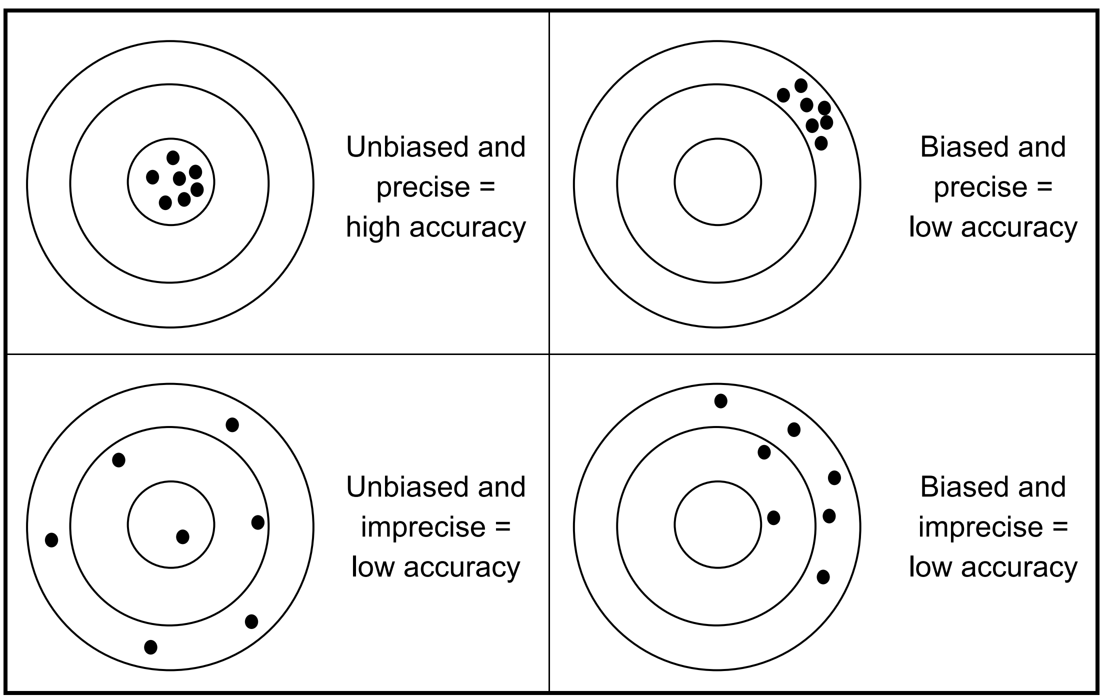
Bias (under or overestimation) is the deviation of a sample statistic (for example, a sample mean), from a population parameter. For instance, if we took five successive sets of thirty 1 L samples of a biosolids prior to dewatering, and determined the Hg concentration in each of the samples, the mean of the 30 samples from each set would be slightly different. This variability among means is referred to as the standard error of the mean. In this example it is a measure of the spread of all possible means of a sample size of 30, from the population. In concept it is similar to standard deviation, but standard deviation is the variability or spread of individual observations, while standard error of the mean is variability or spread of sample means.

If we presumed we could take all possible sets of thirty 1 L samples and find the average of all these means, the difference between the average Hg concentration from these and the actual population Hg concentration would be the bias. The distribution of means resulting from measurement of all possible thirty 1 L samples is termed the sampling distribution. If the mean of a sampling distribution (the mean of the means) has a value equal to the population mean, the statistic is said to be an unbiased estimate of the population parameter. In practice this latter population characteristic (parameter) is frequently unknown, instead we use the sample characteristics (statistic) to estimate the population characteristic (parameter), and the precision of the sampling distribution to make a decision whether a sample mean differs from the population mean.

It should be noted that repetition, or increased sampling does not affect bias as it does precision. For example, if the Hg concentration of a biosolids is 1.45 µg g^{-1} but the process by which it is measured results in an underestimation of the concentration, every subsequent sample will also be underestimated. In this scenario, bias remains constant while precision increases.

The relationship between precision, bias and accuracy is illustrated in Figure 2.

Figure 2: Precision, bias and accuracy.



Determining the Number of Samples

In many cases, the residual generator or producer will have historical trace element, nutrient and pathogen information. This data can be used to determine mean long-term trace element, nutrient and pathogen concentrations and provide the ability to assess the variability of the residuals. However, prior to initiating a land-application program a fresh sample[1] of the

[1] Note: 'sample' may be a single sample or several samples as determined by these guidelines.

material to be applied should be analyzed for such concentrations. This is especially important if there have been variations in the process or influent/feedstock content, quantity or concentration or if the material has been stored for a long period of time.

Since, under the OMRR, retail-grade organic matter can be freely distributed without volume restriction, material may be distributed in any size of lot including those smaller than 5 m^3. It is unrealistic to expect producers to test each small lot, however, due diligence must be undertaken to ensure the material meets the OMRR standards. It is suggested that sampling frequencies as determined in the following Sections be related to or reflect facility batch processing (a set of samples per batch). Sampling frequency may be increased by the generator to confirm product quality in addition to following the OMRR requirements.

This sample number determination can also be applied in receiving environment monitoring.

Trace Elements and Nutrients

The OMRR and the SACoP outline levels of trace elements that cannot be exceeded in residuals and the receiving environment. It also requires nutrient analyses of residuals. The following provides a step-by-step outline to follow for calculating sample variance, estimating sample size based on the variance, calculating a corresponding confidence interval and comparing your results to the regulatory limits. The protocol for what to do if samples are over the regulatory limit is also addressed.

General Procedure: The number of samples to collect from a population for such determinations is dependent on the following 3 questions:

1. How large a shift do you wish to detect with confidence (e.g. a concentration difference of 1.5 to 1.6 $\mu g\ g^{-1}$ Hg or 1 to 2 $\mu g\ g^{-1}$ Hg)?
2. How much variability is present in the population? Will estimates of variance or standard deviation be required?
3. What are the levels of confidence you require (e.g. 80, 95 or 99% of the time your population parameter will be within a specified range)?

A judgment must be made regarding the degree of sampling accuracy and precision required to reliably estimate the characteristic of the material for the purpose of comparing those characteristics with regulatory thresholds. In general, high accuracy and precision are required if the contaminant of interest is present at a level close to the regulatory threshold. Conversely, lower accuracy and precision are required if the contaminant is well below the regulatory threshold.

The approach taken by the BC MoE “Contaminated Sites Statistical Application Guidance Document” suggests a 95% level of confidence for characterization and analysis. Since we are only concerned with the incidents in which the concentration of the regulated trace element may be beyond the upper end of the upper confidence limit, there is actually only a 2.5% chance rather than a 5% chance that the mean will be greater than the upper confidence limit, and not comply with the regulation. An estimate of the sample numbers required is calculated from the following formula:

$$n = \frac{t_{.\alpha}^{2} s^{2}}{\Delta^{2}}$$

where:

n = the number of samples required

$t_{.\alpha}^{2}$ = two-tailed (Figure 3) tabulated 't' value for a confidence interval of a given probability (e.g. if α = 0.05, the CI is 1 – α yielding a 95% degree of confidence), and based on n-1 degrees of freedom.

s^{2} = sample variance from previously collected data

Δ = OMMR limit – sample mean

Note: confidence intervals are two-tailed by their nature as they have an upper and a lower confidence limit

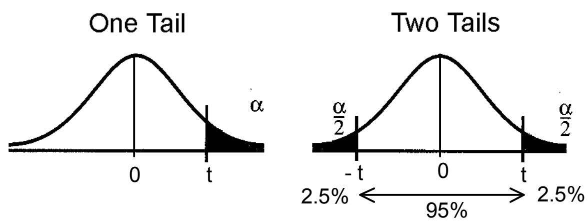


Figure 3. Student's 't' distribution. Center of the distribution is '0'; if calculating a CI (Equation 9, Table 1), use a two-tailed 't' value, or the value for α/2 if only one-tailed values are provided.

Estimates of the number of samples needed increase as the distance between the sample mean and the regulatory threshold (Δ) decreases and/or the 't' value increases (either through low initial sample numbers or increased degree of precision desired). To ensure the correct number of samples are collected, calculated n values should always be rounded up (e.g. n = 8.1 rounds up to 9)

A demonstration of this general procedure as applied to the sampling requirements of the OMRR and SACoP is provided below

Methodology:

The general procedure for determining the number of samples required from a population to achieve a specific CI was outlined in the preceding Section. These steps have been applied to the determination of trace element concentration in materials covered by the OMRR as an example (but would also apply to soil amendments regulated under the SACoP). This methodology is similar to that used by the US department of Agriculture and US Composting

Council for characterization of compost[2]. It should also be noted that each sample may be a single sample or a composite sample.

1) If data for the regulated elements are available from the generator, determine the $\bar{x}$ and s^2 using formulas 2 and 4 in Table 1 (a minimum of 3 samples are required). The sample analyses used must not span any significant changes in treatment process.

2) For each regulated element, estimate the appropriate number of samples to be collected from the organic matter using equation 10 in Table 1 and an α of 0.05. The appropriate number of samples is the greatest of the individual estimates for each element. For example, if the *n* estimated for arsenic is 1 and the *n* estimated for mercury is 3, the appropriate number of samples to collect is 3.

> Note: in some cases where the element concentration is substantially less than the regulatory limit or the variance is very low the estimated *n* may be less than 1 or 2. In such cases a minimum of 3 samples should be collected. If the estimated number of samples required is 10, you may wish to collect 3 to 5 for analysis initially, recognizing the possible need of increasing the number of samples as suggested in Step 8.

3) Collect the samples (n_1) and analyze.

4) When greater than 2 samples have been collected and analyzed the data should be examined for departures from normality. Such assessment methods are beyond the scope of this document but can be found in statistical reference texts. If there are departures from normality the data should be transformed using an appropriate transformation as found in statistical reference texts (e.g. the square-root transformation may be applicable if the $\bar{x}$ is roughly equal to the s^2; the arcsin transformation may be applicable if the $\bar{x}$ is less than the s^2 etc;). If the transformation addresses the departure from normality, the remaining calculations should be based on the transformed data. However, once at the reporting stage, always report the untransformed data as the units and values will have little meaning otherwise.

5) Calculate $\bar{x}$, s^2, s and $s_{\bar{x}}$ for each set of data using the formulas appropriate for the sampling plan (Table 1).

6) If the $\bar{x}$, of the data is equal to or greater than the OMRR limit and is believed to be an accurate estimator of μ (population mean), the element is considered to be present at over the OMRR limit.

7) If the $\bar{x}$ is not over the OMRR limit, determine the 95% CI for each regulated trace element. If the upper CI is less than or equal to the regulatory limit the element is considered consistent with the limits for that Class.

8) If the upper CI is greater than the regulatory limit, re-estimate the total number of samples to be collected from the organic matter using the newly calculated values

[2] The major differences are the degree of uncertainty accepted as 5% for these guidelines (versus 20% for the US guidelines) and the two-round ceiling of sampling (noted below) to compare the upper confidence level against the regulatory limit within these guidelines.

for $\bar{x}$ and s^2 (not the original values). Collect and analyze any additional samples (n_2).

9) Recalculate the $\bar{x}$, s^2, s and $s_{\bar{x}}$ for each regulated element using the combined n_1 and n_2 sets of data.

10) Recalculate the 95% CI and check the upper CI against the OMRR limit.

Note that the purpose of Steps 8, 9 and 10 was to increase the number of samples, thereby increasing the precision of estimation and narrowing the CI.

11) If the upper CI is less than the OMRR limit, the concentration is consistent with the regulation, if it is greater than the OMRR limit the concentration is considered over the OMRR limit.

Should data not exist for the characteristic under consideration, choose a sampling plan and take a minimum of 3 samples. Determine the $\bar{x}$ and s^2 using the formula appropriate to the sampling plan. Follow through from Step 3 onwards.

Should the estimated number of samples required be quite large (for example, 10), you may wish to collect 3 to 5 for analysis as a starting point. If the upper CI is less than the OMRR limit the concentration is consistent with the regulation. If the upper CI is greater than the OMRR limit collect and analyze the remaining samples.

For the mercury example in the latter half of Table 1, presume we took 3 samples as suggested by the sample formula calculation for a 95% level of confidence, an initial sample mean of 10 and a regulatory limit of 15. Presume the Hg concentrations for the 3 samples were reported as 4.8, 4.6 and 8.6. µg g^{-1}.

S^2 = 5.1
S = 2.3
n = 3
$t^2_{.05}$ and 2 degrees of freedom = 4.303
$\frac{s}{\sqrt{n}} = \frac{2.3}{\sqrt{3}}$
$\bar{x}$ = 6.0
α = 0.05

$$\mathrm{CI} = \bar{x} \pm t_{\alpha/2}\frac{s}{\sqrt{n}}$$

$$= 6.0 \pm 4.303(1.3)$$

$$= 6.0 \pm 5.7$$

lower confidence limit (LCL) = -0.3
upper confidence limit (UCL) = 11.7

Since the UCL is above the Class A OMRR limit of 5 but below the Class B OMRR limit of 15, the material is in agreement with Class B regulations for this trace element. All regulated elements should be tested in the same way and a class designation assigned to the residual based on the lowest class acceptance. If all elements fit in with Class A requirements except one (which meets Class B designation), the material would be classified as Class B.

Table 1: **Statistical definitions, formulae and examples as applied to sampling of residual and receiving environments and suggested methods for determining compliance with the OMRR.**

Terminology	Symbol	Equation and supporting information	EQ #	Example
Variable e.g. mercury, arsenic, phosphorus concentration	x	-		A compost pile composed of 8,322 spadefuls. Simple random and systematic random sample plan: with a sample size of 10. Stratified random sample: a total sample size of 10 is taken but the pile is stratified into: stratum 1) 3 samples from the exterior upper half; stratum 2) 3 samples from the exterior lower half; and, stratum 3) 4 samples from the interior Variable is nitrogen concentration.
An individual measurement of variable x	x_i	where i = 1 to N or n and N is the population size and n is the sample size		E.g. x_1 = 2.4 % nitrogen, x_2 = 2.35 % nitrogen, etc;
Mean of all possible measurements of the variable x (population mean)	μ	$\mu = \sum x_i / N$ where: x_i = each individual measurement of the variable in the entire population N = the total number of observations in the population	(1)	E.g. x_1 = 2.45, x_2 = 2.5, x_3 = 2.7, …. $x_{8,322}$ = 2.53 $\sum x_i = 21{,}637$ N = 8,322 $\sum x_i / N = 21{,}637 / 8{,}322 = 2.6$ The sum of the individual nitrogen concentrations (one for each spadeful) divided by the total number of observations (spadefuls) in the population.

Terminology	Symbol	Equation and supporting information	EQ #	Example
Mean of the measurements generated from a sample (sample mean)	$\bar{x}$	Simple random and systematic random samples: $$\bar{x} = \sum x_i / n$$ where: x_i = each individual measurement of the variable in the sample n = the total number of observations in the sample Stratified random samples (weighted sample): $$\bar{x} = \sum W_k \overline{x_k}$$ where: $\overline{x_k}$ = mean for a stratum W_k = proportion of the population represented by the stratum	(2) (3)	Simple random and systematic random samples: E.g. x_1 = 2.3, x_2 = 1.98, x_3 = 2.6, …. x_{10} = 2.8 $\sum x_i = 25.2$ $n = 10$ $\sum x_i / n = 25.2/10 = 2.52$ The sum of the individual nitrogen concentrations for each observation in the sample (one for each spadeful) divided by the total number of observations (spadefuls) in the sample. Stratified random samples (weighted sample): E.g. $\overline{x_1}$ =2.45; W_1 =0.3; n_1 = 3 $\overline{x_2}$ =2.68; W_2 =0.3; n_2 = 3 $\overline{x_3}$ =2.8; W_3 =0.4; n_3 = 4 $\sum W_k \overline{x_k} = 0.3(2.45) + 0.3(2.68) + 0.4(2.8) = 2.66$ The sum of the stratum proportion x the mean concentration of the samples from that stratum.

Terminology	Symbol	Equation and supporting information	EQ #	Example
Sample variance	s^2	Simple random and systematic random samples: $$s^2 = \frac{\sum x_i^2 - (\sum \bar{x})^2 / n}{n-1}$$ Stratified random samples (weighted sample): $$s^2 = \sum W_k s_k^2$$ where: s_k^2 = mean for a stratum W_k = proportion of the population represented by the stratum	(4) (5)	Simple random and systematic random samples: E.g. Calculate from sample observations as discussed in the text. s^2 = 0.12 Stratified random samples (weighted sample): E.g. Calculate variance for each stratum and then weight by stratum proportion. E.g. s_1^2 =0.10; W_1 =0.3; n_1 = 3 s_2^2 =0.08; W_2 =0.3; n_2 = 3 s_3^2 =0.11; W_3 =0.4; n_3 = 4 $\sum W_k s_k^2 = 0.3(0.10) + 0.3(0.08) + 0.4(0.11) = 0.10$
Sample standard deviation	s	$\sqrt{s^2}$	(6)	Simple random and systematic random samples: $\sqrt{0.12}$ = 0.35 Stratified random samples (weighted sample): $\sqrt{0.10}$ = 0.32
Coefficient of variation	CV	$CV = \frac{s}{\bar{x}} \times 100$	(7)	Simple random and systematic random samples: = 0.35/2.52 x 100 = 13.9% Stratified random samples (weighted sample): = 0.32/2.66 x 100 = 12.0%

Terminology	Symbol	Equation and supporting information	EQ #	Example
Standard error of the mean	$s_{\bar{x}}$	$$s_{\bar{x}} = \frac{s}{\sqrt{n}}$$	(8)	Simple random and systematic random samples: = 0.35/3.16 = 0.11 Stratified random samples (weighted sample): = 0.32/3.16 = 0.10
Confidence interval	CI	$$\mathrm{CI} = \bar{x} \pm t_{\alpha/2} \frac{s}{\sqrt{n}}$$ where: $t_{\alpha/2}$ is the two-tailed Student's 't' value for $n-1$ degrees of freedom and a probability of $\alpha/2$ in Table 2.	(9)	Simple random and systematic random samples: If $\alpha = 0.05$ (95% level of confidence) *CI* = 2.52 $\pm$ 2.262 (0.11) LCL = 2.27; UCL = 2.76 Stratified random samples (weighted sample): If $\alpha = 0.05$ *CI* = 2.66 $\pm$ 2.262 (0.10) LCL = 2.43; UCL = 2.88 where: LCL = lower confidence limit UCL = upper confidence limit
Regulatory limit	RL	As defined in the OMRR and SACoP for each particular variable of interest in the residual or the receiving environment.		Since there are no regulatory limitations for nitrogen we will use mercury (Hg) as an example. E.g. Class A biosolids RL for mercury = 5 Class B biosolids RL for mercury = 15 SACoP RL for mercury = 5

Terminology	Symbol	Equation and supporting information	EQ #	Example
Sample size	n	$$n = \frac{t_\alpha^2 s^2}{\Delta^2}$$ where: Δ = RL - $\bar{x}$	(10)	Continuing the Hg example using Class B biosolids RL = 15 If $\alpha = 0.05$ ($\alpha / 2 = 0.025$) and n - 1 = 9; t = 2.262 (from Table 2Table 2) S^2 = 16.98 If Δ = 15 – 10 = 5 n = 2.262^2 (16.98)/5^2 = 3.4 $\approx$ 4 samples If Δ = 15 – 12 = 3 n = 2.262^2 (16.98)/3^2 = 9.6 $\approx$ 10 samples If Δ = 15 – 13 = 2 n = 2.262^2 (16.98)/2^2 = 21.7 $\approx$ 22 samples If $\alpha = 0.20$ ($\alpha = 0.10$) and n - 1 = 9; then t = 1.383 (from Table 2) S^2 = 16.98 If Δ = 15 – 10 = 5 n = 1.383^2 (16.98)/5^2 = 1.2 $\approx$ 2 sample If Δ = 15 – 12 = 3 n = 1.383^2 (16.98)/3^2 = 3.6 $\approx$ 4 samples If Δ = 15 – 13 = 2 n = 1.383^2 (16.98)/2^2 = 8.1 $\approx$ 9 samples Therefore '*n*' increases as the sample mean approaches the RL. '*n*' also increases with greater precision required: $\alpha = 0.05$ vs $\alpha = 0.20$.
Degrees of freedom	df	n - 1		= 10 - 1 = 9

Table 2: The *t* distribution.

Confidence Intervals		80%	95%
α $\alpha/2$		**0.20** **0.10**	**0.05** **0.025**
d.f. (n-1)	**1**	3.078	12.706
	2	1.886	4.303
	3	1.638	3.182
	4	1.533	2.776
	5	1.476	2.571
	6	1.440	2.447
	7	1.415	2.365
	8	1.397	2.306
	9	1.383	2.262
	10	1.372	2.228
	11	1.363	2.201
	12	1.356	2.179
	13	1.350	2.160
	14	1.345	2.145
	15	1.341	2.131
	16	1.337	2.120
	17	1.333	2.110
	18	1.330	2.101
	19	1.328	2.093
	20	1.325	2.086
	21	1.323	2.080
	22	1.321	2.074
	23	1.319	2.069
	24	1.318	2.064
	25	1.316	2.060
	26	1.315	2.056
	27	1.314	2.052
	28	1.313	2.048
	(z) ∞	1.282	1.960

Appendix Two – Sample LAPs

The following three fictitious LAPs have been prepared to provide examples of:

1. biosolids application as a fertilizer for forage grass on a farm near Prince George;
2. biosolids fertilization of mature stand of hybrid poplar growing on an island in the Fraser River; and
3. biosolids and biosolids compost application to a gravel mine, to be reclaimed into a regional park.

Example Land Application Plan #1

The following example Land Application Plan has been prepared for a fictitious application of biosolids as a fertilizer for forage grass on a farm near Prince George. This plan addresses the requirements of the OMRR, including site-specific management requirements.

Although this LAP is written for biosolids application under the OMRR, it contains the main elements required for a LAP for the application of a soil amendment under the SACoP. The qualified professional is advised to consult the regulation and this guideline to ensure that all required elements are included.

Land Application Plan – Hooligan Beef Ranch

Biosolids production facility: Prince George Wastewater Treatment Plant (include contact name and number)

Owner of proposed application site: Mr. R. Smith, Hooligan Beef Cattle Ranch (include address and phone number)

Proposed date of start of application: May 1, 2006

Time period of plan: February 1 – December 31, 2006

Location and boundaries of site: The proposed application site is the NE field on Mr. Smith's property. The location of Mr. Smith's farm is approximately 8 km south of the city on the highway, off Landview Rd. (an area map with farm and field highlighted and a legal description must be included).

Plan prepared by: J. Agrologist, P.Ag. (address, phone number and professional designation required)

Summary

This Land Application Plan outlines the proposed application of biosolids on the Hooligan Beef Ranch near Prince George. Dewatered City of Prince George Class B biosolids will be applied to the site and used as the sole fertilizer for a new seeding of forage grasses. The agronomic application rate of biosolids for the crop and site is 49 tonnes per hectare 'as-produced'. Predicted post-application trace element concentrations in the soil suggest that no trace element will exceed allowable concentrations. Public health requirements such as buffers, signage, access restriction and crop harvest waiting period have been outlined in the LAP as per the OMRR requirements. Biosolids will be surface applied using standard rear discharge manure spreaders, and will be incorporated soon afterwards when the field is ploughed. Biosolids application is planned to occur in May, the optimal time of year for application, but may be delayed if soil and weather conditions prohibit field work. There are two special management concerns on the site; the first is a seasonal stream running next to the north side of the field and the second is residential buildings located near the property line along the east side of the field. Buffers have been increased in both instances to reduce the impact of the biosolids application. Forage harvested from the field will be sampled at harvest and tested for nitrate to ensure concentrations are within an acceptable range.

Notification

Notification in the form of OMRR Schedule 13 has been submitted to the MoE Regional Manager, the Agricultural Land Commission and the local Medical Health Officer.

Crop and Site Management Information

The Smith family farms 80 ha near Prince George. They currently have 49 ha of land in older perennial forage stands (grass-legume mix) for winter hay production for their 100 cow herd. Mr. Smith is ploughing 19 ha of forage land in spring of 2006, and is planning to reseed it with a grass:legume forage mix (80% grass:20% legume). Biosolids will be used as the sole fertilizer source for this 19 ha portion of reseeded land during the 2006 cropping season. The biosolids are to be surface-applied on the existing stand, and the field will be ploughed immediately after biosolids application. With ploughing and disking, the biosolids will be incorporated very quickly. One crop of 4 tonnes per hectare (2 tons per acre) will be taken off in late summer. The proposed application site was determined to have poor fertility after discussions with the farmer about his previous manure and fertilizer schedule on the field. The field has received regular applications of nitrogen fertilizer that were somewhat below crop requirements, and the field was lightly manured once (layer manure) 2 years previously. The field is not irrigated.

Site Assessment and Soil Sampling Protocol

There do not appear to be any nutrient, soil quality or trace element issues that would limit use of this field for biosolids fertilization. The field will benefit from the nitrogen in the biosolids as it is currently very poorly supplied with this nutrient.

Soil samples were collected from the proposed application site on October 15, 2005, and submitted to an analytical lab in Edmonton for trace element, nutrient and quality assessment. The site was subdivided into two equal portions for sampling, along the middle of the field from north to south. Two composite samples were submitted to the lab, each consisting of 15 subsamples collected in a zig-zag pattern from the sampling area to a depth of 15 cm. As the data was very similar between the two areas of the field, the data was combined for inclusion in the LAP.

The topography of the proposed application site is flat to slightly sloping. The site is located on Pineview clay, a heavy clay soil. Because of the high clay content of the soil, the site is poorly drained and remains wet well into the spring. Equipment use on the site is limited to times of the year when the soil is sufficiently dry to prevent compaction; if the spring is abnormally cool and wet, biosolids application may be delayed. The site was cleared from forest 10 years ago, and has been planted to perennial forages ever since. There is a small stream running along the north edge of the proposed application site. The east boundary of the field abuts a neighbouring farmstead and residence. The west and south fields abut other fields belonging to the farm.

Background soil nutrient and quality parameters, and trace element concentration

The field currently has a low concentration of crop-available nitrogen, and is moderately to well-supplied with crop-available phosphorus and potassium. The concentrations of other soil macronutrients are normal. The soil pH is neutral which is excellent for the production of forage crops. Soil electrical conductivity is moderate and is acceptable for crop growth.

The trace element concentrations in the soils are presented in Table 3, column 5. All trace elements were well below maximum allowable soil concentrations for agricultural sites as stipulated in the OMRR at the time of soil sampling.

Biosolids Information

Prince George treatment plant biosolids are generated using a trickling filter process. Biosolids are then anaerobically digested to reduce the volatile solids content by at least 38%, and are dewatered to approximately 24% dry matter. Fecal coliform concentrations are less than 2,000,000 MPN per gram of dry sample as per wastewater treatment plant lab analysis completed in the past 6 months, but more than 1,000 MPN, classifying the biosolids as Class B (pathogens). The biosolids contain less than 1% foreign matter and meet OMRR requirements for Class B trace element concentration (Table 3). The E.C. of the biosolids is 6.0, and pH is 7.8. Plant available P and K are 2,827 and 1,040 mg per kg (dry basis) respectively.

Determination of Biosolids Application Rate

The agronomic application rate of nitrogen for this site was determined to be 130 kg N per hectare. The biosolids application rate that will provide this amount of available nitrogen is 11.7 dry tonnes per hectare (49 'as-produced' tonnes per hectare). The calculations to determine these values follow.

Assumptions:

- Estimated volatilization losses of inorganic nitrogen: 40%
- Estimated mineralization of organic nitrogen during cropping season: 15%
- Agronomic application rate of nitrogen for crop (forage grass-legume mix, central Interior, 4 T ha^{-1} yield, poor fertility site): 130 kg N ha^{-1}

Table 1: Biosolids nutrient concentrations (average of composite sample taken from stockpile)

Parameter	%	kg $tonne^{-1}$ (dry)
TKN	4.3	43
NH_4+NH_3	0.86	8.6
NO_3	0.08	0.8
P	2.5	25
K	0.2	2
DM	24	

Table 2: Application rate calculations

Parameter	Calculation	Result
Total organic nitrogen	43 kg $tonne^{-1}$ TKN – 8.6 kg $tonne^{-1}$ inorganic N	34.4 kg $tonne^{-1}$
Mineralized organic nitrogen in 1st growing season	34.4 kg $tonne^{-1}$ * 0.15	5.16 kg $tonne^{-1}$
Inorganic nitrogen less volatilization loss	8.6 kg $tonne^{-1}$ * 0.6	5.16 kg $tonne^{-1}$
NO_3	0.8 kg $tonne^{-1}$ * 1.0	0.8 kg $tonne^{-1}$
Total nitrogen available in 1st growing season	5.16 + 5.16 + 0.8 kg $tonne^{-1}$	11.12 kg $tonne^{-1}$
Nitrogen required by crop	-	130 kg ha^{-1}
Biosolids application rate (dry basis)	130 kg ha^{-1} / 11.1 kg $tonne^{-1}$	11.7 tonnes ha^{-1}
Application rate (as produced basis)	11.7 tonnes ha^{-1} / 24% dry matter	49 'as-produced' tonnes ha^{-1}

Trace Element Addition Rate

Table 3 below provides the City of Prince George biosolids and receiving soil initial trace element concentrations, and the predicted soil concentration of the 11 identified trace elements following biosolids application. All are below allowable maximum concentrations for an agricultural site as outlined in the OMRR.

Table 3: Trace element concentrations

Trace Element	Biosolids (ppm)	Class B biosolids criteria (ppm)	Biosolids addition (kg ha^{-1})	Background soil (ppm)	Final soil (predicted) (ppm)	Agricultural soil limits* (ppm)
Arsenic	5	75	0.06	2.1	2.1	25
Cadmium	2	20	0.02	0.2	0.2	9
Chromium	44.1	1,060	0.51	22	22.3	50
Cobalt	3.6	150	0.04	6	6	40
Copper	1,100	2,200	12.87	26	34.6	150
Lead	50	500	0.59	11	11.4	350
Mercury	4.3	15	0.05	0.15	0.2	0.6
Molybdenum	8.9	20	0.10	4	4.1	5
Nickel	21.9	180	0.26	25	25.2	150
Selenium	2	14	0.02	0.2	0.2	2
Zinc	641	1,850	7.5	52	57.0	200

* As per OMRR soil standards for agricultural sites.

Soil fertility assessment

The soil test fertilizer recommendation showed that the soil concentration of P and K is low to medium. The biosolids will provide enough P for crop growth, but supplemental K fertilizer may be required.

Soil pH is 6.5 and conductivity is 0.32 dS m^{-1}. Both are within the normal range and are not expected to be negatively impacted by the biosolids application.

Public Health requirements

Class B biosolids are proposed for application at this site. The following public health measures must be observed (buffers are required for all biosolids applications) to ensure that the biosolids are managed and applied in an environmentally protective manner:

Buffers: 30 m buffers are required from any watercourse, well, off-property occupied dwellings, and major roads. The west and south edges of the application site abut other fields; no buffers are required along these boundaries. The north edge of the field abuts a stream and the east side is adjacent to a neighbouring residence. See special management concerns for increased buffer requirements along these boundaries of the site.

Signage and access restriction: signs must be posted on the road into the field stating that biosolids have been applied to the site. These signs must be maintained for 38 months after the application.

Crop harvest waiting period: Forage on this site cannot be harvested for 60 days following biosolids application; livestock cannot graze the site for the same period. There are no ‘food for human consumption’ harvest restrictions as the site is used for growing livestock forage only.

Application method and timing

Method: biosolids will be surface applied on an existing grass stand that is scheduled for renovation. Field will be ploughed immediately following biosolids application, which will incorporate the biosolids. Spreading and ploughing will occur simultaneously, and spreading will not begin until a period of ideal weather allows the completion of application and incorporation.

Timing: Biosolids application is planned for May, which is an appropriate time of year for application, but may be delayed until later in the summer as dictated by weather and soil conditions. Biosolids will be stockpiled on site for several months prior to application with the stockpile located at least 30 m from surface water sources and wells.

Special management concerns

A seasonal stream that runs into a salmon bearing stream runs along the north side of the proposed application site. The proposed application site slopes slightly towards the stream.

The application buffer from the stream will be increased to 50 m to ensure that there is no risk of runoff entering the stream. Biosolids to be applied have been dewatered to approximately 24% dry matter, and will be incorporated soon after application which will minimize the risk of material moving to the stream. However, in the event of a heavy rainfall before the biosolids can be incorporated, the additional buffer will reduce the risk of runoff.

The houses and farm buildings of the ranch to the east of the proposed application site are close to the property line. The buffer along the east side of the proposed site will be increased to 50 m to minimize any perceived risk of public health concerns. Biosolids will be tilled in as soon as possible after application. If possible, biosolids will be spread in calm, cool weather to avoid odour, dust and vector considerations. Neighbours will be notified in person of the pending application.

Post-application monitoring of the site

Monitoring of trace element addition at the site

If it is deemed necessary to determine the post-application concentrations of soil trace elements, the following protocol will be followed:

- Re-sample receiving soil as with pre-application composite sample using tube sampler or similar method,
- Sample 0-15cm depth,
- Collect one composite sample of 15 samples per ha evenly distributed over field in Z pattern, and
- Submit samples for total elemental analysis to same lab as pre-application samples.

Routine post-application monitoring

Because biosolids are to be applied at an agronomic rate, there is no requirement for post-application monitoring. However, forage nitrate concentration will be tested at the time of forage harvest to ensure forage is safe for beef cattle consumption. Two composite samples from throughout the field will be collected and submitted for laboratory analysis.

Written certification from a qualified professional will be completed following application as per Section 5 (3) of the OMRR.

J. Agrologist, PAg

December 1, 2005

Example Land Application Plan #2

The following example land application plan has been prepared for a fictitious WWTP, forestry company and qualified professional in the biosolids fertilization of mature stand of hybrid poplar growing on an island in the Fraser River. This plan addresses all the requirements of the OMRR, including site-specific management requirements. Notification with Schedule 13 of the OMRR to the Regional Waste Manager is assumed. Authorization from the Medical Health Officer is not required.

Although this LAP is written for biosolids application under the OMRR, it contains the main elements required for a LAP for the application of a soil amendment under the SACoP. The qualified professional is advised to consult the regulation and this guideline to ensure that all required elements are included.

Managed Forests Inc. – Polygon 66

Date:	January 30, 2006
Reference #	2006-66
Biosolids production facility:	Central City WWTP 1299 Effluent Avenue Vancouver, BC V3M 5P8 Attn: John Brown Biosolids Project Manager Phone: (604) 555-2211 Fax: (604) 555-1122
Owner of proposed application site:	Managed Forests Inc. 22nd Flr 888 Economy Rd. Vancouver, BC V1X 1X2 Attn: Mr. I.G. Rowtree Operational Forester Phone: (604) 555-1212 Fax: (604) 555-2121
Proposed start of application:	March, 2006
Time period of application:	60 days
Location and boundaries of application site:	Polygon 66, Humphrey Island, Chilliwack, BC. Sections 19,20,21, Township 4 Range 30 West of the 6th meridian, New Westminster District
Plan prepared by:	Ms. D. O. Right, RPF #12 3456 Milltown, BC V9X 1X9 Phone: (250) 555-1212 Fax: (250) 555-2121

Summary

Managed Forests Inc. (MFI) owns and manages over 4,000 ha of hybrid poplar plantations in the Fraser River Valley. As part of an operational fertilization program, MFI proposes to use biosolids from Central City WWTP, located in Vancouver to fertilize a mature stand of hybrid poplar. The site vegetation and soils were assessed, and samples of the soil collected and analyzed for fertility and trace element concentration. Concentrations of nitrogen and phosphorus were very low. The soils have a low organic matter content. Class B biosolids

meeting < 1,000 MPN g^{-1} fecal coliform are to be surface applied in April, 2007 to the poplar stand by standard rear discharge manure spreaders. The calculated application rate is 27 dry tonne ha^{-1}, providing 1,022 kg N ha^{-1}. Special site management considerations have been identified with respect to biosolids stockpiles, transportation and application. Calculation of the estimated trace element concentrations in the soil suggest that no element will exceed the allowable concentration. No post application environmental monitoring program is to be conducted.

Objective

Polygon 66, a stand management unit located on Humphrey Island outside of Chilliwack BC is proposed to be fertilized with an agronomic application rate of biosolids to provide the nitrogen that the trees and understory vegetation require to optimize growth, while ensuring no adverse environmental impacts.

Site Characteristics

Polygon 66 is a 29.3 ha plantation of approximately 30 year old hybrid poplar trees located on the western portion of Humphrey Island. This stand of poplars is one of the few remaining polygons of the first established hybrid poplar plantations in the Fraser Valley. A map of the application area is found in Appendix 1. No portion of the site is located within 30 m of a surface water body, and there is no indication of water ponding during Fraser River freshet. This management polygon is completely enclosed within other stand management polygons.

The hybrid poplar trees are planted and maintained at a relatively wide spacing, providing ease of access to the stand for fertilization. The topography is described as gently undulating, and is located on a series of elevated benches above the high water freshet. There is no appreciable slope to the land in any specific direction. Windrows exist at periodic spacing through the plantation. These windrows consist of woody debris piled following the last clearing. These piles contain dense, smaller diameter poplar trees in competition with significant understory vegetation that was not controlled in the initial stand establishment and maintenance. This vegetation is described in detail below. Several gaps exist in the overstory and scattered throughout the stand. It is thought that these gaps result from the failure of the plantation in small pockets where an extended seasonal water table is present. Identification of these two forms of gaps can be made visually through the identification of indicator species in the minor vegetation, and soil profile characterization. Previous stand records indicate that the stand has not been fertilized. Due to the size of the trees, a fertilization regime in this system will be designed to significantly increase the diameter of the poplar boles to produce a high quality peeler log, or lumber stock material.

A small abandoned homestead exists within the plantation midway up the western perimeter on the plantation. The existing plantation of hybrid poplars was planted through this location. The site holds no historical significance.

Vegetation

The vegetation of the area is dominated by the overstory of *Populus* spp. (400 stems per ha), planted on a spacing of over 6m between rows. Significant components of the understory vegetation include:

- Hooker's Willow (*Salix hookeriana* (Barratt ex Hook): a shade intolerant deciduous shrub that occurs on moist to wet soils on medium productivity sites on the Island. This shrub is indicative of disturbed and early seral or secondary succession, and is located in the greatest densities around the plantation on the western perimeter. Very little Hooker's willow is found in the interior of the stand under the hybrid poplar due to the intense competition for light.
- Red Elderberry (*Sambucus racemosa* L.): a shade tolerant to intolerant deciduous shrub that occurs on fresh to very moist medium productivity soils on the island. This shrub is indicative of nitrogen rich soils, and is found on recent cutovers and is indicative of rapid rates of decomposition of forest floor materials. Usually identified with nitrogen rich sites, this shrub is present on the island in scattered associations. Somewhat misleading of site productivity, this shrub is found in the openings associated with the edges of the plantation, and along the windrows.
- Trailing Blackberry (*Rubus ursinus* (Cham. & Sechelt): again, a shade tolerant to intolerant deciduous shrub that occurs on fresh to very moist medium productivity soils on the island. This shrub is common on disturbed sites in early seral communities, and is present along with other *Rubus* spp. including *Rubus leucodermis* ((Torr. & A. Gray) black raspberry), *Rubus laciniatus* ((Willd) evergreen blackberry) and *Rubus spectabilis* ((Pursh) salmonberry) that dominates the vegetation associations found on the windrows. These species can form formidable barriers in combination with the slash present in the windrows.
- Common Snowberry (*Symphoricarpos albus* (Blake): another deciduous shrub that is indicative of nitrogen rich soils on water shedding and receiving sites. An early colonizer of recent cutovers, its presence on the island is limited to the edges of openings dominated by the *Rubus* spp.
- Other species include the oval leafed mitrewort (*Mitela ovalis* (Greene)), water parsley (*Oenanthe sarmentosa* (J.S Presl)) and buttercup (*Ranunculus repens* L.) on the gap openings with prolonged seasonal groundwater table present.

The understory described above is sparse in nature, and occurs primarily around openings created through the presence of windrows or gaps. Although usually indicative of a nitrogen rich ecosystem, the spatial distribution and density do not represent the true nature of the nutrient status of the site. Species identified above do, however, allow for the identification of gap openings resulting from an extended seasonal groundwater table.

Soils

Soils within this polygon belong to an association of orthic regosols comprised of Grevell and Seabird associations. Grevell soils are found throughout the majority of the polygon, with a minor component of Seabird series. These soils are formed from coarse textured (sandy), stone free Fraser River flood plain deposits. Surface textures are loamy sand, varying to sandy loam, while subsurface and subsoil horizons textures are medium to coarse sand, sometimes changing to gravelly sand at depth. Thin, finer textured silt lenses may occasionally found (more typical of Seabird series). These soils are considered well drained, and are rapidly pervious and have slow surface run off and a low water holding capacity. A very temporary water table may develop in the subsoil during the freshet of the Fraser River in parts of the association, and those with a larger proportion of silt lenses may be classified as imperfectly drained.

The soils have a very thin organic surface layer (less than 2 cm thick) consisting of mostly deciduous leaves and twigs. This is underlain by a thin (less than 5 cm) discontinuous, grayish-brown sandy layer slightly enriched with organic material, which then grades into over 1 m or more of loose greyish sand sometimes containing a few weak reddish or brown mottles in the lower portions.

Average nutrient concentrations in the soils in Polygon 66 are found in the table below.

Nutrient	**Concentration (mg kg^{-1})**
Ammonium	8.0
Nitrate	1.25
Phosphate plant available	7.25
Potassium plant available	158.0
Sulphate	3.8
Calcium	1,517
Magnesium	313
Iron	158
Copper	4.8
Zinc	1.3
Boron	0.6
Manganese	14.75
pH	6.15
EC	0.4 dS m^{-1}
Organic matter (%)	1.2

Concentrations of nitrogen in the forms of ammonium and nitrate are very deficient. Concentrations of phosphate are low. Humphrey Island soils are low in organic matter. Possible plant nutrient deficiencies may exist with zinc and boron.

Biosolids Information

The biosolids from Central City WWTP are produced from a secondary anaerobic thermophilic digestion facility. The pathogen reduction process employed at this WWTP produces a Class B biosolids with fecal coliform concentrations less than 1,000 MPN per gram biosolids. The biosolids would meet Class A biosolids criteria except mercury concentrations are 7.6 mg kg^{-1}, over the 5 mg kg^{-1} limit. The moving average of biosolids quality as determined from monthly sampling (n = 12) for one year is found in the table below.

Trace elements, Nutrients, and Bacteriology ($mg\ kg^{-1}$)	Mean (n = 12)
Arsenic	5.9
Cadmium	4.1
Chromium	77.8
Cobalt	8.1
Copper	1,690
Lead	230
Mercury	7.6
Molybdenum	11.0
Nickel	61.9
Selenium	5.3
Zinc	996
pH	8.0
EC ($dS\ m^{-1}$)	5.8
Total Solids (%)	27.4
TKN ($mg\ kg^{-1}$)	38,368
Total-Phosphorous ($mg\ kg^{-1}$)	20,232
Plant available phosphorus ($mg\ kg^{-1}$)	3,207
Ammonia Distillation ($mg\ kg^{-1}$)	6,937
Total Potassium ($mg\ kg^{-1}$)	33,126
Plant available potassium ($mg\ kg^{-1}$)	1,127
Fecal Coliform (MPN g^{-1} dry weight)	963
Salmonella (MPN g^{-1} dry weight)	<0.41

Reviewing the monthly analysis, there is little variation in biosolids quality, and the mean values in the table above are used in the determination of trace element additions and the application rate.

Proposed Application Rate

Design values used in the calculation of the biosolids application rate reflect the nitrogen demand from the crop trees and minor vegetation. The highest demand for nitrogen occurs in years three to five in intensive plantations of hybrid poplar. With no minor vegetation control in these stands, there will be a reduction in the immobilization of nitrogen in organic matter as returned to the soil. The estimated nitrogen uptake and transformations are found in the table below.

Nitrogen Uptake - Trees ($kg\ ha^{-1}$)	110
Nitrogen Uptake – Understory ($kg\ ha^{-1}$)	45
Volatilization (%)	50
Denitrification (%)	10
Immobilization ($kg\ ha^{-1}$)	150
Mineralization Rate (%)	30
Total Nitrogen Required (kg/ha^{-1})	1,022
Application Rate (Dry Tonnes ha^{-1})	27
Application Rate (Bulk Tonnes ha^{-1})	100

The mineralization rate of the biosolids was provided by Central City, who determined their biosolids mineralization rate through a research program.

Application Method and Timing

Biosolids from Central City's WWTP will be transported and stockpiled on the island in February, 2006. Stockpiles will be located on high ground a minimum of 30 m from any surface water body. Application of biosolids will be completed by standard rear discharge manure spreaders between the rows in April, 2006. No applications will be made to openings dominated by understory vegetation indicative of possible high water. Biosolids will be surface applied and not incorporated, due to the existing root structure of the trees. Applications will be completed and all equipment removed from the island prior to the Fraser River freshet.

Transportation and application of biosolids will occur during the period of low Fraser River water level, as during this time the groundwater level will be well below 1 m in depth.

Special Site Management Considerations

The application is scheduled to occur in the spring, when the roots of the hybrid poplar will be actively growing and developing a new network of fine roots to supply the tree with the required nutrients and water for the upcoming bud break and resulting leaf development. The requirement of the stand for nutrients, especially nitrogen, is high during this time period.

The active portion of the root network (the area of the root biomass that will contribute the most to nutrient uptake) in these hybrid poplar stands occurs around the canopy drip line, or towards the center of the rows. It is proposed that applications of biosolids be made in the mid-corridor of the planted rows where the highest concentration of poplar fine roots exist and therefore the areas of highest nitrogen demand.

Applications should avoid those gaps as identified by the indicator understory vegetation and topography as having an extended seasonal high water table. Although these gaps do not exist in high concentrations, there exists a lack of a dominant overstory of crop trees. These locations will not benefit from a biosolids application, and thus applications of biosolids should be focused in areas with a dominant poplar overstory. These areas will be buffered out of the application area. While no significant adverse environmental impact will occur from the application of biosolids to these areas, best management practices warrant no application to these areas. Increased growth response of the understory vegetation in these opening would result in undesirable competition with the trees for limited summer moisture.

Access to Humphrey Island is obtained by crossing a dry river channel while the river is low. Managed Forests Inc. is coordinating the necessary approval from Federal Fisheries. As MFI has received approval over the past years (used in moving harvesting equipment, planting stock and stand maintenance equipment to the island) they have indicated that they expect no problems. Trucks transporting biosolids to and from the island will be required to ensure that they are clean (no biosolids may be present on mud flaps and tail gates) prior to crossing the river channel. Truck traffic from the WWTP to Humphrey Island will traverse no sensitive areas. The necessary contingency plan is found in Appendix 2. Signs will be posted at key access points to the island, informing any visitors of the biosolids fertilization activities.

The closest neighbour, Mr. D. Airy, has been contacted and told of the proposed fertilization activity. We anticipate contracting his manure spreaders to apply the biosolids. Odour concerns are not anticipated, as the surrounding farmland is in hog and dairy production.

The stand management plan for polygon 66 identifies biosolids fertilization as a planned silvicultural activity.

Post Application Site Monitoring

No environmental post application site monitoring is proposed. Following the biosolids application the polygon boundary will be walked to ensure the application has not extended into any adjacent polygons. Mr. I.G. Rowtree from MFI has agreed to assess the condition of the stand and growth of the trees at high water. He has knowledge and experience in this area, as hybrid poplar trees do not grow in soils waterlogged for extended periods of time. In cooperation with MFI, a small portion of the polygon will not be fertilized, and growth response as measured by a change in diameter will be assessed between the fertilized and non-fertilized trees.

Estimated Trace Element Concentrations

Elevated arsenic concentrations were noted in the background soil. It is thought that this trace element is present in the Humphrey island soils as a result of arsenic-based pesticides (now banned) used on attempts to grow agricultural crops on these soils prior to poplar establishment.

Trace Element	Concentration in Biosolids (mg kg^{-1})	Addition to Soil (kg ha^{-1})	Pre-Application Soil Concentration (mg kg^{-1})	Pre-Application Soil Concentration (kg ha^{-1})	Estimated Post Soil Concentration (kg ha^{-1})	Estimated Post Soil Concentration (mg kg^{-1})
Arsenic	5.9	0.2	32	72.0	72.2	32.1
Cadmium	4.1	0.1	0.5	1.1	1.2	0.5
Chromium	77.8	2.1	33	74.3	76.4	33.9
Cobalt	8.1	0.2	14	31.5	31.7	14.1
Copper	1,690	45.6	32	72.0	117.6	52.3
Lead	230	6.2	11	24.8	31.0	13.8
Mercury	7.6	0.2	0.05	0.1	0.3	0.1
Molybdenum	11	0.3	2	4.5	4.8	2.1
Nickel	61.9	1.7	45	101.3	102.9	45.7
Selenium	5.3	0.1	0.2	0.5	0.6	0.3
Zinc	996	26.9	50	112.5	139.4	62.0

Application Rate: 27 dt ha^{-1}

Soil Bulk Density 1500 kg ha^{-1}

Soil Depth 0.15 m

The estimated post soil concentrations are calculated based on the assumption that there is no change in bulk density following application, and that the biosolids is incorporated into the top 15 cm of the soil. In the application proposed in this LAP, the biosolids will not be incorporated, but remain on the surface.

Ms. D. O. Right, RPF
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January 30, 2006

Example Land Application Plan #3

The following is a sample land application plan for the application of biosolids and biosolids compost to a gravel mine, to be reclaimed into a regional park.

This plan addresses all the requirements of the OMRR, including site-specific management requirements. Notification with Schedule 13 of the OMRR to the Regional Waste Manager is assumed.

Although this LAP is written for biosolids application under the OMRR, it contains the main elements required for a LAP for the application of a soil amendment under the SACoP. The qualified professional is advised to consult the regulation and this guideline to ensure that all required elements are included.

Central City Maplethor Regional Park Reclamation

Date:	January 30, 2006
Reference #	2006-79
Biosolids production facility:	Central City WWTP 1299 Effluent Avenue Vancouver, BC V3M 5P8 Attn: John Brown Biosolids Project Manager Phone: (604) 555-2211 Fax: (604) 555-1122
Owner of proposed application site:	Central City Regional District. 10234 232 Street Maplethor, BC V2X 2X3 Attn: Mr. G. Reenpark District Supervisor Phone: (604) 555-1212 Fax: (604) 555-2121
Proposed start of application:	August 2006
Time period of application:	60 days
Location and boundaries of application site:	Southwest corner of Central City Maplethor Regional Park Sections 18, Township 6 Range 28 West of the 6th meridian, New Westminster District
Plan prepared by:	Ms. P. I. Topark, RPF #12 3456 Milltown, BC V9X 1X9 Phone: (250) 555-1212 Fax: (250) 555-2121

Summary

Following the completion of gravel extraction operations in a 12 ha portion of Central City's Maplethor Regional park, the area will be re-contoured in accordance with a land use plan and biosolids and biosolids compost from Central City's WWTP will be applied at a 1:1 ratio (v/v) at an application rate of 179 dry tonnes per ha. The application is scheduled for August, 2006. Immediately following application by rear discharge manure spreaders the amendment will be incorporated into the soil. The area will be drill seeded with parkland grasses and lightly rolled.

As the park is located above the shallow, and quality compromised Abbotsford-Sumas aquifer, a comprehensive study was completed to assess the site condition – including topography, soil, geology, aquifer characteristics and recharge rates. A lysimeter study, which duplicated the application of the proposed amendment was conducted over one year. This study supports the application of biosolids and biosolids compost at 179 dry tonnes per ha as being protective of human health and the environment. A public consultation process has informed and involved the local area residents and stakeholders in the reclamation process and there is general community support.

All requirements of OMRR are met, and an extensive post application monitoring program, consisting of soil, surface water, ground water and vegetation monitoring will be implemented. A contingency plan has been prepared should the monitoring indicate any possible adverse impact.

Objective

In the SW corner of Central City's regional park there exists a 12 ha section of land that has been used by an adjacent company for the removal of aggregate. With the aggregate mining complete, Central City's Parks Department in cooperation with the mining company would like to re-contour the pit into useable park – complete with picnic area, canoeing pond and concert bowl. Central City would like to use biosolids and biosolids compost generated from their wastewater treatment plant in the reclamation of this disturbed area.

Background

In 1970, the Central City Regional District (CCRD) purchased land for inclusion within the Maplethor Regional Park; however; the gravel extraction rights were not included with this purchase. The owner of the gravel rights, BC Aggregates Ltd. and the CCRD Parks department have agreed to work together in the reclamation of this area following gravel extraction. With the extraction to be completed in 2005, there is 12 ha in the southwest portion of the park requiring rehabilitation.

Within the overall rehabilitation plan, the CCRD has proposed the use of biosolids and biosolids compost combined as an amendment to increase the fertility and moisture holding capacity of the coarse textured substrate remaining after gravel excavation. The application of these amendments is to result in the development of a productive top soil which is capable of sustaining a diverse community of vegetation.

Site Characteristics

This study was conducted at Central City's Maplethor Regional Park, located between 234 Street and 272nd Avenue in Maplethor, BC.

The gravel formation that exists in the park is a result of a geologically recent melt water channel scouring into outwash glacial fluvial deposits laid down previously. The resulting sand and gravel deposits range to 40 m in depth, with periodic lenses of silt and clay resulting from glaciomarine sedimentation.

Groundwater in the park flows from south to southwest, and is recharged through the vertical infiltration of winter precipitation. The park is located over the western extent of the Abbotsford-Sumas aquifer. In the BC Ministry of Environment, 1995 Fraser Valley Groundwater Monitoring

Program, wells in this aquifer were found to have consistently high nitrate-nitrogen concentrations, with the 75th percentile being above the drinking water quality standard of 10 mg L^{-1}. The major source was hypothesized to be inappropriate use of animal manure and inorganic fertilizers on agricultural lands.

There are no standing water bodies on the site, however there is a small creek which flows adjacent and south of the park into a roadside ditch.

In one corner of the disturbed area there exists a large old growth tree, which holds special significance to the local residents and First Nations. A buffer was maintained around this tree during the aggregate extraction.

In conjunction with the CCRD Parks Department, a land use plan has been developed that will see this area re-contoured to include a picnic area, concert bowl, recreational lake and a small parking lot. Following re-contouring, on the areas where vegetation is to be established, the previously existing topsoil (overburden) will be replaced.

The environmental consulting company Earth Management and Associates was retained to complete a comprehensive site assessment. Their report assessed the topography and site geology, groundwater flow and quality and, as well, developed a water budget and estimated groundwater recharge from the area to be reclaimed. A copy of this report is available upon request.

A map showing the location of the area, as well as a map showing the proposed re-contouring and end park use is included in Attachment A.

Vegetation

There is no vegetation present on the site. Low maintenance low growing grasses are to be established following the amendment addition. One year post application, trees will be planted into the site at location as identified by the CCRD Parks department.

Soils

The stockpiled overburden is coarse textured and is of low fertility. The average soil fertility, CEC and texture from a series of five composite soil samples collected over the site is found in the table below.

Parameter	Average	Units
pH	5.9	pH Units
Organic Matter	1.7	%
C:N ratio	16.7	
Total Carbon	0.99	%
Available Ammonium	4	ppm
Available Nitrate	2	ppm
Available Sodium	8	ppm
Salts	0.28	mhos cm^{-1}
Total Nitrogen	0.06	%
Available Phosphorous	5.9	ppm
Available Potassium	44	ppm
Available Calcium	733	ppm
Available Magnesium	70	ppm

Parameter	Average	Units
Available Copper	2.5	ppm
Available Zinc	12.7	ppm
Available Iron	1.47	ppm
Available Manganese	48	ppm
Available Boron	0.1	ppm
Available Sulfate-Sulfur	3.1	ppm
Available Aluminum	1,000	ppm
CEC	8.7	Me $100g^{-1}$
Sand*	70	%
Silt*	24	%
Clay*	6.0	%

Trace element concentrations in these soils pre-application are found below, under the heading "Estimated Trace Element Concentrations".

Amendment Information

The biosolids from Central City WWTP are produced from a secondary anaerobic mesophilic digestion facility. The pathogen reduction process employed at this WWTP produces a Class B biosolids with fecal coliform concentrations greater than 1,000 MPN per gram, but less than 2,000,000 MPN per gram total solids. The OMRR vector attraction reduction criteria have been met. The average of three samples, consisting each of seven composites for both the biosolids and biosolids compost is found in the table below. The biosolids compost is mature, has been stockpiled for two years and meets all the OMRR criteria. Fecal coliform count for both the biosolids and compost in this table are reported from seven discrete samples.

Parameter	**Units**	**Biosolids (*n*=3)**	**Biosolids Compost (*n*=3)**
Total Solids	% (w/w)	24	68
Ammonia as N	mg kg^{-1} dry	11,416	173
Total Kjeldahl Nitrogen	mg kg^{-1} dry	42,600	12,867
Nitrate/Nitrite as N	mg kg^{-1} dry	13	80
Phosphorus Total as P	mg kg^{-1} dry	23,600	8,243
Phosphorus Available	mg kg^{-1} dry	3,114	750
Potassium Total as K	mg kg^{-1} dry	5,263	8,689
Potassium Available	mg kg^{-1} dry	1,118	2,248
pH	-	8.1	7.5
EC	dS m^{-1}	6.3	8.2
Fecal Coliform *(n=7)*	MPN g^{-1} dry	5,362	65
Arsenic Total	mg kg^{-1} dry	6	8
Cadmium Total	mg kg^{-1} dry	2.7	2.1
Chromium Total	mg kg^{-1} dry	70	75
Cobalt Total	mg kg^{-1} dry	6	6
Copper Total	mg kg^{-1} dry	1,340	395
Lead Total	mg kg^{-1} dry	116	109
Mercury Total	mg kg^{-1} dry	5.5	1.4
Molybdenum Total	mg kg^{-1} dry	5	4
Nickel Total	mg kg^{-1} dry	74	29

Parameter	Units	Biosolids (*n*=3)	Biosolids Compost (*n*=3)
Selenium Total	mg kg^{-1} dry	6	1
Zinc Total	mg kg^{-1} dry	846	450

Proposed Application Rate

The application rate of biosolids and biosolids compost for the Maplethor Park reclamation was calculated based on a 1:1 (v/v) mixture of biosolids and biosolids compost applied at a rate sufficient to supply sufficient nitrogen to the vegetation in the establishment year. As such, the application rate is agronomic for the vegetation to be established.

The application rate was determined using a biosolids fertilization model accepted for use throughout the Pacific Northwest. While typically used in the calculation of forestry based application rates, it is suitable for use in this application. This model calculates the application rate designed to meet the needs of the vegetation without resulting in excess nitrogen leaching. An application rate of 179 dt ha^{-1} will provide 280 kg N ha^{-1} of available plant nitrogen in the first full growing season following application.

Even with the application rate based on the agronomic requirements of the vegetation there may exist a differential between the vegetation's maximum utilization period, and the availability of nitrogen from the amendment. If this occurs, it is expected that some nitrogen leaching will occur.

Related Studies and Activities

As this is a sensitive site, and the first time in the Fraser Valley that biosolids and compost are to be used to reclaim a gravel mine a lysimeter study was completed to assess the movement of nitrogen and other constituents from the proposed application. Lysimeters are used to measure the concentration and quantity of substances moving through the soil. This information will be used in confirming the application rates and environmental impacts for this site, as well as for other similar sites in the area. The environmental consulting company Rehabilitation Inc. was retained to conduct an extensive lysimeter study at the Maplethor park site. The objective of this study was to assess the amount of nitrogen expected to move down through the soil profile and potentially enter and recharge subsurface aquifers. Three replicates of five treatments were randomly applied to lysimeters constructed and installed at the rehabilitation site. The five treatments were:

- Biosolids from the CCRD's Central City WWTP,
- CCRD biosolids compost,
- Biosolids with biosolids compost,
- Inorganic chemical fertilizer, and a
- Control

These treatments were based upon the calculated amendment application rate of biosolids and biosolids compost. The objective of this trial was to compare the rehabilitation treatments of leaving the area alone, applying inorganic fertilizer or the amendment proposed. The biosolids alone and biosolids compost alone treatments were included so that the effects of the biosolids and compost applications applied together could be assessed separately. The biosolids with biosolids compost treatment is a combination of the 'biosolids compost alone' application rate and the 'biosolids alone' application rate.

The lysimeter construction allowed for quantification and characterization of soil water moving down through the soil profile. The lysimeters were constructed and treatments applied in August 2003. Lysimeter water was collected every two weeks from September 14, 2003 through April 26, 2004 from each lysimeter and analyzed for forms of nitrogen, phosphorus and carbon. Every four weeks an additional sample was collected and analyzed for trace metals. Assessments were made of the germination and growth of the vegetation at each sampling interval. At the end of the lysimeter water collection, the vegetation established in the lysimeters was removed, dried, weighed and analyzed for plant essential nutrients.

Vegetation germination was rapid on the control and chemical fertilizer treatments. A delay in germination was noted in the organic amendment treatments. Upon germination the 'biosolids' and 'biosolids with biosolids compost' treatments resulted in the most vigorous growth and the largest quantity of vegetation. The control treatment, while germinating first, grew slowly and became chlorotic as compared to the other treatments.

Vegetation biomass at the end of the study was greatest in the 'biosolids' and 'biosolids with biosolids compost' treatments. These treatments produced more than 13 times the above ground vegetation as produced by the control treatment. The biosolids compost and chemical fertilizer treatments resulted in a marginal increase in vegetation biomass.

In assessing the quality of vegetation determined through foliar nutrient analysis, the biosolids and 'biosolids with biosolids compost' amendments were the only treatments to significantly increase the foliar nitrogen concentration above that of the control. The biosolids and 'biosolids with biosolids compost' treatments increased the concentrations of all deficient plant essential nutrients tested, and reduced one micronutrient found in excess in the control treatment.

Nitrate nitrogen comprised the largest component of the total nitrogen lost in all treatments except the control. The biosolids treatment resulted in the largest total nitrogen losses, although representing less than 4% of the nitrogen applied. The application of chemical fertilizer resulted in nitrogen losses greater than that of the compost, and 'biosolids with biosolids compost' treatments. The 'biosolids with biosolids compost' treatment composed of the same amount of both biosolids and biosolids compost as applied in the respective individual treatments did not result in an additive nitrogen loss. A significant reduction in the amount of water moving down and out of the 'biosolids with biosolids compost' treatment was observed. This can be attributed to the establishment of a dense community of vegetation resulting in both increased evapotranspiration losses and water storage in this treatment.

The biosolids and 'biosolids with biosolids compost' treatments resulted in less phosphorus in the lysimeter water as compared to all the other treatments, including the control. As phosphorus plays an important role in the promotion of eutrophication, treatments that reduce the movement of phosphorus out of the soil profile and into subsurface receiving water bodies are preferable. The control and biosolids compost alone treatments resulted in the largest total phosphorus concentrations in the lysimeter water.

In assessing the trace metals in the lysimeter water, the concentrations of arsenic, cadmium, chromium, cobalt, lead, mercury, molybdenum, nickel, selenium and silver, were all below detection limits in all treatments at all sampling intervals. While soil water is not drinking water, the concentrations of the remaining trace metals in the lysimeter water were well below levels specified in the Health Canada's Guidelines for Canadian Drinking Water Quality with the exception of iron and manganese in the biosolids compost alone treatment. While these concentrations do not pose a health risk, they are deemed higher than the standards set for aesthetic objectives in drinking water. Similar concentrations of iron and manganese have been observed in drinking water wells throughout the Fraser Valley as a result of soil specific conditions.

This study confirmed that the nitrogen moving down and out of the soil profile following the proposed treatment would have a negligible effect on aquifer water quality. A copy of this report is available upon request.

While not related to the protection of the environment, it is important that the local area residents understand and accept the proposed amendment application. Central City conducted an extensive public consultation process, initiated in 2003, designed to increase the awareness of the local area residents and stakeholders about the proposed reclamation activities to occur within the park. While the gravel extraction was ongoing, this area remained fenced and the public restricted from entering, the fence line bisected a portion of the park and park visitors were able to observe the extraction operation and re-contouring. Support for the program from the local area residents was an important requirement in the rehabilitation of the park.

These activities include the formation of a local stakeholder advisory group, public open house conducted in the reclamation area, a direct mailed information package to 160 people in the area – mainly near the park, a presentation to town council, and ongoing interactions with local area residents.

Groundwater contamination and odour concerns were the two main issues raised, and following subsequent correspondence and meetings these concerns were addressed. The majority of the local area residents are in support of the reclamation activities.

Transportation, Application Method and Timing

Biosolids and biosolids compost from Central City's WWTP and new composting facility will be transported and stockpiled on site in July, 2006. The separate stockpiles of each will be located on high flat ground a minimum of 30 m from the artificial pond. Standard rear discharge manure spreaders will apply the biosolids and biosolids compost over the site. The biosolids and biosolids compost will be layered into the manure spreaders and mixed as distributed through the beater bars. Applications will be made across the slopes. Buffers to the artificial pond will be clearly flagged. Within 24 hours following application the amendment will be incorporated into the existing soil-like substrate. Two weeks following the area will be drill seeded with a mixture of park grasses and lightly rolled. The amendment application and incorporation will occur in August, 2006, and the seeding in early September.

Special Site Management Considerations

The area proposed for the amendment application is restricted to public access, and will remain that way for two years following application, as the park continues to be developed. Required signs have been posted around the site perimeter, and at a "look-out" over the disturbed area an information board has been set-up.

The artificial lake created in the center of the re-contoured park will discharge excess water received during the winter to a nearby ditch, which subsequently drains into a stream. The lake will not be filled to capacity during the winter following the application and no water will be discharged into the ditch. The required 30 m buffer will be maintained around this water body perimeter.

Following application, incorporation and seeding the area will be inspected following intense rainfall events for indications of erosion through surface run-off.

A contingency plan has been developed in conjunction with the local environmental health officer and is detailed in the section titled “Contingency Plan”.

Post Application Site Monitoring

Soil

Three replicate soil samples consisting of a minimum of seven subsamples were collected prior to application. These were analyzed for soil fertility and trace elements. Samples were collected from 0-15 cm in depth, the anticipated depth of incorporation of the biosolids and biosolids compost mixture. Post soil samples, collected as per the same sampling program will be collected one-year post application, at the similar time period as the pre-samples were collected. These samples will be analyzed for the same parameters, and soil fertility and trace element concentrations will be compared.

Surface Water

In the re-contouring and development of this disturbed land there will be an artificial lake created through the fabrication of a clay liner. This pond will be used for canoeing and kayaking to and around two islands created in the middle of this water body. Two water samples at 3 months intervals will be collected from this pond prior to the amendment application. Samples will be analyzed for pH, conductivity, nitrogen (TKN, ammonia, and nitrate), phosphorus (ortho and total P), total organic carbon, total trace elements (As, Cd, Cr, Co, Cu, Pb, Hg, Mo, Ni, Se, and Zn) chloride, and fecal coliform. Another sample will be collected within one month following amendment application or immediately after the first intense rainfall event, whichever is sooner. Subsequent monitoring will occur every three months for one year following amendment application.

Groundwater

One groundwater well has been installed on site, and water will be pumped from this well to maintain the water level in the surface water pond throughout the summer months. In conjunction with discussions with area residents, and based on hydrogeological flow patterns in the aquifer, seven neighbouring domestic drinking water wells have been identified for monitoring. The owners of these wells have all agreed to participate in this monitoring program. The one on-site groundwater well and seven proximal wells will be sampled at the same frequency and duration as the surface water monitoring program. These groundwater samples will be monitored for the same parameters as the surface water monitoring program with the addition of iron and manganese.

The results of these analyses will be made available to the area residents, the local environmental health officer and MoE regional hydrologist.

Vegetation

In the first full growing season, three representative samples of the vegetation established on the site will be analyzed for plant essential nutrients, trace elements and nitrate concentration.

Estimated Trace Element Concentrations

Based upon the existing soil chemistry and constituents present in the biosolids-biosolids compost amendment it is possible to estimate the final concentration of nutrients and trace elements in the soils post application. This information can be found in the table below. All trace element concentrations are below OMRR specified ceiling limits.

Parameter	**Units**	**Concentration**		
		Soil (pre-application)	**Biosolids with Compost Amendment**	**Estimated Soil (post application)**
Total Solids	% (w/w)	79.0	38.5	n/c
Volatile Solids	% (w/w)	5.4	41.2	n/c
Ammonia as N	mg kg^{-1} dry	0.5	2,540	n/c
Total Kjeldahl Nitrogen	mg kg^{-1} dry	1,216	16,200	2,348
Nitrate/Nitrite as N	mg kg^{-1} dry	2.3	39.6	n/c
Phosphorus Total as P	mg kg^{-1} dry	1,018	10,900	n/c
Arsenic Total	mg kg^{-1} dry	4.8	8.9	5
Cadmium Total	mg kg^{-1} dry	< 0.5	2.4	0.4
Chromium Total	mg kg^{-1} dry	46	58	46.2
Cobalt Total	mg kg^{-1} dry	12	7.3	11.4
Copper Total	mg kg^{-1} dry	18.3	688	69.5
Lead Total	mg kg^{-1} dry	3.3	76	8.8
Mercury Total	mg kg^{-1} dry	< 0.1	2.2	0.6
Molybdenum Total	mg kg^{-1} dry	< 1.5	4.9	1.1
Nickel Total	mg kg^{-1} dry	33	27	32
Selenium Total	mg kg^{-1} dry	0.3	3.1	0.4
Zinc Total	mg kg^{-1} dry	65	547	101

n/c = not calculated

Contingency Plan

These procedures are to be followed in the event that either the surface water or groundwater has been impacted by the application of biosolids or biosolids compost in the reclamation of Central City Maplethor Regional Park.

In the event that a post application water sample collected returns values significantly higher than background or pre discharge, or there is indication that the nearby surface and/or groundwater has been adversely affected the following contingency plan is to be implemented:

- Verification with the analytical lab that the concentration of the particular analyte of concern is valid and check corresponding QA/QC data.
- Collect five replicate water samples as soon as possible and analyze for the analyte in question. Determine the average and variation around the mean. Replicate

samples are to be collected from a “control” area upstream to out of the zone of influence for comparison.

- Notify the Ministry of Environment if the analyte is present at concentrations significantly higher than background or pre discharge. Implement an expanded water-sampling program to determine the extent of the impact. This expanded program will include both surface and ground water sampling locations. This water sampling program again requires replicate samples be taken as soon as possible and these and prior results provided to Ministry of Environment. Notify other agencies and local residents, businesses as required.
- Mitigation of the impact is to commence immediately. In the event that surface water is affected through siltation, a ditch shall be constructed around the pond and siltation fences erected to prevent off-site movement. If the impact is the result of a specific point source input this source is to be removed and care should be taken to ensure it does not re-occur. Similar areas that may experience the same impact will be identified and the potential reduced through re-contouring or other appropriate measures.
- In the event that lateral subsurface flow is deemed responsible for the impact to surface water, and nitrogen concentrations are shown in excess of approval standards, denitrification dams are to be constructed.
- While mitigation is ongoing a water sampling program should be implemented with increased intensity and sampling frequency to assess the effectiveness of mitigation efforts on the analyte(s) of concern. Refine mitigation activities depending on water sampling results.
- The potential for an adverse environmental impact to the groundwater will be precluded by impacts to the surface water on and adjacent to the site. Preventing impacts to the surface water is key in preventing potential groundwater impacts. Should sampling of the groundwater post recharge demonstrate adverse impacts resulting from the amendment discharge, studies will be implemented to determine the extent, effect and mitigation options available.

This contingency plan provides a basic outline to validate and determine the extent of any potential adverse environmental impacts. Mitigation efforts range from ditching and siltation fences to the installation of denitrification dams. These mitigation efforts will be completed in conjunction with discussions with MoE and related agencies.

Respectfully submitted,

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